Energy, Science and Technology 2015

Book of Abstracts

EST ENERGY SCIENCE TECHNOLOGY
INTERNATIONAL CONFERENCE & EXHIBITION
20 – 22 May 2015 | Karlsruhe | Germany

The energy conference for scientists and researchers

Scientific Partners:
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Preamble

We are pleased to present you this **Book of Abstracts**, which contains the submitted contributions to the “Energy, Science and Technology Conference & Exhibition EST 2015”. The EST 2015 took place from May, 20th until May, 22nd 2015 in Karlsruhe, Germany, and brought together many different stakeholders, who do research or work in the broad field of “Energy”.

Renewable energies have to present a relevant share in a sustainable energy system and **energy efficiency** has to guarantee that conventional as well as renewable energy sources are transformed and used in a reasonable way. The adaption of existing infrastructure and the establishment of new **systems, storages and grids** are necessary to face the challenges of a changing energy sector.
Those three main topics have been the fundament of the EST 2015, which served as a platform for national and international attendees to discuss and interconnect the various disciplines within energy research and energy business.

We thank the authors, who summarised their high-quality and important results and experiences within one-paged abstracts and made the conference and this book possible. The abstracts of this book have been peer-reviewed by an international Scientific Programme Committee and are ordered by type of presentation (oral or poster) and topics. You can navigate by using either the table of contents (page 3) or the conference programme (starting page 4 for oral presentations and page 21 for posters respectively).

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Programme | **Wednesday, May 20th**

10:00 – 10:30	**Registration / Coffee**
	Welcome (Weinbrenner-Saal)
10:30	**Opening** Britta Wirtz, Managing Director, Karlsruher Messe- und Kongress-GmbH, Germany Prof. Dr. Detlef Löhe, Vice President for Research and Information, Karlsruhe Institute of Technology, Karlsruhe, Germany Dr. Frank Mentrup, Lord Mayor, Karlsruhe, Germany Dr. Georg Menzen, Head of department for Energy Research and Innovation, Federal Ministry for Economic Affairs and Energy, Berlin, Germany
11:00	**Plenary Lecture** **Technological drivers of the energy mix transformation** Dr. Jean-François Minster, Senior Vice-President Scientific Development, TOTAL S.A., Paris, France **EDF R&D contribution to the energy transition: focus on key innovative enabling technologies** Bernard Salha, Senior Executive Vice President of EDF Group, President of EDF Research and Development (EDF R&D), Paris, France

	Mombert-Saal **R.1a: Geothermal energy systems** Session Chair: Ladislaus Rybach	**Thoma-Saal** **R.1b: Photovoltaics** Session Chair: Nicola Armaroli
13:00 – 13:30	Session Keynote Speaker **Geothermal Energy Systems: Prosperous or Marginal?** Ingo Sass, TU Darmstadt, Darmstadt, Germany	Session Keynote Speaker **Photovoltaic solar energy: prepare(d) for impact** Wim C. Sinke, ECN Solar Energy, Petten, The Netherlands
13:30 – 13:50	**Experiences from geothermal projects and necessity for a geoscientific underground laboratory** Thomas Kohl, Karlsruhe Institute of Technology, Karlsruhe, Germany	**Properties of organic-inorganic $APbI_3$ perovskites as solar cells materials** Lucangelo Dimesso, TU Darmstadt, Darmstadt, Germany
13:50 – 14:10	**Quality Management and Improvement for Geothermal Energy Projects using the Platform Based Tool Development Technology – ZWERG** Benedict Holbein, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Organic Nanoparticles for an Eco-Friendly Fabrication of Organic Solar Cells from Alcoholic Dispersion** Stefan Gärtner, Karlsruhe Institute of Technology, Karlsruhe, Germany
14:10 – 14:30	**Migration based detection and location of the microseismicity induced at Rittershoffen geothermal field (Alsace, France)** Emmanuel Gaucher, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Testing the Overall Performance of Offshore PV System** Malte Schöfer, Active Innovation Management, Palaiseau Cedex, France
14:30 – 14:50	**Synthetic clay logs to assess the mechanical behavior of a geothermal reservoir** Carola Meller, Karlsruhe Institute of Technology, Karlsruhe, Germany	**Analysis of performance of photovoltaic systems: comparison of panel and inverter brand** Odysseas Tsafarakis, Utrecht University, Utrecht, The Netherlands

14:50 – 15:10	**Simulation and Optimization of Deep Borehole Heat Exchanger Arrays** Daniel Schulte, TU Darmstadt, Darmstadt, Germany	**Comparison of DC- and AC-coupled photovoltaic energy storage systems with Lithium-ion batteries** James Barry, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
15:10 – 15:30	**Geothermal power generation – a comparison of development trends with other renewable sources** Ladislaus Rybach, ETH Zurich, Zurich, Switzerland	**DESERTEC and beyond** Michael Düren, Justus Liebig University Gießen, Gießen, Germany
15:30 – 16:00	**Coffee Break**	

	Mombert-Saal **R.2a: Chemical and solar fuels** Session Chair: Jordi Llorca	**Thoma-Saal** **R.2b: Solar thermal technology** Session Chair: Thomas Wetzel
16:00 – 16:30	Session Keynote Speaker **Fuels from solar energy and water – an overview of the solar fuel field** Stenbjörn Styring, Uppsala University, Uppsala, Sweden	Session Keynote Speaker **Concentrating Solar Thermal Technologies – Status and Perspectives** Kai Wieghardt, German Aerospace Center (DLR), Jülich, Germany
16:30 – 16:50	**Production of Oxygenate Fuels from Renewable Resources** Ulrich Arnold, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Potential for deserts to supply reliable renewable electric power** Mercé Labordena, ETH Zurich, Zurich, Switzerland
16:50 – 17:10	**Photoelectrochemical Routes for the Generation of Solar Hydrogen** Peter Bogdanoff, Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany	**A new concept for hybrid sensible/thermo-chemical storage of solar heat in cascaded redox-oxide-based thermochemical reactors/heat exchangers** Christos Agrafiotis, German Aerospace Center (DLR), Cologne, Germany
17:10 – 17:30	**Scalable Particle-Based Photoelectrodes for Solar Hydrogen Generation** Simone Pokrant, EMPA Academy, Dübendorf, Switzerland	**Liquid metals as efficient heat transfer fluids for next generation CSP systems** Luca Marocco, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
17:30 – 17:50	**Proposed Liquid Fuel Production on Artificial Islands** Bruce Patterson, Paul Scherrer Institute, Villigen, Switzerland	
17:50 – 18:10	**Methanol for Renewable Energy storage and utilisation** Ludolf Plass, TUBA Freiberg, Freiberg, Germany	

	Clubraum **E.1a: Demand-side strategies to reduce energy needs** Session Chair: Enrique Kremers	**Hebel-Saal** **E.1b: Efficient industry and manufacturing processes** Session Chair: Albert Albers
13:00 – 13:30	Session Keynote Speaker **Simulating the Complexity of Demand Side Management Strategies using Agent-Based Models** Enrique Kremers, European Institute for Energy Research, Karlsruhe, Germany	Session Keynote Speaker **Product Generation Development – The Path to Agile and Efficient Processes in Product Development** Albert Albers, Karlsruhe Institute of Technology, Karlsruhe, Germany
13:30 – 13:50	**Optimization of the Energy Performance in the Hospitality Sector in UAE by Using the Integrated Control Methodology in the Guest Rooms** Fadi AlFaris, The British University in Dubai, Dubai, United Arab Emirates	**Characterisation of the product quality of a novel environmentally friendly cementitious material by estimation of auxiliary quantities with near-infrared-spectroscopy** Carolin Lutz, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
13:50 – 14:10	**Energy Efficiency Policies in the Russian Residential Sector** Andrey Kazakov, University of Nordland, Bodø, Norway	**Computational Fluid Dynamics for energy efficient multiphase flow processes** Dirk Lucas, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
14:10 – 14:30	**Virtual Storages as Theoretically Motivated Demand Response Models for Enhanced Smart Grid Operations** Simon Waczowicz, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Microwave technology for energy efficient processing of fibre composites** Guido Link, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
14:30 – 14:50	**SMARTICITY – A Feedback System for Energy Consumption and Costs** Carl Heckmann, University of Mannheim, Mannheim, Germany	**Efficient multiphase chemical processes – from advanced modelling, simulation and measurement to novel reactor concepts and technologies** Uwe Hampel, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
14:50 – 15:10	**Extended Method to Forecast Price Elastic Consumption Behaviour** Stefan Klaiber, Fraunhofer IOSB, Ilmenau, Germany	**Increasing the energy efficiency of air jet weaving based on a novel method to exploit energy savings potentials in production processes of the textile industry** Achim Schröter, RWTH Aachen University, Aachen, Germany
15:10 – 15:30	**Assessing Industrial Consumptions' Curtailments for Demand Response Valorisation** François de Sousa Lopes, EDF R&D, Moret-sur-Loing, France	**Efficient low temperature N_2O decomposition from HNO_3-exhaust streams over $K\text{-}Cu_xCo_{3-x}O_4$ catalysts** Tanja Franken, RWTH Aachen University, Aachen, Germany
15:30 – 16:00	**Coffee Break**	

	Clubraum **E.2a: Efficiency in lighting** Session Chair: Ulrich Lemmer	Hebel-Saal **E.2b: Nuclear power plants** Session Chair: Claude Degueldre
16:00 – 16:30	Session Keynote Speaker **Energy-efficient lighting – yes, we can** Martin Zachau, OSRAM GmbH, Munich, Germany	Session Keynote Speaker **Sustainability of Nuclear Power: Fuel cycles** Marco Streit, Paul Scherrer Institute, Villigen, Switzerland
16:30 – 16:50	**Recent LED innovations** Cornelius Neumann, Karlsruhe Institute of Technology, Karlsruhe, Germany	**Nuclear energy for a sustainable French energy mix** Françoise Touboul, CEA, Saclay, France
16:50 – 17:10	**Silicon carbide for efficient power conversion in lighting** Christoph Simon, Karlsruhe Institute of Technology, Karlsruhe, Germany	**Uranium as a renewable for nuclear energy** Claude Degueldre, Paul Scherrer Institute, Villigen, Switzerland
17:10 – 17.30	**Bionic cooling systems for LEDs** Chris Herbold, franzkann* Herbold und Herrmann GbR, Karlsruhe, Germany	**Research for safe nuclear waste management options** Concetta Fazio, ITU Joint Research Centre European Commission, Karlsruhe, Germany
17:30 – 17:50	**LED Lightning Projects in Practice** Tom Vermast, luminatis Deutschland GmbH, Landau in der Pfalz, Germany	**MiniRadMeter: a miniature detector for gamma rays** Gianluca Alimonti, INFN-Milano, Milan, Italy
17:50 – 18:10		**Geochemical research for nuclear waste disposal safety** Marcus Altmaier, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
18:10 – 18:30		**Challenges in the decommissioning of nuclear facilities** Martin Brandauer, Karlsruhe Institute of Technology, Karlsruhe, Germany

	Weinbrenner-Saal **S.1: Electrochemical energy storage** Session Chair: Horst Hahn
13:00 – 13:30	Session Keynote Speaker: **Facile Synthesis of Carbon-Metal Fluoride Nanocomposites for Lithium Batteries** Anji Reddy Munnangi, Helmholtz Institute Ulm, Ulm, Germany
13:30 – 13:50	**Graphene oxide based synthesis of a high energy $FeF_3.0.33H_2O$/rGO cathode for Li-ion batteries** Alexander Pohl, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
13:50 – 14:10	**Modeling Thermal Runaway Of Li-Ion Batteries - A Mathematical Ansatz** Andreas Melcher, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
14:10 – 14:30	**Table-driven Li-Ion Battery Cell Model for a BMS Development Platform** Matthias Gulbins, Fraunhofer-Institute Integrated Circuits IIS/EAS, Dresden, Germany
14:30 – 14:50	**In situ investigation of gases evolving in $LiNi_{0.5}Mn_{1.5}O_4$/graphite full-cells** Barbara Michalak, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
14:50 – 15:10	**Electrochemical characteristics of LaY_2Ni_9 alloy at different discharge rates** Yassine Ben Belgacem, University of Tunis, Tunis, Tunisia
15:10 – 15:30	**Primary frequency control by using a 1 MW battery: study at grid scale on the Concept Grid EDF platform** Benoît Puluhen, EDF, Moret-sur-Loing Cedex, France

15:30 – 16:00	**Coffee Break**
	Weinbrenner-Saal **S.2: Electrochemical energy storage** Session Chair: Horst Hahn
16:00 – 16:30	**High Capacity Si-Carbon Composite for Li-Ion Battery Anode Synthesized by Self-Regulated Microwave Heating Process** Nai-Hsuan Yang, National Taiwan University, Taipei, Taiwan
16:30 – 16:50	**Thermal material properties of Li-ion batteries** André Loges, Karlsruhe Institute of Technology, Karlsruhe, Germany
16:50 – 17:10	**New advances in room-temperature fluoride ion batteries** Fabienne Gschwind, Helmholtz Institute Ulm, Ulm, Germany
17:10 – 17:30	**Effect of modified graphene oxide on high-voltage cathode materials for high energy lithium-ion batteries** Francesca De Giorgio, University of Bologna, Bologna, Italy
17:30 – 17:50	**Electrochemical Investigation of VOCl for the Rechargeable Chloride Ion Batteries** Ping Gao, Helmholtz Institute Ulm, Ulm, Germany
17:50 – 18:10	**Local structure and Transport in Ionic Liquid-based Electrolytes for Magnesium Batteries** Guinevere Giffin, Helmholtz Institute Ulm, Ulm, Germany
18:10 – 18:30	**Efficiency Evaluation of Electrochemical Storage Systems** Johannes Kathan, AIT Austrian Institute of Technology GmbH, Vienna, Austria

	Poster Session including Best Poster Award
18:30	**Foyer (with snacks & drinks)**

8:00 – 8:30	**Welcome Coffee**
	Weinbrenner-Saal
8:30 – 9:00	**Plenary Lecture** **Decarbonizing the global energy system: insights from the new IPCC Report** Prof. Dr. Thomas Bruckner, Chair for Energy Management and Sustainability, Director of the Institute for Infrastructure and Resources Management (IIRM), Faculty of Economics and Management, University of Leipzig, Leipzig, Germany; Head of the Department for Sustainability Management and Infrastructure Economy, Fraunhofer MOEZ, Leipzig, Member of the Intergovernmental Panel on Climate Change

	Thoma-Saal **R.3: Biomass and biomass conversion technologies** Session Chair: Kay Schaubach
9:00 – 9:30	Session Keynote Speaker **Syngas as Platform from Sustainable Feedstocks to Fuels** Jörg Sauer, Karlsruher Institute of Technology, Eggenstein-Leopoldshafen, Germany
9:30 – 9:50	**Materials development against hot corrosion in biomass gasification facilities** Uwe Gaitzsch, Fraunhofer IFAM, Dresden, Germany
9:50 – 10:10	**Processing and Atomization of Complex Fluids for Entrained Flow Gasification Application** Alexander Sänger, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
10:10 – 10:30	**HTHP Syngas Cleaning at bioliq® BTL Process Commissioning and First Results** Robert Mai, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
10:30 – 10:50	**Doubling of synthetic biofuel production via hydrogen from renewable electricity** Ilkka Hannula, Technical Research Centre of Finland, Espoo, Finland
10:50 – 11:20	**Coffee Break**
	Thoma-Saal **R.4: Biomass and biomass conversion technologies** Session Chair: Kay Schaubach
11:20 – 11:50	Session Keynote Speaker: **EU wide overview of biomass potentials** Berien Elbersen, Alterra Wageningen UR, Wageningen, Netherlands
11:50 – 12:10	**Projecting environmental benefits and drawbacks of short rotation coppice-based energy production strategies** Benedetto Rugani, Luxembourg Institute of Science and Technology, Esch-sur-Alzette, Luxembourg
12:10 – 12:30	**Ultra-low emission wood combustion by seamless adaptation of an electrostatic precipitator to a modern grate boiler** Hanns-R. Paur, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
12:30 – 12:50	**Economic and ecological evaluation of biogas plant configurations for flexible power generation** Henning Hahn, Fraunhofer IWES, Kassel, Germany

13:10 – 14:30	**Lunch**

	Thoma-Saal **R.5: Biomass and biomass conversion technologies** Session Chair: Kay Schaubach
14:30 – 15:00	**Final results of the SECTOR project: Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction** Kay Schaubach, DBFZ Deutsches Biomasseforschungszentrum gGmbH, Leipzig, Germany
15:00 – 15:20	**BIO-GO: Conversion of Bio Gas and Pyrolysis Oil to Synthetic Fuels** Gunther Kolb, Fraunhofer ICT-IMM, Mainz, Germany
15:20 – 15:40	**Green Production of High Cost Solvents from Bio-Ethanol Using Alumina and Metallic Co-doped Al_2O_3 catalyst** Bandith Chokcharoenchai, Chulalongkorn University, Bangkok, Thailand
15:40 – 16:00	**Production of hydrogen from biomass via gasification in supercritical water** Nikolaos Boukis, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

16:20 – 16:50	**Coffee Break**

	Thoma-Saal **R.6: Water** Session Chair: Klaus Krüger
16:50 – 17:20	Session Keynote Speaker **Hydropower – renewable and sustainable electricity generation with fast response times** Stefan Riedelbauch, University of Stuttgart, Stuttgart, Germany
17:20 – 17:40	**A Study of Ocean Kinetic Energy Harvester using Graphene-Based Ionic Polymer Metal Composite** Hyung-Man Kim, Jungkoo Lee, Kyungcheol Kim, INJE University, Gimhae-si, Republic of Korea
17:40 – 18:00	**Hollow-Hub Turbine for Run-of-the-river Small Hydropower** David Volk, TU Darmstadt, Darmstadt, Germany
18:00 – 18:20	**Energy Storage through Synchronous Hydropeaking Function for Cascaded Run-of-River Power Plants** Arnaud Koehl, EDF Hydro Engineering Center, Le Bourget-du-Lac, France
18:20 – 18:40	**Experimental Validation of an Analytic Approach to Optimization of a Tidal Turbine Fence** Manuel Metzler, TU Darmstadt, Darmstadt, Germany

	Clubraum **E.3: Efficiency in cooling and heating** Session Chair: Ursula Eicker
9:00 – 9:30	Session Keynote Speaker **Renewable energy systems in urban areas** Ursula Eicker, University of Applied Sciences Stuttgart, Stuttgart, Germany
9:30 – 9:50	**Refrigeration Plants with Trapezoid Cycles** Michael Löffler, European Institute for Energy Research, Karlsruhe, Germany
9:50 – 10:10	**Investigations of thermal parameters addressed to a building simulation model** Christian Brembilla, Umeå University, Umeå, Sweden
10:10 – 10:30	**Heat Exchanger Design Analysis for the Energy Reduction of a Household Air-Conditioning System** Alex Magdanz, ITI GmbH, Dresden, Germany
10:30 – 10:50	**Energy and Efficiency Breakthrough Innovations** Bruno Michel, IBM Research, Rüschlikon, Switzerland
10:50 – 11:20	**Coffee Break**
	Clubraum **E.4: Efficiency in cooling and heating** Session Chair: Ursula Eicker
11:20 – 11:50	**Plus-Energy School Campus: Comparison of Supply Concepts** Peter Engelmann, Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany
11:50 – 12:10	**Numerical and experimental analysis on thermal behaviour of refrigerated chamber's envelope incorporated with Phase Change Materials (PCMs)** Benedetta Copertaro, Università Politecnica delle Marche, Ancona, Italy
12:10 – 12:30	**TOR – Towards the Energetically Optimal Ventilation System** Christian Schänzle, TU Darmstadt, Darmstadt, Germany
12:30 – 12:50	**Adsorption air-conditioning of an electric bus – challenges in tailoring the ideal adsorbent material** Swantje Maaz, RWTH Aachen University, Aachen, Germany
12:50 – 13:10	**Energy Efficiency in Buildings – Results and Expierences from the German Research Programme „Energy Optimized Buildings (EnOB)“** Andreas Wagner, Karlsruhe Institute of Technology, Karlsruhe, Germany
13:10 – 14:30	**Lunch**

	Clubraum **E.5a: Energy efficient buildings and districts** Session Chair: Andreas Wagner	**Room 2.08** **E.5b: Fuel cells** Session Chair: Robert Slade
14:30 – 15:00	Session Keynote Speaker **Long term perspectives for low-carbon heating and colling technologies** Hans-Martin Henning, Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany	Session Keynote Speaker **Material improvements enabling larger scale liquid fed fuel cells** Jens Tübke, Fraunhofer Institute for Chemical Technology ICT, Pfinztal, Germany
15:00 – 15:20	**Towards Energy Efficiency Solutions and Low Carbon Economy in Urban Areas: The Sustainable Urban MOdel (SUMO) Toolkit** Nicolas Dr. Moussiopoulos, Aristotle University, Thessaloniki, Greece	**Solid Oxide Cells – Development Status at Forschungszentrum Jülich** Norbert Menzler, Forschungszentrum Jülich GmbH, Jülich, Germany
15:20 – 15:40	**Hardware-in-the-Loop environment for design and test of energy-efficient room automation systems in buildings** Alexander Adlhoch, Biberach University of Applied Sciences, Biberach, Germany	**Think Different! Carbon Corrosion Mitigation Strategy in High Temperature PEFCs – A Durability Study** Tom Engl, Paul Scherrer Institut, Villigen, Switzerland
15:40 – 16:00	**Modelling distributed mCHP-systems in German residential applications and their potential to integrate the gas and power grids** Praseeth Prabhakaran, Karlsruhe Institute of Technology, Karlsruhe, Germany	**A 2D modeling study of PEM fuel cell durability in a virtual car under catalyst degradation** Manik Mayur, Offenburg University of Applied Sciences, Offenburg, Germany
16:00 – 16:20		**Challenges facing the future implementation of Solid Polymer Fuel Cells and Electrolysers** Robert Slade, University of Surrey, Guildford, United Kingdom
16:20 – 16:50	**Coffee Break**	

	Clubraum **E.6: Energy efficient buildings and districts** Session Chair: Andreas Wagner
16:50 – 17:20	Session Keynote Speaker **Grid interaction of buildings – analysis and operation** Sebastian Herkel, Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany
17:20 – 17:40	**Spatial and multi-energy modelling integrated into district urban planning at master plan phase** Jean-Marie Bahu, European Institute for Energy Research, Karlsruhe, Germany
17:40 – 18:00	**A software platform to help Singapore to build a more smart and sustainable city** Alberto Pasanisi, European Institute for Energy Research, Karlsruhe, Germany
18:00 – 18:20	**Energy efficiency of buildings – the aspect of embodied impacts** Thomas Lützkendorf, Karlsruhe Institute of Technology, Karlsruhe, Germany
18:20 – 18:40	**Business and Technical Concepts for Deep Energy Retrofit** Rüdiger Lohse, KEA Climate Protection and Energy Agency of Baden-Württemberg, Karlsruhe, Germany

	Weinbrenner-Saal **S.3a: Electrochemical energy storage** Session Chair: Maximilian Fichtner	Mombert-Saal **S.3b: Hydrogen** Session Chair: Jordi Llorca
9:00 – 9:30	**Rutile-TiO_2 core-shell felt electrodes for all High-Performance Redox Flow Batteries** Cristina Flox, Catalonia Institute for Energy Research, Barcelona, Spain	**Synchronous measurement of FTIR-ATR spectra and desorbed hydrogen mass in-situ: Novel method for investigating the kinetics of hydrogen storage materials** Hans-Dieter Bauer, RheinMain University of Applied Sciences, Ruesselsheim, Germany
9:30 – 9:50	**Vanadium and Chromium Molecular Cluster Batteries (MCB): Li- storage and kinetic studies by electrochemical analysis** Julia Rinck, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**PEM water electrolysis MEAs with WO_3 supported $Ir_xRu_{1-x}O_2$ catalysts** Nils Baumann, Fraunhofer ICT, Pfinztal, Germany
9:50 – 10:10	**Ionic liquid electrolytes for Li/air batteries** Lorenzo Grande, Helmholtz Institute Ulm, Ulm, Germany	**9000 hours operation of a 25 solid oxide cells stack in steam electrolysis mode** Gaël Corre, European Institute for Energy Research, Karlsruhe, Germany
10:10 – 10:30	**Active Charge Balancing in Lithium-ion Battery Systems and its Benefits** Manuel Raeber, Zurich University of Applied Sciences, Winterthur, Switzerland	**Polymeric Catalysts for Catalytic H2 production from Formic Acid** Peter J.C. Hausoul, RWTH Aachen University, Aachen, Germany
10:30 – 10:50	**Phase-field simulation of the interaction of mechanics and diffusion in cathode particles of lithium ion batteries** Marc Kamlah, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Geochemical modelling of hydrogen interaction with minerals and aqueous species** Neda Hassanayebi, University of Leoben, Leoben, Austria

	Hebel-Saal **S.3c: Energy System Analysis and Modelling** Session Chair: Kai Hufendiek	Room 2.08 **S.3d: Thermal Energy Storage** Session Chair: Stefan Zunft
9:00 – 9:30	**Novel method of heat storage integration in heat exchanger networks using a time resolved three dimensional pinch approach** Michael Tielsch, Montanuniversität Leoben, Leoben, Austria	**Session Keynote Speaker** **Thermal Energy Storage: A Key Element of Tomorrow's Energy System** Stefan Zunft, German Aerospace Center (DLR), Stuttgart, Germany
9:30 – 9:50	**Examination and Optimisation of a heating circuit using TOR** Philipp Pöttgen, TU Darmstadt, Darmstadt, Germany	**A study on characteristics of phase change materials (PCMs) for the enhancement of thermal conductivity by using additive particles** Byungkwon Kim, Korea Institute of Industrial Technology (KITECH), Seoul, Republic of Korea
9:50 – 10:10	**Spatial and temporal disaggregation of GB energy scenarios depicting increasing wind capacity and electrified heating to 2035** Ed Sharp, UCL Energy Institute, London, United Kingdom	**Measurement and modelling of the maximum storage capacity of two salt hydrate based PCM as a function of the water/salt concentration** Simon Pöllinger, ZAE Bayern, Garching, Germany
10:10 – 10:30	**Storage demand in the context of Renewables from a European Perspective** Stefan Weitemeyer, NEXT ENERGY - EWE Research Centre, Oldenburg, Germany	**Novel Molten Alkali Chloride Salts for Thermal Energy Storage up to 700°C** Louis Maksoud, German Aerospace Center (DLR), Cologne, Germany
10:30 – 10:50	**Components and Technical Feasibility Considerations for Multi Terminal HVDC Transmission Grid Structures** Simon Wenig, Karlsruhe Institute of Technology, Karlsruhe, Germany	

10:50 – 11:20	Coffee Break	
	Weinbrenner-Saal **S.4a: Electrochemical energy storage** Session Chair: Maximilian Fichtner	**Mombert-Saal** **S.4b: Hydrogen** Session Chair: Jordi Llorca
11:20 – 11.50	**Battery Operation from a Neutron Point of View** Martin Mühlbauer, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**A Study of Ni-Ca catal-sorbent prepared by novel-modified method to improve catalytic activity during multiple cycles in SESMR reaction** Eun Ji Lim, Kyungpook National University, Daegu, Korea
11:50 – 12:10	**Battery Energy Storage for Grid Support** Richard Rocheleau, University of Hawaii, Honolulu, USA	**Technical feasibility and design study of Methane cracking in a liquid metal** Leonid Stoppel, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
12:10 – 12:30	**In-Situ X-ray Radiography Analysis of Lithium Sulfur Cells** Sebastian Risse, Helmholtz-Zentrum Berlin, Berlin, Germany	**Hydrogen production by thermal pressure hydrolysis of lignocellulosic biomass** Sonja Wiesgickl, Fraunhofer UMSICHT, Sulzbach-Rosenberg, Germany
12:30 – 12:50	**Renewable energy high-efficient power supply using a direct current system** Shinsuke Nii, Fuji Electric Co. Ltd., Tokyo, Japan	**Energy storage using Liquid Organic Hydrogen Carriers** Karsten Müller, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
12:50 – 13:10	**High Capacity Anode Materials based on mixed Conversion/Alloying Energy Storage Mechanism for Lithium-Ion Batteries** Franziska Müller, Helmholtz Institute Ulm, Ulm, Germany	**Pressurized alkaline electrolyser with high efficiency and wide operating range – the project RESelyser** Regine Reißner, German Aerospace Research Center (DLR), Stuttgart, Germany

	Hebel-Saal **S.4c: Energy System Analysis and Modelling** Session Chair: Kai Sundmacher	**Room 2.08** **S.4d: Thermal Energy Storage** Session Chair: Stefan Zunft
11:20 – 11:50		**Thermochemical tetramethylguanidine-based heat storage** Maria Tyukavina, Fraunhofer UMSICHT, Oberhausen, Germany
11:50 – 12:10	**High-Precision Modelling, Simulation and Optimisation of Cogeneration Plants** Stephanie Chen, University of Bremen, Bremen, Germany	**Thermochemical systems for the utilization of process waste heat: thermal storage and heat transformer** Margarethe Molenda, German Aerospace Center (DLR), Stuttgart, Germany
12:10 – 12:30	**Distributed multi-energy-hub systems: a review and techno-economic assessment of new integrated forms of energy production and consumption** David Grosspietsch, ETH Zurich, Zurich, Switzerland	**Thermo-physical Properties of Nano Coated CaO / $Ca(OH)_2$ Powders** Sandra Afflerbach, University of Siegen, Siegen, Germany
12:30 – 12:50	**Improved efficiency of combined heat and power plants using electric energy storage** Axel Haupt, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany	**Examination of reversible metal oxide redox reactions for high- temperature thermochemical energy storage** Michael Wokon, German Aerospace Center (DLR), Cologne, Germany
12:50 – 13:10	**Identification of Optimal Connection Points between Electrical and Natural Gas Transmission Networks using Power-to-Gas-Technology** Steven Hotopp, Clausthal University of Technology, Clausthal-Zellerfeld, Germany	

13:10 – 14:30	**Lunch**	
	Weinbrenner-Saal **S.5a: Electrochemical energy storage** Session Chair: Maximilian Fichtner	**Mombert-Saal** **S.5b: Chemical Energy Storage and SNG** Session Chair: Frank Graf
14:30 – 15:00	**High-Performance Li-ion Battery Anodes from Recycled Solar-Grade Kerf-Loss Silicon** Tzu-Yang Huang, National Taiwan University, Taipei, Taiwan	Session Keynote Speaker **P2G perspectives on- and offshore: the general picture** Catrinus Jepma, University of Groningen, Groningen, Netherlands
15:00 – 15:20	**Effects of Surface Coating on Performance of High-Capacity Lithium-Rich Manganese-Nickel Oxide Cathode of Lithium-ion Batteries** Yun Chu, National Taiwan University, Taipei, Taiwan	**Improving the conversion efficiency of a Power-to-Gas plant by coupling a dynamic SOEC system with a three-phase methanation reactor** Regis Anghilante, European Institute for Energy Research, Karlsruhe, Germany
15:20 – 15:40	**In-Operando Optical Microscopic Study on Polysulfide Dissolution and Dendrite Formation of Lithium-Sulfur Batteries** Jing Luo, National Taiwan University, Taipei, Taiwan	**Combining PtG-technology with gasification: The KIC-Project „DemoSNG“** Siegfried Bajohr, Karlsruhe Institute of Technology, Karlsruhe, Germany
15:40 – 16:00	**Disordered Dilithium Oxyfluoride as New Li^+ Intercalation Host** Ruiyong Chen, Helmholtz Institute Ulm, Ulm, Germany	**German Energiewende as Driving Force for New Technologies – Power Industry meets Process Industry** Arthur Heberle, Mitsubishi Hitachi Power Systems Europe GmbH, Duisburg, Germany
16:00 – 16:20	**Template-Free Electrochemical Synthesis of High Aspect-Ratio Tin Nanowires** Rihab Al-Salman, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Mesoporous Ni/Ce based catalyst for low temperature high throughput production of synthetic natural gas** Joan Ramon Morante, Catalonia Institute for Energy Research, Barcelona, Spain

	Hebel-Saal **S.5c: Electric grids and network integration at all levels** Session Chair: Johannes Kathan
14:30 – 15:00	Session Keynote Speaker **Intelligent energy networks for smart cities** Johan Driesen, KU Leuven, Leuven, Belgium
15:00 – 15.20	**Operation and Stability of Hybrid Transmission Systems** Julia Dragon, TU Darmstadt, Darmstadt, Germany
15:20 – 15:40	**Vehicle to Grid storage potential based on fleet test data of user behaviour** Mathias Kammerlocher, Volkswagen Group Research, Wolfsburg, Germany
15:40 – 16:00	**MCCF-based control of active harmonic filters for power quality enhancement** Peter Krasselt, Karlsruhe Institute of Technology, Karlsruhe, Germany
16.00 – 16:20	**Integration of Renewable Energy Sources with Time Constrained Optimal Power Flow** Nico Meyer-Huebner, Karlsruhe Institute of Technology, Karlsruhe, Germany
16:20 – 16:50	**Coffee Break**

	Weinbrenner-Saal **S.6a: Electrochemical energy storage** Session Chair: Maximilian Fichtner	**Mombert-Saal** **S.6b: Chemical Energy Storage and SNG** Session Chair: Frank Graf
16:50 – 17:20	**Synthesis and Characterization of Mg-Mn-O Spinel Cathodes** Johannes Schwank, University of Michigan, Ann Arbor, USA	**Power to Gas industrialization solutions for hydrogen and SNG** Christian Meyne, ETOGAS GmbH, Stuttgart, Germany

17:20 – 17:40	**Technical and Economic Potential of Storage Systems in Distribution Grids** Soeren Schrader, P3 Energy & Storage, Aachen, Germany	**CO2freeSNG2.0 – Advanced Substitute Natural Gas from Coal with Internal Sequestration of CO_2** Peter Treiber, Friedrich-Alexander-University Erlangen-Nuremberg, Nuremberg, Germany
17:40 – 18:00	**Flow Phenomena in Liquid Metal Batteries** Tom Weier, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany	**Process Technology** **Energy-efficient wastewater treatment in a two-stage activated sludge process** Martin Kaleß, RWTH Aachen University, Aachen, Germany
18:00 – 18:20	**The Role of Energy Status Data in Solar Power Plants with Li-Ion Batteries** Thomas Blank, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Green catalytic processes converting refinery naphtha cuts to strong anti-knocking ingredients of gasoline** Nikolaos C. Kokkinos, Eastern Macedonia and Thrace Institute of Technology, Kavala, Greece
18:20 – 18:40	**Thermo-electrochemical modeling of LiC_6/LFP and LTO/NCA lithium-ion batteries for lifetime and safety prediction** Wolfgang Bessler, Offenburg University of Applied Sciences, Offenburg, Germany	

	Hebel-Saal **S.6c: Electric grids and network integration at all levels** Session Chair: Johannes Kathan	**Room 2.08** **S.6d: Capacitors and supercapacitors** Session Chair: Nae-Lih Wu
16:50 – 17:20	**Optimal size of stationary energy storages for solar home systems** Martin Uhrig, Karlsruhe Institute of Technology, Karlsruhe, Germany	Session Keynote Speaker **How to boost energy density in Supercapacitors?** Thierry Brousse, University of Nantes, Nantes, France
17:20 – 17:40	**Conductor Materials** Session Keynote Speaker **Energy efficiency with superconductors – simply irresistable** Michael Bäcker, Deutsche Nanoschicht GmbH, Rheinbach, Germany	**Flow Capacitors: A Novel Technology for Scalable Energy Storage** Volker Presser, INM – Leibniz Institute for New Materials gGmbH, Saarbrücken, Germany
17:40 – 18:00	**SuperConductors with improved critical currents** Bernhard Holzapfel, Karlsruhe Institute of Technology, Karlsruhe, Germany	**Novel Electrolytes for Supercapacitors based on Ionic Liquids** Thomas Schubert, IoLiTec Ionic Liquids Technologies GmbH, Heilbronn, Germany
18:00 – 18:20		**Springer Materials Database** Michael Klinge, Springer-Verlag GmbH, Heidelberg, Germany

18:45	**Public Lecture** (Weinbrenner-Saal) **Neue Energie: Die zweite Erfindung des Automobils** Dr. Dieter Zetsche, Chairman of the Board of Managment Daimler AG, Head of Mercedes-Benz Cars, Stuttgart, Germany (simultaneous translation German -> English)
20:00	**Conference Dinner** (Schwarzwaldhalle)

	Room 2.08 **R.7: Low grade energy utilisation** Session Chair: Cheng-Liang Chen
9:00 – 9:30	Session Keynote Speaker **Organic Rankine Cycle for Waste Heat Recovery in Refinery Industry** Cheng-Liang Chen, National Taiwan University, Taipei, Taiwan
9:30 – 9:50	**Sulphur removal from waste tyre-derived oil and enhanced ethylbenzene formation over Ni catalyst supported on MCM-41** Witsarut Namchot, Center of Excellence on Petrochemical and Materials Technology, Bangkok, Thailand
9:50 – 10:10	**Identification of nitrogen compounds in tyre-derived oil using powerful GCxGC-TOF/MS for better analysis** Supattra Seng-eiad, Chulalongkorn University, Bangkok, Thailand
10:10 – 10:30	**Thermal Energy Harvesting Based on Metamagnetic Shape Memory Alloys** Marcel Gueltig, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
10:30 – 11:00	**Coffee Break**
	Room 2.08 **R.8: Wind energy** Session Chair: Stefan Emeis
11:00 – 11:30	Session Keynote Speaker **Meteorological aspects of wind energy conversion** Stefan Emeis, Karlsruhe Institute of Technology, Garmisch-Partenkirchen, Germany
11:30 – 11:50	**Redesign of wind turbines based on LiDAR technology, is it worth it? – A discussion based on a simple model for the tower's initial costs** Thorsten Beuth, Karlsruhe Institute of Technology, Karlsruhe, Germany
11:50 – 12:10	**Overview of Advanced Control Design for Optimal Wind Turbine Operation** Bastian Ritter, Industrial Science GmbH, Darmstadt, Germany
12:10 – 12:30	**Fault-Tolerant and Reliable Design of a Pumping Kite Power System** Felix Friedl, Delft University of Technology, Delft, The Netherlands

	Clubraum **E.7a: Fossil fuel power plants** Session Chair: Hans-Jörg Bauer	**Hebel-Saal** **E.7b: Energy efficient magnetic materials** Session Chair: Elisabetta Agostinelli
9:00 – 9:30	Session Keynote Speaker **AG Turbo – Joint Turbo Machinery Research to support the German Energiewende** Dirk Goldschmidt, Siemens AG, Mülheim an der Ruhr, Germany	Session Keynote Speaker **Re-thinking rare earths: Demand, sustainability and the reality of alternatives in magnetic materials** Oliver Gutfleisch, TU Darmstadt, Darmstadt, Germany
9:30 – 9:50	**Co-Combustion of Biomass in Pulverized Fuel Boilers** Hans-Joachim Gehrmann, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Exploring the magnetic properties of ferrite nanoparticles for the development of rare-earth-free permanent magnet** Claudio Sangregorio, CNR-ICCOM Firenze, Florence, Italy

9:50 – 10:10	**Materials for Advanced Ultra-Supercritical Fossil Power Plants: Materials Properties, Microstructure and Component Behaviour** Magdalena Speicher, University of Stuttgart, Stuttgart, Germany	**Magnetocaloric effect in Ni-Fe-Ga-Nd Heusler alloys** Felicia Tolea, National Institute of Materials Physics, Bucharest, Romania
10:10 – 10:30	**Heat Transfer during Depressurization of Supercritical Steam** Thomas Schulenberg, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Magnetic shape memory materials for energy applications** Franca Albertini, CNR-IMEM, Parma, Italy

	Thoma-Saal **E.7c: Efficiency in transport & mobility** Session Chair: Thomas Koch
9:00 – 9:30	Session Keynote Speaker **Pathway to Sustainable Energy Supply in Mobility** Kurt Kirsten, APL Automobil-Prüftechnik Landau GmbH, Landau, Germany
9:30 – 9:50	**Alternative Fuels in Euro VI Heavy Duty Applications** Olaf Röhl, Daimler AG, Stuttgart, Germany
9:50 – 10:10	**Energy consumption of BEVs in intensive use – Expanding theoretical models based on empirical data** Maximilian Schücking, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
10:30 – 11:00	**Coffee Break**

	Clubraum **E.8a: Fusion power** Session Chair: Friedrich Wagner	**Hebel-Saal** **E.8b: Thermoelectrics** Session Chair: Anke Weidenkaff
11:00 – 11:30	Session Keynote Speaker **The JET programme in support of ITER and the plans for DT operation** Lorne Horton, EUROfusion, Oxfordshire, United Kingdom	Session Keynote Speaker **State of the art, opportunities and challenges for thermoelectricity as competitive renewable energy source** Gilles Dennler, IMRA Europe, Sophia Antipolis, France
11:30 – 11:50	**Improved energy confinement in tokamaks** Yves Martin, EPFL, Lausanne, Switzerland	**Characterisation Method for Thermoelectric Power Modules** Ernst Höftberger, BIOENERGY 2020+ GmbH, Graz, Austria
11:50 – 12:10	**Thermal Energy Storage System Proposal for DEMO Fusion Power Plant** Evaldas Bubelis, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany	**Direct energy conversion for concentrating solar power using AMTEC clusters** Alexandru Onea, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
12:10 – 12:30	**Relativistic Fluid Dynamics for Modelling Inertial Confinement Fusion** Laszlo Csernai, University of Bergen, Bergen, Norway	**Toward Improved Chalcogenides Based Thermoelectric Modules for Renewable Energy Applications** Hazan Eden, Ben-Gurion University of the Negev, Beer-Sheva, Israel

12:30 – 13:15	**Panel Discussion** **A Sustainable Energy Future - Performed by Science and Technology** **Chair:** Dr. Karl-Friedrich Zieghahn, Karlsruhe Institute of Technology, Karlsruhe, Germany **Speakers:** Prof. Dr. Hardo Bruhns, Vorsitzender des Arbeitskreises Energie, Deutsche Physikalische Gesellschaft, Bad Honnef, Germany Prof. Dr. Joan Ramon Morante, Head of Advanced Materials for Energy Executive Committee of E-MRS Catalonia Institute of Energy Research, Barcelona, SpainProf. Dr. David Young, Civil and Environmental Engineering Department, University of North Carolina UNC, Charlotte, USA

	Mombert-Saal **S.7a: Carbon Capture and Storage/Carbon Sequestration** Session Chair: Frank Schilling	**Weinbrenner-Saal** **S.7b: Chemical energy storage and synthetic fuels** Session Chair: Georg Schaub
9:00 – 9:30	Session Keynote Speaker **Development of Carbon Capture Technologies with highest energy efficiency** Bernd Epple, TU Darmstadt, Darmstadt, Germany	Session Keynote Speaker: **Improvement of Fischer-Tropsch Synthesis through Structuring on Different Scales** Thomas Turek, Clausthal University of Technology, Clausthal-Zellerfeld, Germany
9:30 – 9:50	**The Indirectly Heated Carbonate Looping Process for CO_2 Capture** Daniel Hoeftberger, University of Erlangen-Nuremberg, Nuremberg, Germany	**Analysis of Fixed Bed Reactors for Flexible Fuel Synthesis Operation** María Iglesias Gonzalez, Karlsruhe Institute of Technology, Karlsruhe, Germany
9:50 – 10:10	**Ionic Liquids as Purification Media for Biogas** Thomas Schubert, IOLITEC Ionic Liquids Technologies GmbH, Heilbronn, Germany	**Concepts to utilize renewable power in chemical production** Julia Riese, Ruhr-University Bochum, Bochum, Germany
10:10 – 10:30		**Conceptual Design of Ammonia-Based Energy Storage and its Dynamic Considerations** Ganzhou Wang, RWTH Aachen University, Aachen, Germany

10:30 – 11:00	**Coffee Break**

	Mombert-Saal **S.8a: Mechanical storage of electric power** Session Chair: Ulrich Platt	**Weinbrenner-Saal** **S.8b: Chemical energy storage and synthetic fuels** Session Chair: Georg Schaub
11:00 – 11:30	Session Keynote Speaker **Thermodynamics and technical feasibility of CAES-TES systems** Adriano Milazzo, University of Florence, Florence, Italy	Session Keynote Speaker **Storage of Electrical Energy by Liquid Hydrocarbons** Andreas Jess, University Bayreuth, Bayreuth, Germany
11:30 – 11:50	**A flywheel energy storage system using reluctance clutch and standard drive** Iason Vittorias, Siemens AG, Munich, Germany	**Container plants for generation of sustainable liquid fuels made by ineraTec** Peter Pfeifer, ineraTec, Eggenstein-Leopoldshafen, Germany
11:50 – 12:10	**Successful energy transition in Germany by pumped storage expansion** Klaus Krüger, Voith Hydro Holding, Heidenheim, Germany	**Nitrogen-Based Alternative Fuel** Alon Grinberg Dana, Technion – Israel Institute of Technology, Haifa, Israel
12:10 – 12:30	**Modelling of mechanical storage systems** Ulrich Platt, University of Heidelberg, Heidelberg, Germany	**CO_2 Activation and Conversion into CO via Chemical Looping** Marcus Wenzel, Max-Planck-Institute for Dynamics of Complex Technical Systems, Magdeburg, Germany

	Thoma-Saal **S.8c: ICT for controlling infrastructures** Session Chair: Veit Hagenmeyer
11:00 – 11:30	Session Keynote Speaker **Information and Communication Technology in Energy Lab 2.0** Veit Hagenmeyer, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
11:30 – 11:50	**The Challenges of Securing the Smart Grid** Lucie Langer, AIT Austrian Institute of Technology GmbH, Vienna, Austria
11:50 – 12:10	**Evaluation of the Interoperability Score in the Smart Grid domain** Marie van Amelsvoort, OFFIS – Institute for Information Technology, Oldenburg, Germany
12:10 – 12.30	**Cyber-Physical Systems in Energy Simulation** Francisco Marzabal, European Institute For Energy Research, Karlsruhe, Germany

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1.01-1.	**Creation of Dipyrrin Metal Complex Nanosheet and Application in Photovoltaics Thereof** Ryota Sakamoto, The University of Tokyo, Graduate School of Science, Tokyo, Japan
1.01-2.	**Development of a data analysis methodology to assess PV system performance** Odysseas Tsafarakis, Utrecht University, Utrecht, Netherland
1.01-3.	**Photovoltaic characterization of manganite-oxide heterojunctions** Birte Kressdorf, Göttingen, Germany
1.01-4.	**Minority and majority carriers properties of n-type silicon RST ribbon** Abdelilah Slaoui, Laboratoire ICUBE – Université de Strasbourg-CNRS, Strasbourg, France
1.01-5.	**Anodized aluminium foils as substrates for polycrystalline silicon solar cells** Abdelilah Slaoui, Laboratoire ICUBE – Université de Strasbourg-CNRS, Strasbourg, France
1.01-6.	**Direct chemical dynamics and chemical reaction mechanism** Dr. Khatuna Kakhiani, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
1.01-7.	**A novel preparation method for high energy Li-ion battery electrodes based on capillary suspensions** Boris Bitsch, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.01-8.	**Fabrication of ZnO/TiO_2 Nanohexagon Arrays Heterojunction for Dye-Sensitized Solar Cells** H.M. Asif Javed, Xi'an Jiaotong University, XI'AN, China
1.02-1.	**Development of Hybrid Solar-Assisted Desalination Cycle in Power Industry of Uzbekistan: A Case Study of Sirdarya Thermal Power Plant** Khusniddin Alikulov, Hiroshima University, Saijo, Japan
1.02-2.	**Thermo-solar harvesting in mild humid climates: Absorber and self- cleaning surfaces on modified polymers** Flavio Horowitz, Federal University of rio Grande do Sul, Porto Alegre, Brazil
1.03-1.	**Electrocatalytical oxygen evolution at surfaces of manganites using RRDE** Garlef Wartner, Georg-August-Universität, Göttingen, Germany
1.04-1.	**Fuel particle properties in biomass fired power plants** Hartmut Mätzing, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.04-2.	**A lab scale measurement device for the air-liquid interface exposure cultured lung cells towards wood burning emissions** Sonja Mülhopt, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.04-3.	**Comparing Different Industrial Transport Scenarios for the Flash Pyrolysis Products within the bioliq®-Project** Thomas Nicoleit, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.04-4.	**Investigation of Catalytic steam Reforming of Tars and Methane for Highly Efficient Power Generation from Pressurized Biomass Gasification Gas** Michael Speidel, DLR German Aerospace Center, Stuttgart, Germany
1.04-5.	**Tailoring the viscosity function of a coke-water-slurry** Leon Jampolski, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.04-6.	**Upgrading of Low-grade Biogenic Feedstocks at STYX Pyrolysis Reactor** Marco Tomasi Morgano, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.04-7.	**Petrochemicals and fuels production using HBeta and hierarchical mesoporous MSU-SBEA catalysts in bio-ethanol dehydration as a function of time-on-stream** Waranpong Choopun, Bangkok, Thailand
1.04-8.	**Hydrocracking/and Hydroisomerization of Long Chain Hydrocarbons over Extrudate Pt/HY Catalysts** Kamonchanok Jariyasin, Chonburi, Thailand

1.04-9.	**Laser Induced Plasma Spectroscopy (LIBS) as a diagnostic tool for pressurized gasification processes** Peter Kutne, DLR e.V., Institute of Combustion Technology, Stuttgart, Germany
1.04-10.	**Properties of torrefied tropical biomass feedstocks** Scott Turn, University of Hawaii – HNEI, Honolulu, USA
1.04-11.	**Syngas cleaning by molten carbonates** Stephan Seidelt, EIFER – Europäisches Institut für Energieforschung, Karlsruhe, Germany
1.04-12.	**Development of bimetallic catalysts for bio-oil upgrading** Thuan Minh Huynh, Rostock, Germany
1.04-13.	**Innovative biomethane processes** Frank Graf, DVGW-EBI, Karlsruhe, Germany
1.04-14.	**Engineering fast pyrolysis of biomass: Influence of product recovery** Daniel Richter, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.04-15.	**Modelling of power demand-oriented biogas plant entities** Enrique Kremers, EIFER – European Institute for Energy Research, Karlsruhe, Germany
1.04-16.	**Formation of by-products during gasification of biomass based suspension fuels in an entrained flow gasifier** Sabine Fleck, Institute for Technical Chemistry, KIT, Karlsruhe, Germany
1.04-17.	**Liquefaction of lignin under conditions of direct coal liquefaction** Marcus Breunig, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.04-18.	**Investigation of Entrained Flow Gasification of liquid Fuels at ambient Pressure** Sabine Fleck, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.05-1.	**A Comparative Study of Medium Deep Borehole Thermal Energy Storage Systems Using Numerical Modelling** Daniel Schulte, TU Darmstadt, Darmstadt, Germany
1.05-2.	**Coupling of Renewable Energies with Medium Deep Borehole Heat Exchangers to Cover the Annual Heat Demand of Larger Buildings by Seasonal High Temperature Heat Storage** Daniel Schulte, TU Darmstadt, Darmstadt, Germany
1.05-3.	**An experimental study on the performance of Earth-Air Heat Exchanger used in an employee's cafeteria in Taiwan** Chien-Yeh Hsu, National Taiwan University, Taipei, Taiwan
1.05-4.	**Corrosion and scaling in the utilization of geothermal energy** Dr. Niklas Mundhenk, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.06-1.	**Sulfur removal from tyre-derived oil using mesoporous MCM-48** Sarinthip Trongyong, Ratchaburi, Thailand
1.07-1.	**Discovering the potential for offshore windfarms trough measurements** Stefan Balluff, Universität Paderborn, Paderborn, Germany
1.09-1.	**GIS-based Approach for the Assessment of Sustainable Biomass Potentials** Martina Haase, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.09-2.	**Impact of intermittent energy sources on the electricity production in Italy** Francesco Romanelli, ENEA, Monte Prozio Catone, Italy
1.09-3.	**Electricity by Intermittent Sources** Friedrich Wagner, IPP, Greifswald, Germany
1.09-4.	**European Energy Policy and Global Reduction of CO_2 emissions** Jozef Ongena, Energy Group of the EPS, Mulhouse, France

1.09-5.	**Residential urban structure and solar PV potentials in the context of Dhaka city, Bangladesh** Sujit Kumar Sikder, Friedrich-Wilhelms-University Bonn, Bonn, Germany
1.10-1.	**GIS-optimized modelling of sustainable biomass potential from forests in Germany and North West Europe** Ahssem Almehasneh, Karlsruhe Institute of Technology, Karlsruhe, Germany
1.10-2.	**Coherent Brownian Motion for Sustainable Energy: Dream or Reality?** Jean-Selva Rattinacannou, Saint Paul lès Dax, France
1.10-3.	**Renewable Fuel from One-pot Reaction of Jatropha Oil using Core-shell Catalysts** Vorachit Umnuaypor n, Renewable Fuel of Jatropha, Bangbuatong, Thailand
1.10-4.	**Properties and characterization of biodiesel from selected microalgae strains** Achilleas Christoforidis, EMA, Kavala, Greece
1.10-5.	**Kinetic Study of Algerian Cuminum cyninum L. essential oil isolated by conventional and microwave techniques** Farid Benkaci-Ali, University Houari Boumediene USTHB, Bab Ezzouar, Algeria
1.10-7.	**Air Conditioning by Sunlight Co-Utilization: Monitoring Results** Flavio Horowitz, Federal University of rio Grande do Sul, Porto Alegre, Brazil **Award**
1.10-8.	**Amorphous Biological molecule in the Human Eye with the unsuspected intrinsic property to split the water molecule** Arturo Solis-Herrera, Centro de Estudios de la Fotosintesis Humana. S.C., Aguascalientes, Mexico

2.03-1.	**Cryogenic Material Testing in CryoMaK** Klaus-Peter Weiss, Karlsruhe Institute of Technology, KIT-Zentrum Energie, Karlsruhe, Germany
2.03-2.	**Reprocessing and Activation of Advanced Tritium Breeder Pebbles** Keisuke Mukai, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.03-3.	**Globus-M plasma physics research the way to the fusion power application** Gleb Kurskiev, Ioffe Institute, St. Petersburg, Russian Federation
2.04-1.	**Energetic and economic analysis of a plus-energy building with electric heating** Claudia Weißmann, Technische Universität Darmstadt, Germany
2.04-2.	**Experimental evaluation of a structural element's thermal transmittance** Danai Georgiadou, Democritus University of Thrace, Xanthi, Greece
2.04-3.	**Simulated and experimental thermal characterization of advanced reflective and PV glazings** Nikolaos Skandalos, University of Patras, Agrinio, Greece
2.04-4.	**Connecting electric mobility to the energy management of blocks of flats** Lorenz Soleymani, Stephan Diekmann, Technische Universität Braunschweig, Germany
2.04-5.	**Control opportunities for occupants – a key to energy efficiency** Marcel Schweiker, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.04-6.	**Experimental assessment of thermal performance of roof materials** Sun Kyu Bang, Chung-Ang University, Seoul, Korea
2.04-8.	**Hybrid heating system for open-space office/laboratory** Christian Brembilla, Umeå University, Sweden
2.04-9.	**Energy Efficiency of Household Appliances and Awarenes Modeling** Meltem Ucal, Kadir Has University, Istanbul, Turkey
2.05-1.	**Shape Memory Alloys for Solid State Micro-Cooling** Hinnerk Ossmer, Karlsruhe Institute of Technology, Karlsruhe, Germany **Award**
2.05-2.	**The New MAX Infrared Technology for Efficient Industrial Solutions** Jürgen Weber, Heraeus Nobelight GmbH, Kleinostheim, Germany
2.05-3.	**Application of open modelling architecture for micro-CHP systems** Márcio Santos, Universidade de Coimbra UC, Coimbra, Portugal

2.05-4.	**Flow Optimization in a Hierarchical Plate Heat Exchanger for an Adsorption Heat Pump** Emmerich Tempfli, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.05-6.	**Transient model of a panel radiator** Christian Brembilla, Umeå University, Sweden
2.05-7.	**Energy Saving Impacts of Solar Radiative Properties of Roof Materials in Humid Continental Climates** Min Hee Chung, Chung-Ang University, Seoul, Korea
2.07-1.	**Capability of mobility systems to meet future CO2 savings targets** Praseeth Prabhakaran, DVGW-Forschungsstelle, Karlsruhe, Germany
2.07-2.	**Simulation based planning processes for the integration of inductively charged vehicles into public transportation services** Felix Burmeister, Deutsches Zentrum für Luft- und Raumfahrt e.V., Braunschweig, Germany
2.07-3.	**Impact of future electric vehicle saturation on the electricity grid** Oliver Warweg, Fraunhofer-Anwendungszentrum für Systemtechnik IOSB-AST, Ilmenau, Germany
2.10-1.	**Assessment and classification of the soft magnetic material cores for EMI filter application** Illia Manushyn, TU Darmstadt, Germany
2.11-1.	**Creep characterization of the SOFC ceramic anode substrate** Jürgen Malzbender, Forschungszentrum Jülich GmbH, Jülich, Germany
2.11.-2.	**Atom probe tomography (APT) on $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ (BSCF) and $Ba_{0.5}Sr_{0.5}(Co_{0.8}Fe_{0.2})_{0.9}Y_{0.1}O_{3-\delta}$ (BSCF10Y)** Lana-Simone Unger, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.11.-3.	**Processing and Characterization of Nanoscaled Ni/YSZ Anodes for Solid Oxide Fuel Cells** Julian Szasz, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.12-1.	**A new type of thermoelectric generator based on organic materials and manufactured through generative microstructuring** Siegfried Kettlitz, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.14-1.	**Crystallization Phase Diagram of m- and p-Chloronitrobenzene: Effects on Seeding** Jatuporn Kanuengnuek, Bangkok, Thailand
2.14-2.	**Optimization of thermal plasma process for the particle fabrication system** Byungkwon Kim, Korea Institute of Industrial Technology (KITECH), Cheonan-si Chungcheongnam-do, Korea
2.14-3.	**Efficient low temperature N_2O decomposition from HNO_3-exhaust streams over $K\text{-}Cu_xCo_{3-x}O_4$ catalysts** Tanja Franken, RWTH Aachen University, Aachen, Germany
2.15-1.	**Materials research for energy supply at Karlsruhe Institute of Technology** Regina Kruessmann, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.15-2.	**Phosphate based ceramics as solid electrolyte for high temperature lithium ion batteries** Yuantao Cui, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.15-3.	**Limitation of Diagnostic Methods for Single Core XLPE-Power-Cable and Requirements for Future Developments** Tobias Maier, Karlsruhe Institute of Technology, Karlsruhe, Germany
2.15-4.	**Low temperature Carnot Engine** Manfred Wilhelm / Ingo Naue, ITCP Karlsruhe Institute of Technology, Karlsruhe, Germany
2.15-5.	**Optimization for Improving Energy Efficiency of an Axial-Flow Fan** Jin-Hyuk Kim, Korea Institute of Industrial Technology, Cheonan-si Chungcheongnam-do, Korea

3.01-1.	**Electrochemical evaluation of electrodes for Microbial Fuel Cells** Jiang Bolong, TU Clausthal, Clausthal, Germany
3.01-2.	**Influence of particle shape on MSMD modelling of Li-ion batteries** Philipp Seegert, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-3.	**Titanium doped LiCoMnO4: High-Voltage Spinels as cathode materials for Li-Ion Batteries** Christoph Dräger, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-4.	**Modification of Graphitization and Surface for Electrodes in all-Vanadium Redox Flow Batteries** Joachim Langner, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-5.	**Controlled formation of nanostructured silicon as potential anode material for lithium ion batteries** Michael Elsaesser, University of Salzburg, Austria
3.01-6.	**Novel Electrolytes for Li-Ion Batteries with Improved Safety Issues** Andreas Hofmann, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-7.	**In-Situ SANS Analysis of Lithium Sulfur Cells** Charl Jafta, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany
3.01-8.	**Lithium-Air Battery Cathode Modification via an Unconventional Thermal Method Employing Borax** Andy Fiedler, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-9.	**Nano-structured lithium manganese phosphate via solvothermal reaction and anion substitution** Lars Esmezjan, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-10.	**New approach to evaluate EASA of carbon electrodes using OsO4** Lukas Pfaffmann, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-11.	**Nafion Coated Sulfur Electrode for High Performance Lithium-Sulfur Batteries** Xin-Hui Ma, Taipei, Taiwan
3.01-12.	**Novel Electrolytes for Batteries** Thomas J.S. Schubert, IOLITEC, Ionic Liquids Technologies GmbH, Heilbronn, Germany
3.01-13.	**Function integrated machine module for the production of cell stacks** Manuel Baumeister, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-14.	**Continuous folding process for the assembly of lithium-ion cells** Sebastian Haag, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-15.	**Sodium-ion batteries for low cost electrochemical energy storage** Christoph Vaalma, Ulm, Germany
3.01-16.	**Influence of substrate material and annealing process on phase and crack formation of LIB electrodes in the system Li-Mn-O** Marc Strafela, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-17.	**Optimal flow rate and load sharing control for flow batteries** Sebastian König, Karlsruher Institut für Technologie, Karlsruhe, Germany
3.01-18.	**Solid state thin film electrolyte for fluoride ion batteries** Le Zhang, Ulm, Germany
3.01-19.	**Lithium ion transport kinetic in ultrafast laser structured $LiFePO_4$ composite electrodes** Melanie Mangang, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-21.	**Influence of particle shape on MSMD modelling of Li-ion batteries** André Loges, Karlsruhe Institute of Technology, Karlsruhe, Germany

3.01-23.	**Multi-dimensional thermal modelling of prismatic Li-ion batteries** Daniel Werner, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-24.	**In situ detection of Lithium plating on Graphite by pulse-relaxation and optical microscopy** Christian Uhlmann, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-25.	**Influence of driving cycles on Li-ion cells studied by electrochemicalcalorimetric measurements** Carlos Ziebert, Karlsruhe Institute of Technology, Karlsuhe, Germany
3.01-26.	**Table-driven Li-Ion Battery Cell Model for a BMS Development Platform** Matthias Gulbins, Fraunhofer-Institute Integrated Circuits, Dresden, Germany
3.01-27.	**Parameter Identification For Equivalent Circuit Models Of Li-Ion Batteries Using The Current Interruption Technique** Andreas Melcher, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.01-28.	**Electrochemical-calorimetric studies on different lithium-ion cells** Boxia Lei, KIT IAM-AWP, Karlsruhe, Germany
3.02-1.	**The Liquid Organic Reaction Cycle - Thermochemical Energy Storage using Liquid Organic Hydrides** Christin Wagner, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.02-2.	**Chemical Heat Storage by the Dehydrogenation of Methylcyclohexane in Microstructured Reactors** Martin Cholewa, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.02-3.	**Energy storage and transportation by solar irradiation-aided CaO-looping** Jonas Obermeier, FAU Friedrich-Alexander Universität Nürnberg, Erlangen, Germany **Award**
3.02-4.	**One-step synthesis of liquid fuels in microchannel reactors** Chenghao Sun, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.02-5.	**Techno-economic Assessment of the Utilization of CO2 to Produce Liquid Fuels by Electrolysis and Fischer-Tropsch Synthesis** Daniel Helmut König, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Stuttgart, Germany
3.04-1.	**Coil Wound Heat Exchangers for Molten Salt Applications** Rosiel Millan Elias, Linde AG, Engineering Division, Pullach, Germany
3.04-2.	**Development of an innovative heat storage system for combined heat and power plants (CHP)** Boris Epple / Akin Simsek, Fraunhofer ICT / NAS, Karlsruhe, Germany
3.04-3.	**Experimental Determination of Heat-Dynamics of a Zeolite Bedding** Wilhelm Eckl, Fraunhofer ICT – Institut für chemische Technologie, Pfinztal, Germany
3.04-4.	**A Study on Transient Heat Transfer of Thermal Insulation with Latent Heat Material** Dongyeol Chung, Korea Institute of Industrial Technology, Cheonan-si Chungcheongnam-do, Korea
3.04-5.	**The Feasibility Study on Solar Greenhouse with Latent Heat Materials** Dongyeol Chung, Korea Institute of Industrial Technology, Cheonan-si Chungcheongnam-do, Korea
3.04-6.	**Test method of thermal conductivity during phase change processes with the HotDisk-technique** Maria Tyukavina, Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik, Oberhausen, Germany
3.04-7.	**Phase Change Analysis of PCM with simultaneous Cooling and Heatin** Donggyu Lee, Chonbuk National University, Jeollabuk-do, Korea
3.04-8.	**Production and regeneration of paraffin based Phase Change Slurries** Lucian Hanu, Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik, Oberhausen, Germany
3.04-9.	**Experimental Determination of Heat-Dynamics of a Zeolite Bedding** Sandra Pappert, Fraunhofer ICT, Pfinztal, Germany

3.05-1.	**Effect of Hollow Silica/Activated Carbon on CH4 Hydrate Formation** Rawipreeya Suesuan, Bangkok, Thailand
3.05-2.	**Zero-emissions power plant for chemical energy storage as well as power and heat generation** Can Yilmaz, Energy Research Centre of Lower Saxony / Clausthal University of Technology, Goslar, Germany
3.05-3.	**CO_2 Neutral Fuels** Adelbert Goede, FOM Institute DIFFER, Nieuwegein, Netherlands
3.05-4.	**The gas network as a controlling factor in the electricity net** Praseeth Prabhakaran, DVGW-Forschungsstelle, Karlsruhe, Germany
3.05-5.	**Comparison of Biological and Catalytic Methanation for Power-to-Gas Applications** Manuel Götz, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.05-6.	**Selective Adsorption of Methane over Carbon Dioxide on Activated Carbon** Pantipa Pranudomrat, Bangkok, Thailand
3.06-1.	**High-pressure Hydrogen Vessel Simulations with the Computational Fluid Dynamics Code GASFLOW** Daniela Piccioni Koch, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.06-2.	**Hydrogen Energy System (H_2ES) as Grid Management Tool for Renewable Energy Systems in Hawaii** Richard Rocheleau, University of Hawaii – HNEI, Honolulu, USA
3.07-1.	**Voltage- and State-of-Charge-managed storage integration for grid stabilization** Dirk Pietschmann, Fraunhofer-Institut für Verkehrs- und Infrastruktursysteme (IVI), Dresden, Germany
3.07-2.	**Reserve Capacity Provision through Flexible CHP and Power-To-Heat Technology in Industrial Applications** Hans Schäfers, HAW Hamburg Center for Demand Side Integration (C4DSI), Hamburg, Germany
3.07-3.	**High-Temperature Superconductor Current Leads as Energy Efficient Current Feeders for Superconductor Applications** Walter H. Fietz, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.07-4.	**Optimization of Large Scale Smart Grids** Arne Berger, Bremen, Germany
3.07-5.	**Advanced algorithm for the energy optimization in Microgrids – laboratory testing and experimental results** Gianluca Alimonti, Milano, Italy
3.08-1.	**A Modelling Language for Energy Consumption Management of Transport Networks: the case study of Karlsruhe** Ellishia Owens Cruz, Biel, Switzerland
3.08-2.	**Addressing the complexity of modeling building energy dynamics using a component-based approach** Muhammad Anas Munir, München, Germany
3.09-1.	**Study on Enhanced Energy Density of Organic Active Carbon-Based Supercapacitors** Jen-Hao Chien, Taipei, Taiwan
3.09-2.	**Electrochemical characterisation and abuse tests of first FSBW-Supercapacitors** Norman Baltes, Fraunhofer ICT – Institut für Chemische Technologie, Pfinztal, Germany
3.11-1.	**Roles of Polybenzoxazine Functionalization on CO_2 Adsorption** Katipot Inkong, Trang, Thailand
3.11-2.	**Measurement of Minimum Miscibility Pressure of CO_2 in Thai Crude Oil. Effect of gas impurity** Supanut Jirarattanawanna, Ratchaburi, Thailand

3.11-3.	**Extraction of Degradation Products in Monoethanolamine Absorption Solution Used in Carbon Dioxide Capture** Wallapa Krajangpit, Phathumthani, Thailand
3.11-4.	**Natural Fiber Adsorbents Treated by Amines for Carbon Dioxide Adsorption** Andaman Taechatada, Samutsakhon, Thailand
3.11-5.	**CO_2 Absorption: Effect of Glycols on CO_2 Solubility of 2-Amino-2-Methyl-1-Propanol (AMP)** Puttipong Jaroenthai, Mukdahan, Thailand
3.12-1.	**Evolutionary Multi-Objective Optimization of Micro Grids** Alexander Wanitschke, Reiner Lemoine Institut, Berlin, Germany
3.12-2.	**Load Analysis of a House with Hybrid Systems and an E-Vehicle** Stamatia Dimopoulou, Ostfalia Hochschule für angewandte Wissenschaften, Wolfenbüttel, Germany
3.12-3.	**Impact of "Energy Turnaround" in Germany on the Nordic Power Market: A Cross-Border Energy System Modeling Approach** Behnam Zakeri, Aalto University Energy Technology, Aalto, Finnland
3.12-4.	**Modelling of Cross-Border Energy Systems – Towards EU-Wide Electricity Markets** Behnam Zakeri, Aalto University Energy Technology, Aalto, Finnland
3.12-5.	**Stabilizing offshore wind farm power feed-in via power to gas storage systems** Stefan Balluff, Universität Paderborn, Germany
3.12-6.	**Gaining insight into meso-level behaviour around collaboration behaviour in the energy storage field within the Dutch heat and cold chain** Jorick Weijers, ING Bank, Balance, TU Delft, Netherland
3.12-7.	**Techno-economical System Optimisation and Its Application to an Energy System** Mario Holl, TU Darmstadt, Chair of Fluid Systems, Darmstadt, Germany
3.12-8.	**In situ study of nano-CeO_2 synthesis using laboratory diffractometer** Olga Narygina, Almelo, Netherland
3.12-9.	**Scenario-Based Assessment of the Economic Feasibility of CCS Power Generation Technology in Central Europe** Tobias Brauweiler, Institute for Future Energy, Consumer Needs and Behavior, Aachen, Germany
3.12-10.	**Concept study – using a hybrid vehicle as a CHP plant** Andreas Kessler, Reutlingen University, Reutlingen, Germany
3.12-11.	**Comparative assessment of representative data driven modelling approaches for medium term electricity price forecasting** Nico Schweiger, EIFER – Europäisches Institut für Energieforschung, Karlsruhe, Germany
3.12-12.	**Energy management modelling for PV-diesel off-grid power plants** Emmanuel de Martel, EIFER – Europäisches Institut für Energieforschung, Karlsruhe, Germany
3.12-13.	**An open-source data infrastructure for storage, analysis and visualization of city energy geospatial data** Jochen Wendel, EIFER – Europäisches Institut für Energieforschung, Karlsruhe, Germany
3.12-14.	**Development of a Market-Based Virtual Power Plant Optimisation Model** David Gohsen, RWTH Aachen, Germany
3.12-15.	**A balanced electricity mix – the role of system costs and material requirements in renewable energy supply systems** Denis Hess, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Stuttgart, Germany
3.12-16.	**Evaluation of energy efficient wastewater treatment concepts of the future using a plant-wide modelling approach** Nina Manig, ISAH, Leipniz Universität Hannover, Germany

3.12-17.	**Indicators for monitoring and assessing the German energy transition** Patrick Lichtner, Karlsruhe Institute of Technology, ITAS, Karlsruhe, Germany
3.12-18.	**Health-related external costs in Europe: impacts of methodological developments since 1999 for a coal-fired power plant** Ute Karl, EIFER – Europäisches Institut für Energieforschung, Karlsruhe, Germany
3.12-20.	**A library and modelling approach for the simulation of holistic multi energy systems** Xiubei Ge, EIFER – Europäisches Institut für Energieforschung, Karlsruhe, Germany
3.12-21.	**Cyber-Physical Systems in Energy Simulation** Enrique Kremers, EIFER – Europäisches Institut für Energieforschung, Karlsruhe, Germany
3.12-22.	**Energy Optimization at the Baden-Wuerttemberg Cooperative State University Mannheim** Linda Steglich, DHBW Mannheim, Mannheim, Germany
3.12-23.	**Simulation of current distribution in parallel-connected cells to achieve homogeneous cell stress** Kevin Stella, Karlsruhe Institute of Technology, Karlsruhe, Germany
3.12-24.	**ELEXTERN: transparently valuing electricity externalities** Frédéric Wertz, Centrum Vyzkumu Rez, Husinec-Řež, Czech republic
3.13-1.	**The viability of distributed energy storage solutions for end-consumers: An assessment of regulatory and financial incentive schemes** Jan Ossenbrink, ETH Zürich, D-MTEC Sustainability & Technology, Zurich, Switzerland

Plenary Lectures

Decarbonizing the global energy system: insights from the new IPCC Report

Prof. Dr. Thomas Bruckner, *Institute for Infrastructure and Resources Management (IIRM), University of Leipzig; Department for Sustainability Management and Infrastructure Economy, Fraunhofer MOEZ, Leipzig, Germany,* bruckner@wifa.uni-leipzig.de

Keywords: Global Change, Mitigation Strategies, Integrated Assessment Models

Introduction

The stabilization of greenhouse gas (GHG) concentrations at levels consistent with the internationally agreed goal of staying below 2°C temperature change requires a fundamental transformation of the energy supply system. Fortunately, multiple options exist to reduce the GHG emissions of the energy supply sector GHG. These include energy efficiency improvements and fugitive emission reductions in fuel extraction as well as in energy conversion, transmission, and distribution systems; fossil fuel switching; and low-GHG energy supply technologies such as renewable energy (RE), nuclear power, and carbon dioxide capture and storage (CCS). The plenary lecture given by the coordinating lead author of Chapter 7 on “Energy Systems” in the third volume of the recently published 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) discusses the related opportunities and the challenges associated with achieving low GHG concentration goals.

Results

Limiting global mean temperature change requires a stabilization of greenhouse gas concentrations in the atmosphere which in turn implies a finite budget of admissible GHG emissions. In the cost-effective mitigation scenarios that are assessed in the IPCC report [1], the associated long-term reductions of GHG emissions are mainly achieved by (1) reducing the final energy demand in the end-use sectors (industry, building, transport, and agriculture and land-use) and (2) by upscaling the usage of low carbon energy supply technologies in order to provide the remaining energy demand with low GHG emissions (see Figure 1).

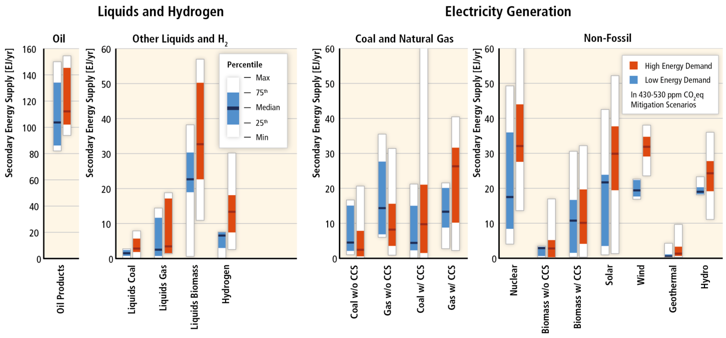

Figure 1: Influence of energy demand on the deployment of energy supply technologies for stringent mitigation scenarios (430 – 530 ppm CO2eq) in 2050. Blue bars for ‘low energy demand’ show the deployment range of scenarios with limited growth of final energy of < 20 % in 2050 compared to 2010. Red bars show the deployment range of technologies in case of ‘high energy demand’ (> 20 % growth in 2050 compared to 2010). Source: Figure 7.11, [1].

The lecture highlights the need for integrated approaches which are capable to determine least-cost portfolios of mitigation options. In addition, it emphasizes that while some mitigation technologies (like nuclear energy) can be excluded from the set of admissible mitigation options without a significant increase in the mitigation costs, excluding carbon capture and sequestration (CCS), especially combined with bioenergy, would increase the costs of achieving stable GHG concentrations considerably.

Acknowledgement: The author would like to thank all colleagues who have contributed to carry out the 5th IPCC Assessment published by Intergovernmental Panel on Climate Change (IPCC).

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Invited Session Keynotes

Renewable Energies

Fuels from solar energy and water - an overview of the solar fuel field

Stenbjörn Styring, *Molecular Biomimetics, Department of Chemistry-Ångström, Uppsala University,*
Stenbjorn.Styring@kemi.uu.se

Abstract

Solar fuels is a quite recent nomenclature for fuels made from solar energy using water (an endless resource) as raw material for the fuel. Most research aims for water oxidation to hydrogen but also strategies involving CO_2 reduction to carbon based fuels are frequent. Solar fuels research is often also called artificial photosynthesis, the artificial leaf or similar. The lecture will analyse the need for solar fuels and compare a global overview with some national perspectives to emphasise their place in any credible, future energy system. Development of solar fuels is still heavily concentrated to basic research and there are several viable options that are pursued internationally. The lecture will overview most of the different scientific paths to achieve solar fuels.

The second half of the lecture will describe the visions and strategies in research in the Swedish Consortium for Artificial Photosynthesis (CAP) [1,2]. The Swedish Consortium is a bottom up initiative created by individual researchers at Swedish Universities. It was founded 1994 and is thus one of the world´s oldest, larger consortia in this field. Our research aims for the production of hydrogen from solar energy and water. We follow both a completely synthetic path and a photobiological path using photosynthetic micro-organisms. In the synthetic path we apply a biomimetic approach where we copy key principles from natural enzymes that accomplish partial reactions. To accomplish reduction of protons to hydrogen we mimic the di-iron center in hydrogenase enzymes[3]. The lecture will also cover a water oxidizing catalyst based on a cobalt nano-particle and very recent results on this catalyst[4, 5]. In the photobiological approach we modify cyanobacteria to produce either hydrogen or carbon based fuels using synthetic biology approaches.

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Syngas as Platform from Sustainable Feedstocks to Fuels

Prof. Dr.-Ing. Jörg Sauer, Karlsruhe Institute of Technology, j.sauer@kit.edu

Keywords: Biomass-to-Liquid, Power-to-Liquid, Lignocellulosic Biomass, Fuels

Introduction

The political discussion around the German "Energiewende" focusses at present mostly on the supply of the energy carrier „Electricity" and also on the sustainable ways to distribute and store energy. Besides the development target for 2050 of 80% for renewables in the electricity sector, the German federal government set also a target of 60% share of renewables for the total energy system in Germany. This will include also liquid energy carriers which account for 37% of the total consumption of secondary energy carriers in Germany [1]. Due to their high energy content and the existing infrastructure for liquid fuels (gasoline, diesel, kerosene), liquid fuels will be needed on longer term even under the conditions of the "electrification" of the transport sector. Unlike biofuels of the first generation, synthetic fuels from sustainable biomass are based on organic residues from agriculture or forestry and other feedstocks which are not competing with food production. Feedstocks which are sustainably available consist mostly of lignocellulosic material. A variety of technologies have been developed for the valorization of lignocellulosic materials. The technologies can be clustered into "lignocellulose hydrolysis-value chains" which have sugar components as key intermediates, whereas the "syngas-value chains" comprise energy dense intermediates from biomass and synthesis gas ($CO/H_2/CO_2$) as key intermediates. Besides from biomass synthesis gas can be produced from a variety of sources including the water electrolysis for hydrogen production and CO_2 from the combustion of biomass or other sources. The electrochemical routes to hydrogen and the pathway from biomass to syngas can be interlinked which offers the potential of synergies especially under conditions of a fluctuating supply of electricity from PV and wind energy.

Discussion

The bioliq® concept is based on the idea of energy densification of lignocellulosic biomass through the pyrolysis and blending of the pyrolysis products to the so called "biosyncrude". The pyrolysis units will be located in areas where large amounts of lignocellulosic biomass are available. The liquid biosyncrude will subsequently be delivered from the pyrolysis units to centralized "syngas-biorefineries" where chemicals and fuels are produced. The bioliq®-plant at KIT is supposed to act as a pilot facility to demonstrate the feasibility of the targeted integrated production system. The pilot plant has been realized in several project steps from 2005 until 2013. In 2014 the complete process chain has been put in operation starting from the conversion of ligno-cellulosic biomass to biosyncrude and subsequent fuel production from biosyncrude. The latter step comprises biosyncrude gasification, purification of the resulting syngas and its conversion to gasoline via dimethylether [2].
This large scale infrastructur will be linked to the EnergyLab 2.0 which will be established at KIT in cooperation with other centers of the Helmholtz society in order to study synergies of energy generation and consumption with the storage of energy and its distribution in a local grid together with the production of synthetic fuels like methane, dimethylether, gasoline and jet-fuel.

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EU wide overview of biomass potentials

Dr. Berien Elbersen*, Alterra Wageningen, Earth Informatics, Berien.elbersen@wur.nl*

Keywords: Biomass, sustainability, mobilisation

Introduction

For developing biomass delivery chains for energy or other biomaterial production processes it is important to have secure and affordable access to sustainable biomass resources. As part of 2 EU projects (*S2BIOM & Biomass Policies*) the biomass potentials (cost-supply) from agriculture, forest and waste sectors were quantified and mapped. The availability of the biomass was assessed under certain sustainability requirements and competing use assumptions and within a certain time period (2010, 2020, 2030). In addition a SWOT analysis was made regarding the suitability of the feedstock to be used in different biomass value chains and the mobilisation options. In this presentation an overview is given of the results of this assessment. First an overview is given of the main biomass feedstock potentials and then the options are discussed for the use of the biomass from the perspective of availability, options for mobilisation, cost and resource efficiency.

Discussion

If we assume a stable stem wood demand and thus no mobilisation of forest production the forest biomass potential is still by far the largest, but stabilises towards 2020 and 2030. This is particularly explained by the fact that there is a large amount of primary residues that can be additionally harvested when removing the main product stemwood, but practice is currently that most of it is left in the forest. After the forest the largest potential can come from agricultural residues and as from 2020 also from dedicated crops grown on unused farmlands. Because of this the growth in agricultural potential between 2010 and 2030 can be large provided the right incentives will come from policy and markets. Biomass from the waste sector provides the lowest contribution to the total and this position remains stable towards 2020 and 2030. The latter is often an attractive category for use in bioenergy production. This is already happening at large scale but many countries can improve their waste treatment considerably, both through conversion in compost and other materials, but also through increased incineration with energy capture and anaerobic digestion.

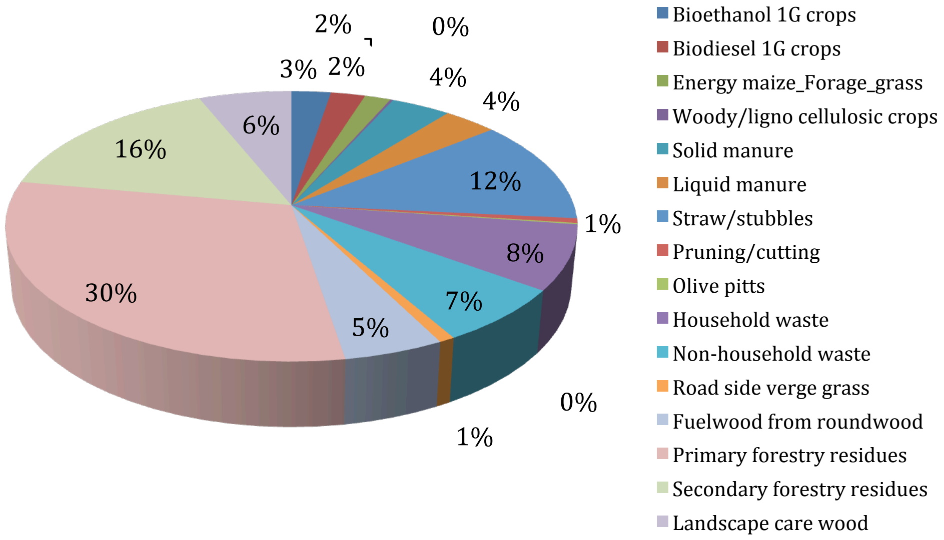

Figure 1: Composition of biomass potentials EU-28 for 2010 (basis for figure is TJ potentials)

Conclusions and/or Outlook

There are large unused potentials at this moment which include manure, straw, pruning potentials, primary forestry potentials, biomass from landscapes and dedicated crops from agriculturally abandoned and more marginal lands. There are several reasons for this but the main are lack of a real market demand that can help to mobilise the production and/or harvest and technologically readiness for efficient biomass conversion into energy and high value added products and for efficient logistics and pre-treatment solutions.

Acknowledgement:
The results presented in this presentation were developed as part of the EC and nationally co-funded projects S2BIOM and Biomass Policies. The results were elaborated with input from several partners participating in these 2 projects. For further details see: http://www.s2biom.eu/ and http://www.biomasspolicies.eu/

Integration of Organic Rankine Cycle and Recirculating Hot Oil for Waste Heat Recovery in Refinery Industry

Cheng-Liang Chen [*], *Po-Yi Li , Jui-Yuan Lee, and Si Le*

Department of Chemical Engineering, National Taiwan University, Taipei 10617, Taiwan, ROC

[*]*Corresponding Author's E-mail: CCL@ntu.edu.tw*

Keywords: *Waste heat, organic Rankine cycle (ORC), Superstructure, Mixed-integer non-linear programming (MINLP), Exergy analysis*

ABSTRACT

An organic Rankine cycle (ORC) uses a low boiling point organic fluid as a working medium. Waste heat recovery is one of the most important development fields for the organic Rankine cycle (ORC). It can be applied to heat and power plants, or to industrial and farming processes. However, some heat sources, such as hot exhausts from furnaces, which contains particles or sulfide might hurt pipes of evaporator. It is suggested to introduce water or heat tranfer oil as an intermediate medium for waste heat recovery.

In this paper, a mathematical model is presented to integrate ORC with the heat tranfer oil recirculated as an intermediate fliud for recovering waste heat from the background process. An ORC-integrated superstructure considering all possible match of heat-exchange between process hot streams, recirculating hot oil and ORC working fluid, is proposed. The possibility of several sets of waste heat sources, the ORC, and the recirculating hot oil is also concerned in the superstructure. On the basis of this superstructure, the model is formulated as a mixed-integer nonlinear program (MINLP). This MINLP model is designed and solved by a high-level modeling system, General Algebraic Modeling System (GAMS). The thermodynamic properties of working fluids are calculated by Matlab. A case study about the crude pre-heat train is solved to demonstrate the application of the proposed model for industrial waste heat recovery. For a given heat source, some organic fluids can be used in both subcritical and transcritical status. The exergy analysis is applied to compare the performance of subcritical and transcritical ORC in a given waste heat source. Furthermore, working fluid selection for this case is also discussed in this paper.

Meteorological aspects of wind energy conversion

***Prof. Dr. Stefan Emeis**, Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, stefan.emeis@kit.edu*

Keywords: Wind Energy, meteorology, wind profile laws, low-level jets, wind farm wakes

Introduction

The atmospheric boundary layer (ABL) consists of the lower logarithmic surface (Prandtl) layer and the Ekman layer above where the wind turns to the wind direction in the free atmosphere. Modern wind energy converters (WEC) are that high that they mainly use winds from the Ekman layer. Planning and operating such WECs thus requires a uniform description of the vertical profiles of wind and turbulence to heights of at least 200 m above ground, i.e. through the Prandtl and the Ekman layer. Furthermore, the assessment of non-stationary phenomena such as nocturnal low-level jets (LLJ) which frequently form in the Ekman layer becomes necessary. Atmospheric turbulence is relevant as well. Turbulence influences not only the fatigue of WECs but also governs the dissipation of wakes behind WECs.

Two-layer wind profile model

A two-layer wind profile model was presented in [1] and recently tested in [2]. This model combines the stability-corrected logarithmic law in the Prandtl layer with turning law in the Ekman layer. The fit between these two laws provides a smooth transition for the mean wind speed and its first derivative, i.e. the vertical wind shear. In [2] it was found, that this two-layer Prandtl–Ekman model compared to other approaches provided the best balance of low bias and variance for the entire stability range.

Low-level jets

Nocturnal low-level jets are a regular boundary layer phenomenon which appears, when the ABL stratification becomes stable after sunset while there is still a large-scale horizontal pressure gradient [3]. Vertical soundings of boundary wind profiles with ground-based remote sensing devices (Sodar and RASS) over several years in Hannover and Augsburg have been evaluated for forming a climatology of the occurrence of LLJs over Northern and Southern Germany. The occurrence of LLJs is linked to the occurrence of certain weather patterns and happens in about 21% of all nights in Northern Germany and in about 15 % of all night in Southern Germany.

Offshore wind farm wakes

The planning of offshore wind farms in the German Bight tries to use the available space as efficiently as possible. Clustering of such wind farms also lowers the costs for connecting them to the existing electrical grid. Therefore, many offshore wind farms have been arranged in larger clusters within which the single farms are quite close to each other. On the other hand, the decay of wakes behind wind farms is proportional to turbulence intensity. As turbulence intensity in marine environments is much lower than over land, farm wakes turn out to be much longer over sea than over land. Evaluation of data in this respect from existing farms has just started. Therefore, [4] developed a simple analytical model for a first assessment of the influence of turbulence intensity and atmospheric thermal stratification on farm wake lengths. The results compare well with the few exiting observations and numerical model studies and give important hints for the necessary spacing of wind farms.

Outlook

Meteorological conditions are an important factor for planning and operating single WECs as well as large wind farms. This contribution highlights a few important issues. More concise overviews can be found in [1] and [5].

Acknowledgement: Part of the measurements used in this study were made during the project VALIUM (reference number 07ATF12) which was part of the greater German atmospheric research initiative AFO2000 of BMBF. Sophia Helgert (now University of Graz, Austria) performed the evaluation of the RASS data for Augsburg during an internship at our institute.

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Hydropower – renewable and sustainable electricity generation with fast response times

Prof. Dr.-Ing. Stefan Riedelbauch, *Institute of Fluid Mechanics and Hydraulic Machinery, University of Stuttgart, stefan.riedelbauch@ihs.uni-stuttgart.de*

Keywords: Hydropower, regulation plant, two-phase flow, transient operation, ocean current

Introduction

The solar radiation maintains the natural water cycle on our planet, where hydroelectric power plants take out energy and change it to electricity. The basic physical principle relates to the conversion of potential energy. Other concepts convert the kinetic energy of moving water flow, e.g. in rivers or in certain parts of oceans. Such ocean currents are generated by gravity forces between earth, moon and sun. Solar radiation and gravity forces are truly renewable as they are inexhaustible within the human time horizon. The energy transition towards renewable energies significantly changed the electricity generation mix towards a substantial increase of wind and photovoltaic power. Owing to their dependence on weather conditions, their electricity generation may vary very much sometimes within very short time intervals. Owing to their active principle, hydroelectric power plants are ideally suited to serve as regulation plant in electrical grids with a high percentage of fluctuating renewable energy. Those plants stand out due to their short mode and load change transition times. They are very efficient because of their high efficiency and they can be operated in an extremely flexible way.

Discussion

The large extension of the operation regime of hydroelectric equipment results in high dynamic loads on all mechanic components of the plant. Those dynamic loadings are primarily caused by the hydraulic turbine producing complex flow phenomena. For off-design conditions there are unsteady full or part load vortices with cavitating fluid structures. The accurate prediction of these kinds of flows for complex geometries at high Reynolds number requires cavitation modelling and at least a hybrid RANS-LES turbulence model, fig.1 left [1]. The fast transient operation mode change of a pump-turbine from steady pump operation to a steady turbine operation at constant guide vane openings is simulated to identify flow behaviour and mechanical loading of the machine.

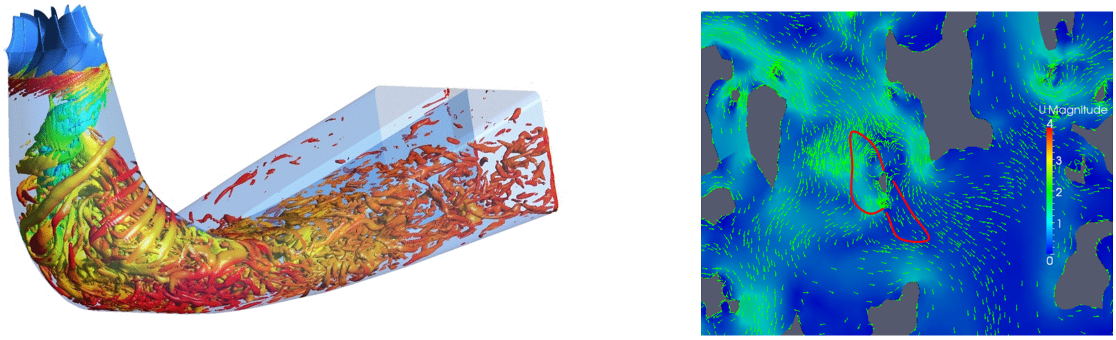

Figure 1: Left: Velocity invariant coloured by pressure for a Francis turbine at part load operation; Right: Simulation of ocean current between islands to identify energy rich locations for turbine positioning.

For the efficient positioning of ocean current turbines the precise flow properties in the area of interest need to be known for maximum energy conversion, fig. 1 right [2]. The interaction between ocean current and turbines is important to assess the electricity output of turbine parks eventually consisting of some thousand turbines.

Conclusions

Hydropower is renewable and sustainable and ideally suited to serve as regulating plant. Those wide operation ranges raise challenges for research, such as cavitating two-phase flows and free surface flows, turbulence modelling for complex high Reynolds flows, transient load changes in turbomachines, and ocean current simulation with turbine interaction to assess the energy conversion potential.

Acknowledgement: Special thanks to my team J Wack, T Krappel, C Stens and A Ruopp for providing presentation material.

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Invited Session Keynotes

Energy Efficiency

AG Turbo – Joint Turbo Machinery Research to support the German Energiewende

***Dr.-Ing. Dirk Goldschmidt**, Siemens Power & Gas, Chair of the AG Turbo Programme Committee*

Abstract

A major Goal of the German Energy Programme is to reach a share of 80% of renewables in gross electricity consumption until 2050. Already today it can be seen that the volatile supply of wind and sun power poses an extreme burden on the stabilization of the power grid. A recent example is the eclipse of the sun last spring, where in Germany gradients as high as 17GW/h had to be balanced by the fossil power plant fleet. It can also be observed, that the increasingly unsteady operation of fossil power plants promotes early damages, which enter more and more into the focus of interest of assurance companies. On the other hand, even in the most optimistic scenarios of increasing the share of renewables and even assuming that power storage options are available, there will be not enough surplus power from renewables filling the gaps of power supply by stored power under realistic power to power efficiencies for a long time. This requires a fleet of highly flexible fossil power plants with thermal turbo machinery operating at challenging conditions for many decades to come.

AG Turbo is a platform, where pre-competitive, application oriented turbo machinery research in Germany is coordinated. It brings together the main industry player in turbo machinery and more than 20 universities and research institutes. Key success factor is the close collaboration of aero engine industry with compressor and stationary turbine industry, which in many technological fields have the same challenges to solve. Since its foundation in 1985 AG Turbo drives the technology development via joint research programs accumulating a budget of more than 300 Mill € until today, provided by industry and governmental funding at equal shares. Whereas at the beginning the focus of the research was clearly set in increasing the efficiency and reliability of turbo machinery it has now moved to answer the complex requirements for residual load in a volatile power grid environment. Future research focus will provide the basis for turbo machinery to play its role in a fully integrated supply system.

The close cooperation of the partners from industry and research ensures the optimal exploitation of technical and financial resources, it generates synergies, it avoids redundant developments, it promotes training and qualification of scientists in various fields of engineering sciences, and it finally contributes to the fact, that Germany has gained a leading position in the international, competitive and seminal field of turbo machinery for years.

Sustainability of Nuclear Power – Fuel Cycles

Dr. Marco Streit *– Nuclear Energy and Safety Department of Paul Scherrer Institut*

Keywords: Energy, Conversion, Technology, Climate, Material

Abstract

In 2005 the World Summit on Social Development identified the three main pillars for a sustainable development as economic development, social development and environmental protection. Since then, the consideration of the sustainability of production has entered all areas of our daily live as well as the energy production.

Having a look on the public opinion, as expressed in the "free encyclopedia Wikipedia", the situation is quit clear: so called renewables are sustainable, fossils are not and nuclear by the fact that it is discussed quit controversially.

Looking at the three pillars nuclear has to be considered as economical profitable as a large industry relies on this technology.

The controversial discussion about nuclear already shows the major issues, public acceptance. If a technology is not accepted by society's philosophy it will by definition not be sustainable for this society. But looking at the pillar social development this might be different from a viewpoint of other value systems, last but not least environmental protection. In case of nuclear, this is strongly linked to the chosen reactor technology and the chosen fuel cycle.

To answer the question if and how much nuclear energy is sustainable, is
a quite challenging task. From a technical point of view the choice of a fuel cycle is one of the major influencing factors of the sustainability of nuclear given an economic and social system. An overview about the potential influence of the different known fuel cycles and their influences to the protection of the environment will be given, discussing points like the amount of used uranium, produced waste, radiation risk in case of an accident, risk of proliferation and further more.

The JET programme in support of ITER and the plans for DT operation

***Dr. Lorne Horton**, JET Exploitation Unit and European Commission, Lorne.Horton@jet.uk*
*JET Contributors**

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK

Keywords: Nuclear Fusion, Tokamak, Deuterium-Tritium

Introduction

The European magnetic confinement fusion programme has a history of multi-national collaboration that stretches back to the 1950s. As part of the Euratom 2014-2018 work programme, this collaboration has been reorganised so that the joint part of the EU magnetic fusion programme is now the responsibility of a consortium, called EUROfusion, of all of the European fusion institutions. Supported by a Euratom grant, EUROfusion is undertaking to implement the community's Roadmap to the Realisation of Fusion Energy [1]. A key element of the roadmap and of the EUROfusion programme is the collaborative exploitation of the Joint European Torus (JET). The JET programme is specifically designed as support for ITER [2], the experimental fusion reactor presently under construction in southern France.

Discussion

The JET programme in support of ITER is based on the installation of a first wall on the interior of the plasma chamber that is made of the same material combination (beryllium near the hot plasma and tungsten in the region of maximum heat and particle loading) as will be used in ITER. This is crucial as plasma-wall interactions influence the achievable fusion performance in a variety of ways. In order to test these influences and thus provide the best possible preparation for ITER operation, the JET heating, diagnostic and protection systems were also upgraded so as to allow safe exploration of performance limits.

The experimental strategy in the JET programme with the new capabilities is divided into three phases. In the first phase, completed in 2011-12, the compatibility of ITER scenarios of operation with the new wall was demonstrated and the expected order of magnitude reduction of fuel retention in the machine – a key safety issue for ITER – was proven. The JET programme is presently focused on delivering the second experimental phase in which the maximum plasma performance will be mapped out in deuterium plasmas. The final phase of JET experimentation, presently scheduled for 2017, will demonstrate this performance in deuterium-tritium mixtures in which several MWs of fusion power will be generated in ITER regimes of operation. These experiments will also explore the physics of variation in fuel isotope and of generated fusion alpha particles.

The JET D-T experiments also provide an opportunity to test a variety of technologies that will be required in ITER and a fusion reactor. The scope of this technology programme includes experiments, analyses and data collection in the areas of tritium handling, retention, removal and fuel cycle, neutronics and activation, radiation damage of functional materials, safety, and waste production and characterisation.

Summary

The European magnetic confinement fusion programme is in a period of transition. Experiments have and are moving more and more towards integration rather than testing the limits and dependencies on individual parameters. The programme is become more and more technology- rather than physics-driven, not least in respect to support for the construction of ITER. Finally, the programme is moving towards nuclear operation with deuterium-tritium fuel mixtures. The JET DT experiment is a crucial element in this transition. According to the chair of the EUROfusion General Assembly, J. Paméla, the JET DT experiment is "the most important deliverable in the EUROfusion work programme". This experiment will be the culmination of decade-long programme designed to provide an integrated test of maximum plasma performance with controlled and ITER-relevant plasma-wall interactions.

Acknowledgement: This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

* See the Appendix of F. Romanelli et al., Proc. of the 25th IAEA Fusion Energy Conference 2014, St. Petersburg, Russia

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Grid interaction of buildings - analysis and operation

***Sebastian Herkel**, Fraunhofer Institute of Solar Energy Systems, sebastian.herkel@ise.fraunhofer.de*
Dr. Doreen Kalz, Fraunhofer Institute of Solar Energy Systems, doreen.kalz@ise.fraunhofer.de
Konstantin Klein, Fraunhofer Institute of Solar Energy Systems, konstantin.klein@ise.fraunhofer.de

Keywords: grid interaction, evaluation method, demand response, heat pumps, CHP, buildings, monitoring

Introduction

The increasing share of fluctuating renewable energy carriers in the energy system leads to an increasing volatility in power availability. A reliable electricity supply based on renewable energies therefore requires flexibility measures such as electric energy storages and energy conversion processes. It seems likely that the building sector can contribute significantly to demand response by shifting the electricity consumption for heating and cooling to more favourable periods of the day.

Discussion

A new method for assessing the grid interaction of a building's electricity consumption and generation is presented. It consists of the dimensionless absolute and relative Grid Support Coefficients GSC_{abs} and GSC_{rel}. GSC_{abs} "weights" the electricity consumption profile with a time-resolved reference quantity which expresses the availability of electricity (here: stock electricity price, residual load, cumulative energy consumption or fraction of wind and PV in the electricity mix). GSC_{rel} relates GSC_{abs} to the worst and best achievable values on a scale of 100 to 100 in order to increase the comparability of the results.

The new evaluation method is applied to analyse the electricity consumption or production of 52 energy supply systems in buildings, where detailed monitoring data are available. These examples include twelve heat pumps or chillers in office buildings, 38 heat pumps in residential buildings and two combined heat and power units (CHP) in multi-family buildings using CHP units, all located in Germany. The in-depth analysis shows that the analysed present-day buildings predominantly consume electricity at times with low or average electricity availability.

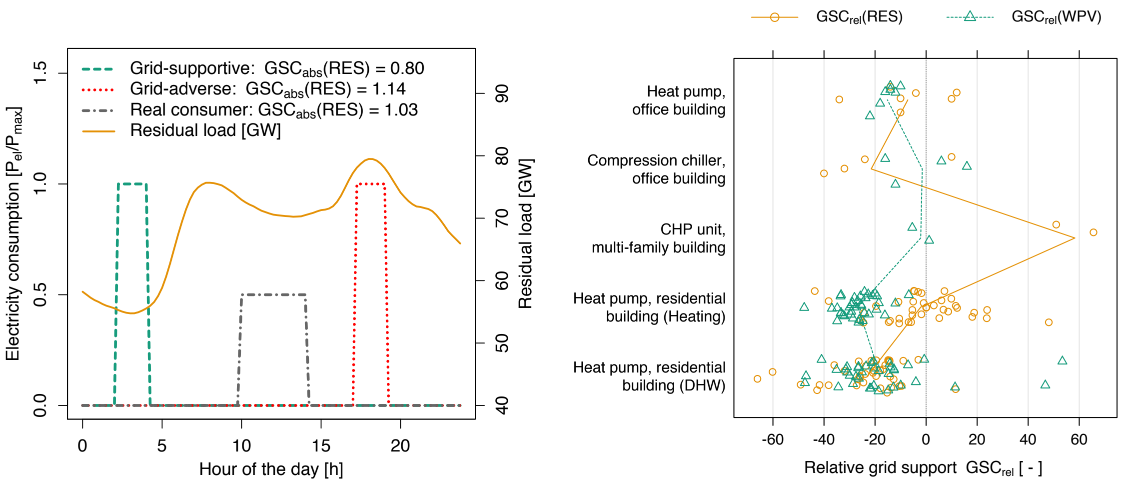

Figure 1: Example of the quantities involved in the calculation of the GSC (left figure). Analysis of 52 building's relative grid support. Using the residual load as indicator (RES), CHP were operated in a grid supportive mode (right figure)

Conclusions and/or Outlook

The grid interaction of building can be quantified. Optimal scheduling of grid connected heat and cold supply systems could contribute significantly to flattening the fluctuations in the grid. In order to achieve this, thermal storages several times larger than the ones currently installed would be required. Flexible tariff schemes are crucial to establish business models for grid supportive operation.

Acknowledgement: The authors gratefully acknowledge the financial support of the project "Netzreaktive Gebäude" funded by the German Federal Ministry of Economic Affairs and Energy under reference: 03ET1111A.

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Renewable energy systems in urban areas

Ursula Eicker, Juergen Schumacher, Eric Duminil, Volker Coors
Research Centre Sustainable Energy Technologies zafh.net, University of Applied Sciences Stuttgart, Schellingstr.24, 70174 Stuttgart, Germany, ursula.eicker@hft-stuttgart.de

Keywords: urban energy simulation, 3D city modeling

Astract

The highest local renewable energy generation potential in urban areas exists for solar technologies, as biomass resources are limited, cause dust emissions and wind energy is mostly not an option in densely populated areas. All the same, solar fractions still remain low due to higher cost of building integrated photovoltaics compared to free standing power plants and to the still cheap fossile fuel supply, which can be efficiently converted by decentral cogeneration engines as a major competitor to solar thermal systems. However, if the CO_2 reduction goals are to be met, significant fractions of renewable production are necessary and local generation reduces the amount of electrical grid extension and enables local renewable thermal energy distribution.

To analyse the urban building energy demand and the renewable supply options with photovoltaic electricity and/or solar thermal energy conversion connected to electrical or thermal networks requires an automated process to parametrize simulation tools. The approach chosen in this work is a fully automated building by building simulation process based on 3D CityGML geometry data. Depending on the analysis questions, an automated process of model generation using the modular simulation environment INSEL is carried out, resulting in either steady state monthly energy balances or dynamic building or renewable energy system models. Urban shading effects from neighbouring objects are included in the analysis by a pre-processing step, where for each meshed building surface element the complete sky patch visibility is calculated and then used in the hourly time step simulation.

The urban simulation process was applied to several case study areas in Munich, Karlsruhe and Ludwigsburg and the entire county of Ludwigsburg with 39 communities. Validation with monitored energy data showed that for an entire district, the deviation between building simulation and consumption measurements were between 2 and 7%, if the refurbishment status of the buildings is rather well known. With the simulated heat density scenarios, the simulation proces was then used to automatically design and simulate district heating network extensions using the thermohydraulic simulation package STANET. The results show that the achievable solar potential is highly dependent on the urban form and the roof integration possibilities. Net zero energy districts can only be achieved if building blocks are compact with roof surfaces fully available for solar integration.

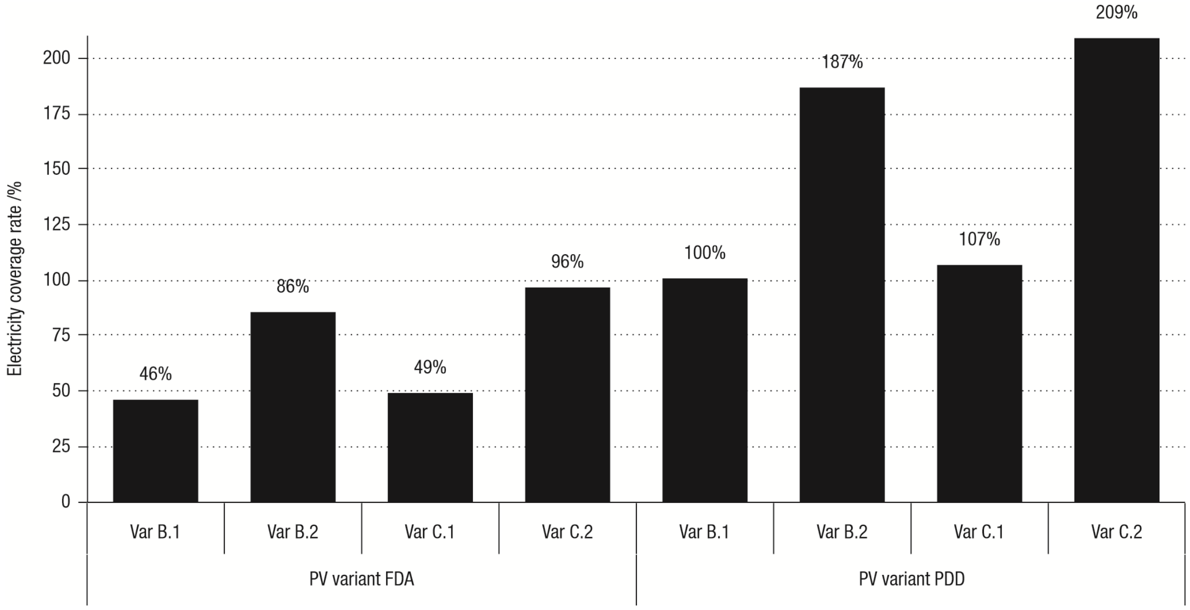

Figure 1: solar fraction of electricty consumption as a function of urban forms and roof shape for a district with renewable geothermal heat supply in Munich Freiham.

Re-thinking rare earths: Demand, sustainability and the reality of alternatives in magnetic materials

Oliver Gutfleisch, *TU Darmstadt, Material Science, Germany*
Fraunhofer Project Group Materials Recycling and Resource Strategy IWKS, Hanau, Germany

Abstract

Due to their ubiquity, magnetic materials play an important role in improving the efficiency and performance of devices in electric power generation, conversion and transportation [1]. Permanent magnets are essential components in motors and generators of hybrid and electric cars, wind turbines, etc. Magnetocaloric materials could be the basis for a new solid state energy efficient cooling technique alternative to compressor based refrigeration [2]. Any improvements in magnetic materials will have a significant impact in these areas, on par with many "hot" energy materials (e.g. hydrogen storage, batteries, thermoelectrics, etc.).

The talk focuses on rare earth and rare earth free permanent magnets [3], also briefly mentioning magnetocaloric materials, with an emphasis on their optimization for energy and resource efficiency in terms of the usage of critical elements. The concept of criticality of strategic metals will be explained by looking at demand, sustainability [4] and the reality of alternatives of rare earths. Synthesis, characterization, and property evaluation of the materials will be examined considering their micromagnetic length scales and phase transition characteristics.

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Material improvements enabling larger scale liquid fed fuel cells

Dr. Jens Tübke*, Dept. of Applied Electrochemistry, Fraunhofer Institute for Chemical Technology ICT, jens.tuebke@ict.fraunhofer.de*
Dr. Carsten Cremers, Dept. of Applied Electrochemistry, Fraunhofer Institute for Chemical Technology ICT, carsten.cremers@ict.fraunhofer.de

Keywords: Fuel Cells, Anion Exchange Membrane, HT-PEMFC, Alcohols, Direct Conversion, Reformers

Introduction

Most commercial fuels today are liquids as the liquid form offers many advantages like high energy density, easy pressure free handling, or a high degree of freedom in tank design. Fuel cells operating on liquid fuels can take profit of these advantages as well. However, slow conversion of the direct electrochemical oxidation and high catalyst loading in both direct converting fuel cells and fuel cells operating on reformate have limited the market access to small scale units. In the presentation material improvements will be reported which shall enable to address larger scale stacks and systems.

Discussion

The use of alkaline anion exchange membrane technology for direct alcohol fuel cells allows the use of less expensive catalyst on both electrodes. For the anode side palladium alloy catalysts have shown high activities. So Pd_xNiM ternary catalyst can achieve mass activities of more than 850 mA/mg for the ethylene glycol oxidation reaction (cf. fig. 1). It was also shown that manganese oxide can be used as PGM free cathode catalyst with high tolerance for alcohols and carbon dioxide.

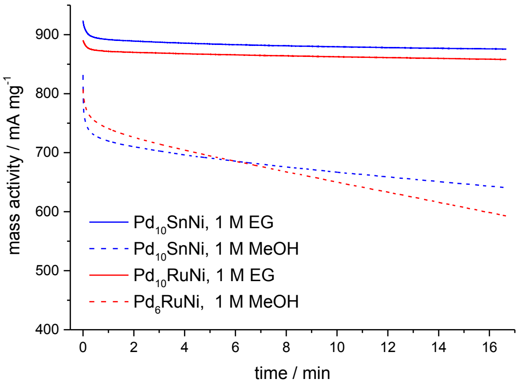

Figure 1: CA measurements of the ethylene glycol (straight lines) and methanol (dashed lines) oxidation at Pd_xMNi catalyst in 1 M KOH 1 M alcohol solution at ambient temperature.

For the direct conversion of ethanol an acidic environment is more useful as it reduces the formation of acetic acid as dead end product. As will be shown PtRh and $PtRhSnO_2$ catalyst show a high activity for the ethanol oxidation reaction at increased CO_2 current efficiency (CCE) even at ambient temperature [1]. Under HT-PEMFC conditions a CCE of more than 70% can be achieved even if 5 molar ethanol solution is used as fuel.

HT-PEMFC can also be used for the conversion of steam reformed fossil fuel. Therefore an optimisation of the hydrophobic properties of the electrode is required to allow for the operation with wet fuels [2]. As will be shown, this modification also enhances the stability of the MEAs for operation with simulated diesel reformate, in particular under start-stop cycling test conditions. Finally it will be shown that the addition of a base metal can tune Pt/C catalyst so that it can tolerate high concentrations of H_2S as impurities of at least 40 ppm [3].

In a last part the presentation will show preliminary results on fuel cell system development of a 3 kW reformed petrol APU and a 5 kW reformed methanol range extender as future applications.

Conclusions and Outlook

Material improvements in particular for catalyst can enhance the performance of fuel cells operated directly with alcohols or with reformate. The enhanced performance should lead to reduce material expenditures and thus reduced costs. This will allow for the use of such systems in application with power requirements on the scale of several kilowatts e.g. for back-up power or APU and/or range-extender solutions in vehicles.

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State of the art, opportunities and challenges for thermoelectricity as competitive renewable energy source

G. Dennler*, IMRA Europe S.A.S., 220 rue Albert Caquot BP 213, 06904 Sophia Antipolis Cedex, France*

Abstract

Thermoelectric Generators (TEG) exploit the Seebeck effect in order to convert a gradient of temperature into an electrical power. As such, they offer a myriad of opportunities within the framework of the decarbonization of the energy sector and the penetration of renewable energies. TEGs appear especially pertinent for the recovery of waste heat in various environments like power plants, combustion engine vehicles, and the Internet of Things (IoT). However, the current standard efficiencies of TEGs and associated cost per watt are still prohibitive and hinder a large deployment of the technology. In this presentation, we will remind the basics of thermoelectricity, discuss the current state-of-the-art of the scientific advancement, and underline the major barriers and associated leverages than are currently investigated to enhance the performances of TE materials.

Simulating the Complexity of Demand Side Management using Agent-Based Modelling

***Dr. Enrique Kremers**, European Institute for Energy Research, EDF & KIT, enrique.kremers@eifer.org*

Keywords: Energy, Conversion, Technology, Climate, Material

Introduction

In the past few years, demand-side-management (DSM) is being mentioned increasingly as a means to adapt the demand side to a more fluctuating production due to renewable energy sources and increase overall efficiency of the power system [1]. Most part of the electrical demand (residential sector for example) is composed of a large number of entities, which however are low powered in comparison to large generation units. Furthermore, the entities usually are of heterogeneous nature. Complexity science is dealing with mainly with large, heterogeneous and interactive systems, in which the global behaviour cannot be easily inferred in terms of the individual constituent elements. Agent-based modelling [2] is a relatively novel approach in engineering, which has been used to model complex systems by representing the entities as individual, autonomous and proactive agents, where the systemic behaviour emerges on the behaviour of the entities and their interactions.

Discussion

The current shift of power system towards a more decentralised and distributed paradigm, as well as the inclusion of more communication and IT encompasses new challenges for modelling these systems.
Current modelling tools are often specialised on one scale or level only and often have specific objectives. However, cross-scale interactions between the different scales are rarely considered. The benefits of DSM can be valued at different scales, from local scale (reducing energy needs for the client, compensating local RES fluctuations, etc.) to more global level (as pools of flexible consumers acting on the balance markets, integrated to VPPs, etc.). Furthermore, combined strategies are possible, providing support to local constraints (voltage regulation, phase balancing) and global constraints (balance markets, frequency regulation) at the same time.
In order to assess their impacts, a complex systems approach is proposed, in which the entities of the system are represented using agent-based models. This approach allows for the representation of the entities of the system in a disaggregated way, allowing for individual instantiation as well as interactions between the components. The approach allows for more decentralised strategies, such as Demand Response, which can be applied locally and have to be represented with higher resolutions at individual level due to their heterogeneity. However, also more centralised and homogeneous strategies can be represented in simplified models, which do not require high levels of resolution, which would be the case for long term policies such as Energy Efficiency strategies. In any case, the communication and interaction of the different agents of the system is crucial. Furthermore, cross-scale interactions, throughout different voltage levels are reflected, for example to show the impacts of individual measures at systemic level.

Different examples will show the application of the approach, by illustrating them with concrete case studies including:

- Large scale introduction of PV and batteries in island systems
- Emergent behaviour in distributed DSM for frequency control
- Impact of Electric Vehicle charging on the grid

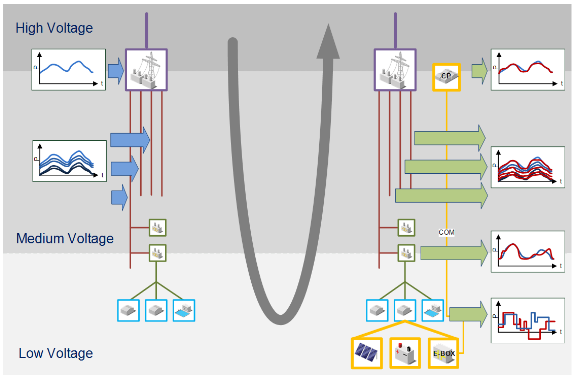

Figure 1: Example of a multi-scale model allowing for individual demand side actions

Conclusions and/or Outlook

This approach may help through the use of explorative models to better understand the complex relationships and cause-effect chains in power systems, when applying largely distributed DSM strategies, as well as to help to extrapolate existing small scale experiments. Furthermore, the approach aims for offering a platform to design and further a way to optimise both the planning and operation of DSM mechanisms and strategies.

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Product Generation Development – The Path to Agile and Efficient Processes in Product Development

***Prof. Dr.-Ing. Dr. h.c. Albert Albers**, IPEK Institute of Product Engineering, Karlsruhe Institute of Technology, Albert.Albers@kit.edu*
Nikola Bursac, IPEK – Institute of Product Engineering, Karlsruhe Institute of Technology, Nikola.Bursac@kit.edu
Nicolas Reiß, IPEK – Institute of Product Engineering, Karlsruhe Institute of Technology, Nicolas.Reiss@kit.edu
Galina Rechenkova, IPEK – Institute of Product Engineering, Karlsruhe Institute of Technology, Galina.Rachenkova@googlemail.com

Keywords: Product Generation Development, Integrated Product Development, agile Product Development, iPeM, XiL

Product development is in more than 90% of all cases a product generation development, in which an already existing reference product is used – for example, as a concrete predecessor, as a technology carrier or as a competition benchmark in an existing market segment [1]. Product generation development is defined as a synthesis process in which for a large part in the overall system the fundamental solution is already known and is not significantly changed. In order to enable more efficient and flexible developments, the development of new innovative (as well successful) solutions is based on the existing fundamental solutions and functional structures of products that are optimized with new materials, new designs and new manufacturing technologies [1]. A differentiation whether the development of a product should be classified as an entirely new development, an adjustment or a variant [2] is therefore not very practical. Instead, every part within the construction should be individually classified: while depending on the goal certain functional units must be newly developed, other subsystems can usually be redesigned based on existing functional structures and fundamental solutions. The structure of reference products stays substantially preserved in the newer generations. For the purpose of reduction of expenses, risks and costs, it is often purposeful to maintain the basic structure of a reference product (generation) and to develop some individual subsystems new. New methods and tools are needed for such a mixed development process, which have to be researched and developed. At the same time, the already available resources should be primarily allocated to the development of solutions and characteristics for differentiation purposes, since according to the Kano Model fascination characteristics are the ones that ensure a long-term competitive advantage [3]. Thus, the goal must be setting up a creative and yet very effective process to introduce innovative products to the market, in which only certain subsystems are newly developed (principle- or design variation). In order to successfully implement innovative subsystems, an agile product development is necessary [4].

The agile approach has been researched for over ten years within the scope of the project "Integrated Product Development". For example, in 2013 there were various innovative cabin concepts developed in cooperation with Daimler Trucks. Six student groups were methodically supported to work in an agile process. The design of the development process is up to the developers, while conditions are predefined by supervisors and the best solutions are selected in cooperation with the project partner.

Likewise, it is not effective to implement an integration of subsystems at the end of product development. A very promising approach for agile product development is called Test-based Development (TbD) and is based on the X-in-the-loop (XiL) methodology. It can efficiently couple virtual and physical models of products, environment and users, so that the product can be simulated and tested in its application environment under real-time conditions. In the consequent product development, the models can already exist or can be carried over or reused with minor modifications for a future generation product-development. This allows early customer integration in order to verify and validate new features of the future product generation.

In the full paper, agile processes within the scope of the "Integrated Product Development" and the approaches for test-based development are further elaborated.

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Invited Session Keynotes

Systems, Storage and Grids

Facile Synthesis of Carbon-Metal Fluoride Nanocomposites for Lithium Batteries

M. Anji Reddy and M. Fichtner

Helmholtz Institute Ulm (HIU), Helmholtzstr.11, D-89081 Ulm, Germany
E mail: munnangi.reddy@kit.edu Tel: +49 (0) 7315034216

Metal fluoride based conversion materials have gained lot of interest as cathode materials for lithium batteries due to their high theoretical energy densities. However, metal fluorides are insulating and generally experience large volume changes during charge-discharge. Further, nanocrystalline metal fluorides are necessary to achieve theoretical capacities. Effective synthesis of carbon-metal fluoride nanocomposites is a key to achieve high capacities with sustainable cycle life.

Recently, we have developed a facile method for the synthesis of carbon-metal fluoride nanocomposites (CMFNCs) using CF_x as the carbon and fluorine source and metal carbonyls as metal source [1-3]. CF_x has great advantage as a precursor for the synthesis of CMFNCs as defluorination may restore the function of the carbon used for its preparation. Further, the thermodynamic reduction potential of CF_x is high; it can react with most of the transition metals in their metallic state and form carbon-metal difluoride or carbon-trifluoride nanocomposites (Figure 1). We have synthesized four different carbon-FeF_2 nanocomposites by reacting four different fluorinated carbons namely, petro-coke, carbon-black, graphite and carbon-fibers with $Fe(CO)_5$ at 250 °C. These four C-FeF_2 nanocomposites showed different electrochemical properties which helped us to understand the microstructure and optimum particle size required for the C-FeF_2 nanocomposites to achieve high reversible lithium storage [4].

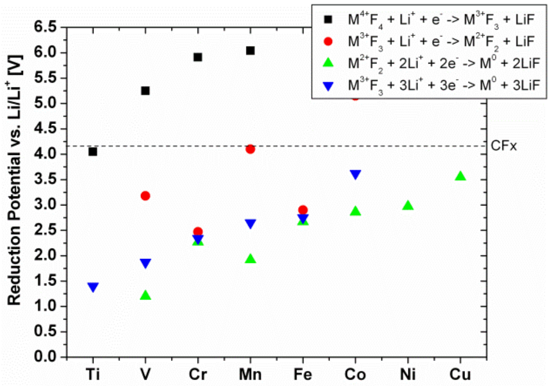

Figure 1 Reduction potentials of various metal fluorides vs. Li, together with CF_x.

We have also identified a rather general approach for the synthesis of CMFNCs at room temperature using CF_x as precursor. CF_x is known as a cathode material for lithium primary batteries. During discharge lithium reacts with CF_x and forms C+LiF. In other words this is an electrochemical method for the synthesis of C-LiF nanocomposites. Fundamentally, it is possible to extend this approach for the synthesis of other C-MF_x nanocomposites if the reaction of metal with CF_x is thermodynamically feasible provided with suitable metal ion transporting electrolyte. We have succeeded in the preparation of several C-MF_x nanocomposites by the proposed electrochemical approach. The as obtained C-MF_x metal fluoride nanocomposites showed excellent reversible lithium storage properties [5]. The detailed synthesis of metal fluorides by these methods, their characterization and electrochemical properties will be presented.

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Improvement of Fischer-Tropsch Synthesis through Structuring on Different Scales

Prof. Robert Güttel*, Institute of Chemical and Electrochemical Process Engineering, Clausthal University of Technology, guettel@icvt.tu-clausthal.de*
Prof. Thomas Turek*, Institute of Chemical and Electrochemical Process Engineering, Clausthal University of Technology, turek@icvt.tu-clausthal.de*

Keywords: Fischer-Tropsch Synthesis, Structuring, Catalyst, Reactor

Introduction

Fischer-Tropsch synthesis (FTS) converts synthesis gas (mixtures of hydrogen and carbon monoxide) over iron or cobalt catalysts to a broad range of hydrocarbon products. FTS is of growing importance as it allows for the manufacture of liquid fuels from carbon sources other than crude oil. Moreover, FTS may be used as storage option in a future energy system through conversion of renewable electric energy via water electrolysis and subsequent hydrogenation of carbon oxides. Thus, considerable research effort is targeted at improvement of the FTS process. The present contribution provides an overview about recent trends in FTS research with special emphasis on structuring at different scales of catalyst and reactor (**Figure 1**).

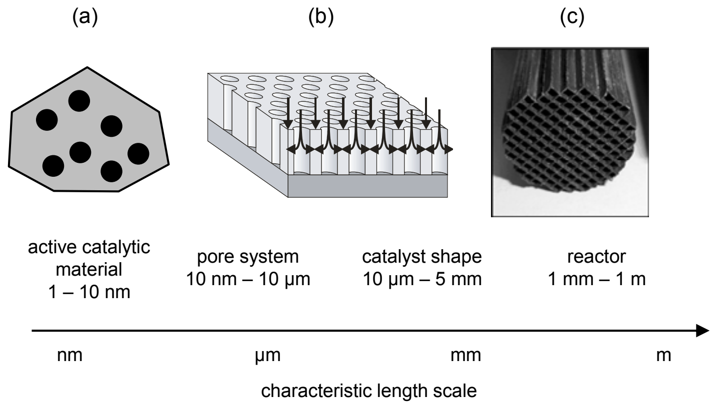

Figure 1: Length scales in catalytic reaction engineering relevant for FTS with selected examples of structuring options

Results and Discussion

It is well known that cobalt particles of specific size (about 5 – 10 nm) are required to obtain highly active and selective catalysts for the low-temperature variant of FTS. A highly interesting novel concept for structuring on this *nanoscale* is the preparation of encapsulated Co catalyst particles (**Figure 1a**). Thereby not only stabilization of the catalyst particles against sintering at elevated temperatures may be achieved but also different catalytic functionalities could be combined. An example is the coupling of FTS and hydroprocessing over Co/zeolite catalysts [1].

A severe drawback of low temperature FTS is the fact that the narrow pores of the catalyst are filled with liquid products under reaction conditions. Due to the low, but clearly different, diffusion coefficients of the reactants (H_2 and CO) limitations of both, activity and selectivity occur above characteristic diffusion lengths of about 100 µm. The introduction of larger transport pores, i.e. structuring on the catalyst *mesoscale*, allows for better accessibility of the active Co particles (**Figure 1b**). It has been shown that significant improvement of the catalyst productivity can be obtained by proper selection of transport pore fraction and diffusion length [2].

Finally, FTS also requires efficient mass and heat transfer properties on the reactor *macroscale*. Since the existing reactor technologies (slurry bubble columns, fixed-bed multi-tubular reactors) have certain drawbacks, different options for structured catalytic reactors such as monoliths (**Figure 1c**) or milli-structured reactors are under development [3].

Acknowledgement: This research was supported by Deutsche Forschungsgemeinschaft (grants GU 1294/2, TU 89/4, TU 89/9).

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Storage of Electrical Energy by Liquid Hydrocarbons

Prof. Dr.-Ing. Andreas Jess (jess@uni-bayreuth.de), Dr.-Ing. Christoph Kern, Ferdinand Pöhlmann, Chair of Chemical Engineering, Center of Energy Technology, University Bayreuth

Keywords: *energy storage, renewable liquid fuel, reverse water-gas shift, Fischer-Tropsch synthesis*

The substitution of fossil fuels by renewable energy sources is needed to decrease CO_2 emissions. Wind and solar power are attractive alternatives for electric power generation, but are not suitable for providing base load due to strong fluctuations in supply on a daily or even weekly basis. Thus, efficient storage of electrical energy is inevitable. Liquid hydrocarbons (HCs) like diesel oil and kerosene exhibit an excellent volumetric energy density; moreover, their use is simple and the infrastructure for distribution etc. already exists. HCs can be produced by CO_2 and renewable H_2 in a three step process [1-3]:

1) At first, H_2 is produced by water electrolysis by use of renewable (off peak) electrical energy:
   $3\ H_2O \rightarrow 3\ H_2 + 1.5\ O_2$
2) Secondly, CO_2 is converted to CO via reverse water gas shift (RWGS) at temperatures > 800°C:
   $CO_2 + H_2 \rightarrow CO + H_2O$
   The CO_2 can be obtained by separation from flue gases of fossil fuel power plants and other sources like NH_3 plants (or in the very long run even from the atmosphere).
3) In the final step, syngas is converted to liquid hydrocarbons by Fischer-Tropsch synthesis (FTS):
   $CO + 2\ H_2 \rightarrow \text{-}(CH_2)\text{-} + H_2O$ (where $\text{-}(CH_2)\text{-}$ represents a methylene group of a normal paraffin)

Thus, the overall reaction equation for this power-to-liquid process is:

$$CO_2 + H_2O \rightarrow (\text{-}CH_2\text{-}) + 1.5\ O_2$$

The experiments on FTS with Fe and Co as catalyst and syngas containing different amounts CO_2 indicate that the influence of CO_2 on CO-conversion and product selectivities (including net CO_2 production by water-gas shift) is insignificant, if the inlet partial pressures of H_2 and CO are kept constant. If CO is substituted by CO_2, less HCs are formed in case of Fe, the water-gas shift is repressed, and methane selectivity increases. With Co as catalyst, CO_2 is only converted (mainly to methane), if the syngas is completely free of CO.

For the modelling of technical multi-tubular fixed bed reactors the combined influence of the effective reaction kinetics (considering internal mass transfer limitations) and the heat transfer to the cooling medium (boiling water/steam) has to be considered. Above all, a temperature run-away has to be avoided, which determines the operating conditions such as the maximum single-tube diameter, the syngas conversion per pass, and the recycle rate of unconverted syngas.

Acknowledgment: This work was financially supported by the German Federal Ministry for Education and Research (BMBF) and by the Helmholtz Association.

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Thermodynamics and technical feasibility of CAES-TES systems

***Adriano Milazzo**, Department of Industrial Engineering, University of Florence, adriano.milazzo@unifi.it*

Keywords: Energy Storage, CAES, TES, Thermodynamics

Introduction

Massive energy storage requires reliable, affordable and environmentally safe solutions. Compressed air energy storage (CAES) is recognized as a promising option [1], but has encountered limited success in practice. A likely improvement of the original, gas fuelled concept is the so-called “adiabatic” CAES, i.e. a pure storage that receives work as the sole energy input and uses a thermal energy storage (TES) to transfer heat from the compression to the expansion phase. This improves the system efficiency, eliminates pollutant emissions and avoids the need for a fuel supply. A CAES-TES system has various possible configurations and optimization parameters. A general thermodynamics analysis may be useful to make some fundamental choices and finally arrive at a technically and economically feasible plant.

Discussion

If compressed air is stored at ambient temperature, the amount of recoverable energy along the compression is ideally equal to the work absorbed. This is true for any sequence of compressors/heat exchangers. In principle, the thermodynamic value of the recovered heat would be higher if the compression were performed in a single stage, delivering air at very high temperature. However, this thermodynamic value is significant only if the recovered heat is converted in work through an independent power plant. If the recovered heat is simply used to reheat the air along its expansion, the global efficiency is independent from the TES temperature. Actually, if the finite size of the heat exchangers is accounted for, the CAES energy recovery efficiency increases with the number of stages, as shown in **Figure 1 [2]**. A simple scheme with water as TES medium was hence proposed and simulated in [2]. Obviously the efficiency of the compressors/expanders is the main issue influencing the overall energy recovery performance. An analysis based on real data of commercially available components has given an exergy efficiency of 56% [3].

Another issue concerns the availability of suitable natural caverns for compressed air storage. To overcome this limit, CAES may use artificial air reservoirs, though in this case the system cost obviously increases. In [3] it was shown that even so, the cost of electricity delivered during peak hours is 84% higher than the base load cost, which could be economically viable in suitable circumstances.

Outlook

CAES may have a future if improvements and new ideas are exploited. For example, the compressed air may be cooled down through direct contact with water, lowering the TES cost. **Figure 2** shows a staged compression with intermediate humidification. In the limit of continuous humidification, compression becomes isothermal.

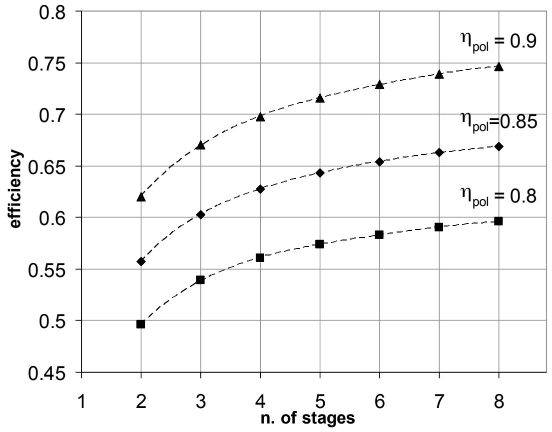

Figure 1: CAES efficiency as a function of number of stages and polytropic efficiency of compressor/expanders

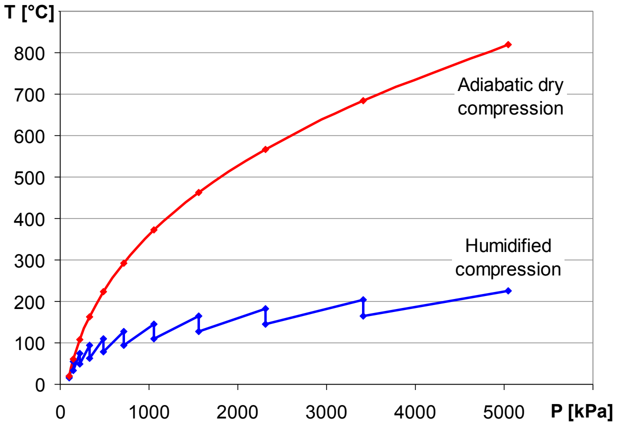

Figure 2: Staged compression with intermediate humidification

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Information and Communication Technology in Energy Lab 2.0

Prof. Dr. Veit Hagenmeyer, *Institute for Applied Computer Science (IAI), Karlsruhe Institute of Technology (KIT), veit.hagenmeyer@kit.edu*
Dr. Hüseyin Kemal Çakmak, IAI, KIT, hueseyin.cakmak@kit.edu
Dr. Clemens Düpmeier, IAI, KIT, clemens.duepmeier@kit.edu
Dr. Timm Faulwasser, IAI, KIT, timm.faulwasser@kit.edu
Dr. Jörg Isele, IAI, KIT, joerg.isele@kit.edu
Dr. Hubert B. Keller, IAI, KIT, hubert.keller@kit.edu
Dr. Peter Kohlhepp, IAI, KIT, peter.kohlhepp@kit.edu
Dr. Uwe Kühnapfel, IAI, KIT, uwe.kuehnapfel@kit.edu
Dr. Uwe Stucky, IAI, KIT, uwe.stucky@kit.edu
Prof. Dr. Ralf Mikut, IAI, KIT, ralf.mikut@kit.edu

Keywords: Energy, Smart Grids, Information and Communication Technology

Introduction

The stable and reliable operation of future energy systems with more than 80% proportion of renewable energy generation requires the development and experimental test of new concepts and components. Hence, the Helmholtz Association, the ministries BMBF (Germany) and MWK (State of Baden-Württemberg) establish the so-called Energy Lab 2.0 [1] to investigate the interplay of different forms of energy (Fig. 1).

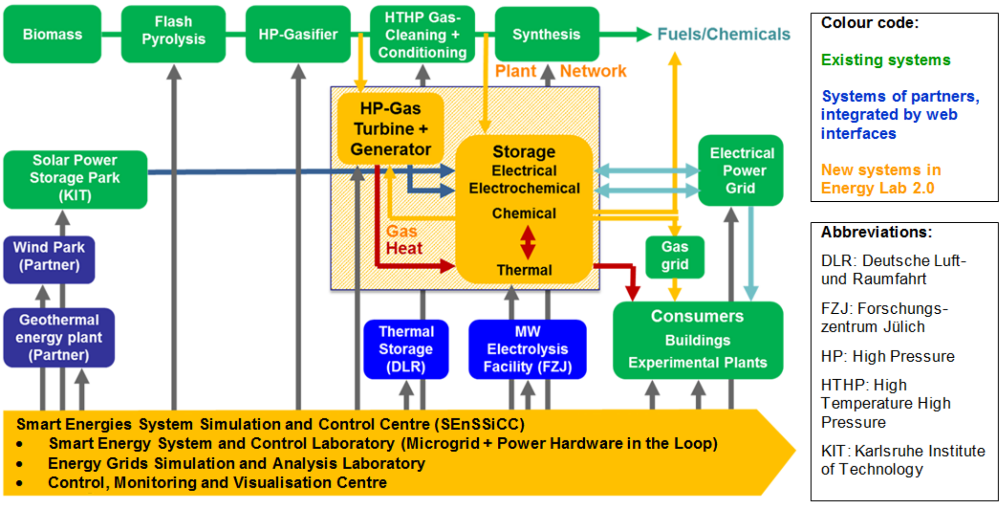

Figure 1: Energy Lab 2.0: components and connections (modified from [1])

Discussion

A central part of the Energy Lab 2.0 is the Smart Energies System Simulation and Control Centre (SEnSSiCC). It contains three parts: (1) The *Smart Energy System and Control Laboratory* represents a power-hardware-in-the-loop experimental field in the 200 kW range. The designed flexibility supports many smart grid experiments. (2) *The Energy Grids Simulation and Analysis Laboratory* aims at in-depth-simulation of energy grids and their interconnections from the microgrid scale to a Germany-wide scale. (3) *The Control, Monitoring and Visualisation Centre* integrates all parts of the Energy Lab 2.0 into a research environment for monitoring, visualisation, and modelling of smart grid constellations. For all of these three labs, the following Information and Communication Technology aspects are of equal importance: *(I) Big Data:* All system components generate large datasets, mainly in form of time series. These datasets are, e.g., a valuable resource to generate models of subsystems using data mining. *(II) Advanced control methods*: Within SEnSSiCC, tailored advanced control methods for smart grids are developed, tested and assessed. A major focus is put on distributed fault-tolerant control for load scheduling. *(III) Reliable, safe and secure software structures*: Intelligent distributed energy systems of the future require reliable, safe and secure software-based functions for communication, cooperation, and control.

Outlook

In order to show exemplarily the depth of investigation in the different parts of the SEnSSiCC, a new data processing pipeline for creating power flow simulation models from raw Open Street Map (OSM) data is shown [2].

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How to boost energy density of supercapacitors

Prof. Thierry Brousse*, Institut des Matériaux Jean Rouxel, UMR 6502 CNRS/Université de Nantes, thierry.brousse@univ-nantes.fr*

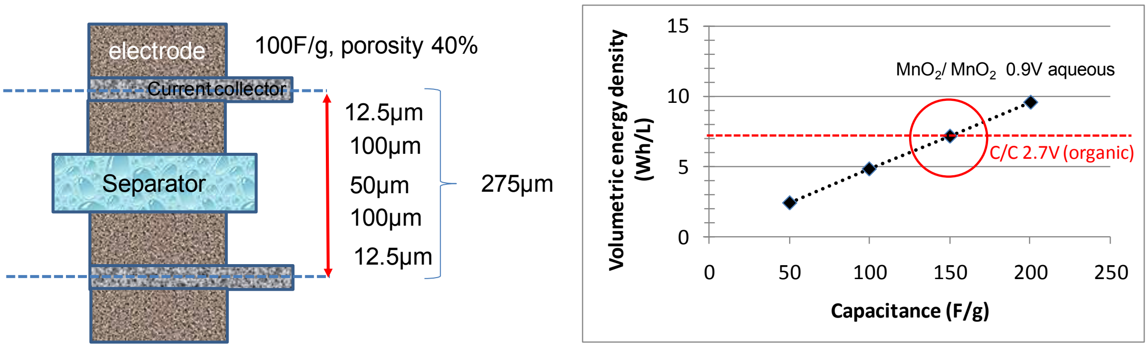
Keywords: Supercapacitor, electrochemical capacitor, EDLC, energy density

Introduction

Electrochemical capacitors (ECs), so-called supercapacitors are energy storage device that combine a high power density with long cycle life. Their main drawback is their moderate energy density that usually hardly exceeds 6 Wh/kg. This limitation becomes even worse when reported as volumetric energy density (7 Wh/L), which is a critical parameter in many applications. Indeed, ECs are often implemented in a given volume which depends on the use (Start & Stop system, brake recovery, etc...) and thus it is necessary to optimize the stored energy in this volume. Carbon based supercapacitors are nowadays state of the art devices, but due to their high porosity, their density is low and thus the electrodes made of activated carbon only display weak volumetric energy density. Their major advantage is their cell voltage which reaches 2.7-2.8 V in organic based electrolyte. However, the optimization of the cell capacitance C using carbon electrodes is quite difficult since the optimization of carbons has now reached a maximum.

Discussion

The use of oxide or nitride based pseudocapacitive materials as electrodes also leads to a dilemma since the cell capacitance is usually enhanced but at the expense of the cell voltage which hardly reaches 1.6V, since most of these alternative electrodes can only be operated in aqueous electrolytes. An option is to couple different oxide or nitride based electrodes in order to enhance the cell voltage, playing on HER and EOR overpotentials at the negative and positive side respectively.



(a) **(b)**

Figure 1: (a) Design of the electrodes used for the calculations and (b) comparison of a standard symmetrical double layer capacitor using organic based electrolyte and activated carbons for the electrodes, and a symmetrical supercapacitor using two MnO_2 electrodes (with individual gravimetric capacitance ranging from 50 to 200 F/g) in aqueous based electrolyte (Na_2SO_4, 0.5M).

Conclusions and/or Outlook

In this communication, different strategies will be detailed in order to improve the energy density of future ECs, mainly based on materials design, tailoring new structure and new microstructure in order to fit tomorrows' needs.

Acknowledgement: The authors would like to thanks French National Research Agency and DGA for financial support, as well as all of his national and international collaborators, current and former PhD students and post-docs.

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Energy efficiency with superconductors – simply irresistable

Dr. Michael Bäcker, Deutsche Nanoschicht GmbH, baecker@d-nano.com

Abstract:

Superconductor revolutionise the use of energy:

- Highest energy efficiency: no ohmic resistance
- Highest material efficiency: up to 10000 time higher energy density

Currently, all leading system manufacturers worldwide design, construct or test prototype applications to gain future prospects for unique energy opportunities. Amongst others, the most promising approaches are generators for wind and hydro power, turbo generators, ship propulsion motors and power cables for urban areas.

Yttrium-Barium-Copper-Oxide is the material which is currently used for HTS wires worldwide. In the production, the main challenge is to transform this brittle ceramic material into flexible high-performance wires required for energy applications. These requirements are fulfilled by deposition of thin HTS layers on metallic substrate tapes.

Deutsche Nanoschicht GmbH is the only company worldwide who successfully established a continuous chemical solution deposition (CSD) processing of the complete complex layer architecture for HTS wires. The production via CSD processes offers HTS wires with medium performance at lowest prices due to low investments, low raw material and energy costs and best process scalability.

Multi-scale Energy Systems Engineering

Professor Efstratios N. Pistikopoulos*, Artie McFerrin Department of Chemical Engineering, Texas A&M Energy Institute, Texas A&M University, College Station TX 77843 (stratos@tamu.edu)*

Keywords: Energy Systems, modelling, optimization, supply chains, control.

Abstract

Energy systems engineering provides a methodological, generic framework to arrive at realistic integrated solutions to complex energy problems by adopting a holistic, system-based approach. This framework address the complex energy and environmental problems existing in design, control and operation of energy systems and their supply chains in an integrated manner, by producing optimal design and operational plans for systems ranging from nanoscale, micro-scale, mesoscale to mega-scale levels over horizons that range from milliseconds to months or years [1, 2].

Typical methodologies in energy systems engineering include superstructure based modelling, mixed-integer linear and non-linear programming, optimisation and control under uncertainty and life-cycle assessment. The concept and methods are illustrated via their application in a set of real-life systems of fundamentally different nature and scale [3, 4, 5]. The set comprises of (i) poly-generation energy systems, where a variety of fuel stocks, such as coal, natural gas and biomass, can be converted into a variety of products, such as electricity, transport fuels and chemicals, (ii) hydrogen infrastructure planning, where the potential for using hydrogen as a sustainable fuel is assessed, (iii) PEM fuel cells experimental facilities, where the fuel cell system is tested under uncertainty via the use of advanced control techniques and (iv) optimally designed and operated series of micro-CHP systems for residential use [6]. The recently introduced PAROC integrated framework & software prototype platform is employed as a modelling, optimization and control tool to guide the various developments applications [7].

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Oral Presentations

Renewable Energies

Properties of organic-inorganic $APbI_3$ perovskites as solar cells materials

Dr. Lucangelo Dimesso, Materials Department, TU-Darmstadt, ldimesso@surface.tu-darmstadt.de
Prof. Wolfram Jaegermann, Materials Department, TU-Darmstadt, jaegermann@surface.tu-darmstadt.de

Keywords: Energy, Solar Cells, Perovskite, Materials

Introduction

The growing demand for renewable energy sources has led to considerable development in many areas related to the research and manufacture of solar cells. Hybrid inorganic-organic (IO) semiconductors are opening up a new insight to low dimensional PV nanostructures. IO hybrids are thus a technologically important class of materials, offering the possibility of combining useful properties of both organic and inorganic components within a single molecular composite.

Discussion

$APbI_3$ (A = alkaline metals, ammonium (NH_4^+), methylammonium (MA^+)) perovskites have been prepared by self-organization processes using different precursor solutions [1]. The X-ray diffractogramms revealed the formation of a tetragonal structure for X = MA, of a orthorhombic structure for A = alkaline metals (with exception for A = K, tetrahedral) and A = ammonium respectively. The morphological investigation revealed that the crystallites habit conform the corresponding crystallographic space group of the $APbI_3$ system. As example, for A = Cs the crystallites exhibit a needle-like morphology with length up to 3-4 mm; on the hand, for A = MA, exhibit faceting consistent with rhombo-hexagonal dodecahedra (as shown in **Figure 1**). During our investigation, we also noted that the differences in the structural and morphological features have a dramatic influence on the optical properties of the prepared materials.Iindeed he alkaline metals containing systems display a strong, abrupt absorption in the visible (Vis) spectral region (as shown in **Figure 2**) whereas the methylammonium containing system displays an absorption in the near-infrared range (N-IR) [1].

Figure 1: Typical SEM image of $MAPbI_3$ crystallite

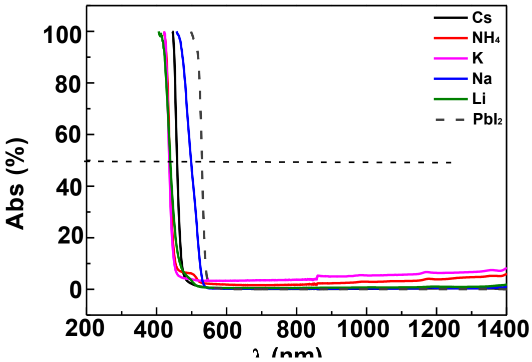

Figure 2: Normalized absorption spectra of $APbX_3$ systems at RT

By observing **Figure 2**, some important points are to note. First, according to the optical absorption measurements an increase of the band-gap energy by decreasing the ionic radius of the anion in the $APbI_3$ systems can be observed. In addition the pre-gap region does not show strong absorption tails indicating that high quality semiconductors with low defect concentration have been prepared. For A = MA^+, the band gap has a value of 1.50eV which is very consistent with the data reported in the literature, e.g. [2 and references therein].

Conclusions and/or Outlook

Perovskitic $APbI_3$ (A = alkaline metals, NH_4^+, MA^+) systems have been investigated. The morphological habit of the crystallites depends upon the structural features of the prepared system. These features influence the optical properties of the prepared materials which showed adsorption in the UV-range for A = alkaline metals and NH_4^+, and in N-IR range for A = MA^+ respectively.

Acknowledgement: The authors thank the Federal Ministry of Research and Development of Germanyfor the financial support during this work (Project: PEROSOL).

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Organic Nanoparticles for an Eco-Friendly Fabrication of Organic Solar Cells from Alcoholic Dispersion

Stefan Gärtner, *Light Technology Institute, KIT, stefan.gaertner2@kit.edu*
Marco Christmann, MJR Pharmjet GmbH, m.christmann@mjr-pharmjet.com
Dr. Sivaramakrishnan Sankaran, Light Technology Institute, KIT, sankaran@kit.edu
Dr. Eva-Marie Prinz, MJR Pharmjet GmbH, e.prinz@mjr-pharmjet.com
Felix Penth, Synthesechemie Dr. Penth GmbH, felix.penth@synthesechemie.de
Akif E. Türeli, MJR Pharmjet GmbH, e.tuereli@mjr-pharmjet.com
Dr. Bernd Penth, Synthesechemie Dr. Penth GmbH, bernd.penth@synthesechemie.de
Dr. Bernd Baumstümmler, MJR Pharmjet GmbH, bbaumstuemmler@mjr-pharmjet.de
Dr. Alexander Colsmann, *Light Technology Institute, KIT, alexander.colsmann@kit.edu*

Keywords: Organic Photovoltaic, Eco-Friendly, Nanotechnology

Abstract

The industrial fabrication of organic solar cells is often hampered by toxic solvents that require strong safety precautions. In this work, we fabricate organic solar cells utilizing aqueous and alcoholic solutions. For the absorber layer, we disperse, investigate and use P3HT:ICBA nanoparticles in environmentally friendly dispersion agents such as ethanol. For the preparation of the dispersions, we intentionally omitted any stabilizers that otherwise remain in the active layer, negatively affecting the device performance. In an inverted solar cell architecture comprising a nanoparticulate P3HT:ICBA layer (see **Figure 1**), the power conversion efficiency exceeds 4% and hence matches the performance of reference devices that were fabricated from dichlorobenzene [1]. Atomic force microscope images of the P3HT:ICBA surface visualize the merging of the nanoparticles upon thermal annealing. Irradiation intensity dependent current measurements show a gradual change from bimolecular recombination towards monomolecular recombination at higher annealing temperatures within the bulk-heterojunction. The universality of this approach allows the use of other common organic photo active materials for the fabrication of solution processable organic solar cells from non-hazardous solvents.

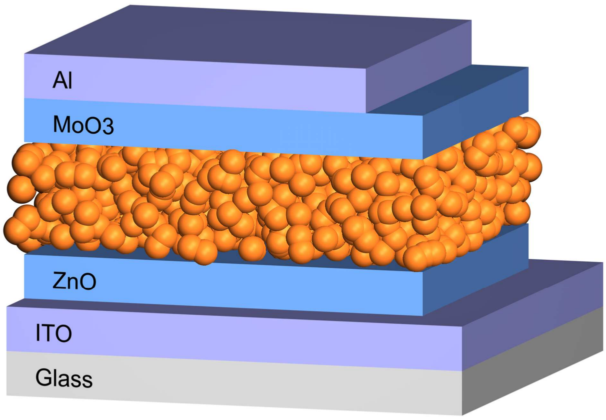

Figure 1: Organic Solar Cells in an inverted architecture comprising the nanoparticulate active layer, processed from eco-friendly alcohols [1].

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Testing the Overall Performance of Offshore PV System

***Dipl.-Ing. Malte Schöfer**, System Engineer/Innovation Consultant, Active Innovation Management, m.schoefer@aim-innovation.com; Giacomo Bersano, Managing Director, g.bersano@aim-innovation.com*

Keywords: Photovoltaic system; increased yield; water installation; TRIZ

Introduction

According to TRIZ (transcription from Russian meaning "Theory of Inventive Problem Solving) [1] Photovoltaic (PV) when a technology is in a mature phase, then the suggested development strategy suggests:

- On the short and middle term: accent on cost reduction, integration of service functions, improvement of visual design and to develop systems for applications/markets where the system remains competitive
- On the long term: application of new physical principles, reduction of components and integration of alternative systems.

The present paper reports on a PV solution which is the result of a consequent pursuit of those suggestions.

Problem Identification

Applications and markets where the PV systems remain competitive are characterized by

- severe difficulties or even impossibility to use other sources of energy and
- an added value of the PV which goes beyond the generation of electric energy.

Major problems of PV technology identified in the recent literature are

- the significant occupation of land surface [2] by the photovoltaic panels, which is increased by the need to reduce shadowing effects. Hence, a "design" paradox is identified,: An increased surface is needed to increase the energy output of the PV system. An increased surface is to be avoided in order not to occupy precious land surface.
- reduced energy yield by the reflection of incoming light at the glass surface [3]
- reduced energy yield and long-term degradation of PV cells by temperature drift [4].

Solution Identification

The search for sites and applications where PV panels provide additional value lead to medium to large water surfaces and particularly water reservoirs and fish farms. Here, the surface occupation is no problem or – in the case of water reservoirs – even helps avoiding the vaporisation of water.

Finally, the main resource present at those sites is water. For the resolution of the above mentioned technological problems, water disposes of three qualities:

- the capability to clean the PV panel surface from remaining particles
- a refraction index of 1.3 (which lies between the refraction index of glass (1.5) and of water (1.0)
- a thermal conductivity of approximately 0.6 W/mK (at 20 °C).

In several experimental setups, those qualities have been found to

- increase the electrical yield and thus the electrical efficiency by 10-15% (cooling effect of water when solar panel is submerged) [4]
- reduce the light reflection by 2-3.6% (obtained by a thin water flow of PV cells) [4]
- increase the electrical yield by 10,3% (combined effect of reflection reduction and PV cell cooling [4]

Application of Solutions into New PV System

In the present paper a PV system is presented, which integrates the following advantages:

- The system is installed on sea water, in connection with offshore facilities like e.g. fish farms.
- It allows cooling effect of the photovoltaic panels by the water.
- It allows an increased light radiation by the reduction of the system's refraction index by water.
- It allows the cleaning of the PV panel surface by water.

Finally, a test comparing floating PV system to those installed onshore will be performed and reported.

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Analysis of performance of photovoltaic systems: comparison of panel and inverter brand

***Odysseas Tsafarakis MSc**, Copernicus Institute, Utrecht University, O.Tsafarakis@uu.nl*
***dr. Wilfried G.J.H.M van Sark**, Copernicus Institute, Utrecht University, w.g.j.h.m.vansark@uu.nl*

Keywords: Photovoltaic performance comparison, Photovoltaic monitoring

Introduction

"Counting the Sun" (Dutch: Tel De Zon) was a one-week measurement campaign in May 2014 where Dutch photovoltaic (PV) system owners measured and shared information about the energy of their PV systems that was generated within one week. Furthermore, irradiation data from meteorological ground stations of the Royal Netherlands Meteorological Institute (KNMI) and the solar model by Olmo et al.[1] were used for the calculation of the Performance Ratio (*PR*). This allowed for the comparison of performance between different brands of panels and inverters.

Discussion

The calculated *PR* was used for different performance analyses:

1. 1,000 PV systems were divided in 13 groups, based on the panel manufacturer and type. For each group the performance of the systems installed in 2013 was compared with the systems installed in 2014.
2. Performance comparison of inverter brands (eight brands) and panel brands (seven brands).
3. Comparison of string versus micro inverters under shadow conditions.
4. Search for the most frequently used and most effective inverter ratio (System power/Inverter Power) per brand.
5. Search for the best inverter brand - panel brand - panel material combination and run a hypothetical scenario in all the PV systems under study were from these brands and the hypothetical energy production was calculated.

The *PR* follows a normal distribution, thus the mean value (μ) and the standard deviation (σ) were used for the comparisons. The statistical tool ANalysis Of VAriance (AN.O.VA.)[2] was used to verify the statistical equality of the samples.

Conclusions and/or Outlook

1. For 10 out of 13 groups systems that were installed in 2013 had higher mean *PR* than those installed in 2014.
2. Within the inverter and panel manufacturers that were used most frequently, there were no significant differences in the average *PR*. However, some inverters are operating better with specific panels, although the difference in the average *PR*, between the best and the last group, is not larger than 0.05.
3. For the systems operating under shadow, the ones with micro inverter system have 0.02 better average *PR*, compared to the systems with string inverters.
4. The ratio of inverter rated capacity and DC PV system power varied between 0.7 and 1.4 in all systems. Especially for ratios lower than 0.9 a lower performance ratio is expected, however this was not observed for the measurement week (Fig 1). Furthermore, when the PV installers are installing an expensive inverter brand of inverter, they strongly prefer a ratio less than one. On the other hand, with lower cost inverters they prefer ratios bigger than 1 (inverter capacity > system capacity)(Fig 2).
5. For the systems installed in 2012, 2013, and 2014 the most efficient inverter brand, panel brand and panel type per year were determined in 2,576 cases. The simulations show that if every year only the best combination per year would have been installed the total production of this week would have been 4.3 % bigger, i.e. 12,677 kWh than the one measured.

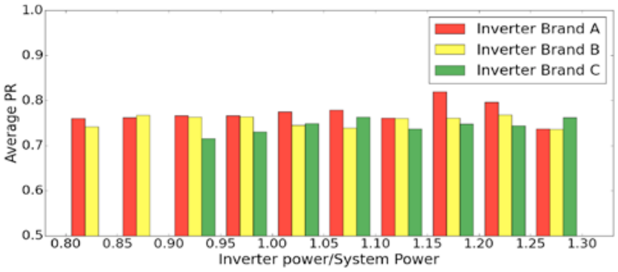

Figure 1: Performance ratio as a function of the ratio of inverter rated capacity and rated DC PV system power.

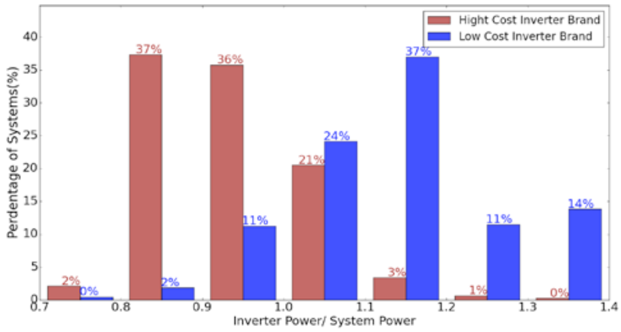

Figure 2: Comparison of installed ratio between low cost & high cost inverter brand

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Comparison of DC- and AC-coupled photovoltaic energy storage systems with Lithium-ion batteries

Dr. James Barry, *Project Competence E, Karlsruhe Institute of Technology, james.barry@kit.edu*
MSc. Nina Munzke, Project Competence E, Karlsruhe Institute of Technology, nina.munzke@kit.edu
Dr. Andreas Gutsch, Project Competence E, Karlsruhe Institute of Technology, andreas.gutsch@kit.edu
Dr. Olaf Wollersheim, Project Competence E, Karlsruhe Institute of Technology, olaf.wollersheim@kit.edu

Keywords: Stationary Energy Storage, Lithium-ion batteries, Photovoltaics, AC coupling, DC coupling

The recent steep drop in the price of photovoltaic (PV) modules coupled with the rapid development of Lithium-ion (Li-ion) battery technology has opened up the market for stationary energy storage systems, at various different scales ranging from several kWh to large utility scale projects on the MWh scale or more. In order for such systems to be economically feasible, the price of Li-ion batteries will need to follow a similar trend to that seen in the PV market; the required research and development is indeed being pushed forward by both the stationary storage and electric vehicle sectors.

An important question in designing PV storage systems is whether to couple the energy generation modules and storage battery directly on the DC side or rather via two separate inverters on the AC side. There are various advantages and disadvantages of both configurations and the installation of choice should be tailored to the specific requirements in each case.

Two prototype systems are used to evaluate those differences, in each case using the same Li-ion cell chemistry and Battery Manage System (BMS). The system control algorithms are nearly identical, barring small differences particular to the different electronic devices. Evaluation of system performance is based on several criteria, such as overall stability, ease of use and ability to smooth rapid fluctuations in PV power. The latter is a crucial aspect of energy storage systems and one that requires a well-designed and efficient control algorithm.

The comparison is performed with a 32 kWh Li-ion battery and a 37 kWp solar array situated on the North Campus of the Karlsruhe Institute of Technology. In the DC system the battery and PV system are directly coupled; in the AC system both real and simulated data from the PV array was used. This is one of the advantages of AC systems: the generation and storage are in a sense decoupled, being only connected at the grid. In addition, AC systems allow one to use existing PV infrastructure without much modification. On the other hand, DC coupling improves efficiency in a sense that the solar power goes directly to the battery. In this case the algorithms must be more carefully designed to prevent unwanted energy flows and special electronics is required to equalize the voltage differences. In both cases it is essential to have an accurate and fast measurement of the power output of the PV plant: the ability of such systems to compensate for changes in solar radiation is highly dependent on the speed at which such data is available.

The control algorithms were designed in order to provide an end user with constant power or to follow a load profile curve. At the heart of the system are various battery control routines that ensure safe and smooth operation of the battery, especially at extremes of voltage and temperature. In those cases the preservation of battery life takes priority over the desired load profile. The systems were tested with various different load profiles and evaluated according to their ability to meet the load demand accurately as well as their overall energy efficiency over the test period.

The results show that the systems show similar performance with small differences in efficiency. The response time and overall synchronization of the electronics is vital in both systems. Larger differences exist in the system design and technical aspects in the sense that one requires very different components and infrastructure in each case. This research can be used as a guide for future energy storage projects: the world's energy landscape will undoubtedly one day be made up of many different battery storage systems, and the correct application of AC and DC coupling of batteries to photovoltaics is an important part of this move towards decentralized power production.

DESERTEC and beyond

***Prof. Dr. Michael Düren**, II. Phys. Inst., Justus Liebig University Giessen, Michael.Dueren@uni-giessen.de*

Keywords: DESERTEC, energy system, sequestration, deserts, solar fuel

Introduction

The DESERTEC idea was originally developed as a concept for power production at large scale, making use of solar energy in the deserts of North Africa with the option to transport a significant fraction of the power to Europe. In the first decade of this century, scientific studies were performed [1,2,3] and set the basis for the formation of an NGO, the DESERTEC Foundation [4], and of an industrial consortium, Dii, with the aim to disseminate the idea and to put the concept into practice.

Current status

In a first generalization, the DESERTEC idea has been extended to a concept that is applicable worldwide (Fig. 1). It is based on four main pillars [5]:

1) The deserts of the world are important sources for strong and reliable solar radiation.
2) The oceans with their coastal areas are an important source of reliable and strong wind power.
3) Large-scale high voltage direct current (HVDC) power grids distribute the power among the centers of generation and consumption. This overlay-grid has to have a size of 1000 x 1000 km^2 or larger, so that the grid is able to average out a significant fraction of the natural fluctuations in the production and consumption of power. It is complemented with short-range AC distribution networks for power distribution to the consumers.
4) DESERTEC includes the nexus between water and energy in arid areas by including concepts of seawater desalination and minimizing cooling water requirements of power stations.

The realization of the DESERTEC concept requires economical and political pre-conditions that have to be created step-by-step in a difficult process. Important socio-economic prerequisites are high ecological standards and the participation of the local population in the value creation chain. The international trade of renewable energy is meant to reduce the steep gradient of wealth (e.g. between Europe and Africa) and to have peacekeeping incentives by intensifying the economical interdependence.

Future options

In a second generalization of the DESERTEC concept, the long- and short-term energy storage, the productions of gaseous and liquid fuels for mobile application and the carbon cycle with carbon as base material for the chemical industry are considered. In a future sustainable world, the currently expanding, global areas of deserted and degraded soils can contribute on a global scale to bio-fuel production and black carbon sequestration without being in competition with food production.

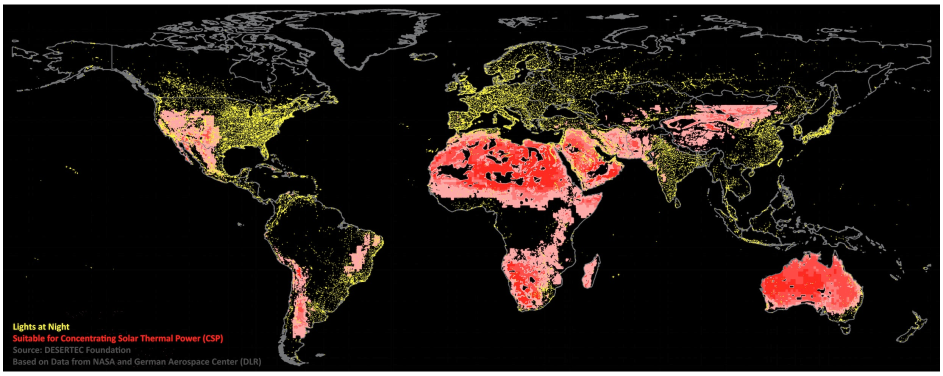

Figure 1: Global desert areas and areas of high electricity consumption (Source: DESERTEC)

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Potential for deserts to supply reliable renewable electric power

***Mercè Labordena**, Department of Environmental Systems Science, ETH Zurich, merce.labordena@usys.ethz.ch*
Dr. Johan Lilliestam, Department of Environmental Systems Science, ETH Zurich, johan.lilliestam@usys.ethz.ch

Keywords: Concentrating solar power, HVDC, Deserts, Reliability

Introduction

If we are to avoid dangerous climate change, the electricity systems of the world must be largely decarbonized by mid-century. Renewable electricity sources like wind and solar have shown from a resource perspective to have significant potential to reduce the carbon dioxide emissions associated with the electric power sector; however, their utilization also poses several challenges. First, wind and solar PV power is significantly different from fossil fuel power in that it is not constant and demand-controlled, but intermittent and supply-controlled. This causes problems of handling this intermittency and securely integrating volatile generation into the power systems. Consequentially, power sources that are both renewable and dispatchable are particularly important. Biomass and hydropower are such sources, as is concentrating solar power (CSP) with thermal storage; sustainability concerns, and a lack of potential for new-build, however constrain the possibilities for expanding biomass and hydropower. Second, renewable power has a low power density and needs extensive areas of land. This characteristic is problematic both due to cost reasons and due to land-use conflicts, especially in densely populated regions, in regions with high or rapidly increasing electric demand, and in regions competing for land for agricultural purposes. Renewable technologies that can provide a high level of reliability, can be expanded at large scale, and can be built in remote, sparsely inhabited regions or on land with low-competing land-use for agriculture, would therefore be especially valuable.

Discussion

Desert regions are such low-competition land, and at the same time are the most suitable places for CSP in terms of solar irradiation. Academics have shown that a dispersed and tightly coordinated fleet of CSP plants equipped with thermal storage can provide large amounts of high reliable power at reasonable costs, in the Mediterranean region and southern Africa (Pfenninger *et al.*, 2014). Desert-based CSP fleets, however, are deployed far from centres of demand (e.g., large cities) where electric power is consumed, necessitating the construction of long transmission lines to transmit power from deserts to where the power is needed (Trieb *et al.*, 2012).

We therefore study the potential for a fleet of CSP plants in desert regions to produce reliable and reasonable-cost renewable electric power for regions with high and/or rapidly increasing electricity demand and with a desert within or adjacent to its borders. The regions in focus are the European Union, North Africa and the Middle East, China and Australia. In addition to modelling the CSP fleets in desert regions across the world, we identify the optimal routes and costs for high-voltage DC (HVDC) transmission lines from the generation sites to the centres of demand. We conduct the analysis in three steps. First, we identify the best solar generation sites in the selected deserts using geographic information systems (GIS), and applying geographical restrictions to land to minimize impact on biodiversity, soils, human heath, and land-use and land-cover change. Second, we identify transmission corridors from the generation sites to the centres of demand in the target regions, using a GIS-based algorithm that minimizes economic, social and environmental costs. Third, we use the multi-scale energy system model *Calliope* (Pfenninger, 2014) to specify the optimal configuration and operation of the CSP fleet to provide reliable electric power, and to calculate the levelized cost of doing so, to which we add the levelised transmission costs. The primary input to the model is hourly weather data – especially direct solar irradiation – for the locations of the power plants, hourly demand curves for the different centres of demand, as well as data on surface temperature and wind speed derived from climate model reanalysis and satellite data.

Conclusions

Our results will show whether and how much reliable renewable electric power can be supplied from CSP plants fleets in desert regions to selected centres of demand. Our results will also show at which costs this is possible, in addition to a detailed description of the routes of the HVDC transmission links. Overall we expect to find that the potential for desert regions to supply reliable CSP to the consumption regions in focus is large in all cases, despite the long distances.

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A new concept for hybrid sensible/thermochemical storage of solar heat in cascaded redox-oxide-based thermochemical reactors/heat exchangers

***Dr. Christos Agrafiotis**, Institute of Solar Research, DLR-German Aerospace Centre, christos.agrafiotis@dlr.de*
Lamark deOliveira, Institute of Solar Research, DLR-German Aerospace Centre, Lamark.de-Oliveira@dlr.de
Dr. Martin Roeb, Institute of Solar Research, DLR-German Aerospace Centre, Martin.Roeb@dlr.de
Dr. Christian Sattler, Institute of Solar Research, DLR-German Aerospace Centre, Christian.Sattler@dlr.de

Keywords: Solar energy, Thermochemical storage, Redox oxides, Porous ceramics

Introduction

The current work is a follow-up of ideas introduced already in the literature, namely of combining active thermochemical redox oxide pairs (e.g. Co_3O_4/CoO, Mn_2O_3/Mn_3O_4, CuO/Cu_2O) with porous ceramic structures in order to effectively store solar heat in air-operated Solar Tower Power Plants. If such oxides are coated on porous heat exchange modules, solar heat produced during on-sun operation can be used to power the endothermic reduction of the oxide; the thermal energy can be entirely recovered by the reverse exothermic oxidation reaction during off-sun operation. Thus the storage concept is rendered from "purely" sensible to a "hybrid" sensible/thermochemical one. In addition, the construction modularity of the current state-of-the-art sensible storage systems provides for the implementation of concepts like spatial variation of redox oxide materials chemistry along the reactor/heat exchanger, to enhance the utilization of the heat transfer fluid [1].

Discussion

Thermogravimetric analysis (TGA) studies with the oxide powders above have shown that the Co_3O_4/CoO redox pair with a reduction onset temperature $\approx$ 885-905^{o}C is capable of stoichiometric, long-term, cyclic reduction-oxidation under a variety of heatup/cooldown rates [2]. They have also demonstrated that the Mn_3O_4/Mn_2O_3 redox pair is characterized by a large "temperature gap" between reduction ($\approx$ 950^{o}C) and oxidation ($\approx$ 780-690^{o}C) temperature, whereas the CuO/Cu_2O pair cannot work reproducibly and quantitatively since its redox temperature range is narrow and very close to the melting point of Cu_2O. In addition experiments with small-size honeycombs and foams coated with such oxides [3] have demonstrated that such systems can also operate in a similar cyclic redox manner, exploiting for the redox reactions the entire oxide material coated, even at very high loadings. Based on that, a combination of two such systems, namely Co_3O_4/CoO and Mn_2O_3/Mn_3O_4 that can be further explored in a cascade (Figure 1) has been further tested, at first in powder form in TGA and then in the form of cascades of coated cordierite honeycombs and foams in a suitably designed test rig. These experiments have demonstrated oxygen/release uptake in complementary temperature ranges, extending thus the temperature operation window of the whole storage cascade.

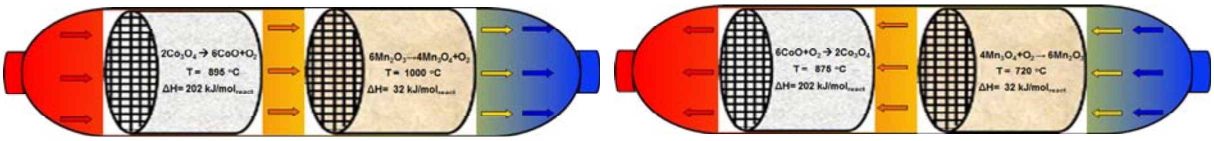

Figure 1: Schematic of cascade configuration during "charging" (left) and "discharging" (right) based on the characteristics of the Co_3O_4/CoO and Mn_2O_3/Mn_3O_4 redox pairs.

Conclusions and/or Outlook

The idea of employing cascades of porous structures, incorporating different redox oxide materials and distributed in a certain rational pattern in space for sensible/thermochemical storage of solar heat has been set forth and tested. On-going research is focused on the comparative testing of such cascades of porous honeycombs and foams in a solar-furnace facility with respect to sensible/thermochemical storage capability.

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Liquid metals as efficient heat transfer fluids for next generation CSP systems

Dr.-Ing. Luca Marocco*, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology, luca.marocco@kit.edu*
Dipl.-Ing. Frank Fellmoser, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology, frank.fellmoser@kit.edu
Dipl.-Ing. Jonathan Flesch, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology, jonathan.flesch@kit.edu
Dipl.-Ing. Klarissa Niedermeier, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology, klarissa.niedermeier@kit.edu
Prof. Dr.-Ing. Thomas Wetzel, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology, thomas.wetzel@kit.edu

Keywords: CSP, heat transfer fluid, liquid metal, central receiver systems, corrosion

Abstract

Concentrated solar power (CSP) systems can play a major role as a renewable energy source with the inherent possibility of including a thermal energy storage subsystem for improving the plant dispatchability. Next-generation CSP systems have to provide an increased overall efficiency at reduced specific costs and they will require higher operating temperatures and larger heat flux densities. In that context, liquid metals are proposed as advanced high temperature heat transfer fluids, particularly for central receiver systems. They have been already adopted in concentrating solar tower test facilities during the mid-1980’s. After a period of reduced interest, recently liquid metals have been re-assessed. Their main advantages are chemical stability at temperatures up to 900 °C and even beyond, as well as largely improved heat transfer capability when compared to conventional fluids like oil or salt mixtures, primarily due to their superior thermal conductivity. However, major issues here are the corrosion protection of structural materials and the development of technology components and control systems, as well as the development of indirect storage solutions, to circumvent the relatively small heat capacity of liquid metals. On the other hand, using liquid metals might enable alternative technologies like direct thermal-electric conversion or use of solar high-temperature heat in chemical processes.

Candidate metal fluids are sodium, lead-bismuth-eutectic or tin. In order to (re-)investigate the operation of solar powered systems with liquid metals, a test loop integrated into a solar furnace is under construction at KIT. One of the critical tasks is the design of test receivers in such a way that the tests are transferable to larger systems. For this test receiver design, preliminary simulations and validation experiments are being performed in KIT’s Liquid Metal Laboratory (KALLA).

Numerical analysis of the thermocline thermal energy storage system of CSP power plants

***Ismael A.S. Ehtiwesh**, Department of Mechanical engineering, University of Aveiro, ehtiwesh@ua.pt*
***Antonio C.M. Sousa**, Department of Mechanical engineering, University of Aveiro, antoniosousa@ua.pt*

Keywords: Thermal Energy, Solar, Thermocline, CSP

Introduction

Energy storage is a critical factor in the advancement of solar thermal power systems for the sustained generation of electricity [1]. In addition, the incorporation of thermal energy storage into the operation of concentrated solar power (CSP) plants offers the potential to deliver electricity without fossil-fuel backup as well as to meet peak demand, independent of weather conditions and during night-time. Thermocline systems have the potential of providing extended storage capability at reduced cost, when compared to two-tank systems; as a consequence, thermocline technology has been receiving increased worldwide attention. However, large-scale utilization of the packed-bed thermocline system is still hindered by several technical problems, among them time-dependence of temperature delivery and sizing requirements. The present work contributes to this specific area through modelling and analysis for a packed bed thermal energy storage system are conducted with the aim of having better understanding of the dynamic temperature response during cyclic storage and recovery. One of the most important objectives of the focusing on thermocline single-tank systems is that the thermocline option would have a potential to reduce around 33% the cost of thermal energy storage [2], where it is recently being seriously considered is the molten salt based thermocline single tank systems with a packed-bed of low-cost solid filler.

Discussion

The study investigates, identifies and develops a numerical model for the thermal storage system that can simulate its behaviour enabling enhancement of effectiveness, economics and operational characteristics of solar parabolic trough electric systems. Comprehensive transient, charging/discharging stages were simulated and analysed with particular emphasis on heat transfer and fluid dynamics within a packed-bed thermocline thermal storage system. This particular non-equilibrium model incorporates two heat transfer equations because the assumption of equal temperature for fluid and packed-bed particles is not made. The model does not consider heat conduction in the fluid and heat exchange between the packed-bed particles; the thermocline system is assumed to be well-insulated with negligible thermal losses to the environment. This non-equilibrium model will be compared with the equilibrium model, in which heat transfer between fluid and solid filler is taken as very high yielding a nearly-negligible temperature difference between liquid and filler particles [3] - [4]. Under these circumstances, a single-phase model can be formulated in which only one heat transfer equation is required. The numerical investigation carried out follows largely [5], the thermocline thickness and effectiveness are examined as a function of the thermocline motion, effective thermal diffusivity and height of the tank. The model was validated with the experimental data presented in study of Zurigat et al. [6].

Conclusions

The numerical model based on the resulting system of equations is solved by using time-implicit and space-centred finite differences within a Matlab environment. The analyses of the thermal storage system during the charging phase led to the following findings: the predictions agree well with the experiments the time evolution of thermocline region, particularly for the regions far-away from the top-inlet. These deviations observed in the near-region of the inlet are most likely due to the high-level of turbulence in this region due to the localized level of mixing resulting; a simple analytical model to take into consideration this increased turbulence level was developed and it led to promising and improved predictions; this approach requires practically no additional computational effort and it relates the effective thermal diffusivity to the mean effective velocity of the fluid at each particular height of the system.

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Transient Analysis of Concentrated Solar Supercritical CO_2-based Power Generation Cycles Under Different Seasonal Irradiations

***Julian D. Osorio**, Department of Mech. Eng., CAPS, ESC, Florida State University, jdo12@fsu.edu*
***Rob Hovsapian**, Idaho National Laboratory (INL), rob.hovsapian@inl.gov*
***Juan C. Ordonez**, Department of Mech. Eng., CAPS, ESC, Florida State University, ordonez@caps.fsu.edu*

Keywords: CSP, Supercritical CO_2, Transient analysis, Efficiency

Introduction

Renewable energy technologies based on solar concentration are important alternatives to supply the rising world energy demand and mitigate the environmental impact caused by the extensive use of fossil-fuels. In this work, the transient behaviour of concentrated solar power (CSP) supercritical CO_2 cycle is studied. The system analysed is composed by a central receiver, hot and cold thermal energy storage units, a heat exchanger, a recuperator, and three-stage compression and expansion subsystems with two intercoolers and two reheaters respectively [1]. Energy models for each component of the system are developed in order to optimize operating and design parameters such as mass flow rate and pressure to lead to maximum efficiency (ratio between the net power output and the energy input) of a 1MW scalable net power system for different irradiation conditions.

Discussion

The mass flow rate of CO_2 in the power cycle subsystem has a direct effect on the efficiency, see **Figure 1**. In all cases, the temperature at the turbines' inlet is limited to 900°C, controlling the solar energy input through the area of the collector field. It can be seen from **Figure 1** that the system exhibits an optimum around 6 kg/s where η_{max} reaches a maximum of about 10.5%. This optimum is practically independent on seasonal conditions and exists because lower mass flow rates imply smaller power generation in the turbine and larger mass flow rates imply a reduction between the operating and heat dissipation temperature and therefore a decrease in the efficiency. The slight difference in the η_{max} is due to a lower heat rejection temperature during winter and higher during summer.

The system operates under four different pressures: critical (P_c=7.38 MPa), high (P_H=20 MPa), low (P_L) and medium (P_M). P_c and P_H are fixed, while P_L and P_M are intermediate pressures in the compression and expansion subsystems. Figure 1 was built using P_L=12 MPa and P_M=16 MPa. **Figure 2**, in turn, presents the efficiency of the system as function of the intermediate pressure distribution using the optimum mass flow rate for a system with a small recuperator (**Figure 2a**) and a system with an optimized recuperator (**Figure 2b**).

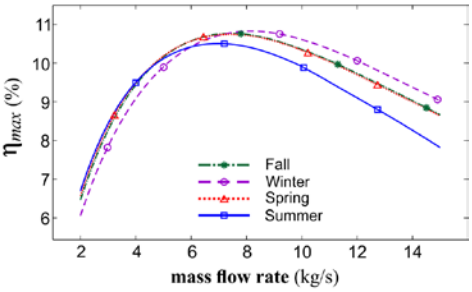

Figure 1: Effect of mass flow rate on the system's efficiency

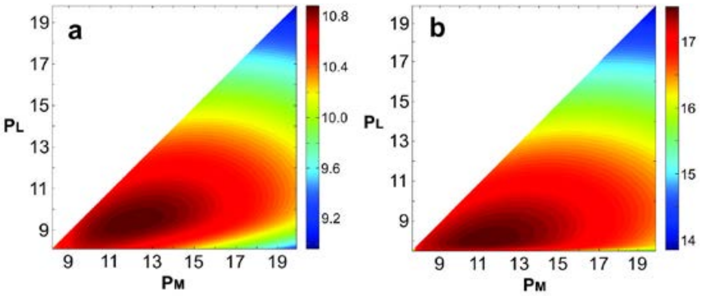

Figure 2: Intermediate pressure distribution with fall season irradiation for different are in the recuperator. **a)** Small area. **b)** Optimized area

Maximum efficiency is reached for intermediate pressures close to the critical point. The low viscosity of CO_2 close to its critical point leads to less compression work, and a higher efficiency. Efficiences up to 17.5% are possible for a system with an optimized recuperator, a mass flow rate of 6 kg/s and intermediate pressures of approximately P_L = 8 MPa and P_M = 12 MPa.

Conclusions

Transient behaviour of CSP generation cycles using supercritical CO_2 is studied. Efficiencies up to 17.5% can be reached in the system for optimized parameters. This efficiency is relatively high for a CSP system which indicates that this system is a suitable alternative for power generation applications.

Acknowledgement: Authors acknowledges Colciencias Colombia, Fulbright Colombia, LASPAU, and INL Energy Systems and Technologies division, for the financial support.

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Production of Oxygenate Fuels from Renewable Resources

Dr. Ulrich Arnold, Karlsruhe Institute of Technology, ulrich.arnold@kit.edu
Ludger Lautenschuetz, Karlsruhe Institute of Technology, ludger.lautenschuetz@kit.edu
Dorian Oestreich, Karlsruhe Institute of Technology, dorian.oestreich@kit.edu
Prof. Dr.-Ing. Jörg Sauer, Karlsruhe Institute of Technology, j.sauer@kit.edu

Keywords: Biomass conversion, Fuels, Oxymethylene dimethyl ethers, Emission reduction, Methanol

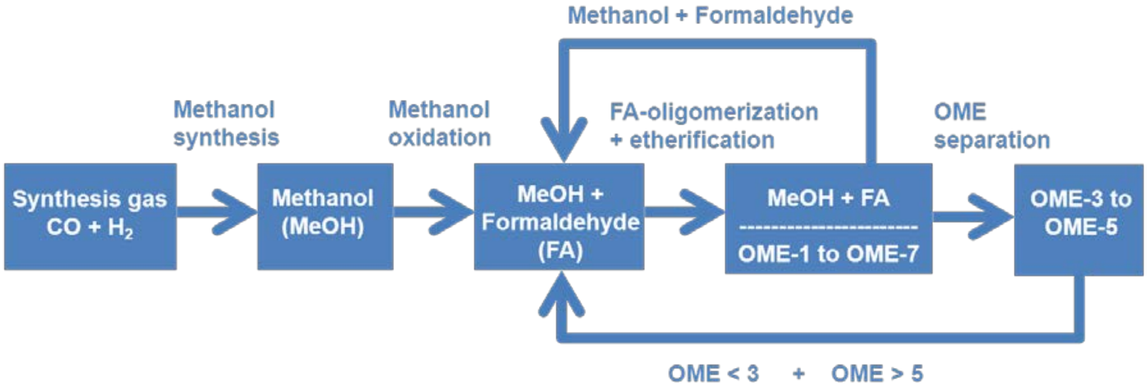
Introduction

Oxygen-containing fuels, so-called oxygenate fuels, are of steadily growing interest, since some representatives of this fuel type can significantly reduce the formation of harmful emissions during combustion. Thus, efficient emission reduction can be realized without costly engine modification and exhaust gas treatment [1]. If oxygenate fuels are produced from renewables, they can also contribute to a reduction of CO_2 emissions. Furthermore, the originally included oxygen can remain to some extent in the product so that synthesis with high energy efficiency and atom economy is possible. Typical oxygenate fuels are lower alcohols, e.g. methanol and ethanol, and ethers such as methyl *tert*-butyl ether (MTBE), ethyl *tert*-butyl ether (ETBE) or dimethyl ether (DME). MTBE and ETBE are widely used while DME proved to be a promising diesel substitute [2].

Discussion

Within this work, the synthesis and use of oxymethylene dimethyl ethers $CH_3O\text{-}(CH_2O)_n\text{-}CH_3$ (OMEs, n = 1-7) is described. These oxygenate fuels exhibit beneficial combustion properties and especially OME-3 to OME-5 are highly desired due to their favorable physico-chemical properties [1]. However, commercial production of oligomeric OMEs on a technical scale is not established yet since there is still a lack of efficient processes, which meet economic and ecologic demands.

With respect to OME production, new strategies starting from methanol and formaldehyde were developed (Scheme 1). Methanol can be obtained from renewable resources, e.g. via gasification of agricultural residues followed by conversion of the resulting synthesis gas. Main objective is the development of a continuously operating process, which leads selectively to oligomeric OMEs with the desired chain lengths.



Scheme 1: Synthesis of oxymethylene dimethyl ethers (OMEs) from methanol and formaldehyde

One key characteristic of these new strategies is the synthesis of OMEs in aqueous solution followed by extraction. If hydrocarbons like diesel are used for extraction, hydrocarbon-OME-mixtures can be produced in a convenient one-step-procedure, which exhibit promising combustion properties.

Outlook

Current activities in the field of OME synthesis range from fundamental challenges, e.g. development of highly active and stable catalysts, to technical topics, e.g. process engineering and scale-up. Furthermore, the synthesized OMEs will be investigated in engine tests to elucidate structure-response relationships and to reveal correlations between their molecular structures and combustion properties.

Acknowledgement: Financial support from the Helmholtz Association and the Helmholtz Research School Energy-Related Catalysis is gratefully acknowledged.

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Photoelectrochemical Routes for the Generation of Solar Hydrogen

Peter Bogdanoff[1], Diana Stellmach[1], Fatwa Abdi[1], Onno Gabriel[2], Bernd Stannowski[2], Rutger Schlatmann[2], Sebastian Fiechter[1] and Roel van de Krol[1]

Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
1 Institute for Solar Fuels, Hahn-Meitner-Platz 1, 14109 Berlin, Germany
2 Competence Centre Photovoltaics Berlin (PVcomB), Schwarzschildstr. 3, 12489 Berlin, Germany

Keywords: solar hydrogen, photoelectrochemistry, electrolysis, artificial leaf, energy conversion,

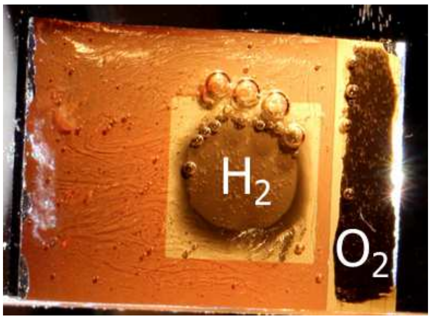
Introduction

Sunlight is a nearly inexhaustible energy source, but its large-scale use requires an efficient storage solution. As a promising approach the Institute for Solar Fuels at the Helmholtz-Zentrum Berlin embarks on different strategies of the direct conversion of light into chemical fuels, especially hydrogen. As a straightforward solution the required photo-voltage for the splitting of water is taken from highly efficient photovoltaic devices whose front- and back-contacts are functionalized with electro-catalysts for the hydrogen and oxygen evolution reactions. Another more challenging approach is the use of photo-electrochemical cells made from suitable and cheap semiconducting materials (e.g. metal oxides) which form directly a semiconductor/liquid junction for the electrolysis processes. Since the photo-voltages obtained with single photo-electrochemical electrodes often are lower than expected and therefore not sufficient, also hybrid systems of photo-electrochemical materials and photovoltaic devices are considered which are able to split water by sunlight without any external applied bias voltage. Furthermore electro-catalysts are being developed and optimized in order to avoid expensive noble metal catalysts in our water splitting devices and to keep the necessarily required overvoltage for the OER and the HER as small as possible.

Material concepts and devises

Triple junction silicon solar cells (a-Si/a-Si/μ-Si) were chosen as a PV device as they provide enough photo-voltage for the water splitting process. The cells were prepared in superstrate geometry so that no shadowing effects by the deposited catalysts and no light scattering by formed gas bubbles is observed. In these first efforts, RuO_2 and platinum nanoparticles are used as proven catalysts for the water oxidation (OER) and the hydrogen evolution reactions (HER). From this, we constructed an artificial leaf with a solar-to-hydrogen conversion efficiency (STH) of 4.5% in an acidic electrolyte under AM1.5 illumination. Recently, we also demonstrated as stand-alone water splitting device based on an n-type $BiVO_4$ photo anode combined with a more simple and cheaper a-Si/a-Si tandem-junction solar cell. Detailed photo-electrochemical analysis of the $BiVO_4$ photo-anode enabled us to identify the performance-limiting factors. One of these, i.e., the charge carrier separation efficiency, which could be significantly enhanced by introducing a gradient doping profile of tungsten. Furthermore, the deposition of cobalt-oxide catalysts accelerated the sluggish OER-rate of the material. The $BiVO_4$/tandem-PV device achieved an STH efficiency of 4.9% in neutral electrolyte under AM1.5 illumination. New metal oxide based photo-anodes with a smaller bandgap are currently under development in order to achieve higher STH efficiencies.

All the materials showed very often slow OER and HER kinetics so that the deposition of catalysts was necessary. For that we studied the electro-deposition of cheap but highly active manganese- and cobalt-oxide catalysts for the OER and the structure activity correlation of the promising layered compound MoS_2 for the HER. For the latter one it was found that the edges of the MoS_2 layers are responsible for the HER activity. Indeed MoS_2 prepared on carbon nano tubes reveals a high ratio of MoS_2-edges and as expected also a significantly increased activity.



Solar water splitting on a triple junction silicon solar cell (a-Si,a-Si,μ-Si) modified with Pt and RuO_2 catalysts (0.5M H_2SO_4, RT, AM1.5).

Conclusion

Hybrid PV-photoelectrodes combined with highly active electrocatalysts are currently a promising concept for efficient solar fuel devices.

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Scalable Particle-Based Photoelectrodes for Solar Hydrogen Generation

***Dr. Simone Pokrant**, Laboratory Materials for Energy Conversion, Empa, simone.pokrant@empa.ch*
Dr. Steve Landsmann, Laboratory Materials for Energy Conversion, Empa, steve.landsmann@empa.ch
Dr.Stefan Dilger, Laboratory Materials for Energy Conversion, Empa, stefan.dilger@empa.ch
Yannick Gaudy, LRESE, EPFL and Lab. Materials for Energy Conversion, Empa, yannick.gaudy@empa.ch
Prof. Dr. Sophia Haussener, LRESE, EPFL, sophia.haussener@epfl.ch

Keywords: Photoelectrochemical water splitting, multiphysical transport phenomena, scalable electrodes

Introduction

Solar water splitting presents a highly attractive approach for the synthesis of environmentally friendly hydrogen. A very promising strategy to convert solar energy into fuel is the use of photoelectrochemical (PEC) cells [1]. Recently presented PEC devices exhibit high solar to hydrogen conversion efficiencies, but are often fabricated by complex deposition processes, which are unpractical and expensive for large-scale applications [2, 3]. We propose an alternative route: the fabrication of particle-based photoelectrodes by simple coating or dipping procedures starting from photocatalytically active semiconductor powders, similar to the fabrication of battery electrodes out of Li-insertion materials.

Discussion

Particle-based electrodes allow for a tailored design of high-performing photoelectrodes. This results from the vast design space available due to the ability to vary the morphology of the particles (e.g. surface to bulk ratio [4] or shape [5]) for a given chemical composition. The resulting particle arrangement on the electrode support promotes or hinders the formation of a conductive network. A variety of approaches exist to further enhance the photoelectrode performance. These include variable necking procedures for enhanced inter-particle connectivity [6], and chemical modification of the semiconductor particles or electrode support by adding cocatalysts.
We use a model system based on $LaTiO_2N$ (LTON) to develop design guidelines for high-performing and scalable particle-based photoelectrodes (**Figure 1.a**). We follow a combined experimental-numerical approach, where photoelectrode synthesis and characterization is coupled to multiphysical modelling of the transport phenomena (**Figure 1.b**) in order to understand how particle morphology and agglomeration influence the PEC activity and to provide guidelines for the synthesis of scalable particle-based photoelectrodes.

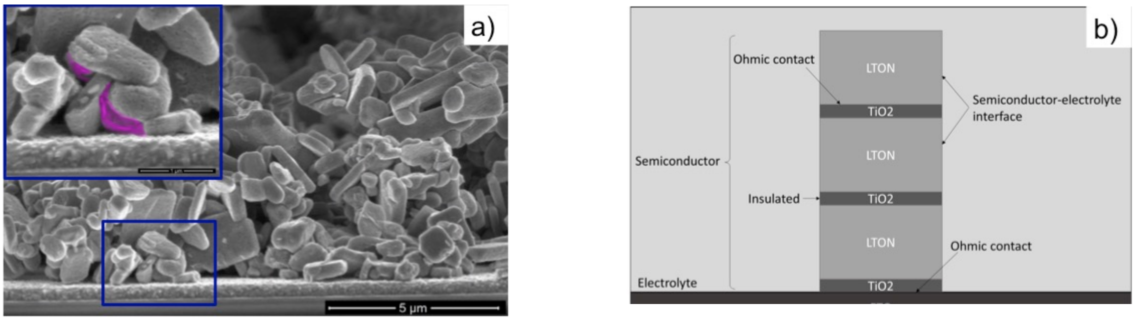

Figure 1: a) SEM image of a particle based electrode: LTON with TiO_2 necking. Inset: Zoom on the area in the blue box. The TiO_2 necking is highlighted. b) Model domain for multiphysical transport investigations.

Conclusion/Outlook

Design guidelines obtained by a combined experimental-numerical approach lead to the fabrication of efficient and reproducible particle-based PEC electrodes using scalable techniques.

Acknowledgement: The Swiss National Science Foundation (SNSF) is gratefully acknowledged for financing this PrecoR project (20PC21_155667) and M. Trottmann, Empa, for the SEM work.

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Proposed Liquid Fuel Production on Artificial Islands

Prof Bruce D Patterson, *SwissFEL Project, Paul Scherrer Institut, bruce.patterson@psi.ch*
Dr Reto Holzner, EconimoDrive AG, reto.holzner@econimo-drive.com
Mr A Kurum, Novaton, armand.kurum@novaton.com
Dr C Rossel, IBM Research, rsl@zurich.ibm.com
Dr HD Willauer, Materials Sci and Techn Division, Naval Research Laboratory, heather.willauer@nrl.navy.mil
Prof JA van Bokhoven, Department of Chemistry and Bioengineering, ETH Zurich, and Laboratory for Catalysis and Sustainable Chemistry, Paul Scherrer Institut, jeroen.vanbokhoven@psi.ch

Keywords: Solar Fuel, CO_2 *Capture, Methanol*

Introduction

It is proposed that concentrated solar photovoltaic and thermal energy be used to power the simultaneous electrolytic production of H_2 and extraction of CO_2 from seawater, as well as the catalytic hydrogenation of CO_2 to produce methanol, and that the process be performed on inflatable, quasi-autonomous "solar islands", which provide solar tracking of non-imaging concentrators by rotation of the islands.

Discussion

An attractive scenario for storing solar energy and providing carbon-neutral fuel is to recycle CO_2 to methanol and derived liquid hydrocarbons [1]. A conventional method of methanol production is hydrogenation of CO_2, typically using a $Cu/ZnO/Al_2O_3$ catalyst at 220^o C and 50 bar and requiring the input of 190 kg H_2, 3.5 tons CO_2 and, respectively, 3.3 and 0.8 MWh of electrical and heat energy, per ton of methanol produced [2].

The standard method of H_2 production is electrolytic water splitting, typically requiring 48 kWh of electrical energy per kg of H_2, corresponding to 9.2 MWh per ton of methanol produced. Long-term CO_2 recycling requires the recovery of CO_2 from the air. Although it is questionable whether direct air capture will be practical, capture from dissolved CO_2 (in the form of carbonates and bicarbonates) in seawater, which is in equilibrium with CO_2 in the air, has the advantage of a 140 times higher mol per volume concentration of CO_2. It has recently been discovered that, using an electrolytic cation exchange process, 92% of the CO_2 may be extracted simultaneously with electrolytic water splitting - at no additional cost in energy [3]. The extracted H_2 to CO_2 molar ratio, set to 3:1 in the demonstration, can be adjusted, and it is believed that an optimized process could be as efficient as commercial electrolysis.

The "solar island" concept of Hinderling, *et al,* foresees inflatable floating structures (see **Figure 1**) carrying linear solar concentrators which track the sun by rotation of the entire island and which produce steam to drive land-based turbines [4]. We propose that such islands instead be used as quasi-autonomous production facilities of solar methanol fuel. Orientation-tolerant non-focusing optics will illuminate concentrator photovoltaic cells, and the sub-bandgap radiation will supply the process heat for the catalytic reaction.

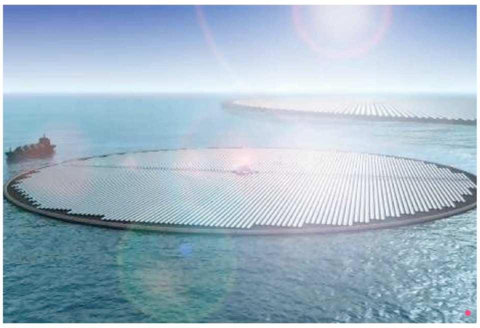

Figure 1: Artist's conception of solar islands [4].

Outlook

With an average yearly insolation of 2 MWh/m^2 and a photovoltaic efficiency of 30%, a solar island 200 m in diameter would supply 19 GWh of electrical energy per year, sufficient to extract 5200 tons of CO_2 and 290 tons of H_2 from seawater and to produce 1500 tons of methanol, representing 2100 and 280 tons of CO_2 and H_2, respectively. Unresolved uncertainties include: optimization of the CO_2 extraction / H_2 electrolysis process, solar collector, receiver and reactor design, simulation of a complete integrated process, island size optimization, analysis of island stability in wind and waves and cost analysis.

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Methanol for Renewable Energy storage and utilisation

Dr.Ing. Ludolf Plass, Kronberg ,dr.ludolf.plass@t-online.de; Prof.Dr.Martin Bertau , TUBA Freiberg; Dr.Hans-Jürgen Wernicke,Wolfratshausen

Keywords:Renewable Energy(RE) generation, Methanol from RE, renewable Methanol storage, Methan versus Methanol, Surplus power,

Introduction

According to present planning, it is the goal of the German "Energiewende" (Energy change) to have more than 85% of the installed power generating capacity based on Renewable Energy (RE) by 2050. Existing power storage capacities in Germany are far too small, and options for a substantial capacity increase are not available. An actual key question is, to what extent Fossil power production will still be required and how it is paid for. It is however demonstrated by various studies, that with a further increase of the RE capacities long-term chemical storage systems will be required beyond 2025, to avoid substantial cutoffs for the RE-Power and the Fossil power producers.

Discussion

Based on different scenarios, required long-term storage capacities for repowering vary from 10 - 40 TWh . The scenarios also show, that "Surplus power" generation in the range of 60 – 170 TWh is by far more as is needed for repowering only. These scenarios imply the question: Is repowering of RE-energy the "best option" regarding the 3 main goals of future power production in Germany/Europe:Secured/ environmentally sound/economical ?

Options for long-term storage are Hydrogen, Methane (SNG) and Methanol. Hydrogen has the lowest chemical conversion losses. Drawbacks are however the substantial energy required for handling (compression/ decompression/transport) , safety and permitting challenges and high costs for a large size completely new infrastructure . The paper compares the RE- based alternatives Methane(SNG) and Methanol from the electrolysis to chemical conversion to storage and the final use as power or chemical and/or fuel. Based on a variety of studies, the overall long-term storage capacity was selected as 100 TWel. This could cover Germany's overall power demand for app. 2 – 3 month by burning Methane or Methanol in selected power stations, which are equipped with CO2 recovery systems. 5 MegaMethanol (5.000 t/d each) , or 5 SNG plants (110.000 Nm3/h SNG each) would produce the 100 TWh. The hydrogen is generated via a PEMEL electrolysis, based on today's efficiency, but also showing the influence of future efficiency and cost improvements. Additional CO2 is recovered from various sources like Power-/ Chemical-/Biogas -plants. Compared are one large size MEOH/SNG plant each, but in addition, a 600 t/d and a 50 t/d MeOH plant to show the effect of economy of scale.It is assumed, that "surplus power" is sold to the chemical storage at marginal prices: (1- 3 – 5 cts/kWh), no EEG compensation/grid charges are paid.[1]

Conclusions and/or Outlook

The generation cost in €/GJ as a function of the plant operating times and different power costs are nearly the same for SNG and for Methanol.

There is nearly no economy of scale, because over 70 % of the capex is for the electrolysis, which consists of a multitude of stacks.

The "surplus Methane" cost will always be substantially above the present cost of natural gas. Selling to the natural gas grid is uneconomic under present German price conditions.

This is Different for "surplus Methanol": For operating times between 5000 and 8.000 h and 1 - 3 ct/kwh power cost ,using future efficiency and cost data for the PEMEL electrolysis, the Methanol cost is app. between 280 – 340 €/t which is in the range of present Methanol prices in Europe . CO2 recovery cost where assumed as 40 €/t, no CO2 credits were included.

"Repowering" of Re-Energy is by a factor of 3 – 5 more expensive against using natural gas or coal. A joint production of RE and FE and CO2 recovery will allow enough capacity for the FE to stay economic, balance the electrolysis and methanol production and result in longer operating times. In summary, this scheme will allow an economic future for the "Energiewende", phasing out the EEG.

Today, app. 120 mio t/y of gasoline are consumed in the EU. 3% of methanol can be added according to present regulations. This would amount to 3,6 mio tpy methanol. RE- methanol is listed as renewable energy according to EU regulations. It is however not yet qualified for greenhouse reduction quota after 2015. Initiatives to amend the regulations are underway and should be strengthend.

Converting a "green methanol" further to gasoline via the MTG process would result in generation cost for "green gasoline" in the same order of magnitude as conventional gasoline today (app 1.200 €/t), based on app 90 $/barrel oil price. Presently low oil prices will again rise at least medium term. "Green Methanol" used in cars in addition to ethanol would be competitive at Ethanol prices beyond 400 €/t. Several initiatives are underway in Germany to build pilot projects to demonstrate the overall process for RE power to RE methanol.

In summary : RE methanol is an attractive pathway to successfully complete the "Energiewende"

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Materials development against hot corrosion in biomass gasification facilities

Dr. Almut Wiltner, Fraunhofer IFAM, Branch Lab Dresden, almut.wiltner@ifam-dd.fraunhofer.de
Dr. Uwe Gaitzsch, Fraunhofer IFAM, Branch Lab Dresden, uwe.gaitzsch@ifam-dd.fraunhofer.de
Gunnar Walther, Fraunhofer IFAM, Branch Lab Dresden
Dr. Thomas Weißgärber, Fraunhofer IFAM, Branch Lab Dresden
Eva Drechsler, Fraunhofer UMSICHT, Institute Branch Su.-Ro., eva.drechsler@umsicht.fraunhofer.de
Gerhard Wolf, Fraunhofer UMSICHT, Institute Branch Sulzbach-Rosenberg
Dr. HDR Patrick Masset, Fraunhofer UMSICHT, Institute Branch Sulzbach-Rosenberg
Dr. Manfred Hülscher, Qalovis GmbH, m.huelscher@qalovis.com
Dr. Horst Hill, Deutsche Edelstahlwerke, horst.hill@dew-stahl.com
A. Ossenberg-Engels, VDM Metals GmbH, andreas.ossenberg-engels@vdm-metals.com

Keywords: biomass gasification, hot corrosion, hot pressing, SPS, powders

Introduction

Biomass gasification is a promising technique within the energy mix. Nowadays, wood pellets are used as fuel. Smaller gasification units in decentralised operation could use waste materials, such as wood chips, straw or chicken dung as alternative feedstocks. In this case, the ashes, slugs and gaseous compositions carry higher sulphur and chloride contents. This results in aggravated hot corrosion at distinct components, such as gas inlet nozzles. Moreover, these parts are stressed by high temperatures as well. In order to avoid premature damage of such parts, materials are developed within the research project KorrMat which provide chemically resistant oxide layers for passivation. Since temperatures above 800°C and 1000°C are reached under operating conditions together with low oxygen contents ($\lambda < 1$), alumina or silica former based materials are favoured. Consequently, the investigated materials are tested in terms of oxide layer formation and hot corrosion resistance. For the oxidation behaviour tests thermal treatments in dry and wet air are used as screening. The hot corrosion conditions are adjusted similar to those in the gasifier from Qalovis by using original ashes from wood chips and controlled sulphur and chloride additions inside the test gas atmospheres. In this paper, the materials choice, first results from thermal treatments in hot corrosion experiments and a detailed characterization of the different gaseous and solid species within the hot zone of the gasification device are thoroughly discussed.

Discussion

Within the project KorrMat materials are developed which provide high Al or Si contents resulting in passivating alumina or silica scales. In addition, the high Al or Si concentrations act as a reservoir at the surface for a possible self-healing behaviour under operating conditions. These new compositions are compared to well established materials exhibiting high Cr contents together with Ni based alloys which are already in use under extreme conditions; such as alloy 625 in waste incinerators. The materials under investigation are based on alloy powders which are consolidated to bulk materials by using hot pressing or the fast sintering technique SPS. Moreover, this powders were deposited by atmospheric plasma spraying (APS) or high velocity oxygen fuel spraying (HVOF) on high temperature materials (Nicrofer 3220H). Bulk materials as well as sintered powders for application experiments were tested in terms of oxide layer formation in a first step. After the oxidation experiments at 850°C and 1000°C in dry and wet air a first sample selection has been done. For the thermal treatments under hot corrosion conditions densified powders as well as coated specimens have been investigated. Since the hot corrosion conditions are the major factors determining the life time of the gas inlet nozzles, the gasification process and especially the ashes and atmospheres have been investigated in detail. From these studies the composition of the ashes and gas components carried by the fuels were derived and used in laboratory hot corrosion experiments. For these experiments test pieces were partially embedded in the original ashes of the biomass gasifier and tested at temperatures of 850 °C and 1000 °C with a constant flow of the named gas composition. This offers the advantage of the investigating three different contact zones at one test piece simultaneously: Zone 1: ash / test piece; zone 2: zone ash / gas / test piece; zone 3: zone gas / test piece. Using alternative feedstocks considerably higher concentrations of elements which initiate corrosive attacks have been determined. Moreover, the change of feedstocks will influence the sticking coefficient of the resulting ashes which, therefore, have been evaluated as an additional possible reason for accelerated corrosion.

Conclusions and/or Outlook

First results on materials development, which can be used in highly corrosive and hot atmospheres, are presented. Parallel to the material development detailed studies on ash composition and gas phases have been done leading to proposals for further materials development. The materials showing the best performances at lab scale will be used for near net shape consolidation of tools as well as a long time application within the gasifier.

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Processing and Atomization of Complex Fluids for Entrained Flow Gasification Application

Alexander Sänger, *Engler-Bunte-Institute, Karlsruhe Institute of Technology (KIT), Alexander.Saenger@kit.edu*
T. Jakobs, Institute of Technical Chemistry, KIT, Tobias.Jakobs@kit.edu
N. Djordjevic, Institute of Technical Chemistry, KIT, Neda.Djordjevic@kit.edu
L. Jampolski, Institute for Mechanical Engineering and Mechanic, KIT, Leon.Jampolski@kit.edu
Prof. T. Kolb, Engler-Bunte-Institute, KIT, Thomas.Kolb@kit.edu
Prof. N. Willenbacher, Institute for Mechanical Engineering and Mechanic, KIT, Norbert.Willenbacher@kit.edu

Keywords: Entrained flow gasification, Gas-assisted atomization, Complex rheology

Introduction

Entrained flow gasification technology is a key technology to provide an efficient method to convert low grade energy resources into a high quality carbon carrier, i.e. syngas. Design and optimization of industrial-scale entrained-flow gasifiers for conversion of fossil fuels (coal, oil) are based on extensive practical experience. When complex low-grade fuels such as biogenic slurries containing high viscous bio-oil and bio-char particles are converted, even the handling of the fuel becomes challenging. Such slurries exhibit complex rheological behaviour. Whilst processing (i.e. storage, pumping and atomization) the slurries are subjected to different shear stresses and thus their dynamic viscosity $\eta = f(\dot{\gamma})$ varies.

Especially a proper atomization is required in order to convert the suspension fuels to gaseous components efficiently. To reach this goal, the slurry has to be distributed in a fine spray by the burner nozzle, as the droplet size distribution has a significant influence on fuel conversion and syngas quality [1]. Steam and oxygen are used as gasification media. These media are also utilized as atomization agent in twin-fluid nozzles. Since gasification reactions have been proceeded at a pre-defined (low) stoichiometry, the amount of oxygen-steam available for atomization is limited and the atomizers operate at a low gas-to-liquid ratio (GLR). Thus, one of the main challenges becomes the atomization of high-viscous fuel with complex rheological behavior using the limited amount of atomization agent.

Discussion

If gas assisted atomizers are applied in slurry fed and oxygen blown entrained flow gasifiers, the amount of atomizing agent is limited by the process stoichiometry i.e. gas-to-liquid ratios GLR<1 are available. In this GLR-range the essential influence of fluid rheology on performance of a twin-fluid atomizer was observed experimentally. Even if Newtonian fluids are atomized, an increase in viscosity has a complex impact on the primary fluid instability leading to a rather surprising, non-systematic effect on generated spray quality. This makes a prediction of the spray characteristic necessary to design and scale-up burner nozzles which are very challenging for high viscous fluids. The non-Newtonian flow behaviour of the suspensions increases additionally the complexity of the model prediction due to the non-linear relationship between the shear stress and the shear rate.

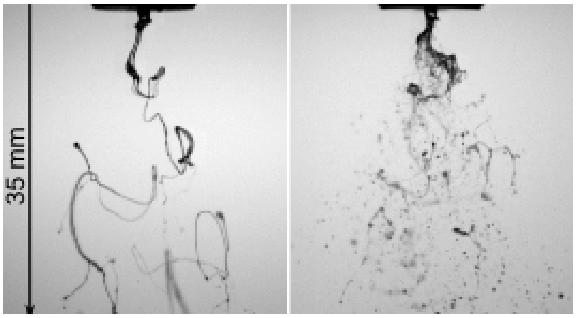

Figure 1: Atomization of Newtonian (η_0=400 mPa s) and non-Newtonian (η_0=1000 mPa s) fluid at GLR=0.7

Biogenic suspension fuels for EFG exhibit also a distinct sedimentation behaviour which is very disadvantageous for their processing (i.e. storage). To stabilize the suspension and prohibit the sedimentation their rheological properties are altered by adding stabilizing agents to the fuel. Such additives were developed to result in formation of capillary bridges between the particles which prevent their sedimentation within the continuous phase. As this generally increases the viscosity of suspension when subjected to low shear stress, it is necessary to ensure that at higher shear stress during pumping and atomization the suspension fuel recovers almost its original rheological properties. However, the impact of these altered fluid properties on gas-assisted atomization must be investigated.

Conclusion

The present work identifies the challenges in processing and atomization of biogenic suspension fuels and gives an approach to tackle them. Such knowledge is essential when energetic and material utilization of biogenic energy resources resulting from residual biomass is used to support the German Energiewende and the reduction of carbon footprint worldwide.

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HTHP Syngas Cleaning at bioliq® BTL Process Commissioning and First Results

***Robert Mai**, Institute of Technical Chemistry, Karlsruhe Institute of Technology, robert.mai@kit.edu*
Hans Leibold, Institute of Technical Chemistry, Karlsruhe Institute of Technology, hans.leibold@kit.edu
Alfred Linek, Institute of Technical Chemistry, Karlsruhe Institute of Technology, alfred.linek@kit.edu
Heinz-Jürgen Blüm, MUT Advanced Heating GmbH, Jena, bluem@mut-jena.de
Dr. Dirk Sprenger, MUT Advanced Heating GmbH, Jena, sprenger@mut-jena.de

Keywords: BTL, Syngas Cleaning, Sorption

Introduction

The bioliq® BTL process was developed at the Karlsruhe Institute of Technology to produce second generation fuels and chemicals from residual biomass. It is designed as a decentralized-centralized concept to reduce transportation and production costs. Feedstock like straw is pyrolyzed in decentralized fast pyrolysis plants producing the biosyncrude®, slurry from condensates and char. Energy density is increased to 20 GJ/m , i.e. 10-fold compared to straw. The biosyncrude® is transported to a centralized entrained flow gasifier, where it is gasified with oxygen and steam producing synthesis gas at maximum 80 bar systempressure. Before the synthesis this syngas is cleaned and conditioned in a staged, dry high temperature high pressure (HTHP) process with ceramic particle filter and staged fixed beds for sorption and catalysis. Final conditioning with CO_2 and water removal is done in the synthesis section. Synfuel is produced in a two-step process - first dimethyl ether is generated, which is further processed to gasoline, diesel or other chemicals. At KIT a bioliq® demonstration plant was designed and constructed for 500 kg/h straw and 2 MW thermal input. The individual sections of the high pressure process line: entrained flow gasifier, hot syngas cleaning and synthesis were commissioned individually. The final commissioning of the bioliq® plant and the production of bio-synfuel was done in 2 campaigns in 2014.

The complete HTHP syngas cleaning is installed in 3 high cube 40 feet containers. The process line can handle a slip stream of 700 m /h STP from the gasifier, which is 40% of the total syngas volume flow (the gasifier is designed for 5 MW thermal input). The rest of the syngas (60%) is decompressed and burned into a flare. The slip stream first is conditioned to max. 800 °C. Then soot and ash particles are separated in the ceramic filter – a compact KIT-design with horizontally mounted filter elements and a CPP (Coupled Pressure Pulse) recleaning system. Afterwards syngas is cooled down in a hairpin cooler to 500 °C and passes 2 fixed bed reactors for sorption and catalysis. Trace contaminants HCl and H_2S are removed and HCN, NH_3 and hydrocarbons are converted. Finally the clean syngas is cooled down in a 2nd hairpin cooler to 350 °C and 60 bar for transfer to the synthesis section. Compared to wet syngas cleaning systems like RECTISOL or SELEXOL 10 – 15 % overall efficiency can be gained by a HTHP system[1].

Results

The HTHP syngas cleaning must provide clean gas levels in a range of 1 – 0.1 mg/m for all relevant particulate and gaseous trace contaminants. Syngas analysis on the clean gas side is done in a slip-stream after decompression by on-line measurement devices (gas chromatograph for H_2S and COS, diode laser for HCl, HCN and NH_3). Raw syngas analysis is done by discontinuously sampling. Results gained in 2 campaigns in 2014 show that H_2S can be separated from 100-200 ppmV in the raw gas to 1-2 ppbV in the clean gas. Separation efficiency is in the range of 99.999 %. With the present configuration of sorption beds a breakthrough of H_2S was detected in the range of 0.2 ppmV due to low total sorption capacity.

Outlook

With respect to long-term operation an entrained-flow process has to be adopted. Sorbent material is injected upstream of the hot gas particle filter into the raw gas tube as a solution or a suspension. After spray drying reaction between sour gases and sorbent particles can take place during the flight phase and during the flow through the porous filter cake made of sorbent particles, ash and soot. On-line syngas monitoring of raw gas in the high pressure section is already designed and will be available in 2015.

Acknowledgement: The work has been funded by BMELV / Fachagentur Nachwachsende Rohstoffe (FNR) and Wirtschaftsministerium Baden-Württemberg / Europäischer Fonds für regionale Entwicklung (EFRE).

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Doubling of synthetic biofuel production via hydrogen from renewable electricity

M.Sc. ***Ilkka Hannula****, Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT,*
ilkka.hannula@vtt.fi

Keywords: Biofuels, Gasification, Electrolysis, Carbon efficiency

Introduction

An analytical framework is set to systematically investigate and compare advanced integrated energy systems that produce synthetic fuels from biomass residues and renewable electricity using hydrogen as an intermediate. Optimal integration strategies and their impact to biofuel output are investigated. The mass and energy balances are calculated with ASPEN Plus process simulation software.

Discussion

Converting renewable energy from wind and solar to hydrogen via electrolysis of water and further to synthetic fuels has garnered a lot of attention in countries like Germany that enjoy high penetration of intermittent energy sources [1]. However, instead of relying on CO_2 as the carbon source, hydrogen could also be mixed directly with biomass-derived synthesis gas. Such "electrolyser enhanced" synthetic biofuels configurations are able to convert considerably larger amount of biomass carbon to final fuel product that would otherwise be possible (See Figure 1.). Other benefits of integration include the use of byproduct oxygen in gasification and exothermic heat from the synthesis in the plant steam system. In addition, ramping up the electrolyser capacity during periods of excess electricity would allow the biofuels plant to participate in grid service and to store excess renewable energy chemically in the form of a synthetic fuel.

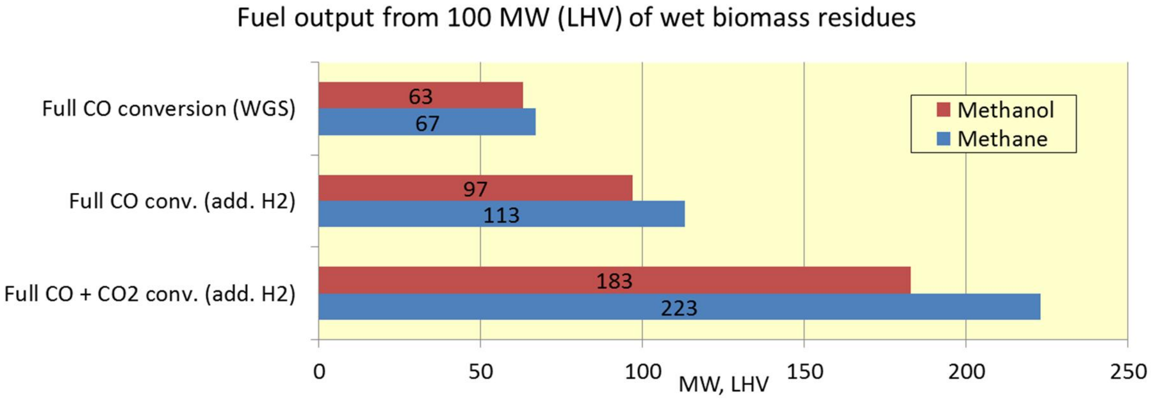

Figure 1: Impact of hydrogen addition to the output of synthetic biofuels at three different levels of integration.

Conclusions and Outlook

A key finding of a recent report [2] was that if all sustainably produced wastes and residues in the EU could be converted to biofuels, they could supply 16 % of road transport fuel demand in 2030. In the light of our analysis, this potential could be doubled to about 30 % if all biofuel production plants would be maximally enhanced with electrolytic hydrogen from renewable electricity.

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Projecting environmental benefits and drawbacks of short rotation coppice-based energy production strategies

Dr. Benedetto RUGANI*, *Dr.-Ing. Katarzyna GOLKOWSKA*, *Mr. Daniel KOSTER
Department of Environmental Research & Innovation (ERIN) / Luxembourg Institute of Science and Technology (LIST), Luxembourg; benedetto.rugani@list.lu / katarzyna.golkowska@list.lu / daniel.koster@list.lu

Keywords: Climate change mitigation; Environmental impact; Life Cycle Assessment, Short Rotation Coppice

Introduction

Exploitation of wood from Short Rotation Coppice (SRC) is more and more recognized as a viable biomass based energy source alternative to fossil fuels [1]. Moreover, the inclusion of native species in SRC plantations can highly increase the biodiversity and the supply of ecosystem services locally, providing synergic benefits to the main energy-oriented goal of the SRC [2]. This study describes a Life Cycle Assessment (LCA) [3] application to evaluate SRC pilots recently implemented on seven experimental sites in Flanders (Belgium), which have multiple land uses: next to generating energy at regional scale, those sites are promoted to enhance the local area conditions (e.g. activation of temporary unused grassland of industrial sites, enhancement of biodiversity and ecosystem service capacity, etc.), implementing a long-term management strategy. Despite the SRC practice has been the subject of economic and environmental cost-benefit analyses for several years, this research adds some insights to current LCA literature. In particular, the life cycle impact profile on climate change was further improved with information retrieved from simulating the carbon dynamics over time using specific carbon accounting models (i.e. CO2FIX [4]). Moreover, alternative uses of SRC-based wood chips are compared, such as for the production of transportation fuel (syngas), and co-generation of heat and electricity.

Results and Discussion

The seven analysed SRC trials extensively differ from each other in terms of planted species and their density (among willow clones, poplar clones or a mix of the two with local tree species). SRC trees were planted in 2012, and a 3-year rotation was simulated up to 2033. The plantation diversity and growth dynamics was modelled in CO2FIX, and the technological supply-chain and production phases with an LCA approach, by quantifying a large number of environmental impact indicators (potentials of climate change, acidification, eutrophication, ecotoxicity, resource depletion, etc.). Yields were first estimated over time with CO2Fix, and results (on average 10.2 ± 6.7 o.d.t/ha/year) were in compliance with data from literature [1]. After entering the CO2FIX outputs (yields and sequestered C flows) in the life cycle models, the analysis revealed that SRC systems mainly composed by poplar species have typically lowest yields, but also the best environmental performance when looking either at 1 m^3 of wood chips delivered or at the total volume of wood produced per ha. However, other systems based on mixed species (willows, poplars, native trees) provide greater opportunities for C seq., and, consequently, utmost potentials of climate change mitigation. Along the seven pilots, the highest impacts were due to the consumption of diesel during the cyclic harvests, but also to the electricity and the use of chemicals for grass killing on industrial soils. This knowledge could help to improve the environmental performance of similar sites in the future by optimizing those most critical processes from an environmental perspective. To make it more robust, however, uncertainty distribution ranges were determined for the most critical parameters and a subsequent Monte Carlo analysis was performed to obtain average impact scores per functional unit (e.g. -0.54 ± 0.31 tCO_2-eq./m^3 of wood chips; minus means 'impact avoided' in this case). Finally, it was observed that the introduction of wood chips from SRC in the supply-chain of heat and electricity production, or syngas production, instead of hardwood chips, seems not so advantageous for some impact categories such as terrestrial acidification, eutrophication, or ozone depletion, while clear environmental benefits occur in terms of land use reduction and climate change mitigation. The trends for the latter impact categories (thanks to the frequent rotations) turned out to be high enough to compensate the negative effects of the other indicators on human health and ecosystems quality at the endpoint impact level.

Conclusions and Outlook

This work gives an overall, predictive, understanding of the 'hidden' environmental impacts that may be generated out of different management strategies of SRC plantation in the Flanders. Results may be useful so far to orientate SRC growers towards the most appropriate mix of species to meet the highest standards of environmental efficiency. The use of CO2FIX in combination with LCA is highly promising, but still challenging, to deepen and broaden the life cycle impact assessment of climate change with more accuracy.

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Ultra-low emission wood combustion by seamless adaptation of an electrostatic precipitator to a modern grate boiler[1]

Hanns-R. Paur, Institute for Technical Chemistry , Karlsruhe Institute for Technology, paur@kit.edu; Martin Ecker, HDG-Bavaria GmbH, : martin.ecker@hdg-bavaria.com; Hans Rheinheimer, CCA-Carola Clean Air GmbH, rheinheimer@carola-clean-air.com, Andrei Bologa, Institute for technical Chemistry, Karlsruher Institut for Technology, andrei.bologa@kit.edu

Keywords: Wood combustion, particle emission, electrostatic precipitator

Introduction

Combustion of biomass uses sustainable, domestic fuels, which are available in large quantities at competitive costs and deliver about 90% of the regenerative heat in Germany. The emission of ultrafine particles from wood combustion is of concern due to their health effects. Accordingly German legislation (1st BImSchV) requires a further reduction of particle emission limits to below 20 mg/m^3 for new wood fired boilers starting from 2015.

Discussion

The technology of wood combustion (wood-chips, pellets, logs) by automatic grate boilers has considerably advanced during recent years. Boiler efficiencies above 90% and low emissions of particles and gaseous pollutants are state of the art. Modern grate boilers achieve particle emissions of 10 – 100 mg/m^3, depending on the fuel quality. Thus further measures are mandatory for new boilers to comply with the new legislation.

Recently compact and cost-efficient Carola$^{®-}$precipitators have been developed, which achieve high particle collection efficiency for submicron particles.. Reliable long-term operation of these precipitators was demonstrated at test facilities and particle concentrations below the new emission limits were achieved.

Besides the technological readiness of boilers and precipitators the combination of both units is an important task concerning the market penetration of the technology. With respect to competitiveness of wood fired boilers their cost should increase only moderately due to the installation of particle control devices. This challenge can be met by seamless adaptation of the precipitator into the boiler, which opens several opportunities for technological progress and cost reduction as well. In this project a first prototype is manufactured, which combines a full mechanical and electronic adaptation of an electrostatic precipitator to a wood fired grate boiler.

Figure 1: Installation of the electrostatic precipitator at a 200 kW wood-chip boiler

Conclusions and outlook

By adaptation of the Carola®-precipitator to the HDG wood chip boiler the technological complexity of the installation is reduced with respect to ducts, casing and electronic components. Moreover the adaptation allows electronic communication between the boiler and the precipitator, which improves the reliability of the whole unit. The first operational experience of this novelty will be discussed. Tests at industrial and domestic boilers are in progress and will be discussed.

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Economic and ecological evaluation of biogas plant configurations for flexible power generation

***Henning Hahn**, Division Energy Process Technology, Fraunhofer IWES, Henning.Hahn@iwes.fraunhofer.de*

Keywords: Biogas, Biogas plant configuration, flexible power generation, renewable energy system

Introduction

The transformation to an electricity system based on renewable sources is characterized by an increasing need for balancing power in order to compensate power supply from fluctuating sources, such as solar or wind. Biomass, more precisely energy from biogas, has the potential to generate electricity flexible on demand. Since electricity from biogas has not been used to balance fluctuations of intermittent renewable energies (RE) in the past, there is a need for new configurations that are able to meet the requirements of highly RE systems and to supply biogas according to the varying demand for balance power generation. In this regard, this presentation focuses on the economic and ecological evaluation of biogas plant configurations for flexible power generation.

Material and methods

A guaranteed biogas supply for flexible power generation can generally be realized through biogas storing concepts (CP-BS; CP-UI) or in combination with flexible biogas production concepts (CP-IFBB, FBPC, FBPC-IFBB) [1,2]. Considering the importance of the need to keep fuel costs for flexible power generation to a minimum, the study focused on the calculation of additional flexibility costs caused by a variable biogas supply in comparison to baseload biogas supply from a conventional biogas plant. Two scenarios with different time spans of biogas demand for electricity generation were investigated. Each scenario represents typical market price fluctuations. The first scenario dealt with daily price fluctuations and the period with biogas demand was assumed to be 8 hours per day (figure 1a). The second scenario required the biogas plant to be more flexible and represented typical situations of several days with high electricity generation from sun and wind. Consequently, a period of 72 hours without biogas demand was considered (figure 1b,c).

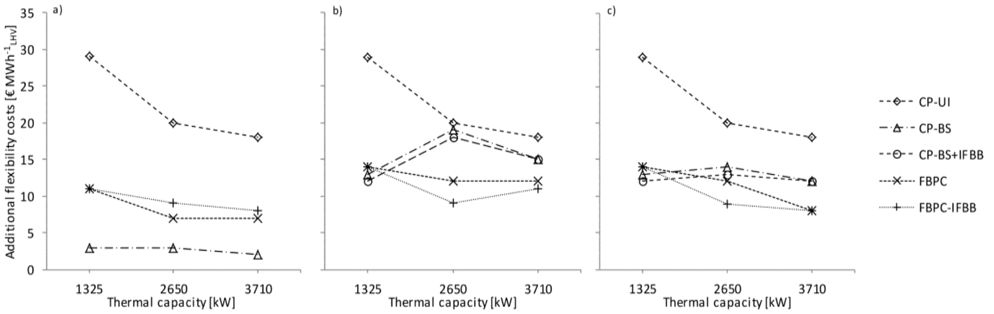

Figure 1: Additional flexibility costs compared to a baseload biogas supply of a conventional biogas plant in a) 8 hours per day, b) 72 hours without biogas consumption and c) without considering extra costs caused by exceeding maximum gas storage quantities [3].

The assessment of the overall ecological efficiency of five biogas plant configurations supplying biogas demand oriented in comparison with biogas supply by a conventional biogas plant and the fossil reference natural gas were investigated by a life cycle assessment of each biogas plant configuration [4].

Results

Biogas plant configurations based on biogas storing or in combination with flexible biogas production concepts are able to supply biogas on demand for flexible power generation. Flexible biogas production configurations manage the biogas supply at the lowest costs, if periods without biogas demand for electricity generation exceed a period of several hours. In contrast to a supply of power generators with natural gas, biogas plant configurations manage to supply biogas variably on demand and CO_2 neutral while achieving primary energy savings.

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Efficient measures of bioenergy powered CHP

Diana Pfeiffer, *DBFZ Deutsches Biomasseforschungszentrum gGmbH, diana.pfeiffer(at)dbfz.de*
Prof. Daniela Thrän, DBFZ Deutsches Biomasseforschungszentrum & Helmholtz Centre for Environmental Research GmbH (UFZ), daniela.thraen(at)dbfz.de
Keywords: Bioenergy, CHP, Heating, Efficiency, Technology

Introduction

The supply of sustainable heating and power from biomass is a great challenge for the future energy transition. Biomass contributes with 88.87 % to the renewable heat production in Germany [1]. Thus, mitigating energy-related GHG emissions through renewable energy in the heating sector is to a large extent the result of the biomass energy use. At the same time, bioenergy technology systems still have a particularly large potential for optimization. For this reason in the programme "Biomass energy use" [2] funded by the Federal Ministry for Economic Affairs and Energy in Germany competitive and climate-friendly bioenergy technologies for a sustainable and efficient generation of power, heat and fuels from biomass, especially from biogenic waste and residues are developed. The paper will give an overview on outstanding exemplary projects within the programme focusing mainly on the production of electricity and useful heat (CHP) at high efficiency with regard to output, environment and costs.

Discussion

During the last five years the programme "Biomass energy use" has supported 100 projects on sustainable bioenergy provision. About 40 of these projects mainly aim to develop and test efficient, decentralized and low emission concepts for combined heat and power (CHP) applications and small-scale furnaces. 20 demonstration & pilot plants have been already successfully tested. In the following four projects are presented with respect to their contribution to controllable and flexible generation of electricity, high efficiency and cost effectiveness, reduction of emissions (GHG, particulate matter etc.) and future potential of market penetration.

Flexibility and cost effectiveness. FlexHKW - Supporting the Electrical Grid with Renewable Heating Plants: The project shows that biomass thermal power plants have the potential for flexible power generation. Almost every plant is able to flexibly produce electricity since the most common energy converters used are ORC turbines and extraction condensing turbines (both > 85 % of the German plant inventory). The flexible operation is able to adjust the overall electricity generation to the electricity demand and the power generation by wind and solar power. From the perspective of thermal power plant operators the profit can be maximised by taking advantage of price spreads when directly merchandising the produced energy and henceforth building a sound basis for refunding the power plant. In order to exploit this extra degree of freedom this project particularly investigates the opportunities of additional thermal buffer plants. Different concepts for sundry thermal power plant types are elaborated. At an existing pilot plant, running already a district heating network, the prequalification tests were successfully passed and it provides balancing energy since autumn 2014. The technical viability and the economic feasibility are monitored permanently.

Emission reduction in small scale biomass furnaces: The combination of integrated measures were developed and investigated in a joint research project to reduce the pollutant emissions from small-scale biomass furnaces. The development and integration of a catalyst, an electrostatic precipitator and the combustion control were carried out by test stand experiments at two firing furnaces. Practical applicability and operator convenience were investigated by field measurements during two heating periods. At the flue gas outlet of a high quality wood log stove a wire mesh catalyst and an electrostatic precipitator were integrated. Furthermore a continuous combustion control was implemented. 50 % reduction of carbon monoxide and particulate matter emission have been achieved. Furthermore, an electrostatic precipitator and a catalyst were integrated in the heat exchanger of a multi-fuel pellets boiler. The combustion control algorithm was improved, especially for the part load operation. During the investigations wood, miscanthus and corn strip waste pellets were used. The carbon monoxide emissions have been reduced by 50 %. A dependency on fuel type has been observed for the electrostatic precipitation resulting in collection efficiencies between 55 and 90 %.

KomInteg & Milestones Bioenergy 2030 – Sustainable integration of bioenergy systems in the context of municipal government processes and future trends: The project shall analyse the specific impacts of the integration of biomass technologies in different communal base cases. Moreover, suitable opportunities for action concerning the energetic use of biomass as well as the optimization of already implemented biomass systems are described for municipalities as a key stakeholder in the energy transition process. For this purpose, around 11'500 typical municipalities are classified in clusters by using different indicators and assigned to possible bioenergy technologies ("Technology-Tool"). Particular focus is put on the use of biomass in the heating market where two thirds of existing potentials can only be used by local grids and municipalities have enormous influence by urban development planning. Furthermore, future scenarios of bioenergy systems in the heating market elaborated in the project Milestones Bioenergy 2030 were evaluated.

Conclusions and Outlook

For a successful energy transition it is important to develop systemic solutions in the heating and electricity market as showcased already by CHP technology systems. Current developments up to the level of prototypes can contribute to a sustainable heat supply. But, there is still a great potential to increase the output on the one side and mitigate the emissions and the costs on the other side.

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Final results of the SECTOR project: Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction

***Kay Schaubach**, Department Bioenergy Systems, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, kay.schaubach@dbfz.de*
Prof.-Dr. Daniela Thrän, Department Bioenergy Systems, DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, daniela.thraen@dbfz.de
Dr. Jaap Kiel, ECN Stichting Energieonderzoek Centrum Nederland, kiel@ecn.nl
Michiel Carbo, ECN Stichting Energieonderzoek Centrum Nederland, carbo@ecn.nl

Keywords: Torrefaction, Biomass conversion technology, Torrefied pellets, Densified biomass

Introduction

The European (FP7) project SECTOR, aiming at the further development and market introduction of torrefaction-based technologies for the production of solid bioenergy carriers has reached its final period. In torrefaction, biomass is heated up in the absence of oxygen to a temperature ranging between 250°C and 320°C. By combining torrefaction with pelleting or briquetting, biomass materials can be converted into high-energy-density bioenergy carriers with improved behaviour in (long-distance) transport, handling and storage. Torrefaction also creates superior properties for biomass in many major end-use applications. The process has the potential to provide a significant contribution to an enlarged raw material portfolio for sustainable biomass fuel production inside Europe by including both agricultural and forestry biomass (residues).

The SECTOR project – with more than 20 partners from industry and science – is expected to shorten the time to market for torrefaction technology through extensive pilot and demo scale torrefaction as well as densification trials. The downstream value chain is elaborately assessed through logistics and end-use testing of the torrefied biomass, in combination with supporting small-scale experimentation and analysis. The technical work is accompanied by safety assessments, development of standards (both for dedicated analysis methods and torrefied products), techno-economic assessment of major biomass-to-end-use value chains and a complete sustainability assessment.

Discussion

This conference contribution will present an elaborate overview of the most important project results that were obtained since the beginning of the project. More than 200 tons of torrefied biomass were produced and densified (pelletised and briquetted) by the four producers. The production of these batches has led to the formulation of dedicated recipes for various feedstocks, through fundamental studies about changes in structure and composition during biomass torrefaction and densification. The torrefied pellets and briquettes have been tested by other project partners to assess the material performance during handling and storage as well as in small- and large-scale end-use applications.
Torrefied pellets and briquettes with different degrees of torrefaction were assessed and tried to characterise their behaviour according to durability, weathering, biodegradation, self-heating, self-ignition and dust explosivity. Larger samples of torrefied pellets have been subjected to outdoor stockpile tests, and to assess handling in existing feed lines of coal-fired power plants. Three principal end-use applications for torrefied biomass were under investigation in this project: co-firing in pulverised fuel boilers, (co-)gasification in entrained-flow gasifiers and combustion in commercial pellet boilers. Results that were obtained during lab-, pilot- and large-scale thermal conversion trials will be presented, in conjunction with results of grindability (milling tests) and feeding experiments.
Parallel to the technical process development several standard test methods for the analysis of physical and chemical fuel properties of torrefied biomass were successfully validated in two extensive Round Robin tests, while new dedicated test methods and a specific product standards (ISO 17225-8) are under development.
Lastly, a methodology has been developed for both the life-cycle-assessment and socio-economic assessment of the torrefaction-based value chains; for the environmental assessment these will be presented in the form of case studies for specific focus regions.

Conclusions

In summary, during SECTOR, project partners have been able to produce torrefied biomass of a better and more constant quality, and consistent data sets on logistics and end-use performance contribute to increasing confidence levels amongst relevant stakeholders. Now, it is time for market implementation of this promising innovative fuel, which markets perspectives are manifold both in the energy sector but also in the bioeconomy or in the chemical industry (e.g. by torrefaction co-product conditioning as organic based pesticide).

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BIO-GO: Conversion of Bio Gas and Pyrolysis Oil to Synthetic Fuels

G.Kolb, *Fraunhofer ICT-IMM, Carl-Zeiss-Str.18-20 D-55129 Mainz;*
Tel.: ++49-6131-990-341; Fax.:-305; email: gunther.kolb@imm.fraunhofer.de

Keywords: Energy, Conversion, Technology, Climate, Material

Abstract

BIO-GO-For-Production is a Large Scale Collaborative Research Project co-ordinated by Fraunhofer ICT-IMM, which was started late 2013 in the scope of the 7th Framework Program of the European Commission. It aims to achieve a step change in the application of nanocatalysis to sustainable energy production through an integrated, coherent and holistic approach utilizing novel heterogeneous nanoparticulate catalysts in fuel syntheses. BIO-GO researches and develops advanced nanocatalysts, which are allied with advanced reactor concepts to realise modular, highly efficient, integrated processes for the production of fuels from renewable bio-oils and biogas. Principal objectives are to develop new designs, preparation routes and methods of coating nanocatalysts on innovative micro-structured reactor designs, enabling compact, integrated catalytic reactor systems that exploit fully the special properties of nanocatalysts to improve process efficiency through intensification.

An important aim is to reduce the dependence on precious metals and rare earths. Catalyst development is underpinned by modelling, kinetic and in-situ studies, and is validated by extended laboratory runs of biogas and bio-oil reforming, methanol synthesis and gasoline production to benchmark performance against current commercial catalysts. The 4-year project culminates in two verification steps: (a) a 6 month continuous pilot scale catalyst production run to demonstrate scaled up manufacturing potential for fast industrialisation (b) the integration at miniplant scale of the complete integrated process to gasoline production starting from bio-oil and bio-gas feedstocks. A cost evaluation will be carried out on the catalyst production while LCA will be undertaken to analyse environmental impacts across the whole chain. BIO-GO brings together a world class multi-disciplinary team from 16 organisations to carry out the ambitious project, the results of which will have substantial strategic, economic and environmental impacts on the EU petrochemicals industry and on the increasing use of renewable feedstock for energy. An overview of the project objectives and the approaches how to reach these goals will be presented along with first results.

Nanocat
Energy self-sufficent
BIO =GO

Green Production of High Cost Solvents from Bio-Ethanol Using Alumina and Metallic Co-doped Al_2O_3 catalyst

Bandith Chokcharoenchai, *The Petroleum and Petrochemical College,Chulalongkorn University*
art.alkyl@gmail.com
Assoc.Prof.Sirirat Jitkarnka The Petroleum and Petrochemical College,Chulalongkorn University
sirirat.j@chula.ac.th

Keywords: Bio-Ethanol, Dehydration, Oxygenate Compounds, Pentanones

Introduction

Expensive solvents such as pentanones have increasingly been used as industrial solvent, medical treatment, preparation of pharmaceuticals and pesticides [1]. Conventionally, pentanones are produced via oxidation of hydrocarbons such as 2-pentanol or hexanoic acid by using metal oxides as catalysts. Nowadays, the catalytic dehydration of bio-ethanol is an alternative route for hydrocarbons and oxygenates production. This process uses less energy consumption, and it is environmental friendly. In this work, 5% metallic Co-promoted alumina catalyst prepared by incipient wetness impregnation method was examined, aiming to produce high cost solvents such as pentanones from the catalytic dehydration of bio-ethanol at $500^{o}C$. The oily liquid products were analyzed by using GCxGC TOF/MS for their compositions.

Discussion

The metallic cobalt-promoted alumina catalyst was examined in the catalytic dehydration of bio-ethanol. It was found that the liquid products mainly contain oxygenate compounds, as shown in **Figure 1A**, such as butanone, pentanones, hexanone, and trace amounts of hydrocarbons; that are, benzene, tolulene, p-xylene, and napthalenes. Moreover, the uses of alumina and cobalt-promoted alumina catalyst enhance the production of pentanones in the liquid products **(Figure 1B)**. The formation of oxygenate compounds, especially pentanones, from ethanol was explained by He *et al.,* 2005 [1]. They found that the important intermediate was aldor species, which occur from condensation of aldehyde, and was further converted to pentanones by losing H_2O molecule and then being hydrogenated.

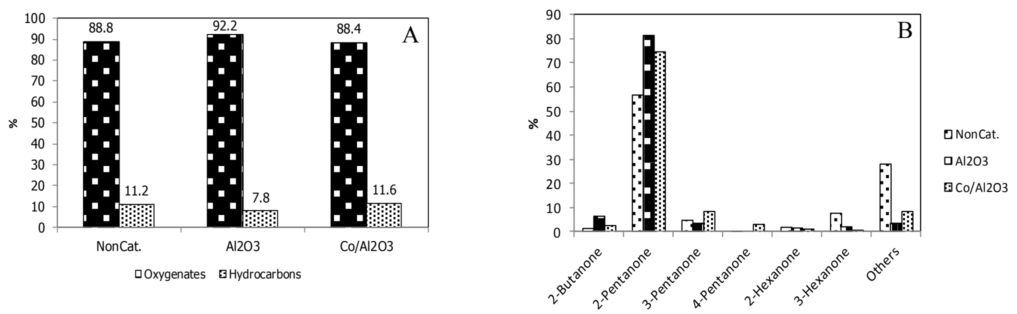

Figure 1: A) Percentage of oxygenates and hydrocarbons in the liquid products, and B) Oxygenate compounds distribution

Additionally, with the introduction of metallic cobalt-promoted alumina, it can be observed that the amount of ethylene decreased. Moreover, other gaseous by-products present in a trace amount are, for examples, methane, ethane, propylene, and butylene. It can be explained that ethylene may act as an intermediate during the catalytic dehydration of bio-ethanol to transform to other hydrocarbons species mainly benzene [2], and trace amounts of toluene, p-xylene, derivatives of benzene, and naphthalenes.

Conclusions and/or Outlook

Metallic cobalt-doped alumina catalyst was found to produce oxygenate compounds in the catalytic dehydration of bio-ethanol. The ratio of oxygenates to hydrocarbons was 7.70, approximately. It was revealed that the catalyst was selective to produce pentanones as the major product in the liquid via condensation and hydrogenation reaction.

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Production of hydrogen from biomass via gasification in supercritical water

Dr. Nikolaos Boukis, *IKFT, Karlsruhe Institute of Technology, Nikolaos.boukis@kit.edu*
Sophia Herbig, Elena Hauer, Ulrich Galla, Herbert Lam and Prof. Dr.-Ing. Jörg Sauer, IKFT, Karlsruhe Institute of Technology

Keywords: Hydrogen, biomass, gasification, supercritical water, phosphorus

Introduction

For the energetic utilisation of waste biomass with high water content the process of the gasification in supercritical water is one of the most efficient options. This has been studied with several different wet biomasses in the last years. Draff [1] and sewage sludge were not studied intensively until now. A new developed reaction system enables the effective separation of solids and inorganic components previous to the high temperature reaction zone. Main focus of the work is the energetic optimisation, the quality of the residual water and the effective separation of the inorganic components of the biomass during the process.

Discussion

Typical reaction conditions for the process of gasification under the conditions of supercritical water are a temperature of about 650 °C and a pressure of about 300 bar. For the treatment of waste biomass or even sewage sludge contaminated with heavy metals, sulphur and chlorine, application of heterogeneous catalysts can become an issue. To avoid this, a high reaction temperature can be applied and only the catalytic effect of potassium salts is used to increase the product yield.

Important from the sustainability point of view and for an uninterrupted continuous flow operation is the effective separation – recovery of the inorganic components of the sewage sludge previous to the high temperature part of the process. This step increases the environmental benefit of the process due to the possibility to recycle elements like phosphorus. The product gas can be used (in many ways) for various hydrogenation reactions or as gaseous fuel for internal combustion motors.

Highlights of the process are:

- High gasification rate up to more than 90 %.
- High hydrogen concentration in the product gas up to 70 %.
- Product gas production at 20 MPa, no dust, no chlorine very low sulphur concentration
- Recovery of phosphorous up to 80 % just by filtration.
- Low consumption of electric energy for compression.
- Demonstration in pilot plant in the 100 kg/h range
- CO_2 separation at low costs

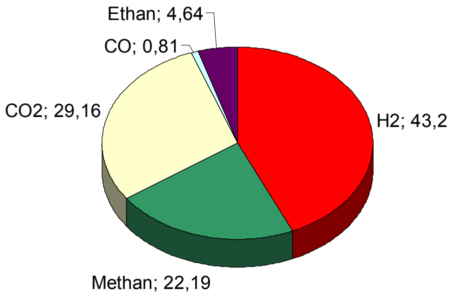

Figure 1: Typical composition of the product gas from draff, in vol %; experimental conditions: T=700 °C, p=280 bar, DM=14 wt.%, mean residence time 1.7 min. The carbon gasification yield is 91 %.

Conclusions and/or Outlook

Gasification of waste biomass in supercritical water can now be performed without blockage of the flow. Effective separation of salts is crucial for this success. Next target is the optimisation of the energy output of the process and the quality of the waste water.

Acknowledgement: The authors appreciate the efforts of Mr. R. Drexle and Mr. K. Weiss, S. Henecka with regard to the mechanical work included in the gasification unit. This work has been supported by the Helmholtz-Gemeinschaft Deutscher Forschungszentren. Part of the work was realized in cooperation with the Paulaner brewery. Another part of the work was realized in cooperation with STOWA, the Dutch Foundation for Applied Water Research.

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Experiences from geothermal projects and necessity for a geoscientific underground laboratory

Prof. Dr. Thomas Kohl, Institute of Applied Geosciences – Division of Geothermal Research, KIT, thomas.kohl@kit.edu
Dr. Eva Schill, Institute for Nuclear Waste Disposal, Reservoir Geology Group, KIT, eva.schill@kit.edu
Dr. Judith Bremer, Institute of Applied Geosciences – Division of Geothermal Research, KIT, judith.bremer@kit.edu

Keywords: geothermal engery, EGS, Upper Rhine Graben, underground laboratory GeoLaB, Controlled High Flow rate Experiments (CHFE)

Introduction

Deep geothermal reservoirs as renewable energy source offer an enormous potential for base-load capable, steerable power and heat provision. The utilization of geothermal energy from crystalline reservoirs by Enhanced Geothermal Systems (EGS) contributes mainly to the geothermal potential in Germany and worldwide. However, this potential has been largely untapped.

The Upper Rhine Graben (URG) offers particularly favorable geologic conditions for geothermal energy usage due to crustal thinning and extensional graben tectonics. Deep seated sediments, fault zones and hydrothermal convection cells result in basal heat flow anomalies and abnormal temperature gradients up to 110°C km^{-1}. It is therefore not surprising that the URG is amongst the leading regions in EGS research and technology development with several pilot and demonstrations projects.

Discussion

A unique and groundbreaking EGS pilot project for research on deep geothermal energy production from fractured low enthalpy reservoirs has been developing in Soultz-sous-Forêts (F) since 1987. The general feasibility of the EGS concept in fractured crystalline reservoirs has been demonstrated. A multi-reservoir EGS up to 5 km depth has been be established with, so far, six years of thermal water circulation. During this time, the reservoir productivity has been drastically increased. Important milestones with respect to environmental impact mitigation and power plant operation have been achieved. EGS projects in Landau, Insheim and Rittershoffen followed.

However, reservoir processes are still not fully understood; e.g. the differences of stimulation and circulation behavior between the different reservoirs cannot be satisfyingly explained and predicted. The hydro-mechanical role of alteration zones have only been partly understood so far. Corrosion and scaling processes still lead to costly maintenance and operational disruptions. Reservoir productivities, i.e. thermal water circulation rates, are still limited. New reservoir engineering concepts have been tested and led to successful hydraulic stimulation without creating perceptible seismicity, but adequate description of such hydro-mechanic interactions during these experiments has not yet been achieved due to lack of fundamental constitutive laws.

Conclusions and outlook

To fundamentally change this situation, research has to lay the basis for the necessary technology development by providing essential process understanding. This requires research on the coupled thermal-hydraulic-mechanical-chemical (THMC) reservoir processes. The formulation of lacking constitutive laws is necessary to predict reservoir behavior during stimulation and operation. Instead of conventional 1D monitoring, 3D coverage of the dynamic processes is necessary. The existing gap between laboratory and field scale has to be closed to study the scale dependency of processes, enable model parametrisations and validations.

These requirements can only be fulfilled by a technology specific underground laboratory tailored to the conditions of geothermal reservoirs. Consequently, “GeoLaB” as a geothermal research laboratory in the fractured crystalline basement is proposed. Controlled high flow rate experiments (CHFE) shall provide new insights into (i) high rate flow and reactive transport processes in 3D structures, (ii) stimulation and earthquake processes, (iii) biogeochemical processes, (iv) scale dependency of parameters and observations, (v) corrosion processes and material resistance in aggressive environments. Furthermore, GeoLaB shall provide an open international platform to tackle research questions regarding complex fracture network systems also beyond geothermal research across geo- and environmental, engineering and material sciences. These disciplines have to be closely interlinked with each other and additionally with social sciences. A close link to industry shall ensure technology transfer to URG and worldwide projects. Only with this transdisciplinary approach it is possible to critically boost technology development and to regain public confidence in geothermal energy as an important cornerstone of a future sustainable energy mix.

Quality Management and Improvement for Geothermal Energy Projects using the Platform Based Tool Development Technology – ZWERG

***Benedict Holbein*[1]*,* *Jörg Isele*[1]*, Luigi Spatafora*[1]*, Veit Hagenmeyer*[1]
benedict.holbein@kit.edu,
[1]*Institute for Applied Computer Science IAI, Karlsruhe Institute of Technology KIT*

Keywords: Quality management, deep geothermal energy, tool development,

Introduction

Geothermal Energy is a renewable energy source with the potential of a base-load supplier, especially in the field of heat distribution grids. However, Geothermal Energy has an acceptance problem: Due to incidents like in Staufen, Basel and Landau, its image in the public opinion is quite poor. This poor image influences the political support for the renewable energy source and makes the situation for investors more difficult. From a technical point of view, the urgent issue is the lack of direct data from geothermal boreholes and the insufficient possibilities for interaction downhole. Since borehole-tools adjusted to the special conditions of geothermal boreholes are extremely rare and often not accessible, necessary operations for quality control of boreholes or investigation and rectification of emerging problems remain undone. In order to improve this situation by increasing the number of geothermal borehole-tools and by reducing the respective development costs, the ZWERG project was started in 2010 at the Karlsruhe Institute of Technology. Its objective is to create a system platform technology for the standardized and modular development of borehole-tools.

The ZWERG philosophy

ZWERG is a complementary approach to many other investigators on borehole probes. While many researchers focus on necessary technical applications like new sensor tool as pH-sensors, Thermal Conductivity Scanning or acoustic data-transfer techniques, ZWERG primarily concerns about the environmental conditions in the deep borehole in order to enable the aforementioned technical applications to survive *in situ*. The standardization of generic components requires unified design conditions. Hence, for ZWERG an operation depth of 5.000 m with 600 bar pressure and 200 °C environmental temperature, based on the conditions at the "Soultz-sous-Forêt" project in France, are assumed. ZWERG carries the idea of an open-source system-platform by providing i.e. solutions for different housing dimensions, non-corrosive housing material, sealing construction, in-borehole cooling and others. The different developers of the aforementioned sensor tools and future applications are encouraged to use the ZWERG components, exchange their know-how and share their solutions on the ZWERG engineering network, with the aim of building a ZWERG community. The quick and reliable access to important information and components for borehole-tools should help engineers to reduce development time and costs and to improve their solution quality. The modular components-of-the-shelf shown in **Figure 1**, are the basis for various tools for investigation or interaction in boreholes.

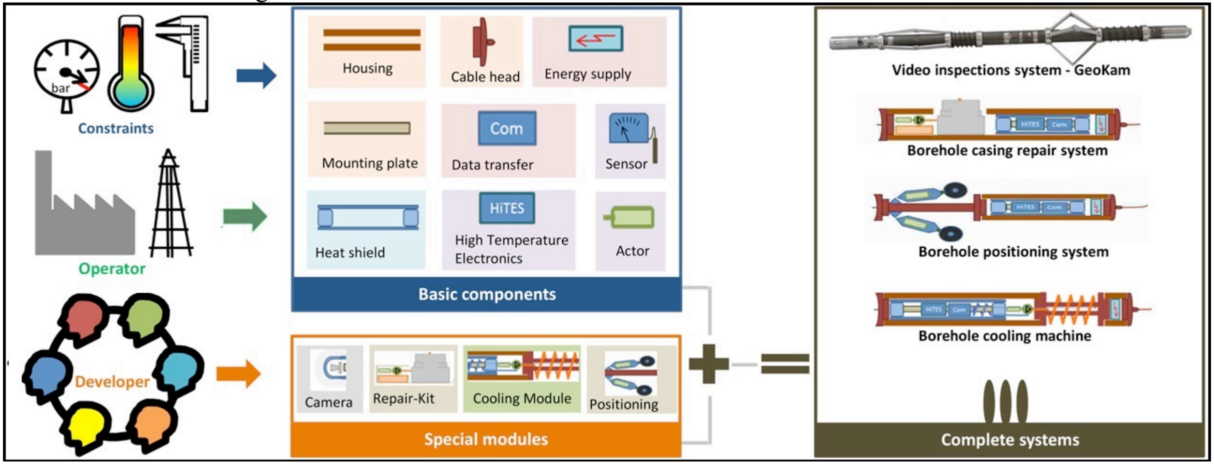

Figure 1: Presentation of basic components of the open-source system-platform ZWERG

Conclusion and Outlook

Finding solutions on the basic engineering challenges for the tools and designing tools in a modular way allows reusing common components and therefore accelerate the development of new tools fit for downhole operations. This gives developers i.e. of sensors for water properties, gamma-ray measurement devices and others the possibility to focus on their application and realize complete systems ready-to-use in geothermal boreholes. In the future these advanced possibilities to investigate the processes and events inside geothermal boreholes will also enable specific interventions. This helps to assure and improve the quality of geothermal energy production and to boost its public acceptance.

Migration based detection and location of the microseismicity induced at Rittershoffen geothermal field (Alsace, France)

***Dr. Emmanuel Gaucher**, Institute of Applied Geosciences – Division of Geothermal Research, KIT, emmanuel.gaucher@kit.edu*
Prof. Dr. Alessia Maggi, EOST, Université de Strasbourg, alessia.maggi@unistra.fr
Dr. Nicolas Cuenot, European Economic Interest Grouping (EEIG) "Heat Mining", cuenot@soultz.net
Dr. Vincent Maurer, ES-Géothermie, Strasbourg, vmagnenet@unistra.fr

Keywords: EGS, induced microseismicity, seismic monitoring, migration based detection, Rittershofen

Introduction

Seismic monitoring of Enhanced Geothermal Systems (EGS) is now required since fluid circulation generally induces microseismicity, especially during reservoir stimulation where felt seismic events may occur and become a concern. Moreover, real-time processing of the seismic data becomes mandatory for setting up robust alarm systems. Hence, the development and application of reliable and automatic techniques for processing the data acquired by these local seismic networks are crucial.

In Rittershoffen, Alsace, France, an EGS plant is being developed by the ECOGI Company. Once operational, the power plant should deliver 25 MW_{th} to a bio-refinery plant located 15 km away. To reach this objective, a geothermal doublet is being developed at 2.5 - 3 km depth, into the Triassic sandstone and the Paleozoic granitic formations. After drilling the first well, hydraulic stimulation was carried out in June 2013 to enhance the connectivity between the well and the geothermal reservoir. This operation induced seismicity which was continuously recorded by a surface network composed of 17 seismic stations.

Discussion

In the framework of this study, we replay the seismic record dataset through an automatic kurtosis-based migration detection and location technique, called Waveloc. The software, developed by EOST (University of Strasbourg) and applied successfully on volcano seismicity, first transforms the raw data into kurtosis-based waveforms which enhances the first arrivals of seismic events observed over the network. By considering only P-waves, the migration step consists in applying source-scanning, move-out and stack of the kurtosis waveforms over the target volume and over time. The resulting movie highlights the location and occurrence time of the seismic events associated to the maximum of the stacks in space and time. Such a procedure, which intrinsically integrates the detection, picking and location of the seismicity, automatically generates a catalogue of seismicity. However, calibration of the parameters is necessary to adapt the automatic processing to the site. In our context, we used a restricted dataset of manually processed data for this calibration.

The results of this processing approach will be analyzed and compared to existing catalogues of the seismicity induced during the stimulation. The aim will be to measure the detection and location capabilities of the Waveloc method using the existing seismological network; especially the trade-off between increased detection capability and decrease of location certainty. This can partly be done through forward modelling of the resolution of the technique within our context (network lay-out, velocity model). Additionally, we should be able to quantify discrepancies in the locations between Waveloc automatic results and other results, and to verify the consistency of the automatic method.

Outlook

If we succeed in qualifying the Waveloc method for use at Rittershoffen, it will be possible to replay the whole dataset acquired on this site, which covers about 1.5 years, with the aim of enlarging the seismic catalogue by applying consistent processing over the period. Furthermore, we will envisage the possibility of applying this technique, in real-time, to continuous seismic records acquired on existing or future sites.

Synthetic clay logs to assess the mechanical behavior of a geothermal reservoir

Dr. Carola Meller, Institute of Applied Geosciences – Division of Geothermal Research, KIT, carola.meller@kit.edu
Prof. Dr. Thomas Kohl, Institute of Applied Geosciences – Division of Geothermal Research, KIT, thomas.kohl@kit.edu

Keywords: geothermal energy, EGS, Upper Rhine Graben, hydrothermal alteration

Introduction

Knowledge of the petrophysical and mineralogical parameters of a geothermal reservoir is essential for the estimation of rock mechanical behavior during hydraulic stimulation. The strength of a rock is determined by manifold petrophysical parameters. Clay bearing zones, which form during hydrothermal alteration, can significantly affect the hydro-mechanical properties of a geothermal reservoir.

On the basis of a neural network, we developed a method to identify clay bearing fracture zones from standard geophysical borehole logs of the geothermal site at Soultz-sous-Forêts in Alsace, France. With this method, synthetic clay content logs (SCCL) are created, which semi-quantitatively indicate the clay content of fractures along a borehole. These logs are used as a basis for the interpretation of hydro-mechanical and seismic data in order to investigate the effects of hydrothermal alteration on the reservoir behavior.

Methods and Results

SCCL logs are a powerful tool to identify hydrothermally altered zones inside a reservoir. Laboratory experiments on samples of different alteration grades suggested that hydrothermal alteration significantly lowers the mechanical strength of samples. Comparison between SCCLs and borehole breakouts demonstrated the cumulative occurrence of breakouts in clay-rich zones, thus indicating a mechanical weakening of the rock by hydrothermal alteration. Effects of aseismic creep on fractures were observed in three wells at the geothermal site in Soultz-sous-Forêts. The SCCLs of these wells suggest that the abundance of clay in such fractures promotes aseismic creep. This is of major importance for hydraulic stimulation as creep can also occur on fractures, which are not optimally oriented in the ambient stress field. By comparison between the occurrence of clay and the magnitude of seismic events, the SCCLs revealed for the first time that the maximum magnitude of seismic events induced during stimulation at Soultz is lower for clay-rich faults than for faults in unaltered rock.

Discussion

By bringing together these observations, the SCCL logs could be used to increase the efficiency of hydraulic stimulation while decreasing the risk of large seismic events. For this purpose, it is assumed that the critical pressure, which is the pore pressure required to rupture a fault, depends significantly on the clay inside the fault. Probabilistic models of the critical pressure of fractures in and around GPK1 taking into consideration the clay content of the fractures are created and compared to microseismic data of the GPK1 stimulation in 1993. It is expected that, the characteristics of induced seismicity should reflect the presence of weak faults. A surprisingly good correlation between observation and model suggests that at least part of the microseismic behavior of a reservoir can be ascribed to mechanical contrasts in the reservoir rock.

Conclusions and outlook

Using a neural network, synthetic clay logs are created indicating the clay content of hydrothermally altered fractures along a geothermal wellbore. On the basis of these logs, geomechanical phenomena related to the appearance of clay inside boreholes could be analyzed. It was shown that:

1) Clay inside the geothermal reservoir lowers the mechanical rock strength. 2) Hydrothermally formed clay zones can foster aseismic creep on fractures. 3) The maximum magnitude of seismic events induced on clay rich fractures is generally lower than that of events on fresh fractures and 4) Clay affects the evolution of microseismicity during hydraulic stimulation.

In future, SCCL logs could be used as a basis for the planning of hydraulic stimulations as they can help identifying target zones. Information about the location of hydrothermal alteration in a reservoir should be used to update mechanical and hydraulic models of reservoirs in order to better assess the reservoir behavior. In order to prevent large seismic events they can help restricting stimulation activity to clay-rich zones, where aseismic creep is the dominating failure mechanism and no large seismic events can evolve.

Simulation and Optimization of Deep Borehole Heat Exchanger Arrays

***Daniel Schulte**, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, schulte@geo.tu-darmstadt.de*
Dr. Wolfram Rühaak, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, ruehaak@geo.tu-darmstadt.de
Swarup Chauhan, Department of Geothermal Science and Technology, Technische Universität Darmstadt, chauhan@geo.tu-darmstadt.de
Prof. Dr. Ingo Sass, Department of Geothermal Science and Technology, Technische Universität Darmstadt, sass@geo.tu-darmstadt.de

Keywords: Optimization, Heat Storage, BHE, FEM, MATLAB

Introduction

Due to their slow thermal response arrays of borehole heat exchangers (BHE) represent suitable storage systems for seasonally fluctuating sources like solar energy. Excess heat is fed in during summer and extracted in winter. Certain requirements have to be met by such a system: the stored heat must remain in place and the working fluid must maintain an extraction temperature sufficiently high for the specific heating purpose at all times. Since drilling is the most critical cost factor, the required number of BHEs and their respective distance and length need to be optimized. For this purpose a MATLAB toolbox code was developed. It deploys a tetrahedron mesh-based finite element code, a thermal resistance and capacity model for BHE interaction and mathematical optimization techniques. It can effectively simulate and optimize a BHE heat storage system.

Simulation Model and Optimization

The storage system is simulated with a set of MATLAB functions, which calculate the co-dependent thermal interaction between the BHEs and the embedding rock on the one hand and the conductive subsurface heat transport on the other hand. The core of the simulation model is a simple MATLAB implementation for finite elements (Galerkin method of weighted residuals, [1]) developed by [2]. It calculates the transient subsurface heat diffusion on an unstructured tetrahedron mesh generated with TetGen [3]. The thermal interaction of the BHEs is calculated by an analytical one-dimensional thermal resistance and capacity model [4]. Fed with inlet temperature and flow rate data as well as thermal and hydraulic parameters of the BHE, it provides the temperature distribution in the inlet- and outlet-pipes in predefined depth levels. Both models are linked to take into account the transient subsurface heat transport. The one-dimensional discretization of the BHE is implemented in the tetrahedron mesh as a line of nodes. The temperature field defined by these nodes sets the borehole wall temperature of the BHE function. In return, the analytical solution's results are passed to the BHE nodes as singular point heat sources.

In finding the ideal setup for a BHE array, its layout can be evaluated: the number of boreholes, their respective distance and their length. Despite the simplified design of the simulation model, a single simulation run is still costly in terms of computational time. Thus, a technique is required, which finds an optimal solution with only a few iterations. The program applies mathematical optimization algorithms to solve these problems in an efficient way. The objective function, i.e. the variable(s) to be optimized with respect to a certain parameter, is chosen along with the optimization algorithm by the user. Our toolbox addresses the cost critical optimization objective for BHE heat storage systems: minimize the number and length of the boreholes with respect to a specific amount of heat to be recovered from the storage, which is defined by the building's heat demand.

Conclusions

The presented toolbox can effectively simulate a BHE heat storage system. In order to avoid an oversized storage, this program can minimize the total drilling length and optimize the axial distance. Consequently, it is a useful tool to design layouts of deep BHE arrays for seasonal heat storage.

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Geothermal power generation – a comparison of development trends with other renewable sources

Ladislaus Rybach, *Prof. em., Institute of Geophysics ETH Zurich, Switzerland*

Abstract

Based on global statistical data the current status of utilizing deep geothermal resources for electricity generation is presented. Particular attention is paid to growth rates. The rates are compared with those of other renewable energies (biomass, hydro, solar PV, concentrated solar, wind). Whereas wind and solar PV exhibit annual growth rates of 25 – 30 % since 2004, geothermal growth is only about 5 % per year. Geothermal electricity production (in TWh/yr) was higher until 2011 than from solar PV but is now falling clearly behind. So far the global geothermal electricity generation is provided nearly completely by hydrothermal resources, which exist only under specific geologic conditions. Further development (=increasing production capacity) based on this resource type alone will therefore hardly accelerate to two-digit (>10 % per year) growth rates. Faster growth can only be achieved by the ubiquitous petrothermal resources, provided that the key problem will be solved: establishing a universally applicable technology. This would enable to create, at any requested site, feasible and efficient deep heat exchangers for EGS power plants – irrespective of the local subsurface conditions. Goals and challenges of this technology will be addressed.

Sulphur removal from waste tyre-derived oil and enhanced ethylbenzene formation over Ni catalyst supported on MCM-41

Witsarut Namchot, *Center of Excellence on Petrochemical and Materials Technology,*
witsarut.namc@outlook.com
Assoc.Prof.Sirirat Jitkarnka, The Petroleum and Petrochemical College, Chulalongkorn University,
sirirat.j@chula.ac.th

Keywords: Waste tyre, Pyrolysis, Nickel, Sulphur, Petrochemical

Introduction

In recent years, waste tyre-derived oils have been proven to contain a the relatively-high concentration of valuable petrochemicals such as benzene, toluene, xylenes, styrene and ethylbenzene , which can be used in petrochemical industry. However, a significantly-high concentration of polycyclic aromatics and sulphur-containing compounds limits the use of waste tyre-derived oil as industrial feedstock. Therefore, mesoporous materials, which posses a large pore size, are attractive to use as a catalyst in waste tyre pyrolysis to handle large molecules of tyre-derived oil. In this work, mesoporous MCM-41 was expected to reduce polycyclic aromatics in the oil. Furthermore, Ni was also introduced to MCM-41, aiming to enhance the petrochemical production and reduce the sulphur contents in waste tyre-derived oil.

Discussion

As a result, when compared to parent mesoporous MCM-41, Ni/MCM-41 slightly decreased mono-aromatics, naphthenes and olefins in the oil, whereas di- and poly-aromatics slightly increased. It indicated that the metallic nickel on MCM-41 promoted the secondary reactions (oligomerization, cyclization, aromatization, etc) of naphthenes and olefins, leading to formation of poly-aromatics. However, the introduction of metallic nickel on MCM-41 significantly reduced the sulphur contents in gasoline, kerosene, gas oil, LVGO and HVGO by 36.6, 21.9, 4.0, 24.4 and 23.5%, respectively. Furthermore, thiophenes (Th), benzothiophenes (BT), benzothiazoles (BTz) and isothiocyanates (ITC) in maltenes drastically decreased (**Figure 1**a). Ni doping on MCM-41 caused the further reduction of sulphur content in oil by 14.2% (**Figure 1**b) since it is favorable for the sulphur compounds to adsorb on the nickel site [1], which well agrees with the increase of sulphur content on the spent catalyst. Moreover, with Ni loading, ethylbenzene was significantly enhanced in the tyre-derived oil. This is a clear indication that metallic nickel species not only promoted the desulfurization activity of catalyst, but also enhanced the petrochemical production.

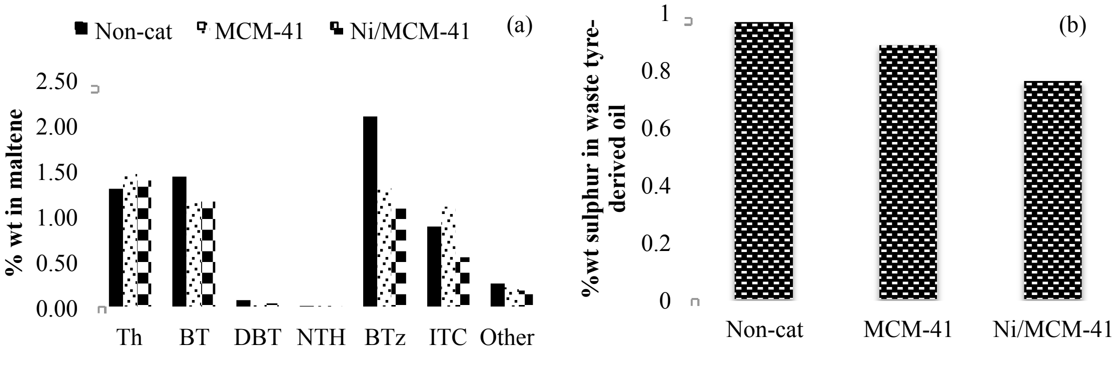

Figure 1: (a) Sulphur-containing species in maltenes, and (b) Sulphur content in waste tyre derived oil

Conclusions

The incorporation of metallic nickel onto mesoporous MCM-41 caused a sigficant change in the catalytic performance. The Ni/MCM-41 catalyst led to the enhanced formation of ethylbenzene, and highly reduced sulphur content in oil.

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Identification of nitrogen compounds in tyre-derived oil using powerful GCxGC-TOF/MS for better analysis

Ms. Supattra Seng-eiad*, The Petroleum and Petrochemical College, Chulalongkorn University, supattra_seng-eiad@hotmail.com*
Assoc. Prof. Sirirat Jitkarnka, Center of Excellence on Petrochemical and Materials Technology, sirirat.j@chula.ac.th

Keywords: Pyrolysis, Tyre-derived oil, GCxGC-TOF/MS, N-containing species, N identification

Introduction

Nitrogen compounds can be formed in tyre-derive oil (TDO) since N-containing curing agents are added in tyre production. In refinery, they can be harmful to cracking catalysts, and induce coke deposition; so, they need to be removed from oils. In this work, the two-dimensional gas chromatography coupled with a time-of-flight mass spectrometry (GCxGC-TOF/MS) was employed to identify and classify N-containing species based on hydrocarbon groups (aliphatic, alicyclic, and aromatic hydrocarbons) and carbon numbers. The results were reported in 3D (surface) and 2D (contour) plots of total ion chromatogram (TIC). The petroleum cuts and the amount of N compounds in TDOs were also analysed using SIMDIST GC and CHN analyser.

Discussion

The identification of N-containing species in TDOs was accomplished using the same GCxGC-TOF/MS technique as reported in a previous work [1].

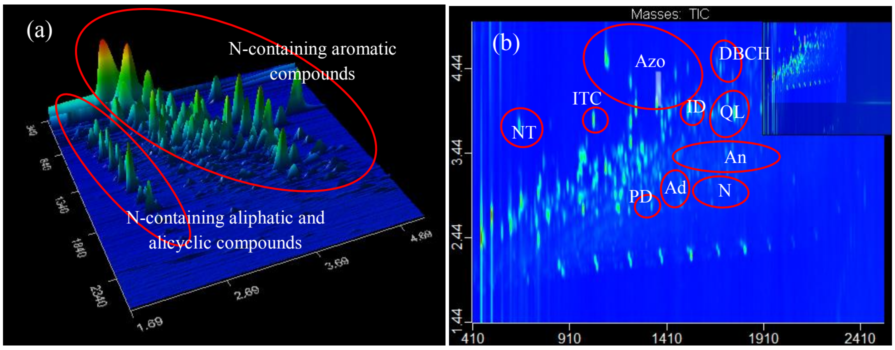

Figure 1: (a) surface plot (3D) of N-containing hydrocarbon compounds, and (b) contour plot (2D) showing the distribution of all groups of N-containing compounds.

As a result, approximately, 100 N-containing species were detected from more than 1,500 hydrocarbon compounds in TDOs. The good separation as seen in **Figure 1a** indicates that N compounds can be divided into aromatic group (92.2%) and aliphatic and alicyclic groups (7.8%). They were classified into 10 different groups; that are, amines (An), amides (Ad), azo compounds (Az), diazabicycloheptenes (DBCH), indoles (ID), isothiocyanates (ITC), nitro compounds (N), nitriles (NT), pyridines (PD), and quinolines (QL). The distribution of each group is displayed in **Figure 1b**. The amounts of N compounds are reported in percentage of total N content in maltene (TDOs after asphaltene precipitation). Most of N-containing species are distributed in the carbon numbers of 6-17 (98.7%), and are mostly in the Az group (50.0%). Moreover, 46.7%, 28.3%, 13.9%, and 11.1% of N compounds are distributed in kerosene, gas oil, gasoline, and long residue, respectively.

Conclusion and/or Outlook

The identification of N-containing species in TDOs was successfully accomplished using the effective GCxGC-TOF/MS for better understanding in further treatment. Approximately, 100 species were detected, and classified into 10 groups according to their structures and carbon numbers. Moreover, N-containing compounds were found highly distributed in kerosene fraction.

Acknowledgements: This work was supported by Thailand Research Fund (Grant Number RSA5680021) and Center of Excellence on Petrochemical and Materials Technology.

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Thermal Energy Harvesting Based on Metamagnetic Shape Memory Alloys

***Gueltig, Marcel**, Karlsruhe Institute of Technology (KIT), IMT, marcel.gueltig@kit.edu*
Dr. Miki, Hiroyuki, Tohoku University, FRIS/IFS, miki@wert.ifs.tohoku.ac.jp
Dr. Ohtsuka, Makoto, Tohoku University, IMRAM, ohtsuka@tagen.tohoku.ac.jp
Prof. Dr. Takagi, Toshiyuki, Tohoku University, IFS, takagi@ifs.tohoku.ac.jp
Prof. Dr. Kohl, Manfred, Karlsruhe Institute of Technology (KIT), IMT, manfred.kohl@kit.edu

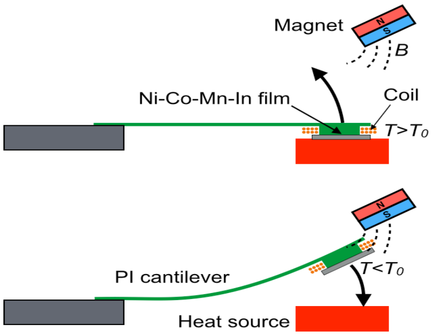
Keywords: Energy harvesting, smart materials, magnetic shape memory alloy, thermal actuation

Introduction

Currently, miniature energy harvesters are being developed to enable novel self-sustaining microsystems in hardly accessible places, where power lines or exchange of batteries are expensive or even impossible. Typical applications are in wireless sensor networks, e.g., for health monitoring of machines, industrial and civil structures, and in ultra-low power electronics. Thermoelectric devices show interesting performance, when sufficiently large temperature differences ΔT exist and means of heat sinking beyond natural convection are available [1]. Due to these restrictions, enormous reserves of energy stored at small temperature difference ΔT below 10 K are not accessible. In this realm, magnetic shape memory alloys (MSMAs) showing a first order phase transformation are highly attractive as they exhibit abrupt changes in lattice parameters beyond 10 % and corresponding large changes in their magnetic properties (magnetization, magnetic anisotropy) at small ΔT. Recently, we proposed the novel mechanism of thermal energy harvesting by MSMA film actuation using the multifunctional properties of MSMA films for both, energy conversion and self-actuation between stationary heat source and heat sink [2]. Here, this mechanism is exploited for metamagnetic SMA films showing a large change of magnetization ΔM due to a transformation between non-magnetic martensite and ferromagnetic austenite.

Operation Principle and Results

As sketched in **Figure 1,** the energy harvesting device consists of a beam cantilever with an integrated metamagnetic film structure and a pick-up coil at the cantilever front. A miniature magnet is placed above the cantilever. While in flat condition, the cantilever is in mechanical contact to a heat source. By heating the film structure above the transformation temperature T_0, the magnetization rapidly increases causing a strong increase of magnetic force in out-of-plane direction towards the magnet. During deflection, the film structure is cooled below T_0 causing an abrupt decrease of magnetic attraction force. Thus, an oscillatory motion is induced allowing for periodic change of magnetization, which is converted to an electrical current in the pick-up coil. Metamagnetic Ni-Co-Mn-In films are fabricated by magnetron sputtering with tailored compositions to exhibit a large temperature-dependent change of magnetization at T_0. After laser cutting, film structures of 2 x 1.5 mm^2 lateral size are integrated on a micromachined polyimide cantilever together with a pick-up coil of 100 turns. First demonstrators show thermal cycles of about 2 Hz for a heat source temperature in the range of 100-150 °C (**Figure 2**). By allowing for eigenoscillations of the cantilever, the low thermal frequency is up-converted to the much higher mechanical frequency in the order of 160 Hz. This leads to induced current peaks of about 10 µA, corresponding to an average power density of 1.6 µW/cm^3. By matching the heat transfer time of the MSMA film structure to the eigenfrequency of the cantilever, the power output can be increased up to several mW/cm^3.



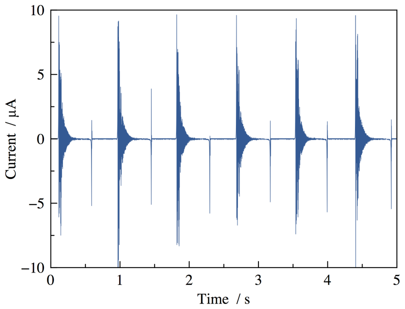


Figure 1: Schematic of harvesting principle. **Figure 2:** Output of a first demonstrator.

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Redesign of wind turbines based on LiDAR technology, is it worth it? – A discussion based on a simple model for the tower's initial costs

Thorsten Beuth, *Institute for Information Processing Technologies, Karlsruhe Institute of Technology, thorsten.beuth@kit.edu*
Camille Porcher, Arts et Métiers ParisTech, 2013-1994@ensam.eu
Leilei Shinohara, Institute for Information Processing Technologies, Karlsruhe Institute of Technology, Leilei.shinohara@kit.edu

Keywords: LiDAR, Wind Turbines, costs of energy

Introduction

Wind energy is one of the most important sources of renewable energy. Supporting LiDAR-preview technologies [1] will help to reduce the cost of energy even more. The most expensive wind turbine element is the tower, followed by the blades [2, 3]. The benefit of the tower's redesign based on LiDAR regulated controller algorithms, can be roughly estimated in the here presented model.

Discussion

The tower is designed to withstand ultimate stress and its life span is usually not limited by fatigue. This fact is used to model the tower costs by the maximum load F_{max} which is connected to the ultimate stress σ_{max}. The tower is idealized as a hollow cylinder of radius R and wall thickness e. The designed natural frequency f_0 is estimated by simple mechanical formulas of the bending moment to calculate the impact of bending with the maximum allowed stress σ_{max} that correlates to the actuator disc model [4] with a cut-out wind speed v_{co} of the wind turbine. To estimate a material reduction, just the wall thickness e is reduced in dependence to the maximum load F_{max} of the wind while all other parameters remain unchanged. In the end, the tower cost is approximately linear to the maximum load F_{max}. Therefore, it is in principle possible to save material this way and lower the initial costs. Although the inertial costs and therefore the cost of wind energy might be lowered, there are several disadvantages to this concept: The sensor should be available at all times to specify the wind turbine for a high turbine class in correspondence to the IEC 61400 norm [5] and redesigning of the elements is extra effort for the manufacturers. In the short run, minimizing of fatigue and ultimate loads by LiDAR technology should rather minimize the maintenance and repair costs which are right now the highest additional operating costs [6].

Conclusions and Outlook

A simple model is designed to estimate the peak strains acting on the tower of wind turbines. Reductions of the peak wind speeds enable a reduction of the material costs by redesigning. Nevertheless, it is doubtable that the towers are redesigned to save material since an all-time available LiDAR signal is needed. It is more likely that manufacturers will ensure longer wind turbines' life spans based on the mechanical behaviour of S-N curve with reduced repair and maintenance costs which will reduce the cost of wind energy as well.

Acknowledgement: We acknowledge support by BMWi (FKZ 0325386A) and the Karlsruhe School of Optics and Photonics.

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Overview of Advanced Control Design for Optimal Wind Turbine Operation

***M.Sc. Bastian Ritter**, Industrial Science GmbH, Darmstadt, bastian.ritter@industrial-science.de*
Prof. Dr.-Ing. Ulrich Konigorski, Chair of Control Systems and Mechatronics, Technische Universität Darmstadt, ukonigorski@iat.tu-darmstadt.de
Dipl.-Ing. Mike Eichhorn, IAV GmbH, Gifhorn, mike.carsten.eichhorn@iav.de

Keywords: Wind Turbines, Control Design, Cost Efficiency, Load Alleviation, Multivariable Control

Introduction

Wind energy plays an essential role in the ongoing energy transition. It offers a free and almost unlimited resource of clean energy. Despite these advantages, wind energy is still in strong competition to fossil energy conversion systems although some people claim it to be more economical yet. However, cost efficiency drives the wind industry and the overall price shall recede, e.g. by increasing energy harvest and/or life-time of components and maintenance intervals. Both can be accomplished by advanced control but deeper insight is advisable for design.

Discussion

This contribution discusses the advanced control design of wind turbines and the trade-offs between technical and economical aspects for optimal operation. On the one hand, advanced control strategies can enhance availability and achieve load alleviations e.g. at the tower base and the rotor blades. But on the other hand, the effort to design and implement more complex controllers for safe operation increases and additional reliable sensors are needed. In the horizon of 10 to 20 MW wind turbines, control is one major measure besides new manufacturing technologies and materials to develop more efficient turbines [1]. Today, most utility-scale wind turbines come with a minimum of four relevant individual actuators and several measured output variables making the system multivariable [5]. For these variable-speed variable-pitch machines, the generator speed control (GSC) maximizes the energy harvest in partial load regime and limits the generator power during full load operation [3]. Moreover, advanced control offers the possibility to minimize mechanical fatigue and extreme loads. During the past decade several authors focussed on load reducing control strategies and successful field tests demonstrated the practicability. Promising concepts incorporate tower vibration control (TVC) via collective and cyclic pitch control [9] and the nacelle tilt and yaw moment compensation via individual pitch control (IPC) [2]. However, applying these on existing turbines might not always be only beneficial for turbine operation [7]. Pitch drives must cover additional loads and might therefore experience an unacceptable level of wear which results in early replacement costs.

From a control point of view, wind turbines are multiple input multiple output (MIMO) systems where inherent interactions between control paths exist. Incorporating these interactions within the control design can lead to several optimal decentralized controllers or even one multivariable controller [8]. Advanced MIMO controllers require further effort for implementation, handling of sensor failures and dealing with faults during operation. Hence, some authors suggest using the model predictive control (MPC) approach for wind turbines which covers actuator and state constraints as well as multivariable control in a more convenient way [4]. But computational effort with a nonlinear model is still a challenge for real-time application since the control problem must be solved each sampling period [6]. Nevertheless, the advantages of MPC for optimal wind turbine control are appealing.

Conclusions

The interesting issue for wind turbine manufacturers and operators can be addressed as follows: Do advanced control strategies (e.g. MIMO-MPC) provide benefits which justify the more complex design procedure and implementation? Technical benefits are, as above mentioned, proved by field tests. But these benefits might not necessarily result in reduced costs because e.g. components designed for extreme loads cannot be built lighter due to fatigue load alleviation in general. Additionally, reliable load sensors for IPC increase costs and the safety system needs revision. Hence, to evaluate the economical benefits one must consider the individual turbine design and use the manufacturer's knowledge of components, respectively, which makes it a quite challenging task.

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Fault-Tolerant and Reliable Design of a Pumping Kite Power System

Felix Friedl, B.Sc., *Faculty of Aerospace Engineering, Delft University of Technology / Institute of Aeronautical Engineering, FH Joanneum University of Applied Sciences, felix.friedl@edu.fh-joanneum.at*
Lukas Braun, B.Sc., *Faculty of Aerospace Engineering, Delft University of Technology / Institute of Flight System Dynamics, Technical University of Munich, braunlukas@gmail.com*
Dr.-Ing. Roland Schmehl, Faculty of Aerospace Engineering, Delft University of Technology, r.schmehl@tudelft.de
Prof. Dr.-Ing. Matthias Stripf, Faculty of Mechanical Engineering and Mechatronics, Karlsruhe University of Applied Sciences, matthias.stripf@hs-karlsruhe.de

Keywords: Airborne Wind Energy, Kite Power, Fault-Tolerant Design, Mobile Renewable Energy

Introduction

Airborne Wind Energy (AWE) systems use tethered flying devices for transforming kinetic energy of wind into electrical energy. One of the major advantages compared to conventional wind turbines is the significant increase in capacity factor, a result of stronger and more constant wind speeds at higher altitudes. Additionally, by replacing the wind turbine's rigid tower by a lightweight tether, not only investment costs and the environmental footprint but also visual and acoustic impacts are reduced. Applications are various, ranging from remote small scale to deep sea offshore applications. The use of flying devices makes reliability a crucial factor. As a consequence the design of such a system has to comply with common aviation industry standards.

System Description

In recent years a variety of different concepts has evolved. The single-line system developed by Delft University of Technology employs an inflatable wing for generating traction force. The system operates in pumping cycles which consist of two alternating phases. During the reel-out phase, the kite flies cross-wind manoeuvres in a pattern of eight, creating a high traction force. In this phase the tether is reeled off a drum which is connected to a generator producing electrical energy. As the maximum tether length is reached the reel-in phase starts. The kite stops flying cross-wind manoeuvres and its angle of attack is decreased (referred to as “de-powering”). Therefore the traction force is reduced and the tether can be reeled back onto the drum consuming only a fraction of the energy produced before. As soon as the kite reaches a desired distance from the ground station the next reel-out phase is initiated.

Fault-Tolerant and Reliable Design

The kite is steered and de-powered by a Kite Control Unit (KCU), suspended about 10 m below the kite and held in place by the main tether. As the KCU is airborne and crucial for the whole operation of the kite, special attention is paid to reliability and robustness. In order to reduce system costs there is no wired electrical connection to the ground and all information is transmitted via three redundant wireless links. The two main links operate on different transmission frequencies while the third link, which is only needed for test platforms, can be used for manual override control in hazardous situations, bypassing the entire information system and directly communicating with the motor controllers. The central on-board control system of the KCU is composed of a three-processor logic, working on three layers. In order to achieve high reliability, these layers can be bypassed regarding the level of criticality and the system can be handled also in case of failure.

The top-layer runs a Linux operating system, handling the communication and the sensor data collection. In future all flight path computations will run on this layer. The second layer, an ARM micro-controller, manages the positioning of the two drive trains, providing the possibility to feed-in manual steering override. The third layer is transforming the position control commands of layer two into motor currents. All layers are designed such that they can not block each other in the top-down direction, which implies that faulty sent data can not affect the operation of the layer underneath.

This architecture achieves a high level of reliability and complies with airworthiness standards. However it cannot ensure that the system does not experience any faults or failures during automatic operation. Therefore the flight control system has to be able to recognise undesired states and to react adequately without human interaction. This ability is realized by employing a Health Supervisor that acts as a guarding loop. It governs the entire flight control system and regularly checks the system for certain health symptoms such as irregularities in the KCU, inconsistency in the predicted flight path or other hazardous flight dynamic states. Based on those symptoms the Health Supervisor assigns a certain health status to the system. The supervisor then has the authority to overrule the autopilot in order to initiate automatic counteractions. Depending to the severity of the diagnosed health status it can change parameters in both the outer navigation loop as well as the inner controller gain layers of the flight control system. The counteractions thus cover a range of minor changes in the system behaviour and updates in the desired flight path as well as immediate landings or emergency touchdown manoeuvres. A highly integrated system structure allows that faults are recognized and handled at an early stage before they lead to more severe hazardous situations.

A Study of Ocean Kinetic Energy Harvester using Graphene-Based Ionic Polymer Metal Composite

M.Eng. Jungkoo Lee, Department of Mechanical Engineering, INJE University, ljk2866@naver.com
M.Eng. Kyungcheol Kim, Department of Mechanical Engineering, INJE University, kkcasdf88@naver.com
***Dr. Hyung-Man Kim**, Department of Mechanical Engineering and High Safety Vehicle Core Technology Research Center, INJE University, mechkhm@inje.ac.kr*

Keywords: Ocean Kinetic Energy, Energy Harvesting, Electrochemical Material, Graphene-based Ionic Polymer Metal Composite

Abstract

The ocean has the most valuable natural resources, which has resulted in the construction of a wide variety of ocean plants all over the world, and these stand-alone plants require electrical energy. In general, turbines can be used to convert ocean kinetic energy into electrical energy but these turbines are not advantageous because turbines are fixed structures. In this study has focused on the transformation of mechanical environmental vibrations into electrical energy. An ocean kinetic energy harvesting module with an electrochemical material consisting of an ionic polymer metal composite has been constructed and operated, and this module can be relocated to accommodate certain applications to efficiently capture the ocean both vertical waves and horizontal ocean currents to supply electricity to stand-alone ocean plants. An ionic polymer metal composite consists of a polyelectrolyte film where both surfaces are plated with metallic electrodes. To perform the ion exchange, more than 45 ml of an aqueous solution of tetraammine-platinum chloride ($[Pt(NH_3)_4]Cl_2$) is required for a 30 cm^2 membrane. Because excess amounts of the platinum complex solution are preferable, current methods for an ionic polymer metal manufacture rely on expensive noble metal platinum complex solution. Therefore, we have developed a highly electrically conductive graphene-based solution that is inexpensive and durable in marine environments to replace the platinum complex solution. When the IPMC bends due to kinetic energy, a voltage is generated between the two electrodes across the membrane in both air and. The instantaneous power density of the state-of-the-art an ionic polymer metal is approximately 20 W/m^3 with an average efficiency of approximately 2% or less. Inspired by the hydrophilic capability of an ionic polymer metal, we were challenged to develop a method where sensor-level powered an ionic polymer metal materials can be scaled-up to a movable power generator utilizing both vertical waves and horizontal ocean currents. Ultimately, we want to build an ocean kinetic energy harvesting structure with an electrochemical material consisting of an ionic polymer metal to supply electricity for stand-alone offshore plants, which can accommodate situations requiring reduced costs and expanded coverage. The ocean kinetic energy harvesting module has the potential to coexist with marine environments and represent an advance toward the sustainable utilization and development of marine resources. An ocean kinetic energy harvesting module has been constructed and operated with newly developed graphene-based ionic polymer metal composite as an electrochemical material.

Acknowledgement: This work was supported by the New & Renewable Energy of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 2012T100100660).

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Hollow-Hub Turbine for Run-of-the-river Small Hydropower

***M.Sc. David Volk**, Chair of Fluid System, TU Darmstadt, david.volk@fst.tu-darmstadt.de*
Univ.-Prof. Dr.-Ing. Peter Pelz, Chair of Fluid System, TU Darmstadt, peter.pelz@fst.tu-darmstadt.de

Keywords: Optimisation, Hydropower, Run-of-the-river, fish-friendly

Introduction

In the context of climate change and a near end of the fossil fuel resources it becomes more important every day that new and renewable energy sources have to be exploited. Being able to support the base load, run-of-the-river hydropower can play an important role in that process.

The German legislation demands several ecological safeguards regarding the fishes and the integrity of the river [1]. Especially the operators of small hydro power plants have difficulties to satisfy these standards. Diminishing the negative effects on the fish fauna and the ecosystem of the whole river and optimising the operation procedure gives the general set-up for developing the Hollow-Hub turbine.

Discussion

The survival odds of the fish fauna in a water power plant are heavily depending on the setup of the turbine. Fast rotating blades which lead to injuries or the pressure decrease causing a bursting air bladder are the main causes of death [2]. Optimising the environmental impacts of these machines with enough power output to maintain ordinary operation displays some difficult challenges. Having a small hydropower plant and thus small volume streams confines the design of the turbine, leading to fast rotating machines with small diameter.

The approach of the Chair of Fluid Systems at Technische Universität Darmstadt is a design based on a Kaplan Turbine in which the hub has been replaced by a bypass pipe. The whole stream is therefore parted and runs through the turbine and the pipe. A screen which is located directly in front and behind the turbine blades leads the fauna through the pipe and prevents them from getting any damage. In addition the screen is used as guide vanes preparing the flowing stream to maximize the energy output.

The power generator is external and radial mounted to directly convert the torque from the turbine blades to electrical power. This leads to a modular setup which can be implemented in already existing power plants or can extend already existing hydraulic structures.

With the possible passage through the turbine expensive fish passes can be avoided. Thus giving the operator a financial scope and also reduces the landscape changes in close proximity of the power plant.

Analytic Approach and Outlook

The concept of the Hollow-Hub Turbine seems to have a lot of answers to the questions regarding fish-friendliness which arise especially for small hydro power plants. A very important part of reducing the harm for fishes passing through the machine is coupled to the relative pressure change in the flow [2]. In combination with the guide vanes a passage through the turbine becomes possible.

Since the bypass causes a loss for the useable stream the harvested energy is diminished. This is directly compared to the volume stream loss in a conventional fish pass. The outline for the work on this topic is finding a setup in which both the energy output and the ecological impact are optimised.

Therefore an analytic model based on axiomatic conservation laws has been constructed. This leads to a set of 15 variables for 15 equations which are part of present examinations. Depending on several input parameters an array of integral values is created which will built up the data basis for constructing a prototype.

The framework in which this work is located, is the optimisation of turbo machinery in an open-channel flow. Past work of the second author [3] has shown the importance and in which amounts the free surface plays its role in optimising the operating procedure.

Future work will focus on the construction of a prototype and testing it in the field. For appropriate realistic testing the prototype will be implemented in an already operating power plant.

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Energy Storage through Synchronous Hydropeaking Function for Cascaded Run-of-River Power Plants

Dr. Arnaud Koehl*, Process Control Department, EDF Hydro Engineering Center, arnaud.koehl@edf.fr*
Frédéric Michaud, Process Control Department, EDF Hydro Engineering Center, frederic.michaud@edf.fr

Keywords: Hydraulic Power Plant, Energy Storage, Ancillary Services, Grid Variability

Introduction

The EDF group (French electric utility company) operates numerous Hydraulic Power Plants (HPP) including cascaded run-of-river power plants, such as the five HPP using the water of the lower part of the *Isère* river for electricity generation. Therefore, the main challenge for the EDF producer is to optimize the economic value of such HPP typology by improving the control system and plants operation. This paper presents the study and the realization parts of Synchronous HydroPeaking (SHP) function used through the five HPP located along the *Isère* river. The goal is to coordinate the HPP to simultaneously increase or decrease the generated load by temporarily increasing or decreasing the turbines water flow. The discussion below presents the technical issues and the benefits to the grid and to EDF producer.

Discussion

As shown in figure 1, SHP concerns the HPP from *Beauvoir* to *Beaumont-Monteux*. The purpose is to synchronously induce a water over-flow or under-flow since *Beauvoir* HPP to *Beaumont-Monteux*. Thus, the water volume is stored or released on the reservoir of *Beauvoir* (the four others HPP don't have storage capability), but the water flow varies in the same way on each HPP. At the same time, the dams water levels must be kept to their set points for the HPP located downstream of *Beauvoir*. Others technical constraints exist, such as: the size disparity of water reaches; the regulation of specific critical levels between two dams (flooding risk); and the non-distortion of the hydrograph (ideally, the output flow in *Beaumont-Monteux* is equal to the intake flow in *Beauvoir*).

Figure 1: Situation of the HPP located in the lower-*Isère* valley and participating to Synchronous HydroPeaking function

For the EDF producer, the main issue concerns the increase of the production performance by responding to the needs of the grid with the best effort: i.e. by responding to high electricity consumption (pike) with over-flow SHP function, or saving hydropower with under-flow SHP in case of lower power-demand (off-pike). In the latter case, the under-flow can be seen as the energy storage function of a virtual pumped-storage HPP. However, an increasing water level at the head reservoir of *Beauvoir* is not the result of water pumping but of adequate SHP control algorithms. The over/under flow schedule is generated by EDF national production optimizer. Moreover, the SHP-function is modeled like a pumped-storage HPP into scheduling tools, operating in parallel with the individual management function (run-of-river) of each HPP represented in figure 1.
Indeed, the Primary Load Frequency Control (PLFC) is one of the individual regulating functions. The whole control system should be designed to avoid interaction between this Ancillary Service (grid stability) and the SHP function (demand response). The structure and the settings of water level control must take into account: the anticipation of the water flow synchronously propagated along the plants; dynamics of hydraulic transients of each HPP; and the variation of the reservoir water level of *Beauvoir,* according to the current hydropeak schedule. The SHP-function feasibility has been determined through a modelization/simulation approach.

Conclusions and/or Outlook

From a practical point of view, the implementation of SHP function had needed: to make an inventory of the turbine governing systems dynamics capabilities; and to adapt the control and supervision algorithms of the lower valley of *Isère* in order to ensure a sufficient robustness level in degraded conduct mode (i.e. the issue of the physical decentralization of regulated levels). Actually, the SHP-function is used in an operational phase.

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Experimental Validation of an Analytic Approach to Optimization of a Tidal Turbine Fence

Manuel Metzler, *Chair of Fluid Systems, Technische Universität Darmstadt, manuel.metzler@fst.tu-darmstadt.de*
Univ.-Prof. Dr.-Ing. Peter Pelz, Chair of Fluid Systems, Technische Universität Darmstadt

Keywords: Tidal Power, Low Head Hydro Power,Free Surface, Optimization, Turbine Array, Turbine Fence

Introduction

Within the efforts of energy transition various technologies for harnessing of tidal energy sources are under investigation. One type of machine for the extraction of energy from tidal currents is the hydrokinetic turbine. To gather as much energy as possible, these machines are planned to be installed in tidal turbine arrays. The results to be presented contain an analytical method for the optimization of such turbine arrays by means of energy yield. The presented method is validated in a Froude scaled experiment. Results of the analytic approach and the validation are presented and discussed.

Discussion

In the case of wind turbine Albert Betz established an analytic optimization based on conservation of mass and momentum. Various studies have shown [1], that Betz Theory is not feasible for hydrokinetic turbines in free surface flows. I.e. in case of shallow water and high blockage ($h_1 \sim d, b \sim d,$ see **Figure 1**) the Betz limit is exceeded. This is not a falsification of Betz' theory but it indicates, that for the case of a shallow tidal currents or any comparable flow, free surface effects have to be taken into account. An analytical description of the optimization problem is established in [2]. For free surface flows, the coefficient of performance is shown to be a function of the blockage ratio σ, the Turbine Head $\bar{H}_T$, and the downstream Froude number Fr_{-}. Figure 1 shows the coefficient of performance for a fixed value of blockage ratio $\sigma = 0.5$. The contour lines represent values of $\bar{C}_P$ calculated analytically by use of conservation of energy, mass and momentum equations. The markers represent values of $\bar{C}_P$ measured in the small scale test rig.

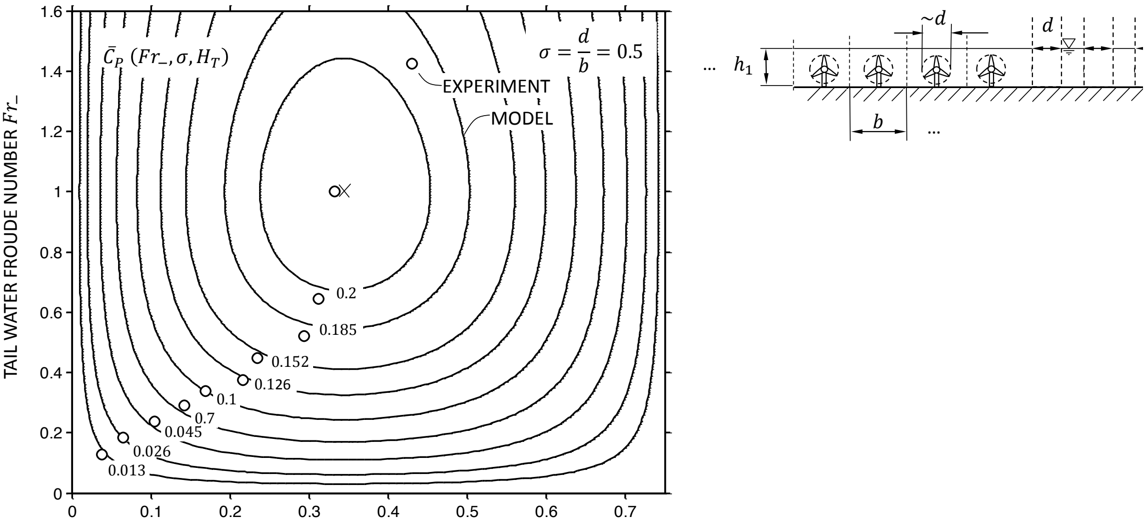

Figure 1: Coefficient of performance for a tidal turbine fence

Conclusions and/or Outlook

The distance in between each marker and the adjacent contour line can be interpreted as gap between calculated and measured values of $\bar{C}_P$. For subcritical Froude numbers $0 < Fr_{-} < 1$ calculation and measurement are in good accordance. Hence the calculation results can be considered as validated. For supercritical Froude numbers $1 < Fr_{-}$ there is a considerable gap between measurement and calculations, which is intended to be closed for the final conference contribution's data by enhancement of measurement systems.

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Oral Presentations

Energy Efficiency

Co-Combustion of Biomass in Pulverized Fuel Boilers

Gehrmann[1], Scherrmann[1], Baumann[1], Hauser[1], Paur[1], Stapf[1], Hock[2], Waibel[2], Matthes[2], Keller[2]
[1]Institut für Technische Chemie (ITC), [2]Institut für Angewandte Informatik (IAI), Karlsruhe Institute of Technology

Abstract

With an increasing share of regenerative wind and solar energy in electricity supply, the aspect of load flexibility of coal/biomass burning power plants will gain even more importance, i.e. there is an increasing need for buffer capacities and / or power plants must be able to react more flexibly to changes of the demand. As an alternative or in addition to the new construction of peak-load power plants (pump storage systems, gas power plants), load-flexible dust burner technologies can be used in existing incinerators to increase load flexibility and fuel flexibility when using local regenerative fuel sources, in particular. Flexibility of the burner concept means an increase in changing fuel compositions and non-steady operation, which may cause changes of the combustion behavior and hence, emission's behavior. Flexibility in fuel sources also changes the combustion and emission behavior, especially when using low-grade fuels with high ash contents containing chlorine and alkali species. To control these non-steady processes in the burner and downstream the boiler region and ensure efficient operation, contact-free optical measurement methods are applied in addition to the measurement systems applied usually in the furnace chamber and other control methods based on computational intelligence.

At Karlsruhe Institute of Technology (KIT), a load-flexible multi-fuel burner with an optical camera system for improved control is being developed.
First results of test series with hard coal and several types of low-rank fuels (LRF) under strongly variable operation conditions are very promising. On this basis, it is aimed at combining fuel and combustion properties of biogenic and fossil fuels such that synergy effects will result with respect to the above key parameters and the combustion behavior.

Materials for Advanced Ultra-Supercritical Fossil Power Plants: Materials Properties, Microstructure and Component Behaviour

Magdalena Speicher, *MPA University of Stuttgart, magdalena.speicher@mpa.uni-stuttgart.de*
Daniel Hüggenberg, *MPA University of Stuttgart, daniel.hueggenberg@mpa.uni-stuttgart.de*
Andreas Klenk, *MPA University of Stuttgart, andreas.klenk@mpa.uni-stuttgart.de*
Stefan Zickler, *MPA University of Stuttgart, stefan.zickler@mpa.uni-stuttgart.de*

Keywords: Efficiency, Ni-base alloys, Creep, Fatigue, Lifetime assessment

Introduction

In the test loop HWT II installed in fossil power plant GKM Mannheim, see Fig. 1, piping and components made of nickel alloys under plant specific loading conditions are tested in order to ensure the feasibility of high efficient coal-fired power plants. Accompanying investigations to proof the performance of the materials and the applicability of advanced numerical simulations for life assessment of components are carried out. Results of material investigations on Alloy 617B and Alloy 263 and their welded joints as well as numerical simulations for selected components under static and cyclic loading are presented.

Discussion

Investigations aimed to provide data and tools for design and lifetime assessments for components of the A-USC plant made from nickel alloys have been carried out in several projects in Germany in the past 15 years [1, 2, 3]. A reasonable data base to characterize the materials under different loading conditions could be established. This database comprises pedigree data, creep strain and creep strength data, information on cyclic behaviour and failure as well as fracture mechanics data. Metallographic and microstructure investigations were applied to characterize the precipitates state, changes during high temperature and the damage mechanisms occurring in different types of loading. The parameters of deformation and lifetime models were determined based upon the observed material behaviour and implemented in Finite Element codes for lifetime assessment. To analyse the behaviour of highly loaded test loop components numerical calculations and fatigue analysis were performed. Test loop with thick-walled boiler components have been operated successfully giving experience on the material behaviour in the plant and the functionality of components. Using the constitutive equations established numerical simulations have been carried out with the aim to predict stresses and strain and lifetime of the component. A prediction for strain accumulation in the statically loaded pipe bend as well as the prediction of cycles to failure was obtained.

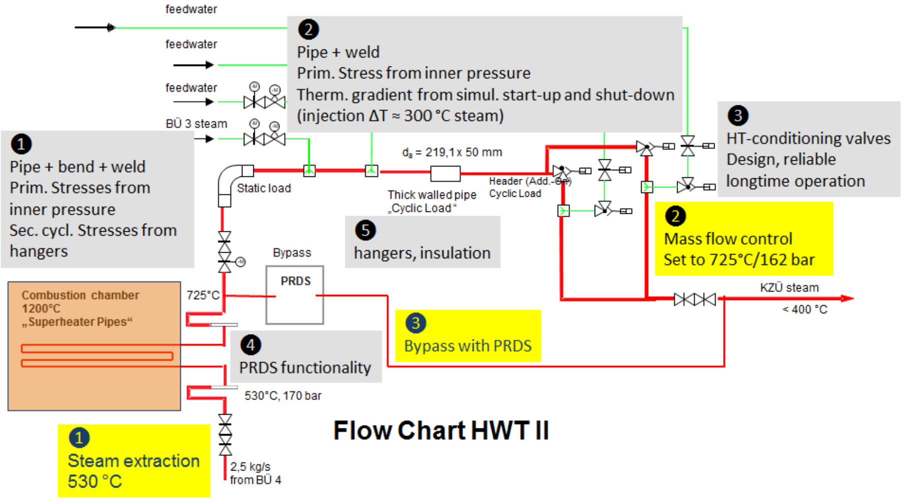

Figure 1: HWTII test loop with thick-walled pipes, bands, T-piece, valves and header made from Alloy 617 and Alloy 263

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Heat Transfer during Depressurization of Supercritical Steam

Prof. Dr.-Ing. Thomas Schulenberg, *Institute for Nuclear and Energy Technologies,*
Karlsruhe Institute of Technology, thomas.schulenberg@kit.edu

Keywords: Heat transfer, supercritical steam cycle, boiling crisis, two phase flow, coal fired power plants

Introduction

Latest coal fired power plants with high thermal efficiency are built today with a supercritical steam cycle, such that the pressure inside high pressure components of the boiler is higher than the critical pressure under full load conditions. As these power plants are operated with a sliding pressure, however, keeping the turbine control valve fully open in the upper load range, the boiler is depressurized to sub-critical conditions with decreasing load. As a consequence, a temporary boiling crisis occurs in the evaporator tubes of the boiler when passing the critical pressure, resulting in significantly higher material temperatures than under full load conditions. This presentation discusses how peak temperatures during such a temporary boiling crisis can be predicted.

Discussion

The physical background of this temporary boiling crisis are tube temperatures under supercritical pressure conditions, which exceed the Leidenfrost temperature at critical pressure. Thus, when passing the critical pressure during depressurization, the tube becomes unwetted, causing tube wall temperatures far above the saturation temperature. The tube is quenched afterwards below the Leidenfrost temperature by thermal conduction inside the tube wall, transferring heat from unwetted to wetted tube regions, and the tube becomes well cooled again. This phenomenon has been modelled analytically by Schulenberg and Raqué [1] using steady state heat transfer correlations for supercritical and for subcritical wetted or dry wall conditions, and by applying a one-dimensional, transient heat conduction equation for the tube wall. The model has been validated with transient heat transfer test data of boiler tubes [2]. A typical result is shown in Fig. 1.

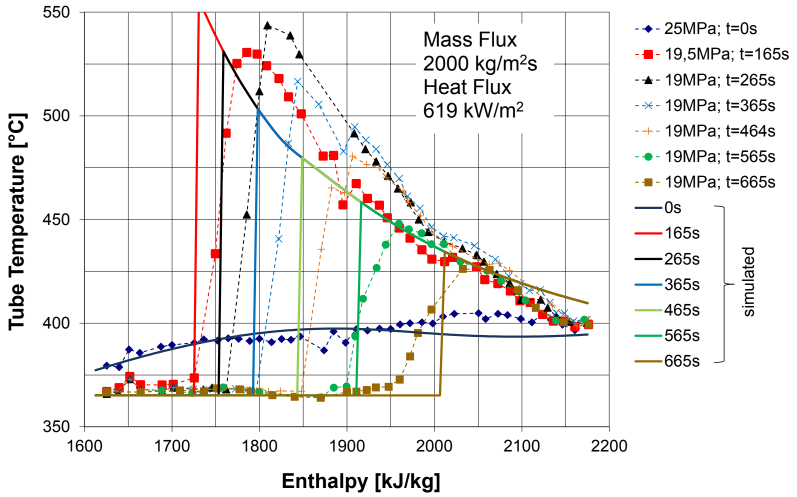

Figure 1: Temporary wall temperatures of a boiler tube during depressurization from 25 to 19 MPa [1], [2].

At an initial supercritical pressure of 25 MPa, the tube wall is cooled to ~ 400°C. These temperatures, however, are hotter than the Leidenfrost temperature of 374°C at the critical pressure of 22.06 MPa, so that almost the entire tube becomes unwetted, heating up quickly to more than 500°C at a subcritical pressure of ~19 MPa. Staying at a pressure of 19 MPa for around 10 min enables a quench front to run downstream, rewetting the tube wall again, until it is well cooled to 365°C. The analytical model can reproduce this effect quite reasonably.

Conclusions and outlook

Prediction of these temporary temperature peaks is important for boiler design as well as for interpretation of corrosion attack of the combustor tube wall of coal fired power plants. It shall be implemented in one-dimensional system codes predicting two-phase flow phenomena of supercritical steam cycles.

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Nuclear energy for a sustainable French energy mix

Dr. Hervé BERNARD, deputy CEO of CEA, CEA Saclay, herve.bernard@cea.fr

Keywords: Energy, Nuclear, electricity production

Affordable, abundant, safe, environmentally benign energy supply is a critical input for a world economic and social balanced development. Fossils, renewables and nuclear are the three choices that public authorities are facing with when they have to define an energy policy for their country and fellow citizens. We all know that fossils based large energy production leads to an unacceptable increase of greenhouse gases with the unacceptable announced consequence on climate change. Renewables energies are very promising relatively to the aim. However, they have inherent limitation due to their variability, diffuse characteristic and their lack of predictability. Nuclear energy which does not suffer similar limits has very valuable assets and is then highly required for facing several of the unavoidable energy needs, since they are also massive and permanent. Furthermore, nuclear and renewables energies can be developed with efficient synergies.

The present French bill on energy transition has defined a pathway for energy production facilities, distribution networks and final users in order to reach the goal of 75% reduction in GHG emission in France in 2050 compared to 1990. Renewable energies (solar, wind, marines, biomass, hydraulics,…) which contribute mainly to the electricity production will take globally a larger place than presently (10%), reaching 32% of the final national consumption energy mix. While keeping the same nuclear capacity (63.2 GW) as now, a share of nuclear of not below 50% of the total electricity production before the mid-century, will allow to pursuit the development of a safe, economic and sustainable nuclear energy. Sustainability of nuclear energy has been considered by public authorities as key in France, and in 2013, a debate on radioactive waste deep disposal project has concluded that the decision to build the underground repository of radioactive high-level long-lived waste, named, CIGEO will be taken in 2015, for an operational service in 2025.

In the field of nuclear energy, economic competitiveness, continuous safety improvement, and a responsible waste management are our challenges for now and for the future. The need to maintain an industrial sector at the highest level of performance, and to prepare the future, commits countries to develop a high level scientific and technological research. R&D is an essential tool to support industrial activity and to prepare the challenges of the middle and long term future.

The nuclear energy division of CEA aims to maintain a high level of expertise in support to industry for the current nuclear fleet and to public decisions for the fourth generation of reactors, and to maintain high level nuclear experimental tools, as the JHR experimental reactor or the project of a new critical mock up ZEPHYR. In the field of nuclear safety, main efforts are on beyond design basis accidents and severe accidents, as the Fukushima event has showed that additional R&D was needed in this field: studies on loss of primary coolant accident, studies on reactivity accidents, hydrogen risk mitigation, corium-water and corium-concrete interactions, in parallel with the development of innovative solutions for In Vessel Retention. CEA prepares the future of nuclear energy by its design activities of the first GEN 4 prototype ASTRID, to be built by 2025, and its significant participation to the ITER fusion technology project. Cleaning up and dismantling old nuclear facilities need also R&D efforts to optimize industrial operations.

Uranium as a renewable for nuclear energy

Claude Degueldre, NES, Paul Scherrer Institute, claude.degueldre@psi.ch

Abstract

Uranium extraction is the first step of the nuclear fuel cycle. In today practice the only extractions are carried out on solid ores such as uranium rich minerals (% level) or minerals such as phosphates (ppm level). Since some years extraction of uranium from sea water (ppb level) has been the topic of investigations more especially in Japan because of its national interest. Taking into account the huge volume of ocean ware, the amount of uranium during practical extraction from sea water would remain quasi constant. The paper shows that for potential industrial extraction of uranium would be balanced by the input of soluble fractions recharged by the rivers in the oceans as well as by desorption from the sea floor. Recommendations for the extraction with use of gel panels (e.g. using amidoxime polymer gel absorbent) in high tide environments or fast oceanic stream over pelagic area are suggested.

Research for safe nuclear waste management options

Dr. Gunnar Buckau, European Commission, JRC- ITU, gunnar.buckau@ec.europa.eu
Dr. Concetta Fazio, European Commission, JRC-ITU, concetta.fazio@ec.europa.eu
Dr. Jean-Paul Glatz, European Commission, JRC- ITU, jean-paul.glatz@ec.europa.eu
Dr. Vincenzo Rondinella, European Commission, JRC-ITU, vincenzo.rondinella@ec.europa.eu
Dr. Joseph Somers, European Commission, JRC- ITU, joseph.somers@ec.europa.eu

Keywords: Nuclear waste, intermediate storage, geological repository, partitioning and transmutation

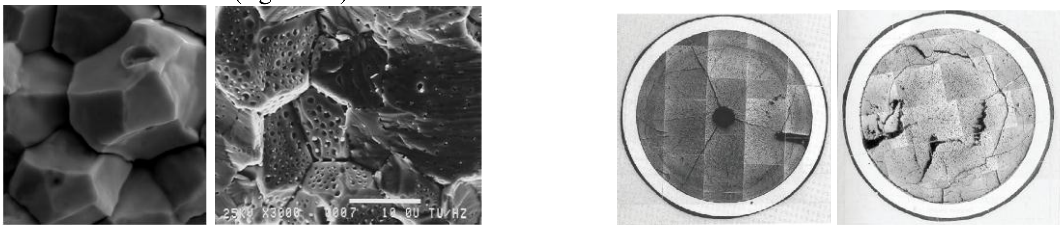
Introduction

In Europe spent nuclear fuel discharged from light water reactors (LWR) is considered either as waste or as recyclable material [1, 2]. Whatever the fate of the spent fuel is, a safe final disposal of high level nuclear waste is a mandatory task of the EU Member States [2, 3]. In this context different waste management options are under consideration and supporting research activities are conducted worldwide. At the Joint Research Centre - Institute for Transuranium Elements (JRC-ITU) research activities address safety aspects of direct spent fuel disposal in a geological repository as well as of partitioning and transmutation (P&T) options.

Discussion

Spent nuclear fuel is composed of about 96% U (per tonne of U in the fresh fuel) and the remaining 4% are fission products and transuranium (TRU) elements (mainly Np, Pu, Am and Cm). Its management is driven by its high radioactivity and the related heat load which requires very long-term isolation from the biosphere, as e.g. in a deep, stable geological repository having multiple containment barriers. In Europe the long-term performance assessment of such a repository is conducted through various research initiatives to collect relevant data [4]. The JRC-ITU contributes to this assessment by providing (micro)structural, physico-chemical and thermo-dynamical data on spent nuclear fuels (figure 1a), in support of extended spent fuel storage assessment; and by investigating fuel matrix dissolution and "instant" release of volatile and rapidly dissolving radionuclides upon first contact between spent fuel and groundwater. Advanced testing and characterisation methods are used to carry out the experimental studies.

A key goal of P&T is to reduce volume, radiotoxicity and heat load of the waste to be sent to the repository [5]. P&T schemes foresee the separation of TRU from spent fuel via aqueous- or pyro-chemical methods, the preparation of new fresh fuel containing TRU and the irradiation of this fuel in fast neutron transmutation systems. There are multiple challenges that are addressed at international level. JRC-ITU contributes to relevant programmes through safety studies on the chemical separation processes, the transmutation fuel synthesis and its irradiation behaviour (figure 1b).



(a) (b)

Figure 1: (a) SEM images of LWR UOX spent fuel at low burn-up (left) and high burn-up (right) [6]; (b) ceramographs of $(U_{0.74}Pu_{0.24}Am_{0.02})O_{1.973}$ fuel and $(U_{0.74}Np_{0.21}Am_{0.19})O_{1.926}$ target irradiated in fast reactor (SUPERFACT) [7]

Outlook

Spent fuel and nuclear waste management is a key component of nuclear energy. Research activities worldwide aim at investigating safety and reliability of different options. JRC-ITU will continue to contribute with its research infrastructure and expertise in support of the European advancement in the field.

Acknowledgement: All JRC and ITU colleagues involved in the waste management research activities. The present scientific-technical results support the Member States in implementing the Council Directive 2011/70/EURATOM on responsible and safe management of spent fuel and radioactive waste.

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MiniRadMeter: a miniature detector for gamma rays.

Dr. Gianluca Alimonti, INFN-Milano, gianluca.alimonti@mi.infn.it

Dr. Paolo Finocchiaro, INFN-Catania & LNS, finocchiaro@lns.infn.it

Dr. Alfio Pappalardo, INFN-Catania & LNS, apappalardo@lns.infn.it

Keywords: radiation detector, dosimeter, Silicon PM.

The Miniradmeter has been inspired by contacts with the EPS Energy Group: the proposal is to bring about a greater understanding of radioactivity and its effects through the use of a miniaturized ionizing radiation detector contained in a device widely used such as a smartphone.

Such a prototype, to be proposed to manufacturers of smartphones and similar devices, is a small USB stick size, low cost and robust and able to make a reliable estimate of the dose arising from the environment radioactivity within a reasonable time (few tens of seconds).

The detector consists of few mm^3 cube of Cesium Iodide coupled to a SiPM; the connected electronics, in addition to providing the power supply, has a small MCA and a USB connection. With an average counting rate of about 1 count per second originated by the natural background, a measurement affected by a small percentage error is expected in less than a minute, but there is also the possibility to have a spectral definition with longer measurement.

Geochemical Research for Nuclear Waste Disposal Safety

Dr. Marcus Altmaier, Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal, (KIT-INE), marcus.altmaier@kit.edu
Dr. Bernhard Kienzler, KIT-INE,bernhard.kienzler@kit.edu
Dr. Jörg Rothe, KIT-INE, joerg.rothe@kit.edu
Prof. Thorsten Schäfer, KIT-INE thorsten.schaefer@kit.edu
Prof. Horst Geckeis, KIT-INE, horst.geckeis@kit.edu

Keywords: Nuclear Energy, Nuclear Waste, Nuclear Waste Disposal, Safety Research, Geochemistry

Introduction

Independent of the decision taken by a society if nuclear energy is to be considered part of a future energy mix or not, a huge amount of long-lived nuclear waste has already been produced in several countries. In addition to large quantities of highly radioactive heat producing waste, an even larger amount of low- and intermediate-level waste is present. In both cases, it is essential to develop safe options to dispose the radioactive waste and separate this potentially highly hazardous material from the biosphere.

Discussion

The disposal of long-lived nuclear waste in deep underground repositories is generally considered the safest option to isolate radioactive materials from the environment over geological timescales. On an international level, three different host rock formations (crystalline, clay, rock salt) are currently considered. For all present disposal options, a detailed understanding of fundamental (geo)chemical processes is required in order to critically assess the long-term safety. As it is important to design technical barriers to immobilize radionuclides and predict the geochemistry of the respective aqueous systems potentially generated, the chemical behavior of the highly radioactive and radiotoxic elements under these conditions likewise must be understood in detail.
In the present contribution, several examples from recent research studies of KIT-INE are introduced in order to emphasize the important role of geochemistry and applied radiochemistry in this particular context:

- Dissolution of spent nuclear fuel and vitrified glass.
- Solubility processes and chemical speciation in the aqueous phase.
- Radionuclide retention by sorption and secondary phase formation.
- Investigations of radionuclide transport in underground laboratories.
- Geochemical and transport modeling of radionuclide behavior.

The main driving force for progress in radionuclide geochemistry over the last decade is related to the frequent use of advanced spectroscopic tools for investigating chemical speciation at the molecular level. Technical progress in synchrotron based techniques (examples are shown from XAFS performed at the INE-Beamline at ANKA [1]) has been directly translated into a significantly improved understanding of radionuclide geochemistry at the molecular level. Based upon new chemical and structural information, a much more detailed picture of radionuclide chemistry under repository relevant conditions is becoming available, generating advanced process understanding, improved geochemical predictions and ultimately improved repository safety. Computational chemistry also has developed into a valuable tool as it offers information from a quantum chemical perspective to complement conventional chemical approaches. Advanced geochemical model calculations are used to quantify potential retention and mobilization processes and derive improved safety. Authoritative review articles on radionuclide solubility phenomena and sorption processes are available [2,3] from KIT-INE authors.

Conclusions

The development of safe nuclear waste disposal facilities is a topic of central relevance related to the use of nuclear energy. Geochemical research is contributing to improved nuclear waste repository safety on several different levels. Based upon detailed geochemical process understanding and the use of advanced analytical techniques to derive information on the molecular level, reliable predictions on the long-term behaviour and retention of radionuclides in a repository system is possible.

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Challenges in decommissioning of nuclear facilities

***M. Brandauer, S. Gentes**, Department of Deconstruction and Decommissioning of Conventional and Nuclear Buildings, Institute for Technology and Management in Construction (TMB), Karlsruhe Institute of Technology (KIT), martin.brandauer@kit.edu*

Keywords: Decommissioning of Nuclear Facilities, decommissioning department at KIT, development of decommissioning technologies

As part of the German energy transition program, the decision to completely phase-out of nuclear power generation was made abruptly in 2011, after the incident in Fukushima. As a consequence, eight running facilities were immediately shut-down by law. These facilities were undergoing life-extension procedures at that time and were at no point concerned with decommissioning yet. This circumstance resulted in a very long transition phase that is still ongoing. The remaining nine facilities still in operation will now subsequently be shut down in the coming years, while a complete phase-out and final shutdown of all facilities is mandatory by the end of 2022. The final phase-out of nuclear power will, however, only be possible, after complete decommissioning of all the remaining facilities.

As a result of the current situation and due to the operators' decision of opting for a direct decommissioning strategy, many large scale facilities will be decommissioned simultaneously in Germany in the coming decades; which is going to be a big challenge. The subject of decommissioning is, however, not a new topic in Germany. There is a substantial amount of facilities which are already in an advanced decommissioning state. To date, three facilities in Germany have also been completely decommissioned and returned to the so called "green-field" state, i.e. the complete demolishing of the facility and reforestation of the former site.

For this reason, decommissioning of nuclear facilities has already proven to be feasible. Nevertheless, many problems have occurred over the past decades and many lessons had to be learned. Furthermore, most of the applied techniques are still rudimentary and usually taken from other application fields, without adapting them for the new tasks. However, the field of research and education for the decommissioning of nuclear facilities at KIT addresses these technical problems, among others, and advances the development of new technologies and contributes to the education of new professionals for the industry.

One technology currently being developed at KIT is related to the fast and efficient decontamination of concrete surfaces. This is an important step to guarantee the removal of all possible contaminations in a nuclear facility before releasing it from the atomic law for complete dismantling. This technology is being addressed in two parallel research projects. The first one is a complete remote controlled and semi-autonomous manipulator for the deployment in radioactively contaminated sites. A virtual reality of the site is created using 2-D and 3-D laser scanners. Specially developed algorithms process this data for an optimized and efficient decontamination [1].

This manipulator assists the operator in fulfilling the decommissioning task and prevents the staff from working in contaminated areas. Since this is still a prototype, a follow-up research project is concerned with the development of a very fast and highly efficient decontamination unit in close cooperation with the industry. This unit is also operated remotely controlled, can be deployed and moved by a crawling chassis and has a very high mechanical decontamination rate of about 10 m /h [2].

These efforts are an important contribution to tackle Germany's decommissioning challenge. By further educating students and providing the industry with qualified personnel, a successful decommissioning of all nuclear facilities in Germany will be achievable. Moreover, the acquired know-how, the development of adequate techniques, and the education of qualified specialists in this process will be of great value for the upcoming task of decommissioning hundreds of other nuclear facilities around the globe.

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Improved energy confinement in tokamaks

Dr Yves Martin*, CRPP, EPFL, CH-1015 Lausanne, yves.martin@epfl.ch*
TCV Team, CRPP, EPFL, CH-1015 Lausanne

Keywords: Fusion, tokamak, energy confinement, H-mode, L-H transitions

Introduction

Energy confinement is a key issue in fusion research, since it describes how well the energy remains in the extremely high temperature plasmas that are required to reach fusion. The parameter used to characterise the confinement is the energy confinement time, defined as the ratio between the plasma energy and the heating power required to maintain it stationary. This parameter directly enters in the Lawson criteria, which tells to what extend the fusion reactor is profitable. Therefore, significant efforts have been devoted worldwide to understand the mechanisms that affect the confinement and to explore operational regimes with improved confinement.

Improved confinement regimes

Inter-machine analyses show that the energy confinement strongly increases with the plasma size and with the plasma current and to a less extent with the plasma density and the toroidal magnetic field. Conversely, it strongly decreases with the injected power.

Besides these variations, experiments performed in 1982 already, in ASDEX [1], showed that the plasma might, in some circumstances, undergo a rapid transition towards a regime with significantly improved confinement, which was named H-mode, for High confinement mode, in opposition to the normal mode, then called L-mode (L for low).

Although H-modes are obtained routinely in most tokamaks, the physics governing the L-mode to H-mode transition is not fully understood. Generally, L-H transitions are observed in diverted plasmas when the heating power exceeds a threshold that depends on plasma density, toroidal magnetic field and plasma size. These observations led to the characterisation of the access to the H-mode by power-law scalings [2]. However, a series of other parameters, such as the distance between the plasma and the vessel, are known to also play a role [3].

The signature of the L-H transition is a sudden decrease in the light emitted by the plasma (Dα line), followed by an increase of the plasma density, as shown in Figure 1. A transport barrier forms at the plasma edge, materialized by the build-up of a so-called edge pedestal in the plasma pressure. It then induces higher density and temperature profiles in the whole plasma and thereby increases the energy confinement.

In some cases, the transport barrier is so strong that the plasma density increases up to a limit at which the plasma disrupts.

Stationary H-modes are generally obtained when the transport barrier regularly releases a burst of particles called ELM for Edge Localised Mode.

The energy confinement, in these ELMy H-mode plasmas can exceed twice the L-mode values. The drawback of these ELMs lies in the detrimental effect their corresponding heat bursts have on the vessel walls. Different techniques have been developed to control their amplitude or even to get rid of them while keeping the tiny leakage necessary for maintaining the plasma in stationary conditions.

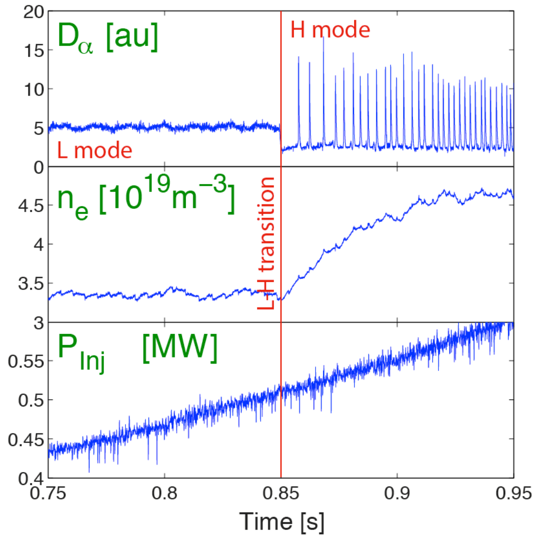

Figure 1: Evolution of a plasma discharge showing a L-mode to H-mode transition: Dα emission at the top, plasma density at the middle. It is induced by the injected power ramp, trace at the bottom.

Confinement regimes in future devices

ITER, the fusion reactor that should reach a power amplification of 10 (P_{fusion} / $P_{injected}$=10), is conceived for operation in the ELMy H-mode regime. ELM mitigation systems are currently being designed.

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Thermal Energy Storage System Proposal for DEMO Fusion Power Plant

Dr. Evaldas Bubelis*, Institute for Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology (KIT), evaldas.bubelis@kit.edu;*
Dr. Wolfgang Hering*, Institute for Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology (KIT), wolfgang.hering@kit.edu.*

Keywords: DEMO Fusion Power Plant, Thermal Energy Storage (TES) System, Balance of Plant (BoP)

Introduction

The EUROfusion Consortium [1] within its Power Plant Physics and Technology (PPPT) work programme is currently focussed on the conceptual design of a demonstration fusion power plant (DEMO) [2] to be constructed in 2030. As the operation of DEMO fusion power plant consists of different phases – charging of poloidal field (PF) coils, plasma burning time, shutdown of PF coils and Dwell time between pulses, the power output is not constant. Also internal needs to start up magnet fields lead to the conclusion to add an energy storage to the DEMO system. Due to the high efficiency, the energy storage will be a thermal energy storage (TES) system, which would allow a constant production of power and would increase the lifetime of power conversion system (PCS). Furthermore, this would allow for load following capability. A proposal for such a TES system for DEMO fusion power plant is presented in this paper.

Discussion

There are three main heat sources to be taken into account when designing the BoP system for DEMO fusion power plant: heat coming from blanket, divertor and vessel cooling circuits. Divertor and vessel is cooled by water, and these two heat sources are implemented into the power conversion system (PCS) of DEMO. Blanket cooling might be done by water or helium. This paper analyse both: the DEMO BoP with water cooled blanket and DEMO BoP with helium cooled blanket. Blanket cooling circuit is part of DEMO primary heat transport system (PHTS). The link between PHTS and PCS is the intermediate TES system, where the coolant is proposed to be solar salt, which transports heat from the blanket cooling circuit to the PCS, where steam is being produced and supplied to the steam turbine for electricity production.

This paper discusses design peculiarities of the TES system, when applied to DEMO BoP with water cooled blanket and DEMO BoP with helium cooled blanket. A proposal for TES system for DEMO BoP is being presented for the two above mentioned cases of blanket cooling. Differences between the two options are being highlighted and conclusions drawn.

Conclusions

In the case of DEMO BoP scheme for water cooled blanket concept, pulsed power operation of DEMO requires the TES capacity for ~50000 t of solar salt (two equivalent tanks for hot and cold salt) in order to constantly produce steam for constant operation of the steam turbine, even during the Dwell time period of the DEMO. This big amount of the required TES capacity results in huge additional costs related to the purchase of the solar salt itself (~25 M$) and also to the cost of the huge salt storage tanks. In the case of DEMO BoP scheme for helium cooled blanket concept, pulsed power operation of DEMO requires the TES capacity for only ~8000 t of solar salt, in order to constantly produce steam for constant operation of the steam turbine. This amount of the required TES capacity is much (~6 times) less than the required TES capacity for the case when blanket is cooled by water, and thus the cost for the solar salt itself is much less (~ 4 M$) and the cost for the salt storage tanks would be much less as well.

This huge difference in the required TES capacity between the two options of DEMO BoP analysed above is mainly due to the usable different coolant ΔT of the main heat source (heat coming from the blanket cooling): in the first case $\Delta T \sim 40°C$, in the second case $\Delta T \sim 200°C$. Having lower coolant ΔT one needs more salt to store the same amount of heat, while having higher coolant ΔT one needs less salt, in order to constantly produce steam for constant operation of the steam turbine. All the above mentioned parameters of the proposed TES system are still very preliminary and should be re-confirmed by further detailed simulations. In general however, the integration of TES system into DEMO BoP reduces thermal loads to the PCS and allows us to offer power to the grid in predictable and controllable manner.

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Relativistic Fluid Dynamics for Modelling Inertial Confinement Fusion

Prof. Laszlo P. Csernai, *Department of Physics and Engineering, Univ. of Bergen, csernai@ift.uib.no*
Prof. Daniel D. Strottman, *Fellow, Los Alamos National Laboratory, danstrottman@gmail.com*

Keywords: Relativistic Detonation Fronts, Volume Ignition, Radiation dominated implosion

Recent considerations [1] on the applicability of relativistic theory of time-like detonations for advances in fusion research. Experimental and theoretical efforts to achieve Inertial Confinement Fusion (ICF) have focussed on the compression of the fuel in a fuel capsule [2, 3]. An ablator layer was placed on the external surface to achieve larger compression. The outcome of these experiments was that most of the pellet broke into pieces due to Rayleigh-Taylor surface instabilities.

Already in the classical literature [4] it is mentioned that the way to avoid these instabilities is to make the compression and the detonation front a high temperature radiation dominated front, which works to smooth out the Rayleigh-Taylor (RT) instabilities propagating with the sound-speed, while the radiation is propagating with the speed of light. The radiation dominated, high temperature process must be described with relativistic fluid dynamics, wherein the pressure is not neglected compared with the energy density, and the propagation of radiative energy is described in a consistent way with all other dynamical processes.

In the present work, we concentrate on the "volume ignition" of the fuel by neglecting compression. We use a relativistic Rankine-Hugoniot description originally described by A. Taub in 1948 [5], which description was then corrected by L.P. Csernai 39 years later [6], and used since then widely in the field of relativistic heavy ion collisions [7]. The relativistic shock relations are based on the energy-momentum tensor, $T^{\mu\nu}$, and baryon charge current, N^μ, conservation across a hyper-surface with a normal 4-vector Λ^μ, where the change of a quantity a across the hyper-surface is denoted by $[a] = a_2 - a_1$:

$$[R^\mu] = [T^{\mu\nu}\Lambda_\nu] = 0 \quad \text{and} \quad [j] = [N^\mu \Lambda_\mu] = 0. \qquad (1)$$

These conservation laws lead to the relativistic shock or detonation equations for the energy density, e, pressure, p, and generalized specific volume, $X = (e + p) / n^2$: $\quad j^2 = \Lambda^\mu\Lambda_\mu\, [p] / [X],$ and $[p](X1+X2) = [(e+p)X]$. (2)

This description treats detonations also across hypersurfaces with time-like normal vectors ($\Lambda^\mu\Lambda_\mu = +1$), and therefore has the name time-like detonation, which actually means simultaneous volume ignition. Taub's description could be applied to "slow", space-like fronts only.

The presented model became relevant and applicable to the recently published ICF experiments performed at the National Ignition Facility (NIF). To achieve a rapid volume ignition the needed total ignition energy should be radiated inward in a time interval, $t_{in} < 1$ or $t_{in} << 1$ (in units of $[R_0/c]$).

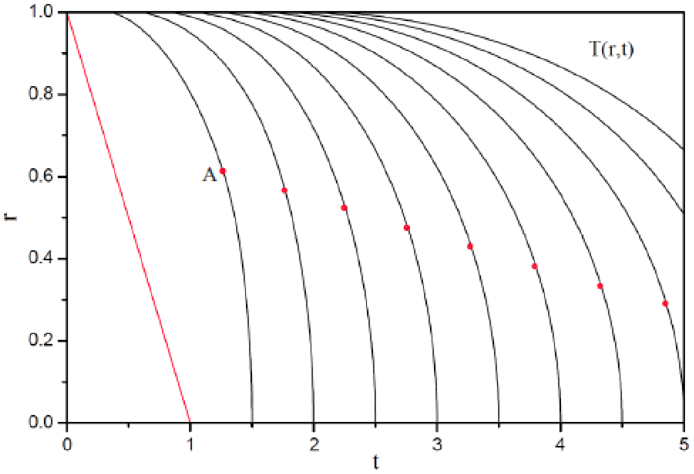

Fig. 1 Acceleration of the detonation fronts, characterized by T = const. contour lines, due to radiation from the outer surface at $r = 1$ inwards to $r = 0$. The heating by radiation leads to a smooth transition from space-like to time-like front at the red points A, where the front propagates with the speed of light.

The longer is tin the greater probability we have for RT instability. If $t_{in} > 3$, the RT instability can hardly be avoided, and the possible volume ignition domain size becomes negligible. Thus for an R0 = 3 mm pellet the ideal irradiation time for volume ignition would be $t_{in} < 10$ ps (while for an $R_0 = 30$ cm target it would be $t_{in} = 1$ ns).

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Towards Energy Efficiency Solutions and Low Carbon Economy in Urban Areas: The Sustainable Urban MOdel (SUMO) Toolkit

Prof Nicolas Moussiopoulos, *Aristotle University of Thessaloniki, Laboratory of Heat Transfer and Environmental Engineering, moussio@eng.auth.gr*
Eleni Feleki, Aristotle University of Thessaloniki, Laboratory of Heat Transfer and Environmental Engineering, feleki@aix.meng.auth.gr
Dr Charisios Achillas, Aristotle University of Thessaloniki, Laboratory of Heat Transfer and Environmental Engineering, achillas@aix.meng.auth.gr
Dr Christos Vlachokostas, Aristotle University of Thessaloniki, Laboratory of Heat Transfer and Environmental Engineering, vlahoco@aix.meng.auth.gr

Keywords: Sustainable urban policies, Mediterranean area, Capitalization of research results, SUMO toolkit, Urban Empathy project

Introduction

Policies aiming at energy efficiency in building and districts, urban transportation and mobility, efficient use of fuels, land use planning, green spaces, air quality and municipal solid waste management, are critical towards urban sustainability. In this framework, a capitalisation project, namely "Urban Empathy", has been funded by the MED Programme. More specifically, Urban Empathy focuses on sustainable urban policies in the Mediterranean Basin. It also aims towards the consolidation of a permanent structure bringing together projects, policy makers and stakeholders to share concrete results so as to improve the efficiency of sustainable urban policies.

Discussion

This paper emphasizes on the structured dialogue which is organized in the framework of the project. The work has been organized in four discrete steps. Initially, a cross-check and evaluation of results' transferability is completed, consisting in evaluating projects results according to analytical predefined criteria. Results are categorized into cross-cutting aspects (territorial management and urban design, social and economic cohesion) and sectorial aspects (energy efficiency, sustainable mobility). In parallel, a structured dialogue is implemented together with the results' evaluation in order to identify what decision-makers really need and the key barriers to the implementation of sustainable urban policies in the EU. The realization of those two parallel activities permits the analysis of how projects' results match with decision-makers' expectations, by cross-checking the capitalized results with the decision-makers' requirements, strategic issues and main barriers. The goal is to provide a tool kit (SUMO toolkit) for decision-makers that includes results in an organized framework according to decision-makers' priorities, in order to offer solutions or to put forward policies able to improve urban sustainability.

Conclusions and/or Outlook

The structured dialogue resulterd into the development of the SUMO Toolkit, an instrument that prepares current and future results to be transferred in a practical way and according to decision maker's needs. The SUMO Toolkit serves as an interactive knowledge centre on urban sustainability where successful results, following a concrete strategy based on the integrated approach to sustainability and responding to decision-makers needs, is available to be capitalized. More information is available in [1].

Acknowledgement: This research has received funding from the European Regional Development Fund (ERDF) through the MED Programme under Grant Agreement No. 1CAP-MED12-34 81289/2013 (Project Acronym: Urban Empathy).

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Hardware-in-the-Loop environment for design and test of energy-efficient room automation systems in buildings

Prof. Dr.-Ing. Martin Becker*, Institute for Building and Energy System (IGE), Biberach University of Applied Sciences (HBC), becker@hochschule-bc.de*
M.Sc. Dipl.-Ing. (FH) Alexander Adlhoch*, IGE, HBC, adlhoch@hochschule-bc.de*
M.Sc. Anita Barth, IGE, HBC, barth@hochschule-bc.de
Dipl.-Ing. (FH) Peter Knoll, IGE, HBC, knoll@hochschule-bc.de

Keywords: Energy Efficiency, Hardware-in-the-Loop, Room Automation, Control Design, Controller Test

Introduction

Due to the implementation of the European Performance of Buildings Directive (EPBD), the topic of energy efficient building operation is becoming more and more significant. Building automation leads to considerable contributions, e.g. by improved and more sophisticated control algorithm or by running hardware-in-the-loop tests in the context of rapid control prototyping. In a hardware-in-the-loop (HiL) environment room controller can be tested under predefined boundary conditions. HiL tools allow configuring room automation systems optimized to the desired demand and energy efficiency. For this purpose a room simulation model (virtual process) which maps the conditions of the real room utilisation is linked to the real room controller using a hardware coupling device.

Discussion

A hardware-in-the-loop environment is composed of a dynamic simulation model of the controlled system (virtual process), a hardware coupling device and the real (physical) controller, which should be tested. The room model consists of an amount of different room type models which can be configured with different parameters. In combination with different load profiles, weather data etc. it is possible to build up test scenarios which match the application conditions of the controller. The hardware coupling device provides an amount of digital or analogue physical inputs and outputs as well as interfaces to different bus and wireless systems. Hence a wide range of different room controllers can be coupled to the HiL system.
The configuration and operation of the HiL environment is performed over an especially developed graphical user interface (GUI). This allows the exchange of information between the user and the HiL system. Specific adjustments can be performed by the user and the results are displayed by the GUI. Only relevant information is shown, so that the real complexity of the HiL environment is reduced for the practice. Therefore also people, which are not familiar to the detailed simulation programs of the HiL environment, can operate a HiL test.
During the research project [1] two different types of HiL environments were developed. A so-called stationary HiL environment enables a user specific and energy efficient development and parametrisation of room automation systems. The so-called mobile HiL environment is constructed for a flexible utilisation in the field level. It supports operational test, error diagnostic and debugging of previously installed controllers. In the stationary HiL environment different controllers have already been tested under several conditions. Using the results different assessment criteria had been developed and tested in a practically environment. The mobile HiL environment has been applied in two real surroundings: a seminar room of a university controlled by a programmable logical controller (PLC) and a classroom of a school building attached to a central building automation system. In both applications some faults could be uncovered by logging and evaluating different data points by running the mobile HiL environment.

Conclusions and Outlook

In this work two types of flexible Hardware-in-the-Loop (HiL) environments were developed and tested in practice. In this environments room controller can be tested under predefined boundary conditions and also various controllers can be evaluated against each other. First practical applications show the eligibility of the HiL environments. Anyway there is some potential for further development. The assessment criteria can be refined, to get an automated evaluation of a controller once a HiL test was performed. Further developments of the mobile HiL should offer the possibility to run already installed controllers against a simulation model for testing and optimisation purposes.

Acknowledgement:
The authors gratefully acknowledge financial support for this project provided by the Ministry of Science, Research and the Arts (State of Baden-Württemberg) and the European Union: European Regional Development Fund (ERDF)

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Modelling distributed mCHP-systems in German residential applications and their potential to integrate the gas and power grids

***Praseeth Prabhakaran**, DVGW-Research Station at the Engler Bunte Institue of KIT, prabhakaran@dvgw-ebi.de*
Wolfgang Koeppel, DVGW-Research Station at the Engler Bunte Institue of KIT, koeppel@dvgw-ebi.de
Daniel Fehrenbach, European Institute for Energy Research (EIFER), fehrenbach@eifer.org

Keywords: Distributed generation, Simulation, Optimisation, mCHP, Residential sector

Introduction

An important part in the German ‘Energiewende’ (Energy Transition) involves analysing the role of distributed energy supply in the residential sector. The energy demand of this sector accounts for 28.1% of the total energy demand in Germany [1]. Here, the large scale implementation of micro-CHP systems could also potentially support the grid integration of intermittent renewables. However, a better analysis of the potential benefits of implementing house based mCHP systems must also involve the mathematical modelling of not only the various mCHP units and their energy distribution and control systems but also the buildings in which they operate.

Discussion

In this study, the building models include details of the various construction materials, size of storage devices, material and dimensions of the heating systems as well as diameters and material of the piping used. In contrast to earlier studies [2] where parametric dynamic models of mCHP systems in buildings were analysed, a fairly large variation in building geometries is incorporated in this study by categorising the residential buildings into 5 indicative types. Each type represents a range of buildings with similar geometries thereby also enabling the potential simulation of city quarters. The resulting systems of equations (DAE) are then simulated dynamically in Modelica for various location based and climatic boundary conditions. The results include dynamic plots of the full load hours of mCHP operation and area specific heat and power demand for different house types simulated for a year with a time step of ~300s. The dynamic values (Figure 1) are then integrated to obtain yearly cumulative results to analyse favourable scenarios benefitting the residential sector. Further, potential feasibility of innovative technologies like Power-to-Gas for energy storage or Biogas injection to increase the share of renewable energy in distributed energy supply are also analysed.

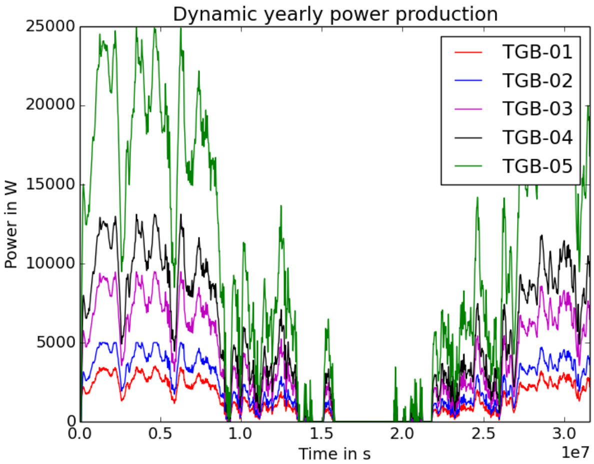

Figure 1: Yearly power production of gas based CHP systems when maintaining constant building temperature (20 degC in Type TGB-01 to 05)

Conclusions and Outlook

In the next step, to extend the relevance of these results to a larger context, the results of this work could be used as constraints in an optimising energy system of residential heating in Germany to highlight the implications of distributed generation on a national level.

Acknowledgement: This work has been supported by the Helmholtz Association programme Helmholtz-Energie-Allianz: Technologien für das zukünftige Energienetz.

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Spatial and multi-energy modelling integrated into district urban planning at master plan phase

Diane Petillon, *European Institute for Energy Research – EIFER, petillon@eifer.org*
Xiubei Ge, European Institute for Energy Research – EIFER, ge@eifer.org
Dr. Enrique Kremers, European Institute for Energy Research – EIFER, kremers@eifer.org
Jean-Marie Bahu, European Institute for Energy Research – EIFER, bahu@eifer.org
Andreas Koch, European Institute for Energy Research – EIFER, koch@eifer.org

Keywords: District modelling, Energy master plan, Multi-energy carriers, Urban planning, Systemic approach.

Introduction

Cities are today facing crucial urban and environmental challenges as most of the world population lives in urban areas which represent almost 40% of the total GHG emissions. In order to achieve their sustainable objectives cities are looking for better solutions for integrating energy issues into their urban planning at different levels. Integrated urban planning has thus been targeted by the IPCC as an important mitigation measure regarding global warming [1]. In the same time the complexity of decision making is increasing due to the high number of domains and stakeholders. This emphasizes the need of integrative expertise for urban decision support based on a systemic and multi-scale approach. Such approach can empower cities to enhance their sustainable development. A large variety of tools exist for decision support in urban energy planning such as the CitySIM [2] or the SynCity [3]. Nevertheless few of them combine spatial and multi-energy aspects for urban planning and energy planning at the early phases of district urban project.

The European Institute for Energy Research (EIFER) in Karlsruhe develops innovative solutions regarding energy planning and management in cities and territories. The institute has a specific expertise in energy modelling and geo-simulation.

Discussion

A prototype model has been developed in EIFER in order to support master planners in integrating energy perspectives in urban planning. More specifically, the prototype aims to simulate the district needs and multi-energy systems for several energy carriers. It combines spatial and energy modelling by using preliminary urban planning zoning of the district. It illustrates the system-wide effects of urban planning measures, infrastructure planning, choice and sizing of energy technologies, and energy management strategies. This model is intended to build a bridge between urban planning and energy system engineering fields, using an integrated systemic approach.

The paper first review similar approaches. After describing the global methodology, a simulation use case is presented in order to show the interactions between urban and energy planning. It investigates the influence of changing the land use type on energy planning issues inside a district. Based on standard demand profiles, the heat and electricity hourly load curves can be modelled at the zone and district levels. Different kinds of analysis are then possible based on several indicators (e.g. load factor) or the profile of the resulting load curves. Finally, the potentialities for implementing different technologies (such as district heating or CHP plant) can be assessed according to energetic and economic aspects.

Acknowledgement: We would like to address special thanks to EDF and EIFER for supporting this project.

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A software platform to help Singapore to build a more smart and sustainable city

David Blin, EDF R&D, david.blin@edf.fr
Fabrice Casciani, EDF R&D, fabrice.casciani@eifer.org
Pierre Imbert, EDF R&D - EIFER, pierre.imbert@eifer.org
Benjamin Mousseau, EDF R&D - EIFER, benjamin.mousseau@eifer.org
Alberto Pasanisi, EDF R&D - EIFER, alberto.pasanisi@eifer.org
Pascal Terrien, EDF R&D, pascal.terrien@edf.fr
Pablo Viejo, EDF R&D Lab Singapore, pablo.viejo@edf.fr

Keywords: Sustainable cities, modelling, 3D visualization, web-services.

Introduction

Since 2013 [1], [2], EDF and the Housing & Development Board (HDB) of Singapore are working together to develop an innovative urban simulation tool to be used by local urban planners for urban diagnosis, and analysing and comparing the short and long-term effects of sustainable development strategies. The tool gathers a number of expert models concerning different technical domains of interest for city planners (energy, water management etc.) and a 3D graphical user interface (provided by Dassault Systèmes) into an entirely web-based architecture. The prototype version is deployed since December 2014.

Main features

The platform is intended to the comparison of different strategies of urban development the outcomes of which are summarized in KPIs (key performance indicators) evaluated by means of simulation models. These ones are based on the expertise of several Departments of EDF R&D, based in France and in Germany (in particular, the European Institute for Energy Research - EIFER - joint EDF-KIT research unit). Simulation models (coupled together following a systemic approach) are concerned with several technical topics: air conditioning, indoor and external lighting, distributed electricity generation (fuel cells, CHP, Photovoltaic), use of regenerative lifts, roofs and vertical greenery, intensifying landscaping, incentives for more energy efficient household appliances. In addition, models dealing with effective management of water and waste are provided by Veolia. The user can easily display results and parametrize urban objects by means of a 3D graphical user interface.
By the software architecture viewpoint, the platform relies on specific web-services and it is fully web-based, so that users do not need any particular “local” installation of software libraries on their workplace. Figure 1 shows some screenshots of the platform.

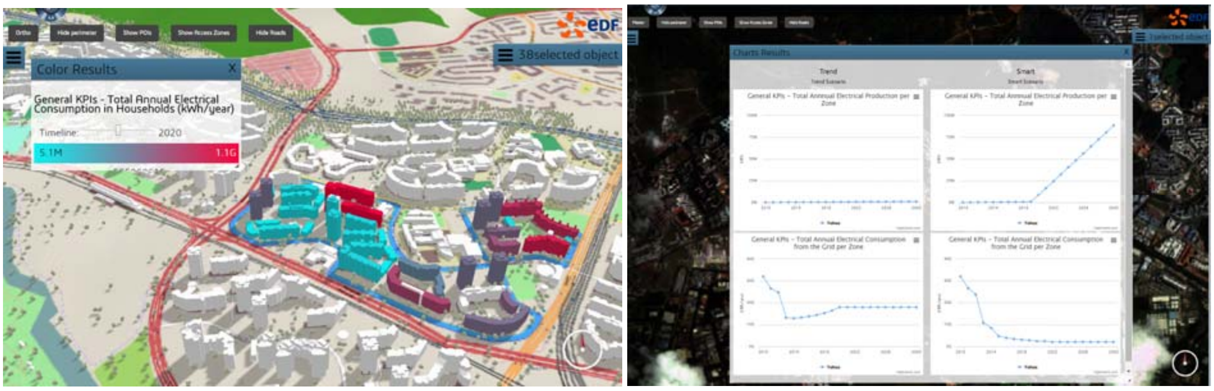

Figure 1: Two screenshots of the city simulation platform. Left: displaying results of a simulation directly on urban objects by means of a colours scale. Right: Examples of output graphs.

Perspectives

The platform could be adapted to the needs and the particular features of other cities or urban areas (e.g. adding and/or modifying existing models or adding data analytics functionalities), so that it can be considered the lead product of software tools intended to support the smart cities business at EDF.

The authors gratefully thank all the team members of the EDF R&D projects “Sustainable and Smart Cities” and “Tools for City Simulation”.

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Energy efficiency of buildings – the aspect of embodied impacts

***Prof. Thomas Lützkendorf**, Karlsruhe Institute of Technology (KIT), thomas.luetzkendorf@kit.edu*
Maria Balouktsi, Karlsruhe Institute of Technology (KIT), maria.balouktsi@kit.edu

Keywords: Embodied energy, Energy efficiency, Net-zero-energy building, Life cycle, Assessment method

Introduction

Through a combination of modern design methods and innovative building products recent research has shown that it is technically feasible to design and construct energy efficient buildings, or even to achieve the net-zero energy target. However, the design and assessment of such building concepts commonly focus only on the operational processes of the building, ignoring the embodied environmental impacts over its life cycle. Nowadays, not only the operational energy efficiency, but also the requirement for reduced embodied impacts, here in terms of primary energy use, is a new challenge for key actors in the construction industry. Thus, this paper attempts to answer the question of how the assessment of embodied energy can be part of an overall optimization of the energy efficiency of buildings and whether the consideration of embodied impacts influences the expected environmental advantage of net-zero building concepts over the conventional ones.

Discussion

Across the total life cycle of a building, the relative importance of energy for its production, construction, maintenance, and end-of life processes, the so-called embodied energy, increases as its operational energy performance improves further. For example, embodied energy in new, well-insulated energy efficient buildings can add up to 40% of the total energy consumption in the life cycle, and even exceed the operational energy [1]. This fact, together with the increasing number of net-zero energy buildings, have contributed to the growing interest within the construction industry in exploring the possibilities for reducing the embodied environmental impacts of buildings, comparing to previous years when the focus was exclusively on the operational impacts [2]. Especially, in the case of a “net zero” concept, considering that embodied energy values are highly influenced by the selection of construction materials and building specific features, the embodied energy consumption may be affected due to an increased use of thermal mass and insulation, as well as the installation of photovoltaic systems. This paper highlights and analyzes fundamental issues needing consideration when evaluating embodied energy – in terms of primary energy use – as part of a life cycle energy analysis of buildings. The content of the paper is partially based on the preparatory work of the international ongoing project IEA EBC Annex 57 “Evaluation of embodied energy and greenhouse gas emissions for building construction”, where the authors actively participate [3]. In this paper the following points are presented: (1) the extended system boundaries when considering the full life cycle of buildings, (2) the need for transparency and traceability in databases, system boundaries and assessment results, (3) the possibility to formulate design goals for embodied impacts (demonstrated here with the example of primary energy), (4) the current state of integration of embodied impacts into the decision-making processes of different groups of actors.

Conclusions and/or Outlook

Nowadays, the currently available standards, databases and tools can support the design professionals in assessing the embodied impacts of buildings. However, these do not always define clearly the calculation methods and system boundaries, leaving a broad scope for interpretation. This paper discussed some of the fundamental conceptual and methodological issues that need to be taken into account and specified when assessing the embodied impacts of buildings and consequently the environmental benefits of net-zero building concepts from a life cycle perspective. The different scopes and boundaries presented with regard to the assessment of embodied energy provide good starting points for further research, standardization and development.

Acknowledgement: The authors would like to acknowledge all the participants of the IEA Annex 57 project. The member list can be found here: http://www.annex57.org/. Finally, the authors are grateful to Project Management Jülich supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) for funding the work as part of the IEA Annex 57.

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Business and Technical Concepts for Deep Energy Retrofit

***Rüdiger Lohse**, Department of Energy Service Development, KEA Climate Protection and EnergyAgency of Baden- Württemberg, Ruediger.Lohse@kea-bw.de*

Keywords: Energy Efficiency in Buildings, business models, technical concepts, deep energy retrofits

Introduction

Many governments worldwide are setting more stringent targets for reductions in energy use in public buildings. In the US state directive is targeting 3% of annual energy savings, in the EU the building stock rate to be refurbished will have to leverage from 1 to at least 3% to meet the ambitious targets. In the 27 EU member states the existing public building stock is about 4 bn m². A deep renovation strategy with indicative savings of 75% will trigger a total investment of 1.200 bn € to be put in place. Besides the know-how the available funding will be crucial for the implementation of refurbishment strategies. The different combination of both, funding and know- how leads to different contract based "business models" to be selected to implement refurbishment strategies.

Discussion

Recent research has shown that the performance of the business model "owner-directed" energy retrofit projects has not kept pace with new requirements to increase the number and pace of energy retrofits and to improve the energy efficiency of existing buildings in an adequate level. Mostly owner- directed business- models lack stimulation to meet efficiency targets and fixed investment expenses. In recent years, Energy Savings Performance Contracting (ESPC) has proven to be a very successful business- model bridging the weak- points of the owner- directed models: ESPC business models are stimulating both contract parties to achieve a high cost effectiveness (providing a better savings- investment ratio), a better life- cycle cost effectiveness and high degree of energy efficiency. With providing a life- cycle- cost orientated structure ESPC business models structure typically sees the Energy Service Company (ESCo) providing the planning and implementation and funding of the investment and the costumer only paying the energy- and cost savings achieved. To date the average savings of ESPC projects are varying between 25 and 40% recapitalizing the investment and life- cycle cost of HVAC retrofit, CHP and biomass implementation within 5- 15 years.

The implementation of some individual measures (e.g., building envelope insulation and improved air-tightness, co-generation) result in significant reductions in building heating and cooling loads or minimization of energy waste, but require significant investments with long paybacks. However, when different technologies are implemented together, or are "bundled," they can result in significant energy use reductions, require smaller investments, and consequently have faster paybacks. Such bundles of energy-saving measures are seldom applied when buildings and building clusters are retrofitted. Decision makers often lack knowledge about the synergy of different energy-saving measures available to them, or about the efficiencies and return on investment that such bundles of measures can yield. The research project IEA EBC Annex 61 targets the improvement of a broader DER strategy by starting with the determination of working bundles of technologies and corresponding business models using combined public and private funding.

First results of the project show, that evaluated DER projects are limited in number, show gaps between predicted and performed energy savings and often exceed the investment cost budgets established in early project phases. Most of the DER projects achieve energy savings of >50%, a few up to 80% with DER measure bundles specified according to the building types. In a next step DER measure bundles have been modeled and optimized for different scenarios of energy savings in representative building types and different climate zones: the baseline scenario is the status quo, (1) the "base-case" scenario describes the minimum requirement of building codes, (2) the"- 50% scenario is considering a reduction of 50% against the baseline scenario, (3) the "new building scenario" considers the adoption of the building codes for new buildings to the building stock and finally (4) a "NZE approach" considers an energetic level close to passive house. The life- cycle cost assessment will be concluded by April 2015, but until today in ASHRAE c.z. 5 the adoption of building codes for new buildings shows the optimum close to scenario (3). In the next step the implementation tools, "business models", are assessed. Here the energy and non- energy related benefits resulting from DER projects are collected, evaluated, monetized and integrated in the accounting and financing mechanism. This effort is an important part of sweeping away a major hurdle for the implementation of DER projects in particular in the public sector where the scarcity of public funding prevents the roll out of DER in the market. Each monetized and accountable benefit reduces the demand for external funding and debts. In the current status of the project, besides the energy savings avoided secondary investments for maintenance and refurbishment are considered in the first approach. To integrate these benefits into the financing mechanism, the reliability of the predicted savings has to be guaranteed.

Acknowledgement: This report refers to intermediate result of IEA EBC Annex 61 participants and the work of operating agents Dr. A. Zhivov, USA and Rüdiger Lohse, Germany.

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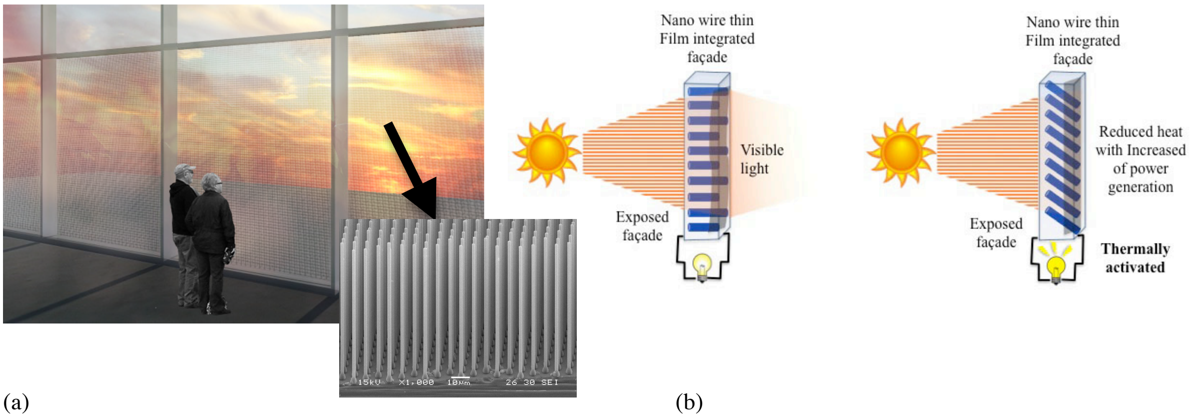
Analysis of the Thermal & Photovoltaic Performance of a Nano-Solar Skin Module

Dr. Mona Azarbayjani, *School of Architecture, University of North Carolina at Charlotte, mazarbay@uncc.edu*
Dr. Michael G. Walter, *Department of Chemistry, University of North Carolina at Charlotte, Michael.Walter@uncc.edu*

Keywords: Nano-Wire Solar Skin, Thermo-Responsive Façade, Semi-transparent PV module; Temperature variation; Photovoltaic performance

Introduction

Responsive envelope strategies can provide energy efficiency and comfort solutions for our built environment through responding to various environmental stimuli like solar radiation. As shown in Figure 1, to optimize the performance of the envelope, the nanoscale (invisible thin solar skin) can be integrated into the facade to generate electricity, while it also reduces the solar heat gain by blocking the unwanted heat and enhances the solar energy harvesting without compromising the aesthetics. This research article investigates how to optimize the façade prototype through balancing between the three variables: daylight intensity, heat gain, and solar cell power generation.



(a) (b)

Figure 1. a) Nanowire thin film reducing the solar heat gain and glare on a window, without blocking the view to the outside b) Depiction of the silicon wire array embedded in polymer and it's thermoresponse to heat from illiumination. (Inset - SEM image of the finished flexible silicon wire array substrate)

As shown in Figure 1b, the photovoltaic nanowires embedded in the façade, upon receiving the solar radiation produce electricity. Bending and stretching of the heat sensitive polymer substrate can change the orientation of the nanowire array in order to reduce the transmission of light through it. Therefore the arrays can be optimized for absorption or transmission depending on their requirement in a façade system, which is integrated into as a thin film window coating application.

Conclusions and/or Outlook

The integration of next generation nanoscale solar skin in order to reduce the solar heat gain and glare while producing electricity is one of the promising technology in the area of integrated pv façade systems. This study investigates the electrical and thermal performance of a semi-transparent nano wire PV modules imbedded in a polymer based substrates that was designed as a glazing component. The study evaluates the effects of the thermal performance of the polymer substrate in relation to integrated nano wires in and electrical generation.

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Refrigeration Plants with Trapezoid Cycles

***Dr.-Ing. Michael Löffler**, Department of Distributed Generation, European Institute for Energy Research, loeffler@eifer.org*

Keywords: Refrigeration, COP, waste heat, pinch analysis, trapezoid cycle, heat pump

Introduction

Heat pumps and refrigeration units mainly base on vapour compression cycles. Usually the referring thermodynamic cycles approximate the Carnot cycle, which is defined as a rectangle in the temperature-entropy-diagram (T-S-diagram). The area of the rectangle in the T-S-diagram equals the theoretic work for running the cycle.

In contrast it is evident, that in case of sensible heat the ideal process looks like a trapezoid in the T-S-diagram.

Discussion

Vapour compression cycles which use water as heat transfer medium are the most common and are discussed following. The water is heated up in the condenser and cooled down in the evaporator. If there is a small temperature difference of the water the condenser and evaporator can work with small dissipative loss. In this case, the trapezoid approximates the Carnot cycle. If there is a large temperature difference of the water the ideal trapezoid differs substantially from the Carnot cycle. The following figure shows the case of a chiller, where the area of the trapezoid and hence the required mechanical power is about 20% smaller compared to the Carnot cycle. Heat sink T_1 could be at 35 °C, cold water T_4 could be at 6 °C, warmed water T_3 could be at 18 °C.

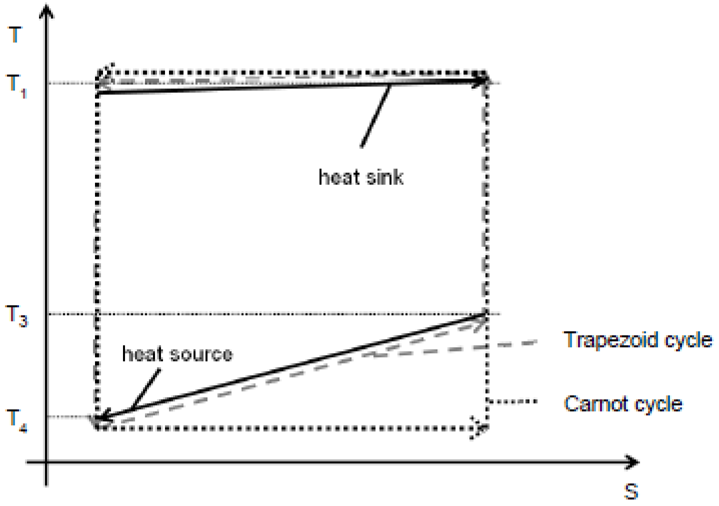

Figure 1: Trapezoid cycle in the case of a chiller

For the case of high temperature differences a setup was designed which helps to adapt the small temperature difference of the water in the evaporator or condenser to the large temperature difference of the water on the side of the heat source or heat sink [1]. This setup can help to increase the COP of vapour compression cycles, the higher the temperature difference of the water, the higher the improvement of COP.

Conclusions and Outlook

The setup will be implemented in many fields of application. Main examples are chillers [3], heat pumps for space heating and hot water supply, industrial fields like pinch analysis [2], thermal food treatment and technical processes where thermal efficiency plays a role.

Within a presentation, the results and perspectives will be outlined.

Acknowledgement: The author thanks EIFER for the support in this field of thermodynamic research.

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Investigations of thermal parameters addressed to a building simulation model

***Ph.D. student Christian Brembilla**, Department of Applied Physics and Electronics, Umeå University, christian.brembilla@umu.se*
Dr. Claude Lacoursiere, High Performance Computing Centre North (HPC2N), Umeå University, claude.lacoursiere@hpc2n.umu.se
Dr. Mohsen Soleimanni-Mohseni, Department of Applied Physics and Electronics, Umeå University, mohsen.soleimanni-mohseni@umu.se
Prof. Thomas Olofsson, Department of Applied Physics and Electronics, Umeå University, thomas.olofsson@umu.se

Keywords: Tolerance of thermal parameters, Hybrid model, Differential sensitivity analysis, Proportional control

Introduction

The uncertainty of setting input parameters in a building model can have a major impact on the simulated output. The tolerance of thermal parameters is a necessary information that helps modeler to know the influence of each factors on the outcomes. This paper shows the allowable tolerance of thermal parameters in order to build an accurate building model. Differential sensitivity analysis of thermal parameters of a room yields the values of acceptable tolerance. A hybrid model is the approach used to simulate the room temperature over the year.

Model

Figure 1 shows the hybrid model of a room made by two thermal capacitances and simulated input data from TRNSYS software. Total hourly solar radiation on horizontal surface, outdoor temperature and internal loads are the input data. The solar radiation that strikes the external wall is split in three components: direct, diffuse and reflected from surroundings. Transmission coefficients for surfaces transfer the heat loads from sun inside the air volume. Standard profile of residential occupancy are patterns of internal loads. The two lumped thermal capacities represent the room air volume and active thermal mass. The heating system consists of panel radiator. A heating curve controls the supplied energy to the radiator. A proportional controller adjust the amount of energy from the panel radiator according to a proportional band of 2˚C.

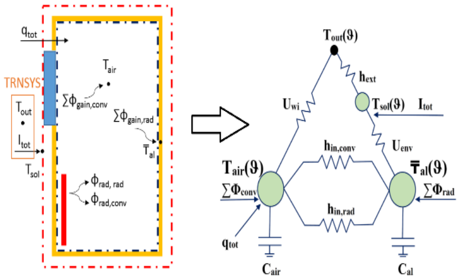

Fig. 1: Hybrid model

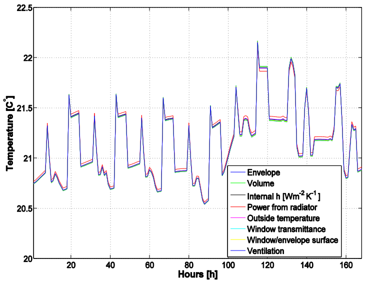

Fig. 2: Sensitivity bands

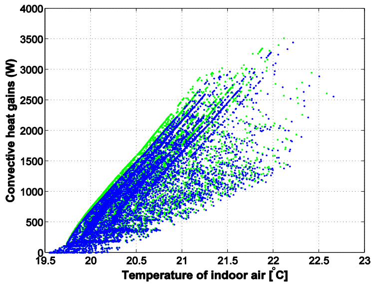

Fig. 3 S.A. of convective heat gains

Figure 2 shows the uncertainty bands of the indoor air. The model reruns at each single perturbed thermal parameter keeping all the other factors constant [1,2]. **Figure 3** shows the sensitivity analysis of the convective heat supplied to the room. The perturbation is ±1% of the nominal value of each thermal parameter. The model is more sensitive to perturbations of environment parameters and thermal loads from free sources and panel radiator.

Conclusions

The allowable tolerance is calculated with the coefficient of variation of root mean square error. Inverting the problem, the model can be perturbed with a magnitude over ±1% till the threshold limit is reached. As final result, the allowable tolerance tells to the modeller that he/she has to asses carefully environment parameters, thermal loads from free sources and panel radiator, meanwhile he/she can neglect deep investigations of the building envelope.

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Heat Exchanger Design Analysis for the Energy Reduction of a Household Air-Conditioning System

***Alex Magdanz**, Fluid Engineering, ITI GmbH, magdanz@itisim.com*

Keywords: Energy, Air-Conditioning, Heat Exchanger, Design, Simulation

Introduction

Rising energy prices and an increase in public familiarity of the role of CO_2 gas emissions on global climate change has put the focus on energy efficiency. In Germany, buildings account for over 40% of the total energy consumption [1]. Optimization of heating and cooling systems has the potential to play a large role in achieving the goals set for the transition to renewable energy. In this project, the design of the heat exchangers of a split-unit household air-conditioning system was analysed in regard to the energy consumption of the whole system.

Discussion

Standard split-unit air-conditioning systems have two types of components that consume electrical energy: the compressor, and the fans for the internal and external heat exchangers. The ratio of energy usage of the compressor compared to the fans is typically in the range 10:1. Based on this ratio, the most potential for energy reduction lies in making improvements to the refrigerant cycle design that allow the compressor to run at a lower power. The most important factors affecting the compressor power in the refrigerant cycle design are the refrigerant mass flow rate and pressure ratios.

A simulation model was created using the program SimulationX to determine the influence of the heat exchangers on the energy consumption of the air-conditioning system. The focus of the analysis was on the indoor heat exchanger. This unit is typically a fin and tube heat exchanger in an L-shaped or U-shaped form around a fan. Several refrigerant pipes run parallel to each other, often in two rows. The air-side heat transfer area of the pipes is increased using fins perpendicular to the pipes. A detailed model of the indoor heat exchanger was achieved by modelling each pair of pipes separately as shown in **Figure 1**. This allowed for the analysis of not only the heat exchanger geometry, but also the flow pattern of the refrigerant circuitry.

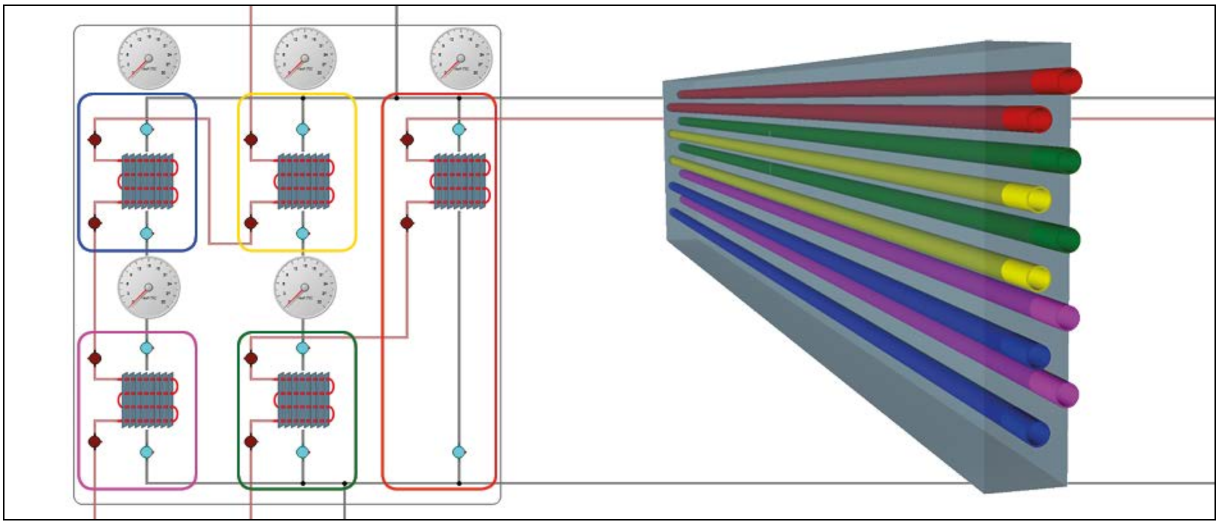

Figure 1: Model Setup of a Section of the Indoor Heat Exchanger

The simulation model was able to calculate the air temperature after each pair of pipes. Additionally, the latent heat of condensation of the air moisture was considered by the heat exchanger elements. By analysing the heat exchange efficiencies of the individual sections, it was possible to make recommendations for adjustments to the design of the indoor heat exchanger that would lead to a reduction in energy consumption of the whole system.

Conclusions and/or Outlook

Simulation of the split-unit air conditioning system using the software SimulationX provided a convenient and efficient method of analysing the design of the indoor heat exchanger. The effect of variations in the heat exchanger geometry and flow configuration could be calculated, and conclusions made about the influence of these variations on the efficiency of the entire system. The technology and approach is also valid for the design of centralized and/or mobile HVAC systems.

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Energy and Efficiency Breakthrough Innovations

Dr. Patrick Ruch, Stephan Paredes, Dr. Brian Burg, and ***Dr. Bruno Michel,*** *IBM Research – Zurich, Säumerstrasse 4, 8803 Rüschlikon, Switzerland, bmi@zurich.ibm.com*

Keywords: Energy, Efficiency, Solar, Adsorption, Heat Pump, Data Centre, Photovoltaic

Introduction

The last years witnessed an increased focus on energy and efficiency, in particular on getting access to sustainable energy sources, and to improve the conversion efficiency of "diluted" energy sources. The available energy is up to now not used wisely: In particular about three quarters of the primary energy input is lost to non-usable lowest grade heat while ~30% primary energy is spent for heating and cooling. A large fraction of energy conversion processes are thermally mediated or inherently create waste heat and have a limited efficiency because not the entire thermal gradient is used. A major reason for limited efficiencies as well as losses are convective and conductive thermal resistances.

Data Centre

To improve cooling of computers convective and conductive thermal resistances were reduced by more than a factor of 10 against the already excellent predecessor technologies (air cooling). With this breakthrough innovation energy flux densities larger than 0.5 kW/cm^2 could be handled on processor chips at only small temperature gradients (<20ºC). The twofold improved the energy efficiency and minimized carbon footprint was demonstrated with the Aquasar and SuperMUC systems [1]. Hot water cooling additionally enables a system-level densification so that, future datacentre efficiency can be improved by several orders of magnitude [2]. The counter-intuitive finding is that high energy flux densities allow high densities and higher efficiencies.

Solar

These technologies also enabled high concentration photovoltaic thermal systems with 2000 fold concentration to reduce the overall system cost while improving the electrical efficiency up to 30%. At the same time waste heat from the PV process is gathered at 90ºC to allow re-use in the form of heat driven cooling and thermal desalination [3] improving the overall efficiency to more than 75%. The second beneficial effect of this high-efficiency solar technology is that radiative forcing is minimized which, in technologies currently in widespread use, leads to a net global warming despite the abatement by the eliminated carbon dioxide emission [4]. Radiative forcing is a stronger effect than the greenhouse effect and low efficient solar technologies especially when mounted on buildings in large cities in the Sunbelt provide more heating than they provide cooling.

Cooling

The second major achievement is excellent conductive thermal transport in particulate matter e.g. thermal pastes. This is used to build processor chip stacks with improved thermal conductivity but also a better thermal contact among nanoporous beads in an adsorption heat pump. The radical innovation is about materials with improved adsorption isotherm, reduced cycling time, and improved mass and thermal transport. This allows a more efficient use of lowest grade heat for heating or cooling [5]. Heat driven heat pump can use low grade datacentre as well as solar heat to provide heating or cooling, or can even be developed to a general "thermal transformer".

Conclusions and Outlook

Optimal match between thermal providers and thermal users is essential to reach high exergetic efficiency and economic profitability [2, 6]. To reach this, individual technologies need to be massively improved requiring breakthrough innovations. These innovations maximally reduce conductive and convective thermal resistance. Minimizing these resistances improves the efficiency of energy conversion processes and allows full use of lowest grade heat.

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Plus-Energy School Campus: Comparison of Supply Concepts

***Dr.-Ing Peter Engelmann**, Niclas Müller MSc., Fraunhofer Institute for Solar Energy Systems, peter.engelmann@ise.fraunhofer.de*

Keywords: Energy, Refurbishment, Energy Concept, Plus-Energy Buildings

Introduction

The school campus in the Hoffmannallee, located in the city of Kleve, is undergoing a substantial restructuring process. The campus consists of buildings from various decades: a newly finished main building, buildings from the late 70s and 60s to a historic building from 1908 (see figure 1 (right)). Existing buildings are refurbished or replaced by new buildings – all according to passive house standard, with the exception of the historic building, where the conservation of the structure limits the potential for efficiency measures.

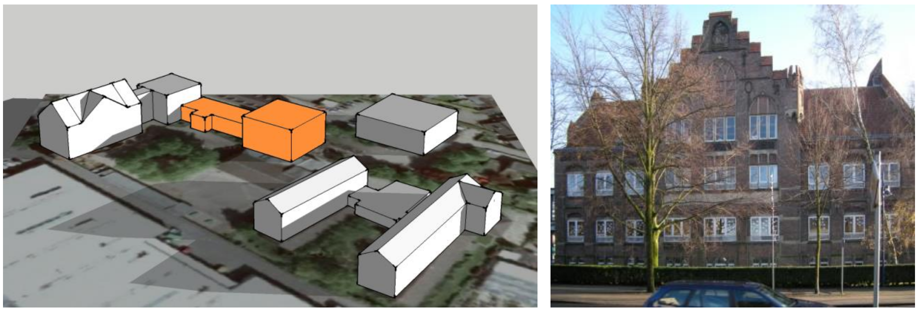

Figure 1: Sketch of the existing school campus (left; orange buildings already match the passive house standard) and the historic building form 1908 (right).

Discussion

The overall goal of the new school is to realise a "plus-energy" campus: on a yearly balance, more energy is produced on site than the school consumes. That includes space conditioning (heating, lighting, ventilation) and school equipment. With the help of model based analysis, different concepts and control strategies are developed and analysed. The campus (buildings and HVAC systems) was modelled in "Modelica" (using the front-end Dymola).

Goal of the analysis was not only to optimize the system for the lowest energy demand, but also to identify the system with the lowest energy cost, as well as taking the situation of the supply grid into account: implementing load shifting strategies to support a grid with a growing share of fluctuating renewables.

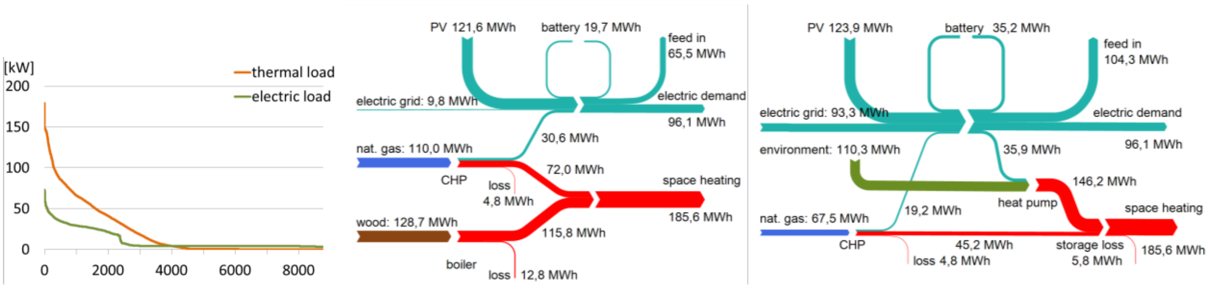

Figure 2: Demand characteristic for thermal and electric loads (left): the heat demand is lower than 4000 hours a year; more than 100kW are only needed for approx. 300h. Different control and supply scenarios were modelled and analysed under different optimisation goals: most economic (example: middle) or most "grid friendly" (example: right).

Conclusions and/or Outlook

To realise a zero- or plus-energy concept, demand reduction for thermal and electric energy is the first and crucial step. Intraday load shifting, by thermal and electrical storage, helps to maximise the self-supply of electric power. The use of CHP is beneficial in all scenarios, even though the operating time is less than 4000 hours/year. For a low primary energy demand, a combination with a biomass-based boiler (wood chips or pellets) is favourable. The combination with a heat pump gives the opportunity of switching from electric generation (CHP) to "power to heat" (heat pump) in order to operating as a "grid friendly" system.

Still, the seasonal mismatch of availability of solar radiation in summer and higher energy demand for space heating and lighting in winter is the major challenge for the supply systems. This is even more noticeable in schools, with a decreased energy demand in summer due to holidays.

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Numerical and experimental analysis on thermal behaviour of refrigerated chamber’s envelope incorporated with Phase Change Materials (PCMs)

Prof. Paolo Principi, *Department of Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche, Ancona, Italy, p.principi@univpm.it*
Dr. Eng. Roberto Fioretti, Department of Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche, Ancona, Italy, r.fioretti@univpm.it
PhD candidate Benedetta Copertaro, Department of Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche, Ancona, Italy, b.copertaro@univpm.it

Keywords: Transportation energy saving, Refrigerated chamber, Phase Change Material, Heat Transfer

Introduction

The increase of global population and consumer’s continuous demand for sensitive goods are contributing to a significant growth of refrigerated transport. Nowadays refrigerated railway transport is widely used in Europe and the transport is carried out by using either refrigerated railcars or refrigerated containers. During refrigerated railway transport, internal temperature of compartment must be kept low and constant in order to ensure safety and quality of the products. This affects an high energy consumption. Refrigerating unit takes a significant amount of energy to maintain temperature in the refrigerated space at the required level because of the exposure to a wide range of weather conditions [1]. In this regard the aim of this work is to develop an high performance refrigerated compartment’s envelope using standard insulating materials and Phase Change Materials (PCMs). This leads to a reduction of the amount of heat transfer rate from the outside environment to the inside refrigerated space, and therefore enhancing energy efficiency.

Discussion

The research investigated, both numerically and experimentally, the energy behaviour of a standard refrigerated chamber’s envelope included by PCM RT35HC as a heat transfer reduction technology. Numerical analysis was carried out by Software at Finite Elements Method (FEM) to simulate two-dimensional unsteady-state heat transfer problems. The model compared two different kinds of refrigerated chamber’s wall: one with only insulating material and the other one with an additional layer of Phase Change Material. The calculation results were compared with experimental values for validation of the numerical finite elements method **(Figure1)**. During experimental activities an indoor analysis was carried out. Energy behaviour of a traditional prototype panel (50cm* 50cm) and that implemented with a layer of PCM was test inside a climatic test room where the most realistic environmental condition were reproduced. Finally, outdoor experimental analysis was performed over two equal refrigerated chambers (one of them PCM containing walls) and monitored under realistic climatic conditions.

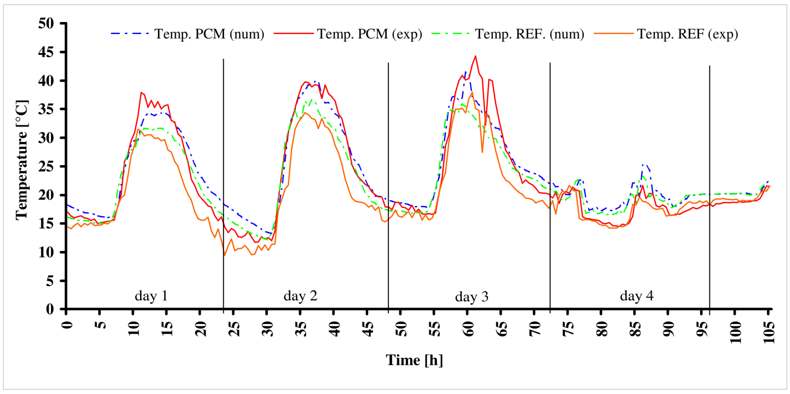

Figure 1: Validation of numerical finite elements method

Conclusions

The numerical and experimental results confirm that Phase Change Material reduces and phase displacements daily incoming thermal load coupled with a reduced internal compartment temperature fluctuation. These results would be translated in a lower energy power request by refrigerating unit and a subsequent energy save.

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TOR – Towards the Energetically Optimal Ventilation System

Christian Schänzle, *Chair of Fluid Systems, TU Darmstadt, christian.schaenzle@fst.tu-darmstadt.de*
Lena C. Altherr, Chair of Fluid Systems, TU Darmstadt, lena.altherr@fst.tu-darmstadt.de
Thorsten Ederer, Chair of Fluid Systems, TU Darmstadt, thorsten.ederer@fst.tu-darmstadt.de
Univ.-Prof. Dr.-Ing. Peter Pelz, Chair of Fluid System, TU Darmstadt, peter.pelz@fst.tu-darmstadt.de

Keywords: Energy, Efficiency, Ventilation System, Fans, TGA, Discrete Optimisation

Introduction

The understanding that optimized components do not automatically lead to energy-efficient systems shifts the attention from the single component to the entire technical system. Following this insight, a new field of study named "Technical Operations Research" (TOR) [1] was developed at TU Darmstadt. It combines technical and mathematical know-how to accomplish the energy optimal design of technical systems. Ventilation systems play an important role in the context of energy consumption and the potential for improvements still is high [2]. Using the methods of TOR, we are able to find the energetically optimal layout of a ventilation system.

Design process combining discrete optimisation and dimensional analysis

We illustrate our optimisation approach by designing an energetically optimal ventilation system for an office building which contains bureaus and conference rooms. Considering the time-dependent occupation density of these rooms (cf. **Figure 1**), we derive a temporal distribution of different loading demands for our future ventilation system. Hence, not only a single operating point, but multiple demands at the same time are considered in the design process. Towards the optimal design of the ventilation system, discrete decisions have to be answered, like: *Is the use of multiple smaller fans more efficient than one big fan?* Each decision affects the energy consumption of the system. We specify a kit of potential axial fans out of which we build the ventilation system. Using dimensional analysis we represent the fans by dimensionless curves: pressure coefficient and efficiency versus flow coefficient. By applying affinity laws for turbomachines

$$\psi = \frac{\Delta p}{\frac{\pi^2}{2}\rho n^2 d^2}, \qquad \varphi = \frac{\dot{V}}{\frac{\pi^2}{4} n d^3}, \qquad \lambda = \frac{P_S}{\frac{\pi^4}{8}\rho n^3 d^5}, \tag{3}$$

the variation of the diameter d and rotating speed n allows us to create head curves for different fan sizes with variable rotating speed, as shown in **Figure 2**. In this way we are able to represent one product line of fans based on geometric similarity. Furthermore the influence of the Reynolds number on the efficiency is taken into account based on a scaling law published by PELZ et. al. [3].

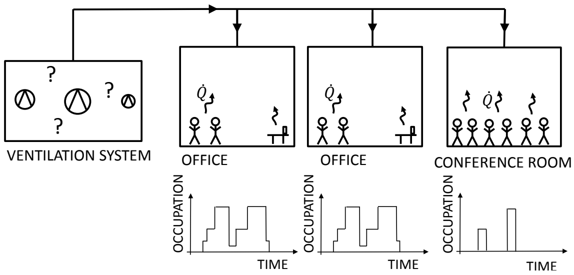

Figure 1: Office rooms with varying occupation density.

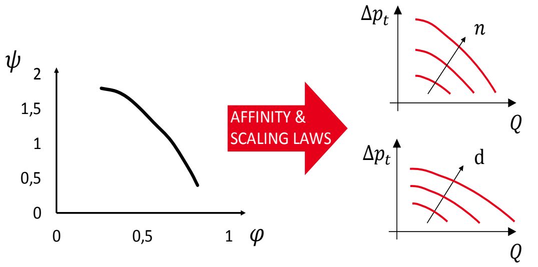

Figure 2: From dimensionless head curves to a product line.

Modelling the potential layouts of the system by a Mixed Integer Program our discrete optimization algorithm finds the global optimal one, i.e., it finds the most energy-efficient ventilation system.

Conclusions

In the design process of a ventilation system not only one operation point but a temporal distribution of different loading demands are considered. Despite of numerous different ventilation system designs and control options, TOR allows us to simultaneously find the energetically optimal combination of fans and the most energy-saving control settings that yield the best energy-efficiency. What distinguishes our approach from conventional heuristics like genetic algorithms is the inherent objective quality criterion. With Mixed Integer Programming we are able to assess solution proposals and to find the global optimal one.

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Adsorption air-conditioning of an electric bus – challenges in tailoring the ideal adsorbent material

M.Sc. Swaantje Maaz*, ITMC, RWTH Aachen University, maaz@itmc.rwth-aachen.de*
Dr. Marcus Rose, ITMC, RWTH Aachen University, rose@itmc.rwth-aachen.de
Dipl.-Ing. Heike Schreiber, LTT, RWTH Aachen University, heike.schreiber@ltt.rwth-aachen.de
Prof. André Bardow, LTT, RWTH Aachen University, andre.bardow@ltt.rwth-aachen.de
Prof. Regina Palkovits, ITMC, RWTH Aachen University, palkovits@itmc.rwth-aachen.de

Keywords: Adsorption, Adsorbent, Adsorption heat transformation, Water uptake, SBA-15

Introduction

Due to an increasing awareness of carbon dioxide emissions from local transportation, electric busses will soon gain an increasing importance in the field of public transport in urban areas. The high operating time of a public bus, about 14 hours per day, provides for an allowance of the high battery costs[1] while also granting a local absence of carbon dioxide emissions. A major drawback of the electrification of public transport has been air-conditioning and heating of the busses which demands a lot of energy and therefore decreases the range of the bus.[2] In order to become economical, a balance between size of the battery and the range of the bus is crucial. An adsorptive air-conditioning provides a highly attractive alternative. It requires only very little electrical energy during operation[3] and can be charged independently of the traction battery of the bus.

Discussion

Adsorption heat transformation (AHT) works with thermal rather than with electrical energy which is why an ideal AHT is working so energy efficient. In reality, however, the coefficient of performance of different AHT systems is not high enough to compete with traditional heating or cooling systems. The efficiency can be increased by optimizing the different components, e.g. the adsorbent material or the design of the adsorber.[3] Nonetheless, adsorbents which are used commercially, like zeolites and silica gel, have never been optimized for this application. Zeolites have the highest water uptake at a very low relative pressure leading to high desorption temperatures, while silica gels show the highest uptake at a relative pressure that is too high for usage in an AHT. In order to optimize the uptake behaviour of an adsorbent it is crucial to understand which physical (pore volume, specific surface area, pore diameter) and chemical (surface polarity) properties of the adsorbent are relevant for their performance in water vapour adsorption.

The mesoporous silica SBA-15 was chosen as a model material for the investigation of relevant parameters for water uptake in the pores. The physical and chemical properties of SBA-15 can be varied independently through different synthetic routes[4] and post-synthetic strategies[5]. Thus the individual influence of these parameters on the water vapour sorption performance can be investigated. The results show that, at low relative pressure, the water uptake is affected by the surface polarity, the micropore volume and the mesopore diameter. However, the uptake at high relative pressure is mainly governed by the total pore volume. For materials with a very similar pore structure, the water uptake increases with an increasing surface polarity. The adsorption behaviour of these materials can be correlated to the existence of certain types of silanol groups on the surface of SBA-15. Furthermore, a steep increase in the water uptake can be observed with an increasing micropore volume in the material. Materials with a similar surface polarity but different pore structure, on the other hand, show a decrease in the water sorption capacity. This effect correlates with an increasing mesopore diameter but could also be due to an increasing order and less defect sites in these materials as a result of different aging temperatures.[6]

Conclusions

The results clearly show a correlation between pore structure, surface polarity and water uptake performance. They provide a basis to establish structure-property correlations which will be very useful for the tailoring of new adsorbent materials for AHT applications.

Acknowledgement: Funded by the Excellence Initiative of the German federal and state governments in the frame of a boost-fund of RWTH Aachen University on "CO_2-neutral climate control of electric busses".

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Energy consumption of BEVs in intensive use – Expanding theoretical models based on empirical data

***Maximilian Schücking**, Project Competence E, Karlsruhe Institute of Technology,*
maximilian.schuecking@kit.edu
Max Nastold, Project Competence E, Karlsruhe Institute of Technology, max.nastold@kit.edu
Dr. Olaf Wollersheim, Project Competence E, Karlsruhe Institute of Technology, olaf.wollersheim@kit.edu
Dr. Kevin Stella, Project Competence E, Karlsruhe Institute of Technology, kevin.stella@kit.edu

Keywords: BEV, energy consumption, energy efficiency, auxiliaries

Introduction

In the context of declining fossil fuels and increasing mobility demands battery electric vehicles (BEV) are one alternative for a more sustainable mobility. Next to the potential emissions savings the electric power train has a significantly higher energy efficiency in comparison to an internal combustion engine vehicle (ICEV). However there are still questions concerning the real energy consumption of BEVs in day-to-day operations and the most significant influence factors.

In this line of research we present the RheinMobil project, where seven BEVs are deployed for business trips as well as shift workers commuting between Germany and France. This study follows a two-pronged approach: firstly, the real energy consumption of the BEV is constantly measured with installed data loggers; secondly, a theoretical energy consumption model has been developed. Within RheinMobil up to today over 250.000 km have been travelled in one and a half years' time with an average distance of over 3,000 km per vehicle per month. Additionally the BEV were set onto a dynamometer to also asses the efficiency of the power train under controlled conditions.

Discussion and Outlook

The long-time comparison of the BEVs energy consumption reveals significant differences between the BEV types, the seasons, and the driving profiles. The measured energy consumption of one single trip is shown in **Figure 1**. A quantitative discrepancy between the model and the measured consumption is evident suggesting that the efficiency factor is less than initially assumed. These results are confirmed by the BEV tests on the dynamometer. Consequently the losses of the individual power train components are investigated separately, showing that especially for the electric motor they depend on various conditions e.g. the temperature.

Besides the indication of a lower efficiency factor the theoretical model suggests reasons for the observed long-time energy consumption variations. As one key influence the auxiliaries are identified. With the BEVs significantly higher energy efficiency in comparison to an ICEV the energy consumed by the auxiliaries makes up a much higher proportion of the total. At an average speed of 20 km/h 40% of the energy is consumed by the auxiliaries (cf. **Figure 2**). Furthermore **Figure 2** illustrates the dependence of the specific energy consumption on the average speed of the driving profile. In our field-test the minimal consumption lies around 28 km/h average speed. At 55 km/h the total specific energy consumption per kilometre is equal to the one at 11 km/h.

The results provide valuable insights for manufactures as well as future for BEV operations suggesting ways to increase the energy efficiency as well as how to identify the most energy efficient mobility applications.

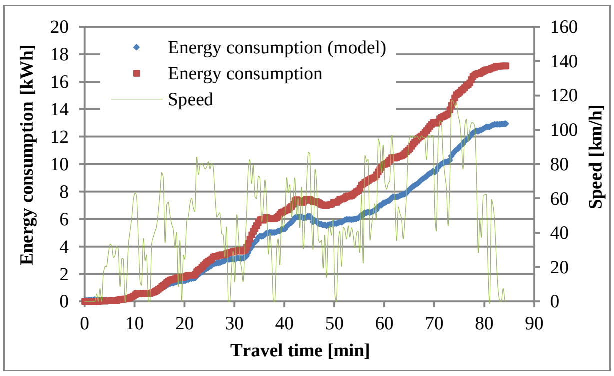


Figure 1: Comparing the real energy consumed with the theoretical model for one trip

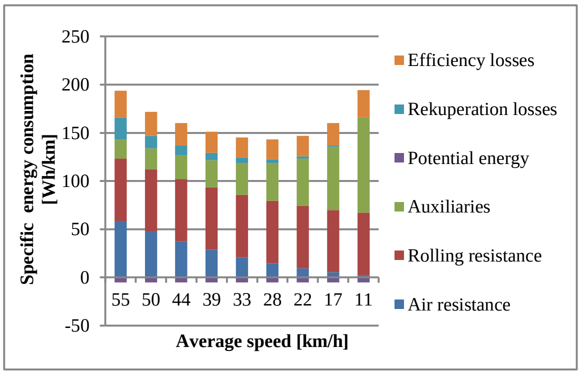


Figure 2: Factors influencing the energy consumption in relation to average speed

Acknowledgement: The authors thank the BMVI – Bundesministerium für Verkehr und digitale Infrastruktur for enabling this project within the framework of the Schaufenster Elektromobilität and the living-lab BW.

Solid-State Microengines for Unmanned Aerial Vehicles

Ankita Ghoshal*, Reebeez Inc., Austin, Texas, ankita@reebeez.com*

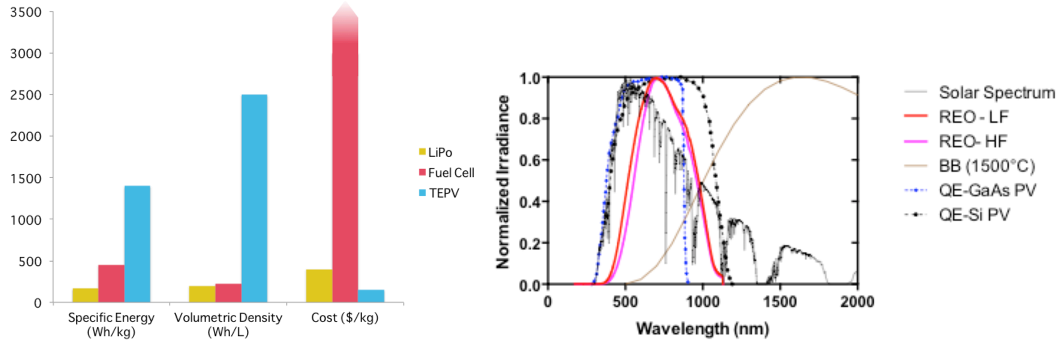
Keywords: thermophotovoltaic, thermoelectric, Microengines, Aerial Vehicles, Drones, UAVs

Introduction

We present the design and implementation of lightweight solid-state microengines that power propulsion systems in unmanned aerial vehicles (UAVs) and solve the low specific energy (< 170 Wh/kg) limitations of lithium-polymer (LiPo) batteries, which result in disappointing flight times and payloads. We describe microengines based on thermoelectrophotovoltaic (TEPV) energy conversion that run on butane combustion, to attain specific energy > 1500 Wh/kg, which is 8× better than LiPo batteries at a third of the cost. *These solid-state microengines have no moving parts.* The important technology metrics of the TEPV vis-à-vis LiPo [1] and fuel cells [2] is shown in Fig.1a.

Discussion

The TEPV microengine includes a fuel-storage where butane is stored in a lighter-sized pressurized cavity, a microcombustor with self-entrained nozzles for jet flames that heat a selective emitter and a thermoelectric generator over refractory metal foam. The inlet air is preheated to ~400°C in a recuperator structure integrated within the system. The fraction of the heat of combustion absorbed by the rare earth oxide emitters at 1500°C is upconverted to radiation in the visible spectrum [3], as shown in Fig. 1b, and converted to electricity by double-junction InGaP/GaAs photovoltaic cells. The remaining fraction is directly converted to electricity by a custom 1000°C SiGe/Mo thermoelectric generator module. The DC-to-DC converter scales the DC voltage level to be compatible with the 11V navigation electronics and propulsion systems.



(a) (b)

Figure 1: (a) Technology metrics of the TEPV microengines vis-à-vis LiPo batteries and fuel cells. (b) Normalized-irradiance response of the Reebeez emitters for different power/flame levels (REO-LF and REO-HF) plotted as function of wavelength. The curve obtained from experimental measurements is superimposed on the solar spectrum, radiation spectrum of a blackbody (BB) at 1500°C, and quantum efficiencies of Si and GaAs PV cells.

Early prototypes, which have no moving parts, use ytterbia-based emitters and Si and single-junction GaAs PV, and show a five-fold increase in time of flight for small drones. The net fuel-to-electricity efficiency is 8%. The net specific energy > 1000 Wh/kg make these prototypes the best engines for UAVs.

Conclusions & Outlook

The paper presents an innovative solid-state engine for powering UAVs and detailed implementation of the engines. The basic prototypes show unrivalled performance characteristics when compared to LiPo batteries and fuel cells. Advanced designs using nanostructured emitters, better photovoltaic cells, insulators, and segmented thermoelectric generators, can result in conversion efficiencies of 20%, performing 20× better than the best batteries or fuel cells.

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Silicon carbide for efficient power conversion in lighting

Karsten Hähre, *Light Technology Institute, Karlsruhe Institute of Technology, karsten.haehre@kit.edu*
Dr. Rainer Kling, Light Technology Institute, Karlsruhe Institute of Technology, rainer.kling@kit.edu

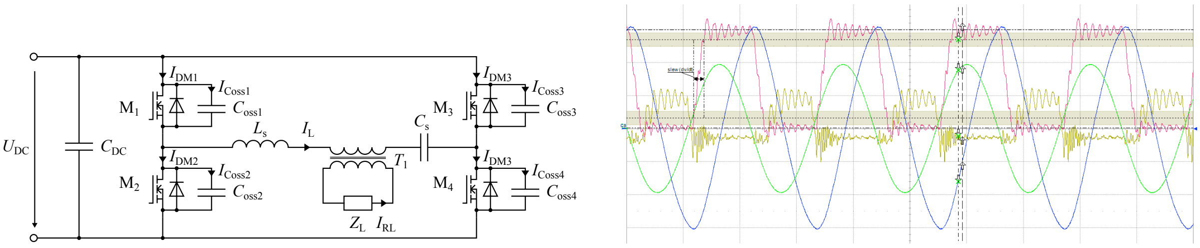
Keywords: DC/DC, DC/AC, LED-lighting, Silicon Carbide, ZVS

Introduction

The increasing demand for energy efficient and reliable solutions in high-power lighting applications, e.g., LED-downlighting and electrodeless fluorescent lamps, is a strong driver of current research activities in the field of power electronics. Recently commercialised power transistors based on the wide-bandgap material Silicon Carbide (SiC), promise to facilitate a significant increase of efficiency and reliability of power electronic devices, as well as the development of completely new power supplies. This work presents a high efficient resonant converter with zero voltage switching (ZVS) for DC/DC- or DC/AC-conversion applications in the field of high-power lighting applications based on SiC transistors.

Discussion

State-of-the-Art light sources for instance high intensity discharge (HID) and electrodeless fluorescent lamps are gradually replaced by LED-equipped luminaires. However, applications with very high-power or maintenance demands are still preserved from LED. Commercially available SiC MOSFETs and JFETs exhibit superior switching and conduction characteristics to their Silicon counterparts [1], and are predestined for the application in high-frequency converters for ballasting electrodeless lamps [2] , as well as for supplying multiple high-power LED-strings. The authors have investigated the performance of a soft-switching full-bridge converter completely assembled with SiC devices when operating at 2 MHz. The utilized transistors are newest 2nd generation SiC MOSFETs with low on-resistance of 80 mΩ. Due to small chip capacitances, very high switching speeds can be achieved. **Figure 1 a)** presents the schematic diagram of the developed system. For filtering the output voltage and current, a series resonant tank and a high frequency transformer with a turns ratio of 1:1 were used. Z_L represents the lamp impedance, but it can also be replaced by a full-bridge rectifier.



a) b)

Figure 1: a) Schematic diagram of the full-bridge resonant inverter with parallel snubber capacitors. b) Waveforms of inverter ballasting an electrodeless lamp with re-entrant cavity at a switching frequency of 2.2 MHz and lamp power of 1.6 kW. (yellow: U_{GS}, 20 V/div; red: U_{DS}(M2), 200 V/div; blue: I_L, 5 A/div; green: U_{out}, 400 V/div; time 200 ns/div.)

The operating waveforms of the inverter, when ballasting an electrodeless lamp, are shown in **Figure 1 b)**. The operating conditions were: $U_{DC} = 600$ V, $f_{sw} = 2.2$ MHz, $I_L = 10.6$ A and $P_{lamp} = 1.6$ kW. The power loss of the inverter stage was measured by means of a calorimetric approach. Thereby, a sum of switching and conduction losses of about $P_{MOS} = 25$ W were measured. The gate driving power was determined as about $P_{Gate} = 53$ W. The losses of the resonant circuit and the cabling were higher than those of the semiconductors and a total efficiency of $\eta = 92.0$ % of the complete system is achieved. Similar results were achieved by operating the inverter loaded with full-bridge rectifier, assembled with SiC Schottky diodes. Then, an efficiency of $\eta = 95.4$ % was achieved at a higher output power of 2.3 kW, including the losses of the rectifier.

Conclusions

The use of SiC-based transistors, such as MOSFET and JFET, enables new high power applications within the area of lighting electronics. Even high frequency inverters for electrodeless lamps can achieve efficiencies of more than 90 %, since the semiconductor devices do not represent the limiting devices any more. The presented inverter can be employed in various applications of modern power electronics, for instance LED-drivers, server power supplies or wireless battery chargers for hybrid electric vehicles.

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Bionic cooling systems for LEDs

***Christian Herbold**, franzkann* Herbold und Herrmann GbR, Karlsruhe, christian.herbold@franzkann.de*
Cornelius Neumann, Light Technology Institute, Karlsruhe Institute of Technology (KIT), cornelius.neumann@kit.edu

Keywords: LED, Lighting, Heat sink, Powder Injection Moulding

Introduction

The development of efficient LED lighting systems is closely related to a powerful thermal management. The luminous flux of LEDs decreases with the rise of the operating temperature. Therefore the dissipation of the heat is, aside with the efficiency of the LED chip itself, an essential part in the development of efficient LED systems. The most common thermal management approach for the current LED light sources are heat sinks with fins. Today's finned heat sinks often do not match the modern designs of the products and therefore are mostly hidden in the housing of the luminaires. In these solutions motivated by design, limited airflow leading to lower heat dissipation is the main disadvantage. A novel approach in the design of heat sinks is to use architectures based on natural geometries. In contrast to conventional heat sinks, these architectures can offer an advanced thermal performance and an aesthetic shape at the same time.

Modelling and Manufacturing

The architecture of tree branches or tree roots serves in the same way as efficient shape to take in and transport plant nutrient while saving material but conserving the structural stability. Although the specific design varies even within the same species influenced by environmental effects, the basic principle of the branched architecture is always the same. Natural models have been derived for utilization in the architecture of heat sinks with respect to the design limitations due to the manufacturing process. For this aim, a mathematical model in conjunction with high-resolution thermal simulations has been used to lead to an improved branched structure. In addition a non-branched structure with same material volume and surface area has been modelled to allow direct comparison of the thermal performance (Figure 1).

Due to their complex geometry, the discussed heat sinks are produced with powder injection moulding. This technology allows flexible shapes in large-scale production parts that are manufactured from thermally well suited metals and ceramics like copper or aluminium nitride. The high freedom of design given with that manufacturing process allows not only to build the heat sink geometry but also to integrate application specific functions for the final luminaire. Reflector surfaces, cable bushings and mounting holders could be integrated directly in the mould.

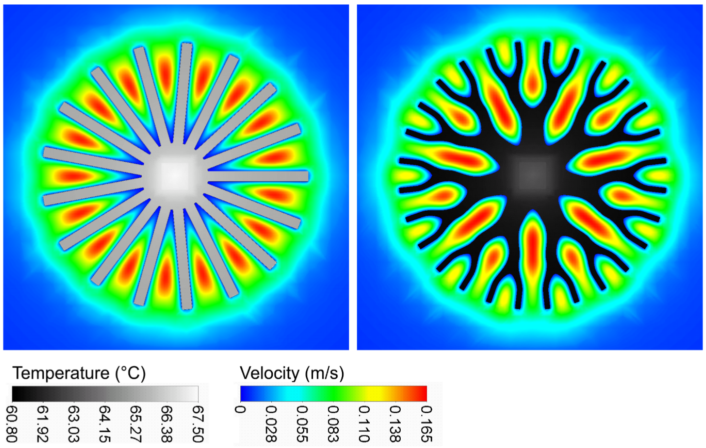

Figure 1: CFD simulation results for temperature and flow velocity for non-branched an branched heat sink

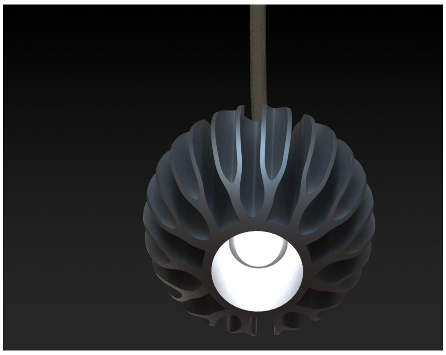

Figure 2: LED heat sink with integrated functions

Results

Manufacturing was difficult due to high forces needed for ejection while the part was not stable enough to withstand these. Nevertheless it was possible to manufacture some proper parts. The comparison between the branched and non-branched heat sinks shows an improvement of 5.2 percent in thermal resistance. An additional design integrates this advantage in a luminaire powered with 10 W (Figure 2).
Thus, this study demonstrates the promising solution acquired by building LED systems with naturally inspired heat sinks and its two advantages: efficiency and aesthetics.

Exploring the magnetic properties of ferrite nanoparticles for the development of rare-earth-free permanent magnet

Dr. Alberto López-Ortega, Università degli Studi di Firenze and INSTM, lopezortega.alberto@gmail.com
Elisabetta Lottini, Università degli Studi di Firenze and INSTM, elisabetta.lottini@gmail.com
Dr. Cesar de Julián Fernández CNR-IMEM Parma, cesar.dejulian@imem.cnr.it
***Dr. Claudio Sangregorio**, CNR-ICCOM Firenze and INSTM, csangregorio@iccom.cnr.it*

Keywords: Permanent Magnet, Nanoparticle, Ferrite, Critical materials, Hard magnet

Introduction

Currently, there is a rising demand for rare-earth elements for a broad range of industrial applications. However, the risk of supply of these strategic materials due to political restrictions, the high environmental impact of their extraction as well as price oscillations have motivated many researchers in finding viable alternatives. Specifically, in the case of permanent magnet applications the research is focusing on finding novel materials that can replace currently used RE permanent magnet in a wide part of the spectrum of industrial necessities where the high performance of rare-earth permanent magnets are not strictly required.
We propose nanometric cobalt ferrite ($Co_xFe_{3-x}O_4$) as candidate to achieve this goal. On one hand cobalt ferrite, thanks to its large cubic magnetic anisotropy, is a hard magnet. On the other hand, the reduction to the nanoscale may offer unique advantage, which can significantly improve the characteristic of the material.

Discussion

A family of monodisperse cobalt ferrite nanoparticles (NPs) with average size covering a broad range (from 4 to 60 nm) was synthesized by thermal decomposition of metal-organic precursors. Metal precursors, surfactants and synthetic parameters were settled in order to fine tuning the particle size while preserving a narrow particle size distribution. The morphological characterization of the nanoparticles revealed an evolution of the particle shape from spheres to octahedrons through cubes for intermediated sizes. Subsequently, the evolution of magnetic properties was studied as a function of particles size and shape, particularly focusing on those determining the best performance as permanent magnet. While saturation and remnant magnetization maintain constant values in the whole investigated particle size range, the coercive field exhibits a non-monotonic behaviour with two distinct maxima values for low and room temperature, respectively (Figure 1). In addition, we evaluated the $(BH)_{max}$ product, the figure of merit of permanent magnets, obtaining the maximum value ever reported in the literature for cobalt ferrite NPs (i.e., 2.1 MGOe (18 MJm^{-3}) for 40 nm NPs). The collected data gave us the opportunity to discuss the feasibility of the application of this material for the realization of permanent magnet.

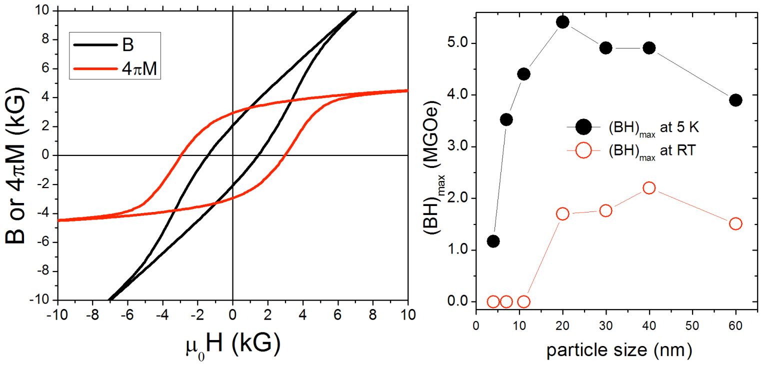

Figure 1: (a) B and 4πM vs. H loops for 40 nm NPs at RT and (b) $(BH)_{max}$ at 5K (black solid circles) and RT (red empty circles) as a function of the particle size.

Conclusions and/or Outlook

This investigation allowed us to establish, at least on the basis of $(BH)_{max}$, the potentiality of cobalt ferrite NPs for the realization of RE free permanent magnet. Indeed, if the possibility of orienting the magnetic anisotropy axes of the nanograins is taken into account, $(BH)_{max}$ as large as 8 MGOe (60 kJ/m3) can be in principle obtained. This value makes cobalt ferrite NPs a viable alternative to replace RE-based permanent magnet at least in the intermediate region of the energy product map where the latter are currently employed simply because standard ferrites do not have large enough $(BH)_{max}$.

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Magnetocaloric effect in Ni-Fe-Ga-Nd Heusler alloys

Dr. Felicia Tolea, *Lab. of Magnetism and Superconductivity, National Institute of Materials Physics, POB MG-7, 77125 Bucharest-Magurele, Romania, felicia.tolea@infim.ro*
Dr. Mihaela Sofronie, idem., mihsof@infim.ro
Dr. Mihaela Valeanu, idem., valeanu@infim.ro

Keywords: Energy efficient magnetic materials, Ferromagnetic shape memory alloys, Magnetocaloric effect

Introduction

The functionality of ferromagnetic shape memory alloys (FSMA) is related, besides the magnetic order-disorder transition, also to a first order phase transformation, the well known martensitic transformation (MT). Simultaneous or delayed structural and magnetic transitions are accompanied by sharp change of magnetization as well as electronic structure. The magnetocaloric effect (MCE) is an intrinsic property of some magnetic materials associated with the well coupled two energy reservoirs: the phonon excitations connected to the lattice degree of freedom and magnetic excitations connected to the spin degree of freedom. The most significant effect occurs at temperatures near magnetic transitions, and strongly depends on the type of transition being highest for first-order transitions [1], which motivated the quest for FSMA with identical –or close- magnetic and structural transformation temperatures. The martensitic phase in the ferromagnetic off-stoichiometric Heusler alloy Ni-Fe-Ga features structural twinning, with exceptional magnetoelastic properties which recommend it as a good candidate to replace the brittle Ni-Mn-Ga [2,3,4] in various applications including magnetic refrigeration.

Discussion

In the present work we investigate the influence of Nd substitutions on the MT, magnetic properties and MCE characteristics of Ni57-xNdxFe18Ga25 (x between 0 ÷ 4), in bulk and also in ribbons prepared by melt spinning method and subjected to different thermal treatments. X-ray, DSC, magnetocaloric and magnetoresistive characterizations have been performed. It is assumed that the thin melt-spun ribbons assure a more efficient heat transfer, and in addition to that, comparing with bulk properties is expected to shed light on the role of interfaces and the microstructure on the MCE. **Figure 1** presents some results for x=2 sample aimed to highlight the differences between the bulk (a) and the ribbons [as prepared –AP (b) and thermal treated (c))]. The black line in (b) exemplifies a M(T) curve at low field. ΔS_m shows a maximum close to the structural transition and, for the annealed ribbons a second peak is also clear, in the Curie temperature area. Other calculations suggest that the relative cooling power (RCP calculated as $-\Delta S_m \cdot \Delta T^*$ where ΔT^* is the thermal half-width of the maximum entropy variation) is higher in ribbons for which Tm and Tc do not coincide but are very near.

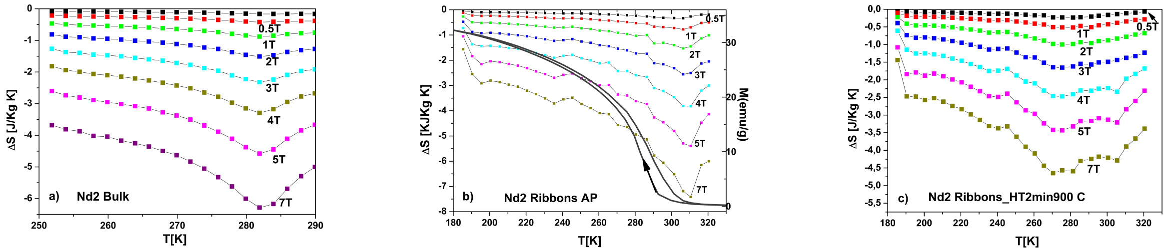

Figure 1: Entropy variation ΔS_m versus temperature for Nd2 a) Bulk, b) AP, c) annealed for 2min at 900°C - note the two maxima: the first in the area of martensitic transformation and the second in the Curie temperature area.

Outlook

MCE around room temperature is an ecological alternative to conventional refrigeration. Therefore, the challenge is to develop novel active ferromagnetic materials, displaying both shape memory and MCE, conveniently prepared by a single step or at least avoiding the time -and energy- consuming thermo-mechanical treatments. Elemental substitutions and the melt-spinning preparation method followed by different thermal treatments are shown to be promising routes towards materials optimization for magnetic refrigeration.

Acknowledgements: Romanian Ministry of Education, project PN-II-ID-PCE-2012-4-0516 and the Core Program 45N.

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Magnetic shape memory materials for energy applications

Franca Albertini[1], *Simone Fabbrici*[1,2], *Giacomo Porcari* [3,1], *Francesco Cugini*[3,1], *Massimo Solzi*[3], *Riccardo Cabassi*[1], *Jiri Kamarad*[4], *Zdenek Arnold*[4]

[1]*Institute of Materials for Electronics and Magnetism, National Research Council (IMEM-CNR), Parco Area delle Scienze 37/A, I-43124 Parma, Italy;*
[2]*Laboratory of Micro and Submicro Enabling Technologies for Emilia-Romagna (MIST E-R),via Gobetti 101, I-40129 Bologna, Italy*
[3]*Dipartimento di Fisica e Scienze della Terra, Università di Parma, Parco Area delle Scienze 7/A, I-43124 Parma, Italy*
[4]*Institute of Physics AS CR, Na Slovance 2, 182 21 Praha 8, Czech Republic*

Abstract

Ferromagnetic shape memory alloys are multi-functional materials suitable for a variety of energy-related applications thanks to their extraordinary phenomenology (e.g giant magnetoelastic, magnetocaloric, barocaloric effects) arising from the coupling between magnetic and structural degrees of freedom. They undergo a martensitic transformation between magnetically ordered phases that can be driven by temperature, pressure, stress and magnetic field [1].

The most representative materials are Ni_2MnX full Heusler compounds, X being a group IIIA-VA element. Among them, one of the most studied systems is Ni–Mn–Ga, which shows magnetic field induced strains up to 12% due to twin variants reorientation and considerable values of direct magnetocaloric effect. On the other hand In- and Sn-based alloys (the so called "metamagnetic Heuslers") are very promising for the possibility to easily induce the transformation from a low moment martensite to a high moment austenite by applying external fields (magnetic field, pressure, stress). This phase change triggers magnetic superelasticity, magnetothermal conductivity, magnetocaloric and barocaloric effect.

We have recently shown that for Mn-rich Ni-Mn-Ga alloys, Co substitutions produce important changes in magnetism and structure, originating a peculiar phase diagram of the magnetic interactions and phase instabilities, giving rise to a metamagnetic behaviour, enhanced magnetization and volume discontinuities at the transformation, and allowing to tune the magnetocaloric effect from direct to inverse [2]. In this talk we will present a thorough study of main basic and functional properties of these alloys, including high field (up to 30 T) and high pressure (up to 1GPa) measurements and discuss their tailoring potential for improving their multifunctional exploitation.

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Solid Oxide Cells – Development Status at Forschungszentrum Jülich

Dr. Norbert H. Menzler*, Forschungszentrum Jülich, Institute of Energy and Climate Research, IEK-1, n.h.menzler@fz-juelich.de*
Prof. Ludger Blum, Forschungszentrum Jülich, Institute of Energy and Climate Research, IEK-3, l.blum@fz-juelich.de
Dr. L.G.J. (Bert) de Haart, Forschungszentrum Jülich, Institute of Energy and Climate Research, IEK-9, l.g.j.de.haart@fz-juelich.de
Dr. Jürgen Malzbender, Forschungszentrum Jülich, Institute of Energy and Climate Research, IEK-2, j.malzbender@fz-juelich.de
Dipl.-Ing. Nikolaos Margaritis, Forschungszentrum Jülich, Central Institute of Engineering, Electronics and Analytics, ZEA1, n.margaritis@fz-juelich.de

Keywords: Solid Oxide Cells, Fuel Cells, Electrolysers, Rechargeable Oxide Battery

Abstract

Forschungszentrum Jülich has been developing **solid oxide fuel cells** (SOFCs) since mid of the 1990's. Meanwhile the cells exhibit extremely high power densities at low operating temperatures (> 1.5A/cm at 600 °C), the high-chromium containing interconnect steel is well established in the community and the sealant withstands numerous moderate thermo-cycles without leakage. For operational experiences three different stack designs have been developed: one for quick and easy tests (F10 design) and one for power stacks (F20 design), both foreseen for stationary, decentralized power generation and additionally one as auxiliary power unit in mobile applications (C-design). Short stacks are operating for more than 60,000 h with low degradation rates (< 1% / 1,000 h, thereof in the last 20,000h with only 0.3%) and for > 30,000 h with ultra-low overall degradation of < 0.3% / 1,000 h. Additionally a 20 kW$_{el}$ system based on four 5 kW stacks has also been operated successfully.
Major future goals for the next decade are the development of a novel stack design based on a window frame (cf. Fig. 1) thus enabling the introduction of commercially available cells, designing a robust stack module and the development of a low-temperature SOFC which operates below 500 °C.

In recent years also the use of the "classical" SOFC as **electrolyser** (SOEC) has been started. Generating hydrogen by using surplus electricity from wind or solar power enables either the use of the hydrogen as fuel for e.g. cars or after methanation it could be integrated into the natural gas system. Major goal in this R&D field is the erection of a combined SOFC/SOEC 5kW system and therefore showing the flexibility of such a system.

A third approach is the use of the SOFC/SOEC system as a rechargeable oxide battery (ROB). In an ROB the fuel side is filled with a water vapour/hydrogen gas mixture and subsequently sealed off. A metal which can be reduced (charged) in SOEC mode and oxidized (discharged) in fuel cell mode is integrated in the steam/hydrogen compartment. As metal / metal oxide iron can be used. By doing so the surplus energy of solar and wind power could be stored by reducing the metal and in case of higher energy demand re-integrated into the grid by discharging (= oxidation).

All three developments, the SOFC, the SOEC and the ROB could be part of a future energy system based on mostly renewable energy sources like wind and solar power as launched by the German federal government for 2050 ("Energiewende"). The presentation gives an overview about the current status in all three R&D fields.

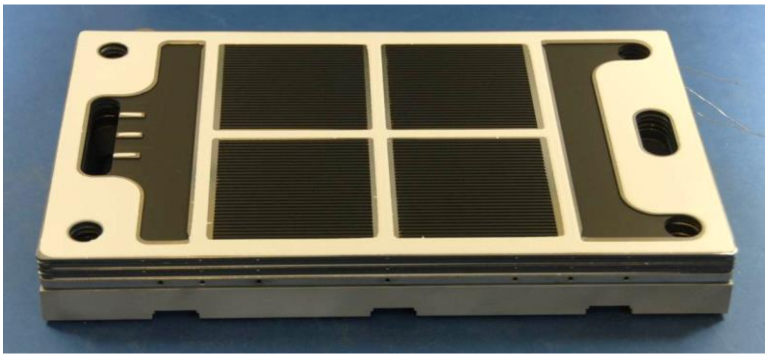

Figure 1: Novel SOFC/SOEC stack design for stationary applications

Think Different! Carbon Corrosion Mitigation Strategy in High Temperature PEFCs – A Durability Study

Tom Engl, *Electrochemistry Laboratory, Paul Scherrer Institut, tom.engl@psi.ch*
Lorenz Gubler, *Electrochemistry Laboratory, Paul Scherrer Institut, lorenz.gubler@psi.ch*
Thomas J. Schmidt, *Laboratory of Physical Chemistry, ETH Zurich, thomasjustus.schmidt@psi.ch*

Keywords: Energy, Fuel Cell, Durability, Electrochemistry, Carbon Corrosion

Introduction

Increasing the lifetime of a fuel cell and reducing its costs are the two most relevant research fields regarding fuel cell commercialization. One of the specific reasons for limited lifetime is known as the "start/stop"- or "reverse-current decay" mechanism[1,2]. During start-up or shut-down of a polymer electrolyte fuel cell a fuel/air gas front propagates through the anode electrode compartment. This gas front causes high potentials (up to 1.5 V) on the cathode side[3] and leads to irreversible carbon corrosion. High surface area carbon is used as support for the noble metal catalyst nanoparticles. Therefore, if the carbon is gradually oxidized the activity towards the oxygen reduction reaction decreases. Consequently, it is necessary to improve the understandings of the start/stop mechanism in order to identify appropriate mitigation strategies.

Discussion

Mitigation strategies can be divided into two categories. One is focused on developing new materials, such as carbon free electrodes or selective hydrogen oxidation catalysts[3]. The second category consists of system strategies, for instance flow rate adjustments[4], potential control[1] or nitrogen purging. Therefore, this investigation is categorized as system based fuel cell degradation mitigation strategy. Carbon monoxide is added to the fuel gas on the anode side. The results reveal that a CO concentration in the fuel gas of around 10 vol.% can inhibit carbon corrosion on the cathode side by up to 85%[5] (cf. Figure 1).

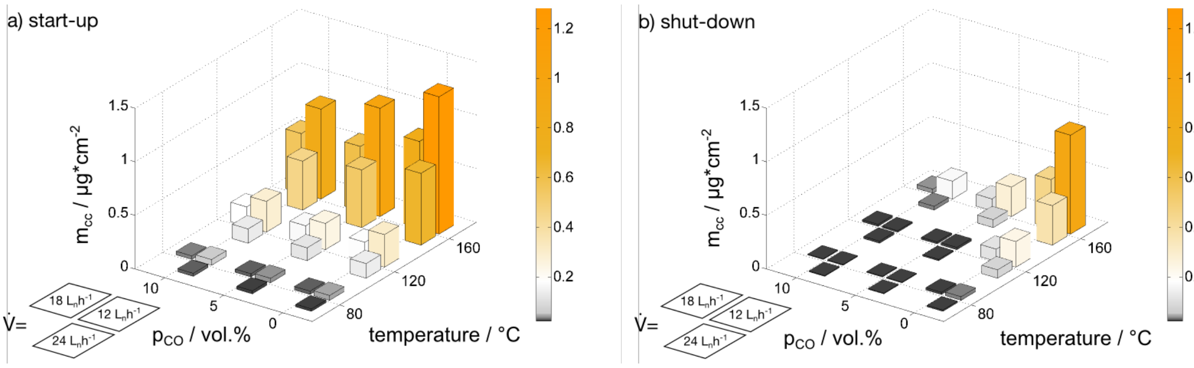

Figure 1: Amount of corroded carbon m_{cc} during start-up a) and shut-down b) as a function of temperature ϑ, flow rate $\dot{V}$ and CO partial pressure p_{CO}.

Conclusions and Outlook

Think different, CO is usually negatively connoted in the fuel cell community as catalyst poison. Nevertheless, we have shown that CO does reduce carbon corrosion within a broad parameter range, especially in case of shut-downs. This is a needed but not necessarily sufficient requirement for improving the lifetime of HT-PEFCs. Therefore, the question remains if CO in the fuel gas is able to increase the lifetime of HT-PEFCs?

This question will be addressed in this contribution!

Acknowledgement: Financial support from BASF SE is gratefully acknowledged. We thank our colleagues at PSI for technical assistance and productive discussions.

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A 2D modeling study of PEM fuel cell durability in a virtual car under catalyst degradation

***Dr. Manik Mayur**, Institute of Energy System Technology (INES), Offenburg University of Applied Sciences, manik.mayur@hs-offenburg.de*
Dr. Manuelle Quinaud, DRT-LITEN/DEHT/SIGE/L2M, CEA Grenoble, manuelle.quinaud@cea.fr
Prof. Dr. Wolfgang G. Bessler, Institute of Energy System Technology (INES), Offenburg University of Applied Sciences, wolfgang.bessler@hs-offenburg.de

Keywords: Polymer electrolyte membrane fuel cell (PEMFC), Modeling, Durability, Catalyst degradation

Introduction

One third of the total world energy production is consumed by the transportation sector, thus making it the leading sector with highest utilization of petroleum products and contributions to harmful emissions [1]. Although, fuel cell vehicles offer a cleaner alternative with negligible emissions, the major bottleneck to their commercialization is durability of a fuel cell stack that eventually increases its cost and maintenance cycles. The highly transient nature of loading cycles in automotive applications leads to an accelerated catalyst degradation, which is the most costly component in a fuel cell stack. This is where a multi-physics based modeling can be used to perform predictive evaluations of cell durability through coupled interactions between cell operating conditions and state variables on cell performance, and degradation [2] while saving time and money.

Methodology

The present study predicts cell durability in an automotive application with the help of a real-time cell degradation framework. Through a multi-scale coupling of a virtual car model (system level) and a fuel cell model (component level), durability study of a 2D PEMFC model is performed based on the highly transient New European Driving Cycle (NEDC). The fuel cell model consists of coupled multi-component transport of fuel, air and water in the gas channels, gas diffusion layers and the polymer membrane in 2D cell geometry. The electrochemical kinetics of oxygen reduction in the catalyst layer is implemented in a modified Butler-Volmer formalism [3]. Our Simulink-based modular representation of an electric vehicle provides on-the-fly interaction between transmission, engine, control, fuel cell, and degradation modules through feedback loops. The loss in active catalyst area over one NEDC is temporally up-scaled to multiple NEDCs to accelerate the durability simulation.

Conclusions

Using the simulation framework discussed above, the degradation of active catalyst area as a function of cell voltage cycling and other operating conditions such as relative humidity and oxygen concentration is demonstrated. With the help of temporal upscaling of the catalyst degradation rate during one NEDC to multiple NEDCs, we have successfully performed a predictive evaluation of the cell durability under a standard automotive loading cycle. The 2D model also facilitates identifying potential hotspots of accelerated catalyst failure that can be demonstrated via spatial distribution of critical state variables such as oxygen and water concentration.

Acknowledgement: The research leading to this work has received funding from the European Union's Seventh Framework Program (FP7 2007-2013) under grant agreement no 303419.

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Challenges facing the future implementation of Solid Polymer Fuel Cells and Electrolysers

Robert Slade*, Department of Chemistry, University of Surrey, Guildford GU2 7XH, United Kingdom*
(email: r.slade@surrey.ac.uk)

Abstract

Widespread application of solid polymer electrolyte H_2/O_2 fuel cells has been 10 years away since 1960s and continues to be the goal of very substantial international investment in RD&D, both in academic and industrial environments. The development and marketing of electrolysers utilising solid polymer electrolytes has resulted in initial sales. The technologies of regenerative fuel cells (offering both fuel cell and electrolyser operation in one) and redox flow batteries (particularly the "all vanadium" flow battery) are related to both of these areas and also the subject of a lesser volume of international research and development, with flow batteries seemingly on the verge of commercialisation.

All of these technologies currently present key challenges to overcome. Thus acid membrane H_2/O_2 PEMFCs require high purity fuel for their operation, currently rely on expensive Pt-based catalysts and are faced with issues of membrane and electrode (MEA) durability under varying load cycles. Such acid environments currently necessitate different electrocatalysts for fuel cell and electrolyser reactions. In regenerative fuel cells (e.g. H_2/Br_2) and flow batteries key issues are an aggressive oxidising environment and the device-based energy densities achievable (with at least one solution half-cell in each case), and in the case of all-vanadium flow cells cost is also an issue.

The talk will highlight these issues and consider alternative approaches to some of these problems. It will also highlight the potential for use of alkaline polymer membranes (alkaline anion exchange membranes, AAEMs) in these applications, as is currently being developed at Surrey jointly with international partners. Thus an APEMFC (A= alkaline) can utilise impure hydrogen gas (a known advantage of all alkaline fuel cells types), can utilise non-Pt (even metal free) electrocatalsyts (e.g. for the oxygen reduction reaction, ORR) and, as is known from solution electrochemistry, may well utilise the same electrocatalsyts for both fuel cell and electrolyser operation. Key recent developments in this area, and also in related flow battery studies, will be highlighted. An approach being utilised at Surrey is the production of ionically conductive, radiation (electron beam) grafted co-polymer electrolytes, which considerably lessen the issues of reagent crossover (through the membrane electrolyte) that can also be a key issue in all of these systems (introducing catalsyst poisoning or a partial chemical short circuit). The development of Pt-free ORR electrocatalysts for APEMFCs will also be highlighted.

Characterisation Method for Thermoelectric Power Modules

Dipl.-Ing. Christine Mair, BIOENERGY 2020+ GmbH, christine.mair@bioenergy2020.eu
Dipl.-Ing. Dr.techn. Wilhelm Moser, BIOENERGY 2020+ GmbH, wilhelm.moser@bioenergy2020.eu
Dipl.-Ing. Dr.techn. Ernst Höftberger, BIOENERGY 2020+ GmbH, ernst.hoeftberger@bioenergy2020.eu
Dipl.-Ing.(FH) Stefan Aigenbauer, BIOENERGY 2020+ GmbH, stefan.aigenbauer@bioenergy2020.eu

Keywords: micro combined heat and power (μ-CHP), thermoelectric power module, biomass combustion system

Introduction

Recently there is a growing interest on cogeneration systems for the low end power segment. This research issue is also attracted by the idea of self powered heating solutions. Thermoelectric power generation is an attractive "green" technology for this purpose. BIOENERGY 2020+ GmbH has a lot of research experience in the integration of thermoelectric generators (TEGs) as power supply into automatic biomass combustion systems. Performance characteristics of thermoelectric power modules (TEMs) are highly dependant on the operating temperatures. For comparison the measurement positions of the effective temperatures of heat source and sink, as well as the thermal coupling are of great importance. Therefore manufacturer specifications are not sufficient for the prototype design of a biomass fired cogeneration system. The aim of this project is to develop a reliable characterisation method for TEMs to simplify the development of biomass based μ-CHP systems.

Experimental method

To achieve comparability between modules of different manufacturers and to prove their suitability, it is necessary to test them under the same conditions close to the demands of the end application. Therefore two different types of test stands were developed. The key element of both is a defined measurement arrangement, in which the thermoelectric modules are sandwiched between standardised heat spreaders and sinks suitable for biomass furnaces under defined thermal coupling conditions.

An electrical heated test bench enables the characterisation of single thermoelectric modules under well defined thermal conditions. The arrangement is close to the application in a biomass furnace, but in this case the heat supply can be varied precisely. In the second setup the heat supply is a biomass combustion system. This setup allows the characterisation of multiple thermoelectric modules simultaneously. Thereby complete TEG-designs can be tested under realistic operating conditions for an inhomogeneous heat distribution.

Discussion

The effective temperature difference is related to material temperatures of a standardised heat exchanger arrangement, which are easily accessible also in future prototype plants. The good conformity between the two test methods is depicted by **Figure 1**. Therefore specifications solely based on the electrical heated test bench allow a sufficient prediction for the application in a biomass combustion system.

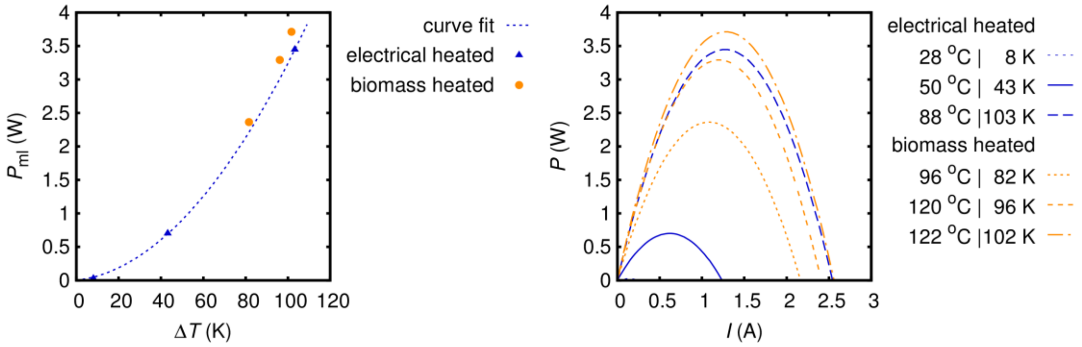

Figure 1: Measurement results for the electrical and the biomass heated test bench: the blue dotted curve on the left (fitted to data points of the electrical heated setup) shows the parabolic behaviour of the electrical power output in case of matched load (P_{ml}). The corresponding power characteristics to the plotted operating points are shown in the right plot for various temperature conditions (mean device temperature | effective temperature difference).

Conclusions and/or Outlook

This test method is an efficient tool for fast and application oriented performance tests for TEMs. Thereby time and cost consuming individual experimental adjustments during plant design can be avoided and the whole process is speeded up. It allows for reliable conclusions on the suitability of power modules for μ-CHP systems.

Acknowledgement:
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Direct energy conversion for concentrating solar power using AMTEC clusters

Dr. Alexandru Onea, *Karlsruhe Institute of Technology, alexandru.onea@kit.edu*
Nerea Diez de los Rios Ramos, *Karlsruhe Institute of Technology, nerea.diez@kit.edu*
Dr. Alfons Weisenburger, *Karlsruhe Institute of Technology, alfons.weisenburger@kit.edu*
Dr. Wolfgang Hering, *Karlsruhe Institute of Technology, wolfgang.hering@kit.edu*
Prof. Dr. Robert Stieglitz, *Karlsruhe Institute of Technology, robert.stieglitz@kit.edu*

Keywords: Energy, Conversion, AMTEC, Sodium, Solar

Introduction

The main drawback of the solar thermal facilities is the fluctuating character of the thermal energy delivered. To by-pass this major disadvantage, such thermal facilities require thermal storage capabilities. In this context, a new concept has been recently proposed by Hering et al. [1] for harvesting the solar energy using liquid sodium as both the heat carrier and heat storage fluid. Furthermore, the concept envisages the increase of the electrical output by the direct conversion of the solar thermal energy using AMTEC (Alkali-metal thermal-to-electric converter) clusters.

Discussion

In this combined AMTEC&CP (concentrated solar power) system, the electrical base load is ensured by the heat transfer from the receiver to the storage system and further to the heat exchanger, which represents the interface to the conventional power conversion system. The AMTEC clusters are activated when peaks in the solar energy occur. Since the cold side of the AMTEC clusters is connected to the hot side of the storage system, the global efficiency of the system can be further increased. The AMTEC technology takes advantage of the unique capabilities of the β-alumina solid electrolyte (BASE) ceramics that allow transport of sodium ions and are characterized by a large electrical resistivity [2].

The activities at KIT are financially supported in the frame of Helmholtz Energy Material Characterization Platform (HEMCP) and the Helmholtz Alliance on Liquid metals (LIMTECH). The focus is on the construction and experimental investigation of AMTEC prototypes and testing and development of high temperatures materials applicable for AMTEC relevant processes. Taking into account the multidisciplinary competence required for these tasks, the HEMCP-AMTEC-Centre (HAC) has been created at KIT, consisting of a network of several institutes.

For these purposes, several experimental facilities are presently in construction at KIT. The AMTEC Test facility (ATEFA) will be employed for the short term tests of different AMTEC prototypes, while the 1000 K SOdium Loop to TEst materials and Corrosion (SOLTEC) facilities will serve for qualification and tests of new materials, ceramics and ceramic-metal joints in hot sodium, corrosion and erosion of steels and long term trials of AMTEC prototypes.

For the AMTEC&CP system, which can range up to 100 MWth, the base layout of the AMTEC cluster has been performed and the appropriate materials that are currently available for the electrodes have been identified [3]. The major drawbacks of the AMTEC technology are the power loss experienced during long time operation and the lower efficiency than the theoretical values. The BASE-metal interface, for which niobium has been considered for the AMTEC test cell represents another issue demanding further optimizations. Nickel-titanium-niobium solutions have been used for the joints required at the BASE-metal interface [2]. Nevertheless, titanium-Al_2O_3 reactions can occur, which lead to BASE degradation and decreased tightness of the bond, affecting therefore severely the structural integrity. Solutions to counterpart these drawbacks have been identified and will be discussed.

The study will be focused also on the influence of the operating conditions on the cell performances. An appropriate balance has to be maintained between the demanding operating conditions ($T_{Na} > 700$ °C) that lead to increased efficiency and the power loss of the cell that can occur on a long-time basis at these conditions.

Acknowledgement: The authors acknowledge hereby the financial support received from the Helmholtz alliances in the frame of the HEMCP platform and LIMTECH project.

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Toward Improved Chalcogenides Based Thermoelectric Modules for Renewable Energy Applications

Eden Hazan, *Department of Materials Engineering, Ben-Gurion University, edenhazan6@gmail.com*
Ohad Ben-Yehuda, Department of Materials Engineering, Ben-Gurion University, ohadbenyehuda@yahoo.com
N. Madar, Department of Materials Engineering, Ben-Gurion University, naormad@post.bgu.ac.il
Prof. Yaniv Gelbstein, Department of Materials Engineering, Ben-Gurion University, yanivge@bgu.ac.il

Keywords: Thermoelectricity, Modules, Chalcogenides, FGM, Efficiency

ABSTRACT

Renewable and sustainable power sources are constantly explored in the recent years, for reducing the dependence on fossil fuels and for keeping a better environment. Thermoelectricity, as a direct thermal to electrical conversion technique, exhibits many attractive advantages with one major disadvantage of a lower conversion efficiency compared to some of the competing technologies, including rankine and stirling cycles. Adoption of thermoelectric converters for utilizing of waste heat generated in industrial plants, automotive engines and others, into useful electricity, requires combined efforts in both novel and efficient thermoelectric materials development and advanced devices simulation techniques. In the current manuscript, an advanced *n*-type functionally graded thermoelectric material based on a phase separated $(PbSn_{0.05}Te)_{0.92}(PbS)_{0.08}$ matrix is reported. For assessment of the thermoelectric potential of this material, combined with the previously reported *p*-type $Ge_{0.87}Pb_{0.13}Te$ showing a remarkable dimensionless figure of merit of 2.2, a finite-element thermoelectric model taking into account temperature dependent thermoelectric materials properties, contact resistances and Thomson heat contribution to the total heat balance, was developed and validated experimentally. The results predict, for the investigated thermoelectric couple, a very impressive thermoelectric efficiency of 14%, which is more than 20% higher than previously reported values for operating under cold and hot junction temperatures of 50 and 500°C, respectively, indicating closer than ever potential for practical incorporation in automotive engines applications.

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Optimization of the Energy Performance in the Hospitality Sector in UAE by Using the Integrated Control Methodology in the Guest Rooms

Fadi AlFaris, MSc Graduate of Intelligent Building Design & Automation Program, the British university in Dubai, fjfaris@gmail.com

Keywords: Energy, Benchmarking, integrated control methodology, energy model

Introduction

This paper aims to present the results of the study that has been conducted on the energy efficiency in the hospitality sector in UAE. It will discuss the energy benchmarking analysis for the lodging buildings to differentiate between the usual practice and best practice in terms of energy performance for the hotels.

Discussion

This paper focuses on developing several criteria such as; the hotel's gross floor area, star classification, building age, occupancy rate, guestrooms number, construction code and regulation and cooling energy source, to appraise the hotel building energy consumption with. The study gathered a real energy data and basic building information, normalization of energy use index. It analyzed these data statistically to ascertain the expected energy performance and consumption in UAE. About 19 hotel buildings energy data was analyzed to provide the energy benchmarking findings in UAE hotels. Besides, the normalized energy use index kWh/m /year has been concluded for the best, usual and poor practice hotels. It was found that the normalized EUI ranges between lower than 241.5 kWh/m /year as a best practice and greater than 361.3kWh/m /year of the poor energy practice for the hotels constructed after the year of 2003. Whereas the hotels' energy data showed higher values for those constructed before 2003, as the normalized EUI varies between lower than 348.4 kWh/m /year as best practice and greater than 511.1kWh/m /year.

In this paper, one of the solutions to optimize the energy performance was examined for the hotels' buildings. The integrated control strategy for the guestroom has been studied and modeled to present the potential of energy savings that might be achieved by using such integrated techniques.

Conclusion

The building energy model in hourly basis has been conducted to assess the energy performance improvement after adopting the proposed system. It shows that at least 31.5% might be improved out of entire energy consumption of the hotel including electricity and gas. 43.2% energy savings for the cooling system and 13.2% for lighting system of the guestroom by installing the integrated control system.

Energy Efficiency Policies in the Russian Residential Sector

***Dr. Natalia Andreassen**, High North Center at Business School, University of Nordland,*
Natalia.Andreassen@uin.no
***Andrey Kazakov**, Advisor, High North Center at Business School, University of Nordland,*
Andrey.Kazakov@uin.no

Keywords: demand-side management, energy efficiency, residential sector, institutional challenges, Russia

Introduction

Russian residential buildings are about twice as energy intensive compared to buildings in many countries (e.g. World Bank Group, 2008; Lychuk et al., 2012). Buildings are particularly energy consuming here due to obsolete building stock, inefficient design and the long heating season. A fundamental transformation in policies, federal and regional legislation, building codes aimed on increase of energy efficiency has taken effect. However, currently the energy efficiency market in residential sector in Russia is still underdeveloped (Andreassen and Kazakov, 2014). One reason might be inefficient development of energy efficiency policies. In this study we refer to demand-side management policies analysis (e.g., Haney et al., 2010) and thus seek to explore recent developments of energy efficiency policies and demand-related programs, their potential and gaps in the Russian residential sector.

Discussion

During President Medvedev's rule from 2008, the Russian economy aimed to create a diversified economy based on technology and innovation, decreasing the country's dependency on oil and gas revenues. Not surprisingly, energy efficiency was identified as one of the priorities for this modernization. In 2010, the Russian Federal "Program for Energy Saving and Energy Efficiency Improvement up to 2020" was launched. It aims at developing an appropriate infrastructure to coordinate and monitor energy efficiency policies. The program identifies five strategic priorities for the country's technological development in the segment of energy efficiency (EE) and energy savings(ES) such as, efficient use of energy resources and reduction of energy consumption; systematic and integrated approach to ES and EE programs; planning and introducing activities and initiatives to boost ES and EE; increasing share of renewable sources; promoting modernization of the energy sector and efficient use of energy resources and reduction of energy consumption.

The Ministry of Energy has been given the responsibility for energy efficiency policy development in Russia. By January 2014, the Russian energy efficiency legislation consists of: 46 government regulations, 14 presidential decrees and federal laws, 45 orders and regulations of ministries and departments, 10 memorandums, 44 regional laws as well as 151 regional and 321 municipal programs. At regional level, the field of energy efficiency is developed through regional laws and programs. All Russian regions have developed advanced action plans to improve energy efficiency, considering local geographical and economic characteristics.

Despite of the great quantity of issued laws and regulations in energy efficiency for residential sector, there is a great number of publications criticizing Russian energy efficiency policies for not being successful. By analyzing the goals, postulates and results of Russian EE policies in residential sector, we argue that it does not look like one integrated policy package, but more like a bunch of single policies running independently.

Conclusions

Our analysis has shown that the Russian EE policy covers all key areas of energy efficiency in residential sector. However, it is not efficient and there is still a substantial need for development or, at least, adjustments. Our conclusion is that the Russian EE policy is not successful due to many still existing energy efficiency gaps, and low synergy and coherence between different policies aimed on different goals. Despite Russia has enormous commercial opportunities in residential segment, underdeveloped energy efficiency policies limit business opportunities in the residential sector in the country.

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Virtual Storages as Theoretically Motivated Demand Response Models for Enhanced Smart Grid Operations

Simon Waczowicz[1], *simon.waczowicz@kit.edu*
Markus Reischl[1], *markus.reischl@kit.edu*
Stefan Klaiber[2], *stefan.klaiber@iosb-ast.fraunhofer.de*
Peter Bretschneider[2], *peter.bretschneider@iosb-ast.fraunhofer.de*
Irina Konotop[3], *irina.konotop@tu-ilmenau.de*
Dirk Westermann[3], *dirk.westermann@tu-ilmenau.de*
Veit Hagenmeyer[1], *veit.hagenmeyer@kit.edu*
Ralf Mikut[1], *ralf.mikut@kit.edu*

[1] *Institute for Applied Computer Science, Karlsruhe Institute of Technology*
[2] *Advanced System Technology, Fraunhofer IOSB*
[3] *Power System Department, Ilmenau University of Technology*

Keywords: Behavioural modelling, demand response, household electricity customer, smart grid

Introduction

Price-based programs, such as *Time of Use* (TOU) or *Real Time Pricing* (RTP) tariffs, incentivize changes in consumption patterns of household electricity customers (Demand Response, DR). In this regard, several model types evolved to describe the customers' consumption behaviour in response to price signals, like *AutoRegressive* models with *eXogeneous* inputs (ARX) [1], physical-based DR models [2], clustering algorithms for classifying price-influenced electricity demand [3] or models based on the load elasticity concept [4]. In [5], a new theoretically motivated DR model, called *Virtual Storage* (VS), is introduced.

Discussion

The basic time-discrete VS model consists of a system of difference equations that describes load reductions/increases in response to price signals. System dynamics are taken into consideration, as well as minimal or maximal load changes [5]. As an extension of the basic VS model a future-oriented and backward-looking evaluation of the price development is integrated in the model structure. Since the customers' response to a price signal, derived from real measurement data [6], is more likely to show load shifting than energy saving [3], this fact is considered as restriction in more specific VS models.

In the present contribution, the model behaviour of several VS models are compared with some of the above mentioned model types and with the real customers' response to a price signal. The comparison is performed on the basis of the smart meter data set of the *Olympic Peninsula Project* [6].

Conclusions

Several *Virtual Storage* models as a new Demand Response model type are introduced in view of future Smart Grid operations.

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SMARTICITY – A Feedback System for Energy Consumption and Costs

Carl Heckmann, *Institute for Enterprise Systems, University of Mannheim, heckmann@es.uni-mannheim.de*
Alexander Mädche, Institute for Enterprise Systems and Chair of Information Systems IV, University of Mannheim, maedche@es.uni-mannheim.de

Keywords: Non-intrusive Load Monitoring, Energy Disaggregation, Utilities Billing System, Consumption Feedback, Demand-side Management

Introduction

Many countries encourage large-scale deployment of smart meter infrastructure, allowing utilities to obtain near real-time information about the state of the grid infrastructure. This brings the potential to create feedback loops between generation and consumption [1]. Several studies showed that providing information about current consumption can positively influence consumption practices. Recent advances in energy disaggregation [2–4] allow to break down a households aggregated electricity consumption into individual appliances with an overall accuracy of about 90 percent [5]. Goal of this research is to develop an energy consumption feedback system that also provides information about energy costs. As tariffs become more dynamic and complex (e.g. time- or load-varying) storing them in redundant ways within energy feedback systems becomes more complicated. Therefore this information needs to be accessed from the utilities billing system

The SMARTICITY Prototype

SMARTICITY has been developed on basis of the NILMTK package [2], which we include as a component into our system ("NILMTK-Wrapper"). The algorithm implemented in NILMTK allow performing energy disaggregation without the need for a) temporary installing sub-meters at each appliance to train the algorithm and b) a more sophisticated metering infrastructure [2]. In this stage of development no actual smart meter is connected but the reference energy disaggregation data (REDD) set is used ("Aggregated Meter Data") [6]. A web application serves as integration layer for disaggregated meter data and tariff- and customer data that is retrieved from a SAP for Utilities billing system ("Billing System"). Consumers interact with the SMARTICITY application via a responsive web interface ("GUI").

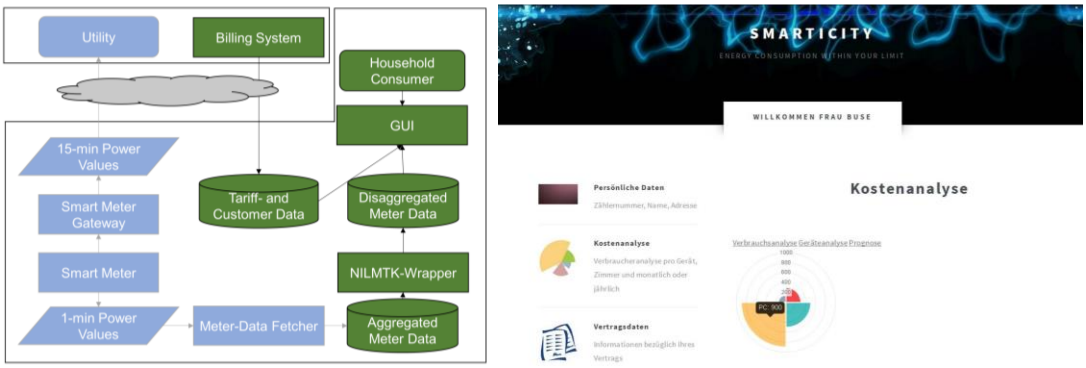

Figure 1: Overview of the overall architecture and screenshot from the web interface of the application.

Summary

A prototype has been implemented that uses latest algorithms for energy disaggregation. Furthermore, tariff data from a SAP billing system has been integrated to enrich the consumption data with cost information. This study extends previous work by adding the possibility to handle complex tariffs for providing cost information in energy feedback systems. Complementing the technical implementation, interviews have been conducted with household consumers to identify the most important features and to validate the design decisions. As a next step, this prototype will be developed further with a focus on performance and data security to allow deployment in a real-life scenario in cooperation with a medium-sized German utility.

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Extended Method to Forecast Price Elastic Consumption Behaviour

Stefan Klaiber[1]*, stefan.klaiber@iosb-ast.fraunhofer.de*
Peter Bretschneider[1]*, peter.bretschneider@iosb-ast.fraunhofer.de*
Simon Waczowicz[2]*, simon.waczowicz@kit.edu*
Ralf Mikut[2]*, ralf.mikut@kit.edu*
Irina Konotop[3]*, irina.konotop@tu-ilmenau.de*
Dirk Westermann[3]*, dirk.westermann@tu-ilmenau.de*

[1]*Advanced System Technology, Fraunhofer IOSB-AST*
[2]*Institute for Applied Computer Science, Karlsruhe Institute of Technology*
[3]*Power System Department, Ilmenau University of Technology*

Keywords: load forecasting, demand response, consumer behaviour

Introduction

Additional flexibility potential in electric supply systems can be provided by adjusting price elastic consumers of the demand side using variable tariffs (demand response). The implementation of price based tariff programs like Time of Use (TOU) or Real Time Pricing (RTP) changes typical consumption patterns of previously unaffected consumers. The resulting consequence is an increasing uncertainty in load forecasting. Accurate forecasts of price elastic consumption behaviour imply new requirements for load forecasting methods. In this paper, the extended requirements for load forecasting methods will be analysed and a novel model approach to forecast price elastic demand is presented.

Discussion

Extended requirements for load forecasting methods result from the specific relationship between price signal and the response of price elastic consumption [1]. In [2, 3], the price elasticity is explained as time-variant function, e.g., depending on day time, seasonal influences or type days. Furthermore, the price elasticity depends on lead time (planning horizon) for which prices are known in advance. In addition to the price elasticity, consumer reactions do not appear directly in response to price changes. A priori or a posteriori time-shifted reactions are expected and potentially leading to “non-causal load reactions”. The influence of the consumption behavior as a measure for load shifting can be interpreted as a virtual storage with special storage properties [4]. These storage properties are also an extended requirement for load forecasting methods. Established approaches for load forecasting methods must be extended to handle the new requirements. A novel extended forecasting method will be present in the full paper. Thereby, additional and pre-processed inputs are added to established methods. The new inputs support the modelling of effects resulting by price elasticity. By introducing the new inputs and a specific re-organisation of specialized sub-models, the novel model approach is able to process the discussed extended requirements. The focus is on the pre-processing of inputs and re-organisation of specialized sub-models so that the used model approach (e.g. established methods like regression methods or artificial neural network [5]) can be chosen at will.

Conclusions

The full paper presents a novel extended method to forecast price elastic consumption behaviour. Case studies will provide the ability of the method to compensate the uncertainty resulting from demand response in load forecasting.

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Assessing Industrial Consumptions’ Curtailments for Demand Response Valorisation

José Blancarte*, Eco-Efficiency and Industrial Processes (EPI) Department, EDF R&D, jose.blancarte@edf.fr*
Dr Valérie Murin*, EPI Department, EDF R&D, valerie.murin@edf.fr*
François de Sousa Lopes*, EPI Department, EDF R&D, francois.de-sousa-lopes@edf.fr*

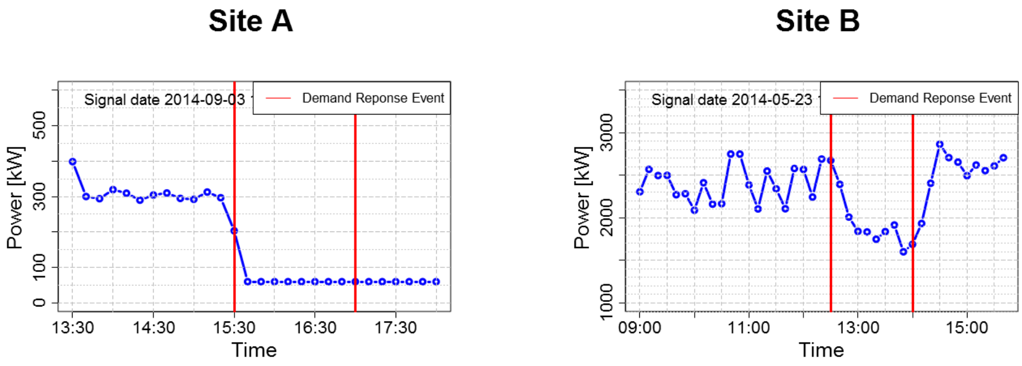
Keywords: Demand Response, Curtailment, Industry Energy Management

Introduction

Within a “Smart Grid” context due to the current increase of intermittent renewable energy sources and electricity consumption, the electric network requires more flexibility from the supply/demand balance point of view. One of the solutions to tackle electricity network equilibrium problems is Demand Response [1]. Industrial electricity consumptions are of great interest due to the amount of energy they represent [2]. However, when an industrial premise has decided to participate to a demand response program, it is necessary to assess how the actual electricity consumption curtailment occurs. The aim of this research work is to investigate how, under real conditions, different industrial sites behave.

Discussion

For the purpose of this research, EDF R&D has launched a project and recruited several industrial sites in order to create a pool of curtailable industrial sites. The pool is composed of about ten sites from different sectors and with different peaking consumptions (from 0.6 MW to 25 MW). Within these sites, about thirty different curtailable endpoint consumptions are available. Several Demand Response events have been simulated under real conditions in order to assess how the different sites and their curtailable workshops react to an order. All the different demand response simulations were carried out during 2014. To illustrate the different outcomes of this experience, the global electricity consumption of two sites from different sectors during a demand response event 90 minutes long are presented in Figure1. The “acceptance ratio” for site A from the different demand response event simulations was 0.5 (5 out of 10). The acceptance ratio for site B was 0.9.


Site A

Site B

Figure 1: Real Load Curve of two different industrial premises during a Demand Response Event

Conclusions and Outlook

From the shown example, it is clear that the response to curtailment orders may be extremely different, and that the “shape” (the “curtailed energy”) depends strongly on this response. The acceptance ratios for both sites were satisfactory as most of the time the site agreed to participate. The way a site behaves under a demand response event depends, among different factors, on the process, the sector and the duration of the order.

The objective of integrating industrial energy consumptions to participate as demand response resources can be a complicated process, due to the variety of behaviours from site to site and from sector to sector. However, in order to standardize the different procedures, assessments of the behaviour of curtailable industrial sites may bring an indication on how the consumption shall be judged and valued. Moreover, it can answer the question on how these consumptions may be integrated to the supply/demand balance.

Acknowledgement: EDF R&D gives special thanks to the different industrial participants for this research work.

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Characterisation of the product quality of a novel environmentally friendly cementitious material by estimation of auxiliary quantities with near-infrared-spectroscopy

Carolin Lutz, Institute for Applied Computer Science, Karlsruhe Institute of Technology, carolin.lutz@kit.edu
Dr. Jörg Matthes, Institute for Applied Computer Science, Karlsruhe Institute of Technology, joerg.matthes@kit.edu
Dr. Patrick Waibel, Institute for Applied Computer Science, Karlsruhe Institute of Technology, patrick.waibel@kit.edu
Ulrich Precht, Institute for Technical Chemistry, Karlsruhe Institute of Technology, ulrich.precht@kit.edu
Dr. Krassimir Garbev, Institute for Technical Chemistry, Karlsruhe Institute of Technology, krassimir.garbev@kit.edu
Uwe Schweike, Institute for Technical Chemistry, Karlsruhe Institute of Technology, uwe.schweike@kit.edu
Dr. Günter Beuchle, Institute for Technical Chemistry, Karlsruhe Institute of Technology, guenter.beuchle@kit.edu
Dr. Peter Stemmermann, Institute for Technical Chemistry, Karlsruhe Institute of Technology, peter.stemmermann@kit.edu
Dr. Hubert B. Keller, Institute for Applied Computer Science, Karlsruhe Institute of Technology, hubert.keller@kit.edu

Keywords: Celitement, cementitious material, NIR spectroscopy, calibration model

Introduction

Cement manufacturing with 5-8 % of worldwide CO_2 emissions [1] is one of the industries with the highest contribution to anthropogenic greenhouse gases. At the Karlsruhe Institute of Technology a novel, environmentally friendly process for the production of a cementitious material (Celitement) was developed, which has a high potential for both saving energy and reducing CO_2-emissions by 50% compared to Ordinary Portland Cement (OPC). In a two-stage process the new hydraulic binder is produced from limestone and sand. In the first step α-C_2SH-phase is formed via hydrothermal synthesis in an autoclave. Subsequently, the α-C_2SH-phase is activated through a reaction grinding in order to obtain hydraulically active calciumhydrosilicate. [2]

However, so far it is difficult to determine the product quality during the process with standard methods. Until now, the product can be only characterised with complex analytical methods. A part of the components can be quantified by X-ray diffraction (XRD). Though, the majority of Celitement consist of amorphous material, which can only be accounted for with a combination of thermogravimetric analysis and spectroscopic methods. In future, a new robust on-line measurement system should allow a reliable monitoring of product quality during its manufacture.

Method for characterisation of the product quality by NIR-spectroscopy

For reduction of the measurement effort and in order to establish an on-line measurement system, various auxiliary quantities for characterisation of the product quality have to be determined. As analytical method for on-line measurements of the auxiliary quantities NIR-spectroscopy was selected because of its simplicity in terms of performance, robustness and easiness of quantification. Using chemometric methods for determination of the desired parameters a broad range of physical and chemical information can be extracted.

For the calculation of the calibration model for process quality measurement different combinations of pre-processing methods, the subdivision of the spectra into several spectral ranges with different permutations and the selection of various model orders were considered. The calculation of the calibration models is performed using partial least squares regression. The assessment of the different models is executed by cross-validation and different quality criteria: coefficient of determination, root mean square error of cross validation and residual prediction deviation. Additionally, the calibration models were calculated for the absolute values and for a relative value related to the initial value (adaption to the working point).

A short overview of the Celitement production and the existing problems with the on-line characterisation of its quality will be presented. Subsequently, methods for systematic development of near-infrared calibration models, their application to new data sets and the selection of the final calibration model will be illustrated.

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Computational Fluid Dynamics for energy efficient multiphase flow processes

***Dr. Dirk Lucas**, Helmholtz-Zentrum Dresden – Rossendorf, Insitute of Fluid Dynamics, d.lucas@hzdr.de*

Keywords: multiphase, simulation, optimisation, CFD

Introduction

Multiphase flows are frequently applied in industrial processes as e.g. in chemical engineering. Reliable predictions of the flow characteristics such as local concentration of species and interfacial area density in gas-liquid flows can contribute to an optimization of the design of corresponding apparatuses and processes. Due to the high energy consumption of such process there is a considerable potential to save energy and materials. Computational Fluid Dynamics (CFD) in principle allows the simulation of such flows and provides local flow characteristics. While it is frequently used for industrial problems in case of single phase flows it is not yet mature for two-phase flows. The reason is the complex gas-liquid interface. For medium and large scale flow domains it is not feasible to resolve all details of this interface. Averaging procedures have to be applied and in most cases the so-called two- or multi-fluid approach is used. It assumes interpenetrating phases and the information on the interface gets lost by these averaging procedures. This information has to be added to the basic balance equations by so-called closure models. The development and validation of such models is done at Helmholtz-Zentrum Dresden – Rossendorf (HZDR) to obtain tools for reliable predictions of multiphase flow characteristics in medium and large industrial scales.

Discussion

There are many activities worldwide to improve the capabilities of CFD-codes for multiphase flows. However the local phenomena are often not yet well understood due to limited experimental data. Accordingly many different proposals for closure models reflecting these phenomena can be found in literature. CFD-simulation often focus on post-test simulations for one or few experiments. In different papers different combinations of closure models and model constants are used. The transferability of such model setups to other flow situations than the experiment they were validated for is usually not assured. To improve the situation recently a so-called base line model for poly-disperse bubbly flow was introduced at HZDR [1, 2]. In this model all closure models and all model constants are well defined. The same setup is applied without any tuning to many different experiments for validation and further improvement. The basic definition of this model and examples for its validation are illustrated in Fig. 1.

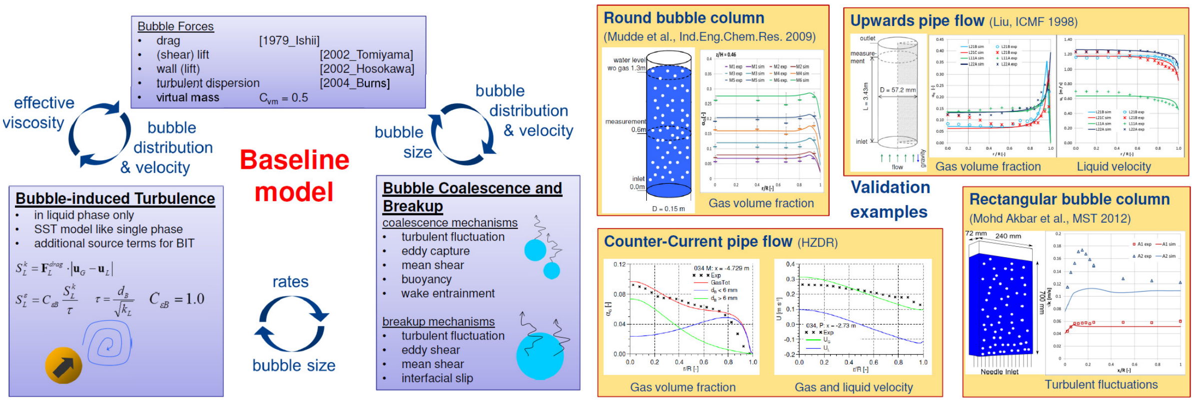

Figure 1: The HZDR baseline model for poly-disperse bubbly flows (left) and examples for its validation (right)

The agreement of the simulations results with experimental data is satisfying for many cases, but especially for cases with broad bubble size distributions also clear discrepancies occur. Analysing the reasons for these deviations is the basis for the further improvement of the baseline model.

Conclusions and/or Outlook

The baseline model strategy aims on the definition of CFD-model setups which allow reliable predictions for industrial scale multiphase flows and thus supports the optimization of related processes for a higher efficiency. A baseline model is also established for segregated flows. New innovative measuring techniques for multiphase flows as well as corresponding experiments to generate CFD-grade experimental data are urgently required.

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Microwave technology for energy efficient processing of fibre composites

G. Link, *T. Kayser, J. Jelonnek, IHM, Karlsruhe Institute of Technology, guido.link@kit.edu*
S. Betz, Vötsch Industrietechnik GmbH
F. Köster, Schunk Kohlenstofftechnik GmbH

Keywords: Energy efficiency, Microwave Technology, Fibre Composite

Introduction

The use of microwave in materials processing has been facing growing industrial interest during the last few decades in various fields of applications due to potential energy and time saving. Conventional thermal processing technologies using convective or radiative heating are limited to surface heating of the products only. Hence the heat transfer into the materials volume depends on the thermal conductivity of the materials itself which is rather low for many materials of interest such as for example powders, polymers, glasses or composites. The use of microwave technology allows a direct and homogeneous heating within the materials volume and therefore the heating processes can be much faster and more energy efficient. KIT has been involved various projects dealing with in design and development of microwave technology for curing of fibre composites.

Discussion

Due to their potential for light weight construction, fibre composites like carbon- and glass fibre reinforced plastic facing growing demands in avionic, space and automotive industries. However a major main drawback of these materials is their complex, time and energy intensive production. Therefore elaborating new process technologies for faster, cheaper and more efficient production is of great interest. An innovative approach in this direction is the application of microwave technology. The main obstacle for industrialisation of such technology so far was the lack of applicators that provide sufficient quality in electromagnetic field distribution in order to provide a homogeneous heating even for large parts. Furthermore the volumetric and selective heating by microwaves requires significant rethinking in process realisation and control.

In close collaboration with various industrial and scientific partners microwave techniques, microwave qualified tools and corresponding processes such as VAP-technique and resin infusion have been successfully demonstrated. Another application is the curing of carbon fibre reinforced plastic preforms in microwave integrated pressing tools [1]. The benefits in microwave assisted pultrusion [2] and microwave curing of high precision winding parts have been verified. It has been shown that microwave assisted processes lead to energy savings of up to 50% as well as to an essential reduction in processing time compared to conventional methods.

Figure 1: HEPHAISTOS industrial microwave technology and (left) and microwave cured CFRP parts – leading edge via VAP process (top right) and thick wall high precision winding part (bottom right).

A brief review of those research activities at KIT will be presented and some exemplary processes will be explained in more details

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Efficient multiphase chemical processes – from advanced modelling, simulation and measurement to novel reactor concepts and technologies

***Uwe Hampel*[1,3], *Holger Kryk*[1], *Markus Schubert*[1], *Dirk Lucas*[1], *Roland Dittmeyer*[2], *Andreas Patyk*[2], *Benjamin Dietrich*[2], *Martin Wörner*[2], *Rüdiger Lange*[3], *Hannsjörg Freund*[4], *Wilhelm Schwieger*[4], *Marcus Grünewald*[5], *Michael Schlüter*[6], *Uwe Petasch*[7]**

[1] Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden
[2] Karlsruher Institut für Technologie, Kaiserstraße 12, 76131 Karlsruhe
[3] Technische Universität Dresden, 01062 Dresden
[4] Friedrich-Alexander-Universität Erlangen-Nürnberg, Schlossplatz 4, 91054 Erlangen
[5] Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum
[6] Technische Universität Hamburg-Harburg, Schwarzenbergstraße 95, 21073 Hamburg
[7] Fraunhofer-Institut für Keramische Technologien und Systeme, Winterbergstraße 28, 01277 Dresden

Keywords: Process Efficiency, Energy Efficiency, Chemical Industry, Process Intensification

Introduction

The chemical and process industry is one of the major industrial consumers of primary energy resources worldwide. Hence, this industry is especially concerned with rising energy prices and demands for reduction of greenhouse gas emissions [1]. In recent years, many advances in energy efficiency have been made especially in the production of bulk chemicals. Efficient heat recovery, efficient plant and production structures as well as improved synthesis routes and catalysts are examples for that. A further increase of efficiency is hardly achievable by simple improvements and game-changing technologies will most possibly only punctually come up. Gradual improvement of processes and equipment still has the highest potential to achieve a broader impact, particularly if a methodological base for optimal process designs is developed that can be applied to many of the different processes and process classes in chemical production [2].

Discussion

With the Helmholtz Energy Alliance “Energy Efficient Chemical Multiphase Processes” a broader network of groups and scientist is dealing with a variety of potential measures for improved chemical processes [3]. Thereby multiphase reactions, such as oxidation, hydrogenation, or hydroformylation, are in the central focus of the research work. As key factors of improved processes, efficient heat recovery of strongly exothermic reactions at elevated pressures and temperatures as well as improved selectivity of complex reactions is targeted. The first topic is demonstrated for the hydrogenation of nitrobenzene to aniline at an elevated temperature level, for which efficient micro-structured reactors as well as novel structured reactor concepts together with new catalyst developments are being considered. As an exemplary reaction with selectivity enhancement potential, the partial oxidation of isobutane to TBHP is under investigation. A further strong fundamental focus is on a multi-scale modelling of chemical reactions and processes from the micro-scale including reaction and kinetics to the device scale with various modelling approaches, such as computational fluid dynamics and compartment modelling. New methodological developments in experimental and measurement techniques target an improved understanding of the multiphase flow, local mass transfer and reaction and comprise tomographic and fluorescence imaging techniques, time-resolved Raman spectroscopy and distributed temperature measurement. Eventually new manufacturing technologies for designed reactor structures, such as additive manufacturing as well as new open-pore foams as catalyst supports and internals for intensified phase contacting are being applied and developed. The technical work is further accompanied by comprehensive analyses of the environmental and economic impacts of the new concepts.

Conclusions and Outlook

The contribution will give an overview over general needs for further progress in chemical process efficiency and discuss the necessity to fully understand and model the full complexity of chemical processes from the reaction via the apparatus to the whole process chain. Recent advances within of the author groups in this field are being discussed in more detail.

Acknowledgement: This work is supported by the German Helmholtz Association within the frame of the Helmholtz Energy Alliance “Energy Efficient Chemical Multiphase Processes”.

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Increasing the energy efficiency of air jet weaving based on a novel method to exploit energy savings potentials in production processes of the textile industry

***Schröter, Achim**, Institut für Textiltechnik, RWTH Aachen, achim.schroeter@ita.rwth-aachen.de*
***Grassi, Corrado**, 3T GmbH, corrado.grassi@3t-gmbh.de*
***Dr.-Ing. Timm Holtermann**, Institut für Textiltechnik, RWTH Aachen, timm.holtermann@ita.rwth-aachen.de*
***Dr.-Ing. Yves-Simon Gloy**, Institut für Textiltechnik, RWTH Aachen, yves.gloy@ita.rwth-aachen.de*
***Univ.-Prof. Thomas Gries**, Institut für Textiltechnik, RWTH Aachen, thomas.gries@ita.rwth-aachen.de*

Keywords: Energy, method, weaving, relay nozzle, compressed air

Introduction

The textile industry is an energy intensive branch of industry. Increasing energy costs are a challenge for textile manufacturers as well as for the developers of textile production machines. As example air jet weaving is the most productive but also most energy consuming weaving method. Technological developments are always concerned about low energy costs, high productivity and constant quality. The high degree of energy consumption of the method can be ascribed to the high need of compressed air.

Discussion

This abstract deals with the use of a novel method to exploit energy savings potentials in production processes of the textile industry. The 6η method by Schenuit [1] provides a framework that allows for the systematic analysis of production machines. Nevertheless, this framework needs some extensions in order to be consistent and universally applicable. These extensions comprise three methodical pillars: first, a consistent assessment of energetic inefficiencies by means of exergy balances, second, a clear focus on economic measures, and third, a tool for the systematic derivation of actions for energy efficiency improvements. These pillars are integrated into the established 6η method. Considering the symbol for the exergetic efficiency ζ (zeta) and the six consecutive steps, the extended method will be considered as 6ζ method [2]. The use of exergy balances is fundamental for assessing the energy efficiency of arbitrary production processes. Exergy balances are of particular value if the considered process consumes energy forms that are not fully convertible such as heat, steam or compressed air. In this method, exergy balances helped to identify energy savings potentials of up to 50% (in air-jet weaving). Conventional approaches are not capable of identifying these potentials. In the case of pure mechanical processes, exergy balances turn into conventional energy balances. The 6ζ method has a clear focus on economic measures that support entrepreneurial decisions. In the analysis phase, subsystems are prioritised according to costs due to energetic inefficiencies instead of applying pure physical measures. The net present value method in combination with scenario techniques ensures a rational economic performance evaluation of generated improvement measures. The 6ζ method comprises a two-step scheme for the development of energy efficiency improvement measures. Firstly, machine components of the target machine are categorised in two dimensions. The first dimension distinguishes the components according to their contribution to value creation. The latter distinguishes whether dissipation is an incorporated attribute of the working principle (e.g. driving a yarn by air friction) or not (e.g. movement of a rapier). The second step provides generic improvement measures depending on the categorisation result. This scheme provides an added value to the user since improvement measures are generated in an efficient as well as effective way.

Results and Outlook

In air-jet weaving, the largest share of energy consumption can be allocated to the pneumatic components. The relay nozzles as well as their valves cause the major share of energetic inefficiencies within the pneumatic system. In this context, a novel relay nozzle concept is the most promising measure to significantly improve energy efficiency of air-jet weaving. A novel nozzle concept has been introduced which provides similar air flows at a reduced level of pressure. Different nozzle prototypes have been characterised on a weaving machine. The preferred nozzle type leads to an exergy saving of 45% in comparison with common relay nozzles.

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Efficient low temperature N_2O decomposition from HNO_3-exhaust streams over K-$Cu_xCo_{3-x}O_4$ catalysts

***M. Sc. Tanja Franken**, Institut für Technische und Makromolekulare Chemie, RWTH Aachen University, tanja.franken@rwth-aachen.de*
Prof. Regina Palkovits, Institut für Technische und Makromolekulare Chemie, RWTH Aachen University, palkovits@itmc.rwth-aachen.de

Keywords: Energy, Climate, Greenhouse gases, N_2O Decomposition, Spinel

Introduction

To reach the climate goals it is not alone constructive to reduce CO_2 emissions but also emissions of other greenhouse gases. N_2O is a very strong greenhouse gas, which is mainly produced during HNO_3 production in industry. Nowadays, strategies to decompose N_2O into N_2 and O_2 need additional energy due to heating of the tail gases for complete removal of N_2O emissions. Therefore, it is highly necessary to introduce new catalysts with high performance in the exhaust conditions of the HNO_3-tail gases avoiding additional heating of these gases. An industrially applied catalyst is Fe-ZSM-5 which achieves 50 % conversion at a temperature ($T_{50\%}$) of 430 °C [1]. Compared to the average temperatures of the tail gases (T = 250 – 500 °C) the activity is still too low for quantitative conversions without energy input. Herein, we present a promising catalyst with high activities at temperatures below 500 °C applying realistic process conditions.

Discussion

As Co_3O_4 shows promising results for efficient N_2O decomposition into N_2 and O_2 [2] varying amounts of Co atoms in the spinel phase were exchanged by Cu. During the use of these materials as catalysts a strong dependency of the catalytic activity on the degree of exchange of Co by Cu was found. The integration of Cu into the unit cell highly increases the catalytic performance compared to Co_3O_4. Reducing the amount of Cu from x = 1 to 0.25 in $Cu_xCo_{3-x}O_4$ increases the performance even more. In the next step a promotion with trace amounts of K was able to increase the catalytic activity and decrease the temperatures for full N_2O conversions to 330 °C. In the presence of H_2O and O_2 the necessary decomposition temperatures increases only slightly, while the presence of NO has a strong influence (**Figure 1**). But still, at a high GHSV of 54000 h^{-1} and in the presence of all inhibitory gases (NO, O_2, H_2O) present under realistic reaction conditions, the catalyst K-$Cu_{0.25}Co_{2.75}O_4$ shows full conversions at temperatures as low as 490 °C. Stability tests in real exhaust gas conditions emphasise stable activities and no further inhibition during a reaction time of at least 60 h. Even an increase of the gas flow rates leads only to minor changes of the conversions.

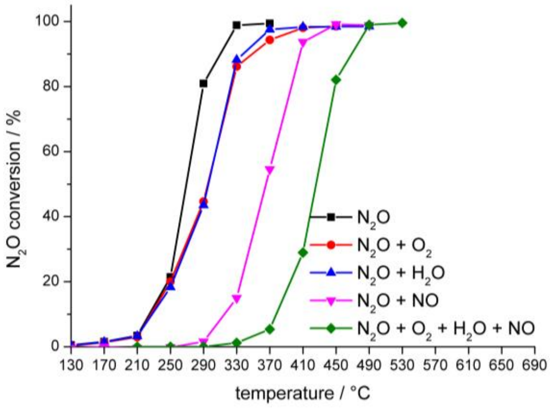

Figure 1: Performances for N_2O decomposition of K-$Cu_{0.25}Co_{2.75}O_4$ in the presence of NO, O_2 and H_2O.

Conclusions

The introduced catalyst shows high activities in the conditions of exhaust gases of HNO_3 production. Introducing this catalyst after the $DeNO_x$ unit could enable operating temperatures of the DeN_2O stage as low as 330 °C. Overall, this development facilitates a more environmentally benign production of HNO_3 with minimum energy requirement for treatment of the exhaust gases.

Acknowledgement: We acknowledge financial support by the Max-Buchner-Foundation.

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Energy-efficient wastewater treatment in a two-stage activated sludge process

***Martin Kaleß**, Institute of Environmental Engineering, RWTH Aachen University, kaless@isa.rwth-aachen.de*
Prof. Dr.-Ing. Johannes Pinnekamp, Institute of Environmental Engineering, RWTH Aachen University

Keywords: renewable energy, municipal wastewater, wastewater treatment, energy efficiency

Introduction

Although unknown to most, municipal wastewater is a source of renewable energy and contains more chemically bound energy (measured as chemical oxygen demand (COD)) than the electrical energy needed to treat it [1]. Chemically bound energy in wastewater mainly comes from human excrements, with carbon being the most relevant energy carrier. Nowadays, during wastewater treatment, microorganisms convert most carbon to CO_2 and biomass. More carbon should be recovered and transferred to digestion for biogas production in the future. Several methods for carbon recovery are available: screening, sieving, sedimentation, precipitation and flocculation, and flotation. Organic compounds can also be recovered by adsorption in a first stage of a two-stage activated sludge process. Pilot-plant scale experiments were carried out to find the sludge age at which most organic compounds are adsorbed. These investigations were undertaken within the project E-Klär, a government-funded joint research project that deals with the topic of energy efficient wastewater treatment plants of the future.

Discussion

Advantages of a two-stage activated sludge system among others are: high load of first stage, separation of biocenosis of first and second stage and operation without primary clarifier. Beside this, in the first stage of a two-stage activated sludge process the COD of the influent is reduced significantly, see **Figure 1**.

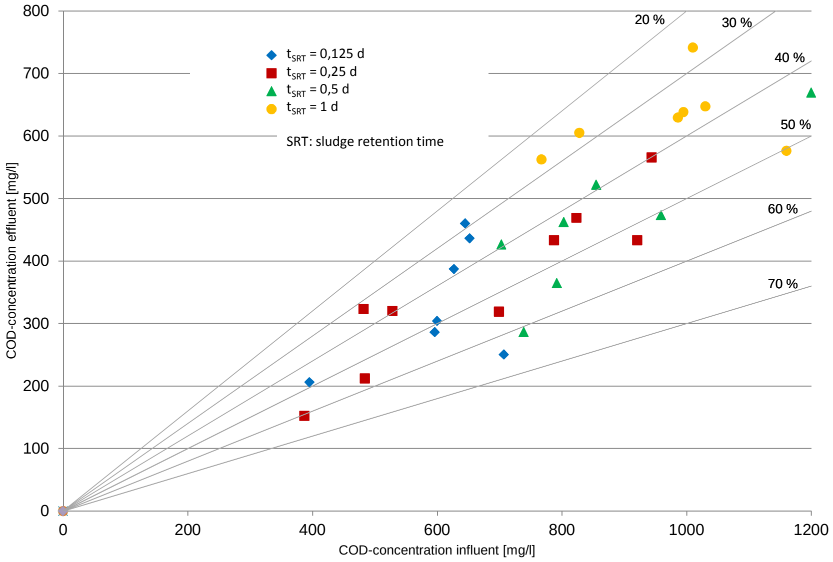

Figure 1: COD elimination in the first stage of a two-stage activated sludge process depending on sludge age

Because there is only low respiration of COD most of the recovered organic compounds can be transferred to digestion. Not only particulate COD is removed but also dissolved COD due to adsorption.

Conclusions / Outlook

While old, the two-stage activated sludge process may enjoy a comeback in times where energy efficiency is becoming essential. Organic compounds - dissolved and particulate - are transferred from wastewater into the sludge more efficiently than one stage processes can do. Sludge should be used for biogas production to increase energy efficiency of wastewater treatment plants. Biological wastewater treatment still needs organics for conventional nutrient removal, so carbon recovery is limited. Research is continuing to find autotrophic processes that do not need organic compounds for nutrient removal freeing carbon for biogas production.

Acknowledgement: The authors would like to express their sincerest thanks to the Federal Ministry of Education and Research for funding the project E-Klär (promotion reference 02WER1319).

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Green catalytic processes converting refinery naphtha cuts to strong anti-knocking ingredients of gasoline

***Dr. Nikolaos C. Kokkinos**, Hephaestus Advanced Research Laboratory, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, nck@teikav.edu.gr*
Dr. Nikolaos Nikolaou, Department of Petroleum and Mechanical Engineering, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, nik.a.nikolaou@gmail.com
Dr. Sophia Mitkidou, Hephaestus Advanced Research Laboratory, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, nck@teikav.edu.gr
Dr. Athanassios Mitropoulos, Hephaestus Advanced Research Laboratory, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, amitrop@teikav.edu.gr
Dr. Etienne Vansant, Department of Chemistry, Laboratory of Adsorption and Catalysis, University of Antwerp, etienne.vansant@uantwerpen.be
Dr. Achilleas Christoforidis, Hephaestus Advanced Research Laboratory, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, achrist@teikav.edu.gr

Keywords: Refinery process, Naphtha, Aqueous biphasic catalysis, Rh/Ru complexes

Introduction

In 1973, Manassen [1] introduced the idea of biphasic catalysis by suggesting the use of two immiscible liquid phases, one holding the catalyst and the other the substrate. Then, the initial idea of biphasic catalysis was appreciably stimulated by Kuntz's applied chemistry at Rhône-Poulenc [2]. In 1984, the so-called Ruhrchemie/Rhône-Poulenc (RCH/RP) process was the first successful industrial scale-up of aqueous biphasic catalysis. In the present research work a conversion *in situ* process of light-light cracked naphtha (LLCN) olefins to strong anti-knocking alcohol mixtures is proposed as a potential solution to the serious negative aspects from the use of gasoline ether oxygenates (MTBE, ETBE, TAME) from the refineries.

Discussion

Aqueous biphasic Rh/TPPTS-catalysed hydroformylation reaction of olefins present in a Greek refinery naphtha cut comprises the first part of the two-step proposed process. The second part of the proposed LLCN upgrade process is the in situ hydrogenation of the produced aldehydes to the corresponding alcohols catalysed by Ru/TPPTS complex in aqueous media. Both catalytic systems of Rh/TPPTS and Ru/TPPTS were revealed as effective catalytic systems for biphasic hydroformylation and biphasic hydrogenation of complicated mixtures, respectively. The effect of the pressure, temperature and time of the reactions, as well as the influence of the L/Me and Sub/Me molar ratios were investigated.

Conclusions

In the first step (hydroformylation reaction) the highest conversion of 95.4% of the olefins present in a real LLCN was observed at 70 ^{o}C, 100 bar, at a short reaction time (6h). The second step (hydrogenation reaction) was significantly boosted in the presence of salt and 66% of the aldehydes were hydrogenated to strong anti-knocking alcohols within the first 15 min of the reaction (TOF= 2607 h^{-1}). The upgraded LLCN could potentially replace the harmful gasoline ether oxygenates (MTBE, ETBE, TAME) from the refinery blended gasoline pools with an in situ and an environmentally friendly catalytic process. Therefore, the ultimate fuel will contain more oxygen; it will have better combustion properties and bigger octane numbers.

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Oral Presentations

Systems, Storage and Grids

Graphene oxide based synthesis of a high energy $FeF_3.0.33H_2O$/rGO cathode for Li-ion batteries

***Dr. Alexander Pohl**, Institute of Nanotechnology, Karlsruhe Institute of Technology, alexander.pohl@kit.edu*
Andreas Schröder, Institute of Thermal Process Engineering, Karlsruhe Institute of Technology
Kiran Chakravadhanula, Helmholtz Institute Ulm, Karlsruhe Institute of Technology
Nele Schwarzburger, Helmholtz Institute Ulm, Karlsruhe Institute of Technology
Thomas Diemant, Institute of Surface Chemistry and Catalysis, Ulm University
Alexander Guda, Research Center for Nanoscale Structure of Matter, Southern Federal University
Viktor Shapovalov, Research Center for Nanoscale Structure of Matter, Southern Federal University
Herman Emerich, Swiss-Norwegian Beamlines, European Synchrotron Radiation Facility
Maximilian Fichtner, Helmholtz Institute Ulm, Karlsruhe Institute of Technology

Keywords: Energy storage, lithium ion batteries, iron fluoride, graphene oxide

Introduction

In 2014, only 29.7 % of the total in Germany consumed electricity was supplied by renewable energy sources including wind, solar, biomass and hydro power [1]. This is still a very low number compared to the amount of electricity produced using coal, gas and nuclear power and to the available capacity of wind and solar power plants [1]. There are huge efforts driven by the ambitious targets of the “Energiewende” to increase the amount of electricity produced by renewable energy sources, but these efforts are impeded by the fact that electricity generated by intermittent energy sources cannot be stored due to the lack of affordable large scale energy storage devices. Recently, high capacity Li-ion batteries have been discussed as an affordable alternative to Na/S and redox flow battery stationary storage systems. We therefore focus on the development of advanced battery materials for Li-ion batteries with higher specific capacities and improved calendar life to be used in stationary or automobile battery applications. These materials are based on iron fluoride conversion materials and achieve 2-3 times the theoretical capacity of conventional Li intercalation materials by utilising multiple Fe redox transitions (160-250 mAh/g for spinel oxide and Li-rich NMC materials vs. 712 mAh/g for FeF_3).

Discussion

We developed a graphene oxide based synthesis of iron fluoride nanoparticles embedded into reduced graphene oxide sheets with good electronic and ionic conductivities of the composite materials. The material offers a stable discharge energy of 600-700 Wh/kg over 100 cycles cycled at 55 °C, which is higher than the widely applied NMC, NCA and $LiFePO_4$ cathode materials (300-500 Wh/kg). We have investigated the materials properties and the electrochemical performance using a host of *in situ* and *ex situ* techniques, among which are XRD, XAS and Raman (*in situ*) and EIS, XPS, TEM, SEM and galvanostatic charge/discharge experiments. The *in situ* XXR approach is especially powerful to investigate the structural changes of the electrode material *in operando*. We show that the composite material consists of $FeF_3.0.33H_2O$ nanoparticles with hexagonal-tungsten-bronze structure and large channels for Li intercalation embedded homogenously into graphene oxide, which undergo complete amorphisation on discharge forming LiF and Fe nanoparticles. On charge, Fe is oxidised to FeF_3 clusters smaller than detectable by XRD, but clearly visible in XAS and HRTEM images. We show that the process is well reversible in the first 100 cycles. However, the long term cyclability is hampered by degradation of the electrode due to electrolyte decomposition and formation of blocking layers on Fe and LiF particles.

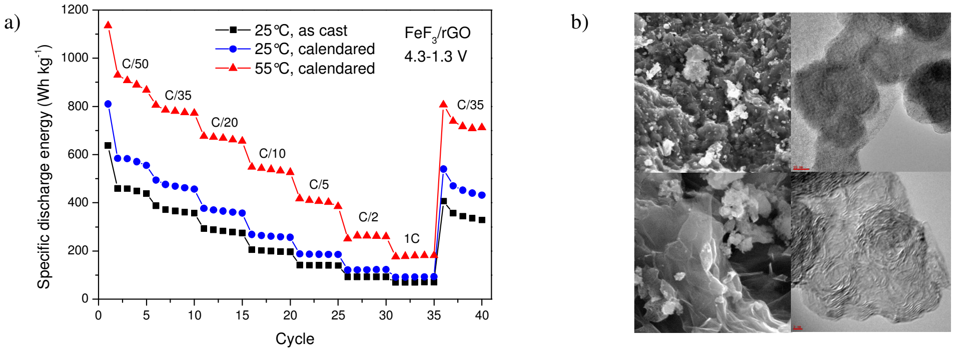

Figure 1: a) Specific capacity and rate capability of $FeF_3.0.33H_2O$ nanocomposite (vs. Li-Foil, coin cell, $LiPF_6$ EC/DMC) at different temperatures, b) SEM and TEM images of individual FeF_3 particles sticking on reduced graphene oxide surface

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Modeling Thermal Runaway Of Li-Ion Batteries - A Mathematical Ansatz

Dr. Andreas Melcher, *andreas.melcher@kit.edu*
Dr. Carlos Ziebert, , carlos.ziebert@kit.edu
Dipl.-Ing. Boxia Lei, boxia.lei@kit.edu
Dr. Magnus Rohde, magnus.rohde@kit.edu
Prof. Dr. Hans Jürgen Seifert, hans.seifert@kit.edu

All authors: Institute of Applied Materials - Applied Materials Physics (IAM-AWP), Karlsruhe Institute of Technology

Keywords: *Thermal Runaway, Li-ion Batteries, Reaction-Diffusion System, Catastrophe Theory*

Abstract:

The thermal runaway of Lithium-ion batteries is the worst case scenario which must be avoided under all circumstances in todays Electric Vehicle (EV), Hybrid Electric Vehicle (HEV) or stationary applications.
On the basis of an extended solid fuel model from mathematical combustion theory [1] the corresponding reaction-diffusion system describes the thermal abuse mechanisms in Li-ion batteries which could lead to a thermal runaway [2] in terms of temperature T and concentrations c_i of the i-th chemical species due to several exothermic decompostion mechanisms. In general all this contributions are governed by nonlinear Arrhenius-type terms depending on chemical concentrations c and temperature T and the corresponding coupled system of concentrations $c_i,\ i=1,\dots,n$ and temperature T is then given as

$$\begin{aligned}\rho c_p \frac{\partial T}{\partial t} &= \kappa \Delta T + \sum_{i=1}^{n} q_i A_i c_i^{m_i} \exp\left(-\frac{E_{a,i}}{RT}\right) + I\left(U_{eq} + T\frac{\partial U_{eq}}{\partial T}\right)\\ \frac{\partial c_i}{\partial t} &= d_i \Delta c_i + A_i c_i^{m_i} \exp\left(-\frac{E_{a,i}}{RT}\right),\ i=1,\dots,n.\end{aligned}$$

Using the well known Frank-Kamenetzki-Ansatz of combustion theory [3] the extended reaction-diffusion system can be reduced to a nondimensional, normalized parabolic equation for temperature Θ of the form

$$\frac{\partial \Theta}{\partial \tau} = \Delta\Theta + \delta \exp(\Theta) + \lambda I\left(U_{eq} + \Theta\frac{\partial U_{eq}}{\partial \Theta}\right)$$

with corresponding initial and boundary values.
In this work the reaction-diffusion system describing a thermal runaway given in the equations above will be reduced to an ordinary differential equation describing the overall temperature inside a Li-ion battery. It will be shown that the resulting equation is independent of the geometry of the battery in such a way that only the volume and surface wil have tol be taken into account. Furthermore applying the mathematical theory of catastrophe we will be demonstrated that a thermal runaway is a swallowtail bifurcation [4]. From this result the region of thermal runaway can be determined in the corresponding parameter space. This gives the possibility to determine critical parameter configurations which can lead to a thermal runaway in a Li-ion battery. Finally an outlook to advanced bifurcation analysis taking the full chemical time dynamics into account will be given.

Acknowledgement:

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Table-driven Li-Ion Battery Cell Model for a BMS Development Platform

Dr. Andreas Melcher[1], andreas.melcher@kit.edu
Dr. Carlos Ziebert[1], carlos.ziebert@kit.edu
Dipl.-Ing. Matthias Gulbins[2], matthias.gulbins@eas.iis.fraunhofer.de
Dipl.-Ing. Thomas Markwirth[2], thomas.markwirth@eas.iis.fraunhofer.de
Dipl.-Ing. Thomas Uhle[2], thomas.uhle@eas.iis.fraunhofer.de
Dr. Joachim Haase[2], joachim.haase@eas.iis.fraunhofer.de

[1] Institute of Applied Materials - Applied Materials Physics (IAM-AWP), Karlsruhe Institute of Technology
[2] Fraunhofer-Institute Integrated Circuits, Design Automation Division (Fraunhofer IIS/EAS Dresden)

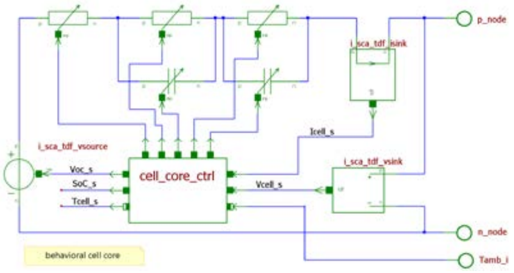
Keywords: System Simulation, Equivalent Circuit Models, Li-ion Batteries

Introduction

As part of the IKEBA project [1], we have created a prototype of a virtual design platform. This platform allows to verify the suitability and the interaction between selected hardware components (Li-Ion batteries and semiconductor circuits for battery monitoring), and of the software of a battery management system (BMS) by simulation. A table-driven Li-ion battery cell model based on an equivalent circuit model approach is used in this platform in order to describe battery packs. Enabling the investigation and comparison of a large number of BMS hardware and software versions requires efficient models and simulation algorithms. Therefore, special effort is necessary in order to increase the efficiency of the cell model evaluation.

Discussion

The basis of the virtual design platform is the design environment COSIDE® for the development of electronic systems. COSIDE® is a tool that can be used to model and simulate highly complex electronic and heterogeneous systems along with software running on those systems [2]. To this end, the hardware components are modelled with the hardware description languages SystemC and SystemC AMS [3]. This approach allows to take into account the characteristics of the batteries, circuits to balance unequal states of charge (charge balancing), and load profiles. In addition, it enables a detailed integration of the components of the battery monitoring integrated circuits (BM ICs) with respect to the characteristics of the A/D converters, delay times etc. and the communication interface (specifically SPI) between BM ICs, and a battery management controller at high simulation speed. The electrical equivalent circuit model of the Li-ion cell has been implemented as electrical linear network (ELN) using SystemC AMS. In order to ensure a quick model evaluation, we developed a special technique yielding a linear problem for each time step. The network model consists of the internal resistance of the cell and of two parallel RC elements in series. The values of these elements depend on the state of charge (SOC) and the temperature and are represented by lookup tables (LUT). The table values were determined by current interruption technique (CIT) measurements [4]. The LUTs approximate the real behaviour by interpolation and extrapolation during the simulation of the BMS.



Conclusions and Outlook

Regarding future work, we intend to include potential faulty behaviour of the components in the models in order to investigate fulfilment of safety requirements of the BMS. Based on a SystemC/SystemC AMS description, an executable virtual prototype can be generated. Therefore, our approach allows for a transition to real-time simulation hardware and thus the application in hardware-in-the-loop testing.

Acknowledgement: This R&D project is partially funded by the Federal Ministry for Education and Research (BMBF) within the framework "IKT 2020 Research for Innovations" under the grants 16N12515 and 16N12440 and is supervised by the Project Management Agency VDI | VDE | IT.

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In situ investigation of gases evolving in $LiNi_{0.5}Mn_{1.5}O_4$/graphite full-cells

B. Michalak, *B. Berkes, H. Sommer, T. Brezesinski, J. Janek*
Institute of Nanotechnology, Battery and Electrochemistry Laboratory, Karlsruhe Institute of Technology
Barbara.Michalak@kit.edu

Keywords: lithium ion battery, $LiNi_{0.5}Mn_{1.5}O_4$/graphite full-cell, DEMS

Lithium ion batteries are generally considered to be the technology of choice for hybrid electric and full electric vehicles. However, further enhancement in the energy and power densities of lithium ion batteries is necessary to fulfill the requirements imposed by automotive applications [1-2].

High voltage $LiNi_{0.5}Mn_{1.5}O_4$ spinel (LNMO) appears to be a very promising cathode-active material in combination with state-of-the-art graphite anodes. This is due, in part, to its low cost, high theoretical specific capacity (147 mAh g^{-1}) and high nominal operating voltage (4.7 V *vs.* Li/Li^+). However, there are severe performance limitations that need to be overcome before commercialization can be contemplated. LNMO/Li half-cells typically show high cycling stability, even at elevated temperatures [3]. Full-cells made of LNMO cathode and graphite anode suffer from capacity fading upon cycling. In recent years, several degradation mechanisms have been identified and correlated with the overall performance. Major issues arise from electrolyte decomposition [4-5] accompanied by formation of gaseous species [6] and manganese dissolution [7]. In this study, our focus is on the in situ gas analysis of LNMO/graphite full-cells during charge and discharge. The gases were studied using an analysis setup allowing for in situ investigation by means of mass spectrometry (DEMS: differential electrochemical mass spectrometry) and FTIR (Fourier transform infrared) spectroscopy. Results on the direct observation and visualization of forming gas bubbles from in operando neutron imaging are presented as well. Mechanistic insights into the decomposition processes were gained by correlating the cell potential to the pattern of the evolving gases. On the basis of these, reaction mechanisms are proposed. Furthermore, the gas formation rate and spatial distribution of evolving gases were analyzed. The influence of other electrochemical parameters, like constant voltage steps, charge/discharge current rate and formation processes (i.e., pre-aging of the electrodes at different temperatures), on the gassing behavior and gas composition was also investigated. These effects and their impact on the cycling stability are discussed.

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Electrochemical characteristics of LaY_2Ni_9 alloy at different discharge rates

***Yassine Ben Belgacem**, Equipe des Hydrures Métalliques, LMMP, ENSIT, Université de Tunis, 5 Avenue Taha Hussein, 1008 Tunis, Tunisia benbelgacemyassine@yahoo.fr*
Chokri Khaldi, Equipe des Hydrures Métalliques, LMMP, ENSIT, Université de Tunis, 5 Avenue Taha Hussein, 1008 Tunis, Tunisia
Jilani Lamloumi Equipe des Hydrures Métalliques, LMMP, ENSIT, Université de Tunis, 5 Avenue Taha Hussein, 1008 Tunis, Tunisia

In this study, the LaY_2Ni_9 hydrogen storage alloy was prepared and the effect of the discharge rate on the electrochemical properties of the active material was investigated.
For this sake, several electrochemical methods such as the galvanostatic charging and discharging (chronopotentiometry: CP), the constant potential discharge (CPD), and the cyclic voltammetry (CV) were used to better understand the effect of the discharge rate on the LaY_2Ni_9 electrode behavior. The decrease of the discharge rate, firstly, facilitates the activation of the alloy, and other hand causes the decrease of the potential difference between charging and discharging that can be correlated with both the maximum discharge capacity and the cycle number of activation. After activation, the electrochemical discharge capacity undergoes a rapid decay before slowing down during a long cycling. A good stability and cycling lifetime are observed for C/10 rate. The exchange current density at initial activation cycles increases as a function of the electrochemical cycling. The smaller the discharge rate is, the faster this growth is. The Nernst potential during the initial activation cycles for all discharge rates shifts towards more positive direction. For a long cycling and except of the C/20 rate, an oscillating stabilization of both the exchange current density and Nernst potential are observed, and the C/10 rate exhibits the best behavior, in good agreement with the good maintaining of performance.

***Keywords:** Nickel-metal hydride batteries; electrochemical characterization methods; Discharge rate; Kinetic and redox parameters.*

Primary frequency control by using a 1 MW battery: study at grid scale on the Concept Grid EDF platform

***Puluhen Benoît**, EDF, Laboratory of Electric Materials, benoit.puluhen@edf.fr*
Lucet Fabien, EDF, Laboratory of Electric Materials, fabien.lucet@edf.fr
Pelletier Aude, EDF, Laboratory of Electric Materials, aude.pelletier@edf.fr

Keywords: Smart Grid, laboratory, distribution, storage, frequency regulation

General context

Generation and load must be permanently balanced in order to maintain the grid frequency at the same value (50 Hz in France) and therefore ensure the grid stability. Indeed a mismatch between load and generation impacts directly the value of the frequency.

To roughly perform this balance, the Transmission System Operator forecasts in the evening for the next day the load curve and plans the generation accordingly. However on the one hand, the load cannot be forecasted with high accuracy because it also depends on variables such as weather, brightness and people behavior. On the other hand some outages can affect the generation plants. Another mechanism is thus needed to ensure a fine balance in real time: the primary power reserve.

This primary reserve is an amount of power delivered automatically and proportionally to the frequency deviation. About 700MW of this reserve is provided by France, and it represents 3000MW in the whole Europe. Primary power reserve must be available in maximum 30 seconds and maintained, if necessary, for 15 minutes. It must be provided by electricity producers, such as EDF, which keep margins for this purpose on its generation plants.

Discussion

Recent large scale energy storage systems such as batteries represent an interesting alternative means to provide this power reserve and contribute to the stability of the grid frequency. Even if several batteries have been deployed, the interest of this type of equipment to control the frequency and its interaction with the grid need to be deeper investigated. Indeed, storage systems are only able to provide power for a limited time. It is an important issue to provide a primary frequency control service and at the same time manage the State Of Charge of the system.

Thus, EDF R&D has just bought a 1MW Lithium-ion battery in order to study the possibility of controlling the primary frequency by using this equipment, identify the associated challenges and tackle them.
In this study, the storage system will be connected to the 20kV network of the Concept Grid platform which is very versatile and where a wide variety of tests can be performed thanks to its different facilities:

- Rotating machine, which can be used as generation or load
- Real loads : houses, heat pumps, fridges, electric vehicle charging stations
- Resistive programmable loads
- Wind turbine, solar panels
- Impedent, compensated or active neutral
- Four quadrant amplifiers, linked to real-time simulation for Power Hardware In the Loop tests

The storage system could be power supplied either by the 20kV network of the "Les Renardières" EDF site, or by low voltage amplifiers through a HV/LV transformer. This second option will permit to generate our own grid and therefore play unusual scenarios of frequency deviation and analyze the battery behavior.
The commissioning tests will be done by the end of 2014 and the study of the system during 2015.

The aim of this paper is to present the first results of these tests.

High Capacity Si-Carbon Composite for Li-Ion Battery Anode Synthesized by Self-Regulated Microwave Heating Process

***Nai-Hsuan Yang**, Department of Chemical Engineering, National Taiwan University, d98524014@ntu.edu.tw*
Dr. Nae-Lih Wu, Department of Chemical Engineering, National Taiwan University, nlw001@ntu.edu.tw

Keywords: microwave, Si-C composites, Li-ion battery, anode

Introduction

Silicon, as an anode material for lithium ion batteries, has drawn much attention recently due to its high theoretical charge capacity, low lithiation potential, and environmental benignity. Large volume expansion from cycling and low columbic efficiency, however, strongly restricts its industrial applications. In order to improve silicon's cyclability, different carbon-silicon composites in which the carbon acts as both a structural buffer media and an electrochemically-active material have been developed. This work includes the synthesis process and the microstructural and electrochemical characterizations of the resulting anode materials.

Discussions

In this work, a unique process which employs microwave treatment has been developed for preparing Si-C composites that contain C@Si core-shell structures with various dimensionalities **[Figure 1]**. This Si-C composite shows reversible capacity double of the graphite capacity and exhibits enhanced cycle stability and rate performance.

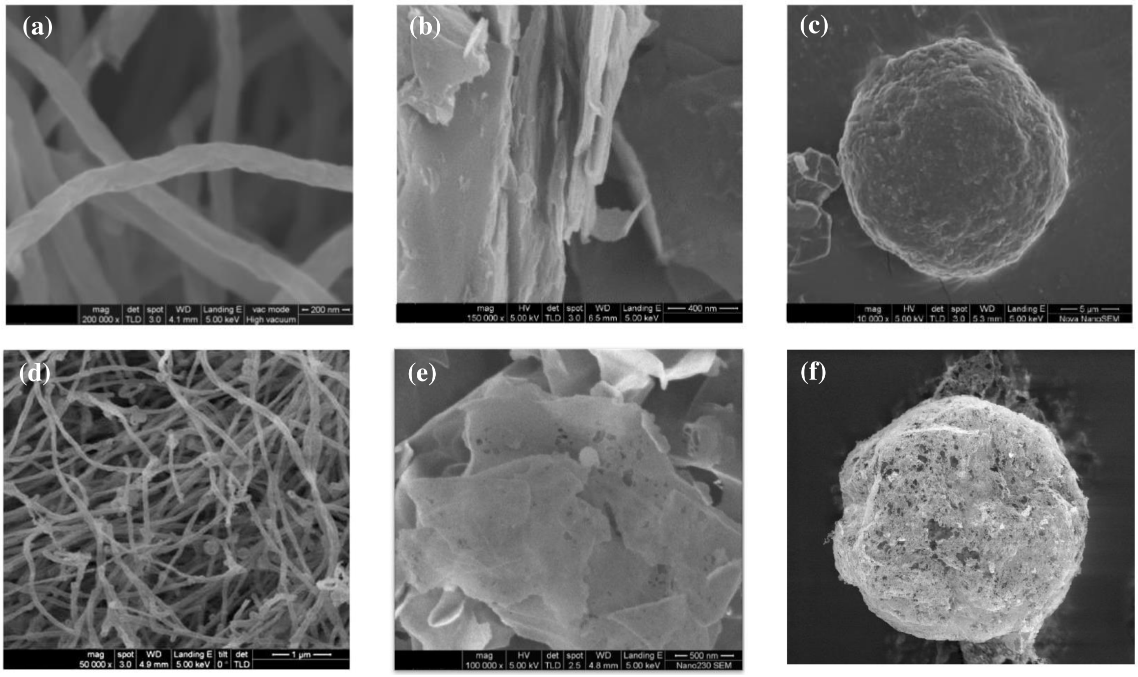

Figure 1: SEM images of the Si-C composites with various dimensionalities (a)(b)(c) after microwave treatment; (d)(e)(f) the coating layer.

Acknowledgement: This work is supported by the Ministry of Science and Technology, Taiwan, under the contract number: NSC 103-ET -E-002 -001 -ET

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Thermal material properties of Li-ion batteries

Dipl.-Ing. André Loges*, Institute of Thermal Process Engineering, Karlsruhe Institute of Technology, andre.loges@kit.edu*
B. Eng. Sabrina Herberger, Institute of Thermal Process Engineering, Karlsruhe Institute of Technology sabrina.herberger@kit.edu
Prof. Dr.-Ing. Thomas Wetzel, Institute of Thermal Process Engineering, Karlsruhe Institute of Technology thomas.wetzel@kit.edu

Keywords: Li-ion battery, thermal management, material properties, numerical simulation

Introduction

The electrical performance and the thermal behaviour of Li-ion batteries are strongly connected and both significantly influence the rate capability, ageing effects and safety of Li-ion batteries [1-2]. Safe operation is limited to a certain temperature range referring to a) the ambient temperature and b) the internal temperature distribution inside the Li-ion batteries. As a result, automotive application with optimized battery performance still remains a challenging task. One of the commonly applied tools to improve battery performance and develop enhanced thermal management strategies is numerical modelling. A large variety of approaches can already be found in literature, but the quality of these simulations is mainly depending on the availability and accuracy of thermophysical material property data. There still is a significant lack of such data for battery electrodes which can be attributed to the variety of applied materials and blends, the lack of suitable structure-property-correlations and the difficulty of comprehensive accurate measurements of electrode material properties in general.

Discussion

In this contribution the results of measurements on thermal diffusivities and specific heat capacities of a large number of active (i.e. electrodes) and passive battery components will be presented. All relevant battery components, such as the electrodes, the casing, the conductors, polymeric spacers etc. are taken in to account, so that this study delivers detailed insight into the thermal behaviour of Li-ion cells and the significant heat transfer paths inside the cells.

Thermal diffusivities of coated electrodes were evaluated in-situ by photothermal beam deflection, which is a contactless and non-destructive measurement technique. Specific heat capacities were determined by differential scanning calorimetry. Temperature dependant characterisation was performed, covering the typical thermal operating and storage range of -40°C to 60°C of Li-ion batteries. The gained measurement data was used to calculate the thermal conductivity of the materials.

The thermal material properties of the investigated anodes and cathodes, which differ in composition, porosity and thickness, are compared and their dependence on the temperature is discussed. Comprehensive results for passive battery components were obtained as well. Based on the measurement data, recommendations for the consideration of the temperature dependence of the thermal material properties in numerical simulation of Li-ion batteries are deduced. Eventually, an outline of representative results of numerical thermal simulations (3D thermal models, coupled electro-thermal models) using the obtained material property data will be given to underline the drawn conclusions.

Conclusions

This study provides a survey of the temperature dependent thermal properties of all relevant battery components based on excessive measurements of thermal diffusivities and specific heat capacities. The results allow generalised recommendations regarding the consideration of temperature dependent thermal properties in numerical simulations of Li-ion batteries.

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New advances in room-temperature fluoride ion batteries

***Dr. Fabienne Gschwind**, Helmholtz Institute Ulm, fabienne.gschwind@kit.edu*
Prof. Dr. Maximilian Fichtner, Helmholtz Institute Ulm and Karlsruhe Institute of Technology, maximilian.fichtner@kit.edu

Keywords: Fluoride, Novel Battery Chemistry, Post-lithium, Sustainable

Introduction

Fluoride—from a chemical point of view—is at the opposite end of the standard reduction potential series from lithium, and therefore, shows interesting possible applications in battery systems. Furthermore, large changes in free energy are observed during the formation of metal fluorides, thus offering high theoretical voltages in electrochemical cells [1, 2, 3].

This system has the potential to achieve capacities higher than those of lithium-ion batteries; therefore, fluoride-ion batteries (FIB) could be a real alternative to lithium-ion batteries. The particular objective of this work is to develop fluoride-ion batteries that work at room temperature (RT-FIB).

Discussion

The general working principle for the RT-FIB (Figure 1) is based on the reduction of the cathodic material and the oxidation of the anodic material via fluoride-ion transport through the electrolyte. For example, a metallic anode like Mg is oxidized to MgF_2, which releases two electrons that travel via an external circuit to the cathode. There, a metal fluoride salt like BiF_3 is reduced to metallic bismuth, which releases three fluoride ions into the electrolyte and assures the ionic transport of the fluoride species.

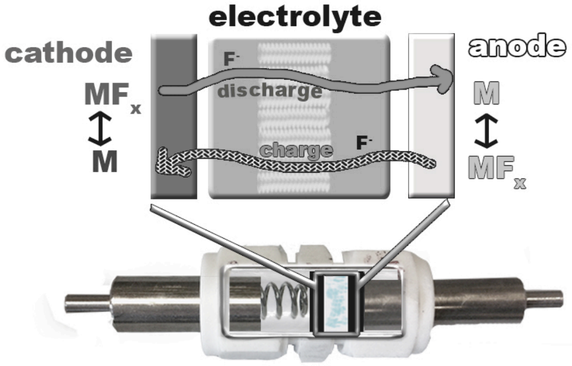

Figure 1: Working principle of a room temperature fluoride battery based on a liquid electrolyte

To optimize the fluoride transport at room temperature it is necessary to develop liquid electrolytes, which can assure mass- and charge-transfer between both electrodes. A solution would be to use fluoride doped polyethylene glycol matrixes, based on organic fluoride salts. Different electrolytes were synthesized with variable PEG-length and they were checked in batteries to select the best ones.

Suitable electrodes also need to be developed for RT-FIB. The best materials for the cathode are in the moment metal fluoride salts. A series of different metal fluoride (BiF_3, CuF_2, FeF_3, etc) salts were investigated and the results will be presented. On the anode side, different elemental metals were checked and the passivation process was analyzed by SEM/EDX. Furthermore different issues concerning leaching of separators and problems with the standard PVDF binder could be investigated and solution for these issues will be presented.

Conclusions

The RT-FIB research is only at the beginning but the first cells tested show discharge capacities around 200mAh/g or greater depending the system parameters. But still large problems concerning reversibility need to be investigated and solved.

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Effect of modified graphene oxide on high-voltage cathode materials for high energy lithium-ion batteries

F. De Giorgio
C. Arbizzani
L. Da Col
M. Mastragostino
F. Soavi

Francesca De Giorgio, M. Sc., Dipartimento di Chimica "Giacomo Ciamician",Via F. Selmi 2, 40126 Bologna (Italy), Alma Mater Studiorum Università di Bologna, francesca.degiorgio6@unibo.it
Professor Catia Arbizzani, Dipartimento di Chimica "Giacomo Ciamician",Via F. Selmi 2, 40126 Bologna (Italy), Alma Mater Studiorum Università di Bologna, catia.arbizzani@unibo.it
Luca Da Col, M. Sc., Dipartimento di Chimica "Giacomo Ciamician",Via F. Selmi 2, 40126 Bologna (Italy), Alma Mater Studiorum Università di Bologna, luca.dacol2@studio.unibo.it
Professor Marina Mastragostino, Dipartimento di Chimica "Giacomo Ciamician",Via F. Selmi 2, 40126 Bologna (Italy), Alma Mater Studiorum Università di Bologna, marina.mastragostino@unibo.it
Doctor Francesca Soavi, Dipartimento di Chimica "Giacomo Ciamician",Via F. Selmi 2, 40126 Bologna (Italy), Alma Mater Studiorum Università di Bologna, francesca.soavi@unibo.it

Lithium-ion batteries (LIBs) are electrochemical energy storage/conversion systems of paramount importance to promote the progress of stand-alone power plants and sustainable transport. Nowadays, great research efforts are devoted to develop LIBs with increased specific energy by the use of high-voltage and high-capacity cathode materials. One of the most promising cathode materials that meets these requirements is the lithium nickel manganese spinel oxide, $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO), which features a high theoretical specific capacity of 146.7 mAh g^{-1} and high nominal operating voltage of 4.7-4.8 V *vs.* Li/Li^+ which is related to the reversible oxidation of Ni^{2+} to Ni^{3+} and Ni^{3+} to Ni^{4+}. Specific energies higher than 200 Wh kg^{-1} are expected by combining LNMO with a graphite anode. However, LNMO's high operating voltage makes the use of conventional carbonate-based electrolytes critical. Indeed, these electrolytes are prone to decompose at high potential leading to the formation of a thick surface layer that is detrimental for the cycling performance of the cathode.
Lithium transition metal phosphates, $LiM_xM_{1-x}PO_4$ (LMP, with M=Fe, Mn) and $Li_3V_2(PO_4)_3$ (LVP), with a high specific capacity close to 170 mAh g^{-1}, are another class of cathode materials that should overcome the interface stability issues as their operating potentials of ca. 4.1 and 3.8 V*vs.* Li/Li^+ not demand the use of advanced electrolytes and make them intrinsically safe and environmentally compatible. However, thepoor electronic and ionic conductivities of these cathode materialsrequire improvements to enhance their electrochemical performance.
The addition of partially reduced graphene oxide in LNMO composite electrode was demonstrated to be effective to enhance conductivity and to limit electrolyte decomposition at the cathode surface [1]. Here, the effect of the use of graphene in LMP/LVP electrodes on cycling performance is investigated. The results of morphological and structural studies and of the electrochemical characterization in conventional electrolyte of LNMO and LMP/LVP composites are reported and discussed.

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Electrochemical Investigation of VOCl for the Rechargeable Chloride Ion Batteries

Ping Gao, Helmholtz Institute Ulm for Electrochemical Energy Storage (HIU), Germany. ping.gao@partner.kit.edu,
Dr. Xiangyu Zhao and Dr. Zhirong Zhao-Karger, Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Germany. xiangyu.zhao@njtech.edu.cn, zhirong.zhao-karger@kit.edu,
Prof. Dr. Maximilian Fichtner, Helmholtz Institute Ulm for Electrochemical Energy Storage (HIU), and Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Germany. m.fichtner@kit.edu

Keywords: Chloride ion battery, VOCl, Magnesium, Conversion, Material

Abstract

The chloride ion battery is a new type of rechargeable battery based on chloride ion transfer. It uses liquid electrolyte at room temperature and offers a broad variety of high potential electrochemical couples and high theoretical volumetric energy density. The overall cathodic and anodic electrochemical reactions are as follows,

At cathode: $MCl_x + xe^- \leftrightarrow M + xCl^-$

At anode: $M' + xCl^- \leftrightarrow M'Cl_x + xe^-$

MCl_x can be a transition metal chloride (e.g. $BiCl_3$, $CuCl_2$, VCl_3, or $FeCl_3$) or a transition metal oxychloride (e.g. FeOCl, BiOCl or VOCl), M' is a metal anode (e.g. Li, Na, Mg, Ca or Ce).

Herein, we report about a rechargeable chloride ion battery using vanadium oxychloride (VOCl) as cathode and lithium anode or lithium-free anode composed of $MgCl_2$/Mg composite. The batteries are denoted as VOCl-Li (lithium as anode) and VOCl-MMC ($MgCl_2$/Mg composite as anode), respectively. A mixture of 0.5 M 1-butyl-1-methylpiperidinium chloride ($PP_{14}Cl$) in 1-butyl-1-methylpiperidinium bis(trifluoromethylsulfonyl)imide ($PP_{14}TFSI$) or a mixture of 0.5 M $PP_{14}Cl$ in propylene carbonate (PC) solvent was used as electrolyte. The charge and discharge mechanism of the VOCl cathode has been investigated by *ex-situ* X-ray diffraction, X-ray photoelectron spectroscopy and electrochemical measurements, demonstrating the chloride ion transfer during cycling. The result of VOCl-MMC showed that the VOCl cathode can deliver a reversible capacity of 101 mAh g^{-1} at a current density of 10 mA g^{-1}, and a capacity of 60 mAh g^{-1} was retained after 53 cycles in this first study. In a first VOCl-Li battery, the VOCl electrode delivered an initial discharge capacity of 201 mAh g^{-1} at 1 C rate and a discharge capacity of 112 mAh g^{-1} was obtained in the 100th cycle with a constant coulombic efficiency of 95 %.

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Local structure and Transport in Ionic Liquid-based Electrolytes for Magnesium Batteries

***Dr. Guinevere Giffin**, 1. Helmholtz Institute Ulm (HIU) Electrochemical Energy Storage; 2. Karlsruhe Institute of Technology (KIT); and 3. Institute of Physical Chemistry and MEET Battery Research Centre, University of Muenster, gwen.giffin@kit.edu*
***Dr. Sebastian Jeremias,**[1] s_jere01@uni-muenster.de*
***Dr. Arianna Moretti,**[1,2,3] arianna.moretti@kit.edu*
***Dr. Sangsik Jeong,**[1,2,3] sangsik.jeong@kit.edu*
***Prof. Dr. Stefano Passerini,**[1,2,3] stefano.passerini@kit.edu*

Keywords: Energy, Storage, Battery, Material

Introduction

The development of rechargeable magnesium batteries is an interesting research avenue in the search for advanced battery materials beyond those based on lithium.[1-3] Magnesium is more abundant, cheaper, and safer than lithium. Mg-based batteries are still in the early stages of development and face several challenges. One significant hurdle that must be overcome is the development of new electrolytes which are not based on nucleophilic components. Air stable electrolytes based on ionic liquid (IL)/ionic salt solutions are currently under investigation for this purpose.

Discussion

On a molecular-scale in the liquid electrolyte, there are two $TFSI^-$ populations coordinating Mg^{2+} in addition to the “free” anions: one in a bidentate coordination with a single Mg^{2+} and one in a bridging geometry between two Mg^{2+}. In the solid state, $Pyr_{12O1}TFSI$ forms a 1:1 crystalline phase with $Mg(TFSI)_2$ where the magnesium ion is octahedrally coordinated by the oxygen atoms of four TFSI anions. The $TFSI^-$ anions can be described as contact ion pair and aggregate solvates (70 and 30% respectively as determined by Raman spectroscopy). The percentages of the bridging (aggregate) solvates are approximately the same in the liquid state above 0.16 mol fraction $Mg(TFSI)_2$ and in the single crystal. The $Pyr_{12O1}TFSI:Mg(TFSI)_2$ 1:1 phase gives insight into the local structure of the liquid electrolyte, which likely contains a mix of 1 Mg^{2+} and 2 or more Mg^{2+} clusters.

The liquid electrolytes, in general, remain amorphous far below ambient conditions, which results in a wide useable temperature range in practical devices. There is a change in the ratio of bidentate:bridging $TFSI^-$ and in the conductivity, viscosity and diffusion behaviour at a salt mole fraction of 0.12 – 0.16. At concentrations above this threshold, there is a more dramatic decrease of the diffusion coefficients and the conductivity with increasing salt concentration due to slower exchange of the more strongly coordinated bidentate $TFSI^-$. The Mg^{2+} cations are mobile in the IL-based electrolytes as demonstrated by the reversible magnesiation/de-magnesiation of V_2O_5 aerogel electrodes.

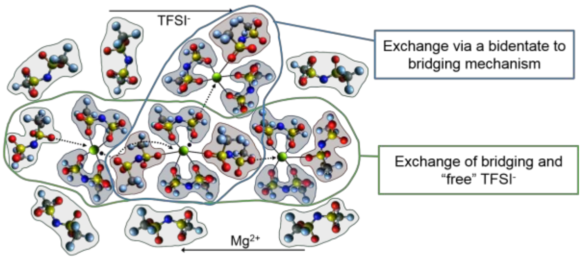

Figure 1: Proposed mechanisms of structural diffusion in the Mg^{2+}-IL electrolytes.

Conclusions

The results above can be used to propose a mechanism of Mg^{2+} ion transport (Figure 1). This mechanism likely proceeds via structural diffusion through exchange of the bridging and “free” $TFSI^-$ anions within adjacent $[Mg_n(TFSI)_m]^{(m-2n)-}$ clusters and exchange of bidentate anions via a bidentate to bridging mechanism. The vehicular mechanism likely makes only a small contribution. At concentrations above approximately 0.16 mole fraction, the structural diffusion is more closely related to the tightly bound bidentate anions.

Acknowledgement: This work is funded by the Helmholtz Gemeinschaft within the project "Stationäre elektrochemische Feststoff-Speicher und -Wandler".

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Efficiency Evaluation of Electrochemical Storage Systems

***Johannes Kathan, MSc**, Austrian Institute of Technology, johannes.kathan@ait.ac.at*
DI Johann Mayr, Austrian Institute of Technology, johann.mayr@ait.ac.at
Christian Messner, BSc, Austrian Institute of Technology, christian.messner@ait.ac.at

Keywords: Electric Energy Storage, Batteries, Efficiency, Photovoltaics

Introduction

Grid connected electrochemical storage systems have increasingly gained attention recently due to the rising share of distributed generation. These systems basically consist of a battery, a battery management system, a power converter and a communication & controls unit. Standardised approaches to evaluate the efficiency of the complete system (including application) are in an early stage of development. Corresponding standard frameworks address rather components than complete systems. However conforming analysis methods for different storage configurations are an essential part for assessment, comparison and development of efficient storage systems.

Discussion

Due to the large number of different system states (state of charge, power levels, etc.) there are numerous possible testing scenarios to account for. That fact increases complexity and time effort for laboratory analysis of real-life systems significantly. To address this matter a "simulation-aided laboratory test" including the following measures is introduced:

- A systematic set of efficiency patterns and indices (component, system, round-trip, application, dynamic/static efficiency) is defined.
- A set of dedicated charge and discharge patterns (standardised testing procedures) for the evaluation of the defined efficiency patterns is introduced and described.
- An approach comprising comparable simulations and laboratory tests is introduced in order to decrease analysis effort as each laboratory analysis can be exactly configured by doing pre-simulations. Additionally, time-consuming tests can be simplified by extrapolating measurement series with simulation data corresponding to the real-life system.

Based on the given approach simulations and laboratory tests as shown in Figure 1 of different system and configurations are carried out and compared.

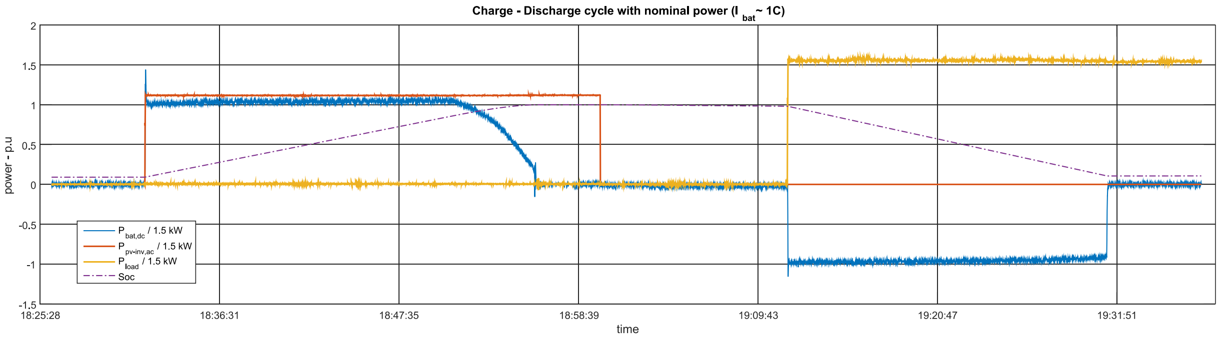

Figure 1Laboratory Test for comprehensive efficiency evaluation of a AC-coupled home storage system with Li-Ion battery

Results from laboratory tests show, high system efficiency can only be achieved if all components integrate with another properly. Preliminary tests depict, that if communications & controls are not well-coordinated, especially if components or interfaces are poorly compatible, overall efficiency will suffer visibly.
In addition, the proposed test approach opens synergies to other fields by allowing for sensitivity analysis with a large number of simulations with validated component models. Consistent comparison between storage systems can then be provided.

Conclusions

Storage testing and analysis is time-consuming and elaborate. Thus efficient approaches for testing are required. Detailed simulations of storage systems decrease the effort and the required time for performing laboratory tests on real-life systems. First results show, that the interaction between all components is essential for providing highest efficiency.

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Rutile-TiO_2 core-shell felt electrodes for all High-Performance Redox Flow Batteries

Javier Vazquez-Galvan, Cristina Flox,
IREC, Catalonia Institute for Energy Research .Jardins de les Dones de Negre, 1, 08930 Sant Adria de Besos, Barcelona.Spain.
Joan Ramon Morante
IREC, Catalonia Institute for Energy Research .Jardins de les Dones de Negre, 1, 08930 Sant Adria de Besos, Barcelona.Spain. and Departament d'Electronica, Facultat de Fisica, Universitat de Barcelona, Spain

Keywords: Energy storage, Flow redox batteries, metal oxides, TiO_2

Introduction

Vanadium redox flow battery offers not only a great promise to provide a robust and constant energy storage system, but also several advantages such as scalability, long cycle life and high efficiency. Besides, its power and energy are independent. Despite all of its merits, VFBs have reached only a limited market presence after the continuous development the last 30 years. The improvements VFB performances require a better reversible kinetics with minimum parasitic reaction (i.e hydrogen evolution).

Discussion

Our approach has been applied several from "nano" to "macro" architectures TiO2 (rutile) on the negative electrode of the VFBs enhancing the electrochemical performance of graphite felt (GF) electrodes. The low-cost TiO2-GFs electrodes have been synthesized by hydrothermal method with tetragonal phases. Linear sweep voltammetry (LSV) study confirmed hydrogen inhibition by rutile in the negative half-cell of the battery. Cyclic voltammetry (CV) confirmed that TiO2 has a catalytic effect towards the redox couple V2+/V3+ at the negative side. The presence of rutile-TiO2, due to the achieved improvement in the hydrogen evolution, allows obtaining 100% charge of the electrolyte, improving the energy efficiency above 90 % at current density (12.5 mA/cm2) as compared with pristine GF. Likewise, these improved characteristics are maintained at higher density of current too. These results suggest rutile based electrodes, replacing expensive noble metals by an affordable material, uniformly decorating GFs holds great promise as high-performance electrodes for VRFB applications. Special attention has been paid on the treatment for achieving high quality of the cover metal oxide. Hydrogen treated samples present the best performances.

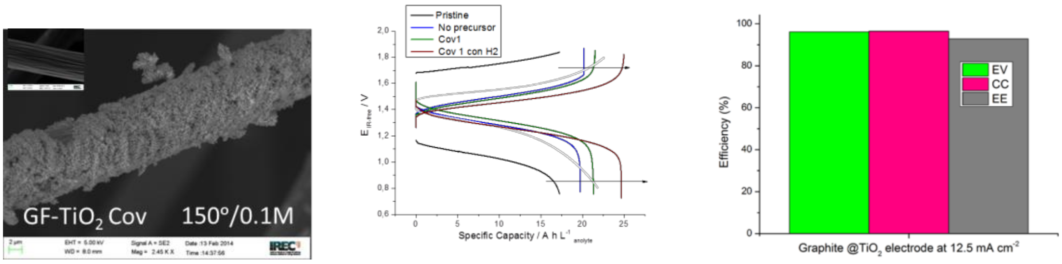

Figure 1: Picture of a PAN fibre cover by rutile-TiO2 and a bare PAN fibre in the insert . Charge discharge curves corresponding to different treatment and preparation of the fibres together with the obtained efficiencies.

Conclusions and/or Outlook

Electrodes material improvements allow achieving higher performances for developing redox flow batteries promoting this approach as a technology with low cost by stored kWh which is a basic requirement for fulfilling in the next future the claim of a broad market defined by the electrical grid end users.

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Vanadium and Chromium Molecular Cluster Batteries (MCB): Li- storage and kinetic studies by electrochemical analysis

Dr. Julia Rinck*, Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Julia.Rinck@kit.edu*
Dr. Bijoy Kumar Das, Helmholtz Institute Ulm for Electrochemical Storage, KIT, Bijoy.Das@kit.edu
Prof. Dr. Maximilian Fichtner, Helmholtz Institute Ulm, KIT, Maximilian.Fichtner@kit.edu

Keywords: Molecular Cluster Battery (MCB), Lithium Ion Battery (LIB), Transition Metal Complexes

Introduction

Increasing energy demands and the need to reduce carbon dioxide emissions at the same time accelerated the world-wide research on renewable energy sources and energy storage. Particularly lithium ion batteries (LIBs) of high specific energy and efficiency have attracted a lot of attention for portable devices. The concept of using molecular transition metal clusters as active electrode materials for reversible Li ion shuttling gives a new direction for energy storage.[1] These metal complexes are interesting electrode materials due to the ability of the transition metal ions to exist in several oxidation states and reversibly reacting with Li [2,3].
In this work we introduce LIBs with molecular clusters of the transition metal ions vanadium and chromium as the cathode active material (with respect to Li), in a so-called molecular cluster battery (MCB).

Discussion

In this study, we prepared vanadium and chromium based molecular cluster compounds and used them as active electrode materials against Li metal. The transition metal complexes in combination with conductive carbon were characterised by IR, XRD and SEM techniques. The Li cycling behaviour was carried out by galvanostatic cycling and cyclic voltammetry (CV). High reversible specific capacities with low capacity loss were found and multi-step redox processes were observed reflecting the various oxidation states of these metals. In addition, the 2D channels of the crystalline compounds, which are revealed in the crystal packing diagram, are suitable for an easy Li ion transportation trough the structure. The Li ion diffusion coefficients were determined by various electrochemical techniques, such as GITT, CV and EIS to understand the Li ion kinetics of these molecular metal clusters.

Conclusions and/or Outlook

The various oxidation steps of molecular cluster compounds allow multi-step redox changes making these materials interesting compounds with potentially high specific capacities and allow a study of the kinetics of the lithium ion diffusion pathway.

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Ionic liquid electrolytes for Li/air batteries

***Mr. Lorenzo Grande**, Helmholtz-Institut Ulm, Karlsruher Institut für Technologie, lorenzo.grande@kit.edu*
Dr. Elie Paillard, Helmholtz-Institut Ulm, Karlsruher Institut für Technologie, lorenzo.grande@kit.edu
Prof. Stefano Passerini, Helmholtz-Institut Ulm, Karlsruher Institut für Technologie, lorenzo.grande@kit.edu

Keywords: ionic liquids, energy storage, lithium metal, lithium air, dendrites

Introduction

Lithium-ion batteries are soon expected to reach their maximum practical specific energy (200-250 Wh/kg) [1]. This value is however deemed not high enough for applications like affordable stationary storage and electric vehicles. For this reason, beyond-Li-ion cell chemistries are currently under intense scrutiny. Li/air batteries have attracted considerable interest both by academics and by the industry in recent years, thanks to the extraordinary practical specific energy that could be attained, up to three times higher than state-of-the-art Li-ion. Although still in its infancy, this technology has already raised some concerns, such as the safe use of a lithium metal anode in presence of oxygen gas [2]. With this scope in mind, our group proposed the adoption of ionic liquid (IL) electrolytes, known to be non-flammable and to have a wide electrochemical stability window.

Discussion

Lithium bis(trifluoromethanesulfonyl)imide (LiTFSI) in N-butyl-N-methyl Pyrrolidinium bis(trifluoromethane sulfonyl) imide (Pyr_{14}TFSI) was chosen as electrolyte thanks to its good electrochemical stability in reduction as well as against the oxygen radical anion $O_2^{\bullet -}$ [3]. Initial tests were carried out to evaluate the compatibility of this electrolyte vs. lithium metal, showing excellent behaviour in terms of cycling efficiency [4] and dendrite suppression [5]. Compared to other electrolytes, LiTFSI:Pyr_{14}TFSI suffers however from a poor $O_2^{\bullet -}$ diffusion coefficient, which limits the total discharge depth. To obviate this, a novel "Li/air flow cell" was then devised to circulate the electrolyte through the cell while enriching it with oxygen via an external gas bubbler. This was made possible by one of the electrolyte's unique properties, i.e. its non-volatility, which prevented any cell drying during operation. The same property was also exploited to perform tests above room temperature, namely at 40°C and 60°C, without observing any electrolyte loss and/or degradation.

Conclusions and/or Outlook

The use of a Pyr_{14}TFSI-based electrolyte in combination with lithium metal showed outstanding results in terms of chemical and electrochemical compatibility. Moreover, the use of a flow cell enabled us to get rid of any concentration gradient-related effects, while the splitting of the O_2-harvesting function from the cell apparatus limited the reaction of oxygen with lithium metal, a phenomenon known as O_2 crossover. Our findings will hopefully pave the way to safe, practical Li/air batteries.

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Active Charge Balancing in Lithium-ion Battery Systems and its Benefits

***MSc ETH Manuel Raeber**, Institute for Energy Systems and Fluid Engineering, Zurich University of Applied Sciences, manuel.raeber@zhaw.ch*
Prof. Dr. Andreas Heinzelmann and MSc Adrian Taeschler, Institute for Energy Systems and Fluid Engineering, Zurich University of Applied Sciences, andreas.heinzelmann@zhaw.ch / adrian.taeschler@zhaw.ch

Keywords: Active Battery Management Systems, Active Balancing, Lithium-ion Battery Charging

Introduction

Individual cells in a battery system tend to vary in capacity, which leads to a reduced battery capacity as weak cells reach charge and discharge limits earlier. Widely used passive balancing electronics protect the battery cells by dissipating excess charge through resistive circuitry. Novel active balancing electronics are capable of efficiently transfer charge from cells with high SoC (State of Charge) to cells with low SoC. To estimate the benefits of such electronics, the theoretical performance concerning energy savings and lifetime extension is analyzed using statistical methods.

Discussion

Measurements published in [1] support the assumption that cell capacities are normally distributed according to the Gaussian density function with the variables μ = mean and σ = standard deviation. The energy loss due to passive balancing during the charging process of a battery system (nSmP configuration, resulting mean $\mu' = m\mu$ and standard deviation $\sigma' = \sqrt{m}\sigma$, see [2]) is then defined as

$$W_{m_{Passive}} = 2n\sqrt{m}\sigma U_{Bal\_avg}\ , \tag{1}$$

with U_{Bal_avg} being the average cell voltage during the balancing process.

The lifetime of a battery pack is usually defined as a minimum remaining capacity in relation to the initial capacity. It is obvious that the EoL (End of Life) criterion of a passive balancing system is reached earlier than it would in an active one. The corresponding extension factor k is shown in Figure 1 for an exemplary battery system with varying m and two different standard deviations, assuming an active balancing efficiency of η and a linear aging function of both σ and μ.

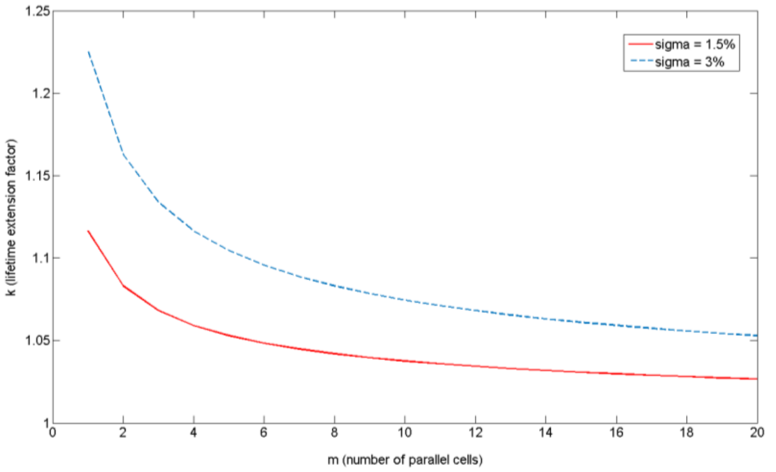

Figure 1: Lifetime extension factor due to active balancing of a battery system with m parallel (η=0.8)

Conclusions and/or Outlook

It has been shown that the theoretical advantages of active charge balancing in battery systems can be calculated analytically with knowledge of just a few cell parameters and the efficiency factor of the active balancing stage. The lifetime extension factor due to active balancing can be estimated independently of the cycle number. Further investigations should be made for battery systems that are not operated only in full cycles.

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Phase-field simulation of the interaction of mechanics and diffusion in cathode particles of lithium ion batteries

Dr.-Ing. Magalie Huttin*, Institute of Applied Materials, Karlsruhe Institute of Technology, magalie.huttin@kit.edu*
Prof. Dr.-Ing. habil. Marc Kamlah, Institute of Applied Materials, Karlsruhe Institute of Technology, marc.kamlah@kit.edu

Keywords: Phase-field simulation, cathode particles, phase transition, mechanical stresses

Introduction

As a result of recent international research, the contribution of mechanical properties and processes on performance and degradation of electrochemical storage systems such as lithium ion batteries (LIB) is generally acknowledged. In this talk, we consider the interaction of mechanics and diffusion in individual cathode particles.

Methods

Most host materials for electrochemical energy storage show phase changes upon intercalation. By phase-field modeling we study the effect of phase changes on the generation of mechanical stresses in electrode particles. Coupling the Cahn-Hilliard-equation to small and finite strain mechanics shows the tremendous stresses due to the strain mismatch caused by phase segregation.

Results

Using this phase-field-method, both the equilibrium and dynamical behavior of the particle has been analyzed. In a first step, we used a spherically symmetric particle model to study the influence of several parameters, like the magnitude of the flux applied at the particle surface or the Young's modulus of the host material.

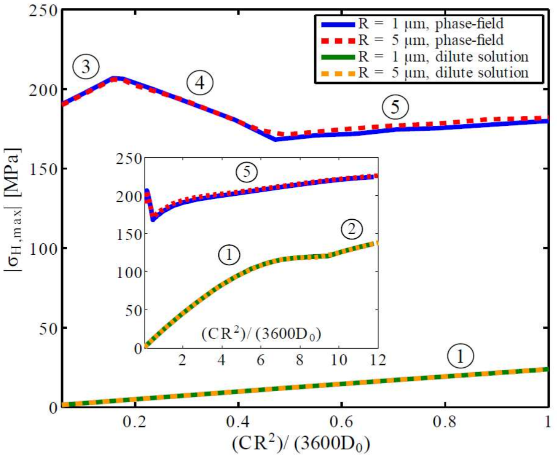

Figure 1: Maximum hydrostatic stress in a spherical particle reached using the phase-field model and the dilute solution model [1].

Fig. 1 summarizes results for dynamical loading of a spherical particle. The curves shown there are obtained during lithium extraction and for two different radii of the particle. Bigger applied C-rate, i.e. loading rate, values are represented in the inset. It can be seen that phase changes lead to severe stresses. And in contrast to the stresses caused by the purely rate induced gradients in the commonly applied dilute solution approach, very high stresses are present in the phase-field model even for arbitrary low loading rates. This observation has recently been confirmed by experiments.

In a further step, imposing symmetries of the geometry on the solution is shown to possibly exclude states of minimum energy, which, for example, questions the so-called core shell scenario. Then, by means of a two-dimensional phase-field model enabling the consideration of ellipsoidal particles, the influence of the particle aspect ratio on both the equilibrium and dynamical states is determined. Here, we demonstrate that the arising stresses are generally lower when the particle shape strongly deviates from the spherical one. Further we will see that, the relaxation towards a hydrostatic stress-free state is facilitated in very elongated particles, as compared to flat or spherical particles.

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Battery Operation from a Neutron Point of View

Dr. Martin Johann Mühlbauer, Institute for Applied Materials (IAM), KIT, martin.muehlbauer@kit.edu
Dr. Oleksandr Dolotko, Heinz Maier-Leibnitz Zentrum (MLZ), TU München, oleksandr.dolotko@frm2.tum.de
Mykhailo Monchak, , Institute for Applied Materials (IAM), KIT, mykhailo.monchak@frm2.tum.de
Dr. Anatoliy Senyshyn, Heinz Maier-Leibnitz Zentrum (MLZ), TU München, anatoliy.senyshyn@frm2.tum.de
Prof. Dr. Helmut Ehrenberg, Institute for Applied Materials (IAM), KIT, helmut.ehrenberg@kit.edu

Keywords: Neutron, Diffraction, Tomography, Li-ion battery, in situ

Introduction

Although Lithium-ion batteries are nowadays part of our everyday life, optimization of their basic parameters like life span and energy density is still a great issue. Besides these basic needs for small mobile devices an increasing amount of applications related to electro mobility and energy storage call for pushing their power densities, rate capabilities and (high) cyclability even further, including the need for stability of their performance parameters over a wide temperature range. Therefore one is aiming for an investigation of single cells or even integrated batteries under real operating conditions. Hereby great emphasis is put on gaining detailed information about the processes taking place inside the cell, reaching down to the atomic length scale, whereby structural changes and phase transitions induced by lithium intercalation and deintercalation can be analysed.

Discussion

Investigation methods based on X-ray and synchrotron radiation are often limited when the cells are embedded in a closed steel container. Neutrons on the other hand offer an ability to investigate even larger cells, because they are capable to penetrate many materials much easier than other kind of radiation. This also enables for the optional use of rather complex sample environment making it possible to conduct in operando investigations on standard size samples (18650 cells or even larger) over an expanded temperature range. In addition neutron radiation shows an isotope specific interaction including large variation of scattering cross sections for neighbouring elements and sensitivity for light elements like lithium. That is why the information gathered with neutrons gives a different perspective for further research. For example it is possible to follow cation exchange reactions in cathode materials [1]. In case of attenuation based tomographic studies neutrons yield complementary information, because their attenuation is rather caused by Lithium and electrode materials than by the copper current collectors. The neutron point of view provides additional information on the homogeneity of the state of charge inside a operating cell checked by spatially resolved neutron diffraction [2]. A movement of the electrolyte caused by expansion and contraction of the electrodes during charge and discharge could be observed [3]. Recent findings revealed a deviation of the expected stage formation for lithiated graphites with low lithium content [4]. A correlation of the active lithium and the cell capacity fade was observed and found to be related to changes of the lithium occupation inside the electrode, which is caused by fatigue [5].

Conclusions

Operating parameters of cells might be adapted according to environmental factors, microstructure and the sequence of the intrinsic phase transformations of the electrodes, which may prevent cell damage, i.e. for low temperature charge. The cell geometry (tab positions), the cell balancing, etc. might also be optimized by taking into account neutron scattering data.

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Battery Energy Storage for Grid Support

Richard Rocheleau, Hawaii Natural Energy Institute, University of Hawaii, rochelea@hawaii.edu
Marc Matsuura, Hawaii Natural Energy Institute, University of Hawaii, marcmm@hawaii.edu
Karl Stein, Hawaii Natural Energy Institute, University of Hawaii, kstein@hawaii.edu
Moe Tun, Hnu Photonics, moetun@hawaii.rr.com

Keywords: Battery, Energy Storage, Frequency Response, Renewable Integration

Introduction

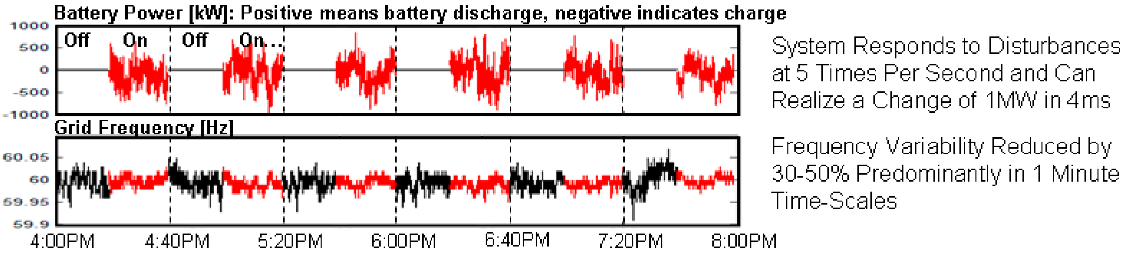
The integration of renewable energy resources into the electricity grid poses a variety of challenges due to the intermittent nature of renewable energy and the reduction of system inertia via displacement of traditional generation. These effects can manifest in such ways as increased frequency variability, voltage transients, power quality reduction, and loss of reliability. Fast-acting Battery Energy Storage Systems (BESS) have the potential to mitigate these adverse effects enabling increased energy generation from renewable sources.

Hawai‘i is at the forefront of tackling the problem of renewable energy integration because of the geographic isolation of the islands’ electricity grids and the rapid growth of renewable generation. These factors make Hawai‘i’s electricity grids particularly susceptible to the adverse effects of intermittent renewable energy sources, but also an ideal test bed for energy storage solutions. The Hawaii Natural Energy Institute (HNEI) at the University of Hawaii has initiated an integrated research, testing and evaluation program to assess the benefits of grid-scale BESS for various ancillary service applications. Specifically, HNEI has procured and is installing three fast-response BESS on the Hawaiian Island grids. The program includes laboratory testing of cells for better understanding of degradation, assessment of battery performance on the grid, and optimization of the BESS closed-loop control algorithms to maximize grid support with minimal battery cycling.

Discussion

The first of these, a 1MW, 250kWhr Li-ion titinate BESS, commissioned in December 2012 on the Big Island grid, is located at the point of common connection with a 10MW wind farm and is being operated to provide, at various times, either wind smoothing or primary frequency response. The second, also a 1MW, 250kWhr BESS, scheduled to be commissioned in summer 2015, will be sited on the island of Oahu on a circuit characterized by a high penetraton of PV and large, variable industrial loads. The primary functions intended for this BESS are power smoothing and voltage/VAr support. Also schedule for commissioning in summer 2015 is a 2MW, 375kWhr BESS. This system will be deployed on a small (5MW peak) isolated grid on the island of Molokai.

The Big Island grid is characterized by a peak load of approximately 180MW, with significant amounts of wind (~32MW) and solar (~ 40MW). Experiments conducted under a wide of grid operations has consistently shown the ability to significantly mitigate frequency variability, even with a BESS of only 1MW. **Figure 1** shows results from one such experiment, in which the BESS was repeatedly cycled on/off to separate BESS impact from normal grid frequency variability. The top half of the figure shows the charge/discharge of the battery. The lower half shows the grid frequency with the BESS off (black) and on (red).



System Responds to Disturbances at 5 Times Per Second and Can Realize a Change of 1MW in 4ms

Frequency Variability Reduced by 30-50% Predominantly in 1 Minute Time-Scales

Figure 1: Experimental results when switching the BESS off (black lines) and on (red lines).

HNEI is currently also tuning the frequency response algorithm to provide the greatest grid benefit while maximizing the longevity of the system. Several lessons have already been learned in this process. For example, during initial testing, HNEI attempted to tune the BESS to run highly aggressively. This resulted in a rapid heating of the battery cells while providing no notable improvement to grid operations. The temperature of the cells increased by more than 15°C over a period of just 3 hours. Since temperature is a known contributor to cell degradation, operations were modified to minimize temperature excursions.

Conclusions

In this paper, we will provide an overview of HNEI’s BESS program, present some of the results from the frequency response experiments from the Big Island, and discuss some of the lessons learned from this work.

In-Situ X-ray Radiography Analysis of Lithium Sulphur Cells

Dr. Sebastian Risse[1]*, Helmholtz Zentrum Berlin, sebastian.risse@helmholtz-berlin.de*
Dr. Charl Jafta[1]*, Dr. Yan Yang*[1]*, Dr. Nikolay Kardjilov*[2]*, Dr. André Hilger*[2]*, Anika Juhl*[3]*, JProf. Simone Mascotto*[3]*, Dr. Boris Ufer*[3]*, Prof. Michael Fröba*[3]*, Dr. Ingo Manke*[2]*, Prof. Matthias Ballauff* [1]

[1]*Institute of Soft Matter and Functional Materials, Helmholtz-Zentrum Berlin (HZB)*
[2]*Institute of Applied Materials, Helmholtz-Zentrum Berlin (HZB)*
[3]*Institute of Inorganic Solid State Chemistry and Material Science, University of Hamburg*

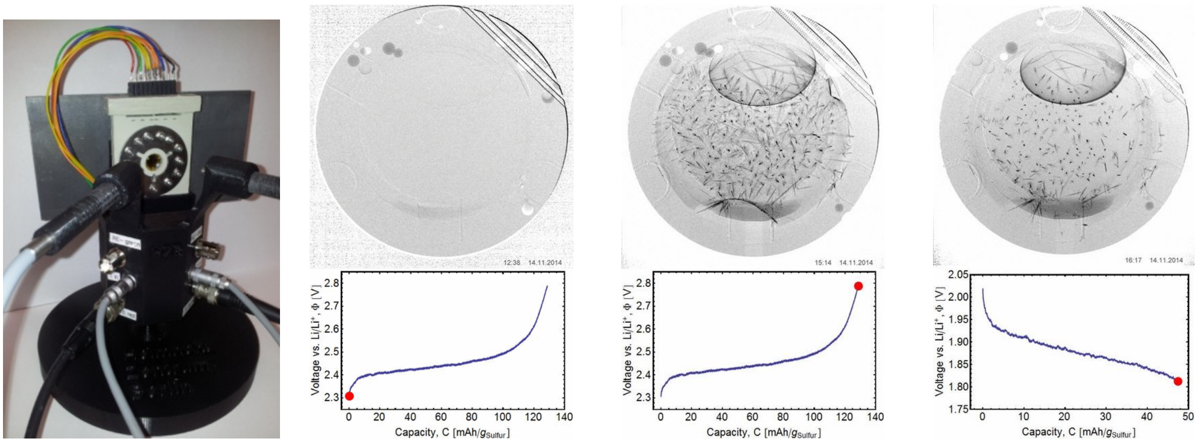
Keywords: operando, lithium sulphur battery, radiography, UV/vis

Introduction

Due to their high theoretical electrochemical capacity of 1675 mAhg-1 Lithium/Sulphur (Li/S) batteries are subjects of intense research [1]. However, there is still a loss of capacity with the number of charging cycles and the complicated processes within the Li/S battery are still not understood. Here we present an operando setup that allows us to analyze the cathode of the Li/S cell with five different measurements.

Discussion

The X-ray radiography measurement gives information about the macroscopic formation of both solid phases, S_8 and Li_2S that are present at the end of each charge and discharge cycle, respectively. Simultaneous performance of electrochemical impedance spectroscopy (EIS) and UV/vis spectroscopy enables the access to kinetic processes at the solid electrolyte interface as well as the composition of the electrolyte.



a) Operando Setup b) Begin of charge c) End of charge d) End of discharge

Figure 1: Operando radiography setup (a) and operando radiography of an monolithic carbon electrode in a lithium sulphur cell (b, c, d).

Conclusions

The use of a monolithic carbon cathode material and the non-application of a separator layer make this cell design a model system for Li/S batteries. The formation of sulfur dendrites at the end of the charge cycle and their incomplete disappearance at the end of the discharge cycle is one interesting result of this experiment Figure 1).

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Renewable energy high-efficient power supply using a direct current system

Shinsuke Nii, Smart Community Grand Dept., Fuji Electric Co., Ltd., nii-shinsuke@fujielectric.co.jp
Dr. Masaaki Bannai, Graduate School of Regional Innovation Studies,, University of Mie, bannai@innnov.mie-u.ac.jp

Keywords: Renewable Energy, Battery, DC system, Energy Management

Introduction

Penetration of renewable energy is advanced as one of global warming measures. The renewable energy (RE) is limited to introduce just as it is for instability of output. .To plan for high-efficient use of the energy and penetration of renewable energy, we're advancing development of a community management system. A community management system is requested to be able to control renewable energy. To make the influence to the power system minimal for penetration of RE as well as contribute to load leveling, it's need to make RE output controllable generation. We would like to introduce a RE controllable generation system using a DC bus which we have developed.

Discussion

Many smart community Demonstration Projects are performed in Japan. It's important to keep a balance of load and generator in the smart community. Therefore community battery systems are installed to adjust fluctuations of generator and load. On the other hand, to use RE by stable output, battery systems are installed beside RE and RE output are adjusted for stabilization by the battery systems. When the system combined RE and battery is changed from AC to DC, easy control gives stable output of RE. Much smart community demonstration projects are performed in Japan. Smart Campus Demonstration Project at Mie University had been executed in FY2011-2013 as one of them. The various ultramodern trials were performed for the purpose of reduction in CO2 which occurs in the university in this project. For example, optimum system operation of co-generation, the air conditioning which considered moisture control and the demand response, etc. As a result, reduction in 27.3% was achieved. In this Project, the proof which uses DC power of RE directly and plans for energy saving was performed. The construction of this direct current system is showed on figure 1.

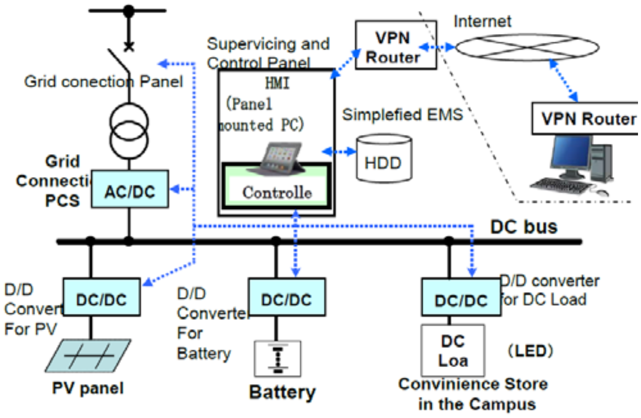

Fig.1 System configuration of DC System

A converter for PV, converters for battery, a converter for connection to Grid and converters for loads are connected through a DC bus bar. The bus bar voltage is kept by control of converters for battery constantly. Photovoltaic generation equipment outputs maximum output by MPPT control. This system can send stable and controllable Power to Grid as well as also supply a direct current load with the stable voltage. The renewable energy power supply which can control the electric power freely was achieved by this system. DC LED lights were employed as DC loads and DC LED and AC one were compered. As a result, a DC system improved 18.2 % in the overall efficiency to AC system.

Conclusion and/or Outlook

The system reduce bad influence to Grid and control output freely was achieved by connecting PV generation equipment and battery through DC bus.We would like to develop large-scaled RE generating equipment for which applies DC control technology and it doesn't have an bad influence for the Grid from now on.We hope to achieve Penetration of RE by DC system.

High Capacity Anode Materials based on mixed Conversion/Alloying Energy Storage Mechanism for Lithium-Ion Batteries

Franziska Mueller, *Helmholtz Institute Ulm, Karlsruhe Institute of Technology and Department of Physical Chemistry, Westfälische Wilhelms-Universität Münster, franziska.mueller@kit.edu*
Dominic Bresser, Helmholtz Institute Ulm, Karlsruhe Institute of Technology and Department of Physical Chemistry, Westfälische Wilhelms-Universität Münster dominic.bresser@kit.edu
Prof. Dr. Stefano Passerini Helmholtz Institute Ulm, Karlsruhe Institute of Technology, stefano.passerini@kit.edu

Keywords: Conversion, Alloying, Anode, Lithium Ion Battery, Capacity

Introduction

Lithium-ion batteries (LIBs) are the state-of-the-art energy storage device for portable consumer electronics due to their high energy, power density and efficiency, as well as long durability [1] [2]. However, for large-scale applications as, for instance, electric vehicles, the energy density of nowadays-commercial batteries is still insufficient. Thus, the utilization of new active materials with higher specific capacity than the currently used anode and cathode materials might enable an improved energy density [1]. Accordingly, instead of insertion or intercalation anode materials alternative higher specific capacity anode materials following an alloying or conversion process for the reversible lithium storage are intensively investigated. Herein, we present our studies on different anode materials based on mixed conversion/alloying lithium-ion storage mechanism. In order to gain deeper insights into the crystal structure of the synthesised samples and into the mixed conversion/alloying lithium storage mechanism of this rather new class of materials various characterisation method as, for instance, X-ray diffraction, X-ray photoelectron spectroscopy, X-ray absorption spectroscopy, scanning electron microscopy and electrochemical techniques were employed.

Discussion

In Figure 1 the long-term galvanostatic cycling tests for several anode materials from the class of transition metal-doped metal and metalloid oxides are presented. All materials show a highly stable cycling behaviour with an extraordinary high specific capacity compared to the conventionally utilised anode material graphite (372 mAh g^{-1}). The specific capacity of Fe-doped ZnO is about 1100 mAh g^{-1} after 60 cycles. Fe-doped SnO_2 reaches a reversible specific capacity of more than 1500 mAh g^{-1} after 10 cycles. With about 660 mAh g^{-1} Co_2SiO_4 shows a rather low specific capacity compared to $Zn_{0.9}Fe_{0.1}O$ and $Sn_{0.9}Fe_{0.1}O_2$. One reason for the different electrochemical performance of Co_2SiO4 compared to $Zn_{0.9}Fe_{0.1}O$ and $Sn_{0.9}Fe_{0.1}O_2$ is certainly a different lithium storage mechanism as shown by our investigations.

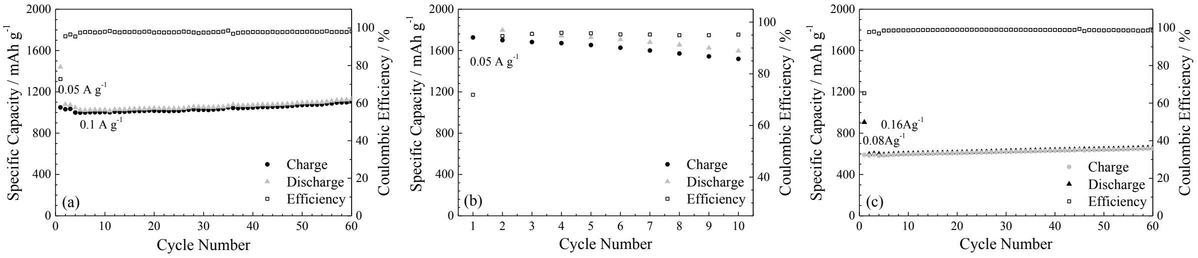

Figure 1: Specific capacity vs. cycle number; cut-off potentials: 0.01 V and 3.0 V vs. Li/Li+. (a) Carbon coated iron-doped zinc oxide [3]; (b) carbon coated iron-doped tin oxide [4]; (c) cobalt-doped silicon oxide [5].

Conclusions and/or Outlook

By means of our studies, we were able to elucidate the crystal structures and to propose lithium storage mechanisms for different Co- and Fe-doped oxides. The family of transition metal-doped metal(loid) oxides show a great potential as high capacity anode material for application in LIBs. However, for fully understanding this rather new class of LIB anode materials further investigations are certainly needed.

Acknowledgement: Financial support from the BMW AG within the ABILE project is gratefully acknowledged.

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High-Performance Li-ion Battery Anodes from Recycled Solar-Grade Kerf-Loss Silicon

***Tzu-Yang Huang**, Department of Chemical Engineering, National Taiwan University, r02524008@ntu.edu.tw*
Hung-Yu Lin, Department of Chemical Engineering, National Taiwan University, r01524045@ntu.edu.tw
Dr. Nae-Lih Wu, Department of Chemical Engineering, National Taiwan University, nlw001@ntu.edu.tw

Keywords: Li-ion batteries, Anodes, Kerf loss, Silicon, Recycling

Introduction

Turning the recycled waste into high-value products is of strategic importance for industrial processes. Despite the fact that more than 50% of the high-purity Si is wasted during wafer slicing in fabricating photovoltaic (PV) modules [1], the applications of recycled kerf-loss Si still remain limited [2] and may not meet the cost of purification from slurry. Si powder in the recovered kerf-loss mixture is approximately nano-sized, which is a potential candidate for anodes in Li-ion batteries due to its high theoretical capacity. The main challenge associated with Si anodes is the pulverization of electrodes caused by the large volume change (~300%) during cycling, resulting in rapid capacity fading. In this work, we developed a novel way to synthesize nano-structured Si-SiC-Ni composite microparticles from processed kerf-loss powder with addition of metal Ni, aiming to tackle the problem thoroughly.

Discussion

Abrasive SiC particles were retained in the recovered kerf-loss powder purposely in our design. Additional nickel serves as robust conductive matrix with silicon carbide as structural supporting pillars (**Figure 1**). Scanning electron microscopy (SEM) and elemental mapping analysis showed similar results to our design (**Figure 2**). From electrochemical characterization, this composite material affords remarkable battery performance. As shown in **Figure 3**, its reversible capacity reached around 600 mAh/g (~60% enhancement of its state-of-the-art carbonaceous counterpart) with 85% of retention after 250 cycles. We believe that superior performance is attributed to the proposed structure with high mechanical strength which can effectively buffer the volume change of Si. In addition, nickel silicide formed on the Si-Ni interface facilitates electron conduction within the material.

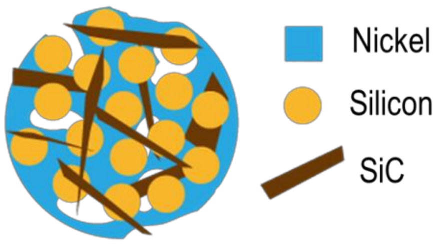

Figure 1: Schematic of the structural design

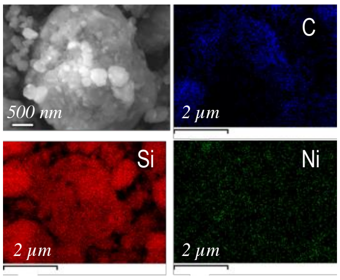

Figure 2: Elemental mapping analysis

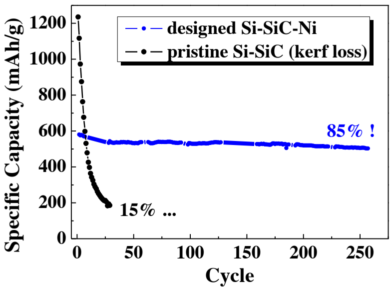

Figure 3: Cycling performance

Conclusions and Outlook

With recycled solar-grade kerf-loss silicon as a raw material, a mechanically robust Si-based composite was synthesized and successfully applied to anodes in Li-ion batteries. We therefore propose an alternative for the usage of Si recovered from kerf loss, transforming waste from PV industry into high-value products.

Acknowledgement: This work is supported by the Ministry of Science and Technology, Taiwan, under the contract number: NSC 103-ET-E-002-001-ET

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Effects of Surface Coating on Performance of High-Capacity Lithium-Rich Manganese-Nickel Oxide Cathode of Lithium-ion Batteries

Yun Chu, *Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, r02524033@ntu.edu.tw*
Pei-Sian Shao, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, r03524055@ntu.edu.tw
Dr. Wen-Chin Chen, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, r97524027@ntu.edu.tw
Dr. Nae-Lih Wu, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, nlw001@ntu.edu.tw

Keywords: Cathode materials, Conductive polymer, PTFE

Abstract

Spherical composite oxide $Li_{1.2}Ni_{0.4}Mn_{0.6}O_{2.2}$ (or $0.2Li_2MnO_3 \cdot 0.8LiNi_{0.5}Mn_{0.5}O_2$) powder as a Li-ion battery cathode has been synthesized by high-temperature calcination of a mixture containing Li_2CO_3 and $(Ni_{0.4}Mn_{0.6})CO_3$, which is synthesized by a continuous co-precipitation method. To improve the electrochemical properties of this material, the poor electronic conductivity and thermal stability should be considered as the major problems to overcome. In this study, we use conductive polymer, Poly(3,4-ethylene-dioxythiophene):poly(styrenesulfonate) (PEDOT:PSS), coating [1] [2] to enhance the electronic conductivity and use membrane, Polytetrafluoroethylene (PTFE), coating to stabilize the cycling in the high temperature. By a liquid mixing and low temperature process, PEDOT:PSS-coated $Li_{1.2}Ni_{0.4}Mn_{0.6}O_{2.2}$ particles have a better rate performance and higher specific capacity. It is demonstrated that the $Li_{1.2}Ni_{0.4}Mn_{0.6}O_{2.2}$ coated with 2 wt.% PEDOT:PSS can substantially enhance the conductivity of $Li_{1.2}Ni_{0.4}Mn_{0.6}O_{2.2}$ powder(**Figure 1**), while it have limited improvement of powder resistance when the amount of PEDOT:PSS is above 2 wt.%. Also, by the Plasma Enhanced Chemical Vapor Deposition method [3], PTFE-coated $Li_{1.2}Ni_{0.4}Mn_{0.6}O_{2.2}$ electrode performed a better stability on high temperature. As a consequent, with the surface coating, the spherical composite oxide $Li_{1.2}Ni_{0.4}Mn_{0.6}O_{2.2}$ is showing a significant enhancement on both its electrochemical properties and high temperature stability.

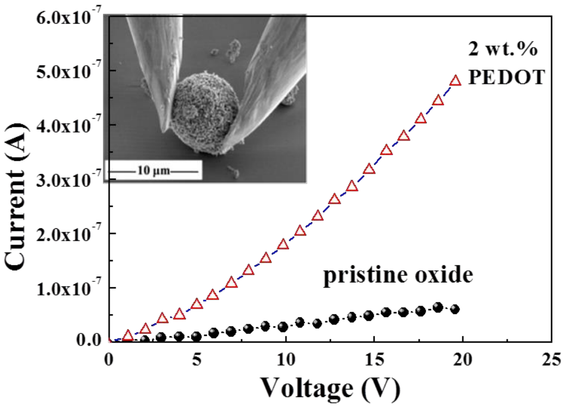

Figure 1: I-V curve of individual $Li_{1.2}Ni_{0.4}Mn_{0.6}O_{2.2}$ particles, showing increasing conductivity by coating of conducting polymer.

Acknowledgement: This work is supported by the Ministry of Science and Technology, Taiwan, under the contract number: NSC 102-3113-P-002 -043

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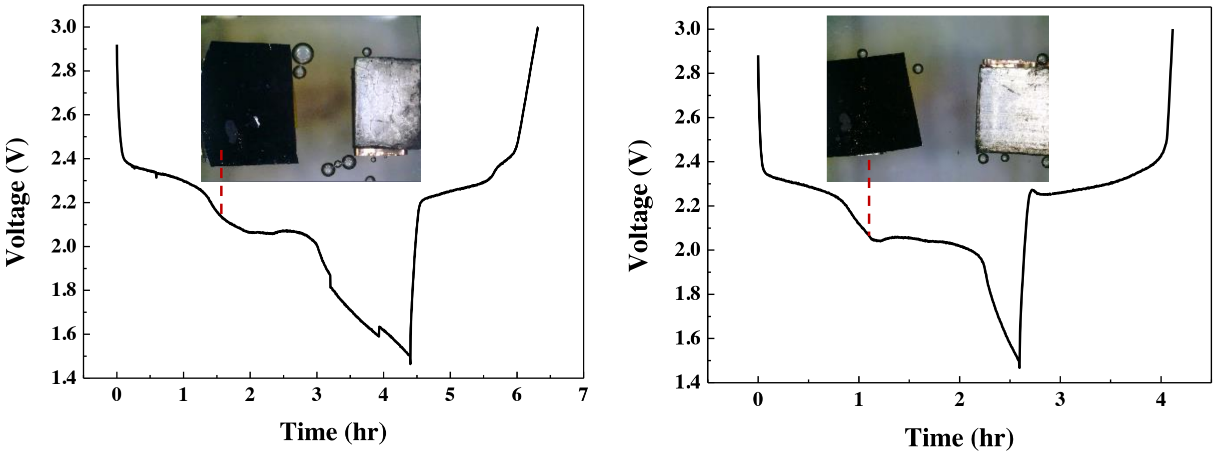
In-Operando Optical Microscopic Study on Polysulfide Dissolution and Dendrite Formation of Lithium-Sulfur Batteries

***Jing Luo**, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, r03524095@ntu.edu.tw*
Dr. Nae-Lih Wu, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, nlw001@ntu.edu.tw

Keywords: Lithium sulfur battery, polysulfide dissolution, dendrite formation

Abstract

The advantages of high theoretical specific energy and low cost of sulfur have recently brought rechargeable Lithium-Sulfur (Li-S) batteries to the spotlight. Yet poor cycle life and low power capability remain major technical obstacles. Various techniques, such as scanning electron microscopy (SEM), transmission X-ray microscopy (TXM), atomic force microscopy (AFM), Raman, X-ray diffraction (XRD), have been used to characterize Li-S batteries. In this study, a special device has been set up to allow for *in-operando* optical microscopy to be utilized for real time observation of the charging and discharging processes of Li-S batteries under various conditions. The dissolution and re-deposition of polysulfide at the cathode as well as the Li dendrite formation at the anode are visualized and investigated. Effects of electrolyte concentration, electrode sulfur loading, and electrode surface modification are studied.



(a)

(b)

Figure 1. Dissolution of polysulfide (appearing yellowish) from sulfur cathode at 0.1 C in (a) 1M and (b) 2.5 M LiTFSI electrolyte. Polysulfide migration is inhibited in higher lithium salt concentration.

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Disordered Dilithium Oxyfluoride as New Li$^+$ Intercalation Host

***Dr. Ruiyong Chen**, Helmholtz Institute Ulm, ruiyong.chen@kit.edu*
Dr. Shuhua Ren, Institute of Nanotechnology, Karlsruhe Institute of Technology, shuhua.ren@kit.edu
Prof. Maximilian Fichtner, Helmholtz Institute Ulm, maximilian.fichtner@kit.edu
Prof. Horst Hahn, Institute of Nanotechnology, Karlsruhe Institute of Technology,horst.hahn@kit.edu

Keywords: Energy storage, Li-ion batteries, Intercalation cathode, Oxyfluoride, Disordered rock-salt

The discovery and synthesis of new battery materials are of great importance for boosting the development of sustainable electrochemical energy storage techniques. Since the first commercialization of Li-ion batteries in the early 1990s, the lithium intercalation compounds have been technically selected as materials of choice. However, the emerging market of electric vehicles and large-scale stationary applications needs higher energy storage capability of Li-ion batteries beyond the current status. Herein, we report that new compounds based on Li_2MO_2F with disordered rock-salt structure are suitable as stable intercalation host for a large amount of Li$^+$ storage per transition metal utilizing M^{3+}/M^{5+} redox couples. Moreover, such material shows good rate capability and low-temperature performance.

A simple ball-milling synthesis route was carried out to obtain Li_2MO_2F [1]. The crystal structure has been determined to be disordered rock-salt [2]. Recent ab initio computation predicted that Li$^+$ diffusion can be facile in Li-rich disordered framework [3]. Figure 1 shows that these new materials (marked with asterisks) exhibit impressive high gravimetric capacities of about 320–400 mAh g^{-1} and volumetric capacity of about 1800–2000 Ah L^{-1}. Despite relatively low operation voltage (2.5–3.2 V) of the new materials in comparison with the classic cathode materials, these oxyfluoride materials exhibit high gravimetric energy densities of about 1000 Wh kg^{-1} (Figure 1a), which is comparable to the Li-rich NMC. Particularly, the oxyfluoride materials show high volumetric energy density 4000–5000 Wh L^{-1} , compared to 3200 Wh L^{-1} for $LiCoO_2$ (Figure 1b) [4]. These electrochemical properties make them promising as cathode materials for Li-ion batteries in terms of the transportation applications. For the first time, we demonstrate the feasibility of employing two-electron intercalation materials for enhanced energy storage using disordered oxyfluorides.

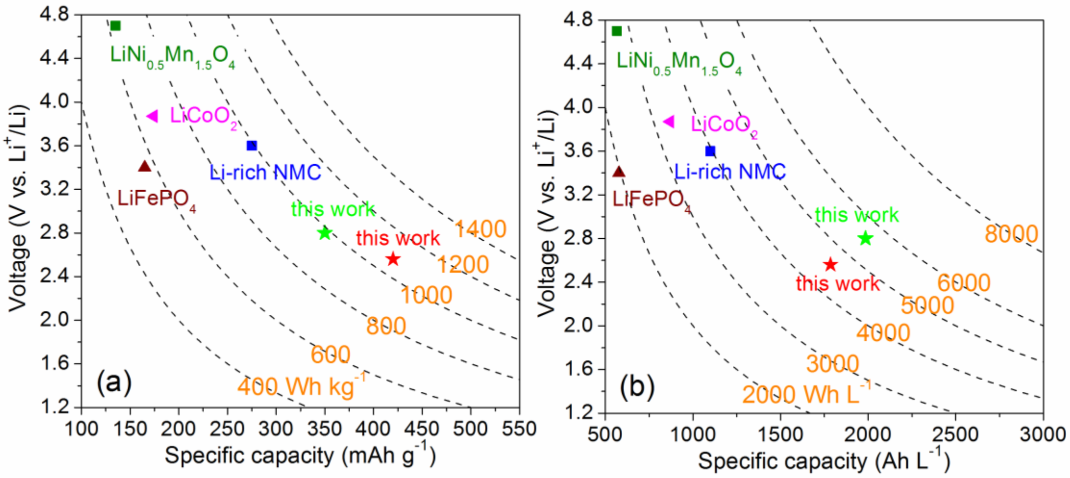

Figure 1: Comparison of the (a) gravimetric and (b) volumetric energy densities of the new proposed oxyfluoride cathode materials with that of the classic cathode materials for Li-ion batteries.

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Template-Free Electrochemical Synthesis of High Aspect-Ratio Tin Nanowires

R. Al-Salman, Eggenstein-Leopoldshafen/DE, H. Sommer, Eggenstein-Leopoldshafen/DE, T. Brezesinski, Eggenstein-Leopoldshafen/DE, J. Janek, Eggenstein-Leopoldshafen/DE

Dr. Rihab Al-Salman, Battery and Electrochemistry Laboratory (BELLA), Institute of Nanotechnology, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen

High aspect-ratio tin (Sn) nanowires are synthesized by a facile, low-temperature and template-free electrochemical method. The nanowires are prepared by electrochemical deposition from $SnCl_4$/1-butyl-1-methylpyrrolidinium bis(trifluoromethylsulfonyl) imide (BMP-TFSI) ionic liquid solution containing $SiCl_4$. $SiCl_4$ strongly promotes the growth of Sn nanowires under specific conditions, whereas no such nanowires were obtained in the absence of $SiCl_4$. The nanowires show a novel hair-like morphology having very high density and a fairly uniform diameter (20 nm to 30 nm) over a length of up to 90 μm, leading to extreme aspect ratios in the order of 10^3 to 10^4. The nanowires are highly crystalline and single phase tetragonal β-Sn, as confirmed by XRD and TEM measurements. The morphology of the Sn deposit can be tailored by changing deposition parameters such as the concentration of $SiCl_4$ and/or $SnCl_4$ and the electrode potential. As an example, closely packed high aspect-ratio Sn nanowires are obtained with a concentration of 0.5 M $SiCl_4$ (see **Figure 1a**) whereas a porous 3-dimensional network of shorter Sn nanowires (see **Figure 1b**) is obtained with a lower concentration of 0.1 M $SiCl_4$. The unusual morphology might be of great interest for applications such as Li-ion batteries, catalysis and others. [1, 2]

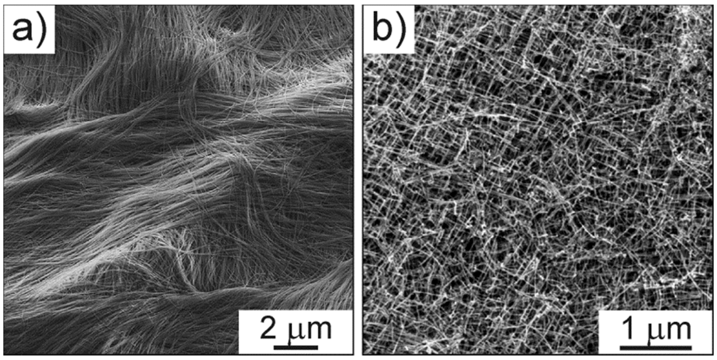

Figure 1. FESEM images of Sn nanowire networks produced with different deposition parameters.

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Synthesis and Characterization of Mg-Mn-O Spinel Cathodes

Dr. Johannes Schwank*, Department of Chemical Engineering, University of Michigan, schwank@umich.edu*
Dr. Xiaoyin Chen, Department of Chemical Engineering, University of Michigan, xychen@umich.edu

Keywords: Energy Storage, Multivalent Batteries, Magnesium Batteries, Cathode Materials, Spinel

Introduction

In recent years, there has been signficant research conducted in the quest to develop rechargeable magnesium batteries [1]. One of the key challenges is to identify Mg cathodes that can reversibly store and release Mg^{2+} cations [2]. This paper focuses on the synthesis and characterization of high performance Mg-Mn-O spinel cathode materials for magnesium batteries.

Discussion

The synthesis of Mg-Mn-O spinel cathode materials was achieved by means of a simple and cost-effective method that involved solid-state interactions of magnesium and manganese precursors. The conditions of forming spinels and parameters that affect the structural properties such as oxygen vacancies were systematically investigated by varying Mg and Mn precursors, as well as heating and cooling rates. A novel method was developed based on thermogravimetric analysis (TGA) that allowed us to directly quantify the amount of oxygen vacancies in the structures that could be reversibly created and filled via cyclic feeding of pure N_2 flow and $10\%O_2/N_2$ flow. These vacancies affect the mobility of oxygen in the structures and thus are relevant to the electrochemical performance of spinel cathodes. The crystallography and surface oxidation states of the obtained cathode materials were characterized by XRD and XPS. The morphology and surface elemental compositions were determined by SEM/EDS.

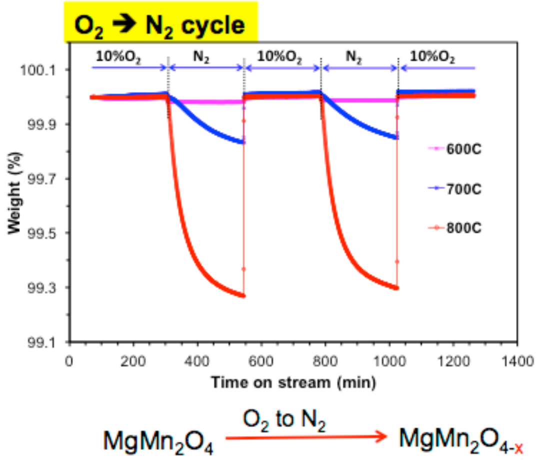

Figure 1: Thermogravic analysis showing the reversible release and uptake of oxygen in MgMn2O4 spinel at different temperatures.

Conclusions and/or Outlook

The synthesis of phase-pure $MgMn_2O_4$ spinel proofed to be difficult. A mixture of $MgMn_2O_4$ and Mg_2MnO_4 phases has been obtained, regardless of Mg-precursor (nitrate vs. acetate) and preparation procedure (cooling rate). XPS results showed that Mn^{2+}, Mn^{3+} and Mn^{4+} co-existed on the surface**.** Magnesium precursor and preparation procedure (cooling rate) affected the surface Mn^{3+}/Mn^{4+} composition. However, the pure Mg_2MnO_4 phase could be successfully synthesized using the solid state interaction. The concentration of oxygen vacancies measured by TGA in Mg_2MnO_4 was higher than that in $MgMn_2O_4$ cathodes, indicating the potentially higher electrochemical activity of Mg_2MnO_4 as compared to $MgMn_2O_4$ cathodes. Understanding how oxygen vacancies affect the structure and electrochemical properties of cathode materials is important for rational design of Mg-battery spinel cathodes.

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Technical and Economic Potential of Storage Systems in Distribution Grids

Soeren Schrader, *P3 Energy & Storage GmbH*
Philipp Goergens, *Institute for High Voltage Technology RWTH Aachen University*
Simon Koopmann, *Institute for High Voltage Technology, RWTH Aachen University*
Dirk Magnor, *Institute for Power Electronics and Electrical Drives, RWTH Aachen University*

Keywords: Smart Grid, Renewable Energy, Battery storage systems, Distribution grids, self-consumption

Introduction

As a consequence of the established support scheme for photovoltaic (PV) battery systems in Germany in May 2013, the penetration of battery storage systems (BSS) in low voltage grids is rising. In addition to increasing the local self-consumption rate of PV energy, BSS have the technical ability to provide services to various interest groups. Therefore P3 energy in cooperation with RWTH Aachen University conducted a study to analyse and quantify the added value of a utilisation of BSS from a technical and economical point of view under consideration of different user perspectives:

- Maximization of local self-consumption ("Self-Consumption")
- Offering grid services ("Grid supportive")
- Many distributed BSS as a virtual large scale storage to attend in energy markets ("Power Trading")

For each perspective a mathematical simulation model has been developed to analyse the effects. This paper aims to outline a representative sample of the results from all points of view.

Discussion

For analysing the self-consumption perspective, a simulation model with detailed battery properties like thermal and aging behavior has been developed. The analysis has been done for one exemplary household with a yearly consumption of about 4,700 kWh and a 4 kW_p PV generator having a yearly energy yield of 4,100 kWh. Focus of the analyses is to find the battery capacity providing the optimal economic gain for the system operator. While increasing the local self-consumption, the battery induces additional costs which show a significant dependence on the battery lifetime. The lifetime itself is strongly dependent on the operation regime of the battery. The proposed model is able to predict the battery lifetime in dependence of the operation regime (according to a proper parameterization) (Figure 1). While lifetimes of up to 25 years can be achieved for very shallow cycle operation, the necessary oversizing increases battery costs. The optimum sizing for the regarded exemplary household leads to energy throughput costs of approximately 40 Cents/kWh which can be reduced to 25 Cents/kWh considering the support scheme and is therefore at the edge to an economic operation.

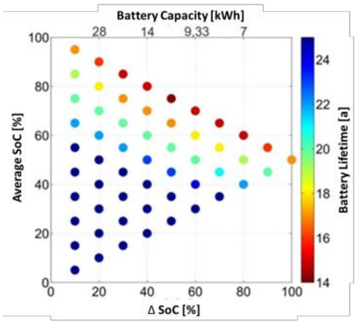

Figure 1: Operating dependent lifetime of a Li-Ion battery

For evaluating a BSS utilisation from the "grid supportive" perspective, a probabilistic optimal power flow model [1] was developed. Two optimization functions have been realized with the objective of loss minimization or keeping the voltages close to their rated values. Two typical grids were simulated for a scenario in 2034 (PV penetration of 43%) where voltage and overload problems occur (cf. Figure 2) [2]. Results show, that a penetration rate of 5 % BSS/houses with a capacity of 8 kWh can achieve a voltage reduction around two percentage points and overload problems can be eliminated.

If many distributed BSS act like a virtual large scale storage and participate in energy markets ("Power Trading"), the break even costs of a Li-Ion BSS without operating costs depend on the lifetime (5 - 20 years) and vary between 1,200 €/kWh and 1,400 €/kWh. Participating on the markets for control reserve is key for reaching these break even investment costs [3]. Nowadays the current costs of domestic BSS are about 1,800 €/kWh and hence still about 23% too high for a profitable operation. However, these break even costs are in the range of current costs for MW scale Li-Ion battery storage.

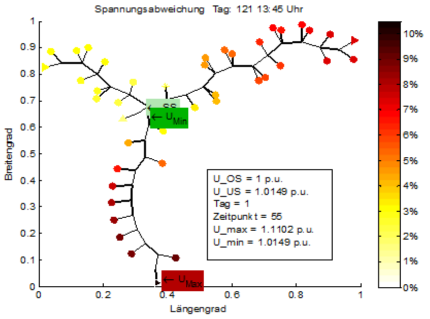

Figure 2: Maximum node voltages in a LV-grid on a summer day

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Flow Phenomena in Liquid Metal Batteries

Tom Weier, Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, t.weier@hzdr.de
Vladimir Galindo, Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, v.galindo@hzdr.de
Frank Stefani, Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, f.stefani@hzdr.de
Norbert Weber, Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, norbert.weber@hzdr.de

Keywords: Liquid metal batteries, Magnetohydrodynamics, Tayler Instability

Introduction

Liquid metal batteries (LMBs) are high temperature systems consisting of liquid metal electrodes and a molten salt ionic conductor. The densities are chosen in such a way that a stable density stratification of the inmiscible layers as shown in the upper left part of **Figure 1** results. LMBs were considered mainly as part of energy conversion systems in the 1960s [1] and have only recently received renewed interest for economic large-scale storage [2]. Our work concentrates on the fluid dynamic aspects of this cell type with a special focus on the effects and properties of the Tayler instability (TI).

Discussion

Due to the completely liquid interior of LMBs, fluid flow is an important aspect of their operation. It can be beneficial, when enhancing mass transfer in the cathode, or it might have harmful consequences, if the integrity of the electrolyte layer is disrupted (**Figure 1**, lower left part). The latter case can result form the action of the current-driven TI. We therefore studied the characteristics of the TI depending on the cell's aspect ratio h/b using an integro-differential approach implemented in the open source library OpenFOAM® [3]. The TI occurs if a critical value of a dimensionless parameter $\mathrm{Ha} = I\mu_0\sqrt{\sigma}/(2\pi\sqrt{\nu\rho})$ is exceeded. Ha, the Hartmann number, is in our case solely determined by the total current I and the material properties density ρ, kinematic viscosity ν, and electrical conductivity σ. μ_0 denotes the vacuum permeability. The critical Ha is lowest for an infinitely high cuboid and corresponds to a total current of approx. 1 kA in the case of Na. Decreasing the aspect ratio increases $\mathrm{Ha}_{\mathrm{crit}}$ since the wavelength selection for the TI becomes more and more restricted. **Figures 1** a, c, e, g display the flow structure and **Figures 1** b, d, f, h the vertical magnetic field contours at the indicated aspect ratios.

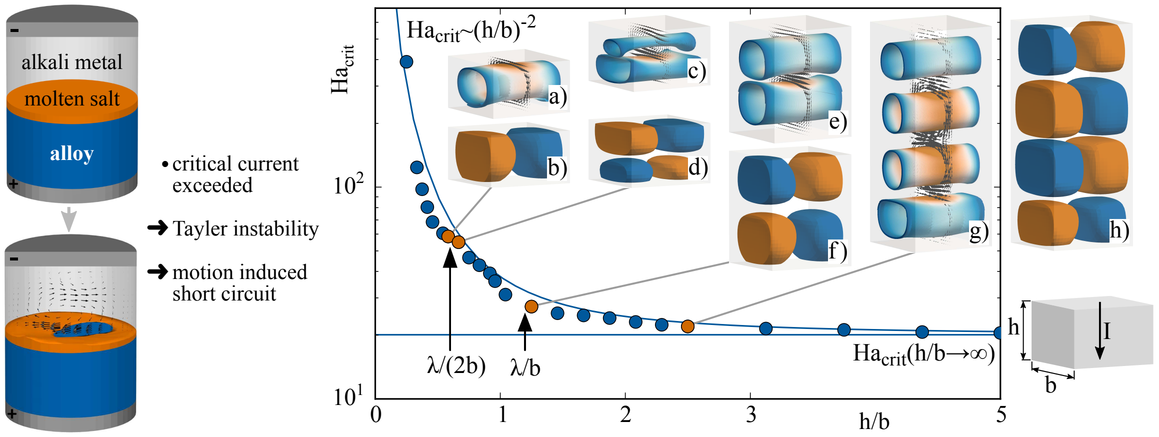

Figure 1: Sketch of a LMB and the possible consequences of the TI (left). Dependence of the critical Hartmann number for the onset of the TI on the aspect ratio of a cuboid with a quadratic footprint (right). Please refer to the text for further details.

Current densities in LMBs are typically very high. A current density of 10 kA/m^2 is a characteristic value for a Na|NI-NaCl-NaF|Bi-system and results in an approximately 10 mm thick sodium layer transferred per hour from the anodic to the cathodic compartment. Depending on the design capacity and cell area, aspect ratios of the anodic compartment up to $h/b \approx 1$ seem imaginable.

Conclusions and Outlook

Flat enough cells will not suffer from TI induced short circuits, for taller ones stabilization measures, as discussed in [4], can be applied to prevent negative consequences.

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The Role of Energy Status Data in Solar Power Plants with Li-Ion Batteries

***Dr. Thomas Blank*[1]*, Dr. Andreas Kopmann*[1]*, Petra Rohr*[1]*, Volker Hartmann*[1]*, Prof. Dr. M. Weber*[1]*, Dr. Olaf Wollersheim*[2]*, Karlsruhe Institute of Technology (KIT),* [1]*Institute for Data Processing and Electronics (IPE),*
[2]*Project competence-E*
Thomas.Blank@kit.edu

Keywords: Energy storage, energy data, Li-Ion Battery, solar power plant

Abstract

Electrical energy produced by solar power plants is very volatile. “Battery Electric Storage Systems” (BESS) can reduce the energy fluctuation. Thus KIT developed solar plants, upgraded by a BESS (SBESS). The SBESS was designed to generate 50 KW of electrical power and to store 48 kWh. However, as local energy production and consumption data is limited, the SBESS cannot be optimized. This paper presents a SBESS with enhanced data collection and storage technologies. It is integrated in an “Advanced Data Extraction Infrastructure” (ADEI) which enables a network of worldwide stations. Three of this systems have been installed, two at KIT and a third one at the Helmholtz Institute Ulm. A further system is currently prepared to serve as experimental plant on a Greek island. The experience gained from operational data will allow the optimization of the design and operation of regenerative power plants with Li-Ion battery storage systems.

Introduction

KIT develops SBESS containing Li-Ion batteries to buffer the energy generated by the solar panels. The battery reduces the volatile character of the solar plant. However, Li-Ion batteries must be handled cautiously because of their high risk to ignite [1]. “Battery Management Systems” (BMS) keep the battery in a safe state and monitor the temperature and charging state of each cell. More than 700 sensor nodes surveil the plant depicted in Figure 1. They are recorded every 500 ms. The data is stored in a SQL-database on an onsite industrial PC, which also controls the plant. The plant can operate fully autonomously with persistent data acquisition. The SBESS is integrated in the ADEI [2]. ADEI has been developed to provide a unified data access layer for large amounts of time-series data. It supports internal data processing, caching, data aggregation and fast visualisation in the web. Hence, the data of all distributed KIT solar plants can be supervised in one integrated environment. For long-term archiving of the data ADEI is connected to the “Large Scale Data Facility” (LSDF). The LSDF aims to store scientific data together with related meta information in a durable data formats [3].

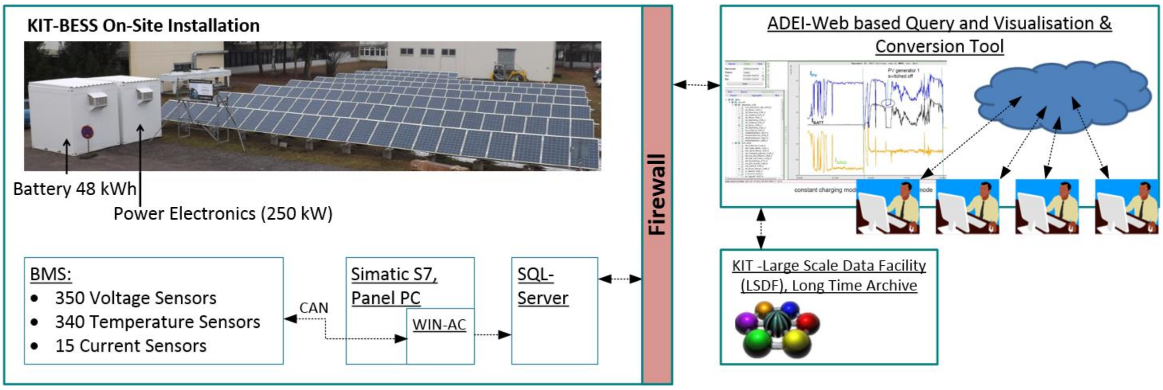

Figure 1: Scientific technology platform for a worldwide data collection, visualization evaluation and long-time storage of energy status data from a solar power plant with a Li-Ion battery storage system.

Conclusions and/or Outlook

SBESS with sophisticated energy data management functions have been proposed. Monitoring worldwide distributed plants and the evaluation of their data will lead to systems with optimized control strategies and system layouts. In future prediction algorithms and individual consumption profiles can even enhance the operational availability, resulting in more reliable and cheaper solar power systems.

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Thermo-electrochemical modeling of LiC_6/LFP and LTO/NCA lithium-ion batteries for lifetime and safety prediction

Christian Kupper, Institute of Energy System Technology (INES), Offenburg University of Applied Sciences, christian.kupper@hs-offenburg.de
Svenja Spitznagel, Institute of Energy System Technology (INES), Offenburg University of Applied Sciences, sspitzna@hs-offenburg.de
***Prof. Dr. Wolfgang G. Bessler**, Institute of Energy System Technology (INES), Offenburg University of Applied Sciences, wolfgang.bessler@hs-offenburg.de*

Keywords: Lithium-ion battery, Modeling, Durability, Safety

Introduction

Lithium-ion batteries are among the key technologies for decentralized stationary electrical energy storage, for example, for diurnal storage of photovoltaic power. Today the most widely distributed material concept is graphite/lithium iron phosphate (LiC_6/LFP). These cells have limited lifetime, mainly due to SEI formation at the negative electrode. Alterative cell concepts include lithium titanate/nickel cobalt aluminum oxide (LTO/NCA) with high cyclic lifetime due to the relatively high potential of LTO against lithium of 1.55 V [1], considerably reducing SEI formation. In addition to lifetime, safety has become a major concern after reports of stationary Li-ion battery fires [2].

Methodology

We present a multi-scale modeling study of two different lithium-ion battery cell types, LiC_6/LFP and LTO/NCA, with focus on performance, lifetime and safety prediction. The thermo-electrochemical modeling approach couples a 1D thermal cell-level (macro-scale) model, a 1D electrode-pair level (micro-scale) model, and a 1D particle-level (nano-scale) model in order to describe all relevant multiphysics processes. Apart from the main intercalation chemistry, degradation reactions are included, particularly, electrochemical SEI formation, thermal SEI decomposition at high temperature, and NCA decomposition [3].

Conclusions

Simulations under nominal operating conditions show good agreement with experimental data. Simulations under elevated temperature and heavy-cycling conditions are carried out to investigate the onset of thermal runaway.

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Flexible Operation of Catalytic Fuel Synthesis Reactors – Experimental and Modeling Analysis of Fixed Bed Reactors

María Iglesias G., *Engler-Bunte-Institut, Karlsruhe Institute of Technology (KIT), maria.iglesias@kit.edu*
Hilko Eilers, *Engler-Bunte-Institut, Karlsruhe Institute of Technology (KIT), hilko.eilers@kit.edu*
Prof. Georg Schaub, *Engler-Bunte-Institut, Karlsruhe Institute of Technology (KIT), georg.schaub@kit.edu*

Keywords: Flexible Operation, Fixed Bed Reactor, Fischer-Tropsch

Electricity-to-fuel: transient operation of catalytic reactors

Large-scale catalytic reactors in chemical industry are, in general, operated under steady state conditions. However, in special cases, transient operation of catalytic reactors could lead to benefits for the overall process. The conversion of electricity into fuels (chemical energy carriers, e.g. hydrocarbon synfuels) is a potential storage technology that may become interesting if electricity from renewable intermittent sources (wind/solar) covers a high percentage of electricity demand [1]. The motivation to operate the reactor under transient conditions is a reduction of H_2 storage size and consequently of required investment. As for transient operation of catalytic reactors in large-scale processes, there are many uncertainties regarding catalyst behaviour, reactor design, operability and robustness of the process.

The aim of the present research is to analyse, from a reaction engineering perspective, relevant features for the flexible operation of catalytic reactors (e.g. catalyst behaviour, reactor design). CO_2 hydrogenation to gaseous hydrocarbons using iron catalyst in a fixed bed reactor (gas/solid system) is the selected fuel synthesis reaction.

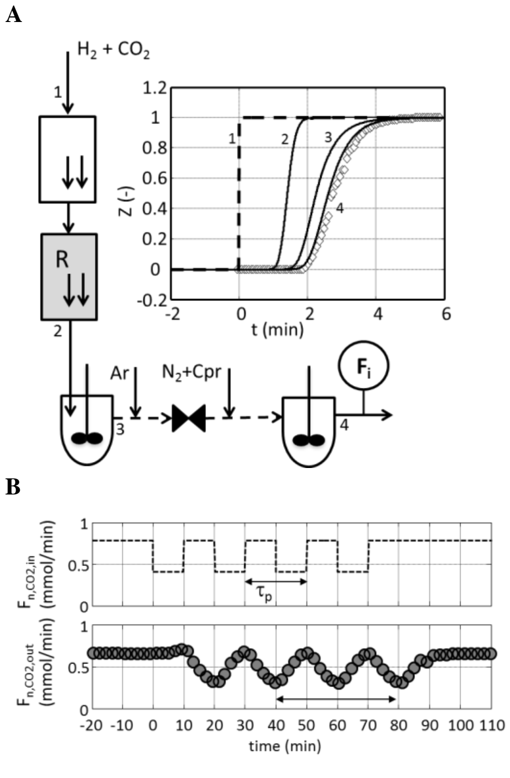

Figure 1: A) Simplified representation of lab-scale setup as a combination of ideal flow models, example: step change in inlet concentration with calculated CO_2 flows at different locations (normalized), symbols: experimental data. B) Example experimental result periodic changes: CO_2 inlet (top) and outlet flow (bottom).

Methodology: Experiments in lab-scale set up and mathematical modeling studies

To determine the catalyst behaviour under transient conditions, the methodology includes experiments and mathematical modeling. Figure 1A shows an example of a step change experiment in lab-scale combined with mathematical modeling of the lab-scale setup to separate effects of the peripheral equipment. Conceptual studies about large-scale reactor design are carried out using one- and two- dimensional mathematical models of a non-adiabatic fixed bed reactor.

Example Result – Catalyst behaviour

Figure 1B shows an example result of an experimental periodic change in H_2/CO_2 inlet ratio to investigate the catalyst behaviour. From these experiments it is possible to conclude that for $\tau_p > 20$ s the catalyst operates under steady state conditions. Kinetics determined under steady state conditions can describe the transient operation of the catalyst in the lab-scale reactor (in the range of operation conditions for which the steady state kinetics were determined).

Conclusions and Outlook

The combination of experimental work and mathematical modelling is in this case a powerful tool that allows the analysis of the catalytic reactor with its periphery under dynamic conditions. A similar methodology is applied in a parallel study for a gas/liquid/solid system using a slurry reactor. The Fischer-Tropsch synthesis with H_2/CO syngas and cobalt-based catalyst is selected as fuel related synthesis.

Acknowledgement: This work was financially supported by the German Bundesministerium für Bildung und Wissenschaft and by the German Bundesministerium für Ernährung und Landwirtschaft (BMBF, FKZ: 033RC1010A and BMEL FKZ: 22403711) .

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Concepts to utilize renewable power in chemical production

Julia Riese, *Laboratory for Fluid Separations, Ruhr-University Bochum, riese@fluidvt.rub.de*
Prof. Marcus Grünewald, Laboratory for Fluid Separations, Ruhr-University Bochum, gruenewald@fluidvt.rub.de

Keywords: flexible production, chemical process industry, wind and solar power

Introduction

To limit the emission of greenhouse gases from energy conversion processes, primarily carbon dioxide, the importance of renewable energy sources increases worldwide. In Germany their share in the gross electricity production was as high as 24 % in 2013. This development is mainly driven by increasing capacities of photovoltaic systems and wind turbines. The output of those technologies is highly volatile due to the dependency on local weather conditions. Thus, a non- or only little elastic overall energy demand faces an energy supply structure being increasingly volatile and less predictable. As a consequence, electrical energy has to be stored on medium or long term. Neglecting issues regarding grid expansion it is alternatively possible to enable more flexibility in energy demand.

Discussion

Within contribution we present pathways to utilize renewably generated power based on volatile sources in the chemical process industry. For the production of base chemicals and intermediates, those processes are characterised by high throughputs and mostly continuous operation. To produce base chemicals material conversion and separation is performed under harsh conditions, e.g. high pressures and high temperatures, resulting in high specific energy demand per tonne main product. Subsequently, the potential leverage effect of the chemical process industry to enable flexibility in energy demand can be comparably significant. This overall potential has already been presented in [1].

However, the apparatus widely used to perform material conversion and separation in chemical processes, e.g. solid catalysed gas-phase reactors or distillation columns do limit flexibility in operation. In general, this flexibility requirements include broader operating limitation and an increased readiness for startup of the apparatus. In detail, for a solid catalysed gas-phase reactor operation temperature has to be ensured throughout all operating points to prevent catalyst deactivation and maintain a high selectivity to reach high product qualities. For distillation columns it is additionally necessary to enable capacity fluctuations.

Due to this, the first part of this contribution deals with concepts to increase flexibility for those apparatus. Startup of distillation columns is a highly transient process resulting in dynamic changes of thermodynamic and hydrodynamic properties. Reaching constant operation conditions with stationary concentration and temperature profiles within the columns takes several hours [2]. Based on an adopted concept for this apparatus presented in this contribution, startup and flexible operation is investigated theoretically. This concept is based on considerations regarding the immobilisation of liquid hold up within the column resulting in defined concentration and temperature profiles for each operation point. In another concept the reduction of liquid hold up within the column, thus resulting in shorter residence times, is investigates. This reduction is made possible by a segmentation of the apparatus.

In a second part of this contribution those concepts are evaluated within the scope of an overall production process. The new operating limitations are transferred to selected production processes serving as case studies. This evaluation is performed from an economic and an ecological point of view. As a result economic boundary conditions needed for a realisation of this concept are derived and potentials for primary energy savings are presented.

Conclusions

Increasing flexibility of widely used apparatus for material conversion and separation for the production of base chemicals and intermediates is possible by the design and evaluation of new apparatus concepts. Thus, the chemical process industry might contribute as an alternative to bridge the gap between energy supply and energy demand with increasing dependency on volatile renewable energy sources.

Acknowledgement: This research is made possible by the Graduate School of Energy Efficient Production and Logistics, funded by the state of North Rhine-Westphalia, Germany.

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Conceptual Design of Ammonia-Based Energy Storage and its Dynamic Considerations

Ganzhou Wang, *Chair of Process Systems Engineering, RWTH Aachen, ganzhou.wang@avt.rwth-aachen.de*
Alexander Mitsos, *alexander.mitsos@avt.rwth-aachen.de*
Wolfgang Marquardt, *wolfgang.marquardt@avt.rwth-aachen.de*

Keywords: Energy Storage, Optimization-Based Design, Dynamics

Introduction

Due to its amenable properties, chemical-based energy storage has been widely recognized as a promising solution on the GWh-level. System engineering methods are proved valuable in design of high efficient storage processes [1]. Since the corresponding processes must operate dynamically, the operating flexibility of the energy storage plant should also be considered. In this paper we present a conceptual design of ammonia-based energy storage and show the first results related to its dynamics.

Discussion

The flowsheet of the design is illustrated in Figure 1. Two main features are demonstrated: firstly, raw materials, water, oxygen and nitrogen are recycled in each cycle of operation and are therefore in a closed loop. Secondly, heat integration is carried out. The enthalpy of formation of ammonia supports the operation of the electrolyzer and the fuel cell. The liquefaction of nitrogen and oxygen is enabled through heat exchange with existing cold streams. Process optimization is conducted in Aspen Plus® V7.3 in order to maximize the utilization of material, heat and equipment. A round-trip efficiency of 60 percent is achieved.

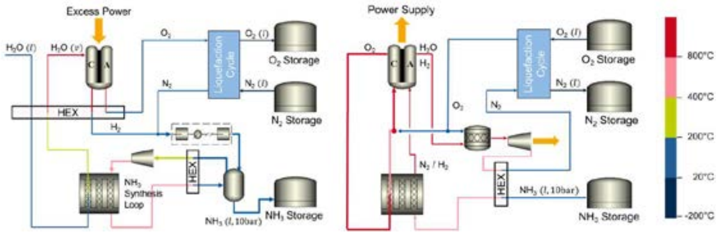

Figure 1 Sketch of the flowsheets in two operation modes. Left: power is used to synthesize ammonia. Right: Ammonia is decomposed and generates power.

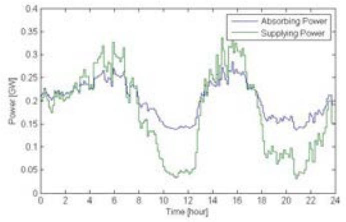

Figure 2 Dynamic response of the designed storage plant in tracking a given wind generation trajectory [2]

To absorb fast dynamics of power inputs, the plant must be flexible and have fast dynamics. A first-principle dynamic mathematical model of major components is therefore built in gProms® and the plant dynamics are studied. As seen from Figure 2, the plant cannot follow the input power trajectory in the full range. This is partly due to a restrictive stability constraint and partly due to the conservative operating strategy. Nevertheless, in the power range between 150 and 250MW the plant shows considerable flexibility.

Conclusion

A novel design of ammonia-based energy storage is presented. It can achieve high efficiency thanks to optimized heat integration. The dynamic response of the plant is acceptable for use on the level of transmission network.

Acknowledgement: the authors appreciate the financial support by the Hans L. Merkle-Stiftung.

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Container plants for generation of sustainable liquid fuels made by ineraTec

***M.Sc. Paolo Piermartini**, ineraTec, paolo.piermartini@ineratec.de*
Dipl.-Ing. Tim Böltken, ineraTec, tim.boeltken@ineratec.de
M.Sc. Philipp Engelkamp, ineraTec, philipp.eneglkamp@ineratec.de
Prof. Dr.-Ing. Peter Pfeifer, ineraTec, peter.pfeifer@ineratec.de and Institute for Micro Process Engineering, Karlsruhe Institute of Technology, peter.pfeifer@kit.edu

Keywords: liquid synthetic fuel, distributed applications, energy storage

Introduction

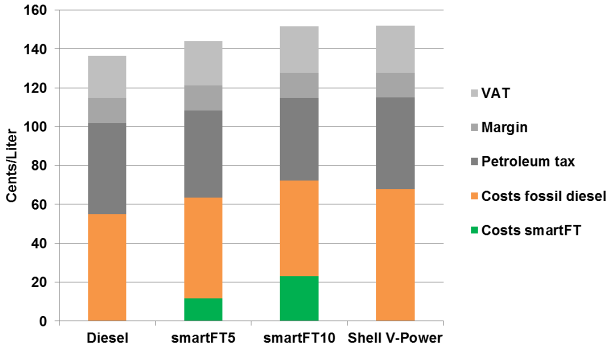
One of the main challenges of society is the storage of renewable energy in the point of generation. Distributed biomass waste for example needs to be converted into a high value liquid fuel to compete with fossil energy and to avoid a necessity for subsidies. Large amounts of electricity from wind power should not be transported throughout Europe. Instead, it should be used to generate fuel for mobility. However, these approaches need efficient technology and modular compact reactors to be technologically and economically viable.

Discussion

It may be almost common knowledge in chemical engineering that exothermic reactions can be controlled in microchannel systems. However, it has been further demonstrated by KIT together with the Norwegian University of Science and Technology and SINTEF that microchannel technology offers real advantages over conventional technologies for fuel synthesis reactions [1,2]. In recent developments of KIT, in the project Syncon funded from KICinnoEnergy, the reactor technology has been proven in long term tests and large reactor modules have been designed. Today these modules are fabricated in order to serve as a basis for technology demonstration with ineraTec's idea of container plants.

Calculations of ineraTec have shown that Fischer-Tropsch (FT) based fuel from gases of waste digestion taking into account a 15 year pay-off period for modular container plants is economically viable along the whole value chain - for ineraTec as supplier, the users of the container plants, the fuelling station and the end user.

Figure 1.compares the total "diesel" price of different additions of ineraTec's smartFT fuel taking into account a margin for the user and full taxation of the sustainable FT fuel with fossil diesel and with the high performance diesel "V-Power" of Shell (which contains 5 % FT fuel from natural gas with some proprietary additives). From these data it seems obvious that a commercial pathway with sustainable fuel is viable for promoting the energy transition in mobility; especially when trying to resolve large distances.



smartFT5: 95% fossil fuel; 5% FT fuel from renewables/waste
smartFT10 in analogy: 10% FT fuel from renewables/waste
Shell V-Power: 5% FT fuel from natural gas

Figure 1: Pricing of a ineraTec's smartFT fuel (full taxation and margin) versus fossil diesel

Outlook

From the data and the reactor and container technology which will be presented, an economic viable way to produce sustainable liquid fuel will be shown. Based on the advantages a first container plant will built and may be accessible soon. The field demonstration is anticipated in 2016.

Acknowledgement: The previous funding of the project Syncon by KICinnoEnergy is highly appreciated. The authors also thank the State of Baden-Württemberg for funding of ineraTec by the Young Innovators program

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Nitrogen-Based Alternative Fuel

***Alon Grinberg Dana**, Grand Technion Energy Program, Technion – Israel Institute of Technology, alon@technion.ac.il*
Dr. Gennady E. Shter, Department of Chemical Engineering, Technion – Israel Institute of Technology, shter@technion.ac.il
Prof. Gideon S. Grader, Department of Chemical Engineering, Technion – Israel Institute of Technology, grader@technion.ac.il

Keywords: Alternative fuel, Combustion, Chemical hydrogen storage, Pollutant abatement

Introduction

As global greenhouse gas emissions are projected to continue to increase, there is urgency to pursue all measures to develop and deploy carbon-neutral energy technologies. The most attractive approach for large-scale energy storage is perhaps in the form of chemical bonds (i.e., fuels). It is well recognized that fuels are unmatched in terms of energy density and transportability for large-scale energy applications, and synthesis of alternative fuels might be advantageous as an energy storage medium for renewable energies. Hydrogen gas is considered a promising clean fuel, yet a pure hydrogen economy approach is non-feasible due to challenges such as extremely low volumetric energy density and danger of explosion. Nonetheless, it is favourable to chemically store hydrogen atoms in the form of more energy-condensed compounds.

Discussion

A comparison between the two major chemical hydrogen carrier approaches – carbon-based and nitrogen-based fuels – will be discussed. In addition, a model nitrogen-based alternative fuel, consisting of an aqueous solution of urea and ammonium nitrate, will be presented. This novel fuel was found to emit less NOx gases per energy unit than the regulation for stationary natural gas power generation turbines. We demonstrated the feasibility of the environmentally friendly continuous combustion of this fuel. Results from continuous combustion experiments – including the dependency of the combustion products on pressure, residence time, and flow rate – will be discussed (Figure 1). During continuous combustion of this fuel, the reaction approached 99.9% conversion at the highest examined pressure of 25 MPa [1].

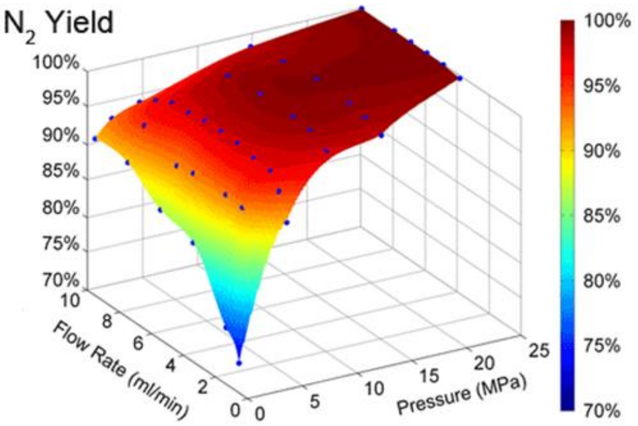

Figure 1: Nitrogen yield vs. pressure and fuel flow rate. Blue dots indicate experimental values.

Outlook

The originality of this work is in demonstrating a continuous, stable and environmentally friendly combustion process using a novel nitrogen-based fuel, rather than the conventional carbon-based paradigm. Conceptually, it is intriguing to think about a future where atmospheric nitrogen becomes the storage hub for hydrogen that will eventually be sustainably mass produced via solar water splitting.

Acknowledgements: We acknowledge the generous support of Mr. Ed Satell, Philadelphia, PA, and the Nancy and Stephen Grand Technion Energy Program (GTEP).

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CO_2 Activation and Conversion into CO via Chemical Looping

Dipl.-Ing. Marcus Wenzel*, Process Systems Engineering, MPI Magdeburg,wenzel@mpi-magdeburg.mpg.de*
Dr. Liisa Rihko-Struckmann, Process Systems Engineering, MPI Magdeburg,rihko@mpi-magdeburg.mpg.de
Prof. Dr.-Ing. Kai Sundmacher, Process Systems Engineering, MPI Magdeburg,kai@mpi-magdeburg.mpg.de

Keywords: CO_2 Activation, Chemical Looping

Introduction

The reverse water gas shift (RWGS) reaction ($CO_2 + H_2 \leftrightarrow CO + H_2O$) enables the conversion of CO_2 to useful CO and, thus, is an important reaction in the context of CO_2 utilization. Unfortunately, considerable product amounts can only be achieved at elevated temperatures (> 800°C), since the reaction is strongly equilibrium limited. Additionally, downstream gas separation is a crucial cost factor, on which the feasibility of the process depends. However, by using a solid oxygen carrier material, the overall RWGS reaction can be decomposed into two separate steps (reduction/oxidation) with only two gases involved in each step. In the first step, the material is reduced with H_2 environment, while H_2O is formed. Subsequently, CO is produced in the second step, as the material is re-oxidized with CO_2. By sequential repetition of the two steps, a cyclic process for CO_2 activation can be established (CRWGS), as can be seen in Figure 1. Hence, the gas separation problem is reduced to the separation of the CO/CO_2 mixture.

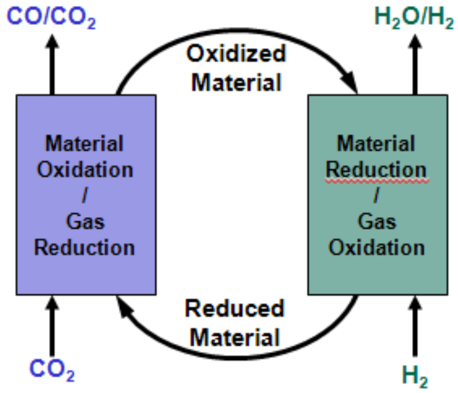

Figure 1: Principle of the CRWGS process.

Discussion

In the present work, 80%-Fe_2O_3-20%-$CeZrO_2$ is used as an oxygen carrier, because of its stability and relatively high oxygen storage capacity [1]. Thermogravimetric experiments were conducted to obtain kinetic information about the redox reactions at the material under varying temperatures and gas compositions. Using the master plot method [2], the most appropriate reaction mechanisms were identified for different steps. Then, suitable kinetic expressions were parameterized with experimental data to allow for modeling and analysis of the whole process. Furthermore, stability of the material is investigated and discussed with regard to future possibilities for a larger scale operation.

Conclusions and Outlook

A kinetic model for the reverse water-gas shift chemical looping process has been proposed based on thermogravimetric experiments. The model is able to describe the reduction and oxidation of the material under different conditions. A concept for CO_2 activation and conversion to CO via the described chemical looping method is presented in the context of sustainable chemicals production.

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A flywheel energy storage system using reluctance clutch and standard drive

Dr. Iason Vittorias, *Siemens AG, Corporate Technology, Research and Technology Center, iason.vittorias@siemens.com*
Dr.Matthias Gerlich, Siemens AG, Corporate Technology, Research and Technology Center, matthias.gerlich@siemens.com
Dr.Georg Bachmaier, Siemens AG, Corporate Technology, Research and Technology Center, georg.bachmaier@siemens.com
Dr.Wolfgang Weydanz, Siemens AG, Corporate Technology, Research and Technology Center, wolfgang.weydanz@siemens.com

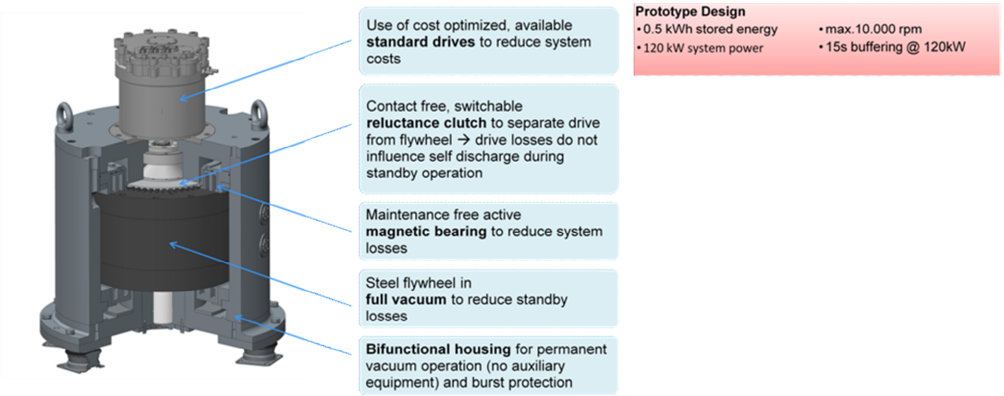
Keywords: Energy Storage, Flywheel, Reluctance coupling

Introduction

Flywheels base their principle of energy storage on the rotational energy stored in a large mass/inertia at high speed, which in turn can drive a generator when demanded. They prove to be efficient energy storage systems which can deliver high amounts of power in very short time, and thus can outweigh electrochemical storage systems (e.g. batteries, supercaps) [1]. Further, even in terms of storage capacity, they often display a significantly better power/volume factor compared to other storage systems [2]. Most flywheel systems operate in vacuum to minimize their rotational losses by avoiding air resistance. In order to achieve full vacuum operation, typically, an induction machine operated also in vacuum is coupled mechanically with the flywheel in order to be able to provide (motor operation) or consume (generator operation) electrical energy.

Discussion

In this paper, a flywheel storage system is presented which is able to operate with any electrical drive due to the simple fact that the drive is kept *outside* of the vacuum. This is made possible through an innovative reluctance clutch, i.e. the flywheel (in vacuum) is not directly mechanically connected with the electric drive (outside of the vacuum) but is coupled magnetically - on demand - via a DC-based magnetic reluctance system (clutch). By this, electric drives with much better power density can be used, such as standard permanent-magnet motors, consequently reducing the volume and costs of such a system. The motor is not required to be always synchronous to the flywheel speed, i.e. they are not mechanically coupled, but is synchronized and coupled only on demand within a range of tenths of a second. Thus the system offers the possibility to use cost optimized standard drives with lower life time compared to the flywheel life time. Also the nominal system power can be adapted to the use case very accurate only by changing the motor but not affecting the remaining storage system. The decoupling also reduces the losses due to the free-running motor (inducted voltage) by the fact that the motor (rotor part) is running only on load and when required. Rotor losses of the system are minimized in that way in the provided system. Further, air resistance is kept at its minimum by enclosing the flywheel in vacuum. Due to the metal encapsulation and absence of any mechanical guides vacuum losses are almost kept at zero and therefore no further vacuum pump is required. Additionally, active magnetic bearings are used instead of mechanical ones to reduce wear, servicing (lubrication in vacuum can be challenging) and thermal losses (friction). In turn, this provides an improved thermal performance to the overall system due to the fact that the proposed flywheel system is not enclosing any ohmic losses in vacuum (such as e.g. in the case of an induction motor enclosed in vacuum).



Use of cost optimized, available **standard drives** to reduce system costs

Contact free, switchable **reluctance clutch** to separate drive from flywheel → drive losses do not influence self discharge during standby operation

Maintenance free active **magnetic bearing** to reduce system losses

Steel flywheel in **full vacuum** to reduce standby losses

Bifunctional housing for permanent vacuum operation (no auxiliary equipment) and burst protection

Prototype Design
- 0.5 kWh stored energy
- 120 kW system power
- max.10.000 rpm
- 15s buffering @ 120kW

Figure 1: 3D view of the developed flywheel system including synchronous motor and reluctance clutch.

Conclusions and/or Outlook

The proposed flywheel system using a novel magnetic reluctance clutch concepts succeeds in separating the motor from the rotating flywheel mass enclosed in vacuum. In that way a) power density is increased, b) system costs are reduced by the use of standard drives, c) thermal behaviour is improving and d) losses of the overall flywheel system are reduced enough to outperform state of the art systems.

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Successful energy transition in Germany by pumped storage expansion

Dr. Klaus Krüger, *Head of R&D, Voith Hydro Holding, Heidenheim, Germany , Klaus.Krueger@Voith.com*
Dr. Niklas Rotering, *Modern Energy Consulting GmbH, Germany, niklas.rotering@gmail.com*
Prof.-Dr. Albert Moser, *Institute of Power Systems and Power Economics (IAEW) of RWTH Aachen University, Germany, am@iaew.rwth-aachen.de*

Keywords: German energy transition, pumped storage expansion, energy system analysis and modelling, CO_2 *emission reduction*

Abstract

Operational flexibility in electrical energy generation and consumption as well as the provision of reliable available capacity are two major challenges of the German energy transition (“Energiewende”). The consistent deployment of cost-effective and proven pumped storage technology can provide significant contributions to meet both challenges. This paper shows that an expansion of pumped storage plants as part of the energy transition is a technically and macro-economically interesting option for Germany. Two future scenarios are investigated, one assumes an energy supply in 2030 with a 60 % share of renewable energy and another expects a renewable energy percentage of 80 % in 2050.

A central result of the investigations is that the appropriate operation of the existing pumped storage inventory and its further expansion can contribute significantly to system adequacy and reduces the necessary fossil-fueled power plant capacity for providing reliable available capacity. In a scenario with 80 % renewable energy, 23 GW pumped storage plants replace up to 16,6 GW thermal power plants. In addition, the pumped storage power plants significantly reduce renewable energy curtailment and substitute fossil energy generation when releasing the stored energy. This also contributes to an overall reduction of CO_2 over-all emissions. Furthermore, the fleet of pumped storage plants actively compensates the volatility of renewable energy from wind and solar generation and allows for a smoother and more economical operation of the remaining fleet of thermal power plants. The compensation of volatility also allows a safer operation of the power system and thereby helps to avoid blackouts.

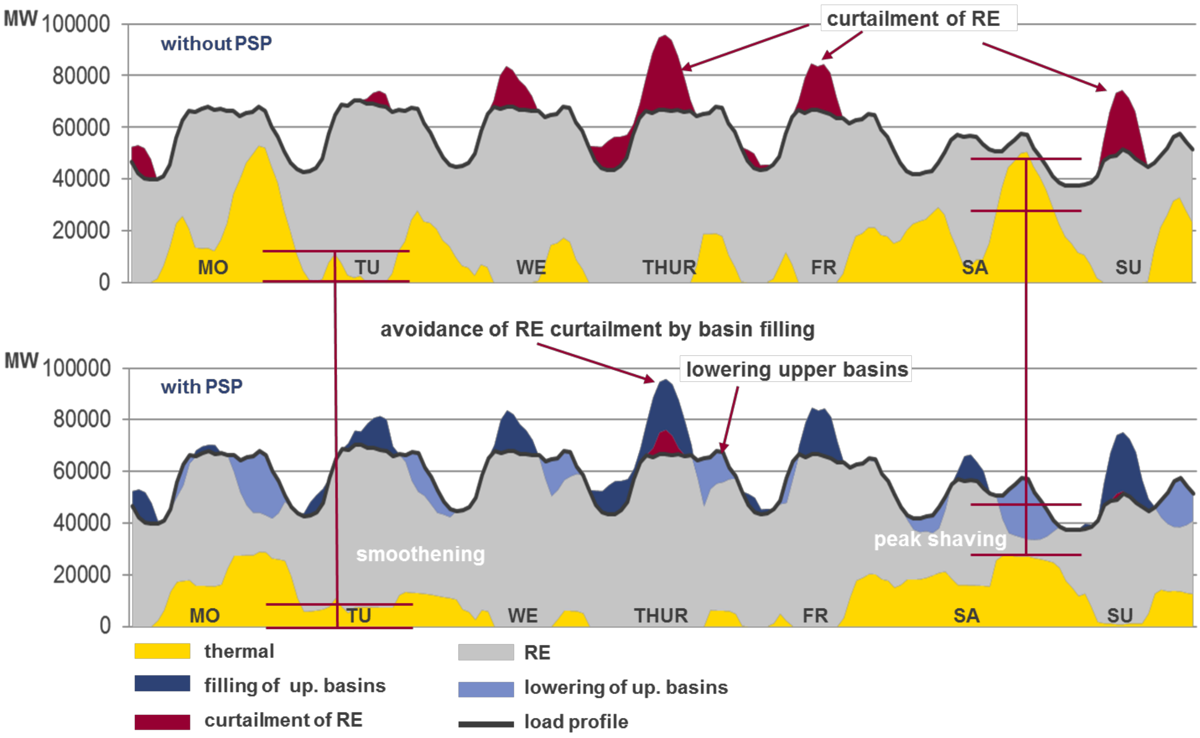

Figure 1: Top: Situation without pumped-storage expansion; Down: effects of pumped storage at 80% share of renewables

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Storage Requirements in a Scenario approaching Electricity Generation from 100% Renewable Sources

Ulrich Platt *and Tobias Tröndle, Institute of Environmental Physics, University of Heidelberg, INF 229, D-69120 Heidelberg*

Abstract

We investigated the relationship of power plant mix and required energy storage capacity with a computer model based on global weather data. The focus of the investigation is on the energy storage requirements of an electricity supply for Europe by wind and solar power. The minimum required energy storage capacity for a totally weather dependent electricity supply occurs at a ratio of about 30% wind and 70% photovoltaic (PV) power plant installed capacity. For a transition of to-day's European electricity supply to a 100% renewable (wind and PV) scenario the required energy storage capacity rises exponentially to about 150 TWh (3.8% of the annual electricity demand).

However the installation of excess wind and PV power plant capacity is shown to be an effective means to reduce the required energy storage. For instance already 10% excess capacity cut the required storage capacity in half, higher excess capacities lead to further, drastic reduction of storage requirements. Furthermore, the storage tasks can be separated into daily (short term) storage and a seasonal (long term) storage.

We investigate the effect of different storage technologies optimised in terms of storage capacity and efficiency. While the seasonal storage capacity has to be about two orders of magnitude larger than the required capacity of the storage for the daily cycle, the annual sum of stored energy is nearly equal for the long term and short term storage. In summary, an electricity supply by wind and PV power is shown to be perfectly feasible with respect to the required energy storage capacity and required land area for power plants, and with competitive electricity generating cost.

A study on characteristics of phase change materials (PCMs) for the enhancement of thermal conductivity by using additive particles

***Mr. Byungkwon Kim**, Thermal Fluid System R&BD Group, Korea Institute of Industrial Technology, KITECH, Mechanical Engineering, University of Yonsei, greatrox@kitech.re.kr*
Mr. Dong-Yeol Chung, Thermal Fluid System R&BD Group, KITECH, dy77k96@kitech.re.kr
Dr. Dongho Park, Thermal Fluid System R&BD Group, KITECH, senna@kitech.re.kr
Dr. Prof. Jungho Hwang, Mechanical Engineering, University of Yonsei, hwangjh@yonsei.ac.kr
Dr. Jeong-Yeol Kim, Thermal Fluid System R&BD Group, KITECH, esperant@kitech.re.kr

Keywords: Phase change material, Thermal storage, Thermal conductivity, , Thermal plasma, Aerosol

Introduction

In the thermal storage system using Phase Change Materials (PCMs), it is important to improve thermal conductivity of PCMs for the high heat transfer performance of PCMs. The addition of particles with a high thermal conductivity can recover the low thermal conductivity of the PCMs [1]. In this study, the effects of size and concentration of additive particles were investigated for improving the thermal conductivity of PCMs. The thermal conductivity of PCMs was measured by a heat flow meter(HFM, model 436, NETZSCH).

Discussion

The additive particle was fabricated by the thermal plasma process. The schematic diagram of particle fabrication system is shown in Fig. 1. The size of raw materials which were injected to thermal plasma were in the range of 90~100 um. Through the thermal plasma process, injected particles were vaporized and then the particles were condensed at the boundary of plasma flame. The fabricated particles were classified by the size. Fig. 2 is aluminium oxide particles which were used as the additive for the thermal conductivity enhancement of PCMs. With smaller particle size, the thermal conductivity of PCMs was increased and with high concentration of additive particle, the heat transfer rate of PCMs was enhanced. The results indicate that the condition of additive particles for the improving thermal conductivity of PCMs has to be considered by the particle size and concentration together. As a result, the thermal conductivity of PCMs is increased more than 15%. And the energy efficiency of PCMs is related with its thermal conductivity. So, the condition of additive particles was optimized for improving energy efficiency of the thermal storage system using PCMs.

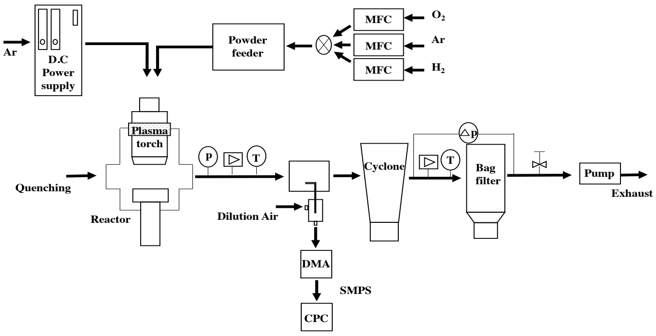

Figure 1: Schematic of particle fabrication system

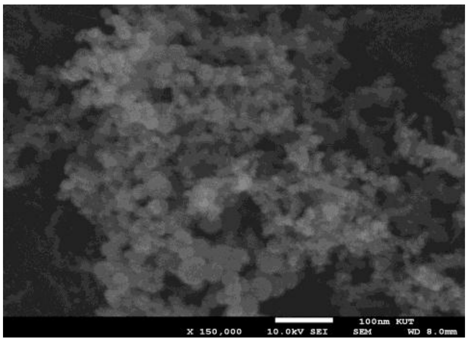

Figure 2: SEM image of additive particles

Conclusions

The thermal conductivity of PCMs was enhanced by additive particles with high thermal conductivities. Optimization was carried out to improve the energy efficiency of PCMs with additive particle size and concentration. The results showed that the smaller particles improve the thermal conductivity of PCMs and high concentration of additive particle also enhances the thermal conductivity of PCMs. The thermal conductivity of PCMs was increased more than 15%. This result elucidates how the energy efficiency of the thermal storage system using PCMs was improved as a result of the present optimization.

Acknowledgement: This research was supported by the Technology Innovation Program (No. 10049090) funded by the Ministry of Trade, Industry and Energy (MI, Korea).

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Measurement and modelling of the maximum storage capacity of two salt hydrate based PCM as a function of the water/salt concentration

Simon Pöllinger, ZAE Bayern, simon.poellinger@zae-bayern.de
Henri Schmit, ZAE Bayern, henri.schmit@zae-bayern.de
Stefan Hiebler, ZAE Bayern, stefan.hiebler@zae-bayern.de

Keywords: Thermal energy storage, inorganic PCM, maximum storage capacity, melting behaviour

Introduction

Thermal energy storages based on phase change materials (PCM) are a promising technology for load shifting. Inorganic PCM based on salt hydrates generally show a large volumetric melting enthalpy and low prices compared to organic PCM. However, the impacts of the water/salt concentration and the melting behaviour of salt hydrates on the maximum storage capacity need to be determined in order to promote their application in thermal energy storages. These two influence factors on the maximum storage capacity are analysed via calorimetric measurements and modelled for the two salt hydrates $CaBr_2 \cdot 6H_2O$ and $CaCl_2 \cdot 6H_2O$.

Discussion

$CaCl_2 \cdot 6H_2O$ is one of the most popular inorganic PCM but it shows a semi-congruently melting behaviour, i.e. reversibility of the melting/crystallisation process is only given under special circumstances. $CaBr_2 \cdot 6H_2O$ is isomorphous to $CaCl_2 \cdot 6H_2O$ and melts congruently but has a lower melting enthalpy (115.5 J g^{-1} compared to 190.8 J g^{-1} [1]). The maximum storage capacity, $\Delta h_{15K,}$ of a PCM corresponds to the enthalpy difference over a temperature interval of 15 K around the phase transition [2]. For 9 concentrations of $CaBr_2 + H_2O$ in a concentration range of 2.6 wt% around $CaBr_2 \cdot 6H_2O$ measurements conducted via differential scanning calorimetry (DSC) show a clear trend of decreasing Δh_{15K} for $CaBr_2$ concentrations differing from $CaBr_2 \cdot 6H_2O$ (**Figure 1**). The model is based on the parameterised liquidus curves from the phase diagrams, melting enthalpies for the invariant points and liquid plus solid specific heat capacity. The straight line in **Figure 1** shows that the model reproduces the trend of the experimentally determined Δh_{15K} of $CaBr_2 + H_2O$ around $CaBr_2 \cdot 6H_2O$.

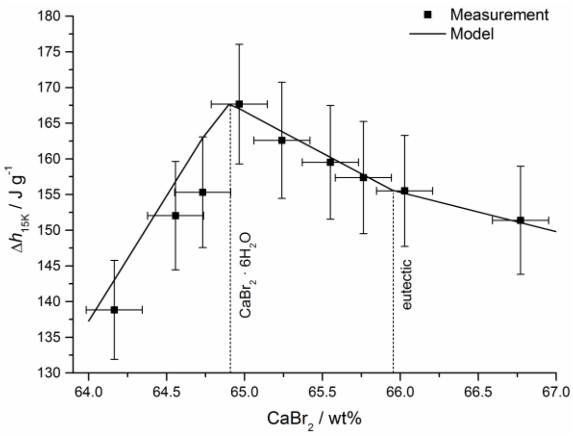

Figure 1: Maximum storage capacity, Δh_{15K}, of 9 concentrations of $CaBr_2 + H_2O$ around $CaBr_2 \cdot 6H_2O$

For $CaCl_2 \cdot 6H_2O$ different scenarios of the impact of the semi-congruent melting on the maximum storage capacity are explored to reproduce the experimental results

Conclusions and/or Outlook

The measurements show a considerable dependency of the $CaBr_2/H_2O$ concentration on the maximum storage capacity around $CaBr_2 \cdot 6H_2O$. The developed model allows to reproduce the trend of the maximum storage capacity and demonstrates that it is possible to predict the behaviour of inorganic PCM with few input values and thus low measurement effort. In addition, the model is a valuable tool to assess the impact of the semi-congruent melting behaviour of $CaCl_2 \cdot 6H_2O$ on the maximum storage capacity.

Acknowledgement: The work of ZAE Bayern is part of the project PC-Cools_S and supported by the German Federal Ministry of Economic Affairs and Energy under the project code 03ESP138D.

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Novel Molten Alkali Chloride Salts for Thermal Energy Storage up to 700 °C

Dr. Louis Maksoud, *Institute of Engineering Thermodynamics, German Aerospace Center, louis.maksoud@dlr.de*
Dr. Thomas Bauer, Institute of Engineering Thermodynamics, German Aerospace Center, thomas.bauer@dlr.de
Dr. Markus Eck, Institute of Engineering Thermodynamics, German Aerospace Center, markus.eck@dlr.de

Keywords: Molten Salts, Thermal Energy Storage, Chlorides, Concentrated Solar Power, Thermal process, Corrosion

Introduction

Suitable material candidates for the use as heat transfer fluid (HTF) and/or for thermal energy storage (TES) are supposed to fulfill a list of requirements concerning physical data (e.g. melting point, density, viscosity, heat conductivity and heat capacity), availability, corrosion behavior, stability as well as toxicity. Taking into account these points, several hundred mixtures have been investigated. It appeared that the commonly used mixtures of sodium and potassium nitrates are so far the most promising candidates for high-temperature heat storage applications. Nevertheless, due to their weak stability at temperatures exceeding 550 °C, nitrates could be replaced by more stable suitable materials when higher operating temperatures are required (up to 700 °C). Due to their physicochemical and thermal properties and high thermal stability, molten alkali chloride salt mixtures are potential liquids to be used for sensible thermal energy storage (TES) such as in Concentrating Solar Power (CSP) plants and in fossil fuel powered plants to increase the operation flexibility. However, the application of molten chlorides at high-temperatures involves additional challenges such as increased corrosiveness. In the present work, we focus on the molten salts purity, because it has a direct influence on the corrosion rate of metals. Because some chloride salts are hygroscopic and heating in presence of water induces hydrolysis of the salt and formation of oxides/hydroxides. These compounds increase the redox potential of the salt and so its corrosion rate.

Experiments and Discussion

First tests using simple heating procedures showed unacceptable salt decomposition and corrosion rates (Figure 1). An advanced process technology method and purification approach has been developed yielding improved salt quality and thus reduced corrosion rates (Figure 2). In this report, the optimized process technology for the dehydration of the salt and simultaneously investigation of the corrosion rate depending on the salt impurities is presented. An ensemble of thermal (DSC/TGA + Mass Spectrometry) and other analytic methods (XRD, Electrochemical Analysis) is employed before and after the process in order to qualify and quantify the purity of the salt. After the drying process, thermal analysis do not show any considerable loss of weight but a stable and repetitive behavior of the salt. First electrochemical analysis allowed us qualifying and quantifying the oxide/hydroxide impurities in the molten state.

Figure 1: Hydrolysis aspect of the alkali chloride salt and oxides deposition on the container after 6 hours heating at 700 °C with no previous drying procedure.

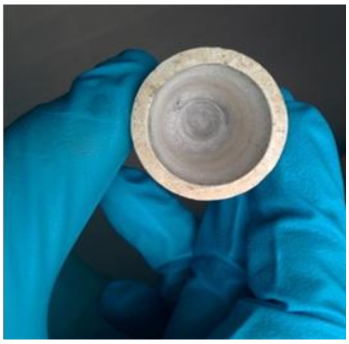

Figure 2: Observation of the alkali chloride salt with additional drying procedure using vacuum and operation at 700 °C under argon gas.

This is an important step for a better utilization of molten halides as liquid media for solar and other application requiring molten salt operation in contact with structural metallic components.

Acknowledgement: The Authors acknowledge the DAAD (German Academic Exchange Service) for the Post-doctoral research fellowship of Dr. Maksoud.

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Thermochemical tetramethylguanidine-based heat storage

Maria Tyukavina, Fraunhofer Institute for Environmental, Safety and Energy Technology,*
maria.tyukavina@umsicht.fraunhofer.de
Heiko Lohmann, Matthias Fischer*, Dr. Barbara Zeidler-Fandrich*, Dr. Stefano Bruzzano*,*
*Prof. Dr. Eckhard Weidner**

Keywords: Thermochemical heat storage, material development, DSC, TGA, tetramethylguanidine

Introduction

New thermal energy storage materials and systems are required to increase the utilisation of low-grade waste heat from power plants and different industries, which is estimated to be 300 TWh/a in Germany [1]. Thermochemical heat storage materials offer new opportunities for effective, environmentally and lossless heat storage with higher energy densities than those of sensible and phase change storage materials. In this paper a new approach for the development of thermochemical heat storage material based on 1.1.3.3-tetramethylguanidine (TMG) is presented. Beside synthesis of different materials, emphasis is laid on the proper thermal characterisation using Differential Scanning Calorimetry (DSC) and Thermogravimetry (TGA).

Discussion

In this work product salts of TMG and different organic acids with varying pK_a values were investigated. At first TMG was mixed with acetic acid, formic acid, pelargonic acid and pyruvic acid, respectively. Resulting solid products were purified and quantitatively assessed for specific enthalpy, thermal stability, and cycle stability by DSC and TGA techniques at lab scale. Promising results were obtained from the reaction between TMG and pyruvic acid in closed DSC cells, showing a specific enthalpy change of 400 J/g accompanied by satisfying cycle stability. However, close examination and matching of DSC and TGA curves pointed to a thermal decomposition of pyruvic acid during the first heating step. Assuming a decomposition into acetaldehyde and CO_2 (according to [2]), the latter might have reacted with TMG in following heating cycles. The measurements were therefore repeated with a TMG salt that contained CO_2 instead of pyruvic acid. Different methods for the synthesis of tetramethylguanidinium carbonate were applied and results of the thermal characterisation were compared to literature data [3]. Although these results were marked by a lower specific enthalpy change then those of the original reaction between pyruvic acid and TMG, they still gave good prospects for a technical application. The comparison of specific enthalpy changes of all tested systems is shown in **Figure 1**.

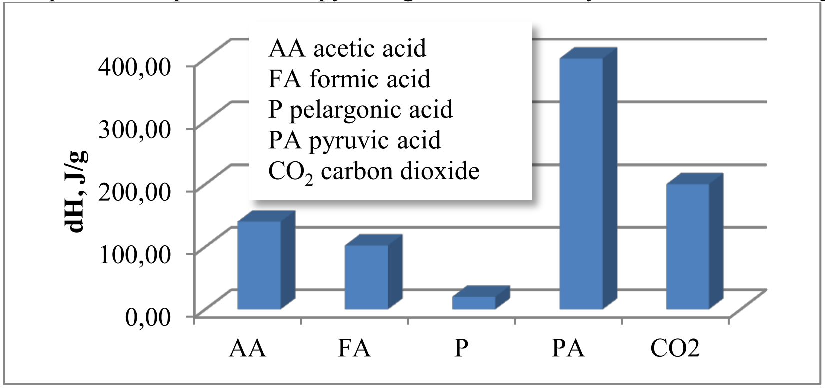

Figure 1: Comparison of specific enthalpy changes for organic TMG-based reaction systems obtained through DSC

Conclusion and Outlook

Salts of tetramethylguanidine and acids exhibit promising characteristics for thermochemical storage, in particular tetramethylguanidinium carbonate. The optimisation of the synthesis method for tetramethylguanidinium carbonate is scheduled for coming investigations. Special emphasis will be put on the technically challenging incorporation of these materials in a heat storage application, since gaseous CO_2 must be conserved within the working system. This application concept is currently being developed.

Acknowledgement: we thank the German Federal Ministry of Education and Research for funding this research work.

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Thermochemical systems for the utilization of process waste heat: thermal storage and heat transformer

Margarethe Molenda, *Eleonore Siebecke, Jana Stengler, Marc Linder*
German Aerospace Center (DLR), Institute of Engineering Thermodynamics, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany, margarethe.molenda@dlr.de

Keywords: Thermochemical storage, gas-solid-reaction, waste heat, heat transformation, chemical heat pump

Introduction

More than 50 % of the primary energy in Germany is used by a demand of thermal energy of which a huge part is process heat [1]. Although big effort is done in heat integration and process intensification, the waste heat potential in Germany sums up to about 476 PJ per year [2]. Therefore, the re-utilization of process waste heat exhibits a great potential for the saving of primary energy and the reduction of CO_2 emissions. However, in many cases, thermal storage of waste heat alone is not sufficient for a potential re-integration. Spoelsta et al. showed that waste heat, e.g. in chemical industry (non-usable thermal energy) occurs at temperatures below 150 °C and the amount increases with decreasing temperature level [3]. A thermal upgrade to temperatures above 150 °C could therefore drastically increase the possibilities for heat integration and thus improve the utilization of thermal energy.

Discussion

Thermochemical systems using gas-solid-reactions can be used for both, thermal storage and thermal upgrade within one single process. The general form of these reactions is

$$AB_{(s)} \rightleftharpoons A_{(s)} + B_{(g)} \qquad \Delta_R H > 0.$$

Thermal energy is necessary in order to decompose the solid AB into the solid A and the gas B. As long as these two products are separated the thermal energy is stored in a chemical way. The reaction temperature can be influenced by the gas pressure. Therefore, the endothermic reaction can be operated at a lower temperature than the exothermic one. In several publications this functionality has already been shown [4]. Hereby, gas handling is one of the most challenging issues as the gaseous reactant needs to be stored in a compressed, condensed or absorbed form. By using water vapour as gaseous component, open systems are possible. Hereby, waste steam from industrial processes can be used. The pressure difference for the heat transformation can be provided by a difference in partial pressure leading to an absolute pressure at ambience level. Therefore, since neither overpressure nor vacuum components are necessary this approach seems especially interesting for large storage systems.

Focusing on reaction temperatures between 100 °C and 300 °C, different reaction systems have been investigated for this process concept. Next to calcium chloride [5], other salt hydrates exhibit good material characteristics for the utilisation as heat transformer.

In order to analyse the technological potential of these materials, an experimental analysis in lab-scale has been done. Thereby, limitations and challenges of the combined system were identified and analysed focusing on heat and mass transfer as well as reaction kinetics.

Conclusions

Thermochemical systems exhibit a high potential to improve the utilization of waste heat in industrial processes. Therefore, suitable materials need to be identified and characterized. Alternative process concepts, e.g. open systems using waste heat and waste steam from industrial processes, reduce the amount of necessary components and thus improve the adaptability of heat transformation to industrial applications.

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Thermo-physical Properties of Nano Coated CaO / Ca(OH)$_2$ Powders

***Sandra Afflerbach**, Institute of Building and Materials Chemistry, University of Siegen,*
afflerbach@chemie.uni-siegen.de
Christian Roßkopf, Institute of Engineering Thermodynamics, German Aerospace Center
Burkhard Görtz, Institute of Building and Materials Chemistry, University of Siegen
Dr.-Ing. Marc Linder, Institute of Engineering Thermodynamics, German Aerospace Center
Prof. Dr. Reinhard Trettin, Institute of Building and Materials Chemistry, University of Siegen

Keywords: Thermochemical Heat Storage, Calcium hydroxide, Agglomeration, Nanostructured particles

Introduction

Thermochemical storage systems, therein the reaction system CaO / Ca(OH)$_2$, are highly promising for applications in concentrated solar power (CSP) plants and can also contribute to an enhancement of energy efficiency by offering the option of reutilization of industrial waste heat. However, agglomeration tendency of the unmodified powder material during thermochemical cycling prevents consistent bed characteristics by generating inhomogeneity of heat and mass transport [1]. In order to minimize attractive interparticular forces, a nanostructured additive of metalloid oxide was mixed to the storage material under variation of the additive amount and mixing intensity [2]. Depending on the mixing intensity, either the additive or the storage material agglomerates are larger.

Discussion

To investigate the thermophysical properties and cyclability of the admixed materials, a method of cycling in Simultaneous Thermal Analysis (STA) over ten reaction cycles has been conceived. It can be shown by these experiments that the hydration reaction of the unmodified storage material can irregularly occur in two separate steps, which were already studied for hydration kinetics of unmodified CaO [3]. The two-step hydration reactions were referred to the presence of two particle size fractions by Statistic Light Scattering (SLS) measurements. In contrast, this trend could be rarely observed for some admixed storage materials (**Figure 1, 2**).

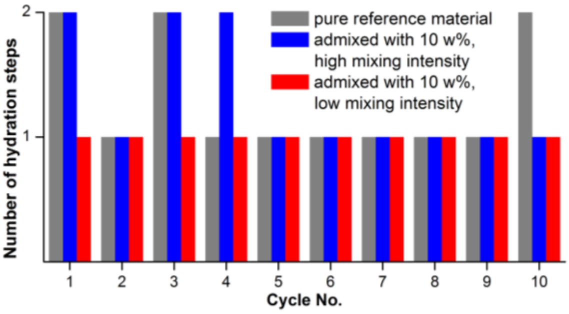

Figure 1: One-step and two-step hydration reactions of an unmodified and of admixed samples in relation to the reaction cycle

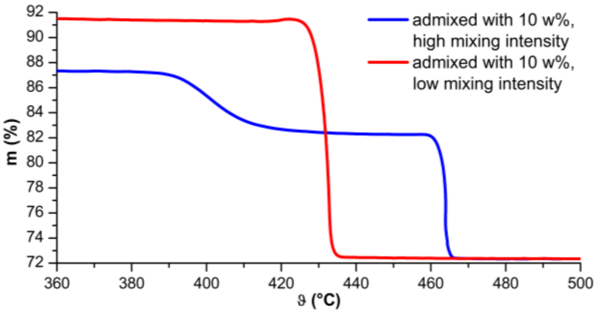

Figure 2: Thermogravimetric signals of first hydration reaction occurring in two steps (blue) and one step (red) for modified materials

Morphological analyses of the cycled samples via Scanning Electron Microscopy (SEM) coupled with elemental mapping hold for an explanation. By the formation of side products, the conversion during cycling of admixed materials decreases in close relation to the amount of admixed nanostructured additive. Cyclability over ten reaction cycles could be proven via STA measurements up to admixtures of 10 w-% nanostructured additive. The formed side products were identified by X-Ray Diffraction (XRD) and quantified via Rietveld analyses.

Conclusions

By cycling the admixed storage materials via STA it can be shown that nanostructured additives provide to decrease fluctuations during cycling due to stabilisation of particle size distribution. This effect could be capable to reduce agglomeration effects even if the respective material is cycled in reactor scale.

Acknowledgement: The authors gratefully acknowledge funding of the TCSPower project by the European Commission.

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Examination of reversible metal oxide redox reactions for high-temperature thermochemical energy storage

***Michael Wokon**, Dr. phil. Thomas Bauer, Dr.-Ing. Marc Linder, Dr.-Ing. Antje Wörner*
Institute of Engineering Thermodynamics, German Aerospace Center (DLR), michael.wokon@dlr.de

Keywords: thermochemical energy storage, metal oxides, redox reaction, thermodynamics and reaction kinetics, packed bed

Introduction

The implementation of thermal energy storage systems is crucial to facilitate the dispatchability of power generation and decouple heat supply and electricity demand in solar thermal power plants, e.g. solar power towers. Furthermore, possible storage applications in high-temperature industrial processes can be found in the steel and glass processing industry, where the recovery of waste heat by means of thermochemical energy storage can potentially increase the energy efficiency.

Thermochemical energy storage has great potential to develop efficient thermal storage solutions with high energy densities. This concept is based on using the reaction enthalpy of reversible gas-solid reactions to store thermal energy. Gas-solid reactions also offer the beneficial possibility of facile product separation.

In the high-temperature application range between 600°C up to 1100°C multivalent metal oxides constitute promising storage materials. Thermal charging of the storage is achieved by means of the endothermic reduction step under the release of oxygen. Recombination of the reduced metal oxide and oxygen leads to the exothermic oxidation, representing the thermal discharging step with heat release.

$$2\ \mathrm{Me_xO_y}\ (s) + \Delta H_R \rightleftharpoons 2\ \mathrm{Me_xO_{y-1}}\ (s) + \mathrm{O_2}\ (g)$$

Metal oxides offer process-technological advantages compared to other thermochemical storage materials, as ambient air can be used as sink and source of the reactant oxygen during the proceeding redox reactions. Accordingly, oxygen does not need to be stored in this open loop process. However, thermochemical storage systems based on metal oxides are yet at an early stage of development [1].

Discussion

Current work at the DLR focuses on the examination of metal oxides for the development of a high-temperature thermochemical storage system. Furthermore, a reactor model with cylindrical geometry has been set up for simulation to gain further understanding of the influence of different storage parameters and operating conditions on a storage reactor.

Various reaction systems of metal oxides have been considered regarding their fundamental applicability as storage materials. Among those, pure manganese oxide was selected as potential storage material for lab-scale experiments. As pure manganese oxide suffers from a lack of cycling stability and exhibits only a slow progress of oxidation, posing the rate limiting step of the redox cycle, mixed oxides of manganese and iron as well as copper and cobalt with superior material properties are examined. These material systems differ in terms of cost effectiveness, toxicity, cycling stability, energy density and further aspects. Important material characteristics for the reactor model such as the thermodynamic equilibrium, reaction kinetics, reversibility and cycling stability of the redox reactions as well as thermophysical properties were investigated in dynamic and isothermal measurements by thermal analysis and thermophysical methods.

A lab-scale test bench with a packed bed storage reactor for about 400 g of storage material has been developed to examine heat and mass transport coupled with the chemical reaction [2]. In this concept air is used as heat transfer fluid, which is in direct contact with the storage material. Thermal characteristics of the oxidation and reduction process are compared. The reaction progress and conversion of the redox reaction were determined based on the oxygen concentration recorded at the reactor outlet. Solid temperatures were measured at different positions along the bed height, gas temperatures were detected at the inlet and outlet of the packed bed. Experimental data of storage cycles also serve to validate the simulation results of the respective reactor model.

Conclusions

The feasibility of the concept to store thermal energy by means of a metal oxide redox reaction using air as the heat transfer fluid and carrier of the reactant oxygen was successfully demonstrated in a lab-scale storage reactor. Within the scope of this presentation different aspects of crucial material properties as well as current experimental results of a packed bed storage reactor will be discussed.

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Sorption Storage System

D. Steininger: *Dipl. – Ing. Daniela Steininger, Department of environmental and energy process engineering, Chair of thermal processing technology, Montanuniversitaet Leoben, Austria,* daniela.steininger@unileoben.ac.at

H. Raupenstrauch: Univ. – Prof. Dipl. – Ing. Dr. techn. Harald Raupenstrauch, Department of environmental and energy process engineering, Chair of thermal processing technology, Montanuniversitaet Leoben, Austria, harald.raupenstrauch@unileoben.ac.at

Keywords: sorption material, salt covered Zeolite, storage for thermal energy, storage system, household;

Sorption Storage System

Introduction

In December 2008 the EU passed the "20-20-20" targets. One of the main aspects is the reduction of energy consumption in all sectors, both in industry and transport, as well as in private households, services, agriculture and forestry. The household sector requires almost 30% of total energy consumption in Austria, so there is a high potential for reduction[1].

Discussion

The energy consumption includes electrical and thermal energy. Thermal energy is mainly used for cooling, heating and hot water preparation. The market for allocation of thermal energy is very large nowadays and characterized by the use of renewable energy as an energy transfer medium. Renewable energy such as wood pellet heating systems or heat pumps, reduce CO_2 – emissions of households containable. To stop CO_2 – emissions completely the most reasonable way will be the heat storage during summer and the use in winter.

This approach serves as the basic concept for the development of the "novelSORP" sorption system: The storage of solar energy during the summer and the use after weeks or months during colder times. The leading part will be a new sorbent material. In this material the energy density will be raised by using a salt covered Zeolite – structure. First results show that the material can emit usable temperature level for a considerably longer time compared with benchmark products. The rise of the energy density of the material is one part of the new sorption system; the second part is a newly designed system, which should be more efficient than other storage systems. The positive properties of the material and a more effective overall system enable the provision of thermal energy in the households.

Objectives of the project "novelSORP":
- Sorption: Better thermal properties than previous materials (energy density, longer useable temperature level)
- Apparatus: A rethink of storage and heat transfer
- System: increase in efficiency compared to existing systems

To fully think through the issue of thermal energy efficiency in households, the renovation has to be taken into account. A revolution in the facade renovation of old buildings would be the integration of the newly developed storage in the facade. Thus, the topics heating and thermal insulation could be united.

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[1] Federal Environment Agency Austria

Improving the conversion efficiency of a Power-to-Gas plant by coupling a dynamic SOEC system with a three-phase methanation reactor

Régis Anghilante, *EIFER, Distributed Energy Group, anghilante@eifer.org*
Jonathan Lefebvre, Engler-Bunte-Institut – Fuel Technology, KIT, jonathan.lefebvre@kit.edu
David Colomar, EIFER, Distributed Energy Group, colomar@eifer.org
Prof. Thomas Kolb, Engler-Bunte-Institut – Fuel Technology, KIT, thomas.kolb@kit.edu

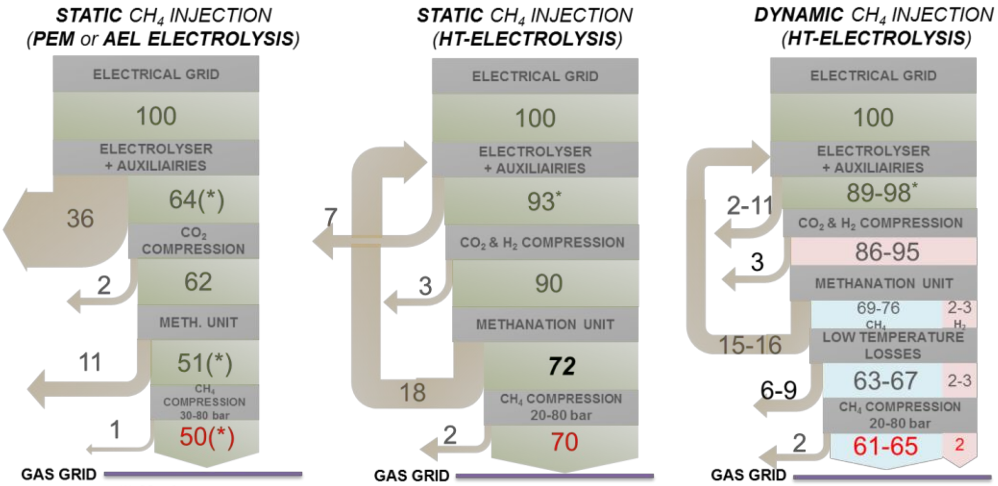
Keywords: Power-to-Gas, SOEC, Three-phase methanation, dynamic operation, SNG

Introduction

The storage of renewable electricity in the gas grid – also known as Power-to-Gas (PtG) – offers interesting advantages to tackle the intermittency of renewable energies such as long term storage capability in an already existing gas infrastructure. Conventional electrolyser concepts (alkaline or PEM) operate at low temperature and cannot take advantage of the heat available from a methanation unit. On the contrary, an SOEC unit usually operates at 1073 K and could benefit from the steam produced during the methanation process. In this publication, we investigated the influence of the thermal integration of an SOEC unit with a three-phase methanation unit on the PtG conversion efficiency using process simulation. The SOEC was simulated in steady-state as well as in dynamic mode of operation. The PtG plant reached an overall efficiency of **67 % LHV (77 % HHV) in dynamic operation**. This would **reduce the electricity consumption by 40 % compared to alkaline and PEM technologies.**

Discussion

Figure 1 compares the PtG conversion efficiency of facilities using different electrolyser concepts. It also highlights the impact of dynamic mode of operation on the process efficiency. The thermal integration of the SOEC technology with a three-phase methanation unit considerably increases the PtG conversion efficiency comparatively to alkaline and PEM technologies. **In dynamic mode, the plant efficiency increases by 13 to 17 %**. This difference can be entirely explained by the thermal integration of the SOEC with the methanation unit and the biogas upgrading plant.



(*) ***Maximum value*** *based on LHV of* H_2 *or* CH_4

** LHV value, electrolyser in thermoneutral mode (97% efficiency), inverter efficiency: 96 %*

** LHV value, electrolyser efficiency (93-102% efficiency), inverter efficiency: 96 %*

Figure 1: Power-to-Gas conversion efficiency for different electrolyser concepts in steady-state or in dynamic operation

The dynamic mode of operation of the SOEC system results in a significant fluctuation of the plant efficiency. When heat cannot be recovered, it is substituted by electrical energy, thus resulting in lower overall efficiency.

Conclusions and outlook

This work has shown that the thermal integration of a SOEC system with a three-phase methanation unit should allow a considerable increase of the PtG conversion efficiency in both static and dynamic operation. A plant cost estimation should be carried out in further work to assess the economics of the PtG concept using SOEC and three-phase methanation technologies. The influence of the methanation mode of operation on the plant economics should be also investigated.

Acknowledgements

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Combining PtG-technology with gasification: The KIC-Project „DemoSNG“

Dr.-Ing. Siegfried Bajohr, *Dipl.-Chem. Dominik Schollenberger; Engler-Bunte-Institut, Karlsruhe Institute of Technology (KIT), siegfried.bajohr@kit.edu, dominik.schollenberger@kit.edu*
Dr.-Ing. Dominic Buchholz; KIC InnoEnergy Germany GmbH, dominic.buchholz@kic-innoenergy.com

Keywords: energy storage, SNG, catalytic methanation, PtG (power-to-gas), metallic monoliths

Introduction

SNG (substitute natural gas) production and distribution in the natural gas grid is one of the most efficient ways for utilization of lignin rich biomasses like wood. Especially the integration of hydrogen from surplus electricity supplied by windmills or photovoltaics into catalytic methanation offers a lot of benefits. E.g. the total carbon exploitation and overall process efficiency can be improved significantly. Furthermore, SNG overcomes all the compatibility problems which might arose from hydrogen injection to the natural gas grid. Therefore, SNG produced from hydrogen and suitable carbon sources like syngas from biomass gasification can be the desired link from power grid to gas grid which is necessary in order to overcome the problems of the fluctuating regenerative electricity production and its growing demand for energy storage capacities.

Discussion

Several pilot scale projects concerning power to gas (PtG) technologies are in development in Germany. Especially the integration of hydrogen from surplus electricity supplied by windmills or photovoltaics into catalytic methanation offers a lot of benefits. Such a process chain is shown in **Figure 1**.

The total carbon exploitation, heat integration and overall process efficiency can be improved significantly. However, methanation technologies have to be adapted to the fluctuating process conditions arising from fluctuating hydrogen production. One promising methanation reactor concept uses metallic honeycomb catalysts. This concept was investigated in the last years at the Engler-Bunte-Institut and was now transferred to demo scale. Supported by KIC InnoEnergy and in collaboration with multiple European project partners (see **Figure 2**) a methanation demo scale module was designed, built and commissioned by DVGW and KIT in Karlsruhe.

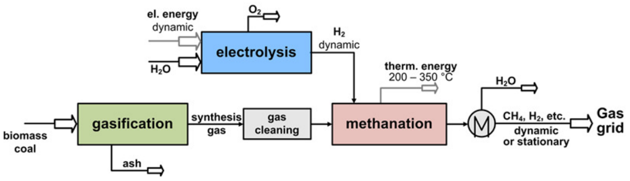

Figure 1: Process chain combining gasification with PtG technology

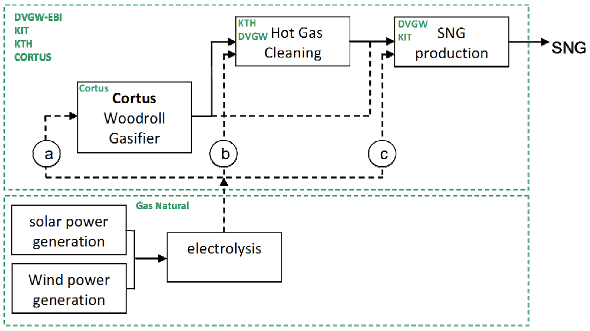

Figure 2: Project partners and tasks for “DemoSNG” (a, b, c = possible points for hydrogen addition to the process)

Outlook

At the time being the methanation module is combined with a hot gas cleaning module developed and built by KTH university of Stockholm (Sweden) and both are linked to the WoodRoll® gasification plant of CORTUS in Köping (Sweden). The results of the following testing campaign will give valuable data for the up scaling of honeycomb methanation reactors to any industrial scale and will be part of the envisaged presentation at the EST conference.

Acknowledgement: The authors would like to thank KIC InnoEnergy and the Federal Ministry of Education and Research (BMBF) for their financial support.

German Energiewende as Driving Force for New Technologies – Power Industry meets Process Industry

Dr. Heberle, Arthur, *Mitsubishi Hitachi Power Systems Europe GmbH,* *a_heberle@eu.mhps.com*
Prof. Dr. Kakaras, Emmanouil*, Mitsubishi Hitachi Power Systems Europe GmbH,* *e_kakaras@eu.mhps.com*

Keywords: Energy Storage, Liquid Air Energy Storage, Carbon Capture and Utilization, Power-to-Fuel

Introduction

The rapid and continuous increase of Renewable Energy Sources (RES) share in Germany but also in Europe has changed the electricity market dramatically. With their fluctuating character, the feed of RES into the grids causes a regional and seasonal imbalance between power generation and energy consumption. The share of RES was approx. 23% in the year 2013 and will increase up to 40-45% in the year 2025. In the year 2050, a RES share of 80% is predicted. Therefore, RES are leading the shift from instant energy storage to long-term and large-scale energy storage technologies.

Discussion

However, technology options for large scale storage are missing: battery technologies are mostly limited to kilowatt-hours to a few megawatt-hours scale due to their module capacity, costs, and service life. Although, pumped hydro storage used in the power industry in the GWh scale is well-proven, environmental concerns and site availability are preventing new projects

Regarding the changes of the electricity market, large scale energy balancing with sustainable technologies with product flexibility and cost-effective operation are being investigated: Liquid Air Energy Storage and Power-to-Fuel.

Liquid Air Energy Storage is the only large-scale electricity storage to be applied without any geological limitations. In addition to its storage application, Liquid Air Energy Storage can be also used as a backup power plant. It can be extended by a gas-fired gas turbine process to provide energy at peak load demand. At a time of low electricity prices, the storage will be charged by liquefaction of ambient air. At peak load demand linked to high electricity prices, it will be discharged for power generation by means of turbo machinery. The efficiencies of Liquid Air Energy Storage are up to 65% or even higher.

Power-to-Fuel as a cross-sector technology is the best choice for long-term and large scale energy storage by applying the concept of Carbon Capture and Utilization (CCU) as a mean for low carbon sustainable industry. Hydrogen and oxygen is processed from water and electrical energy. Carbon dioxide is taken from a fossil power plant or from the process industry with carbon dioxide emissions. From the conversion of carbon dioxide and hydrogen, methane (known as Synthetic Natural Gas “SNG”) or methanol can be produced. Compared to hydrogen having the lowest exergy losses during the conversion, methane is easier to handle than hydrogen because it is quite similar to natural gas. Methane can be stored in the existing natural gas grid mostly without any limitations. Therefore methane is preferred over hydrogen according to many studies e.g. because of costs for a new hydrogen infrastructure, permitting and safety issues related to hydrogen. Methanol is produced in the Power-to-Fuel concept. It is a widely world-wide used and very important chemical. Methanol can be processed to different derivatives like e.g. olefins, DME, gasoline and is easy to store. The efficiencies of the Power-to-Fuel technology are up to 67%. In terms of profitability, methanol has a significant higher market price compared to methane which leads methanol to a favoured chemical and energy feedstock.

Both innovative technologies, Liquid Air Energy Storage and Power-to-Fuel, use mostly mature technology.

Conclusions and Outlook

As peak power demand will remain high and fossil power plants still will be needed, LAES and Power-to-Fuel will not only improve the energy supply security and flexibility of power plants. In fact, those technologies provide an excellent link between electric, gas and fuel grids in the future and will promote the integration of the process industry into the energy market leading to a maximum of energy efficiency. New business models can be generated.

Mesoporous Ni/Ce based catalyst for low temperature high throughput production of synthetic natural gas

Teresa Andreu, Katherine Villa, Sebastian Murcia
IREC, Catalonia Inst. for Energy Research, Jardins de les Dones de Negre 1, Sant Adrià de Besòs, 08930, Spain
Magadalena Nizi, Stéphanie Ognier, Simeon Cavadias, Jacques Amouroux,
Inst. Recherche de Chimie Paris, CNRS – Chimie ParisTech,11 rue Pierre et Marie Curie, 75005, Paris, France
Joan R. Morante
IREC, Catalonia Inst. for Energy Research, Jardins de les Dones de Negre 1, Sant Adrià de Besòs, 08930, Spain
Electronics Dept, Faculty of Physics, U. Barcelona, C/Marti i Franqués, 1, Barcelona, 08028, Spain
jrmorante@irec.cat

Keywords: CO2reduction, DBD reactors, catalyst, metanation.

Introduction

Dielectric barrier discharge, DBD, reactor working with a plasma activated catalyst constitutes a very interesting alternative to produce methane from CO_2 with a very low consumption of electricity power, < 12kJ/mole of CH4 and, at the same time, fulfils all the requirements for a large volume production of methane with an overall consumption of 1.64MJ/ mole of CH4 considering that the energy required to produce 1 mol H2 by water electrolysis is 407KJ/mol for a yield of 70%. Therefore 1,628MJ are consumed to produce 4 moles of H2 necessary for the CO2 hydrogenation. Alternatively, it can extraordinarily be reduced if solar hydrogen is used and if complementarily such as it is presented in this contribution, the reactor can work without any extra heating.

Discussion

A mesoporous catalyst based on Ni/Cem is placed between the electrodes allowing the gas species to flow through this catalytic material being activated by means of the application of high voltage (in the range of few tens of kV) pulsed discharges with a duration in the range from nanosecond to microsecond. The estimated electrical consumption is below 3W/g of catalyst and it is enough for inducing adsorption and desorption reactions even at low temperatures (<200°C). Without high voltage polarization (conventional process) the working temperature is higher, typically, above 250ºC up to 420°C.

As the DBD reactor is working with the catalyst activated by the generated plasma, there are two working region. In the first one, the reactor does not need extra heating supply and it is working under adiabatic. So, the process starts at room temperature and as the discharge increases the temperature due to the exothermicity, the process is carried out until a new steady state is reached, stabilizing the working point of the reactor at this isothermal condition in the range of 130-160ºC depending of the thermal conductivity of overall system including specially the catalyst. Here the combination of nickel and ceria/zirconia play a basic role in the catalytic functionality.

Under isothermal conditions, in the range 200°C-420°C, the reactor must be externally heated for achieving these thermal values independently if plasma is or not used. Nevertheless, better selectivity and conversion are achieved always with plasma.

Under adiabatic conditions, at low temperatures, selectivity of 100% is achieved for the production of synthetic methane using 20% of CO2 and 80% of H2 with a conversion percentage around 85%. Under conventional conditions, selectivity is maintained and conversion stays above 80% up to 300ºC. For higher temperature conversion decreases a little bite although the selectivity and conversion percentages are always much better than without plasma.

Conclusions and/or Outlook

In summary, it has been proved that the catalytic properties of a Ni/(Ce+Zr) mesoporous based catalyst are extremely enhanced and activated due to the interaction with the generated plasma using a DBD reactor. These characteristics allow the production of synthetic methane with an interesting energy balance and catalyst life time to facilitate better cost of the methane. Moreover, the presented technological approach can be easily scaled up for a large production volume of synthetic natural gas production from reusing CO2 with a high throughput.

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Power to Gas industrialization solutions for hydrogen and SNG

Stephan Rieke, ETOGAS GmbH, Stuttgart, Stephan.Rieke@etogas.com

Abstract

PtG is a disruptive technology for building a smart energy ecosystem based on renewable sources and allows the conversion of volatile renewable electricity into durable renewable synthetic gases (H_2 or SNG), methanol or subproducts like jetfuel which have an unmatched low carbon footprint and can be stored, transported and eventually commercialized in mobility markets (as green synthetic fuels) and in industrial markets (as green raw material).
PtG adds flexibility to energy systems and thus enables efficient integration of high shares of volatile renewables into energy markets at low costs. It makes is possible to generate electricity at some point of time somewhere and to sell it in the form of synthetic fuel anywhere and anytime. PtG facilitates this by creating a connection between the two large existing energy networks, the power grid and the gas grid with its ample storage and transport capacity and by continuous recharging of the gas grid without timing/technical restrictions.
In the presentation ETOGAS shows, how the technology of today enables commercialized solutions for different stage of industrialized, reliable technology solutions and the conversion process starts with electrolysis. It follows a possible Methanation of the generated H2 with CO2 from different resources, the optional second PtG process step, which is an exothermal chemical reaction, which transforms the hydrogen with injected carbon dioxide into methane (also referred to as synthetic natural gas, SNG).
ETOGAS is the one of the early market and technology promoters due to early activities beginning in 2009 with small solutions based on proven electrolyzer and methanation systems. The company designs and builds multi-megawatt PtG turnkey plants based on its proprietary technology portfolio comprising water electrolyzers and methanation systems as well as balance of plant.
In the presentation it will reported about the technology and project road map, with close to $7MW_{el}$ installed capacity. In detail it will be presented the utilization of pressurized high efficiency electrolyzers for the production of hydrogen for industrial markets (green raw material) and automotive applications (green fuel for FCEVs); and fixed bed methanation systems for the production of SNG as a green fuel for gas-powered vehicles and as a feedstock cost optimizer for industrial processes. ETOGAS' proprietary technology is specifically designed for the requirements of volatile renewable electricity supply: minimized technology risk and costs (capex and opex), highest conversion efficiency and full dynamic intermittent operation.
The presented technologies for the industrialization are pressurized alkaline electrolyzer technology: world's largest cell stack capacity ($300kW_{el}$; $62.5Nm^3/h$ Hydrogen) and an active area per cell ($6,000cm^2$) that is 2-3x large than usual. Methanation technology with patented fixed bed plate reactor-membrane concept allowing for conversion efficiency consistently at the theoretic maximum (83%), high gas quality (up to 99 Vol% CH_4) on low standard nickel catalyst consumption as well as for high tolerance to the use of a variety of CO_2 sources and for integrated reactor cooling with steam and avoiding hot spot problems due to high heat transfer coefficients.
Examples of concrete realized projects for Hydogen, sng and also the use of CO2 as a feedstock for real hardware production by incorporating methanation technology will be shown.

CO2freeSNG2.0 - Advanced Substitute Natural Gas from Coal with Internal Sequestration of CO_2

***Peter Treiber**, Chair of Energy Process Engineering, Friedrich-Alexander-University Erlangen-Nuremberg, peter.treiber@fau.de*
Michael Neubert, Chair of Energy Process Engineering, Friedrich-Alexander-University Erlangen-Nuremberg, michael.fw.neubert@fau.de
Prof. Dr.-Ing. Juergen Karl, Chair of Energy Process Engineering, Friedrich-Alexander-University Erlangen-Nuremberg, juergen.karl@fau.de

Keywords: Gasification, Syngas, CO_2 removal, Benfield process, Methanation

Due to rising gas prices and increasing dependence on gas imports the generation of synthetic natural gas (SNG) from coal is again becoming a frequently discussed topic within the European Union. For the generation of SNG different process steps are necessary. On the thermochemical conversion follow the gas cleaning and conditioning steps to remove particles, undesirable gases and sulphur components from the raw syngas. Subsequently the syngas enters the methanation unit where the syngas is converted by heterogeneous catalysis. Before the final injection into the gas grid the raw SNG is dried and conditioned to fulfil the technical requirements.

Within the European research project CO2freeSNG2.0 the research efforts concerning gasification and methanation of previous research project CO2freeSNG [1] are continued and intensified. In addition to the formerly proposed hot gas cleaning a gas scrubbing unit based on the Benfield process shall be integrated in the process chain to provide the removal of CO_2, heavy tars, organic and inorganic sulphur components. The purpose of such a chemical gas scrubbing unit is an enhanced integrated removal of undesirable components within the raw syngas accompanied by less thermodynamic losses. Compared to conventional gas cleaning processes the Benfield process can reach higher thermodynamic efficiencies when integrated in smaller decentralized plants.

This paper summarizes the concept for methanation of syngas from coal as proposed in the previous project and discusses the process options for the integration of a gas cleaning unit and CO_2 removal step in the process chain. Using the simulation tool AspenPlus the process options will be compared and evaluated on the basis of the overall thermodynamic and removal efficiencies. In particular a gas scrubbing unit for the cleaning of SNG from a 50 MW brown coal gasification plant was simulated, since the energy required during the solvent regeneration influences the whole process efficiency strongly. Additionally, the overall coal-to-SNG process chain consists of an allothermal steam gasification and the combustion unit for the supply of thermal energy for the gasification. After the gasifier a hot gas filter will remove particles and alkalis and the scrubbing unit captures part of the CO_2 and H_2S fraction from the raw syngas. The process chain is completed by the methanation reactor and a steam cycle to utilize excess thermal energy. As part of the project a screening of European brown coal was performed to determine the coal quality and identify possible locations for the proposed coal-to-SNG plant.

The comparison of the process types shows that for small and medium-scale plants the Benfield process [2] reaches higher efficiencies. Based on these simulations the complete process chain shall be demonstrated on two scales within the research project CO2freeSNG2.0. On one hand the process will be based on an allothermal lab scale gasifier (5 kW) and on the other hand a pre-pilot scale process chain (100 kW) will be commissioned. The pre-pilot scale process chain will operate with raw syngas from a 100 kW Heatpipe Reformer (HPR). Prior tests with the lab scale gasifier and methanation reactor will determine the catalysts and operation conditions for a tar tolerant methanation allowing a temperature peak at the inlet of the methanation reactor to reform light tar components and make them available for methanation [3]. In addition to conventional catalysts a new impurity tolerant catalyst will be subject of investigation within the current research project. The focus of research is set on the raw syngas cleaning evaluated on the basis of removal efficiency of CO_2, organic and inorganic sulphur components as well as higher hydrocarbons.

Acknowledgement: The research project CO2freeSNG2.0 (RFCR-CT-2013-00008) is funded by the Research Fund for Coal and Steel.

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Synchronous measurement of FTIR-ATR spectra and desorbed hydrogen mass *in-situ*: Novel method for investigating the kinetics of hydrogen storage materials

Prof. Dr. Hans-Dieter Bauer, Department of Engineering, RheinMain University of Applied Sciences, hans-dieter.bauer@hs-rm.de
M.Sc. Ingo Franke, Mainova AG, i.franke@mainova.de
Prof. Dr. Birgit Scheppat, Department of Engineering, RheinMain University of Applied Sciences, birgit.scheppat@hs-rm.de

Keywords: Hydrogen Storage, Storage Materials, Hydrides, Desorption Kinetics

Introduction

Hydrogen storage using powdered solid-state materials is a promising possibility for achieving increased hydrogen densities at low pressure. One of the most thoroughly investigated materials for this kind of hydrogen storage is sodium alanate, a sodium aluminum hydride that undergoes different phase changes during the desorption process. Primarily looking for a level sensor effect for this kind of hydrogen tank, we carried out two measurements in parallel during hydrogen desorption: We took the FTIR-ATR spectra and the weight values. These measurements were done at different temperatures and with loose and compacted material. To do so, a special sample chamber for ATR spectroscopic measurements had been developed, integrated into a commercial FTIR spectrometer and combined with a high precision balance. For our work we used 2 mol% $CeCl_3$-doped $NaAlH_4$, the "fully loaded" material. The material was mixed and powdered in our lab using a planetary ball mill. More details of the sample preparation and the setup have been described in [1].

Discussion

The ATR spectra, taken between 700 and 2200cm^{-1} showed the typical Al-H vibration bands. During desorption, the changes of these vibration bands (some gradually vanish, others emerge) correlate with the hydrogen mass desorbed. This clearly reveals the two-phase process from $NaAlH_4$ to Na_3AlH_6 (further desorption to NaH was not in the scope of our investigations). Subsequently spectroscopic and gravimetric data were fitted by Johnson-Mehl-Avrami and Arrhenius equations to obtain the rate constants of the dehydrogenation and the activation energy of the $NaAlH_4$-Na_3AlH_6 phase change. For example, at 90°C the gravimetric rate constant was measured ($7.5 \pm 0.1 * 10^{-3}$) weight%/min, the ATR rate constant was ($8.2 \pm 0.1 * 10^{-3}$) weight%/min. The difference may be due to the fact that the evanescent field senses the surface of the sample whereas the gravimetric value stands for the bulk behavior. The activation energy was found (134.8 ± 0.6)kJ/mol (gravimetric) and (134.6 ± 0.2)kJ/mol (ATR). The measurements further showed that cycling of the powder compacts enhances the dehydrogenation reaction kinetics, whereby a decrease of the activation energy by 3.4kJ/mol was measured. The detailed results and a more thorough discussion are given in [2].

Conclusions and Outlook

Our results show that the dual method presented here offers a helpful tool to investigate the reaction kinetics of hydrogen storage materials, but may also be utilized for other solid-state chemical reactions, of course. Moreover, the correlation of optical signal and desorbed hydrogen mass is a promising onset for designing a fuel level sensor for solid state hydrogen tanks.

Acknowledgement:
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PEM water electrolysis MEAs with WO_3 supported $Ir_xRu_{1-x}O_2$ catalysts

***M. Sc. Nils Baumann**, Fraunhofer-Institut für Chemische Technologie ICT, nils.baumann@ict.fraunhofer.de*
Dr. Carsten Cremers, Fraunhofer-Institut für Chemische Technologie ICT, carsten.cremers@ict.fraunhofer.de
Dr. Karsten Pinkwart, Fraunhofer-Institut für Chemische Technologie ICT, karsten.pinkwart@ict.fraunhofer.de
Dr. Jens Tübke, Fraunhofer-Institut für Chemische Technologie ICT, jens.tuebke@ict.fraunhofer.de

Keywords: water electrolysis, anode catalyst, tungsten oxide support, MEA, degradation

Introduction

Water electrolysis is a promising technique to produce very pure hydrogen for use in a hydrogen energy economy. It is technologically simple, has fast response times to dynamic load and is carbon dioxide neutral, if electricity from a renewable source is used [1]. The drawbacks include the use of expensive noble metal catalysts. To reduce the costs the catalysts can be dispersed on a support to increase the electrochemically active surface area and stability. In this work we manufactured membrane electrode assemblies (MEAs) from in house synthesized $Ir_xRu_{1-x}O_2$ catalysts supported on WO_3 using several commercial membranes. Different catalyst/support ratios and loadings were tested. Catalyst /support ink was sprayed either on the membrane or on different Gas Diffusion Layers (GDL). Electrochemical activity and stability were evaluated and compared.

Discussion

$Ir_{0.5}Ru_{0.5}O_2$ (theoretical composition) was synthesized using Adam's Fusion protocol. RuO_2 is one of the most active materials for the oxygen evolution reaction (OER), but has to be stabilized with a mixed oxide [2]. WO_3 was chosen as support as it is stable at the harsh anode conditions. Catalyst was loaded onto support by mechanical mixing and optional annealing under inert atmosphere and showed good dispersion in TEM imaging. Activity of Nafion 115 membrane loaded with 5 mg cm^{-2} 50 wt% $Ir_{0.5}Ru_{0.5}O_2$ / WO_3 is shown in **Figure 1**. Measurements were taken potentiostatically at 1.9 V and 25 °C using distilled H_2O at anode and cathode.

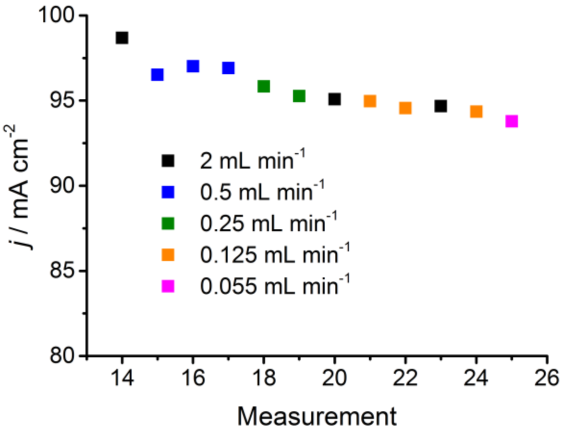

Figure 1: Potentiostatic measurements of MEA at 1.9 V, 25 °C with different flow rates of bid. H_2O at the anode.

As can be seen even very low flow rates do only slightly reduce MEA activity. The values of **Figure 1** extend over a measurement time of 6.2 h. Post Mortem SEM / EDX imaging confirms homogeneous distribution of catalyst and support, as well as stability of RuO_2, which is easily oxidized to RuO_4 and flushed out of the cell, when not stabilized. Single cell tests of catalyst/support sprayed onto Ni-foam GDLs depend largely on the porosity of the GDL, as more catalyst is inactive the higher the porosity of the GDL is.

Conclusions and/or Outlook

In house synthesized supported catalyst shows good activity and stability during single cell tests. Further studies in fine tuning MEA fabrication parameters as well as extended long term and degradation experiments are necessary next steps.

Acknowledgement: Financial support by the German Federal Ministry of Education and Research (BMBF) under the contract number FKZ 03SF0432A is greatly acknowledged.

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9000 hours operation of a 25 solid oxide cells stack in steam electrolysis mode

***Dr. Gaël Corre**, EIFER, European Institute for Energy Research, corre@eifer.org*
Dr. Annabelle Brisse, EIFER, European Institute for Energy Research, brisse@eifer.org

Keywords: Energy storage, Solid oxide cells, Electrolysis, Hydrogen

Introduction

Hydrogen production through water electrolysis is one of the key processes required in the conversion of electricity to fuels. Carbon free hydrogen produced through water electrolysis can be used as a fuel for hydrogen powered applications (such as fuel cell cars) or grid injection, or as a reactant in downstream processes to produce synthetic fuels such as SNG or methanol. Among available technologies, high temperature electrolysis potentially offers significantly higher electrical to chemical conversion efficiencies compared to alkaline and PEM electrolysers, with values in excess of 100% achievable if additional thermal energy is supplied to the system. High temperature electrolysers are essentially solid oxide fuel cells operated in reverse. Hence, the development of solid oxide electrolysers (SOE) has hugely benefited from the intensive research carried out for the development of Solid Oxide Fuel Cells (SOFCs) in the past decades. A 25 cells stack manufactured by Topsoe Fuel Cells has been tested at EIFER in high temperature electrolysis mode at about 750°C and current densities of 0.57 and 0.72 A/cm2. The applied steam conversion rate was 50%, with a 90 % absolute humidity gas feed.

Discussion

The total duration of the test was almost 9100 hours, split between 8300 current hours and 800 standby hours induced by incidents that occurred during the test. Incidents included losses of the steam and current supplies. After each incident, the stack performance was recovered, indicating a good robustness of the stack towards unexpected and potentially damaging conditions. The main issue during the test has been the considerable increase of the voltage drop between the positive end plate and the bottom stack repeat unit (SRU), before a sharp improvement occurred after about 2000 hours of operation, which has influenced the stack temperature distribution and in turn individual SRU degradation. The maximum observed voltage drop culminated at 2.73 V, before stabilising around 0.6V.

The stack has shown an overall voltage degradation of 2% per thousand hours, as can be seen on **Figure 1.** The corresponding voltage losses were 613 mV and 678 mV per thousand hours, for 0.57 and 0.72 A/cm2 current densities, respectively. This in turn corresponds to an average degradation in the range 0.24 – 0.27 mV per thousand hours per SRU.

Moreover, the stack temperature has been adjusted on a few occasion during the test, which highlighted the possibility of using the wide operating temperature range of the solid oxide technology to counter balance the stack degradation and increase the lifetime. Indeed, allowing the stack to increase at a rate of 3°C per thousand hours produced a reduced degradation rate of 1.80 % per thousand hours.

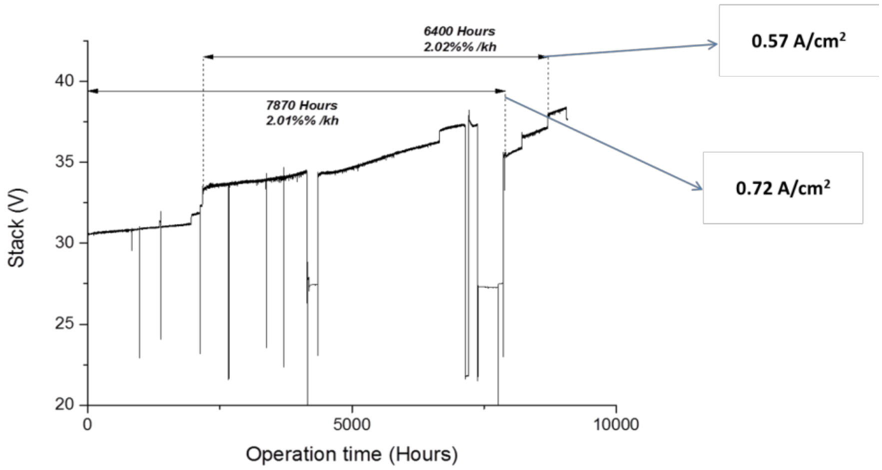


Figure 1: Evolution of the stack voltage as a function of the operating time and calculated degradation rates.

Polymeric Catalysts for Catalytic H_2 production from Formic Acid

Dr. Peter J. C. Hausoul, *ITMC, RWTH Aachen University, Hausoul@itmc.rwth-aachen.de*
Cornelia Broicher, ITMC, RWTH Aachen University, cornelia.broicher@rwth-aachen.de
Severin Foit,M.Sc. ITMC, RWTH Aachen University, Foit@itmc.rwth-aachen.de.
Dr. Marcus Rose, ITMC, RWTH Aachen University, Rose@itmc.rwth-aachen.de.
Prof. Dr. Regina Palkovits, ITMC RWTH Aachen University, Palkovits@itmc.rwth-aachen.de.

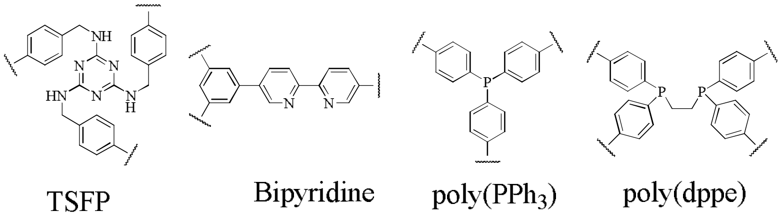
Ruthenium, polymeric phosphine, Formic acid, hydrogen production

Introduction

H_2 is considered a highly suitable energy carrier for renewable energy as it can be generated from water by photoelectrolysis and is compatible with many existing technologies. However, concerns regarding the cost and safety of handling gaseous H_2 have spurred the search for new ways for its condensation to high energy density materials. In this regard, the interconversion between formic acid and H_2 and CO_2 has received considerable attention because it combines carbon sequestration with energy storage.[1] Furthermore formic acid can also be obtained from cellulosic biomass via dehydration.

Discussion

It has been demonstrated that homogeneous ruthenium- and iridium-based complexes with phosphorus- and nitrogen-donor ligands are effective for both reactions under mild conditions.[2] Inspired by these systems, several new cross-linked polymers containing N- and P-donor centers have been prepared to facilitate immobilization. Various linkers and connecters were employed for polymerization and gave rise to surface areas up to 1000 m^2 (Scheme 1).



Scheme 1. Monomeric units of N- and P-donor center functionalized polymers (TSFP: triazine super functionalized polymer).

Both ruthenium on phosphorus-based polymers[3] and iridium on nitrogen-based polymers[4] showed high activity for the decomposition of formic acid over a broad range of conditions, which rivals that of the homogeneous analogs. High selectivities toward H_2/CO_2 (>99.9%) were obtained. Recycling tests revealed low levels of leaching and only a gradual decrease in TOF over more than 10 runs.

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Geochemical modelling of hydrogen interaction with minerals and aqueous species

Siroos Azizmohammadi, *Department of Petroleum Engineering, Montan University of Leoben, Austria, siroos.azizmohammadi@unileoben.ac.at*
Neda Hassannayebi, Department of Petroleum Engineering, Montan University of Leoben, Austria, neda.hassannayebi@unileoben.ac.at

Keywords: *underground hydrogen storage, geochemical modelling, pH variation, solid-solution, mineral alteration*

Abstract

Large-scale underground hydrogen storage is a promising way to store the renewable energy. Feasibility of such a storage need to be thoroughly investigated. Geochemical modelling and study of probable reactions that could occur as a consequence of hydrogen injection in the reservoir, is one of the key steps in performing such projects.

This work is part of the unique collaborative research project of the underground storage of wind and solar energy (Underground Sun Storage) funded by “Klima- und Energiefonds” which is currently conducting in Austria. The available dataset from the upper Austria Molasse basin was used to build a geochemical model and investigate the effects of injected hydrogen into the system.

The geochemical model involving hydrogen, formation water and minerals was setup using GEM-Selektor (GEMS) package. Charge balance analysis of the formation water sample was determined. SUPCRT92 thermodynamic database of GEMS, was selected as the main database for the modelling. Chemistry and thermodynamic data of the mineral assemblage has been reviewed and solid solutions for clay minerals were created and integrated into the main thermodynamic database. The Gas–water–mineral interactions and the non-ideality of the gas phase were considered in the numerical simulations. Thermodynamic model of the formation water, minerals and gas phase at *in situ* P = 107 bar and T = 40°C was created, then hydrogen was introduced into the system. Despite limitations and uncertainties of geochemical modelling, such as not considering kinetic rates in the modelling, the main results can be summarized as follows: (1) as H_2 introduced, CH_4 is formed, (2) H_2 only appears in the gas phase when enough amount of H_2 gets injected, (3) there is a decreasing trend in the contribution of H_2 to reactions in aqueous, gas, and mineral phases with increasing amount of injected H_2, (4) there is an increasing trend in pH as H_2 is injected, and (5) as the system is titrated by H_2, some mineral alterations (dissolution and precipitation) are observed. These results will be validated by further experimental data.

A Study of Ni-Ca catal-sorbent prepared by novel-modified method to improve catalytic activity during multiple cycles in SESMR reaction

Eunji Lim[a], Sukyong Jung[b], Yonghee, Park[a], Seongmin Chio[a], Yongmok Kwon[a], Minsun Cho[a], Sochool Lee[b], Jaechang Kim[a*]
[a]Department of Chemical Engineering, Kyungpook National University, Daegu, 702-701, Korea
[b]Research institute of advanced energy technology, Kyungpook National University, Daegu, 702-701, Korea
**Corresponding author: Fax: +82 53 950 6615, E-mail: kjchang@knu.ac.kr*

Keywords: H_2 Energy, CaO sorbent, Ni catalysis, SESMR

Introduction

Hydrogen has wide applications in the chemical and energy industries, and is also identified as a promising clean energy source for electrical generation like fuel cells [1]. Recently, to produce the high purity H_2 in single step reactor, the sorption enhanced steam methane reforming (SESMR) has being studied, which is simultaneously processed the steam methane reforming and CO_2 removal reactions [2]. In the case of SESMR reaction, dry absorption method for CO_2 capture by solid absorbent like CaO is used as shown in eq 1.

SESMR : $CH_4 + 2H_2O + CaO \leftrightarrow CaCO_3 + 4H_2$ $\Delta H°_{25°C} = - 13$ kJ/mol (eq 1)

Results and Discussion

First, to investigate the property of SESMR on the commercial catal-sorbent, 0.45g of Ni-Al-based catalyst was mixed with 1.05g of the CaO (NAC-P) and tested in a fixed-bed reactor at 600ºC, S/C=3 after reduction (10% H_2 at 750ºC for 2hr). Second, to compare properties of the SESMR on the Ni-Ca-based catal-sorbents, the Ni-Ca-based catal-sorbents of one body type were prepared by various methods such as impregnation (CNAim) and novel-modified method (CNAmm) and tested as same SESMR condition. The SESMR reaction and regeneration reaction were operated at 600ºC and 800ºC, respectively. Figure 1 shows the CH_4 conversion (%) and CO_2 concentration (%) emitted from reactor of NAC-P (a) , CNAim (b) and CNAmm (c) catal-sorbents for SESMR reaction during multiple cycles. In the case of NAC-P catal-sorbent, the start time of breakthrough step decreased from 30 min to 10 min during the 1 cycle and 5 cycle, because CO_2 capture capacity of CaO sorbent was rapidly decreased during multiple cycles by thermal sintering. As shown in Figure 1 (b) and (c), In the case of CNAmm catal-sorbent, CH_4 conversion about 95% and CO_2 concentration about 0 % were maintained for 30 min as the pre-breakthrough step in during multiple cycles, while those of CNAim catal-sorbents were not observed pre-breakthrough step. It was found that the CNAim catal-sorbent was not indicated even any activities such as CH_4 conversion and CO_2 removal. Finally, the CNAmm catal-sorbent showed excellent CH_4 conversion, CO_2 capture capacity and long-term stability properties for SESMR reaction during multiple cycles. In the work, we need to be more investigate that characterization of Ni-Ca-based catal-sorbents during multiple cycles, SESMR properties with various weight ratio of catalyst and CO_2 sorbent.

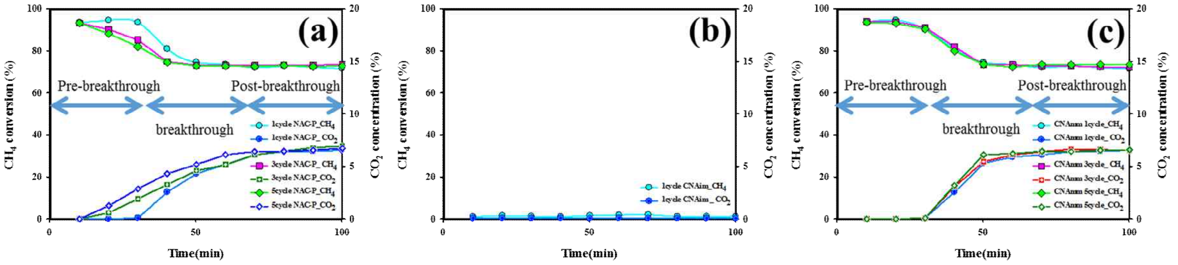

Figure 1: CH_4 conversion (%) and CO_2 concentration (%) emitted from SESMR reaction of NAC-P (a), CNAim (b) and CNAmm (c) catal-sorbents for SESMR reaction during multiple cycles.

Acknowledgement: This work was supported by Energy Efficiency and Resources R&D program (2011201020004A) under the Ministry of Knowledge Economy, Republic of Korea and we acknowledge the financial support by grants from Korea CCS R&D Center, funded by the Ministry of Education, Science and Technology of Korean government.

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TECHNICAL FEASIBILTY AND DESIGN STUDY OF METHANE CRACKING IN A LIQUID METAL

***Dr.-Ing. Leonid Stoppel**, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology,*
leonid.stoppel@kit.edu

Dipl.-Ing. Tobias Geißler, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology,
tobias.geisslerr@kit.edu

Dipl.-Ing. Michael Plevan, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology,
michael.plevan@kit.edu

Prof. Dr.-Ing. Thomas Wetzel, Institute for Nuclear and Energy Technologies, Karlsruhe Institute of Technology,
thomas.wetzel@kit.edu

Prof. Dr. Alberto Abánades, Institute for Advanced Sustainability Studies, Potsdam, Germany,
alberto.abanades@iass-potsdam.de

Dr. Kian Mehravaran, Institute for Advanced Sustainability Studies, Potsdam, Germany,
kian.mehravaran@iass-potsdam.de

Dr. Renu Kumar Rathnam, Institute for Advanced Sustainability Studies, Potsdam, Germany,
renu.rathnam@iass-potsdam.de

Keywords: hydrogen production, methane pyrolysis, liquid metal, bubble column reactor

Abstract

In many concepts of the future energy system, hydrogen plays an important role as energy carrier. Presently, most hydrogen is produced from natural gas through steam methane reforming. A large amount of carbon dioxide is emitted by this process (about 5% of worldwide CO_2-emission). In view of this, the presented work aims to investigate the possibility of hydrogen production without CO_2 formation by using direct methane cracking in a liquid metal bubble column [1, 2, 3].

To be able to carry out the experimental research on methane pyrolysis in a liquid metal based reactor like a bubble column, the test facility HELiS (**H**ydrogen production **E**xperiment in **Li**quid **S**n) has been designed, manufactured, instrumented and put into operation in the Karlsruhe liquid metal laboratory (KALLA) at the Karlsruhe Institute of Technology (KIT). The facility consists of the gas supply system, experimental port for liquid metal reactor, outlet gas analysis system, instrumentation and the control system. With regard to the operation with explosive and flammable gases in the presence of liquid metal at temperatures up to 1200°C, a sophisticated safety system and carefully selected precautionary measures were developed.

Several experimental campaigns were conducted to test and optimize different reactor concepts. One of the key elements of the bubble column is the gas injection device, which forms methane bubbles rising in the reactor. Different types of bubbling devices were considered and tested. A major emphasis has been put on an analysis of the reactor material behaviour at very high temperature. Because liquid metals have highly corrosive behaviours, the lifecycle of the reactor strongly depends on the according interactions. Another important subject of the investigation is the development of innovative measurement techniques, suitable for high temperature and liquid metal environments. All these mentioned aspects were studied during the experimental work in detail. Additionally, various experiments with different packed beds in the a vertical tube reactor were performed in water to estimate significant hydro-dynamic parameters such as the gas bubble residence time and liquid level hold-up inside of the reactor.

Further experimental investigations on the direct thermal decomposition of methane in liquid metal bubble column are under progress and will be part of the presentation.

Acknowledgement: This work was performed using grants from the Institute for Advanced Sustainability Studies (IASS) in Potsdam and from the LIMTECH (Liquid Metal Technologies) Helmholtz Alliance.

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Hydrogen production by thermal pressure hydrolysis of lignocellulosic biomass

Sonja Wiesgickl, *Fraunhofer UMSICHT, sonja.wiesgickl@umsicht.fraunhofer.de*
Andreas Weger, Fraunhofer UMSICHT, andreas.weger@umsicht.fraunhofer.de
Fabian Stenzel, Fraunhofer UMSICHT, fabian.stenzel@umsicht.fraunhofer.de
Prof. Dr. Andreas Hornung, University of Birmingham, Università di Bologna and Fraunhofer UMSICHT, andreas.hornung@umsicht.fraunhofer.de

Keywords: Lignocellulose, Thermal Pressure Hydrolysis, enzymatic pre-treatment, hydrogen

Introduction

In addition to the current main application of hydrogen in chemical processes it is also considered as key component for a sustainable energy market. However, the largest content of hydrogen is currently still produced from fossil carbon. One option for CO_2-neutral hydrogen production is the use of lignocellulosic biomass. Due to their high cellulose content pre-treatment is necessary to improve the enzymatic breakdown. For this reason Fraunhofer UMSICHT, institute branch Sulzbach-Rosenberg started small-scale technical experiments with the Thermal Pressure Hydrolysis (TPH process) to explore the possibility to produce hydrogen from straw as a cost-saving biomass which is climate neutral and free of competition with the food sector.

Approach

The pre-treatment of straw by TPH process makes cellulose more available to enzymatic breakdown and solubilizes hemicellulose sugars. Hence, a substantial part of hemicellulose can be almost quantitatively removed from the straw and improves the anaerobic degradation of the hemicellulosic sugars for hydrogen production. The TPH process has been successfully used as a pre-treatment method for sewage sludge, bio waste and animal by-products. Compared to not pre-treated biomass the biogas yield increased about 30 %. According to these results, the TPH process could increase the hydrogen production during anaerobic hydrolysis and offers the opportunity to enlarge the substrate basis for lignocellulosic biomass.

The screening parameters for the TPH trials were the temperature (range of 120 to 180°C) and the retention time (range of 30 to 60 min). Therefore a correlation between the achievable hydrogen yield of the anaerobic hydrolysis and the organic transfer ratio measured as Chemical Oxygen Demand (COD) during the TPH process was used to characterize optimal pre-treatment parameters.

Results

During our experiments we have been able to show, that TPH process conditions with higher temperature or retention time leads to an increased organic amount in the liquid phase of the hydrolysate. By subsequent addition of enzymes a further increase of the organic transfer rate of the hydrolysate could be observed by an increase in COD of about 295 % at a temperature of 160 °C and a retention time of 30 minutes. A further increase of temperature (180 °C) and retention time (45 minutes) led to increased COD of 120 % compared to the TPH process (T= 160 °C and t= 30 min). The COD concentration of the hydrolysate after different pre-treatment routes is shown in **Figure 1**.

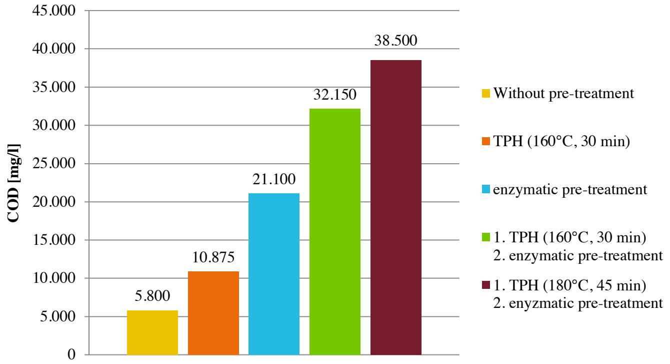

Figure 1: COD concentration of the hydrolysate after different pre-treatment routes

Conclusions

The aim of the work is the development of a new cost-effective pathway for hydrogen production using lignocellulosic biomass. From the first results it can be expected that the chosen combination of TPH and enzyme assisted anaerobic hydrolysis offers promising alternative to common hydrogen production. The crucial question is how the TPH process conditions influence the enzyme activity and by this the achievable hydrogen yield. Next steps include the adaption of the process conditions for TPH and anaerobic hydrolysis to reach a maximum hydrogen production.

Energy storage using Liquid Organic Hydrogen Carriers

***Dr.-Ing. Karsten Müller**, Institute of Separation Science & Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg ,karsten.mueller@fau.de*
Prof. Dr.Wolfgang Arlt Institute of Separation Science & Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg

Keywords: Hydrogen, Energy Storage, Heat integration, Organic Hydrides

Introduction

Storage of hydrogen is challenging due to low energy density. Compression, liquefaction or adsorption are options to overcome this limitations, but still storage density is insufficient for most applications. Metal hydrides can achieve higher energy densities, but especially kinetics of hydrogen uptake and release are rather poor. Organic hydrides haven attracted increasing attention in recent years.

Approach

So called Liquid Organic Hydrogen Carriers (LOHCs) are a widely discussed as a promising option for the storage of energy. [1] These unsaturated compounds can be hydrogenated reversibly and can release hydrogen again when energy is needed. The hydrogen is bound chemically, making storage at ambient conditions possible. LOHCs can be used to store hydrogen energy in a safe and dense manner e.g. for residential buildings or remote systems. Other than batteries the supply of the raw storage material is not critical. N-ethylcarbazole and dibenyltoluene are in the focus of present works. However, a number of challenges still exists and is addressed by ongoing research.

The thermodynamic driving force of the hydrogenation reaction is high making this reaction rather easy. On the other hand this means a low driving force for the dehydrogenation. To realize the dehydrogenation rather high temperatures have to be applied for the reaction. An intelligent selection of the LOHC material is therefore needed to allow for reasonable process conditions and optimize the overall energy balance. [2]

Since this technology deals with a multiphase system phase equilibria are observed. This leads to the solving of unreacted hydrogen in the LOHC, evaporation of LOHC into the released hydrogen or demixing of LOHC and water in the storage tank. Intelligent design of the process is able to reduce these effects, but further separation steps are needed to reach the purity requirements.

Research and development of LOHC systems depend on reliable substance data for the materials used. Until now the respective data are missing for many of the relevant compounds. Separation science has to isolate the pure intermediate forms, before subsequent measurements can provide the pure substance data.

Conclusions and Outlook

Hydrogen storage based on LOHCs is an interesting option to storage nameable amounts of surplus energy. Efficiencies higher than for e.g. conversion using Fischer-Tropsch are possible if heat integration is done in a reasonable way. [3] Performance of modern LOHC materials could be significantly improved compared to the first compounds under research. Currently research in the field of LOHC focuses on the implementation of the technology, but works to achieve fundamental improvements, like better carrier materials, are still ongoing.

Acknowledgement: This work has been done within the framework of the Energy Campus Nürnberg and of the Bavarian Hydrogen Center.

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Pressurized alkaline electrolyser with high efficiency and wide operating range – the project RESelyser

Regine Reissner*, Institute of Engineering Thermodynamics, DLR German Aerospace Research Center, regine.reissner@dlr.de*
Dr. Guenter Schiller, Institute of Engineering Thermodynamics, DLR, guenter.schiller@dlr.de
Erich Guelzow, Institute of Engineering Thermodynamics, DLR, erich.guelzow@dlr.de
Y. Alvarez-Gallego, VITO NV, yolanda.alvarezgallego@vito.be
W. Doyen, VITO NV, wim.doyen@vito.be
B. van Craenendonck, Hydrogenics Europe NV, bvancraenendonck@hydrogenics.com
J. Vaes, Hydrogenics Europe NV, jvaes@hydrogenics.com
J.R. Bowen, Technical University of Denmark (DTU),jrbo@dtu.dk

Keywords: Electrolysis,Hydrogen generation, Technology, Material

Introduction

For wide-spread use of electrolysers for energy storage by converting surplus renewable electrical energy to hydrogen the main obstacles are the costs of the device and the limited adaptation to fluctuating power supply. To adress these points the project RESelyser has developed concepts and materials for high pressure, highly efficient, low cost alkaline water electrolysers that can be integrated with renewable energy power sources (RES) using an advanced membrane concept, highly efficient electrodes and a new three-compartment cell design. A new separator membrane with internal electrolyte feeding and an adapted design of the cell to improve mass transfer, especially gas evacuation has been investigated and demonstrated. Intermittent and varying load operation with RES has been addressed by improved electrode stability and a cell concept for increasing the gas purity of hydrogen and oxygen especially at partial load and high pressure operation.

Discussion

High performance electrodes with a plasma sprayed coating layer give an overpotential reduction of 330 mV compared to uncoated electrodes thus showing high performance and stability with lowcost material. Detailed investigation of the electrode pore structure and microstructure at beginning of life and after operation shows possible degradation mechanisms. It was found that by feeding KOH solution from inside the internal compartment of a double layer diaphragm towards both the anolyte and catholyte compartments improves the gas purities of the cell significantly. The novel three-compartment cell concept using this double layer diaphragm (E-bypass separator) was realized in single cells of 300 cm^2 area and in a 10 kW stack.

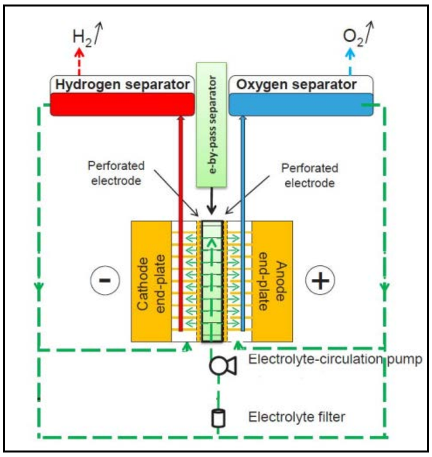


Figure 1: Scheme of system with double layer diaphragm

Conclusions and/or Outlook

Despite being an old technique further improvements for alkaline electrolysers can still be achieved to make them better adapted to new applications in hydrogen fuelling and energy storage.
For further information see www.reselyser.eu.

Acknowledgement: *The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant agreement n° [278732] 10.*

Operation and Stability of Hybrid Transmission Systems

Julia Dragon, Henning Zimmer, Jutta Hanson, *E5, TU Darmstadt, j.dragon@e5.tu-darmstadt.de*
Philipp Schäfer, Hendrik Vennegeerts, *FGH e.V.*
Tim Bongers, Sebastian Dierkes, Albert Moser, *IAEW, RWTH Aachen University*
Thomas Leibfried, *IEH, Karlsruhe Institute of Technology*
Marco Greve, Theresa Noll, Christian Rehtanz, *ie3, TU Dortmund University*

Keywords: Electric Energy Transmission, HVDC, Ancillary Services

Introduction

National governments throughout Europe as well as the European commission itself push for a power system based on renewable energy sources (RES). This creates substantial challenges for the electricity transmission system and the need for new transmission solutions in order to ensure stable and reliable operation of the power system. This poster presents the scope and intermediate results of a research collaboration of RWTH Aachen University, Technische Universität Darmstadt, TU Dortmund University and Karlsruhe Institute of Technology. In the course of this project, two main challenges for future transmission grids have been investigated.

AC/DC Transmission Grid expansion and control

RES are constructed in advantageous geographical locations which can be remote from load centres. This creates a substantial need for long-distance transmission capacities throughout Europe. High Voltage Direct Current (HVDC) systems have become an attractive option for these grid reinforcements. So far, grid expansion planning is being conducted mainly on national level, leading to locally instead of globally optimised solutions. This is why in this project, integrated grid expansion strategies for a hybrid AC/DC transmission grid are being investigated. As first steps, an aggregated dynamic model of the European transmission system has been developed (**Fig. 1a, [1]**). Using a market simulation based on [2], load/infeed-scenarios have been created for the years 2011, 2020 and 2030. This has enabled first evaluations for grid expansion as well as studies of the future dynamic behaviour of the European transmission system. In further studies, the existing approach for a DC expansion strategy will be applied. Dynamic studies will show the improved system behaviour.

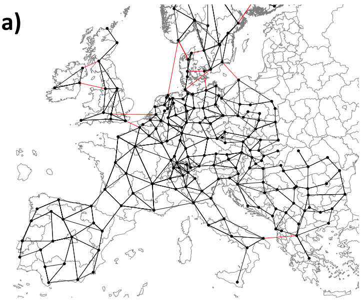
Stability and ancillary services in the future transmission grid

Another crucial aspect of the future transmission system is the change in power generation technology and its infeed voltage level. In conventional power systems, synchronous machines connected to the transmission grid generate most of the power. RES are predominantly feeding in via converters and on lower voltage levels.
In this project it is investigated, if ancillary services for the transmission grid such as reactive power, frequency control and short-circuit current contribution can be partly passed to RES and which conflicts arises from this change between distribution and transmission grid. This includes the following aspects:

- Voltage and frequency stability for a highly volatile future power system, demand of balancing power
- Concepts for the future reactive power exchange between distribution and transmission grid (see **Fig. 1b**)
- Provision of ancillary services by RES in the distribution grid

In further steps, the preliminary results will be used for the development of suitable control strategies.

1a)



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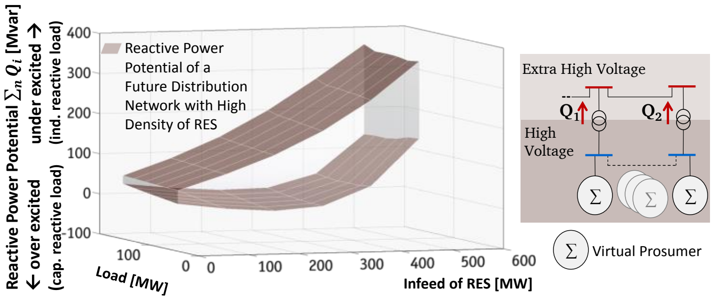

Figure 1a: Structure of the aggregated model of the European transmission grid [1]
Figure 1b: Reactive power potential of a generic distribution grid depending on load/infeed and control strategy

Acknowledgement: This work is supported by the Initiative and Networking Fund of the Helmholtz Association, in the frame of the Helmholtz Energy Alliance "Technologies for the Future Power Grid".

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Vehicle to Grid storage potential based on fleet test data of user behaviour

Dipl. Phys. Mathias Kammerlocher [1,2], Ricardo Brodale [2], Prof. Michael Kurrat [2]
[1] Environmental Affairs, Strategy and Mobility Department, Volkswagen Group Research, mathias.kammerlocher@volkswagen.de
[2] Technische Universität Braunschweig, Institut für Hochspannungstechnik und Elektrische Energieanlagen (Elenia), Braunschweig, Deutschland

Introduction

Intelligent charging strategies for electric vehicles (EV) have generated much interest over the last decade due the potential to support the power grid. In particular, load shifting can decrease charging cost and promote the integration of renewable energy sources into the electricity system. Furthermore, ancillary services delivered by electric car battery storage can balance short term variation of demand and supply in the electricity grid. The potential of these services depends on the mobility behaviour and acceptance of the users as they have to specify their driving needs [1]. These driving needs define constraints for the charging strategy. The user has to define a minimum battery level for unanticipated trips which limits discharging along with a timer for the next planned trip including the end of charge time and required battery level. The impact of EVs has been studied in simulation models based on average parking time and trip durations [2] or by Monte Carlo simulations of the travel behaviour based on data from travel surveys [3]. However, it is unclear how people are interacting with the system in reality and how much storage they are willing to provide.

In this paper, we present data about the mobility behaviour and the storage potential from a 12 month fleet test of 20 e-up!s equipped with communication technology and a bidirectional charger for providing ancillary services. In this system, the users had to specify their driving needs via a smartphone app. These data have been collected in the frame of the project INEES (Smart Grid Connection of Electric Vehicles Enabling Ancillary Services) in order to demonstrate the potential of EVs for V2G services.

Discussion

Figure 1(a) shows the average parking and plug-in times of all EVs at home for one week. Both curves follow the regular weekly rhythm with 95% of cars parking at home during night and a reduction during daytime. We observe a minimum of 30% during weekdays, which is comparable to previous studies based on travel surveys [3]. However, the plug-in probability is about ten percent less and cannot be derived from travel data of conventional cars.

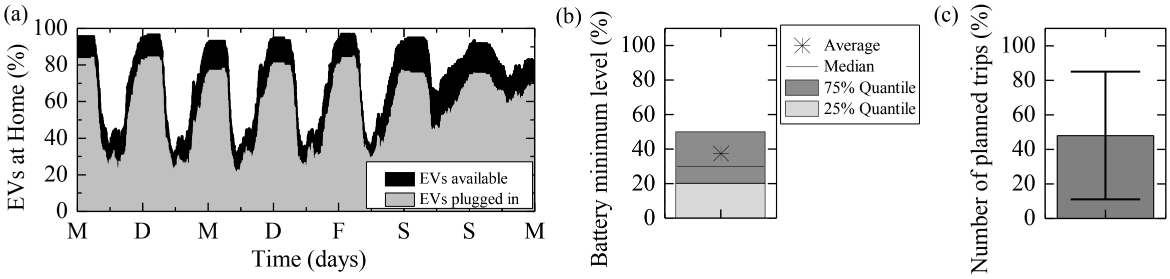

Figure 1: INEES fleet test data: (a) Parking and plug-in times of EVs at home. (b) Average setting for the minimum SoC. (c) Percentage of planned trips.

In addition to previous transportation data, users during the INEES fleet test had to define the required minimum state of charge (SoC) and they were able to plan their trips with timers as described before. To compensate the effort an incentive was given for every kWh the people provided to the utility. The car used for the fleet test was a Volkswagen e-up! with a battery size of 18 kWh. The results obtained on average for all drivers are plotted in **Figure 1(b)** and **(c)**. For the minimum battery level we observe a mean value of 37.5% and a 75% Quantile of 50%. Furthermore, 48% of all trips were planned. The results prove that people are willing to provide storage for V2G Services as they allowed discharging down to the minimum SoC. However, intelligent charging strategies need to consider unpredicted trips (52%) and diverse individual mobility behaviour. In the full paper, we present these charging strategies and analyse the resulting storage potential for V2G services.

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MCCF-based control of active harmonic filters for power quality enhancement

***Peter Krasselt**, Institute of Electric Energy Systems and High-Voltage Technology, Karlsruhe Institute of Technology, peter.krasselt@kit.edu*
Dr. Michael R. Suriyah, Institute of Electric Energy Systems and High-Voltage Technology, Karlsruhe Institute of Technology, michael.suriyah@kit.edu
Prof. Dr.-Ing. Thomas Leibfried, Institute of Electric Energy Systems and High-Voltage Technology, Karlsruhe Institute of Technology, thomas.leibfried@kit.edu

Keywords: Electrical power distribution, ac-dc power converters, power quality, power harmonic filters

Introduction

Energy efficiency, electric vehicles and distributed renewable energy (DRE) all together are changing low-voltage networks operation. All three trends base on power electronic devices connected to the distribution network. Offering a compact efficient device design and a flexible load- and generation response, these semi-conductor based devices will dominate customer connected load and generation behaviour in the near future.

Discussion

As power electronics emit a wide harmonic current spectrum, the technological transition to power electronics has an impact on harmonic levels in distribution grids. In distribution network operation, nominal power derating of cable systems and transformers and decreased power quality are the main effects of rising harmonic levels. One method for harmonic mitigation is the installation of dedicated power converters used as active harmonic filters. Steadily increasing computational resources in embedded control hardware allow nowadays a hybrid concept: power converters used for a customer application, e.g. electric vehicle fast charging stations, can also be used as active harmonic filter. A voltage-based harmonic detection method for harmonic elimination [1] is integrated in an electric vehicle fast charging station (**Figure 1a**). The voltage-oriented control of the active-front end is extended by a parallel harmonic compensation control structure. Control loop interactions are suppressed using multiple complex coefficient filter (MCCF) for control decoupling (**Figure 1b**). Simulative results are shown in **Figure 2**: A low-voltage network scenario [1] is tuned to a total harmonic disturbance of 10 %. Integration of the proposed harmonic compensation algorithm reduces harmonic disturbance to 3 %.

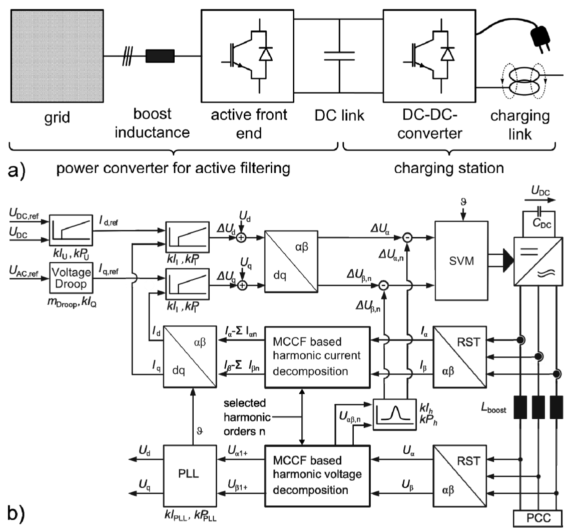

Figure 1: Proposed harmonic control concept
a) Electrical vehicle fast charger topology
b) Block diagram of control concept

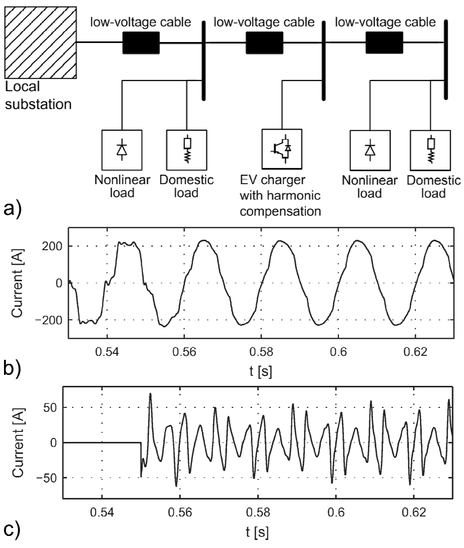

Figure 2: Simulative results
a) Network scenario setup
b) Current measured at local substation
c) Electric vehicle fast charger current, operation in harmonic filter mode starts at t = 0.55s

Conclusions and Outlook

A MCCF based concept advancing grid-tied power electronic control for enhancement of power quality in distribution networks has been proposed. Simulative results prove the effectiveness of the harmonic compensation algorithm. For experimental verification, the algorithm is implemented in an 80 kVA electrical vehicle fast charging demonstrator and is currently under testing.

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Integration of Renewable Energy Sources with Time Constrained Optimal Power Flow

***Nico Meyer-Huebner, Michael Suriyah, Thomas Leibfried**, Institute of Electrical Energy Systems and High Voltage Technology, Karlsruhe Institute of Technology (KIT), nico.meyer-huebner@kit.edu*

Keywords: Optimal Power Flow, Energy Storage, Smart Grid

Introduction

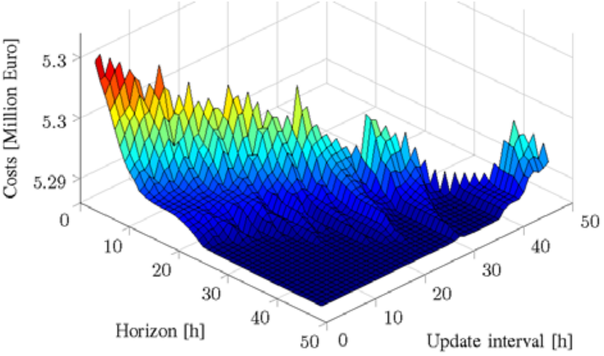
Today's electrical grids are confronted with new challenges. The rising number of renewable energy sources (RES) lead to so far unchartered territories and pushes the grid more and more frequently towards its limitations. If those limits are not considered during the dispatch of the generators, expensive redispatch will be necessary to avoid outages. However, the limits can be integrated into the search for the most economic generator dispatch, meaning the distribution of the demanded power to a pre-defined set of generators considering their individual costs, which is called an optimal power flow (OPF). Energy storage will be a crucial piece of the puzzle for a successful integration of RES. With a provided forecast of wind or solar power, it is possible to minimize the costs over a certain time period considering inter-temporal constraints like storage energy or generator ramping.

Discussion

A general OPF problem can be described as $\min_x f(x)$, subject to $g(x) = 0$ and $h(x) < 0$. The state vector x contains all optimization variables like generated power and voltages of all time steps. Main goal is the minimization of the cost function $f(x)$, which depends on the generator outputs. Energy from renewable sources is much cheaper than from conventional sources, and therefore a cost minimization is attained by integrating the maximum possible of RES. The equality constraints $g(x)$ describe the power flow of each time step, which must meet the laws of physics. The inequality constraints $h(x)$ contain all kinds of limited variables, which might be time-independent (voltage and line constraints) or time-dependent (generator ramping, storage energy). The problem is solved with the Lagrangian relaxation, which assigns a multiplier to each constraint. The equality constraints are represented in λ, and the inequality constraints in μ. To include the inequalities in a function which shall be minimized, slack variables $z > 0$ are introduced. With $h(x) + z = 0$, the inequalities are transformed to equality functions and the Lagrangian is formed to $\mathcal{L}(x, \lambda, \mu, z) = f(x) + \mu(h(x) + z) + \lambda g(x)$. Common Newton steps are applied to solve the KKT-conditions [1]. It is therefore necessary to provide first and second gradients of $\mathcal{L}$. A detailed description of the Primal-Dual Interior Point Method can be found in [2].

The receding horizon principle is applied. The optimization is done for a certain horizon, but the resulting dispatch is only applied for a shorter update interval. After this interval, the predictions of the RES and the loads are updated and a new optimization for the horizon is done.

It is of big interest how to choose the horizon and the update interval. Each optimization is time-consuming and the update interval should therefore be chosen as large as possible without raising the overall system costs. At the same time, the simulation time grows with a larger horizon, which is necessary for large update intervals. In the figure it can be seen that the cost minimum for a modified IEEE14 test case is found above a certain offset of 20-24 hours between horizon and update interval. This provides enough information to the storage devices to maximize the RES in-feed.



Conclusions and Outlook

A time constrained optimal power flow is used to maximize the integration of renewable energy into the grid by controlling the storage devices. It is shown that a simple rule can be found for the relationship between the necessary prediction horizon and the update interval to reach the cost minimum. So far, no prediction errors were considered, which will be part of future work. Additionally, further scenarios will be tested to verify the assumption.

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Optimal size of stationary energy storages for solar home systems

Martin Uhrig, *Benedikt Neu, Prof. Dr.-Ing. Thomas Leibfried, Institute of Electric Power Systems and High-Voltage Technology, Karlsruhe Institute of Technology, martin.uhrig@kit.edu*

Keywords: stationary energy storage dimensioning, solar home system, energy autarchy, own consumption

Introduction

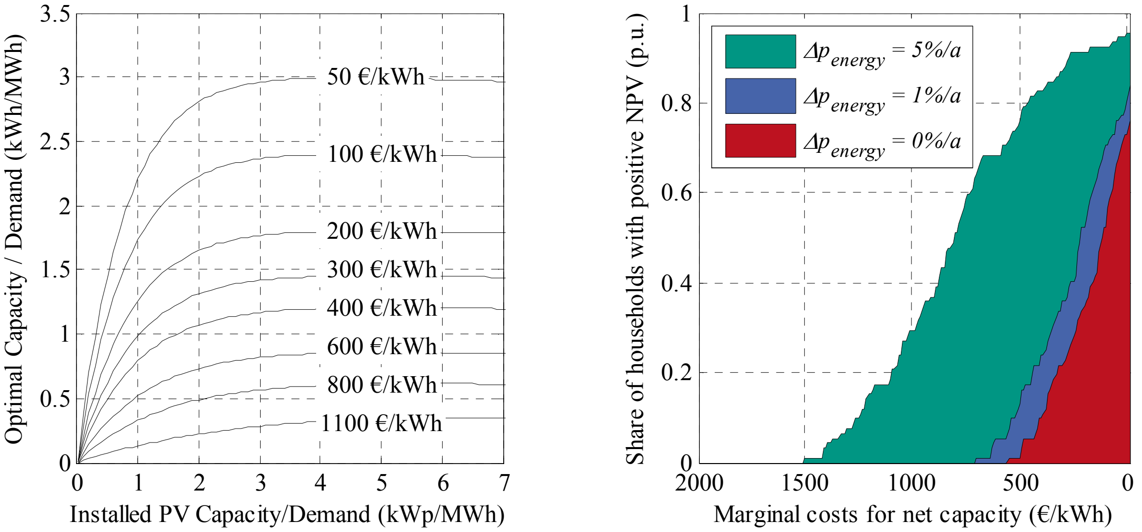
Due to rising energy prices and falling feed-in tariffs for photovoltaic (PV) energy, self-consumption becomes more interesting especially in Germany. Further decreasing prices for energy storage systems (ESS) stimulate energy autarchy of households. Anyhow solar homes systems must be dimensioned cost-effectively to achieve a breakthrough. Thus we present guidelines for dimensioning ESS depending on battery systems' market prices.

Methodology

We perform load flow calculations for 92 households with variable ESS capacities over a period of 20 years in 15 min intervals, considering variable feed-in tariffs and energy prices, initial operation years as well as system components' degradation (1 %/a). In contrast to the ESS, whose capacity reduces to 80 % of the nominal capacity within 20 years, the lifetime of the PV inverter is expected as 10 years, so that it is replaced once within 20 years. The analysis of system components' market prices leads to a linear relationship between component costs and nominal power and capacity values respectively. Further the households' annual energy consumption and the installed capacity of the relevant PV-plants are given. The individual load profiles are generated synthetically [1], whereas the PV-profile is modelled by real measurement data. We operate the ESS in such a way that the exchange energy as well as power peaks to the grid are minimal and power peaks higher than 60 % of the installed PV capacity do not occur. Therefore the household's energy management system forecasts the energy demand and production for the next 72 h every 24 h.

Results

The optimal ESS capacity depends on the installed PV capacity (the annual energy production respectively), the household's annual energy demand and fundamentally on the battery systems' market prices. By analysing the net present values of different system configurations, we determine the optimal capacity depending only on marginal costs for every configuration, so that we can determine optimal ESS capacities for an underlying scenario as exemplarily shown in **Figure 1** (a). Furthermore we can determine the share of households within certain distribution grid areas, for whom the investment in an ESS is profitable **Figure 1** (b).



(a) (b)

Figure 1: Optimal ESS capacity depending on marginal costs (initial operation year: 2014; $\Delta p_{energy} = 1\%/a$) (a) and share of households with a positive net present value (NPV) dependent on energy price increase Δp_{energy} (b)

Outlook

Further simulations will be executed to distinguish cases with negative NPVs in Figure 1 (a). Additionally the optimal system design for households with heat pumps and electric vehicles will be analysed. Finally the impact of those systems on distribution grids as well as the smart grid integration is subject of ongoing investigations.

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The Challenges of Securing the Smart Grid

Dr Lucie Langer
Dr Paul Smith
Digital Safety & Security Department, AIT Austrian Institute of Technology, firstname.lastname@ait.ac.at

Keywords: Smart Grid, Cybersecurity, Risk Assessment

Introduction

Future power grids will make extensive use of ICT to enable new functionalities. Consequently, energy suppliers and Distribution System Operators (DSOs) will have to prepare for threats from cybersecurity attacks. Smart grid security issues are currently being studied in two major research projects lead by the AIT Austrian Institute of Technology: *(SG)*^{2} *(Smart Grid Security Guidance)* and *SPARKS (Smart Grid Protection Against Cyberattacks)*. This abstract outlines the results achieved so far, and how these can be leveraged to increase the security of ICT systems deployed in future power grids to sustain the high level of supply security in Europe.

Contributions

As a first step towards improving smart grid cybersecurity, a holistic ICT architecture model for Austrian smart grids was defined in the (SG)^2 project, based on the *Smart Grid Architecture Model (SGAM)* [1]. It reflects the current power grid ICT technology, as well as its short- to mid-term extension towards future smart grid functionalities (see Figure 1). Next, a catalogue of relevant cybersecurity threats was defined and applied to the architecture model, developing possible attack scenarios and taking into account existing works by BSI and ENISA [2,3,4]. The risk was assessed by estimating probability and impact (determined by monetary loss, customer impact, and geographic range of effects). In parallel, a security analysis of two subsets of the architecture model (*Secondary Substation* and *Advanced Metering Infrastructure*) was carried out. Potential attack vectors and vulnerabilities were explored, focusing on network communication, and using deep firmware analysis methods for an in-depth analysis of selected components. Currently, mitigation strategies addressing the identified risks are being developed to support DSOs in securing their infrastructures. Our work has shown that applying state-of-the-art authentication and encryption standards is of paramount importance for the security of smart grids. The main challenges are to employ mechanisms that will remain safe for years while keeping maintenance costs low, to address interoperability issues between devices from different vendors and/or different generations, and to reduce the attack surface of smart grid components by disabling ancillary services.

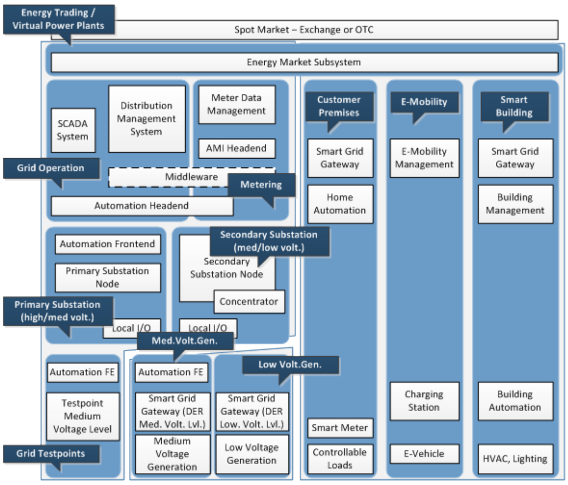

Figure 1: Simplified version of (SG)2 architecture model.

The work carried out in the (SG)^2 project is currently being continued in the SPARKS project. Smart Grid use cases are mapped to the (SG)^2 architecture model and subject to a risk assessment following the M/490 approach [1], focusing on the impact that tampering with measurement signals can have on smart grid control algorithms. A major goal is to understand the potential physical impact of a cyber-attack on the smart grid. To this end, attack scenarios are being simulated based on existing tools such as GridLAB-D (http://www.gridlabd.org/).

Conclusions and Outlook

The integration of a comprehensive ICT infrastructure will change the attack surface of future power grids, requiring an assessment of risks emerging from cybersecurity threats. The close relation of safety and security risks, the mix of legacy and novel systems, or the potential of cascading effects are only a few of the challenges that take effect here. AIT is addressing them in several research projects, which are seeking to support smart grid stakeholders in understanding vulnerabilities and cybersecurity threats in smart grids, and to provide guidance on effective risk management by integrating cybersecurity and power systems security assessment approaches.

Acknowledgement: This research has received funding from the Austrian Ministry for Transport, Innovation and Technology (grant agreement n° 836276), and from the EU 7th Framework Programme (FP7/2007-2013, grant agreement n° 608224).

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[3] BSI; Protection Profile for the Security Module of a Smart Metering System; BSI-CC-PP-0077; 2013.
[4] ENISA; Smart grid threat landscape and good practice guide; December 2013.

Evaluation of the Interoperability Score in the Smart Grid domain

Marie van Amelsvoort, Division Energy, OFFIS – Institute for Information Technology, vanamelsvoort@offis.de
Christina Delfs, Division Energy, OFFIS – Institute for Information Technology, delfs@offis.de
Dr. Mathias Uslar, Division Energy, OFFIS – Institute for Information Technology, uslar@offis.de

Keywords: Energy, Interoperability, Metrics, i-Score, Maturity Models

Introduction

Due to the progress in information and communications technology, smart grid technologies were developed to modernise and improve traditional electrical grids into smart grids. A vital part of well-performing smart grids is the interoperability of devices and components communicating with each other. Thus, for evaluating a smart grid architectural solution, an assessment of the interoperability should be taken into account. Since interoperability is not only a topic in the smart grid domain, we will analyse an existing approach from another domain for the rating of interoperability and check whether it is applicable in the smart grid domain. The rating-approach taken into consideration is the Interoperability Score (i-Score) introduced in [1], which was developed for network-centric operations at the U.S. military.

Discussion

The Interoperability Score (i-Score) is introduced in [1]. The i-Score methodology consists of six steps depicted in Figure 1. Besides auxiliary calculations, it provides four scores which can be used for further analysis. These scores are the i-Score I calculated in step 3, the Optimum i-Score I_{opt} from step 4, the gap between reached score and optimum I_{gap} (step 5) and finally the Normalized i-Score I_{norm}, which is introduced in step 6 of the methodology.

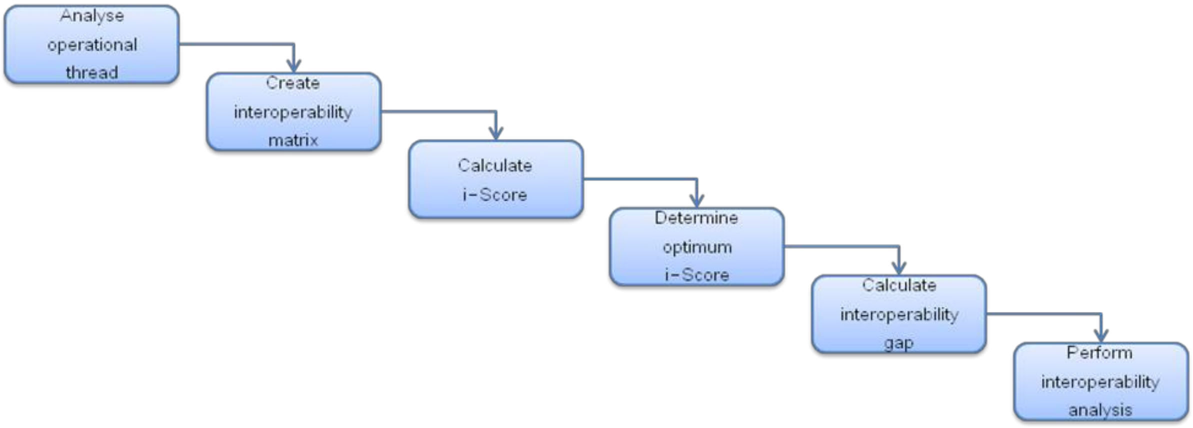

Figure 1: Steps of the i-Score methodology from [1]

As a first step, we can discuss which of the five interoperability layers of the Smart Grid Architecture Model (SGAM) [2] are addressed by the Interoperability Score. Second we can adapt the i-Score for a smart grid use case and analyse it.

From the four scores, the Normalized i-Score qualifies most for checking the methodology within the smart grid domain. The Normalized i-Score compensates the number of systems supporting an operational thread, so two different threads with different numbers of supporting systems can be compared. In this way, we can check whether an architectural decision for one thread (instead of another thread for the same task) is reflected in the Normalized i-Score.

Conclusions and Outlook

Within the smart grid domain, there are many different actors like distributed energy resources, virtual power plants and distribution system operators performing a task together. So individual desiderata need to be considered, which include stable grid operation, economic use of resources and privacy issues. With the Normalized i-Score, we can analyse where and how these requirements influence the score and furthermore examine how the score can be improved considering and reflecting smart grid issues.

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Cyber-Physical Systems in Energy Simulation

Ing. Francisco Marzabal., European Institute For Energy Research (EDF-KIT). marzabal@eifer.org
Dr. Enrique Kremers. European Institute For Energy Research (EDF-KIT). kremers@eifer.org
Dipl-Eng. Andreas Koch. European Institute For Energy Research (EDF-KIT). koch@eifer.org
Dr. Jose Juan Hernandez. SIANI. josejuanhernandez@siani.es
Ing. Jose Evora., SIANI. jose.evora@siani.es

Keywords: Agent Base Modelling, Virtualisation, Internet of Things, Smart Grid, Urban Modelling

Introduction

A cyber-physical system refers to the tight conjoining of and coordination between computational and physical entities. Nowadays, cyber-physical systems can be found in many diverse areas as avionics, air traffic control, military defense systems, harvest automation in agriculture, renewable energy control, energy efficient buildings… Ongoing advances on the link between computational elements and physical resources will dramatically increase the efficiency, functionality, reliability, safety and usability of these systems. These advances could help to improve the management of many systems, even on the case of risky or emergency situations for humans.

Discussion

In the world of computational simulation, the validation of models that are representing the real world elements is an important milestone. This task requires an important amount of time invested in the comprehension, analysis, coding and comparison of the behaviour to the equivalent real system.
As it is represented in **Figure 1**, the real physical systems could be used during the simulation process. This would minimise the impact of the model validation in simulation environments and increase the reliability of the exported data.

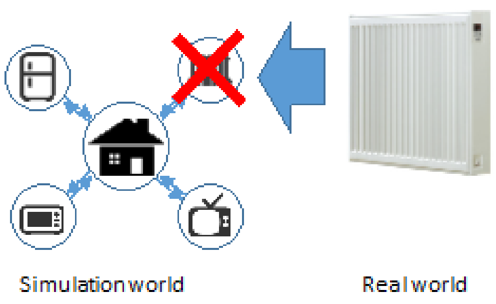

Figure 1: Case study 1, substitution of a mathematical heating system model with a real one

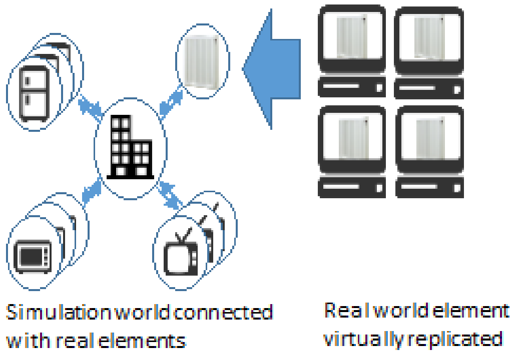

Figure 2: Case study 2, virtual replication of real elements for their application in larger-scale simulations.

The simulation with real devices could become economically inaccessible in large scale scenarios. As shown in **Figure 2**, a cyber-physical system could replicate, virtually, an unlimited number of real elements during the simulation, reproducing, intrinsically, the behaviour of the real system.
Cyber-physical systems can set a step forward to the smart grid and urban simulations. Where sensors and real devices could give valuable and accurate information that would not be possible with mathematical models.

Work

A cyber-physical system prototype will be designed and implemented. A real system will be connected to a simulation platform via an interface. This interface will manage actuators based on the simulation commands, receive information from the sensors and send them to the simulation platform for their processing. This real model will be after compared to mathematical models already implemented to test their validation.

Outlook

The application of cyber-physical systems in this simulation world bring numerous advantages:

- The test of new hardware solutions in simulated environment.
- The test of expensive technologies application in simulated large scale scenarios.
- The comparison and collaboration of proprietary energy solutions and the study of their application in urban areas or isolated systems (Micro grids, Islands).

Flow Capacitors: A Novel Technology for Scalable Energy Storage

***Juhan Lee**, **Dr. Slawomir Porada**, **Dr. Daniel Weingarth**, **Prof. Dr. Volker Presser**, Energy Materials Group, INM – Leibniz Institute for New Materials & Saarland University, volker.presser@inm-gmbh.de*

Keywords: Electrochemical Energy Storage, Supercapacitor, Flow Electrodes

Introduction

Efficient and scalable storage of electrical energy has emerged as a key bottle neck for transitioning to renewable energy generation. To meet the demands for both the energy market and grid stability, scalable and energy efficient technologies are highly desired. Supercapacitors are highly efficient, long-term stable, and fast energy storage systems, but are inferior in energy density and scalability compared to batteries. Batteries, however, suffer from medium or low power density, limited lifetime, and cost considerations (especially lithium ion technologies). Yet, especially redox flow batteries are highly attractive for scalable grid applications if it were not for their limited cycle efficiency and limited power handling. Recently, we have developed a new approach to consolidate cost efficiency, power performance, and scalability known from redox flow batteries and supercapacitors when introducing the electrochemical flow capacitor (EFC) [1]. Here, electrical energy is stored efficiently by ion electrosorption at the interface of carbon particles with high specific surface and environmentally friendly, non-flammable aqueous electrolytes. The key element of the EFC technology is the use of a carbon suspension as a flowable electrode which enables facile and scalable storage of charged material in a container while the power handling of the system is determined by the design of the charge/discharge cell. The general EFC concept is schematically shown in **Figure 1**.

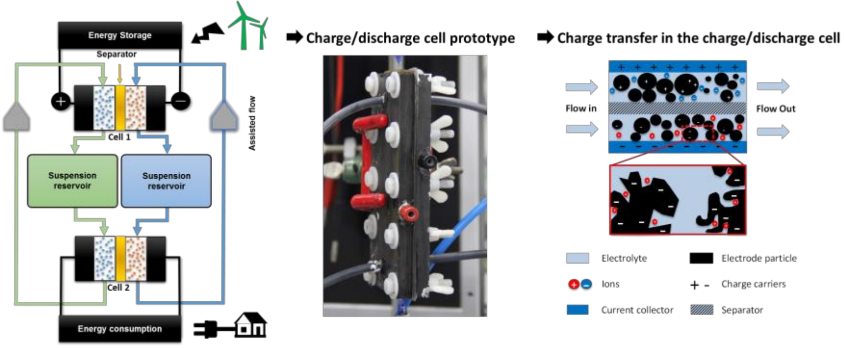

Figure 1: Concept of using a carbon suspension for scalable capacitive energy storage.

Discussion

Research on the EFC technology has significantly advanced since the first proof-of-concept in 2012. For one, the complex interplay between flow electrode constitution and resulting properties is of high importance. Especially the energy and power performance depend on the mass loading with carbon particles. The effective resistance of the flow electrode is proportional to the carbon particle loading which enables a desirable combination of low resistance and high energy density. Yet, the suspension viscosity increases with carbon particle loading in the electrolyte which is detrimental to the overall system efficiency considering the energy spent on pumping [2]. Optimized system design can balance these aspects and yield stable system operation in a fully continuous matter, which we have demonstrated recently for the first time [3]. In fact, we have shown that, per mass of active material, the energy storage capacity of the EFC technology is similar to that of conventional supercapacitors when using the same carbon and electrolyte system. Further optimization in carbon flow electrode viscosity has been demonstrated by chemical functionalization to enable high particle mass loading.

Conclusion

The EFC technology is an interesting and emerging perspective to potentially provide a novel solution for scalable, rapid, and efficient storage of electrical energy based on renewable and environmentally friendly materials (activated carbon, aqueous electrolytes).

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Novel Electrolytes for Supercapacitors based on Ionic Liquids

Dr. Boyan Iliev*, IoLiTec Ionic Liquids Technologies GmbH, info@iolitec.de*
Dr. Bettina Blumenröder, IoLiTec Ionic Liquids Technologies GmbH, info@iolitec.de
Dr. Thomas J.S. Schubert, IoLiTec Ionic Liquids Technologies GmbH, info@iolitec.de

Keywords: Electrolyte, Supercapacitors, EDLC, ionic liquids

Introduction

Supercapacitors (also known as electric double layer capacitors (EDLCs)) provide several exceptional properties like a remarkable high power density, long operational life, the ability to be charged and discharged within seconds, and a reliable performance even at extreme temperatures. Common supercapacitor electrolytes are using organic solvents, which leads to drawbacks like significant vapor pressure at high temperatures and flammability. Some of these drawbacks can be overcome by using new electrolytes based on ionic liquids (ILs).

Discussion

Ionic liquids, compounds composed entirely of ions and liquid per definition below 100°C have gained popularity over the past 10 years and have become products of industrial interest, instead of just being lab curiosities. ILs are providing large electrochemical stability, which can be directly correlated to the EDLC capacity, combined with high thermal as well as chemical stability and negligible vapor pressure. Another advantage of ILs is their incombustibility and being liquid over a wide temperature range. In this regard, new electrolytes based on ionic liquids (ILs) are promising alternatives to organic solvents [1]. In the cases where the viscosity of the pure IL is too high, we can use eutectic mixtures in order to increase performance (**Figure 1**).

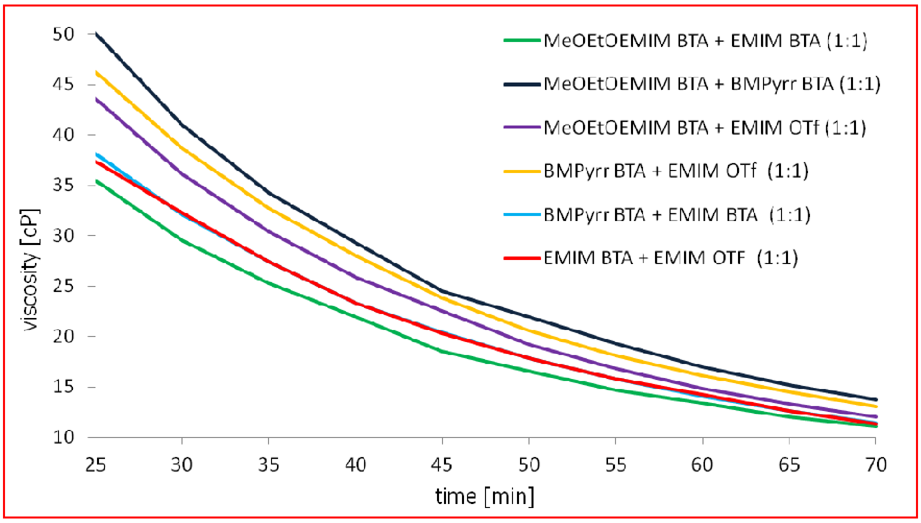

Figure 1: Viscosity of some IL mixtures

We will try to present the view of a start-up company, specialized in the synthesis and technology development in the field of ionic liquids, which has been on the market for more than 10 years. We would like to present the development of novel types of cations and anions as well as on the utilization of eutectic mixtures in order to increase the performance at low temperatures and the safety of EDLCs in general. We would also discuss the problems and needs, both of us as a supplier and those of our industrial customers, including, but not limited to purity, price and availability.

Conclusions

Ionic liquids are providing a selection of beneficial properties such as low melting point, good thermal and electrochemical stability, low vapor pressure and non flammability. This is making them to interesting and sustainable alternative electrolytes for the use in supercapacitors. Potential difficulties, in particular the higher viscosity or solidification at lower temperatures, can be avoided through the functionalization of cations and through the utilization of particular eutectic mixtures.

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SpringerMaterials

***Dr. Michael Klinge**, Director Product Management SpringerMaterials, Springer-Verlag GmbH, Heidelberg, Germany*

Abstract

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SuperConductors with improved critical currents

***Dr. Jens Hänisch**, ITEP, KIT, jens.haenisch@kit.edu*
Dr. Maria Sparing, IMW, IFW Dresden, m.sparing@ifw-dresden.de
Dr. Manuela Erbe, ITEP, KIT, manuela.erbe@kit.edu
Prof. Dr. Bernhard Holzapfel, ITEP, KIT, bernhard.holzapfel@kit.edu

Keywords: Material, Superconductors, Thin Films, Electrical Transport Properties

Introduction

$YBa_2Cu_3O_{7-x}$ based coated conductors have large potential in diverse applications such as wires/cables, motors/generators, high-field coils, and superconducting permanent magnets. Each of these applications requires certain conditions in temperature and magnetic field as well as a certain magnitude and isotropicity in critical current density J_c. There are two main mechanisms limiting J_c in these superconductors. In low magnetic fields, grain boundaries constituting so-called weak links limit J_c. Therefore, a sharp texture of epitaxially growing $YBa_2Cu_3O_{7-x}$ on metallic substrates is necessary. This macro-engineering via textured substrates (RABiTS) or texturing of the very first buffer layers via ion-beam assisted deposition (IBAD) or inclined substrate deposition (ISD) is mainly solved. The second J_c limiting mechanism, in high magnetic fields, is (de)pinning and movement of magnetic flux lines under transport current. Therefore, pinning centres have to be introduced to immobilise these flux lines. In order to use the full potential of $YBa_2Cu_3O_{7-x}$ (YBCO), it is mandatory to tailor its transport properties, and therefore to nano-engineer the microstructure, for the envisaged application. This is done by inserting artificial pinning centres, such as perovskites (e.g. $BaZrO_3$) or (mixed) double-perovskites, which precipitate as nanoparticles and/or nanorods.

Discussion

We use pulsed laser deposition, PLD, and chemical solution deposition, CSD, as main methods to fabricate thin film heterostructures consisting of a superconducting matrix, e.g. $YBa_2Cu_3O_{7-x}$, and non-superconducting nanoparticles, e.g. $BaZrO_3$ and $BaHfO_3$, on 10 × 10 mm single-crystal or metallic substrates. For PLD, we developed the method of Quasimultilayers [1], i.e. a multilayer structure of complete YBCO layers and incomplete dopant layers. With this method, a wide range of dopant materials and dopant amount can be investigated in a short time. To increase flexibility, the generation of the nanoparticles can be decoupled from the deposition of the superconducting matrix. This is done in combining inert-gas condensation of nanoparticles and PLD of the superconducting layers [2]. With this method, particle size and density can be varied independently.

Due to its scalability, CSD is widely investigated with respect to material improvement and possible industrial application [3]. Here, the material for the nanoparticles is, in most cases, added as respective salts in the starting precursor solution. The growing nanoparticles are usually slightly larger than PLD-grown ones and randomly oriented.

Whether the added nanoparticles/nanocolumns and their associated defect structures increase J_c and in which range of temperature, field and orientation depends strongly on the deposition conditions. Since the growth of these nanoparticles is a diffusion-driven process, the density of nanoparticles and/or nanocolumns and hence the J_c performance depend on both interlayer thickness and deposition temperature [4]. Also in CSD-grown films, the effect of the nanoparticles depends on substrate, growth temperature, and type of rare earth in the matrix [5].

References:

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The Indirectly Heated Carbonate Looping Process for CO_2 Capture

Daniel Hoeftberger, *Chair of Energy Process Engineering, University of Erlangen-Nuremberg, daniel.hoeftberger@fau.de*
Prof. Dr.-Ing. Juergen Karl, Chair of Energy Process Engineering, University of Erlangen-Nuremberg, juergen.karl@fau.de

Keywords: Carbon Capture, Carbonate Looping, Heat Pipes, Fluidised Bed

Introduction

The carbonate looping process is a promising way to reduce the emissions of CO_2 [1]. CaO particles decarbonise flue gas in a fluidised bed reactor (carbonator) at about 650°C within an exothermic reaction by forming $CaCO_3$. The $CaCO_3$ particles flow into a second fluidised bed reactor (calciner) with a temperature level of about 900°C. In this reactor $CaCO_3$ decomposes endothermal to CaO and CO_2. CaO flows back to the carbonator closing the loop while CO_2 leaves the calciner in nearly pure condition depending on the heating concept. This can be directly by means of burning coal with pure oxygen in the calciner or indirectly by means of an integrated heat exchanger [2]. In the latter named concept the purity of the captured CO_2 and also of the circulating sorbent is very high. In our concept of the indirectly heated carbonate looping process heat pipes accomplish the heat transfer from an air-blown combustor to the calciner (see **Figure 1**). The technology shall be demonstrated in a 300 kW_{th} scale [3] by the end of 2014. It is suitable for a retrofit of existing coal fired power plants as well as for new built plants.

Discussion

Figure 2 shows the specific heat demand of the indirectly heated calciner (blue line) for the combustors flue gas, a certain coal and 90 % capture efficiency for different CaO-conversion rates. The sensible heat for heating up the incoming sorbent from 650 to 900°C increases for decreasing CaO-conversion rates, while the heat-of-reaction (for calcination) is constant. If the heat pipes transfer e.g. 70 % of the combustors heat input to the calciner, the residual amount (violet arrow) is free for decarbonising flue gas of an existing plant. So in case of a retrofit the thermal power of the capture process is higher than that of the existing plant, for given CaO-conversion rates. This contribution will therefore deal with different measures (e.g. a solid-solid heat exchanger for internal heat recovery) for reducing the calciners heat demand and therefore plant size.

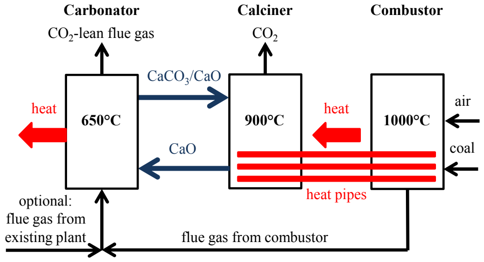

Figure 1: Scheme of the indirectly heated process

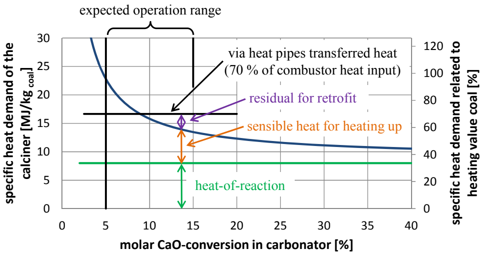

Figure 2: Heat demand of the indirectly heated calciner

Furthermore, the dimensioning of heat pipe heat exchanger and calciner will be discussed. For this purpose experiments in an electrically heated lab-scale batch reactor concerning gas release due to the calcination reaction and heat transfer between pipes and fluidised bed in pure CO_2 atmosphere as well as under presence of small amounts of steam were conducted. Long-term performance tests on a large-scale heat pipe with a length of 6 m show the feasibility of an upscale.

Conclusions and Outlook

The indirectly heated carbonate looping process is a promising technology for the capture of CO_2 in existing and new coal power plants. The heat demand of the indirectly heated calciner plays a major role for the plant size, especially in case of a retrofit. This challenge can be faced by means of different modifications of the process.

Acknowledgement: The research leading to these results has received funding from the European Union´s Research Fund for Coal and Steel (RFCS) research programme under grant agreement No RFCR-CT-2010-00011.

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Ionic Liquids as Purification Media for Biogas

Dr. Maria Ahrens, IOLITEC Ionic Liquids Technologies GmbH, Heilbronn, Germany, info@iolitec.de
Dr. Thomas J. S. Schubert, IOLITEC Ionic Liquids Technologies GmbH, Heilbronn, Germany, info@iolitec.de

Keywords: ionic liquid, biogas, CO_2 absorption

During the next years natural gasoline will be more and more replaced by biomethane [1]. Therefore, the production of biogas has to be increased during the next years. One promising approach is the enhancement of the efficiency of biogas production by optimization of production process. At the moment, aqueous solutions of amines are used as washing fluids for the raw biogas. One major disadvantage of these washing fluids is their low vapor pressure, which leads to vaporization of the fluid during the regeneration process.

Ionic liquids (ILs) (**Figure 1**) are a comparatively new class of substances which distinguish themselves by interesting combinations of properties like high thermal stability, low vapor pressure, incombustibility, and good solubility for selected gases like carbon dioxide. These properties are making them promising solvents for the purification of biogas.

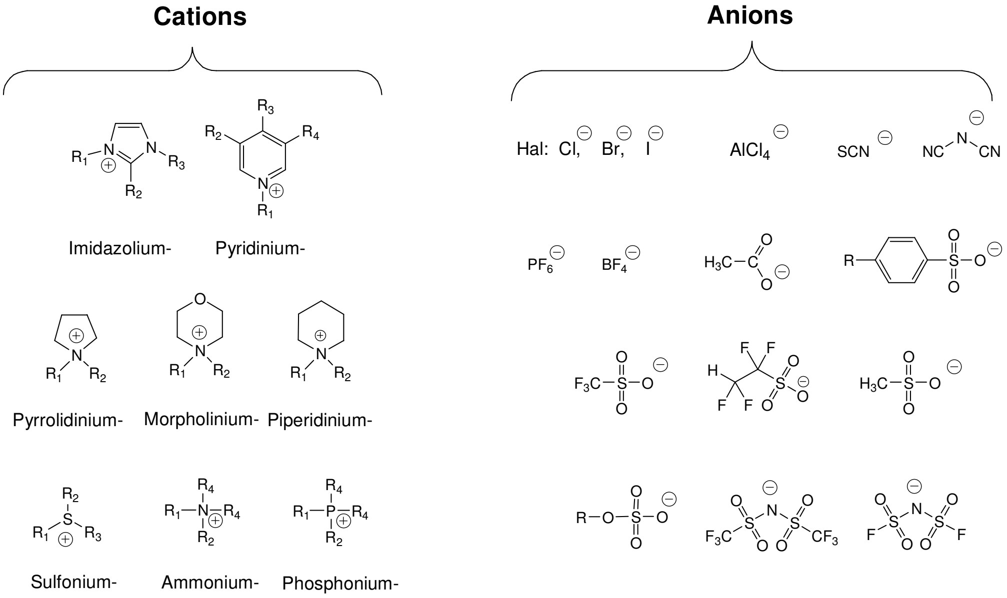

Figure 1: Examples of typical cations and anions of ionic liquids.

It was already shown that some ionic liquids can be suitable washing fluids for the purification of biogas [2]. One of the major impurities of biogas is carbon dioxide. Due to the low solubility of methane in ionic liquids, ionic liquids can be used as washing fluid for removing carbon dioxide from the raw biogas. Depending on the structure of the ionic liquid the carbon dioxide is removed either by chemisorption or physisorption [3].

In our contribution we will report on task specific ionic liquids which can be used as interesting novel alternatives for chemisorption or physisorption of carbon dioxide from biogas feedstock.

Acknowledgement: We thank Felix Ortloff, Manuel Götz and Dr. Frank Graf from DVGW Forschungsstelle at Karlsruhe Institute of Technology as well as Wolfgang Sontheim and Dr. Rainer Gottschalk from Powerfarm Holding GmbH for the excellent cooperation. We are grateful to the Bundesministerium für Wirtschaft und Energie for support of our research.

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Novel method of heat storage integration in heat exchanger networks using a time resolved three dimensional pinch approach

DI Michael Tielsch, Chair of Energy Network Technology, Montanuniversität Leoben, michael.tielsch@unileoben.ac.at; DI Dr. mont. Andreas Hammer, Chair of Energy Network Technology, Montanuniversität Leoben, andreas.hammer@unileoben.ac.at; Univ. Prof. DI Dr. tech Thomas Kienberger, Chair of Energy Network Technology, Montanuniversität Leoben, thomas.kienberger@unileoben.ac.at;

Keywords: Heat Storage, Pinch, Heat Integration, Heat Exchanger Network

Introduction

This paper introduces a novel time resolved, pinch based method to implement heat storage for maximum heat integration in a heat-exchanger-network operating in different load conditions in their respective time frames. This includes a checking routine if heat-storage can be implemented, the sizing of the heat-storage equipment and the implementation of the storage units into the heat-exchanger-network as an add-on to the classic Pinch heat exchanger network design process [1].

In comparison to previous works [2] the method developed in this paper makes it much easier to get an overview over the task at hand, as it uses the same number of diagrams and tables regardless of the complexity of the problem to be solved.

The main diagrams used, are derived from a single 3-dimensional plot of the time-discrete Pinch-problem. A case study illustrates the method in order to make it easier for the reader to understand the newly developed method. The paper focuses on the mathematics and the abstract heat exchanger network with heat storage implementation.

Discussion

The main elements used to solve the heat storage implementation problem are the following:

Storage sizing plot:

This is the main and most important plot. It is used in order to check if there is unimplemented heat available for storage and to correctly size the storage units. It is generated by projecting the surface plot areas into the time-heatflow pane, thus the resulting areas are heat quantities.

Heat storage integrability plot:

The heat storage integrability plot compares the amount of heat and the temperature levels of the heat areas marked in the storage sizing plot. It is used in order to check if the temperature differences allow heat transfer from potential sources to sinks.

Delta T min compliance check table:

For each load case the corresponding heat exchanger network has to be developed according to the rules described by the classic pinch method. As there are different loads transferred over one and the same heat exchanger at different times. The highest requirement for heat transfer capability for a certain heat exchanger has to be the one defining it. In this way it can be assured that the delta_T_min condition for the heat-exchanger-network is kept or exceeded at all times. Only in this case maximum heat recovery can be achieved.

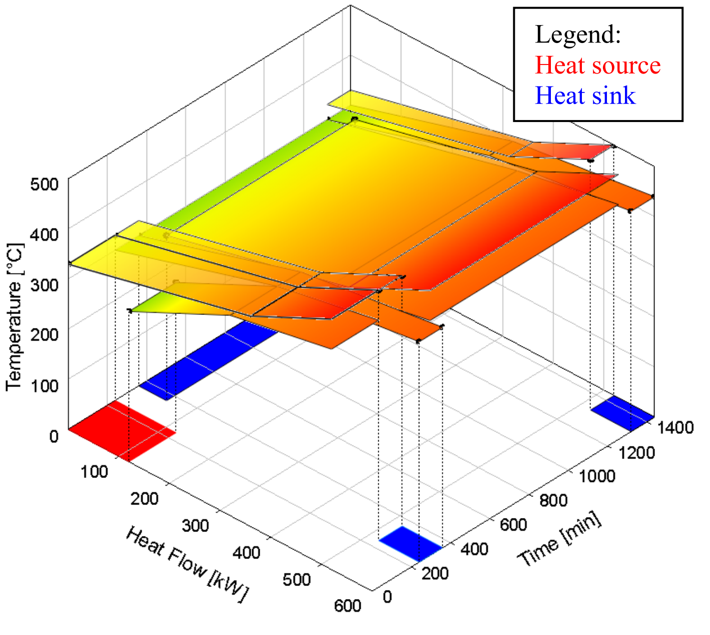

Figure 1: Three dimensional view of the time discrete pinch problem

Conclusions and/or Outlook

As a novelty, time resolved energy recovery problems in heat exchanger networks that require heat storage can be optimized in an efficient and orderly way. The presented method results in a suggestion for a heat exchanger network for a given heat integration problem. While it defines the necessary performance parameters of the heat exchangers and the storage units it does neither detail the design of the heat exchangers nor elaborate on the storage technology.

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Examination and Optimisation of a heating circuit using TOR

Philipp Pöttgen, Chair of Fluid Systems, TU Darmstadt, philipp.poettgen@fst.tu-darmstadt.de
Thorsten Ederer, Chair of Fluid Systems, TU Darmstadt, thorsten.ederer@fst.tu-darmstadt.de
Univ.-Prof. Dr. Ulf Lorenz, Chair of Technology Management, Universität Siegen, ulf.lorenz@uni-siegen.de
Univ.-Prof. Dr.-Ing. Peter Pelz, Chair of Fluid Systems, TU Darmstadt, peter.pelz@fst.tu-darmstadt.de

Keywords: Energy, System, Heating, Pumps, Measurement, Discrete Optimisation, Mixed Integer Program

Introduction

Technical machines and components are very energy efficient, but systems still offer many opportunities for savings. By the time we know the operation point of a single component in the system we can rate the real energy consumption and efficiency. We apply methods of Technical Operational Research to an existing heating system and show possible improvements. We gain these suggestions from considering the whole system to be revised instead of just one module.

The Optimisation Process

The conference centre *darmstadtium* in Darmstadt is a prominent example of energy efficient buildings [1]. The heating system of the building consists of different source and consumer circuits connected by a Zortström-distributor. Our aim is to reduce the energy costs of the system as much as possible. Therefore we analyse the supply circuits. The supply of the building is energized by a biomass-boiler (**Figure** 1, left) and a connection to the local community heating circuit (**Figure** 1, middle). Electrical energy drives the pumps in these two circuits. The first step towards an optimisation is a complete examination of the system. The tasks for the examination are: 1. Compilation of an objective list for the system, 2. Collection of the characteristic curves of the components, 3. Measurements of the load profiles of the heat and volume flow demand. Based on this information, we set up a physical simulation model of the heating circuit and calculated the daily heat demand (**Figure** 1, right) depending on the time of the year.

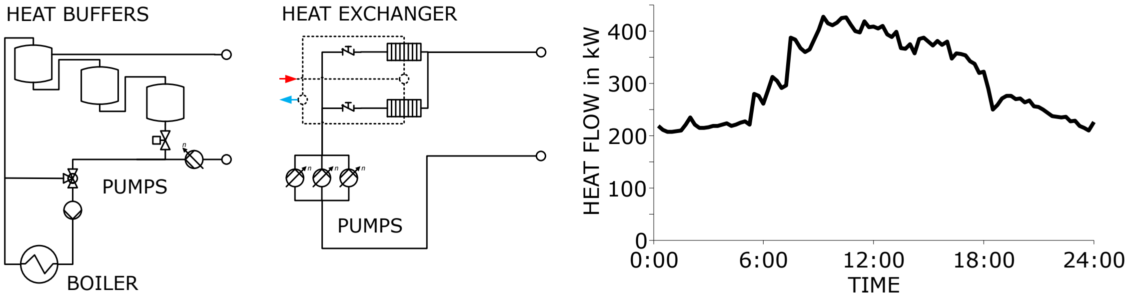

Figure 1: Left: Hydraulic diagram of the Boiler circuit. Middle: District heating circuit. Right: Average daily load cycle.

The next step is the creation of a Mixed Integer Program (MIP). This program has to contain all physical and technical constraints, as well as the load demand in a linearized form. The decision variables are the discrete and continuous control settings of the system. *Which heat source is to be used? Which rotational speed for a pump is the best?* The optimisation objective is to minimise the total energy costs for one year. MIPs are often used to optimise scheduling problems. Thus powerful commercial solvers can be used to solve the problem.

The calculated control strategy allows savings of 7941 *€/a*. In addition we considered a topological option for the hydraulic diagram by relocating the heat buffers. The optimal control strategy for this systems allows savings of 9578 *€/a*.

The last step is the validation: We insert the optimisation result into the physical simulation model and prove them to be a valid solution for the physical problem.

Conclusions

Instead of increasing the energy efficiency of a single component, we consider the whole system for a change. This allows us to review and revise the heating system of the *darmstadtium*. Even good systems can be improved by applying an appropriate method. A global optimal system topology can only be found, if the whole system stays in the focus of the planning process. Improvements within modelling and algorithms allow us to optimise the topology of the whole system without any restrictions.

Acknowledgement: The authors thank the VDMA and the SFB 805 for funding the research as well as the facility management team of the darmstadtium for their support.

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Spatial and temporal disaggregation of GB energy scenarios depicting increasing wind capacity and electrified heating to 2035

Ed Sharp | ***UCL Energy Institute*** | ***ed.sharp.09@ucl.ac.uk***
Dr Mark Barrett | *UCL Energy Institute* | *mark.barrett@ucl.ac.uk*
Dr Paul Dodds | *UCL Energy Institute* | *paul.dodds@ucl.ac.uk*
Dr Catalina Spataru | *UCL Energy Institute* | *catalina.spataru@ucl.ac.uk*

Keywords: Wind, Electrification, Great Britain, Variability, Spatiotemporal Disaggregation

Introduction

The UK Future Energy Scenarios, developed by National Grid [1], the network operator in Great Britain, describe four future pathways for the energy system where wind capacity increases up to 20 GW onshore and 35 GW offshore and the number of domestic heat pumps to 10 million by 2035. Like most other analyses of future energy systems, modelling and analysis is carried out at a highly aggregated spatial (national) and temporal (annual) resolution. In reality, wind speeds that drive generation vary across space and time at fine resolutions. This means that generation will vary temporally, and that the spatial configuration of the wind fleet and therefore the diversity of wind speeds experienced by it will influence this variability. Increasing the number of heat pumps will mean that temperature, which also varies over space and time, will drive electricity demand to a greater extent than experienced in the past. This study presents a method for disaggregating these scenarios to a 0.5° spatial and hourly temporal resolution, linking the subsequent simulation of both demand and supply to accurate homogeneous weather data. By modelling at this resolution, the consequences of the increased spatiotemporal complexity on each scenario can be investigated.

Methods

The capacities described by National Grid's four scenarios are redistributed to the model grid following a multi criteria analysis of suitable land for development. The analysis takes into account the quality of the wind resource, planning restrictions and access to infrastructure. Hourly wind generation from the redistributed output is simulated in each grid square, for each scenario using manufacturer wind turbine curves and spatially homogeneous hindcasted wind speed data from a climate reanalysis (NCEP CFSR). The use of realistic locations means that the simulated generation reflects the geographically diverse winds that will be harnessed by potential future wind fleets.

Demand for electricity is simulated using the Spatiotemporal Dynamic Energy Agents Model (SpDEAM, [2]). SpDEAM calculates electricity demand from all sectors. Non-heat demand is calculated top down; values from the National Grid scenarios are proportionally allocated to end uses, spatially disaggregated using census based population and building stock databases and temporally redistributed using activity profiles that vary diurnally, weekly, seasonally and annually. Heat demand in domestic buildings is calculated from the bottom up, based on a GB building and heat technology stock model which incorporates the effects of heat gain from other end uses, people and solar gains. Activity profiles are used in a similar manner to non heat demands. Population and building stock projections are used alongside National Grid's scenarios.

Results

In each scenario capacity factors are shown to vary between <2% and 100% over the course of a year, in comparison to the annual value of 28% onshore and 38% offshore used by National Grid, demonstrating the variability of wind over fine temporal resolutions. Maps of the allocated wind capacities show that the geographical diversity is similar for all but the most conservative of the scenarios, due to the restrictions on offshore development and the availability of suitable land in all onshore grid squares. Larger capacities generate more electricity, but the temporal pattern is similar owing to the base capacity for each scenario being the same. Geographical diversity improves the capacity factor, primarily through the introduction of offshore capacity, but the most ambitious scenarios display diminishing returns in this respect. The introduction of a large number of heat pumps means that the electricity demand curve changes shape with a more exaggerated peak in the morning and evening in winter when domestic dwellings require heat. Normalisation of this demand demonstrates that some of this apparent increase is due to the increased demand from a larger population and building stock. The analysis builds upon an annual picture of how much demand can be satisfied by wind to show the residual demand on an hourly basis, demonstrating that this varies between 0% and 98% and that hourly changes may be up to 40 GW. This quantifies the amount of demand that must be satisfied by other measures, demonstrates the challenges of variability and the need to model at a disaggregated resolution.

This study was supported by the UK Doctoral Training Centre in Energy Demand, which is funded by the EPSRC (EP/H009612).

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Storage demand in the context of Renewables from a European Perspective

Stefan Weitemeyer, *NEXT ENERGY - EWE Research Centre for Energy Technology at the University of Oldenburg, Germany, stefan.weitemeyer@next-energy.de*
Dr. David Kleinhans, NEXT ENERGY - EWE Research Centre for Energy Technology at the University of Oldenburg, Germany, david.kleinhans@next-energy.de
Dr. Thomas Vogt, NEXT ENERGY - EWE Research Centre for Energy Technology at the University of Oldenburg, Germany, thomas.vogt@next-energy.de
Prof. Dr. Carsten Agert, NEXT ENERGY - EWE Research Centre for Energy Technology at the University of Oldenburg, Germany, carsten.agert@next-energy.de

Keywords: Energy system modelling, energy storage, large-scale integration

Introduction

The share of Renewable Energy Sources (RES) in the European power supply system has increased significantly over the last years, and it is likely to increase further on the pathway towards a prospective sustainable and low-carbon energy supply system. With solar and wind energy being the most powerful RES in Europe, there will probably be a need for large-scale installations of costly storage capacities to ensure a stable electricity supply. However, it is not yet clear which storage characteristics are most adequate for scenarios with high shares of RES.

Discussion

In order to systematically study the role of storage in a prospective European renewable power system, we apply a recently published method [1] to data for Europe. For this, we use long-term solar and wind power production data as well as corresponding historic load data for 27 European countries, which are connected by an expanded grid to allow for unconstrained power exchange. In our simulations we found that more than 55% of the total load can be met by an optimal combination of solar and wind resources without both installation of additional storage capacities or usage of curtailment, provided that sufficiently flexible power plants supply the remaining electricity share. In these scenarios, the installation of small storage capacities is already highly beneficial for the integration of RES (cf. Figure 1 left). Furthermore, our simulations show that seasonal storage devices with high capacity but low round-trip efficiency are only beneficial in scenarios with very high shares (>95%) of RES (cf. Figure 1 right).

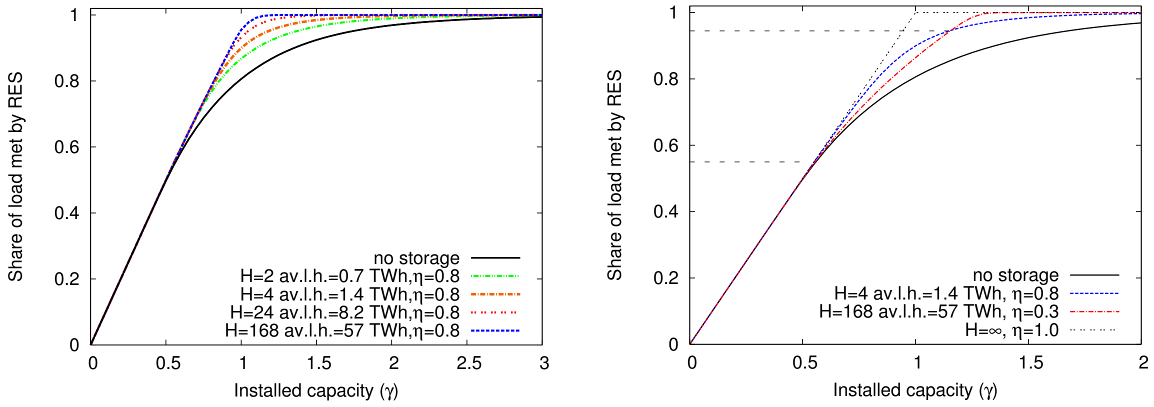

Figure 1: Share of load met by RES as a function of the installed capacity γ for storages with round-trip efficiency η and different sizes H (in average load hours). A value of γ=1.0 corresponds to a scenario where the average production from RES is equal to the average load. In all scenarios, the share of RES energy provided by wind energy is α=60% (solar: 1-α=40%). Left: Scenarios for storage devices with round-trip efficiency η=0.8. Right: Comparison between efficient, small storage devices and less efficient large storage devices as used for seasonal storage.

Conclusions and/or Outlook

The expansion of the European transmission grid is an important option to consider when trying to reduce the required storage capacities (and hence costs) for integrating very high shares of RES. Our simulations show that with a strengthened European transmission grid, the need for storage capacities can be significantly reduced. Very high shares of RES can already be integrated into the system when combined with small highly-efficient short-term storage capacities as well as significantly flexible back-up power plants.

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Components and Technical Feasibility Considerations for Multi Terminal HVDC Transmission Grid Structures

Dipl.-Ing., Wenig, Simon, *simon.wenig@kit.edu, Institute of Electric Energy Systems and High-Voltage Technology (IEH), Karlsruhe Institute of Technology (KIT)*
M. Sc., Sander, René, *rene.sander@kit.edu, IEH, KIT*
Dr.-Ing., Suriyah, Michael, michael.suriyah@kit.edu, IEH, KIT
Prof. Dr.-Ing., Leibfried, Thomas, thomas.leibfried@kit.edu, IEH, KIT

Keywords: DC circuit breaker, HVDC grid, Modular Multilevel Converter, power transmission, RES integration

Introduction

Recent high voltage direct current (HVDC) projects within Europe are mainly carried out as point to point connections to feed in offshore wind energy, eliminate transmission grid bottlenecks or link different market areas. Caused by the technical maturity of modern multilevel voltage source converter (VSC) systems HVDC grids, as concluded in [1], seem to be within range. This offers the possibility to strengthen network reliability and security of supply in a future European power system mainly based on renewable energy sources (RES).

Main Scope

This contribution mainly focusses on two substantial aspects, which arise in the scope of multi terminal direct current (MTDC) systems. Following a brief overview of existing and planned DC transmission links and their suitability to be interconnected, see **Figure 1**, basic components to build meshed MTDC networks, their functionality and advanced control methods are introduced. Furthermore, technical design considerations are presented, evaluated and verified by simulations which show the dynamic performance of a MTDC system under grid contingencies.

Components of MTDC Systems

In contrast to traditional AC networks DC systems are highly penetrated with power electronic based components. The development of Modular Multilevel Converters (MMC) is offering superior dynamic control possibilities, but also changes the traditional system behaviour and structure including the protection systems and fault ride through sequences, see [2] for a general overview. As shown in **Figure 2**, ACDC interactions can be blocked if suitable control and design methods are utilized. Another important key enabler of MTDC systems is the DC circuit breaker. For proper fault isolation and clearing strategies in meshed network structures, this device represents the most critical component and requires therefore detailed attention.

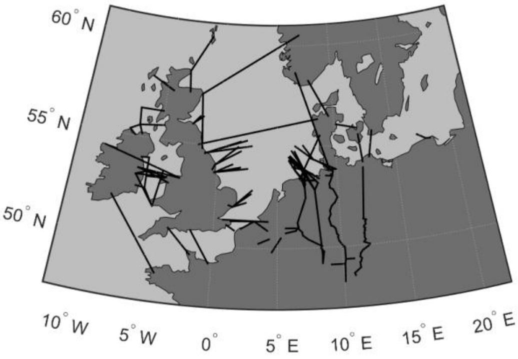

Figure 1: VSC link projects in GB & the EU mainland

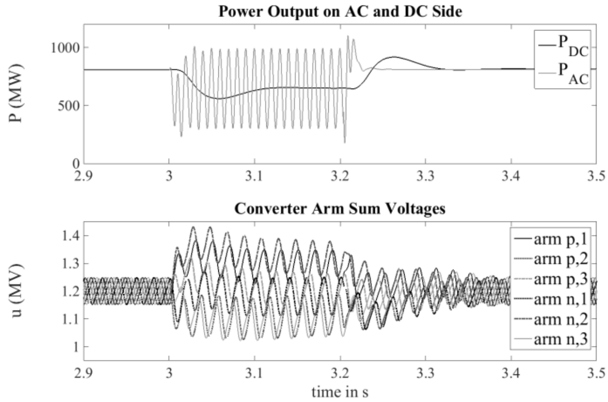

Figure 2: MMC dynamic response to an AC line to ground fault

Conclusion

A reliable and sustainable energy supply in Europe requires an appropriate mix of decentralized and interregional structures. Therefore, meshed HVDC overlay grid structures are able to contribute a significant part to increase the share of RES in-feed and boost a liberalized European energy market. In this context, this work provides a comprehensive overview on design and control aspects for those systems.

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High-Precision Modelling, Simulation and Optimisation of Cogeneration Plants

Stephanie Chen, Center of Industrial Mathematics, University of Bremen, schen@math.uni-bremen.de
Dr.-Ing. Dennis Wassel, Steinbeis Innovation Center Optimisation and Optimal Control, dennis.wassel@stw.de
Prof. Dr. Christof Büskens, Center of Industrial Mathematics, University of Bremen, bueskens@math.uni-bremen.de
Nawid Bahar, enable energy solutions GmbH, N.Bahar@enable-e-s.de
Carsten Hollmann, enable energy solutions GmbH, C.Hollmann@enable-e-s.de
Olaf Kebschull, enable energy solutions GmbH, O.Kebschull@enable-e-s.de

Keywords: energy efficiency, cogeneration plants, modelling, optimisation, energy system analysis

Introduction

Cogeneration plants are currently modelled by using characteristic curves or physical and technical laws. The resulting models are usually rather imprecise or expensive to compute. It is therefore difficult to precisely predict the behaviour of a plant, and mathematical optimisation of its operation is infeasible. Furthermore it is difficult to convince operators and other stakeholders to deviate from their tried-and-tested plant operation without reliable and sufficiently precise models. The result is less efficient operation of cogeneration plants than technically and logistically possible, which implies untapped potential for reductions of costs and CO_2 emissions.

Discussion

To improve the present situation we have developed a mathematical method to generate physically agnostic models based on data, which are both adaptive in real-time and able to provide high precision; the relative error of these models is typically lower than 0.1%. Despite their precision, the models are inexpensive to evaluate, typically in the order of 10 milliseconds for the state of a facility. Together with their mathematical properties, this makes these models suitable for algorithmic optimisation, since these methods often require many model evaluations. Since the models are exclusively based on measured data, their application is not limited to newly-designed plants, but particularly suitable for existing and operating plants.

The real-time adaptability of these data-based models enables us to monitor and implicitly model effects like soiling and wear or aging, which is difficult to achieve with physical models or characteristic curves that are fitted to model an average (or brand-new) state of a particular component; they are usually unable to model how use and time affects them.

Basing the models on data also allows for a high degree of modularity, and enables us to virtually reconfigure existing cogeneration plants, if component data is available. This simulation can help facility owners to decide on the profitability of potential investments in advance by providing quantitative information of different plant variants.

We also used these models to develop an algorithm to automatically identify data correlations in measurement data of a plant, which usually takes considerable human effort to identify on the basis of schematics and physical understanding of the respective plant. This helps us to achieve a quick overview over big amounts of data, and can be used to guide a human user in the selection of inputs for particular component models, which helps to limit their size and complexity by distinguishing and removing redundant bits of information. This input data reduction achieves further improvements of the computational time.

Fast model evaluations enable the use of mathematical optimisation algorithms of SQP-type. By selecting appropriate objective functions, we can focus on aspects such as costs or CO_2 emissions, or arbitrarily weighted compromises between both. We have computed an example recommendation for the operation of an existing cogeneration plant which would have achieved a reduction of about 1,000,000 Euros per year in costs and a reduction of CO_2 emission of about 7,000 tons per year.

Conclusions and Outlook

There is a high potential of optimisation in the operation of cogeneration plants, which is not exploited. Our algorithms have shown that this potential is usable and show the scale of possible benefits. None of these results could have been achieved without the high-precision, fast and real-time-adaptive data-based models. Since the method to generate these models depends only on the data, it can be applied to other plants. This has already been demonstrated for applications in the food industry and the automotive sector. The long-term objective is to construct an expert system that helps engineers and operators make better use of existing and planned cogeneration plants.

Acknowledgement:
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Distributed multi-energy-hub systems: a review and techno-economic assessment of new integrated forms of energy production and consumption

David Grosspietsch*, Dep. of Management, Technology, and Economics, ETH Zurich, dgrosspietsch@ethz.ch*
Dr. Bastien Girod*, Dep. of Management, Technology, and Economics, ETH Zurich, bgirod@ethz.ch*

Keywords: Distributed energy resources, multi-generation, multi-energy systems, integrated energy systems

The growing integration of renewable energy sources (RES) shifts the energy systems more and more toward a decentralised structure. However, the intermittent nature of electricity generated by PV and wind presents new challenges to the system and charges the debate for integrated solutions and flexibility measures such as storage technologies. A variety of innovative integrated concepts are put into practice covering a broad scope of technologies and applications, i.e. from utility level, such as a wind turbine including power-to-hydrogen storage [1], to residential level, e.g. a single-family house with rooftop PV and a battery storage system installed [2].

On district or neighbourhood scale, integrated concepts, so called hub systems, are characterised by the pooling of multiple residential (and small industrial) units that produce and consume decentralised energy from different RES and store excess energy. Hub systems employing more than one energy carrier, e.g. electricity, heat, gas, have been investigated in numerous publications under different terminologies [3-6] and are referred to as multi-energy-hub systems herein. Researchers have investigated multi-energy-hub systems from various, but mostly technical perspectives focusing on the seamless integration of either one specific technology or a few selected ones into the overall system concept. However, the existing literature lacks certain aspects. First, the selection of technologies to be integrated in the system is often not comprehensive and power-to-gas (P2G) storage is rarely included. Second, system simulations are mostly based on technical or environmental requirements and incorporate economic simulations only to a limited extent. Thus, thirdly, techno-economic optimisation of the overall system is mostly underrepresented or neglected.

To address these gaps, we first give an extensive review of the literature on multi-energy-hub systems, thereby providing an overview of integrated technologies, deployed modelling and assessment methodologies and covered case studies. Secondly, we are developing a holistic, techno-economic model of a multi-energy-hub system that integrates multiple technologies, e.g. solar PV, combined heat and power (CHP), P2G. This model builds on previous techno-economic models [7], extends them to the neighbourhood level and includes additional technological options. It enables the assessment of the deployment of certain technologies within the system according to both technical and especially economic aspects. As the model is able to add or remove different technologies depending on their suitability of the test case specific context, the optimal technological configuration for the overall system can be simulated techno-economically. In addition, these system optimisations are not only performed for a single test case, instead they cover various defined test cases accounting for different e.g. geographic conditions (irradiation, temperature), intended purposes (residential, industrial), or dimensions (number of inhabitants, apartments).

With this work, we contribute to the existing literature on multi-energy-hub systems by extending the knowledge toward a more comprehensive, techno-economic assessment. Depending on the test case, we provide an overview of which technologies are most viable to be included at which overall life-cycle cost. Thereby, we lay the foundation for decision-makers in reflecting the application of related demonstration projects. Lastly, this assessment enables the further integration of RES toward more decentralised system solutions.

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Improved efficiency of combined heat and power plants using electric energy storage

Axel Haupt, M. Sc., *Institute of Separation Science & Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg*
Dr.-Ing. Kasten Müller, Institute of Separation Science & Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg, karsten.mueller@fau.de
Prof. Dr.-Ing. Wolfgang Arlt, Institute of Separation Science & Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg

Keywords: combined heat and power plant, electric energy storage, simulation

Introduction

In order to reduce greenhouse gas emissions and energy consumption combined heat and power plants (short: CHP plants) are considered as a major alternative to traditional heat or power systems and are increasingly applied in modern households replacing conventional heating systems [1], [2]. Therefore, in the presented paper, CHP plants, particularly CHP plants for domestic use, are examined in more detail. CHP plants can be classified in two basic operation modes. The distinguishing criterion depends on the mainly provided form of energy.
A CHP plant is called current-controlled, if the focus is on the production of electricity so that both the supplied heat and power are adapted to the demand for electric energy. In contrast to current-controlled plants, systems that adjust the amount of supplied energy to the heat consumption are called heat-controlled CHP plants.
Since electricity and heat load profile do not coincide over time, it is often not possible to totally use both, heat and power. It is therefore necessary, to store the overshoot of energy. Storage for thermal energy is already integrated in state-of-the-art heat-controlled CHP plants. However, storage of the electric energy currently is usually not implemented to improve energy utilization. Thus, this study aims at analysing the potential of integrated electric energy storage for heat-controlled CHP systems considering a possible higher degree of utilisation of the produced electric energy.
In this context different storage technologies for electric energy are investigated with respect to their suitability for their integration in heat-controlled CHP plants. Furthermore, a simulation tool is implemented to determine the optimal storage capacity of heat and power for a given CHP plant based on technical and economic aspects.

System configuration

For a detailed investigation of the storage system and its interaction with a heat-controlled CHP plant, the system was described with the help of block orientated models. For this purpose the CHP plant structure, its storage systems and its different control methods were modelled using MATLAB and MATLAB Simulink.
Afterwards specific load profiles were used to dynamically simulate the CHP plant model. The load profiles were taken from the VDI 4655 [3], which can be used to design CHP plants up to 70 kW. The daily load profiles depending on weather data and climatic properties were expanded to an annual load profile with the use of standardized weather data obtained from the *Deutscher Wetterdienst*.

Achievements

With the generated model, an optimal storage size for power and heat was calculated, depending on the building type, number of inhabitants, motor characteristics and climatic regions. Thereby, it was determined whether the engine of the heat-controlled CHP plant should be controlled only by the filling level of the heat storage or by the filling level of both the heat and the power storage. In both cases, the impact of a variation of the storage size on the own power utilisation and the power consumption was examined. It was observed that there is a correlation between the storage size of heat and electric energy that influences the utilisation by the household itself. Furthermore, it was shown that the optimal storage size for electric energy is strongly dependent on whether the CHP plant is only controlled by the heat demand or additionally by the demand for electric energy too. Subsequently, the cost-effectiveness of an additional storage system for electric energy in the form of a battery was calculated for a heat-controlled CHP plant. The calculations of cost-effectiveness and the variation of the storage size yielded that the storage capacity of heat and power is only reasonable up to a certain amount considering of energetic and economic aspects.

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Identification of Optimal Connection Points between Electrical and Natural Gas Transmission Networks using Power-to-Gas-Technology

***Steven Hotopp**, ITE, Clausthal University of Technology, steven.hotopp@tu-clausthal.de*
***Kevin Münch**, IAEW, RWTH Aachen University, kevin.muench@iaew.rwth-aachen.de*
***Tim Bongers**, IAEW, RWTH Aachen University, tim.bongers@iaew.rwth-aachen.de*
Univ.-Prof. Dr.-Ing. Joachim Müller-Kirchenbauer, ITE, Clausthal University of Technology
Univ.-Prof. Dr.-Ing. Albert Moser, IAEW, RWTH Aachen University

Keywords: Flexibility Potential, Network Coupling, Grid Integration, Power-to-Gas

Introduction

The European power system is foreseen to gain a rapidly growing share of renewable energy sources (RES) in the future. As the feed-in of RES is mainly in rural regions with low demand, the electrical transmission network has to manage new challenges to transport the energy into urban demand centres. The network was not designed for this task, which results in a high increase of congestions in future, if no reinforcements of the network are applied. Management options are a reduction of feed-in of RES on one side of the congestion and an increase of generation of conventional power plants on the other side. One approach preventing energy wastage is the activation of flexibility potential by coupling different energy infrastructures. The considered concept connects electrical and natural gas transmission networks via Power-to-Gas-Technology (PtG). PtG facilities are acting as an extra load in the electrical network as they transform electricity into synthetic gas. If PtG facilities are installed near large congestions, they can reduce those and increase the integration of RES simultaneously. Synthetic gas injected into the gas transmission system can contribute to a sustainable power, heat and non-energy supply. In order to couple both networks regional aspects have to be addressed, where a surplus of energy in the electrical network can be combined with free capacity for synthetic gas in the natural gas network. Therefore, the aim of this paper is the identification of optimal locations for PtG facilities taking into account restrictions of the electrical and natural gas network.

Discussion

This paper contains a new method in finding optimal locations of PtG facilities by using an iterative approach. Therefore, the method combines two models describing electrical transmission and natural gas transmission system of one country including all relevant input data, as shown in **Figure 1**. Using an AC network load flow, the approach identifies congestions in the electrical transmission network and calculates the required PtG capacity to remove the congestions. Furthermore, the method identifies possible coupling points to the natural gas network and available capacities by steady-state network calculation. By exchanging required and available capacities between the networks, the approach identifies optimal connection points, until no congestion is left.

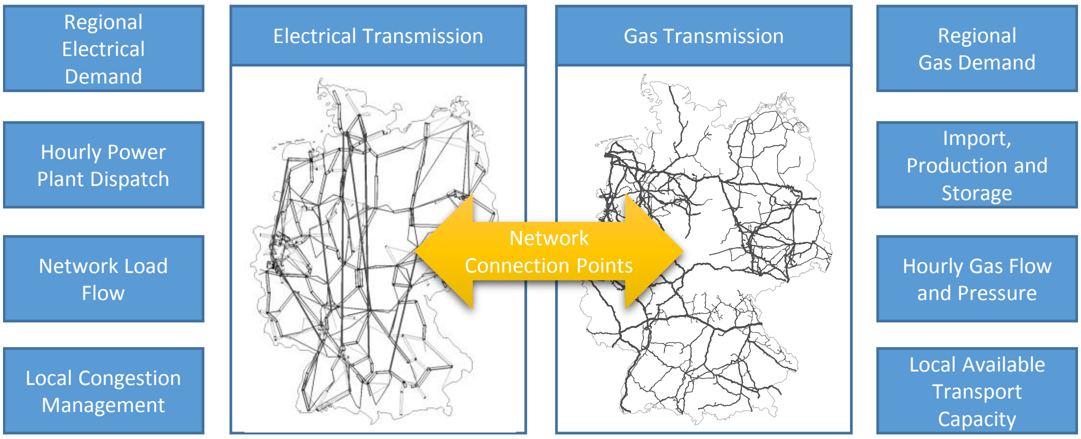

Figure 1: Overview of the method to determine optimal positions for PtG facilities

Outlook

The paper contains a description of the used network models as well as the new method for finding optimal positions of PtG facilities, which is applied to a future scenario.

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Bundesministerium
für Umwelt, Naturschutz,
Bau und Reaktorsicherheit

Poster Awards

Air Conditioning by Sunlight Co-Utilization: Monitoring Results

Prof. Dr. Flavio Horowitz*, Institute of Physics, Fed. Univ. Rio Grande do Sul, flavio.horowitz@ufrgs.br*
Prof. Dr. Marcelo B. Pereira, Institute of Physics, Fed. Univ. Rio Grande do Sul, marc1637@gmail.com
Eng. Roberto S. Ribeiro, Institute of Physics, Fed. Univ. Rio Grande do Sul, spinato@if.ufrgs.br
M.Sc. Jamuare A. Strauss, Graduate Program on Materials Science-PGCIMAT/UFRGS, jamuare@gmail.com
Arch. Giovani B. de Azambuja, HABILIS Architecture Ltd., arqgiovani@terra.com.br

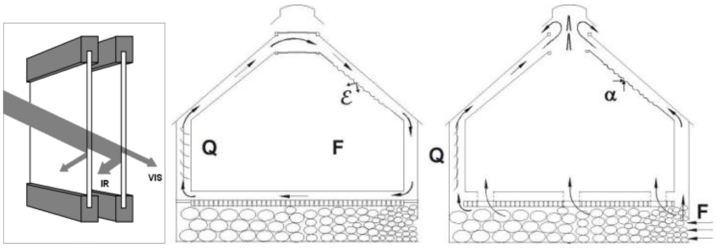
Keywords: Solar Energy, Thermal Comfort, Cooling, Illumination, Co-utilization

Introduction

Double glazings have been increasingly used in contemporary buildings, since they provide thermal insulation with small losses of natural illumination. However, in summer, much compressed air conditioning may be needed to keep interior comfort, with consequent financial and environmental costs. A spectrally selective, heat mirror coating can be added to keep out the non-illuminating infrared, but then solar energy is wasted that could be useful for heating in wintertime. This is achievable with a Trombe Wall, but at the expense of natural illumination. In this context, a double-glazed solar window that combines a passive heat mirror coating on glass with active control of natural illumination was developed, allowing co-utilization of sunlight by means of the reflected infrared for either cooling or guided heating [1], and monitoring results of the resulting CasaE (E-House) thermal performance are presented.

Results and Discussion

The smart window concept and its integration into the building envelope structure are shown in **Figure 1**. Solar radiation, after transmission through the first glazing, is divided in the second by spectral selectivity. This is produced by a metal-dielectric coating, described in [1], which transmits most of the visible light to maintain natural illumination and reflects the infrared. The radiation energy thus trapped between the two glazings heats up Venetian blinds (active control of illumination) and produces air flow by convection. This is guided, during winter mode in a closed system configuration – from which the clerestory is kept isolated - to the shadowed area in the house interior, where the sub-ceiling exchange surface enhances functionality, and from there to the over-floor channel, which completes the heating cycle. In the summer mode with an open system configuration, the hot air exit through the clerestory produces a superior region of lower pressure, which induces entrance of air from the shadowed region, via rock sub-corridors and floor windows by natural convection, thus cooling the house interior. Monitoring results from air convection by co-utilization of infrared sunlight, where cooling was prioritized for (sub)tropical climates, are exemplified in **Figure 2**. Here temperature values are shown, in rock corridor and in shaded external areas, after measured every one hour and averaged over 24 hours for each value.



(a) (b) (c)

Figure 1: Building schemes of E-house, showing (a) concept of spectrally selective window and its operation in: (b) winter closed system and (c) summer open system configurations, where Q = heat source (sunny side); F = cold source (shadowed side).[2]

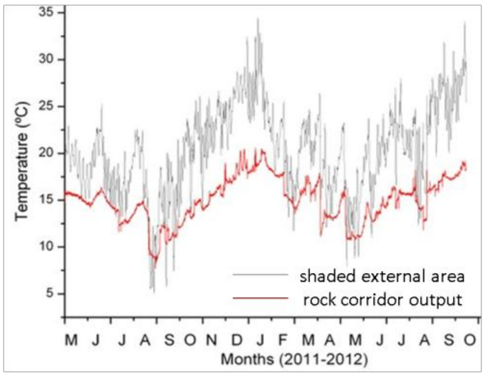


Figure 2: Temperature evolution for 19 months.

Daily and seasonal fluctuations are much smaller for the rock corridor, between 8 and 20°C due to its higher thermal inertia, whereas the external air variation lies between 5 and 35°C. Daily average difference is maximum in typical summer days, then reaching around 10°C. A corresponding average house interior cooling of 5°C, obtained from measurements in the living room, has been attained.

Conclusions and Outlook

Clear evidence of significant cooling by natural convection, induced by a double-glazed solar window with an infrared reflective coating that allows active control of natural illumination, was shown in CasaE for the (sub)tropics. This co-utilization concept of sunlight may also be used for heating of buildings at higher latitudes.

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Shape Memory Alloys for Solid State Micro-Cooling

Hinnerk Ossmer, *Karlsruhe Institute of Technology, IMT, hinnerk.ossmer@kit.edu*
Prof. Dr. Shuichi Miyazaki, University of Tsukuba, Division of Materials Science, miyazaki@ims.tsukuba.ac.jp
Prof. Dr. Etienne Patoor, ENSAM, Laboratoire LEM3, etienne.patoor@ensam.eu
Prof. Dr. Manfred Kohl, *Karlsruhe Institute of Technology, IMT, manfred.kohl@kit.edu*

Keywords: Solid state cooling, elastocaloric effect, pseudoelasticity

Introduction

Solid-state cooling has been recognized as a promising alternative to conventional vapor-compression cooling technology due to its potential to save energy and minimise green house gas emission in macroscopic applications as well as due to its potential for down-scaling.The elastocaloric effect in shape memory alloys (SMAs) appears to be particularly promising as SMAs undergo a stress-induced first-order phase transformation, associated with a large latent heat [1]. The use of these properties in miniature devices enables fast heat transfer and high cycling frequencies allowing for innovative cooling devices. Applications are, for instance, temperature control of electronic components and novel lab-on-a-chip systems in bio-analytics or medical technology. In this study, we evaluate the cooling performance of three pseudoelastic foil and wire samples with low cross-section.

Results

Samples are prepared from (1) cold-rolled textured $Ti_{50.5}Ni_{49.1}Fe_{0.4}$ foils (thickness t = 30 µm), (2) cold-drawn textured Ti-Ni-wires (diameter d = 254 µm) and (3) single crystalline Cu-Al-Be wires (d = 400 µm) produced by the Czochralski process. The critical temperatures and latent heat L of the phase transformation are determined by differential scanning calorimetry (DSC). The elastocaloric effect is investigated by strain-controlled uniaxial tensile tests [2]. Fig. 1 shows a compilation of superelastic stress-strain characteristics for the different samples revealing the elastic modulus E_A, the critical stress σ_{crit} and work input for a full transformation cycle ΔW. Monitoring the surface of the samples during tensile test at high strain rate (>0.1 s^{-1}) by infrared thermography reveals the adiabatic temperature changes ΔT_{load} and ΔT_{unload} due to release (loading) and absorption of latent heat (unloading). The experimentally determined material properties are summarized in Table 1. For all three samples, the critical force is about 20 N. However, the surface-to-volume ratio, the mechanical performance and the elastocaloric effect size differ. Ti-Ni-based wires and foils both show a significant cooling effect of -18.6 K and -17.2 K, respectively, and low accumulation of remanent strain below 0.6% within the first 10 cycles. The Ti-Ni-Fe foil sample shows the smallest transformation strain of about 5% and lowest work input of 8.2 J m^{-3} resulting in a large coefficient of performance COP. The foil-geometry also provides the best surface-to-volume ratio with a time constant of 1.46 s for heat absorption. The single crystalline Cu-Al-Be wires, on the other hand, have the lowest critical stress and are good thermal conductors, which favours heat transfer. However, due to the small latent heat, the COP is lower than that of TiNi-based samples. The obtained results are important for the design of novel SMA-based solid-state cooling devices, where material specimens should fulfil the compromise of large effect size, low work input and long-term stability.

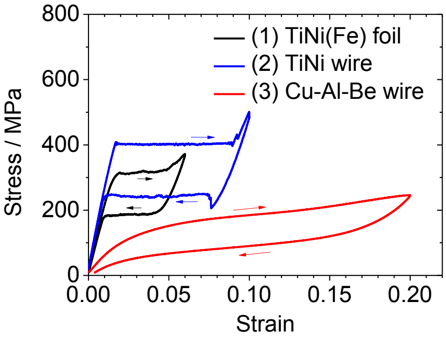

Figure 1: Stress-strain characteristics of superelastic SMA foil and wire samples as indicated determined under quasi-static loading conditions.

	(1)	(2)	(3)
E_A / GPa	20	24	6
σ_{crit} / MPa	315	400	145
ΔW / MPa	8.2	29.7	17.3
ΔT_{load} / K	21.5	24.7	8.8
ΔT_{unload} / K	-17.2	-18.6	-5.5
L / J.g^{-1}	17.2	R-phase: 3.8	2.2
A_f / °C	9.3	4.2	-74.1
τ / s	1.46	3.0	1.37
COP	6.0	1.8	0.9

Table 1: Thermo-mechanical properties of pseudoelastic foil and wire materials: (1) Ti-Ni-(Fe) foil, (2) Ti-Ni wire, (3) Cu-Al-Be wire.

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Energy storage and transportation by solar irradiation-aided CaO-looping

Dipl.-Ing. Jonas Obermeier, *Institute of Separation Science & Technology, University of Erlangen-Nuremberg*
Dr.-Ing. Karsten Müller, Institute of Separation Science & Technology, University of Erlangen-Nuremberg, Karsten.Mueller@fau.de
Prof. Dr.-Ing.Wolfgang Arlt, Institute of Separation Science & Technology, University of Erlangen-Nuremberg

Keywords: Energy Carrying Compounds, thermochemical energy storage, renewable energy, CaO-looping,

The efficient usage of surplus renewable energy is an important aspect for the energy supply in the future. In this contribution a trans-regional energy storage, transportation and distribution concept is introduced. The process is based on the concept of Energy Carrying Compounds (In German “Energie Tragende Stoffe”, ETS) using a material system which could exist in an energy-lean and energy-rich state [1]. The cheap, available and non-toxic components calcium oxide (CaO) and calcium carbonate (CaCO3) have been identified as suitable materials for the storage and trans-regional transportation of solar energy [2].

The handling and performance of the reactants are well investigated. The energy storage reaction (R1) represents the classical lime burning process and the calcination reaction (R2) is demonstrated in several projects concerning flue gas purification and CO_2 sequestration. The high storage density ($0{,}86\ kWh_{th}/kg_{CaO}$) and the high temperature of energy release reaction are important for a high efficiency of the process performance.

$$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)} \qquad \Delta^R h^+ = +178\ kJ\ mol^{-1} \qquad T > 800\ °C \qquad (R1)$$
$$CaO_{(s)} + CO_{2(g)} \rightarrow CaCO_{3(s)} \qquad \Delta^R h^+ = -178\ kJ\ mol^{-1} \qquad T < 800\ °C \qquad (R2)$$

The concept scheme is shown in **Figure 1**. On the site of high solar intensity (SSI, e.g. Southern Europe), high temperature heat generated by a concentrated solar irradiation system is used in a solar calcination reactor for the decomposition of $CaCO_3$ to CaO and CO_2. The CaO represents the energy-rich state of the ETS and is transported (e.g. with a bulk carrier) to the site of high energy demand (SED, e.g. Central Europe). With the help of a CO_2 source the energy release reaction is introduced and the high temperature heat can be used in an existing power plant for heat and power supply [3]. The energy-lean $CaCO_3$ is transported back to the SSI and the cycle is closed.

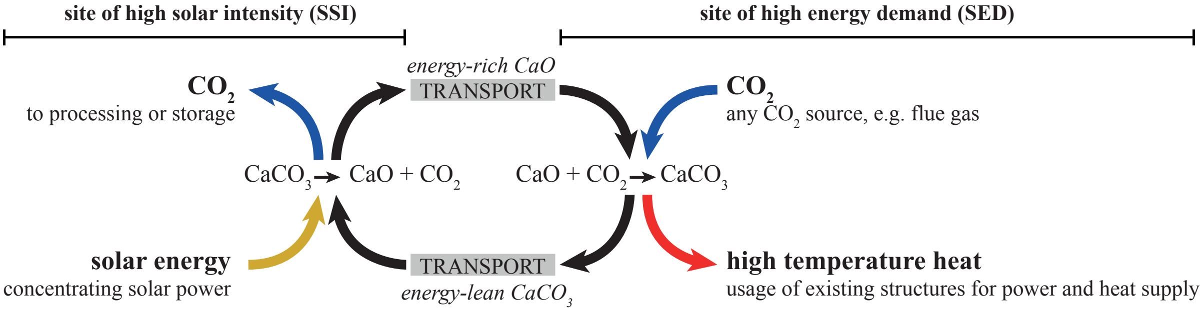

Figure 1: Process design of a trans-regional energy storage and transportation concept based on solar irradiation-aided CaO-looping

In this contribution the aspects of material selection, material synthesis and different process designs are discussed. Besides the evaluation of CO_2 sources on the SED and possibilities of CO_2 recycling on the SSI, process simulations and efficiency calculations are presented.

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Poster Presentations

Renewable Energies

Creation of Dipyrrin Metal Complex Nanosheet and Application in Photovoltaics Thereof

Dr. Ryota Sakamoto*, Department of Chemistry, Graduate School of Science, The University of Tokyo, sakamoto@chem.s.u-tokyo.ac.jp*
Ken Hoshiko, Department of Chemistry, Graduate School of Science, The University of Tokyo, hoshiko@chem.s.u-tokyo.ac.jp
Tatsuhiro Nagayama, Department of Chemistry, Graduate School of Science, The University of Tokyo, nagayama@chem.s.u-tokyo.ac.jp
Toshiki Yagi, Department of Chemistry, Graduate School of Science, The University of Tokyo, nagayama@chem.s.u-tokyo.ac.jp
Mizuho Tsuchiya, Department of Chemistry, Graduate School of Science, The University of Tokyo, nisihara@chem.s.u-tokyo.ac.jp
Prof. Dr. Hiroshi Nishihara, Department of Chemistry, Graduate School of Science, The University of Tokyo, nisihara@chem.s.u-tokyo.ac.jp

Keywords: Nanosheet, Dipyrrin, Photoelectric conversion

Introduction

Monolayer nanosheet materials have attracted significant attention due to their unique physical and chemical properties. Graphene is one of the most prominent nanosheet materials because of its various attractive properties and potential applications in electronics, optonics, and spintronics. The anticipated practical success of graphene has prompted researchers to investigate other types of two-dimensional nanosheets, such as metal sulfides. This series of nanosheets are synthesized via exfoliation of bulk layered materials (top-down method). We have focused on the bottom-up type of nanosheets. The advantages of the bottom-up approach are substantial. Firstly, the composition, structure, and various properties can be tuned at will by tailoring the utilized components (e.g., metal ions and ligand molecules). Secondly, and importantly, the nanosheets that can be produced are not limited to the layers of bulk materials. However, bottom-up nanosheets reported thus far have lacked valuable functionalities.

Discussion

The bis(dipyrrinato) metal complex features spontaneous and reversible complexation between a dipyrrin ligand and metal ion, and intense absorption and fluorescence in the visible and near-IR region. The author created a bis(dipyrrinato) metal complex nanosheet (Fig. 1a). The nanosheet is fabricated using the gas-liquid interfacial synthesis (Fig. 1a). An AFM image for the nanosheet is shown in Fig. 1b, featuring a large domain size (>10 μm). The nanosheet attached onto a SnO_2 electrode serves as a photoanode for photoelectric conversion.[1]

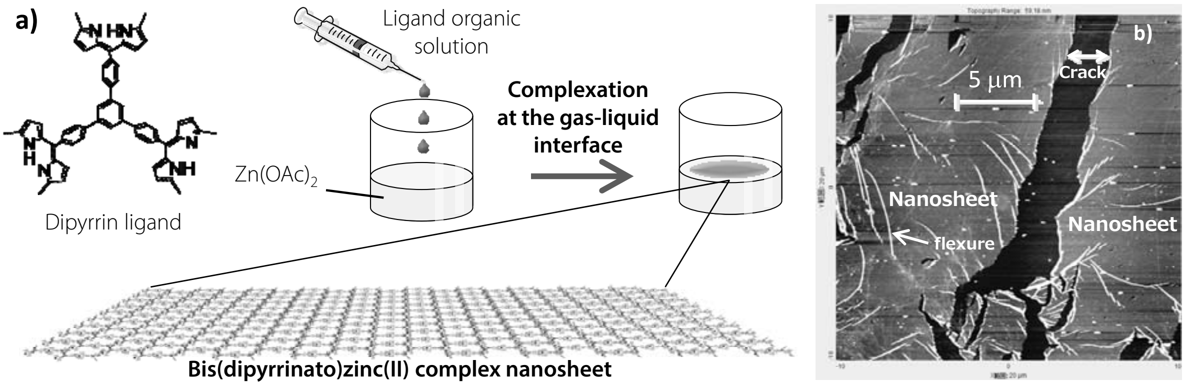

Figure 1: (a) Gas-liquid interfacial reaction for bis(dipyrrinato)zinc(II) complex nanosheet. (b) AFM image of the nanosheet.

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Development of a data analysis methodology to assess PV system performance

***Odysseas Tsafarakis MSc**, Copernicus Institute, Utrecht University, O.Tsafarakis@uu.nl*
***dr. Wilfried G.J.H.M van Sark**, Copernicus Institute, Utrecht University, w.g.j.h.m.vansark@uu.nl*

Keywords: Photovoltaic monitoring, fault detection, photovoltaic systems

Introduction

Apart from solar radiation, the performance of a PV system is depending on PV system's characteristics and on their condition during its lifetime, in which operational malfunctions may be occurring. Clearly, the sooner these get identified and repaired, the lowest the energy loss will be [1]. As a solution to this problem, in the framework of the IEA PVPS Task 13, "Performance and reliability of PV systems" a malfunction detection and identification method was proposed, named as the "Stamp Collection" [2], where its principle is to plot one performance parameter of the PV system versus another and study their (linear) relation (LR).

Discussion

In this study the effectiveness of this method, in the aspects of the malfunction detection and application to small residential PV systems, without complicated monitoring tools, was examined.

A literature review and a survey with participating PV owners and installation companies revealed that the most common malfunctions are causing variable energy loss and that they are linked to the operation of the inverter. Furthermore, the proposed plots for the identification of these types of malfunctions cannot be used in the majority of residential systems due to lack of advanced monitoring tools (e.g., temperature sensors).

For the solution of this major problem, the statistical parameter Mean Square Error (MSE) [3] (fig. 1) is used in the plot which is made from the components of the so-called Performance Ratio (PR)[4] of the system, i.e, System Yield (Y_f) vs Reference Yield (Y_r). PR is the standard unit in PV performance analyses. In this study, the feasibility of the MSE method is examined.

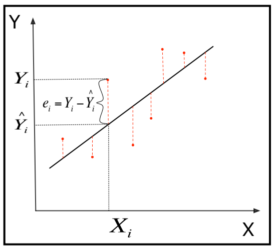

Figure 1: Mean Square Error (MSE)

Using the MSE as parameter in the plots of available monitoring data, inverter malfunctions and low partially shading were identified, while the change in the hourly Performance Ratio and the linear regression of the plot was insignificant. An example is pictured in figure 2. The system is affected by partial shade. In figure 2 the power of the system and the tilted irradiance are illustrated, during a clear day (2a) and a day (2b) under the influence of shade (undetected from the solar radiation sensor). In figure 3, the Yf vs Yr plots of these days are compared and the values of PR and LR are presented in table A.

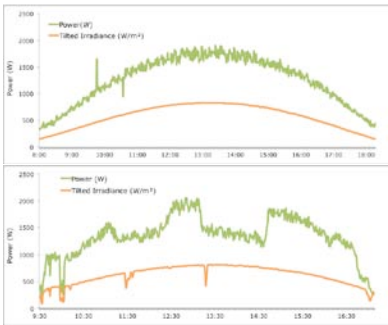

Figure 2

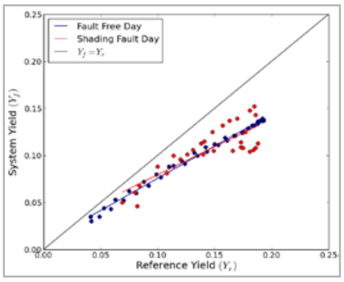

Figure 3

	PR	LR
Fault Free	73.7%	0.68/34°
Shading	73.1%	0.59/31°

Table A

$$\frac{MSE\ Power\ Derating}{MSE\ Fault\ Free} = 7$$

Conclusions and/or Outlook

We thus prove that the inverters of residential PV systems can be monitored in detail by only using a simple data logger, as for the creation of this plot only the energy production of the system is needed while the solar radiation can be obtained from data from local weather stations in combination with application of the Olmo et al [5] irradiation model.

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Photovoltaic characterization of manganite-oxide heterojunctions

Birte Kressdorf, *Institute of Materials Physics, University Göttingen, bkressdorf@ump.gwdg.de*
Benedikt Ifland, Institute of Materials Physics, University Göttingen, bifland@ump.gwdg.de
Dr. Christian Jooß, Institute of Materials Physics, University Göttingen, joss@ump.gwdg.de

Keywords: Photovoltaic, Perovskites, heterojunction, manganite-oxide

Introduction

New generation solar cells with their diversified chemical nature and properties represent the opportunity for new mechanisms and different characteristics in photovoltaics. In a conventional solar cell model the photovoltaic energy conversion is limited by thermal and transmission loses. Manganite-oxide perovskite heterojunctions show a photovoltaic effect even though they exhibit vastly different properties in comparison to conventional Solar Cells like narrow band gaps and trapped hopping transport. In strongly correlated oxides the excitation of the quasiparticles is a complex system of interaction between spin, charge, orbital and lattice degrees of freedom. These perovskites are correlated electron systems with a strong electron-phonon and electron-electron interaction with a variety of exotic behaviours, such as long living states of small polarons [1].
They represent an opportunity for new photovoltaic mechanism beyond the Schockley-Queisser-Limit by slowing down the charge carrier thermalization time and harvesting these “hot carriers".

Results

We study pn- heterojunctions composed of epitaxial thin films of p-doped $Pr_{0.67}Ca_{0.33}MnO_3$ deposited on single crystal substrate of n-type $SrTi_{0.998}Nb_{0.002}O_3$ (STNO) with ion beam sputtering. Although PCMO has no optical band gap at 300K, a photovoltaic effect with a strongly rectifying behavior is measured.
In order to characterize and analyze the pn-junction, IV-characteristics are measured as a function of both temperature and wavelength. Wavelength depended measurements show that the main contribution to the photovoltaic effect are caused by the UV part of the illumination with a Xe lamp, which can be attributed to polaron interband transitions in the PCMO. The small electronic overlap in the interface Mn e_g and t_{2g} orbits is presumably limiting the separation of IR induced excited carriers. Concepts for pn-junction with improved orbital overlap at the interface will be presented.
Additionally the relationship between energy depended photovoltaic effect, energy depended absorption of PCMO and different absorption effects will be discussed. The measurements show that the main photovoltaic effect can be linked to the transition from O_{2p} to Mn_{t2g}.
This system shows a possibility for conversion of optical polaronic excitations into a photovoltaic energy.

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Minority and Majority carriers Properties of N-type SILICON RST RIBBON

A.Derbouz[1*]***, A. Slaoui***[1]***, F. de Moro***[2]***, C. Belouet***[2] , [1]*Laboratoire ICUBE, Université de Strasbourg-CNRS - 23 rue du Loess, BP 20 CR, F-67037 Strasbourg Cedex 2, France,* [2] *Solarforce S.A., 1, rue du dauphin, 38300 Bourgoin-Jallieu, France*

Keywords: silicon, ribbon, photovoltaics

Introduction

In this work, we report on the electronic properties and the solar cell fabrication on N-type silicon ribbon grown by the RST method. We have investigated the majority charge carriers' parameters (resistivity and mobility) using Hall measurements versus temperature. The Minority Carrier Lifetime (MCL) of the as grown n-type silicon RST ribbons are deduced using the photoconductivity decay and Sinton methods on RST wafers. The effect of hydrogen plasma treatment on the electronic properties of the as-grown RST ribbons was also studied.

Discussion

Figure 1a gives the mobility of the majority carriers (electrons) before and after hydrogenation of n-RST silicon doped with Antimony. It can be seen that the plasma hydrogenation operated at 400 or 500 ° C results in a strong increase of carriers mobility reaching values comparable to a reference Fz silicon of equivalent bulk doping. Figure 1b presents the behavior of the mobility versus temperature. The recovery of mobility curve as a function of temperature after optimum hydrogenation demonstrates a significant reduction in the potential barrier induced by grain boundaries and twins present in the ribbon silicon.

Similarly the hydrogen plasma treatment, carried out at temperatures above 350°C for more than 1 hour, strongly improves the minority carrier lifetime in the n-RST ribbons.

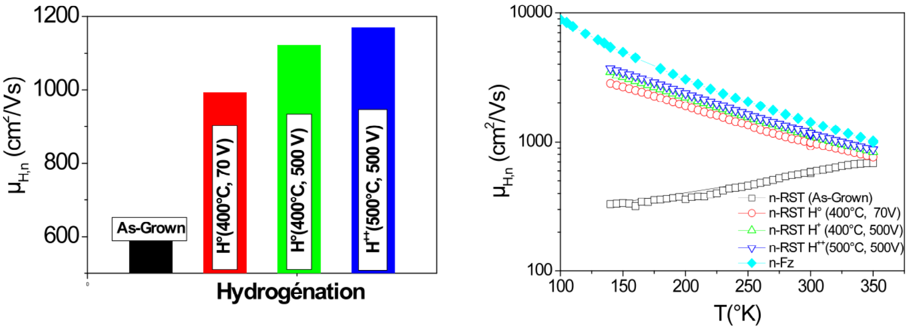

Figure 1: (a) majority carrier mobility of n-RST silicon before and after plasma hydrogenation at different temperatures; (b) majority carrier mobility versus temperature as measured for unhydrogenated and hydrogenated n-RST silicon.

P^+NP^+ and P^+NN^+ structures were prepared on RST ribbons grown in optimized conditions and passivated by plasma hydrogenation. Different types of P^+ emitters were tested namely by boron-spin-coating (B-SOD), boron from BSG solid source (B-BSG) and boron ion implantation (B-II) followed by thermal annealing or thermal oxidation. The N^+ region serving as a back surface field for the P^+NN^+ structures was made by phosphorus spin-coating. We show that a strong effect of the oxidation temperature on the emitter saturation current and on the implied voltage as deduced from the SunsVoc measurements. So far the best RST cells having B-II and B-SOD Emitters exhibit conversion efficiencies (SunsVoc) of about 15.1 % and 13.6 %, respectively for a 90 µm thick wafers.

Conclusions and/or Outlook

Very thin Ribbon silicon (<100µm) is an interesting alternative to multicrystalline silicon based solar cells because it is less energy consuming during its production and also much thinner wafers can be reached without kerf loss. Here we demonstrate that the electrical activity of the grain boundaries and twins can be strongly reduced thanks to hydrogen atoms introduced by plasma. Solar cells with efficiencies as high as 15% were produced. Further investigations are underway to improve the materials and cells performances.

Acknowledgement: This work was supported by ADEME under contract DEMOS.

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Anodized aluminium foils as substrates for polycrystalline silicon solar cells

P. Bellanger[a], A. Minj[a], S. Roques[a], O. Lunder[b], A. Ulyashin[c], A. Slaoui[a]; [a] ICube, University of Strasbourg-CNRS, 23 rue du Loess, F-67037 Strasbourg, France; [b] SINTEF, Material and Chemistry, Høgskoleringen 5, NO- 034 ,Trondheim, Norway; [c] SINTEF, Material and Chemistry, Forskningsveien 1, NO-0314, Oslo, Norway

Keywords: silicon, crystallization, solar cells

Introduction

Thin film silicon solar cells on low cost foreign substrates could be attractive for highly efficient and low cost production of photovoltaic electricity[1]. This work aims at the synthesis of high-quality continuous polycrystalline silicon (*pc*-Si) layers on flexible aluminium based substrates using direct crystallization (DC) or through the aluminium induced crystallization (AIC) process[2] of amorphous silicon. Pure aluminium (Al) or anodic alumina (Al_2O_3/Al structures) were used as substrates to measure the effect of alumina pores on the quanlity of the poly-Si films. The use of these substrates has two purposes : accelerating the crystallisation procès thanks to the Al-Si alloy, and serving as a back contact for future solar cells.

Discussion

Amorphous silicon films with thicknesses ranging from 200 to 1000 nm were deposited by ECR-PECVD and PVD on the substrates. The direct crystallization using a conventional furnace was carried out at temperatures ranging from 450 to 550°C and durations from 1h to 5h. Rapid thermal annealing using halogen lamps at températures of 700-800°C and durations lower than 15min were attempted. For the AIC process, a 200nm aluminium layer was first evaporated on the substrates prior to depositing amorphous silicon. Similar thermal treatments than above were performed. The resulting crystallized layers were characterized by Raman, UV reflectance spectroscopy as well as by XRD analysis.

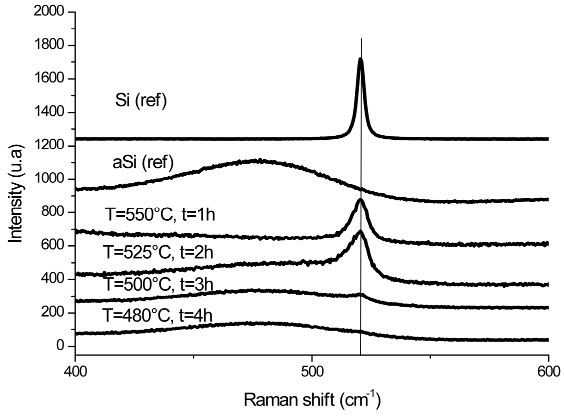

Figure 1 : Raman spectra of 0,5mm silicon films obtained on aluminium substrate (named 1h) before and after direct solid phase crystallization (DC) using different thermal budgets.

Conclusions and/or Outlook

Crystalline silicon films were synthesized either by direct solid phase crystallization (SPC) or by aluminium induced crystallization (AIC) of amorphous silicon on aluminium substrates. The direct contact of amorphous silicon on aluminium induces a strong dissolution of silicon into aluminium which results in poor quality films. First experiments show that anodizing the aluminium substrates led to a better control of the crystalline silicon thanks to the alumina membrane layer that limits the interaction between Si and Al. Parameters such as temperature, time and size of the anodized regions will be varied to better control the film quality.

Acknowledgement: This work is partially funded by the European Commission Under project EUROSUNMED.

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Direct chemical dynamics and chemical reaction mechanism

Dr. Khatuna Kakhiani, *Faculty of Exact and Natural Sciences, Ivane Javakhishvili Tbilisi State University, Khatuna.kakhiani@tsu.ge*

Keywords: Energy, Biofuel, Technology, Material, Direct Dynamics

Introduction

Increasing gasoline prices, depleting fossil fuels, and rising greenhouse-gas emission stimulate global efforts to find alternative transportation fuels. Advanced engine technologies increasingly rely on fuel properties to time ignition and optimize engine performance, so that understanding the fundamental chemistry of alternative fuel candidates is essential. One very important research direction is the search for economically affordable, yet ecologically friendly, renewable biofuels. The efforts include understanding the underlying chemical reaction mechanisms for combustion of novel biofuels, such as alcohols, ethers, esters, furans etc., whose combustion chemistry is known about less and can be significantly different from the more-studied, traditional hydrocarbon based fuels. Complex combustion reactions are characterized by multiple different pathways and some specific details of these reactions cannot be understood and even observed experimentally, thus have to be investigated theoretically, preferably at the molecular level. The processes at the molecular level is governed by quantum theory so that the design of biofuels, tailor-made to combustion engines is neither quick nor easy process. The limitations show up when we attempt to model such processes at the molecular level by means of classical theory and address challenges using the conventional, serial programs and computers. Fortunately, IT industry has already moved to massively parallel pattern, which gives us the choice to apply quantum theory to a real-world problems.

Discussion

Direct chemical dynamics [1-2] can be used to investigate the short-time dynamics of selected features on the Potential Energy Surface (PES) of biofuel reactions, to check the mechanism of reactions obtained via electronic structure theory calculations. In direct dynamics, the trajectories are integrated “on the fly”, with the potential energy, gradient, and also Hessian obtained directly from an electronic structure theory without the need for an analytic potential energy function [1].

Outlook

The aim of this work in progress is to investigate details of 2-methylbutanol combustion chemistry in low-pressure premixed flames are of particular interest to study because this compound is potentially a lignocellulosic-based, next-generation biofuel. The study of short-time dynamics on the potential energy surfaces (PES) related to chain reactions is recommended to gain deeper insight into the chemical dynamics.

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A novel preparation method for high energy Li-ion battery electrodes based on capillary suspensions

Boris Bitsch *and Norbert Willenbacher, Institute for Mechanical Process Engineering and Mechanics, Karlsruhe Institute of Technology, boris.bitsch@kit.edu*
Stephan Lippert, Tobias Gallasch and Martin Winter, MEET Battery Research Center / Institute of Physical Chemistry, University of Muenster

Keywords: energy storage, Li-ion battery, ultra-thick electrode, electrode processing

Introduction

High energy lithium-ion batteries (HE-LIBs) exhibit superior storage capacities compared to electrochemical alternatives but suffer from high acquisition costs per storage capacity. Cost efficient fabrication of high energy LIBs includes the use of robust and cheap materials, namely focusing on abundant and non-toxic components by skipping N-Methyl-2-pyrrolidone (NMP) and going for aqueous processing as well as reducing the number of process steps for electrode preparation. One promising approach is to fabricate thick electrodes with a high mass loading to reduce the amount of inactive materials, namely current collectors, separators and materials for contacting and housing.

Discussion

A novel and enhanced processing route for the preparation of ultra-thick graphite anodes designed for high energy applications is introduced. The use of capillary forces in aqueous electrode slurries by addition of a secondary fluid, immiscible with water, requires only slight adjustments of the slurry processing [1]. The secondary fluid is supposed to act as a network stabilizing agent, the resulting composite electrodes exhibit a homogeneous microstructure and morphology. The secondary fluid evaporates during drying and is not involved in the cell chemistry.

The slurry reveals beneficial processing properties due to network formation induced by the secondary fluid octanol. Electrodes with a dry film thickness of up to 500 μm can be fabricated without thickness deviations preserving sharp edge contours. Deliquesce effects due to gravitation or capillary forces are suppressed. Based on capillary suspensions higher electrode porosities are achieved (see Fig. 1) leading to improved ion diffusion and a better state-of-charge distribution within the electrode layer which are key factors for high energy electrodes. In further investigations fundamental properties of ultra-thick electrodes such as mechanical strength, morphology and electrochemical behavior in half-cell cycling are evaluated focusing on the influence of the secondary fluid octanol. Finally the concept of electrode processing using capillary suspensions is planned to be transferred to cathode materials as well.

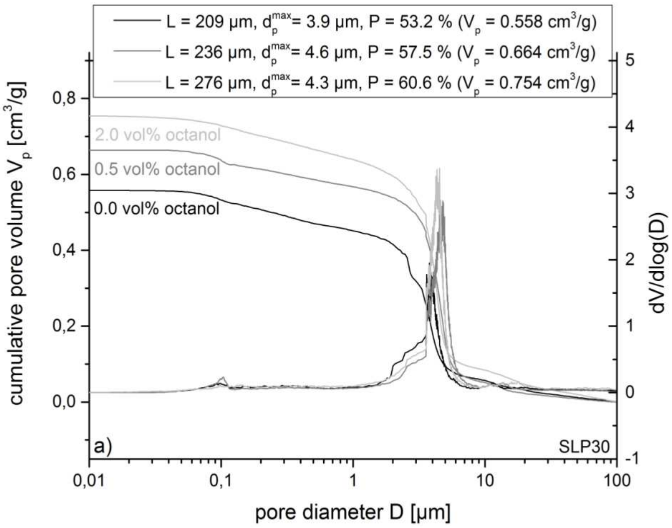

Figure 1: Cumulative pore volume and pore size distribution for secondary fluid stabilized SLP30 electrodes measured via mercury intrusion experiments.

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Fabrication of ZnO/TiO$_2$ Nanohexagon Arrays Heterojunction for Dye-Sensitized Solar Cells

Dr. H. M. Asif Javed, Electronic Materials Research Laboratory, International Centre for Dielectric Research, Xi'an Jiaotong University, Xi'an 710049, China, majavedphy@yahoo.com

Prof. Wenxiu Que, [*] ***Electronic Materials Research Laboratory, International Centre for Dielectric Research, Xi'an Jiaotong University, Xi'an 710049, China, wxque@mail.xjtu.edu.cn***

Dr. Xingtian Yin, Electronic Materials Research Laboratory, International Centre for Dielectric Research, Xi'an Jiaotong University, Xi'an 710049, China. yinxtlegend@gmail.com

Dr. Yonglei Xing, Electronic Materials Research Laboratory, International Canter for Dielectric Research, Xi'an Jiaotong University, Xi'an 710049, China, yongleixing1988@163.com

Prof. Ling Bing Kong, [*] ***School of Materials Science and Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798, Singapore, ELBKong@ntu.edu.sg***

ABSTRACT

TiO$_2$ nanohexagon arrays (TNHAs) were grown by an electrochemical anodization of Ti foil in fluoride-glycol containing electrolytes, and then the detached TNHAs were transferred onto FTO glass by using a drop of TiO$_2$ sol containing Ti(OBu)$_4$ and polyethylene glycol for front-side illumination. In order to improve the efficiency of the dye-sensitized solar cells, ZnO was introduced into the TiO$_2$ nanohexagon arrays by an electro-deposition technique. ZnO/TiO$_2$ nanohexagon hetrojunction was used as the photo-anode for dye-sensitized solar cells, which has low recombination rate and high absorption of visible light.

The results indicate that under AM 1.5 illuminations, the DSSCs based on the ZnO/TNHAs heterojunction exhibit a better short circuit current density, higher power conversion efficiency and incident photon-to-current conversion efficiency. Furthermore, electrochemical impedance spectroscopy analysis shows that the ZnO/TNHAs heterojunction-based DSSCs have optimized properties, such as a longer electron lifetime, lower impedance of electron transport, higher impedance of electron recombination.

Keywords: TiO$_2$ nanohexagon arrays, Dye-sensitized solar cells, Electro-deposition, Hetrojunction.

Development of Hybrid Solar-Assisted Desalination Cycle in Power Industry of Uzbekistan: A Case Study of Sirdarya Thermal Power Plant

Master's student Khusniddin Alikulov*, Department of Development Technology, Graduate School for International Development and Cooperation, Hiroshima University, husi.alikulov@gmail.com*

Associate Professor Dr. Tran Dang Xuan, Department of Development Technology, Graduate School for International Development and Cooperation, Hiroshima University, tdxuan@hiroshima.ac-u.jp

Keywords: Desalination, Solar Field, Solar Heat and Parabolic Trough Collectors

Introduction

The Republic of Uzbekistan is one of the Central Asian countries with high Direct Normal Irradiance (DNI). That is why it is possible to utilize solar energy for saving fossil fuel and improving energy efficiency in the existing Thermal Power Plants. In contrast to the previous research works [1] and [2], this research work mainly emphasized coupling solar field with desalination plant for delivering solar heat by parabolic trough collectors. Sirdarya Thermal Power Plant (Shirin town) was chosen as a research site for ISCC simulation. Integrated solar combined cycle was conducted by using the Ebsilon professional software for evaluation of deliverable heat energy from solar field to desalination plant.

Discussion

Figure 1 depicts conducted scheme of the ISCC, which contains steam compressor, 1st,2nd, and 3rd evaporation stages, red and blue lines (i.e. steam and distillate), solar field, sun, and auxiliary components (e.g. controller, value transmitters, mixer, splitter, general input value, and others). After simulation of design, and time series models, results (i.e. solar field efficiency, solar heat, and mass flow of saved fossil fuel) were calculated on the basis of meteodata that acquired from Meteonorm. **Table 1** shows the main results for the proposed research site. DNIs for the both period are in marginal difference. However, in summer period optical efficiency of the parabolic trough at 20:00 with high DNI suddenly becomes zero %, due to the shading of neighbouring row. Therefore, average efficiency of the solar field has great difference according to the shading of rows and all corresponding parameters for the shaded hours will become zero too.

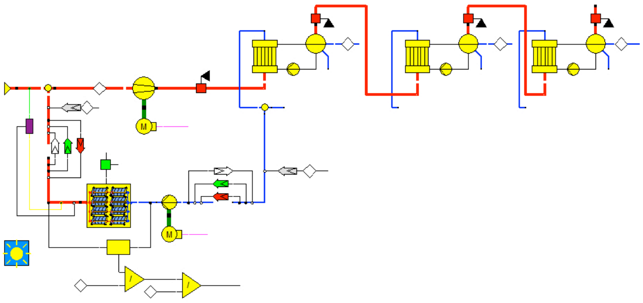

Figure 1: Solar field combined cycle for desalination plant

№	Name of the results	Summer: Aug.7th(18:10)-8th(18:10),2014	Winter: Jan.8th(17:10)-9th(17:10),2014
1	Average DNI, W/m^2	614	533
2	Useful area of solar collectors, m^2	36 511	36 511
3	Maximum hourly solar field efficiency per particular period, %	71	41
4	Average solar field efficiency %	55	20
3	Maximum hourly solar heat per particular period, kW	22 263	11 811
4	Hours of operation	14	10
5	Total saved fossil fuel-natural gas per particular period, kg/s	4.36	1.319

Table 1

Conclusions and/or Outlook

In conclusion, solar field is able to deliver necessary heat (T=200°C, P=8 bar), but saved fossil fuel amount can differ due to the optical efficiency of the PT collectors. Therefore, parabolic trough with small dimension will be more efficient that large one, due to the shading factor of neighbouring row.

Acknowledgement: Author thank to Assoc. Prof. Dr. Tran Dang Xuan and JDS budged for supporting and elaboration of the conference trip.

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Thermo-solar harvesting in mild humid climates: Absorber and self-cleaning surfaces on modified polymers

M.Sc. Jamuare A. Strauss, *Graduate Program on Materials Science-PGCIMAT/UFRGS, jamuare@gmail.com*
Dr. Paulo A. Soave, Institute of Physics, Fed. Univ. of Rio Grande do Sul (UFRGS), pasoave@gmail.com
Eng. Roberto S. Ribeiro, Institute of Physics, Fed. Univ. of Rio Grande do Sul (UFRGS), spinato@if.ufrgs.br
Prof. Dr. Flavio Horowitz, *Institute of Physics and PGCIMAT/UFRGS, flavio.horowitz@ufrgs.br*

Keywords: Solar energy, Thermo-solar collector, Polymer, Superhydrophobicity, Self-cleaning

Introduction

Polymers are used in solar harvesting due their easiness of processing, at costs much lower than those of traditional copper collectors, for swimming pools in summertime or equatorial latitudes in low efficiency applications [1], with uncovered operation to prevent deformations by overheating. In (sub)tropical regions, however - even though sophisticated insulation, metal-based absorbers or multi-layer coatings are unnecessary - mild winters do require a heat mirror cover for proper collector performance. Consequently in this work, as a simple solution for all-year operation in the (sub)tropics, a cost-effective polymeric solar absorber concept and its feasibility are pursued to allow collector covering and withstand up to boiling water temperature. Also self-cleaning is pursued, through superhydrophobicity on the polymeric surface [2], to occur under rainy conditions.

Results and Discussion

The basic concept for sunlight collection is illustrated in **Figure 1**. Since the heat exchange with the fluid occurs on the bottom surface of the transparent polymeric plate, a film was chosen that could be the light absorber and the heat distributor simultaneously. Samples were produced using poly(methyl methacrylate) (PMMA, Tg = 105°C) or polycarbonate (PC, Tg = 150°C), coated with films produced from carbon black (Cabot, 20 nm diameter) or graphite (Nacional Grafite Ltda, 2.05 µm diameter) or a 50% vol. mixture of both. High absorptance was achieved, as shown for coated PMMA plates in **Figure 1**, especially with carbon black (> 95%) along the whole solar spectrum. In addition, trimethyl(2-propyn-yloxy)silane (TMPSi) and silica nanoparticles were added to produce a superhydrophobic, self-cleaning surface (contact angle: 158° ± 1°; hysteresis: 2° ± 1°). Further increase of contact angle (up to 165° ± 1°) was achieved by deposition of poly(tetrafluoroethylene) (PTFE), without significant decrease of transmittance, as shown in **Figure 2**. This method is described in [3].

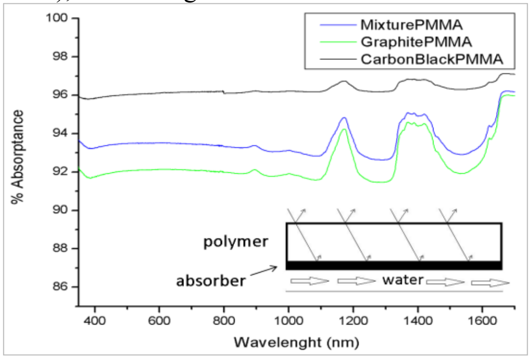

Figure 1: Collector scheme (cover not shown) and absorptance of PMMA coated with distinct materials (light incidence on the transparent side).

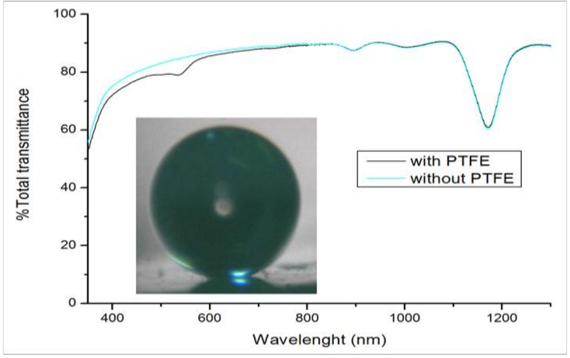

Figure 2: Transmittance of self-cleaning plate (TMPSi and 1 wt% of silica nanoparticles on PMMA), with and without PTFE, with water drop on surface shown at inset.

In first tests, using the highest average carbon black roughness achieved (0.369 µm) on PMMA over still water, and a polyester cover whose minimum transmittance matched the black body radiation emissivity range at 50°C (5-15 µm), a 30°C water temperature increase was attained in about 100 minutes.

Conclusions and Outlook

Concept and feasibility of a polymeric thermo-solar collector that allows an infrared reflective cover for all-year operation with mild winters were demonstrated, with a perspective of outer surface self-cleaning. These results are promising for large-scale, cost-effective collector production in humid (sub)tropical regions.

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Electrocatalytical oxygen evolution at surfaces of manganites using RRDE

***Garlef Wartner**, Institute of Materials Physics, University of Göttingen, gwartner@ump.gwdg.de*
Julius Scholz, Institute of Materials Physics, University of Göttingen, jscholz@ump.gwdg.de
Prof. Dr. Christian Jooss, Institute of Materials Physics, University of Göttingen, jooss@ump.gwdg.de

Keywords: Energy Conversion, Manganese Oxides, Cyclic Voltammetry, Catalysis, Stability

Introduction

The process of splitting water into hydrogen and oxygen facilitates to store electric- or light energy in form of chemical energy, while the backward reaction proceeds in hydrogen fuel cells. The efficiency of water-splitting depends on the nature of the applied catalyst, which should affect a high Tafel-slope on hydrogen- and oxygen evolution at preferably low overpotentials.

Due to their diverse electronic properties, that can be varied in a wide range depending on stoichiometric composition, manganites are promising as catalyst material [1].

Description

In order to optimize the properties of a catalyst it is necessary to understand the processes at electrode surface exactly. Our goal is to get information about the kinetics of redox processes occurring on the electrode surface by using electrochemical methods. Thereto we are going to investigate thin films of $La_{1-x}Sr_xMnO_3$ (LSMO) epitaxially grown on $SrTi_{1-x}Nb_xO_3$ (STNO) depending on their composition. This perovskite manganite represents a model system for catalysis of oxygen evolution. The usage of epitaxial thin films ensures geometrically and crystallographically well defined surfaces for our kinetic studies.

For electrochemical characterizations Rotating Ring Disk Electrodes (RRDE) are used, as can be seen in **Figure 1**. This setup allows to detect reaction products or intermediates applying different methods of measurement like cyclic voltammetry (CV) or chronopotentiometry (CP), which could already be shown exemplarily. So for instance we have measured the Faradic efficiency of oxygen evolution on $La_{0.6}Sr_{0.4}MnO_3$, which is shown in **Figure 1c**).

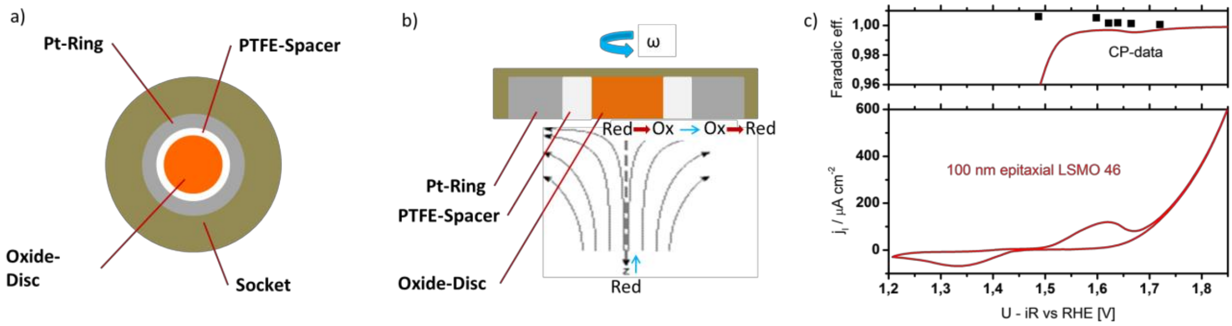

Figure 1: a) topview of the RRDE b) fluid flow along the RRDE c) measured data of LSMO

In combination with information, that can be directly obtained by CV and CP, this method yields a revealing view of the electrode processes. Regarding the reaction mechanism of oxygen evolution on perovskite oxides there are existing several postulations [3, 4], from which none already could be verified. In particular, the defect chemistry at the manganite surface seems to have dramatic impact on the surface electronic state of the manganese [1, 2]. Via systematically changing A-site doping, electrolyte properties and surface pre-treatment, we correlate properties of the electrode-electrolyte interface to measured electro-chemical properties via RRDE techniques. This also includes the study of the competition between high catalytic activity for oxygen evolution and corrosion stability.

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Fuel Particle Properties In Biomass Fired Power Plants

Dr. Hartmut Mätzing, *Daniela Baris M.Sc., Dr.-Ing. Hans-Joachim Gehrmann, Prof. Dr.-Ing. Helmut Seifert, Institute of Technical Chemistry, Karlsruhe Institute of Technology, hartmut.maetzing@kit.edu*

Keywords: Biomass Combustion, Particle Properties, Characteristic Numbers, Reciprocating Grate, Modelling

Introduction

In Europe and worldwide, there is an increasing need for small scale (< 20 MW_{th}) power plants which are fired with biomass and biogenic fuels preferentially for reasons of sustainability. At KIT, the combustion characteristics of such fuels is investigated in a fixed bed reactor (KLEAA). Therefrom, characteristic numbers are derived which allow to estimate the combustion behaviour on reciprocating grates. The procedure has been confirmed at a pilot scale grate (TAMARA) and model calculations have been validated by the experimental results.

Results

Both the fuel composition and the particle geometry were investigated for their relevance on the combustion behaviour and on characteristic numbers like reaction front velocity, ignition rate and mass conversion rate. The most important parameters were found to be

- the fuel moisture which slows down the combustion process; this may lead to higher operating costs
- the bulk density which is inversely proportional to the reaction front velocity; although favourable for fast combustion, the operation at low bulk density may require a large plant size and high capital costs
- while the particle shape was found to be unimportant for the combustion behaviour, the plain specific surface was found to be highly important for convective and radiative heat transfer; therefore, the fuel particle size is recommended to be kept around 20 mm or smaller.

Discussion

In addition to fast and complete combustion, the formation of undesired by-products is an important criterion for power plant operation. Waste wood and low rank biogenic fuels may contain significant amounts of alkalines, alkaline earths, halogens etc. which may give rise to the formation of bulky deposits and to corrosion. As example, **Figure 1** shows the mineralogical composition of boiler ashes during the combustion of wood chips (HHS) and two solid recovered fuels [1]. Additions of elemental sulphur were found to suppress the chlorine induced corrosion significantly.

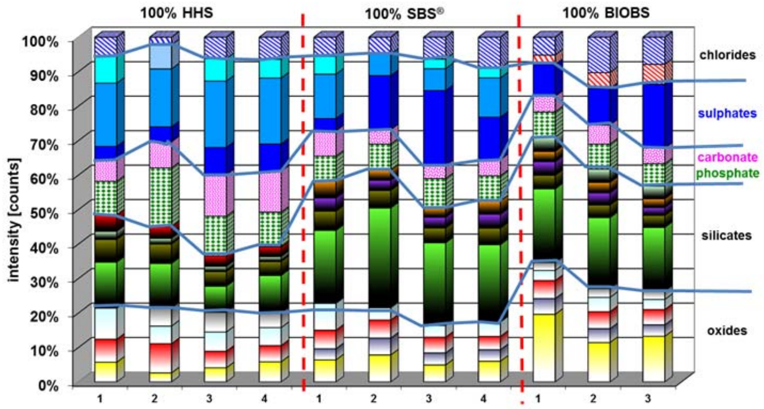

Figure 1: Composition of boiler ashes from the combustion of wood chips (HHS) and two SRF.

Conclusions and Outlook

Fixed bed experiments were used to study the combustion behaviour of several types of biogenic fuels in dependence of chemical composition and particle geometry. The results were used for the validation of model calculations and, they are applicable for the design of reciprocating grates. Studies on the formation and properties of corrosive by-products have led to the development of efficient remedies. This provides a solid basis for the development of optimized small scale power plants.

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A lab scale measurement device for the air-liquid interface exposure cultured lung cells towards wood burning emissions

Sonja Mülhopt, Institute for Technical Chemistry, Karlsruhe Institute of Technology (KIT), muelhopt@kit.edu
Marco Dilger, Institute of Toxicology and Genetics, KIT, marco.dilger@kit.edu
Christoph Schlager, Institute for Technical Chemistry, KIT, christoph.schlager@kit.edu
Tobias Krebs, VITROCELL Systems GmbH, t.krebs@vitrocell.com
Dr. Silvia Diabaté, Institute of Toxicology and Genetics, KIT, silvia.diabate@kit.edu
Dr. Carsten Weiss, Institute of Toxicology and Genetics, KIT, carsten.weiss@kit.edu
Dr. Hanns-Rudolf Paur, Institute for Technical Chemistry, KIT, paur@kit.edu

Keywords: Exposure, Health effects of aerosols, Human lung cells, Combustion aerosols

Exposure to ambient aerosols can epidemiologically be linked to increased morbidity and mortality rates, while aerosols formed during combustion processes seem to be the most potent hazards [1]. Current attempts to replace fossil fuels by regenerative sources create new additional sources for emissions of combustion derived aerosols. Despite of their high impact on human health, combustion aerosols, especially from regenerative sources, are insufficiently characterized. The aerosol components responsible for the adverse effects as well as the underlying mechanisms are yet to be identified.

Most in vitro studies on aerosol health effects rely on submerged exposure of cells to collected particulate matter, suspended in the medium. However this method does not represent the actual process in the human lung. It even changes the original properties of the investigated aerosol. Research on exposure of cells at the air-liquid interface can eliminate these disadvantages, but requires a well-engineered system to guarantee reproducible conditions [2]. Therefore, KIT and VITROCELL Systems developed a fully automated Exposure Station. It offers a lab scale measurement technique for parallel exposure of up to 24 human lung cell cultures towards aerosols. The exposure station provides direct aerosol sampling via a size selective inlet, a control system for flow, temperature, and humidity to simulate the conditions in the human lung and a programmable controller leading the user through standard exposure protocols while recording all data. The deposited particle dose is monitored online. An internal negative control using humidified synthetic air is implemented as well as an electrostatic particle deposition to increase the particle dose per time. Several measurement campaigns were successfully performed with these systems: Aerosols from biomass heating were characterised using classical toxicological methods, e.g. cytotoxicity and metabolic activity, as well as state-of-the-art -omics methods. The data are discussed with focus on the dose determination which is essential for generation of a dose-response-relationship for biological endpoints.

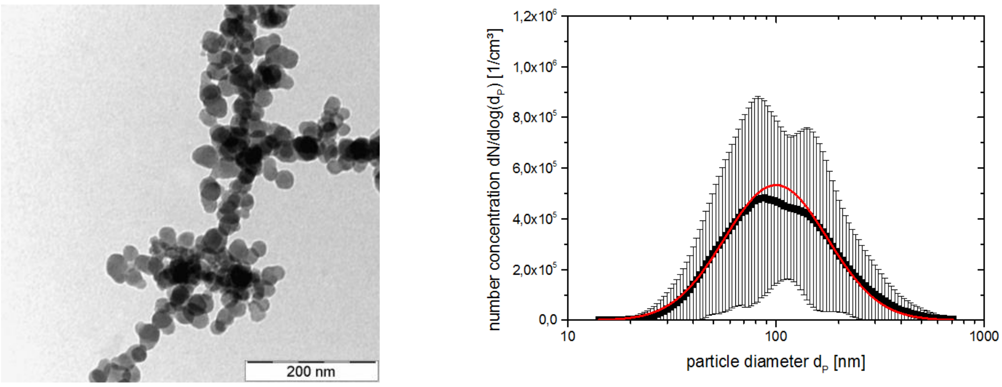

Figure 1: TEM image and number size distributions measured by Scanning Mobility Particle Sizer (SMPS) of particles from wood combustion aerosol from a log wood stove.

Acknowledgement: This work was supported by the KIT-Seed-Fonds and by the Helmholtz Association within the virtual institute HICE. Further Information: www.hice-vi.eu

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Comparing Different Industrial Transport Scenarios for the Flash Pyrolysis Products within the bioliq®-Project

***Thomas Nicoleit**, Karlsruhe Institute of Technology, thomas.nicoleit@kit.edu*
Simon Loskyll, Karlsruhe Institute of Technology
Alexander Böhme, Karlsruhe Institute of Technology
Dr. Klaus Raffelt, Karlsruhe Institute of Technology, klaus.raffelt@kit.edu
Prof. Dr.-Ing. Jörg Sauer, Karlsruhe Institute of Technology, j.sauer@kit.edu

Keywords: Pyrolysis Condensate, Char, Mixing, Transport, Sedimentation

Introduction

At Karlsruhe's bioliq®-project, dry biomass is converted into synthetic chemicals and fuels, also referred to as biomass to liquids (BtL). The lignocellulosic biomass is first liquefied by fast pyrolysis in distributed regional plants to produce an energy-dense intermediate composed of a viscous bio-oil and a high-energy char powder. Both products are mixed to a suspension converted into synthesis gas through a centralized entrained flow gasifier and then by catalysis to synthetic fuels or platform chemicals [1].

There are two possibilities of transporting the pyrolysis products to the centralized gasifier: either the char powder and the pyrolysis condensates are mixed directly mixed to a more compact, but also settling suspension, or the pyrolysis products are transported separately. The second possibility causes larger transport volumes, but the stirring energy could be saved, as the suspension is mixed directly before the gasification.

Discussion

For estimating the power consumption for the mixing and storage of the suspensions, previously published lab scale experiments ([2], [3], [4]) have been scaled up to an industrial plant. The power consumptions for mixing, stirring or pumping of the mixed suspension are negligible, also for long time storage. Thus, directly mixing all of the pyrolysis products just as received, and transporting a suspension is the most economic option. Over transport distances from more than 220 km, the truck costs step up significantly due to constitutional driving- and rest-times.

Conclusions and/or Outlook

The gained knowledge allows more precise research: the defined target scenario for the product strategy specifies new approaches and more goal-oriented research, like settling stability (over tensides), transport of chunky products or storage of challenging suspensions

Acknowledgement: This paper summarises a PhD thesis, which has been funded by the German Foundation of Business (Stiftung der Deutschen Wirtschaft)

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Investigation of Catalytic steam Reforming of Tars and Methane for Highly Efficient Power Generation from Pressurized Biomass Gasification Gas

***Michael Speidel**, Institute of Engineering Thermodynamics, German Aerospace Center, michael.speidel@dlr.de*
Gerard Kraaij, Institute of Engineering Thermodynamics, German Aerospace Center, gerard.kraaij@dlr.de
Dr. Antje Wörner, Institute of Engineering Thermodynamics, German Aerospace Center, antje.woerner@dlr.de

Keywords: Biomass, Hybrid System, SOFC, Gas Turbine, Tar Reforming

Introduction

A promising option for attaining high electrical efficiencies in the conversion of biomass is the combination of a gasifier and a hybrid power plant consisting of a solid oxide fuel cell (SOFC) and a gas turbine. The use of a pressurized gasifier allows the direct use of the product gas after hot gas cleaning without intercooling. The catalytic steam reforming of tar, which is one aspect of hot gas cleaning, is investigated for the model tar component naphthalene at temperatures from 600 °C to 800 °C and pressures up to 7 bars.

Discussion

As gasification gas can only be converted partly in a SOFC and high amounts of air are required to cool the SOFC, it is advantageous to use the remaining energy content as well as the waste heat of the SOFC off-gas in a gas turbine (see **Figure 1**) to raise the electrical efficiency. At a pressure of 5 bars relatively low temperatures from 650 °C to 750 °C are required in the SOFC, which has a positive influence on the lifetime of the SOFC. At steam reforming conditions in the tar-reformer upstream of the SOFC, methane is also converted. This endothermic reaction requires a high energy input. Operating the tar-reformer at low temperatures shifts the chemical equilibrium towards methane. Thus, the energy input can be reduced.

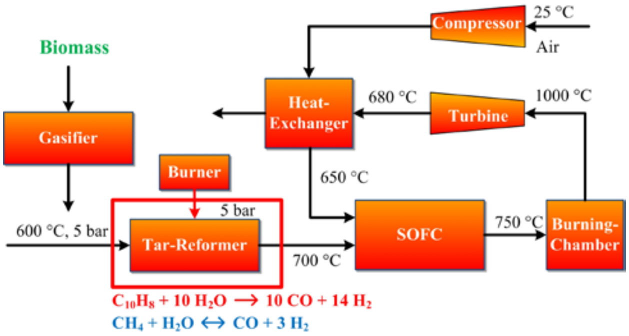

Figure 1: New concept for power generation from pressurized gasification gas in a hybrid system (SOFC and gas turbine)

In a laboratory-scale test rig, the steam reforming of naphthalene and methane is investigated for a nickel catalyst. As it can be concluded from **Figure 2**, methane is less converted than naphthalene and additionally coke formation on the catalyst caused by naphthalene at low reforming temperatures (< 800 °C) inhibits the conversion of methane.

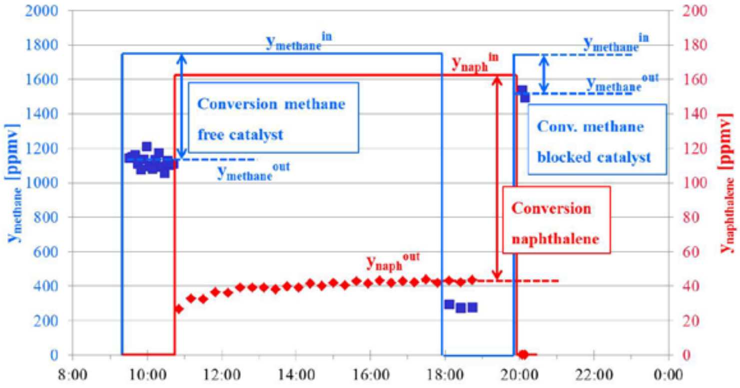

Figure 2: Inhibition of methane conversion by coke formation caused by naphthalene (5 bar, 700 °C)

Conclusions

Power generation from pressurized gasification gas in a hybrid system consisting of a SOFC and a gas turbine is a good concept to reach high electrical efficiencies using biomass feedstock. As the methane steam reforming is slower than naphthalene steam reforming, it is possible to reduce the conversion of methane in the tar-reformer and save energy input resulting in a higher electrical efficiency of the overall process.

Tailoring the viscosity function of a coke-water-slurry

***Dipl.-Ing. Leon Jampolski**, Institute for Mechanical Process Engineering and Mechanics, Karlsruher Institute of Technology, leon.jampolski@kit.edu*
Dipl.-Ing. Alexander Sänger, Institute for Technical Chemistry, Karlsruher Institute of Technology
Dr.-Ing. Neda Djordjevic, Institute for Technical Chemistry, Karlsruher Institute of Technology
Prof. Dr.-Ing. Thomas Kolb, Institute for Technical Chemistry, Karlsruher Institute of Technology
Prof. Dr. Norbert Willenbacher, Institute for Mechanical Process Engineering and Mechanics, Karlsruher Institute of Technology, norbert.willenbacher@kit.edu

Keywords: Biomass, Rheology, Sedimentation, Capillary forces, Coke-Water-Slurry

Introduction

A pyrolysis of dry biomass takes place in the bioliq-process. The result of the pyrolysis are an organic and an aqueous condensate plus pyrolysis coke. After producing synthesis gas in an entrained flow gasifier (EFG), it can be refined into synthetic fuels, fuel components and chemical basic products. The pyrolysis coke has to be mixed into the aqueous condensate to use all pyrolysis products efficiently, the energy density of the organic condensate is already sufficient for use in an EFG. A wide range of shear rates are relevant for the bioliq-process. Low shear rates control sedimentation, intermediate shear rates appear at pumping, and high shear rates occur during atomisation in the burner nozzle of an EFG. Sedimentation is a major issue during processing of pyrolysis coke–aqueous condensate-suspensions (coke-water-slurries).

Discussion

A new concept was developed to stabilise the suspension and prevent the settlement of particles. By adding small amounts of a second immiscible fluid into the slurry a sample-spanning and stable network between the particles and the secondary fluid is formed.[1] This increases the low-shear viscosity of such slurries and prevents sedimentation. In contrast, intermediate- and high-shear viscosities are less affected due to the break-up of those capillary bridges at higher stresses. Rheological behaviour is tuneable depending on choice and amount of the second immiscible fluid. While the temperature has a minor effect on the viscosity function, the origin or nature of the coke and its particle size distribution strongly affect the flow behaviour. Suspensions of highly porous particles have a higher level of viscosity than milled less porous particles because of the immobilisation of the main liquid. Moreover, the specific surface area increases due to milling, so the slurries are able to build more capillary bridges up and become stiffer.

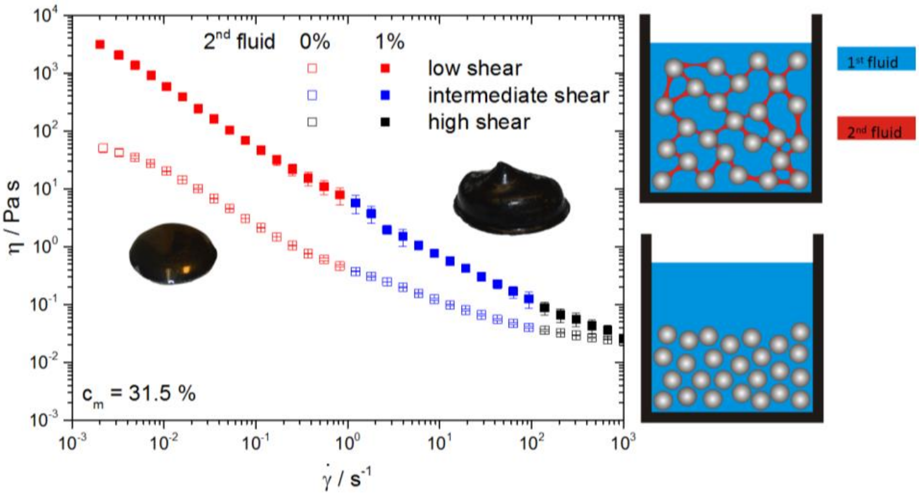

Figure 1: Viscosity in dependency of the shear rate for a coke-water-slurry with and without a second immiscible fluid

Conclusions and/or Outlook

By using capillary forces in suspensions it is possible to increase the low shear viscosity drastically. This concept can be applied to improve storage and transport properties of coke-water-slurries with high energy densities used in the bioliq-process and sedimentation is successfully suppressed with a lower effect on the high shear viscosity, which is relevant for mixing and pumping operations. In contrast, polymeric thickeners increase the viscosity in the whole shear rate range. The effect of polymeric thickeners in combination with the capillary suspension concept will be studied in a next step.

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Upgrading of Low-grade Biogenic Feedstocks at STYX Pyrolysis Reactor

M.Sc., Marco, Tomasi Morgano, *Institute for Technical Chemistry, KIT, marco.tomasimorgano@kit.edu*
Dipl.-Ing., Hans, Leibold, Institute for Technical Chemistry, KIT, hans.leibold@kit.edu
Dipl.-Ing (FH), Frank, Richter, Institute for Technical Chemistry, KIT, frank.richter@kit.edu

Keywords: Energy, Pyrolysis, Biomass

Introduction

The thermal conversion of low-grade solid biogenic feedstocks with high ash and/or inert contents enables the upgrading of the original material to high valuable fuels. Pyrolysis with hot gas filtration at STYX reactor [1] appears to be a potential technology with the aim of producing suitable, particle free fuels for high temperature thermal engines (micro gas turbine, Stirling motor, etc.) and storable char for the co-combustion in available coal power plants [2]. The yields, lower heating values (LHV) as well as the chemical and physical characteristics of the upgraded fuels are pre-requisite for the appropriate application in CHP processes.

Discussion

Different low-grade biomasses have been processed at STYX (Fig. 1). The feedstocks (Fig. 2) present low calorific values (only 13.3 MJ/kg for chicken manure), high oxygen and ash contents with variable compositions. The products yields distribution is influenced by the process parameters (mainly the reactor temperature) and by the composition of the biomass feedstock (Fig. 2). The pyrolysis of beech wood at STYX gives a condensate yield of 48% wt. while for chicken manure only 34% wt were received. Due to the high ash content, the char yield from chicken manure is about 45%, half of which is ash. Potassium appears to be the major factor, thus reducing the liquid organics and CO yields and favouring the release of CO_2. The nitrogen and the sulphur distributions among the pyrolysis products are of interest with respect to the valorisation of the char. Only about 40% wt. of the initial nitrogen content is retained in the char. The distribution is similar for every feedstock. The sulphur distributions show, that most of it is released into the vapours phase.

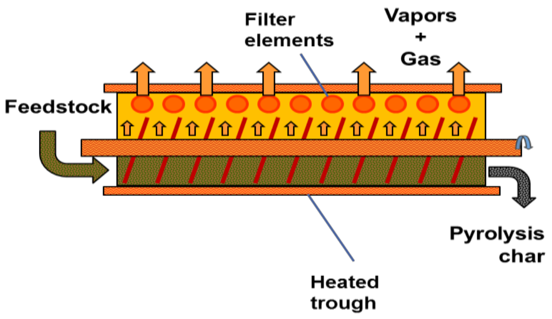

Figure 1. The STYX pyrolysis reactor

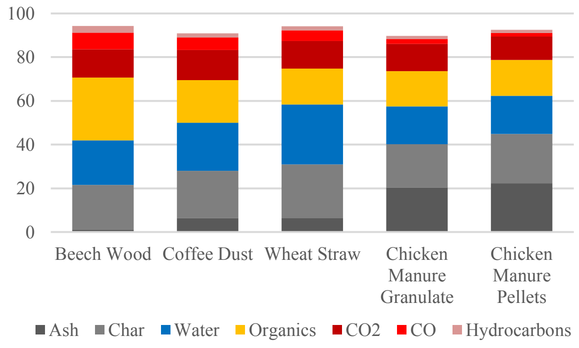

Figure 2. Mass yields (Ma.-%) at STYX at 450°C of low-rank fuels

For the potential application in thermal engines, the viscosity of the pyrolysis oils has been determined. It varies between 80 mPas for the beech wood condensate and 1600 mPas for the condensate from granulates of chicken manure and increases further with storage time. The pH of the oil from beech wood and wheat straw is very low (about 2.5) while that from chicken manure and residues from the production of coffee is about 9.5 due to a high ammonia content. The calorific values of the pyrolysis products have also been determined. The calorific value of the chars is in the range of 14-30 MJ/kg, while that of the oils is about 22-30 MJ/kg.

Conclusions and Outlook

The innovative STYX pyrolysis reactor enables the upgrading of low-grade biogenic fuels, producing particle-free vapours and condensates respectively. The pyrolysis vapours may be used directly in high temperature engines for the production of electricity, as well as for the generation of the required process heat. The char is a valuable fuel and may be adopted for co-firing in pulverized coal power plant, thus reducing the carbon balance of such facilities. However, it must be remained that low-grade biogenic fuels contain nitrogen and sulphur compounds which require additional emission control devices.

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Petrochemicals and fuels production using HBeta and hierarchical mesoporous MSU-S_{BEA} catalysts in bio-ethanol dehydration as a function of time-on-stream

Waranpong Choopun *, Center of Excellent on Petrochemical and Materials Technology,*
waranpong.c@gmail.com
Assoc.Prof.Dr. Sirirat Jitkarnka, The Petroleum and Petrochemical College, Chulalongkorn University,
sirirat.j@chula.ac.th

Keywords: Bio-ethanol Dehydration, MSU-S_{BEA}, HBeta Zeolite

Introduction

Many zeolite catalysts have been studied in the transformation of bio-ethanol into hydrocarbons. One of the best known zeolites is HBeta, it has pore size about 7.4 Å, which is considered as a microporous zeolite. However, due to its high acidity and micropores, large hydrocarbon molecules cannot pass throughout the pores, which causes deactivation of catalysts. So, the hierarchical mesoporous MSU-S_{BEA} that has larger pores and lower acidity has been introduced to overcome such problems. In this work, HBeta zeolite and MSU-S_{BEA} were employed as catalysts for the dehydration of bio-ethanol. MSU-S_{BEA} was synthesized by using TEAOH as a structure directing agent and CTAB as a surfactant. The reaction was conducted in the U-tube fixed bed reactor at 450^{o}C with 0.5^{-1}h LHSV for 24 h, 48 h, and 72 h time-on-stream, respectively. Moreover, the liquid products were analyzed by using GCxGC-TOF/MS for oil composition.

Discussion

Both MSU-S_{BEA} and HBeta catalysts exhibited about 99% ethanol conversion. For HBeta zeolite, the ethylene yield was rapidly increased during the first 8 hours in opposite to propylene yield, and after 60 hours ethylene was the only component in the gas phase. For MSU-S_{BEA}, ethylene was the main component from the beginning. In the oil obtained from HBeta, the yield of mixed xylenes still unchanged while benzene, toluene, and C9 aromatics yields are increased adversely with C10^{+} aromatics when time-on-stream increases as shown in **Figure 1(a)**. In **Figure 1(b)**, as time-on-stream increases, the oil obtained from MSU-S_{BEA} contains a high amount of non-aromatic fraction, which is mostly composed of olefin products that tend to convert to C9 and C10^{+} aromatics. It can be noted that larger hydrocarbon molecules can be formed in the MSU-S_{BEA} and pass throughout the pore due to its higher pore size than HBeta, which large hydrocarbons tend to form coke in the pore.

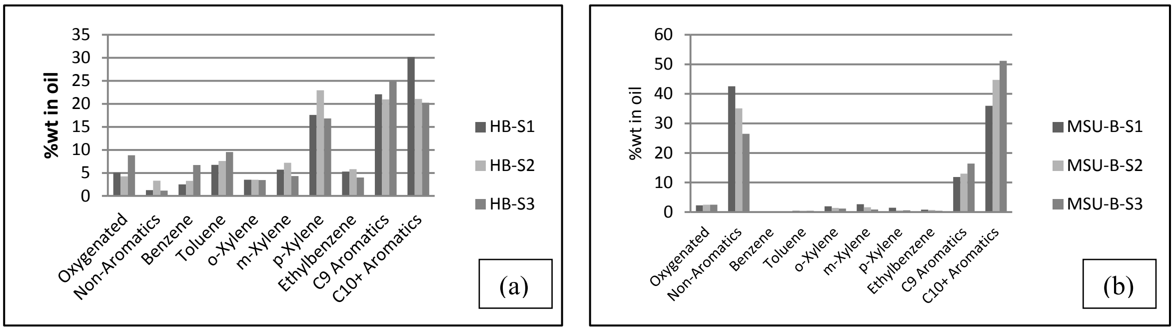

Figure 1: The oil compositions obtained from (a) HBeta, and (b) MSU-S_{BEA} as a function of time-on-stream (S1, S2, S3 = 24, 48, 72 hours time-on-stream, respectively)

Conclusion

Large hydrocarbon molecules were favorably produced by the hierarchical mesoporous MSU-S_{BEA} due to its larger pore size that can improve the diffusion of large molecules. HBeta exhibited the higher amount of coke deposition than MSU-S_{BEA}

Acknowledgement: This work was carried out with financial support of Center of Excellent on Petrochemical and Materials Technology, Chulalongkorn University

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Hydrocracking/and Hydroisomerization of Long Chain Hydrocarbons over Extrudate Pt/HY Catalysts

Kamonchanok Jariyasin, *The Petroleum and Petrochemical College, Chulalongkorn University, k.jariyain@gmail.com*
Dr.Siriporn Jongpatiwut, The Petroleum and Petrochemical College, Chulalongkorn University; Center of Excellence on Petrochemical and Materials Technology, siriporn.j@chula.ac.th
Dr.Thanakorn Wasanapiarnpong, Material Science, Chulalongkorn University; Center of Excellence on Petrochemical and Materials Technology, thanakorn.wa@chula.ac.th
Dr.Suchada Butnark, PTT Research and Technology Institute, PTT Public Company Limited, suchada.b@pttplc.com
Mr. Chaiwat Tachakritikul, PTT Research and Technology Institute, PTT Public Company Limited, chaiwat.ta@pttplc.com

Keywords: Pt/HY zeolite, Biojet, Pseudo boehmite

Introduction

Generally, jet fuels are produced from petroleum source which its price have always been unpredictable. As a result, bio-derived jet fuel has become an interest option due to its independence on petroleum import as well as its environmental-friendly advantages. Previously, the Pt supported on HY zeolite has been widely used as catalyst to convert hydrogenated biodiesel to biojet fuel. In this work, we aim to study the Pt/HY catalyst formulation for producing biojet from hydrogenated biodiesel derived from jatropha oil. The catalysts were formulated by extrusion. The experimental was done by varying the amounts of pseudo boehmite binder. Then, the extruded HY zeolite was loaded with 0.1 wt% of Pt by ion-exchange method. In addition, the physical, chemical properties, and catalytic activity of the extrudates were investigated.

Discussion

This research investigated the ability of pseudo boehmite binder which added into the HY zeolite for formulation. All of specimens were calcined at 500 °C. The mechanical properties of the extrudates were measured by Lloyd instrument with applying force at a uniform rate in the range of 0.1 mm/s until the samples crushe~~s~~d or collapse~~s~~d. **Figure 1** displays the strength of extruded HY zeolite:pseudo boehmite at different compositions. The result indicated that the more pseudo boehmite, the higher strength of the catalysts.

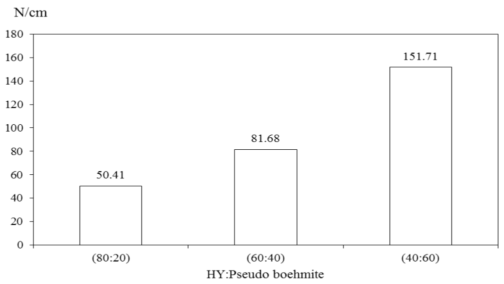
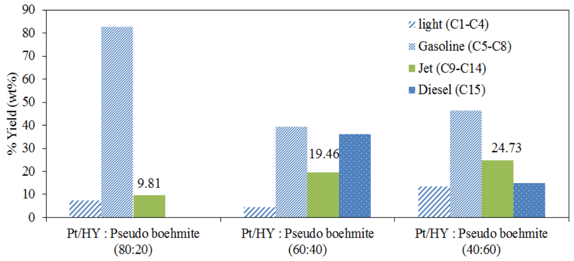


Figure 1: Radical crushing strength of extruded HY:Pseudo boehmite.



Figures 2: Product distribution obtained from extrudated catalysts with different HY:pseudo boehmite ratios.

Figure 2 shows the comparison of products defined as light gas range (C_1-C_4), gasoline range (C_5-C_8), jet range (C_9-C_{14}) and remaining feed or diesel range (C_{15}-C_{18}) over catalysts. The results showed that the main products obtained over extruded Pt/HY(80:20), (60:40), and (40:60) catalysts were in the gasoline range. The long chain hydrocarbons were cracked to lighter products because of acidity over HY supports. The products were obtained from extruded Pt/HY(40:60) catalysts, giving the highest jet yield.

Conclusions and/Outlook

The Pt/HY zeolite which were formulated by adding pseudo boehmite binder resulted in high yields of gasoline and jet range with higher isomerized paraffins. The catalyst with Pt/HY:pseudo boehmite of 40:60 gave the highest yield of jet fuel (24.7 wt%). In addition, the reaction conditions will be further optimized to maximize the jet fuel range hydrocarbons.

Acknowledgement: The Petroleum and Petrochemical College, Chulalongkorn University, Center of Excellence on Petrochemical and Materials Technology, PTT Public Company Limited

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Laser Induced Plasma Spectroscopy (LIBS) as a diagnostic tool for pressurized gasification processes

***Dr. Peter Kutne**, Institute of Combustion Technology, DLR e.V., peter.kutne@dlr.de*
Dr. James D. Gounder, Institute of Combustion Technology, DLR e.V., james.gounder@dlr.de
Dr. Ing. Sabine Fleck, Institute for Technical Chemistry, KIT, sabine.fleck@kit.edu

Keywords: Energy, Conversion, Biomass, Diagnostic, LIBS

Introduction

High pressure entrained flow gasification is an efficient tool for sustainable energy conversion for the medium- and long-term future in Europe and worldwide. For process development and scale up of the process an improved understanding and validated numerical simulation codes are essential. While numerical sub models have to be validated by experiments which investigate isolated process steps, experiments to validate the overall model have to be carried out at a technical scale. Conventional probe measurements can help to determine the mass balance, mean temperature, and species concentration, but they are not capable to measure short time fluctuations or turbulent flow phenomena. Laser optical measurement techniques are contact free methods with high temporal and spatial resolution. They can provide a deeper insight into the gasification process and deliver valuable validation data for detailed computational fluid dynamics simulations, which are not accessible by other techniques.

Discussion

Due to the harsh conditions inside a pressurized gasifier, the adaptation of laser optical measurement techniques is not straight forward. The first challenge which needs to be solved is the optical access to a slagging high temperature process. Subsequently, measurement techniques have to be developed which are able to work under the conditions of the gasification process. Laser induced breakdown spectroscopy (LIBS) is one of the measurement techniques, which in principle could be applied in a technical gasifier. It yields the local atomic composition within a probe volume, from which information of the local mixture fraction and the concentration of minor species are available [1].

In this presentation the development of LIBS for its application in a technical pressurized entrained flow gasifier is described. Results from laboratory tests are discussed, showing the ability of this technique. Results from measurements at the atmospheric lab scale research entrained flow gasifier (REGA) at the Karlsruhe Institute of Technology are presented, which were carried out during gasification of different liquid and suspension fuels. The major aim of the experiments was to evaluate the applicability of the measurement technique in a particle loaded, high temperature atmosphere and to evaluate the accuracy of the system. **Figure 1** presents four atomic emission lines (left: calcium, hydrogen, right: nitrogen, oxygen) measured simultaneously at a position 682 mm downstream of the burner during gasification of a mixture of glycol with straw char.

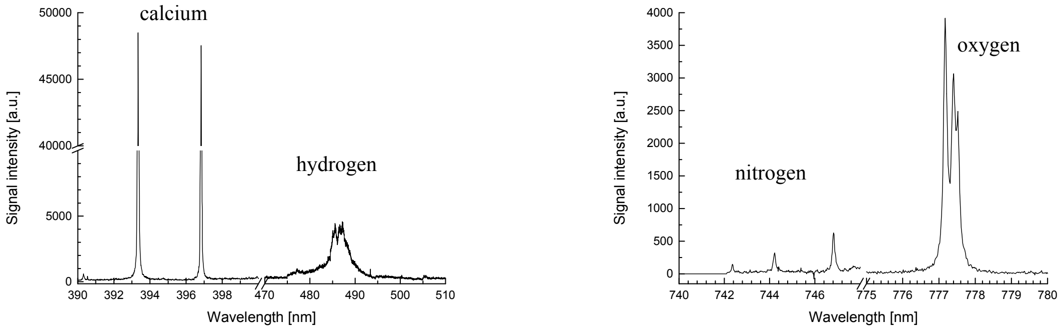

Figure 1: Emission lines of calcium and hydrogen (left), nitrogen and oxygen (right)

These signals are used to deduce the molar concentration of the different species in the measurement volume. In the presentation the applicability of this technology at pressurized conditions in an entrained flow gasifier is discussed and the technical challenges of the optical access to a pressurized gasifier are highlighted.

Acknowledgement: The authors gratefully acknowledge the financial support by the Helmholtz Association of German Research Centres (HGF) in the frame of the Helmholtz Virtual Institute for Gasification Technology (VH-VI-429)

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Properties of torrefied tropical biomass feedstocks

Dr. Tim Petrik, *Hawaii Natural Energy Institute, University of Hawaii, tipetrik@gmail.com*
Mr. Dong Li, Hawaii Natural Energy Institute, University of Hawaii, lidong@hawaii.edu
Dr. Scott Turn, Hawaii Natural Energy Institute, University of Hawaii, sturn@hawaii.edu

Keywords: torrefaction, fuel properties, banagrass, grindability

Introduction

The inorganic fraction of a model biomass material, purple banagrass (*Pennisetum purpureum x Pennisetum glaucum)*, was reduced using leaching techniques [1]. Effects on the fuel properties (e.g. HHV, mass loss, composition, and grindability) of the torrefied products are reported across a range of torrefaction temperatures. Purple banagrass has been identified as promising renewable resource for the Hawaiian Islands and the tropics due to its high yield potential.

Discussion

Figure 1 presents Hardgrove Grindability Index (HGI) values, HHV, and mass loss data for purple banagrass that was freshly harvested and (1) dried (PB-S0) or (2) treated for inorganic removal (PB-S3) and dried. The three indices are shown as a function of torrefaction temperature. The 25 °C torrefaction temperature represents the untorrefied parent material. HGI values increased slowly from an initial value of ~20 as torrefaction temperatures increased to210 °C. At higher temperatures, HGI increases sharply from ~50 to nearly 100. In the lower temperature range, the S3 materials had higher HGI values than the untreated S0. This trend was reversed at temperatures above 210 °C. Mass losses were less than 3% at the lowest torrefaction temperature and as high as 38% at the highest torrefaction temperature. Mass loss values are in a range of 5-10% at an HGI of 40. HHV increased across the range of torrefaction temperatures with the reduced inorganic S3 consistently higher than its S0 counterpart.

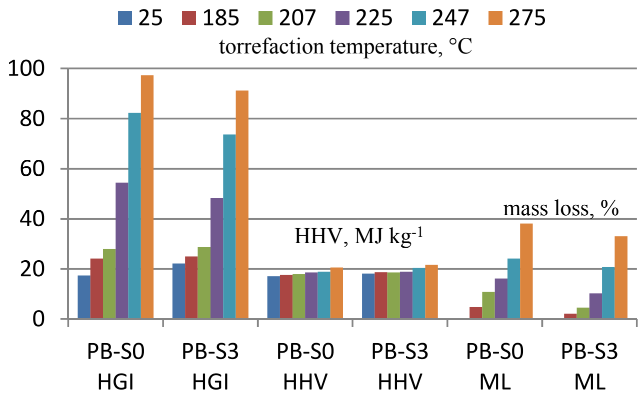

Figure 1: Properties of untreated (S0) and treated (S3) purple banagrass as a function of torrefaction temperature.

Conclusions

Torrefaction of the investigated banagrass feedstocks generally improves their fuel properties with respect to grindability and HHV. For both feedstocks, effective torrefaction temperatures between 200-225°C improved grindability (HGI) to a value comparable to coal (HGI 40) fired in the largest coal fired power plant in Hawaii. It is therefore likely that a combination of leaching and torrefaction of the purple banagrass will result in a fuel which can be used as a coal substitute with little to no modifications to the power plant.

Acknowledgement: This work was supported in part by the U.S. Department of Energy.

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Syngas cleaning by molten carbonates

***Seidelt, Stephan**, EIFER, seidelt@eifer.org*
Nikkanen, Ville, FhG-ICT, ville.nikkanen@ict.fraunhofer.de
Guschin, Viktor, FhG-ICT viktor.guschin@ict.fraunhofer.de

Keywords: Biomass, gasification, tars, gas cleaning, molten salts

Introduction

Biomass as a primary and renewable energy source is thought to play an important role for future energy and chemical production. One promising way of utilization is the thermochemical conversion of solid biomass into a CO/H2 rich product gas. “Syngas”, also called “product gas” or “synthesis gas” is a fuel presenting advantages regarding homogeneity, fuel handling and energy density. Usage of syngas ranges from chemicals to consumer energy production, e.g. catalytic production of methanol or Fischer Tropsch fuels, or usage as fuel for gas engines or fuel cells. However, the gasification process produces unwanted by-products in the syngas, like particles, tars, S- and N-containing species, alkali metals and chlorine, which have to be costly removed. Among all these pollutants, tars are the main problem; they are often mentioned as the bottle-neck of the gasification process.

A former study shows the possibility of using molten carbonates for syngas cleaning from tar model compounds [1] and inorganics [2]. A lab-scale pilot plant was set up for further experimental investigation. Besides real biomass tars, degradation rates of model compounds for inorganic syngas impurities (HCl, NH3, H2S) were determined. A concurrent fixed bed reactor was used for syngas production. Hot syngas passes a ceramic filter for particle removal and subsequent a molten salt reactor (MSR). MSR is a stainless steel tube containing a mixture of Li2CO3/Na2CO3/K2CO3 corresponding to a melting point around 550°C. Experiments were carried out with pellets as well as aqueous solutions of inorganic impurities at MSR temperatures between 600-900°C. Product characterization is done by IR spectroscopy for gaseous species (CO, H2, CO2, CH4), and by offline analysis for tars and inorganic pollutants.

Discussion

Molten carbonates are absorbent for desulfurization and dehalogination, and act as catalyst for tar cracking. Investigation of four typical syngas impurities (HCl, NH3, toluene as tar model compound and H2S) were done. At 800°C, following rates were determined:

Table 1: Degradation rates of model impurities of molten salts

Impurity	Degradation rate
HCl	95%
NH3	93%
Toluene	63%
H2S	74%

In general, the higher the temperature of molten carbonates, the higher the degradation rates.

Conclusions and/or Outlook

These results confirm the ability of molten carbonates to remove real biomass tars from syngas, in agreement with former studies on coal and waste gasification in molten carbonates [2, 3, 4].

Acknowledgement: The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2013) under grant agreement n° 308733

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Development of bimetallic catalysts for bio-oil upgrading

Thuan Minh Huynh, Heterogeneous Catalysis, Leibniz Institute for Catalysis, thuan.huynh@catalysis.de
Dr. Udo Armbruster, Heterogeneous Catalysis, Leibniz Institute for Catalysis, udo.armbruster@catalysis.de
PD Dr. Andreas Martin, Heterogeneous Catalysis, Leibniz Institute for Catalysis, andreas.martin@catalysis.de

Keywords: bimetallic catalyst, phenol, bio-oil, hydrodeoxygenation, batch experiments, continuous flow reactor

Introduction

Upgrading of bio-oil obtained from fast pyrolysis of biomass is necessary for further use as a drop-in fuel or a co-feed in conventional refineries because of high oxygenate and water content. Among the available upgrading strategies, catalytic hydrodeoxygenation (HDO) is considered as interesting technology. Recently, we developed highly active bimetallic Ni based catalysts for bio-oil HDO to replace noble metal catalysts and to overcome some drawbacks (deactivation, coke formation, price) using phenol as model compound in batch reactor [1]. To deeper understand the relationship between the catalysts' structure and performance, HDO tests with various active catalysts in a continuous fixed bed reactor and the transfer from the model reaction to conversion of bio-oil have been conducted and presented in this study.

Discussion

Various HDO catalysts based on Ni and Co were prepared by incipient wetness method using zeolite (H-ZSM-5, H-Beta, H-Y) and ZrO_2 supports. The prepared catalysts were first evaluated in batch runs using phenol as model compound (0.5 g Phenol, 10 g H_2O, 25 mg catalyst, T = 250 °C, p = 50 bar H_2 at RT, t = 2 h). The activity tests showed that bimetallic catalysts (10%Ni10%Co) outperformed the corresponding monometallic catalysts (20%Ni) in terms of activity and saturated hydrocarbon selectivity for all named supports. The bimetallic catalysts with HZSM-5 support showed the best catalytic performance compared to other materials. Then, the activity and stability of several catalysts were checked in continuous runs of the model reaction ($V_{reactor}$ = 6 ml, T = 250 °C, p = 80 bar, WHSV = 1.8 h^{-1}, H_2:Phenol molar ratio = 28). The results confirmed the better performance of bimetallic catalysts compared to monometallic catalysts. After 3 h for stabilization, the bimetallic catalysts gave complete conversion over 8 h on-stream with a slight decrease in selectivity to deoxygenated products (**Figure 1**). These results seem to be closely attributed to Ni dispersion and catalyst acidity as proved by studies of fresh and spent catalysts using various characterization methods (N_2 sorption, XRD, XPS, TPR, TPO, TEM, IR).

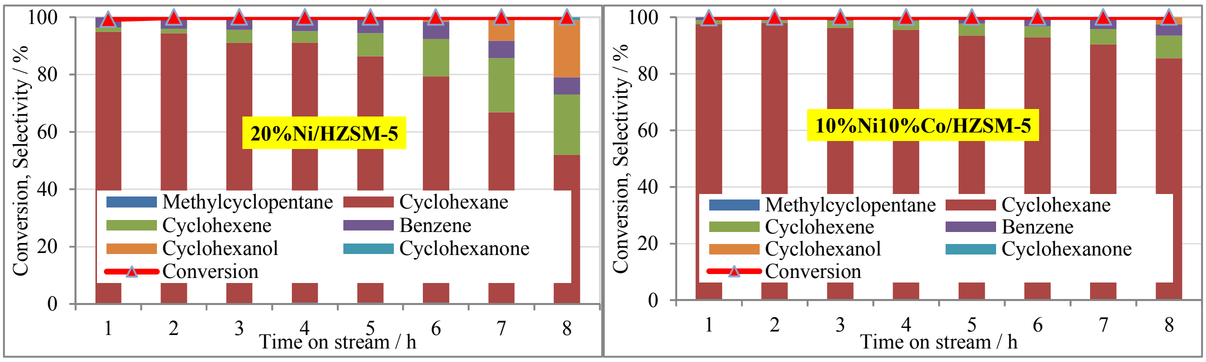

Figure 1: Catalytic performance of 20%Ni/HZSM-5 (left) and 10%Ni10%Co/HZSM-5 (right) in phenol HDO in fixed bed reactor (T = 250 °C, p = 80 bar, WHSV = 1.8 h^{-1}, H_2:Phenol molar ratio = 28).

Application of these catalysts for bio-oil HDO in batch runs (5 g bio-oil, 25 g H_2O, 1 g catalyst, T = 300 °C, p = 60 bar H_2 at RT, t = 4 h) was next investigated. The results revealed that the bimetallic catalyst (10%Ni10%Co/HZSM-5) was more active than 20%Ni/HZSM-5 and other materials in terms of degree of deoxygenation and oil yield which again confirmed the results of model reaction. The investigation of bio-oil HDO in continuous runs is currently in progress.

Conclusions

In summary, we have developed an outstanding bimetallic Ni based catalyst (10%Ni10%Co/HZSM-5) for bio-oil upgrading by stepwise development from the model reaction to bio-oil conversion and from batch to continuous runs. Further HDO long-term tests (100 h) for phenol and bio-oil are now in progress.

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Innovative biomethane processes

Dr. Frank Graf, Felix Ortloff, Manuel Götz, Prof. Dr. Thomas Kolb, *DVGW Research Center at the Engler-Bunte-Institut of the Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany (DVGW-EBI)*

Keywords: biomethane, technology, economics, efficiency, further development

Introduction

In large parts of Europe, biomethane production is a growth market. Currently, in Germany about 8.000 biogas plants are operated with about 3.75 GW installed capacity for power generation, of which approximately 150 inject biomethane into the natural gas grid[1]. At present, Germany is the world´s largest biomethane producer.

Biomethane exhibits manifold advantages over other renewables, such as sustainability, base load capability, compatibility to natural gas infrastructure, high efficiencies and various options for utilization. DVGW-EBI works on the optimization of the process chain of biomethane production, upgrading and injection with respect to environmental, economic and energy efficiency factors.

Discussion

For further improvement of biomethane economy in Germany, identification of sustainable raw material potentials, technological advances and innovations in biomethane production and upgrading are the desired approaches. In the conference contribution two innovative technological approaches a) two-staged pressurized fermentation[2], b) biogas upgrading with ionic liquids[3] developed at Engler-Bunte-Institut in cooperation with further industrial and scientific partners will be presented in detail. Beside laboratory scale experiments and reactor design practical aspects with respect to process development will be shown.

The two-staged pressurized fermentation process (Fig. 1) already produces a gas with considerably higher methane content than conventional processes. In addition, the product gas is available at high pressure which is helpful with respect to biomethane injection into the gas grid. Due to the advantages of this process, the costs of gas upgrading and injection can be significantly reduced (20 % savings are possible) as the need for energy-intensive compression of the biogas is reduced or even eliminated.

Another process engineering innovation, which is under ongoing research, is a physico-chemical scrubbing process for CO_2-removal, based on the application of ionic liquids. Again, considerable benefits in terms of lower energy consumption (-25 %) and a higher degree of process integration, resulting in lower upgrading costs compared to state of the art technologies can be achieved.

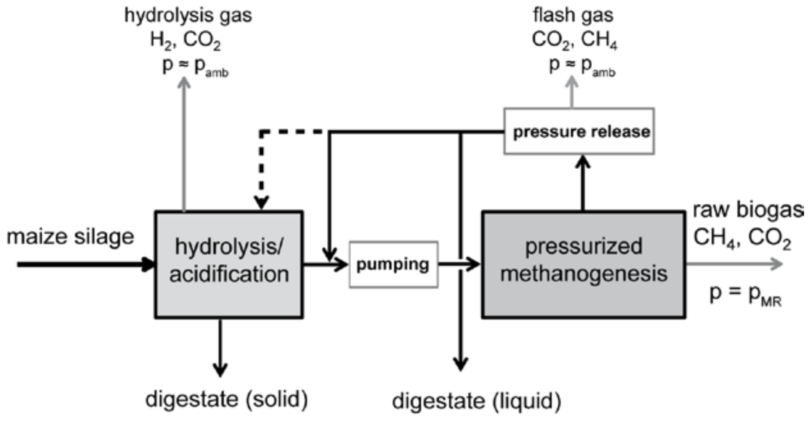

Fig. 1: Two-staged pressurized fermentation process

Summary and Conclusions

The results are highly relevant with respect to the prospective biomethane strategy. In particular, new process engineering developments indicate considerable potential for improvement of energy and cost efficiency and could therefore have a positive effect on public and political discussions concerning the future use of bio-energy in Germany and beyond. Furthermore the new process developments show promising possibilities in context with Power to gas concepts.

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Engineering fast pyrolysis of biomass: Influence of product recovery

***Axel Funke**, Daniel Richter, Andreas Niebel, Nicolaus Dahmen, Jörg Sauer, Institute of Catalysis Research and Technology, Karlsruhe Institute of Technology (KIT), Axel.Funke@kit.edu*

Keywords: Biomass Conversion, 2nd Generation Fuels, Fast Pyrolysis, Agricultural Residues

Introduction

Biofuels of the 2nd generation are currently being developed for industrial scale production. The beneficial impact of this conversion chain can be increased if agricultural residues are utilized instead of a biomass source which is being purpose grown for energetic usage. On this background, the bioliq® process aims at converting (wheat) straw to high quality fuels which can be readily used in existing engines. Fast pyrolysis is an essential part of the process to convert the biomass into an intermediate energy carrier of high energy density, consisting of a mix of solid and liquid pyrolysis products.

Next to the bioliq® fast pyrolysis pilot plant, a process development unit is under operation at KIT since seven years in order to investigate the suitability of different types of biomass and to investigate important process parameters. Some experimental results from this unit will be presented in the following.

Discussion

The experimental results shown in Figure 1 have been obtained using the same reactor but different types of feedstock and process parameters. As long as the product recovery remains unchanged, the biooil yield follows a characteristic trend which can be described by the CO/CO_2 ratio of the pyrolysis gas, which is a by-product of fast pyrolysis [1]. Two different process variants have been tested to recover the solid and liquid products. The characteristic behaviour for these two different processes and the biooil yield has significantly improved with the new design [2]. Moreover, the system is sensitive to changes as indicated by three outliers to the right. Only these three experiments have been conducted with an additional change in the inlet of the quenching system.

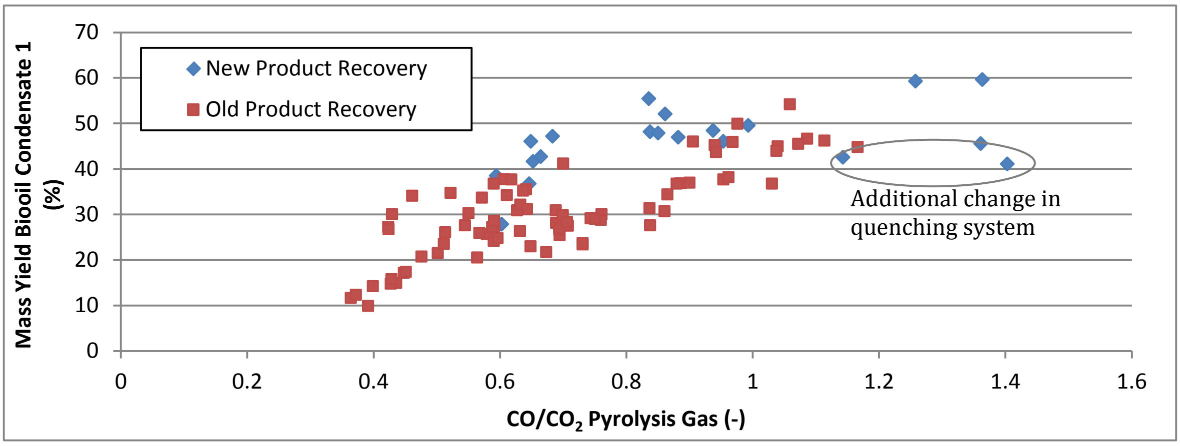

Figure 1: Comparison of trend lines with two different kind of product recovery

A variety of feedstock has been used in the experiments which are summarized in Figure 1. These included residues such as e. g. different types of straws, corn cobs, bagasse, waste wood and filer residues but also miscanthus, softwood, bark and eucalyptus. Process parameters changed also, including the mixing behaviour inside the reactor, type of heat carrier and heat carrier temperature. The reactor temperature was held constant at 500 °C. Despite this huge variety of feedstock and process parameters it is surprising that the characteristic trend of one experimental setup can be described with such a consistent trend line as indicated in Figure 1.

Conclusions and Outlook

It is shown that the CO/CO_2 ratio of the pyrolysis gas produced by fast pyrolysis is suitable to characterize the fast pyrolysis process in total, independent of feedstock choice and some important process parameters. Changes in the product recovery set-up and procedure have a significant impact on this characteristic trend, which is directly reflected by a change in biooil yield. Future work will focus on better understanding the underlying physical effects in order to enable a precise engineering of fast pyrolysis processes.

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Modelling of power demand-oriented biogas plant entities

Dr. Enrique Kremers, *EIFER, kremers@eifer.org*
Rainer Bolduan EIFER, bolduan@eifer.org

Keywords: Biogas plant, Flexibility, Demand-orientation, agent-based modelling, system dynamics, ancillary system service, energy market

Introduction

Since sustainable energy solutions should be applied to reduce environmental burden and enhance resource efficiency by concurrently ensuring service security, biogas power plants flexible to on-demand operation could play an important role to make the energy supply more sustainable. Currently, continuous biogas production shifts from continuous power supply running the risk of local oversupply or storage problems during periods of low demand, to demand-oriented power supply. These flexible plants can store constantly produced biogas for some hours in order to shift from periods of low to periods of high power demand. At least as important is the option to compensate fluctuations of weather dependent renewable PV and wind power production to stabilize the grid, especially in the German context in which steep power gradients are predicted for the residual load for the grid development plan 2033. Thus, flexible biogas power production can contribute as one dispatchable and renewable energy source in this challenge, by participating in the spot and balance markets and/or even ancillary service, as an extension of the current participation through a market and flexibility premium, which were put into place with the EEG 2012.

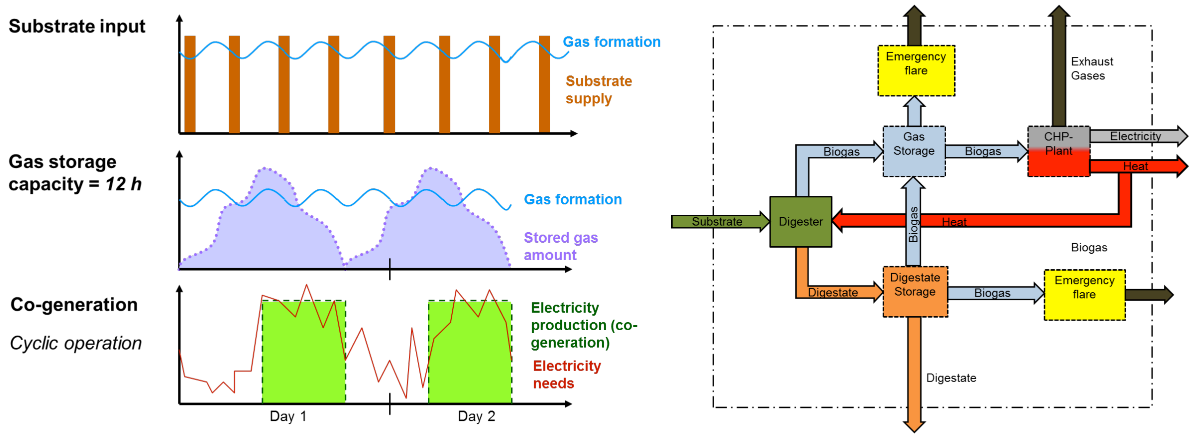

Figure 1: Operation principle of a flexible biogas plant and flexible biogas plant model

Discussion

The present work is based on a model for (single and multiple) biogas power plants that can simulate demand-oriented power production for application on different spatial areas. An individual model of a biogas plant was created which allows to determine the real-time biogas production based on amount and type of substrate and storage capacities. It was extended with enhanced storage and additional CHP modules, respecting the most common practice to extend a one CHP block plant to flexible operation (further flexibility options are also possible). The model also includes an economical dimension, which considers investment and operational costs, as well as remunerations by the current German renewable energy act (EEG). The individual model is then replicated and populated with data of a region, to create a pool of plants which can be managed according to achieve different objectives:

a) By driving through different strategies, the pool of biogas plants can be managed in terms of "pure" technical constraints in order to adapt the technical feasibility such as response times and slopes to face steep power gradients.
b) A second strategy considers market prices and analyses its actual correlation with regional demand scenarios

Conclusions and/or Outlook

The aim is to determine to what extent the biogas power production can satisfy a given power demand/compensate renewable power fluctuations and to evaluate the economy of flexibility options. An agent-based representation allows the inclusion of individual plant constraints and considers individual market actor decisions. The aggregation of multiple individual effects is then captured on aggregated load/supply level, to assess the energy balance at a regional or national level, as well as on the energy market.

Formation of by-products during gasification of biomass based suspension fuels in an entrained flow gasifier

***Dr.-Ing. Sabine Fleck**, Institute for Technical Chemistry, KIT, sabine.fleck@kit.edu*
Dr. Klaus Peter Geigle, Institute of Combustion Technology, DLR e.V., KlausPeter.Geigle@dlr.de
Dipl.-Ing. Christian Hotz, Institute for Technical Chemistry, KIT, christian.hotz@kit.edu
Dr.-Ing. Neda Djordjevic, Institute for Technical Chemistry, KIT, neda.djordjevic@kit.edu
Prof. Dr.-Ing. Thomas Kolb, Institute for Technical Chemistry, KIT, thomas.kolb@kit.edu

Keywords: Entrained Flow Gasification, Biomass, Diagnostics, LII

Introduction

Low grade fuels will play a prominent role in worldwide long-term energy supply, with biomass as a fuel fraction with CO_2 reduction potential. High pressure entrained flow gasification is an efficient technology for the conversion of this type of fuels into high-quality synthesis gas, which can be further converted to liquid fuels of the 2nd generation or other chemical products. In the bioliq® process developed at KIT, straw and other abundant lignocellulosic agricultural by-products are pre-treated by fast pyrolysis. The resulting suspension of pyrolysis oil and char is afterwards converted to synthesis gas by high pressure entrained flow gasification. The present research is focused on the basic understanding of the thermo-chemical processes during reaction of a multi-phase system at high pressure and temperature. Experiments carried out under atmospheric conditions showed that especially the processes in the burner near region influence syngas quality and yield. Additionally to conventional probe measurements laser-optical measurement techniques provide complementary information with the advantage to be non-intrusive and having a high spatio-temporal resolution.

Experimental

Experimental investigations are carried out at the laboratory Research Entrained Flow Gasifier REGA (thermal load 60 kW). Heat loss is minimized by electrical heating in order to perform the experiments under technically relevant temperatures up to 1500 °C. Liquid or suspension fuels are fed to the reactor by twin-fluid nozzles, using air with variable oxygen enrichment as atomization and gasification medium, which allows for the independent variation of stoichiometry, process temperature and atomization parameters. At ambient process pressure, the reactor provides access for conventional sampling probes as well as for optical measurements. With a vertical moveable burner construction, radial temperature or gas phase composition profiles can be measured at variable burner distance, providing an entire data mapping of the reactor. For the experiments reported here the reactor was operated with glycol and slurries mixed from glycol and pyrolysis char. The concentration of permanent gases and gaseous hydrocarbons was determined by a µGC, using conventional sampling probes. However, besides hydrocarbons also soot or tar may be formed depending on the operational conditions and fuel specification. In order to investigate the formation of soot, laser-induced incandescence (LII) was applied. LII has the advantage to monitor soot particles of nanometer size while being insensitive to the much larger char particles in the µm size range. Those may be differentiated by their luminosity when hotter than the reactor ambience with an intensified CCD camera. The LII measurements show that, in contrast to pure glycol, the soot is formed during the gasification of slurry mixed from glycol and beechwood char. The soot particles detected have sizes of 15 to 20 nm and appear in very low concentrations and homogeneous spatial distribution (Fig. 1). Distinct soot filaments known from rich combustion processes [1] are not identified, at least in the location of optical access 300 mm downstream of the burner. In contrast, char particles travel in larger lumps through the measurement volume (Fig. 2). Visible without laser excitation, char particle cloud luminosity appears spatially unresolved in the line of sight of the camera.

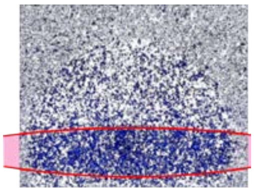

Figure 1 Instantaneous soot distribution

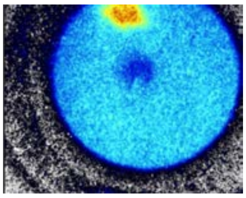

Figure 2 Char particle cloud (yellow-orange)

Conclusion

The results show the influence of by-products formation in the burner near zone on syngas quality and yield. During the measurements applicability of optical and laser-based diagnostics to harsh gasification conditions was proven. The resulting information on char particle and soot distributions provides valuable complementary data to conventional gas phase measurements for a better understanding of the gasification process.

Acknowledgement: The authors gratefully acknowledge the financial support by the Helmholtz Association of German Research Centres (HGF) in the frame of the Helmholtz Virtual Institute for Gasification Technology (VH-VI-429)

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Liquefaction of lignin under conditions of direct coal liquefaction

Dipl.-Chem. Marcus Breunig, *Institute of Catalysis Research and Technology (IKFT), Karlsruhe Institute of Technology (KIT), marcus.breunig@kit.edu*
Dr. Ursel Hornung, IKFT, KIT, ursel.hornung@kit.edu
Marc Jerjen, IKFT, KIT, marc.jerjen@kit.edu
Dr.-Ing. Thomas Krumsdorf, EDL Anlagenbau Gesellschaft mbH, thomas.krumsdorf@edl.poerner.de
Prof. Dr. Andrea Kruse, Institut für Agrartechnik, Universität Hohenheim, andrea_kruse@uni-hohenheim.de

Keywords: Energy, Biomass, Lignin, Chemical, Bio Fuel

Introduction

As a waste-product from paper industry with an amount of more than 50 Mio t/a lignin is an underestimated resource for chemical industry. So far more than 98% of the processed lignin is used in form of thermal utilisation, but there are other promising possibilities [1]. With its elemental composition and molecular structure showing certain similarities to lignite it seems reasonable to transfer existing technologies for liquefaction of lignite to lignin. The well-known Bergius process of direct coal liquefaction by high pressure heterogeneous catalysed hydrogenation used on lignin could aim for aromatic components for chemical industry as well as for bio based liquid fuels or additives.

Discussion

A preliminary screening was done using unstirred micro autoclaves with a volume of 25 ml. Different commercially available lignins were liquefied using an iron catalyst (10%) and a molybdenum catalyst (5%) as well as 1,2,3,4-tetrahydronaphthalene as a hydrogen donor solvent. The conditions were chosen to be alike the conditions of direct coal liquefaction in the Bergius process. The autoclaves were filled with solvent, lignin (2:1) and catalyst, supplied with hydrogen gas at a pressure of 120 bar and heated up to a reaction temperature of 500°C which results in a reaction pressure of 300 bar. After 1 h the heater was deactivated and the autoclaves were cooled down to room temperature.

The product phases of the liquefaction of the commercial lignosulfonates Waffex Ca, Borrespers AM and Lignex MgF and kraft lignin Indulin AT under the chosen conditions are shown in Fig. 1. The amount of liquid product thereby reaches up to 55% referring to the used lignin, meanwhile the gaseous phase has 40 % with a minimal amount of solid residue which is similar to the ash content.

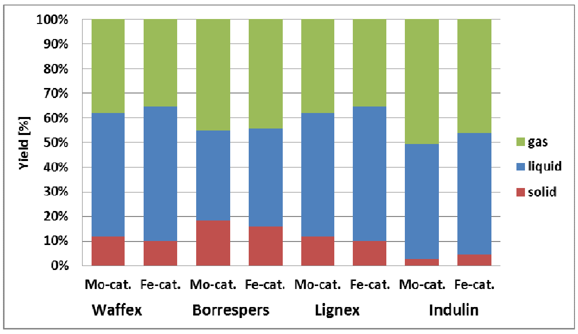

Fig. 1: product phases of the liquefaction of Waffex Ca, Borrespers AM, Lignex MgF and Indulin AT with iron and molybdenum catalyst (500°C, 300 bar, 1 h).

As the results of GC-MS show the liquid phase consists in majority of aromatic monomers without heteroatomic functional groups which indicates that the ether and methoxy groups dominating the lignin structure were almost entirely removed by hydrogenation as water or ammonia or in form CO and CO_2.

In the molecular weight distribution obtained by GPC there are only signals of the monomeric compounds with molar masses less than 150 g/mol. Therefore it is presumable that the lignin was

Conclusions

The results of the preliminary testing show, that lignin can be liquefied under the conditions of coal liquefaction obtaining good yields of monomeric compounds while removing hetero atomic functional groups.

Outlook

For the ongoing experiments a bigger reactor will be necessary. A stirred batch autoclave with a volume of two litres was established to gain higher amounts of product, which allows better analytic testing as well as a fractionated distillation of the liquid product.

Acknowledgement: Special thanks go to Thomas Tietz and Matthias Pagel for helping to establish the used setup and building all the used autoclaves as well as the big reactor.

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des deutschen Bundestages**

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Investigation of Entrained Flow Gasification of liquid Fuels at ambient Pressure

Dipl.-Ing. Christian Hotz, Institute for Technical Chemistry, KIT, christian.hotz@kit.edu
Dr.-Ing. Sabine Fleck, Institute for Technical Chemistry, KIT, sabine.fleck@kit.edu
Dr.-Ing. Neda Djordjevic, Institute for Technical Chemistry, KIT, neda.djordjevic@kit.edu
Prof. Dr.-Ing. Thomas Kolb, Institute for Technical Chemistry, KIT, thomas.kolb@kit.edu

Keywords: Entrained Flow Gasification, Biomass, Influence of Atomisation

Introduction

Biomass as a CO2-neutral energy carrier has the potential to contribute significantly to sustainable and stable energy supply. As the only renewable source of carbon, biomass can be processed to second-generation biofuels and basic chemicals. Therefore, a lot of research has already been done to advance the development of Biomass-to-Liquid processes. A possible approach for a BtL chain is the bioliq®-process, developed at Karlsruhe Institute of Technology (KIT), producing high-quality gasoline from straw and other abundant lignocellulosic by-products. Thereby, entrained flow gasification is used to convert biogenic suspension fuel obtained from pre-treatment of biomass via fast pyrolysis, into syngas and eventually into synthetic biofuel. The present research work of the Gasification Group at the Institute for Technical Chemistry (ITC) is focused on an elementary understanding of the gasification process as the essential step in conversion of residual biomass to a chemical energy/carbon carrier - syngas.

Experimental

At the bench-scale Research Entrained Flow Gasifier REGA (thermal load 60 kW) the influence of process parameters and fuel composition on syngas quality are under investigation. At ambient process pressure, radial profile measurements of temperature and gas composition inside the reactor are feasible at continuously variable burner distance. Thus a unique temperature and gas composition mapping of the gasifier can be achieved. Heat loss from reactor is compensated by electrical heating to carry out the experiments under technically relevant temperatures up to 1500 °C. In the process, the fuel is atomized in an external mixing twin-fluid nozzle by a gas being both, atomization and gasification medium. Variable oxygen enrichment allows the independent variation of stoichiometry, process temperature and atomization parameters. In order to characterise spray quality during gasification process, cold pre-tests with identical nozzles and relevant gas-to-liquid ratio are performed at the Atmospheric Spray Test Rig- ATMO, where Sauter mean diameter of the droplets are determined by laser-based measurement techniques. In the presented work either glycol with well-defined fuel properties or a straw ash suspension based on pyrolysis oil as a technical fuel is fed to the gasifier.

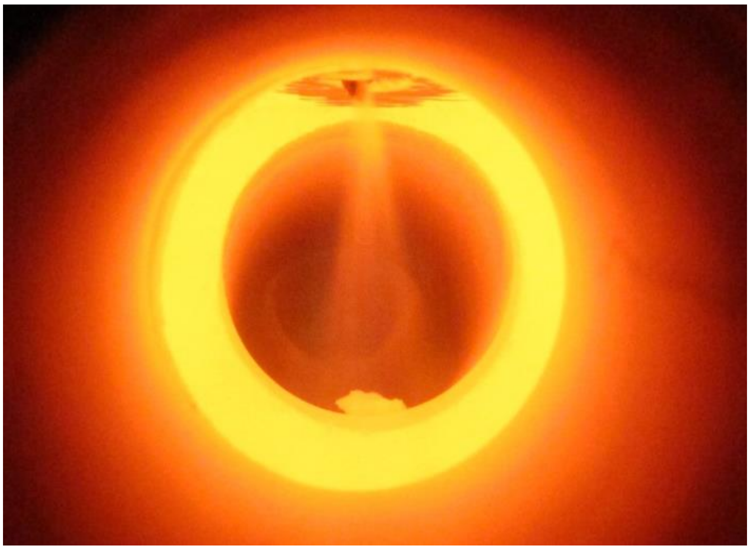

Figure 1: Fuel atomisation in entrained flow gasification

Profile measurements of temperature and gas composition inside the reactor provide unique information about local effects of atomization and fuel properties on the gasification process. Conducted experiments with constant process parameters (stoichiometry, flow rates), but varied nozzle designs reveal a significant change in temperature distribution and gas phase composition. Hereby, the processes in the near-burner field have been found to be essential for the overall gasification process. For further investigations of the influence of droplet size and flow field close to fuel injection, optical measurements have been conducted. Detailed information about the flame and the oxidation zone are obtained by OH*-Chemiluminescence Images.

Conclusion

Present results show the influence of fuel atomization due to a shift in spray quality and flow conditions generated by varied inlet momentum of the nozzle. The results are discussed especially regarding the formation and degradation of by-products like methane and higher hydrocarbons.

A Comparative Study of Medium Deep Borehole Thermal Energy Storage Systems Using Numerical Modelling

Bastian Welsch, *Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, welsch@geo.tu-darmstadt.de*
Dr. Wolfram Rühaak, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, ruehaak@geo.tu-darmstadt.de
Daniel O. Schulte, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, schulte@geo.tu-darmstadt.de
Dr. Kristian Bär, Department of Geothermal Science and Technology, Technische Universität Darmstadt, baer@geo.tu-darmstadt.de
Prof. Dr. Ingo Sass, Department of Geothermal Science and Technology, Technische Universität Darmstadt, sass@geo.tu-darmstadt.de

Keywords: Medium Deep Borehole Thermal Energy Storage, MD-BTES, borehole heat exchangers, BHE

Introduction

In this study the potential of Medium Deep Borehole Heat Exchanger (MD-BHE) systems for seasonal heat storage is presented. Storing heat at temperature levels of 90 °C and higher has a key benefit. Compared to low temperature energy storage higher loading temperatures in the summer season result in higher unloading temperatures during the heating period in winter. Thus, a higher overall efficiency of the heating system can be achieved. However, higher temperature levels in the storage system increase the heat losses, due to a higher lateral temperature gradient into the surrounding subsurface. As ground temperature increases with depth the installation of MD-BHE systems with depths of 400 m to 1000 m is considered to minimize these thermal losses.

Numerical Modelling

200 different borehole thermal energy storage configurations were compared, using the numerical program FEFLOW [1] for modelling the heat transport processes in the BHEs and in the subsurface. The influence of different design parameters on the storage performance was studied by varying the BHE length, the number of BHEs, the spacing between the BHEs and the inlet temperature during the extraction period. Additionally, another 18 models with the same storage design, but varying underground properties were analysed. A simplified underground model was assumed and a simplified operation procedure was applied in all scenarios over a period of 30 years of storage operation.

Conclusions

The simulation results show, that medium deep storage systems can be suitable for the storage of heat with temperatures of 90 °C and higher. All considered storage systems improved their performance significantly with time. There is a strong influence of the studied parameters on the efficiency and the specific heat extraction rate of such storage systems. Depending on the selected parameters, the storage efficiency ranges between about 25 % and 78 % in the 10th year of storage operation. The average specific heat extraction rate for the preset extraction time of 4380 hours reaches values of more than 100 $W \cdot m^{-1}$ in the 10th year of operation, which correlates to an annual specific heat extraction of more than 435 KWh per meter of BHE. Although the performed simulations are considerably simplified and geological settings are usually far more complex in reality, the results, which were obtained in this study, are expected to be realistic.

Acknowledgement: The presented work is part of the research project "Simulation and evaluiation of coupling and storage concepts for renewable forms of energy for heat supply" (Simulation und Evaluierung von Kopplungs- und Speicherkonzepten regenerativer Energieformen zur Heizwärmeversorgung). This project (HA project no. 375/13-14) is funded within the framework of Hessen ModellProjekte, financed with funds of Energietechnologieoffensive Hessen – Projektförderung in den Bereichen Energieerzeugung, Energiespeicherung, Energietransport und Energieeffizienz. We want to thank for the financial support by the DFG in the framework of the Excellence Initiative, Darmstadt Graduate School of Excellence Energy Science and Engineering (GSC 1070)

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Coupling of Renewable Energies with Medium Deep Borehole Heat Exchangers to Cover the Annual Heat Demand of Larger Buildings by Seasonal High Temperature Heat Storage

Dr. Kristian Bär, *Department of Geothermal Science and Technology, Technische Universität Darmstadt, baer@geo.tu-darmstadt.de*
Bastian Welsch, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, welsch@geo.tu-darmstadt.de
Daniel Schulte, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, schulte@geo.tu-darmstadt.de
Wolfram Rühaak, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, ruehaak@geo.tu-darmstadt.de
Sebastian Homuth, Züblin Spezialtiefbau GmbH Ground Engineering, sebastian.homuth@zueblin.de
Ingo Sass, Chair of Geothermal Science and Technology, Technische Universität Darmstadt, sass@geo.tu-darmstadt.de

Keywords: Borehole Thermal Energy Storage, BTES, Borehole Heat Exchanger, BHE, Geothermal Heating,

Introduction

Heating of buildings requires more than 50% of the overall energy consumption in Germany. Worldwide many people live in a comparable climate. Therefore, especially in this sector, new techniques are needed to save energy and reduce greenhouse gas emissions. Shallow geothermal systems for indirect use as well as shallow geothermal heat storage systems like aquifer thermal energy storage (ATES) or borehole thermal energy storage (BTES) typically provide low temperatures only. The temperature levels and ranges usually require a coupling with heat pumps and are only usable for low temperature heating systems in state of the art buildings.

Project Description

Based on a case study of an office building at the University of Darmstadt (Germany), the feasibility and design criteria of a coupled renewable energy system designed to store and supply high temperature heat, which is needed for conventional heating systems, are assessed.

Heat sources are solar panels installed on the building's roof and a local district heating system fed by a combined heat and power station (CHP) on the campus with temperatures of 90 °C and more. In summer both the solar panels and the CHP, which is operated for electricity generation, produce excess heat, which can be stored in a medium deep high temperature heat storage (MDHTS) operated on high temperature levels. The MDHTS consists of several custom made coaxial BHEs with depth of 400 to 1,000 m. They operate in thermal interaction with modelled seasonal storage efficiencies strongly depending on the geometry and size of the system of 20 to 80%. The modelled temperature level of about 50 °C after ten years of operation is high enough for conventional radiator based high temperature heating systems at the beginning of winter. If the system is combined with heat pumps, it can be used during the whole heating period to fully provide the required heat demand of the building. The energy demand of the heat pumps and therefore their costs are reduced significantly compared to shallow low temperature BTES systems. Thus, this system is ideal for old or renovated buildings with conventional heating circuits. Furthermore, target depths of more than 400 m below the surface typically avoid conflicts with groundwater use.

Conclusions and/or Outlook

Especially the coupling of different renewable energy sources – solar thermal and geothermal – with already existing district heating systems – e.g. combined heat and power stations (CHP) – as presented here, seems to be a very promising approach to cover the heating demand of renovated or old buildings at higher temperature levels with renewable energies. Since conventional heating systems are still installed in approximately more than 90% of Germanys building stock, the presented concept is a viable option to reduce the heating energy demand and the related greenhouse gas emissions.

Acknowledgement: The presented work is part of the research project "Simulation und Evaluierung von Kopplungs- und Speicherkonzepten regenerativer Energieformen zur Heizwärmeversorgung" [Simulation and evaluation of coupled systems and storage concepts for different renewables energies to supply space heating]. This project (HA project no. 375/13-14) is funded in the framework of Hessen ModellProjekte, financed with funds of Energietechnologieoffensive Hessen – Projektförderung in den Bereichen Energieerzeugung, Energiespeicherung, Energietransport und Energieeffizienz. We thank Michael Thompson, Marcin Wronowski and Bishnu Prasad Koju for their work on this project.
This work is also financially supported by the DFG in the framework of the Excellence Initiative, Darmstadt Graduate School of Excellence Energy Science and Engineering (GSC 1070).

An experimental study on the performance of Earth-Air Heat Exchanger used in an employee's cafeteria in Taiwan

Chien-Yeh Hsu, Department of Mechanical Engineering, National Taiwan University, d00522028@ntu.edu.tw
Yuan-Ching Chiang, Department of Mechanical Engineering, Chinese Culture University, jyj3@staff.pccu.edu.tw
Sih-Li Chen, Department of Mechanical Engineering, National Taiwan University, slchen01@ntu.edu.tw
Pei-Yu Yu, Green Energy & Environment Research Lab., Industrial Technology Research Institute of Taiwan, stevenyu@itri.org.tw
Yu-Choung Chang, Green Energy & Environment Research Lab., Industrial Technology Research Institute of Taiwan

Keywords: Passive climate control technique, Earth-Air Heat Exchanger, Swallow Geothermal Energy, Taiwan

Introduction

The Earth-Air Heat Exchanger (EAHE) is a passive climate control technique that has application in agricultural building utilizes the underground soil temperature that stays fairly constant at a depth of about 2.5–3 m [1][2]. The present study undertakes performance evaluation of EAHE and applies to an employee's cafeteria in Nantou city Innovation & Research Park located in Central Taiwan. The main purpose of this study is the achievement of the transient behaviour of temperature fields for the external air, soil and buried air ducts and the best periods of the operation time for EAHE system device.

Discussion

The EAHE system in this study consist of seven parallel air ducts buried in the soil at a depth of 3.5m, a catch basin based drainage well which is designed for air ducts cleaning, and a centrifugal fan breathed air in the duct. The temperature variations in the soil are monitored at different depth: 1m, 2m, 3m, and 4m. The soil temperatures, air humidity and air flow rate are measured by T type thermal couples, resistive humidity sensors and air flow capture hood, respectively. The transient heat exchange rate of the EAHE is calculated by the mass flow rate of air travelled through the air ducts and the enthalpy difference between ambient air and the outlet air of the air ducts. **Figure 1** shows the results of transient heat exchange rate during July 2014 to December 2014. The design operation hours of the outdoor air ventilation for the cafeteria is the lunch time (from 10:00 to 14:00), therefore the period of the heat exchange between air and the air ducts is defined by four hours a day. The amplitude of the transient heat exchange rate seemed large because the uncovered inlet field of the EAHE led to the influence of direct sunlight and wind on the ambient air temperature and humidity. However, the outlet air condition was stable, and it means the average daily heat exchange rate is still significant. The mean heat exchange rate including sensible and latent heat decreased from about 28kW (cooling) to -10kW (heating) during the operation days. This descent indicated that for a short-term intermittent operation, the heat exchange performance of EAHE is strongly depend on the ambient air condition.

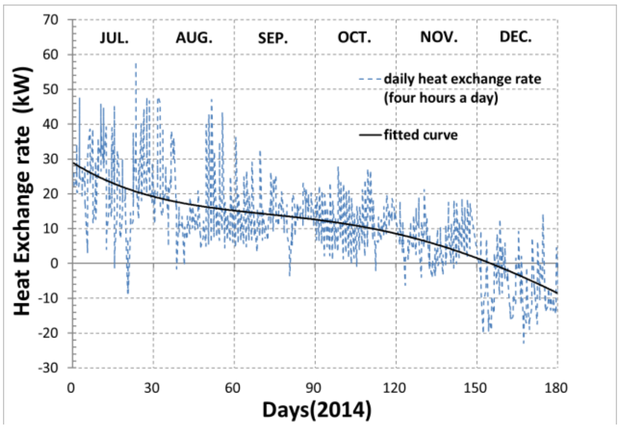

Figure 1: The transient heat exchange rate of EAHE since July 1, 2014

Outlook

The study has developed a 6-months database about the transient temperatures of the soil, external air in Nantou city and inside the cafeteria building until now. According to this ongoing research project, the yearly performance of the EAHE and the system COP will be calculated to develop the complete database.

Acknowledgement: The authors gratefully acknowledge the financial support provided by the Bureau of Energy, Ministry of Economic Affairs, Taiwan, R. O. C.

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Corrosion and scaling in the utilization of geothermal energy

Dr. Niklas Mundhenk, Institute of Applied Geosciences – Division of Geothermal Research (KIT); niklas.mundhenk@kit.edu
Prof. Dr. Thomas Kohl, Institute of Applied Geosciences – Division of Geothermal Research (KIT); thomas.kohl@kit.edu

Keywords: geothermal energy, geothermal fluids, corrosion, scaling

Introduction

Geothermal energy can contribute a significant portion of electricity to the future energy mix. However, technical challenges towards a viable use of these virtually infinite resources have remained unsolved so far. In Germany and France, the Upper Rhine graben (URG) offers favorable conditions for geothermal utilization and several projects producing electricity in binary-type power plants have emerged in the last decades. However, due to physicochemical characteristics of the geothermal fluids encountered (mostly Na-Cl dominated CO_2-rich brines), operators face major challenges to achieve a high availability of the power plant. Major obstacles are corrosion of materials that are in contact with corrosive high-temperature geothermal fluids and scaling within the geothermal loop. Predicting these phenomena remains challenging due to the complex chemistry, the presence of dissolved gases, varying temperatures, and flow conditions.

Methods & results

Extensive experimental work has been conducted in order to assess the behavior of metallic materials (C-steels, CrNiMo alloys, Ni-base alloys and non-ferrous metals) exposed to natural and synthetic geothermal fluids at temperatures that are relevant to the utilization of geothermal energy. By using electrochemical polarization methods, the thermodynamic behavior could be assessed and critical electrochemical potentials could be determined from current density-potential curves. Not only qualitative, but also quantitative results could be obtained, by using weight-loss and the linear polarization resistance methods (LPR).

In a series of experiments under varying environmental conditions the major corrosion mechanisms could be identified for the above mentioned materials, including uniform, localized, and selective corrosion. Conventional C-steels corrode with a considerable rate of up to 1 mm y^{-1}, more or less uniformly. Interestingly, the corrosion rates have a maximum below 100°C and decline towards higher temperatures. The results suggest that the cathodic partial reaction is the rate-limiting step in CO_2-containing corrosion environments. Alloyed materials have a much higher resistance owing to the formation of a non-conductive oxide (mostly Cr-oxide) layer, a process called passivation. However, once the stability limits of the oxide layer are exceeded, chloride-induced localized corrosion will occur. Exceptions are higher-alloyed austenites, Ni-base alloys, and Titanium that have sufficient corrosion resistance.

A key point addressed is the interrelation between corrosion and scaling. Under reducing condition and in the presence of CO_2 in the geothermal loop siderite ($FeCO_3$) is the main corrosion product of iron-based materials. It can provide a good barrier against corrosion, conferring a state of passivation that significantly lowers the corrosion intensity of the substrate. However, it was found that rough siderite surfaces facilitate the formation of fluid-derived scales, such as barite/celestine ($(Ba,Sr)SO_4$) solid solutions and galena (PbS). These scales may incorporate natural radionuclides (^{226}Ra, ^{210}Pb) in their crystal lattice and may be a source of radioactivity that necessitates monitoring and frequent scale removal. Against this background it becomes clear, that corrosion has to be regarded in conjunction with the scaling potential of a given geothermal fluid.

Conclusions & outlook

This research shows that particular attention has to be drawn to the physicochemical characteristics of a geothermal fluid that is processed in the geothermal loop. Detrimental effects, such as corrosion, scaling, and their interaction, have been addressed. For a reasonable material selection the corrosion resistance of a given material has to be regarded as a system behavior that also includes the scaling potential of the geothermal fluid. With increasing size of future geothermal power plants, corrosion engineering requires increased attention.

Sulfur removal from tyre-derived oil using mesoporous MCM-48 catalyst

***Sarinthip Trongyong**, The Petroleum and Petrochemical College, Chulalongkorn University,*
pu_scorpio24@hotmail.com
Assoc.Prof.Sirirat Jitkarnka, Center of Excellence on Petrochemical and Materials Technology,
sirirat.j@chula.ac.th

Keywords: Waste tyre, Mesoporous material, Sulphur removal

Introduction

Nowadays, waste tyre discarding is a serious environmental issue. Tyre is a hardly degradable material; so, pyrolysis is one of the interesting methods to reduce waste tyres. Normally, tyre-derived oil is an aromatic-based hydrocarbon mixture that consists of some large aromatic hydrocarbons. They not only reduce combustion efficiency of fuel, but also increase the toxicity to the environment. Moreover, tyre-derived oil consists of a high amount of sulphur due to the valcanization process in manufacture of tyres. Many researchers used catalysts to improve the quality of oil. In this work, MCM-48 (Mobil Composition of Matter number 48), silica material with a cubic mesoporous structure, was used as a catalyst. It was expected to decrease the bulky molecules of hydrocarbons and sulphur compounds in oil due to its large pore size. The oils were analysed by using GCxGC-TOF/MS and S analyzer.

Discussion

MCM-48 with pore size of 27.8Å, synthesized at room temperatue[1], was used as a catalyst in waste tyre pyrolysis in this work. As a result, the concentration of di- and poly-aromatics in oil decreased while mono-aromatics increased (**Figure 1a**), indicating that 3D cubic structure of mesoporous silica MCM-48 allows large molecules to pass through inside the pores. In addition, the complex pore structure gave high contact time in pores. Moreover, MCM-48 can reduce sulphur in oil by 34%. **Figure 1b** shows the distribution of sulphur in pyrolytic products. It can be seen that MCM-48 can remove sulphur from oil in association with the deposition of sulphur on the catalyst, indicating that MCM-48 can help C-S bond to break. Furthermore, sulphur species in oil can be classified into five groups: thiophenes (Th), benzothiophenes (BT), dibenzothiophenes (DBT), benzothiazoles (BTz), and isothiocyanates (ITC). **Figure 1c** shows that MCM-48 can reduce sulphur-containing compounds (BT and DBT) with the increase of Th, indicating that MCM-48 tends to increase nitrogen-containing sulphur compounds (BTz and ITC).

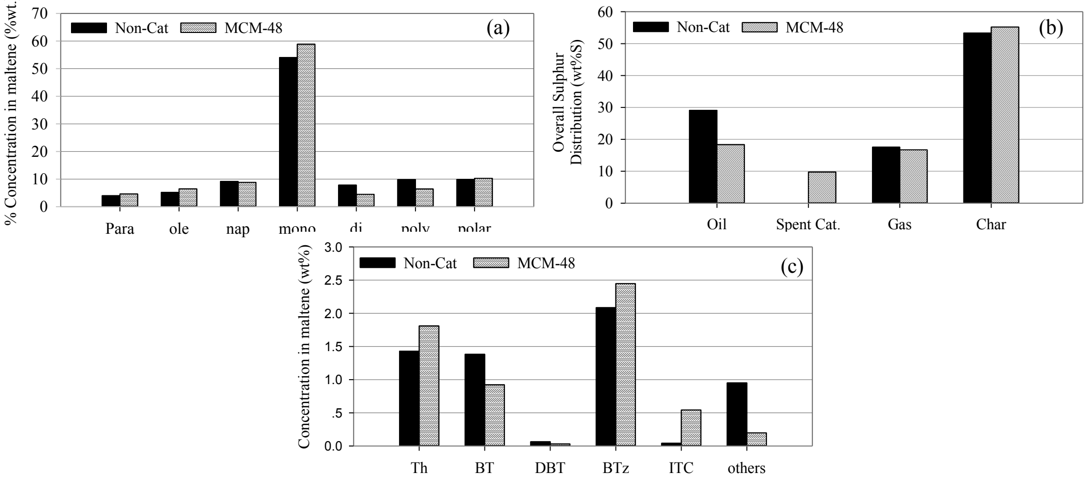

Figure 1: (a) Concentration of each group of components in maltene, (b) Overall sulfur distribution (wt%S), and (c) Concentration of sulfur-containing species in maltene

Conclusions

MCM-48 exhibited a high reduction of di- and poly-aromatics due to its large pore size. Moreover, it promoted sulphur removal in oil by 34%wt. MCM-48 catalyst reduced N-free sulphur-containing compounds, but tends to increase nitrogen-containing sulphur compounds.

Acknowledgement: The authors would like to appreciatively thank Thailand Research Fund (TRF) (Grant Number RSA5680021).

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Discovering the potential for offshore windfarms trough measurements

Jörg Bendfeld, *Department of Electrical Engineering - Sustainable Energy Concepts, University of Paderborn, joerg.bendfeld@upb.de*
Stefan Balluff, *Department of Electrical Engineering - Sustainable Energy Concepts, University of Paderborn, Stefan.balluff@upb.de*
Prof. Dr.-Ing. Stefan Krauter, *Department of Electrical Engineering - Sustainable Energy Concepts, University of Paderborn, Stefan.krauter@upb.de*

Keywords: offshore wind farm, energy management, measurement

Introduction

Offshore wind should be discussed in the context of the challenge of climate change. It is widely accepted that developed countries by 2050 will have to make very significant cuts in their greenhouse gas emissions, around 80%, to limit the climate change to a manageable level. Because of this the electricity generation system needs to become carbon neutral in the next three to four decades. In that context the winds over the seas are a huge resource of clean energy.

Discussion

For the estimation of the average annual wind speed and thus the energy production of offshore wind farms it is imperative to know the exact wind conditions at each project site. Suitable prognosis-methods are missing so far. Methods used onshore cannot easily be transferred. The only available approach to achieve exact information about the wind conditions is a met mast. An Offshore met mast has to deliver data for many different purposes:

1. 1. In the first stage to get a project bankable the data for the realistic prediction of annual energy production is important.
2. The second aim is the identification of seasonal time slots for maintenance of the offshore wind farm.
3. The third aim will be the identification of the turbulences for load-calculation, or the direct load measurement.
4. During the operation of the wind farm the performance has to be monitored.

Conclusions and/or Outlook

For the dimensioning of the metmast it is recommendable to measure wind speeds within the entire rotor operating range of the future wind plant. With planned hub heights of approximately 100 m and a rotor diameter of approximately 140 m the measuring range extends from 30 m up to 170 m above sea level. Most promising are the new (for wind energy purposes) remote sensing techniques: For example Lidar. Lidar is based on laser doppler scatterometry.

GIS-based Approach for the Assessment of Sustainable Biomass Potentials

***Dr. Martina HAASE**, Karlsruhe Institute of Technology (KIT), Institute for Technology Assessment and Systems Analysis (ITAS), martina.haase@kit.edu;*
Dr. Christine RÖSCH, KIT, ITAS, christine.roesch@kit.edu

Keywords: Bioenergy, Sustainability, Crop Residues, Spatial Analyses, Geographic Information System

Introduction

Cereal straw and other agricultural residues are gaining increasing interest as largely untapped possible energy resource that can contribute to mitigate climate change and enhance energy security. Besides, their use is not associated with food or land use competition. In this paper, a GIS (Geographic Information System)-based approach for the assessment of sustainable potentials of crop residues (residues from cereal, root crop, and oil plant cultivation) is presented. The approach has been developed within the EU project BioenNW and applied to five European regions, i.e., West Midlands, South Netherlands, North Rhine-Westphalia (NRW), Wallonia, and Île-de-France (IF), considering natural regional and local conditions and distinct environmental sustainability issues. The aim is to determine the amount and geographical distribution of crop residues that could be used in a sustainable way.

Method and exemplary results

The GIS-based model has been developed using the programming language Python and the software ArcGIS. Besides theoretical potentials, sustainable biomass potentials are estimated considering specific ecological restrictions. The biomass potentials are calculated for a spatial resolution of 1 km x 1 km and 10 km x 10 km grid cells respectively [1]. The theoretical potential is defined as the total amount of crop residues produced on arable land, regardless of current use or ecological restrictions. Ecological restrictions include soil threats, i.e., soil erosion and low organic carbon content in the topsoil, as well as protected areas. In a second step, the calculated sustainable residue potentials are compared to the estimated quantities required for existing types of use. For all model regions, cereal straw shows the highest sustainable biomass potential (dry mass) amongst crop residues. The maximum total sustainable cereal straw potential accounts for approx. 3.2 million t_{wet}/a in NRW, 1.6 million t_{wet}/a in Île-de-France, 1.1 million t_{wet}/a in Wallonia, 1.0 million t_{wet}/a in West Midlands, and 0.2 million t_{wet}/a in South Netherlands. Depending on the respective region, the maximum sustainable cereal straw potential is approx. 40–50 % of the theoretical potential. **Figure 1** shows the spatial distribution of the sustainable cereal straw potential in NRW and IF. Considering the amount of straw currently used for animal husbandry in the respective regions, in NRW approx. 69 % (2.2 million t_{wet}/a) and in IF approx. 99 % (1.5 million t_{wet}/a) of the sustainable cereal straw potential could be used energetically.

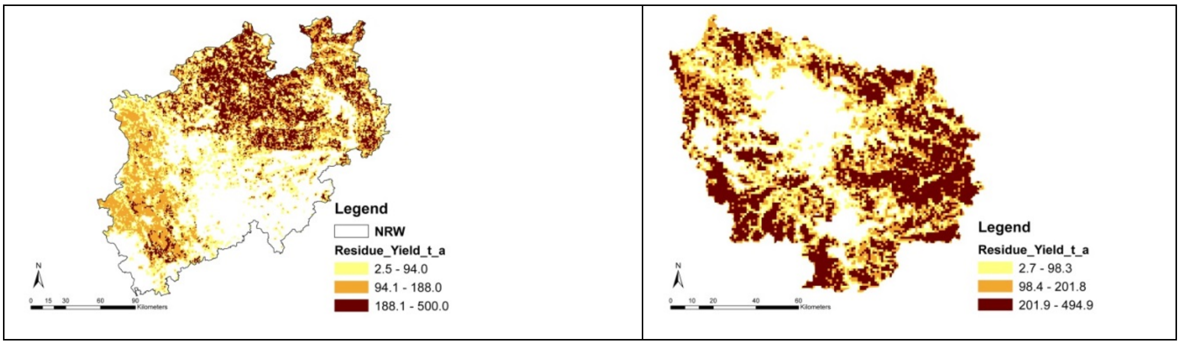

Figure 1: Spatial distribution (1 km x 1 km grid cells) of the sustainable cereal straw potentials in NRW (left) and IF (right)

Conclusions

Crop residues are potentially major contributors to sustainable decentralized bioenergy supply. However, some residues are needed for sustainable land management, i.e., depending on local conditions, crop residues are needed to maintain e.g. soil fertility and biodiversity, and some residues are already used for other purposes. Thus, spatially differentiated potential analyses with high resolutions are required to improve the assessment of crop residues available for energy recovery. The results can help prospective investors and stakeholders identify possible biomass plant sites with sufficient biomass availability, calculate biomass transport distances, and develop suitable policy options to govern sustainable crop residue applications.

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Impact of intermittent energy sources on the electricity production in Italy

Francesco Romanelli, UTS Fusione ENEA, Frascati (Roma) Italy

Abstract

Italy is pursuing an aggressive programme to increase its share of renewable energy (RE) generation. In 2013 hydro-electric power produced 16% of the total demand but is almost fully exploited. Geothermal power produced only 1.7% of the total demand. Wind (4.7% of the total electricity demand in 2013) and photovoltaic power (7%) are rapidly growing. As the share of electricity production by intermittent RE sources is expected to increase substantially, it is essential to investigate the impact on the electrical system.

In order to satisfy the demand in the presence of a large share of intermittent RE sources, either back-up energy sources (in the form of thermoelectric plants) are maintained in operation or a substantial amount of energy storage must be provided.

The year 2013 is taken as a reference for this study. The hourly electricity demand and production data provided by TERNA have been analyzed. The reference scenario considered here assumes that 100% of electricity production is obtained from RE sources. Following previous studies [1], this is achieved by scaling up the hourly production of wind and photovoltaic energy and by optimizing their mix by minimizing the amount of back-up energy. The hourly productions of geothermal and hydroelectric power are assumed identical to the 2013 values.

The results of this simplified model show that above a share of 40% of RE production the impact on the grid system becomes very large. The grid power increases by almost a factor three while the reduction in the back-up (thermoelectric) power is modest (<20%) unless a substantial storage capacity becomes available. In the absence of storage capacity the total amount of back-up energy to be provided is in the range 20% of the total electricity demand which, together with the modest reduction on back-up power, implies a strong reduction of the capacity factor of conventional plant. On the other hand, the total amount of storage needed to avoid the use of back-up energy sources is ~22TWh well beyond the capability of present storage technologies. The trade-off between energy storage and the amount of back-up energy will be discussed. We conclude that a limit to the share of fluctuating RE generation is likely to arise.

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Electricity by Intermittent Sources

Prof. Dr. Friedrich Wagner, Max-Planck-Institut für Plasmaphysik, fritz.wagner@ipp.mpg.de

Keywords: Energy

Introduction

In this paper we describe the major characteristics of an electricity supply system being predominantly composed of the scalable renewable energy (RE) forms wind and photovoltaic (PV) power. The analysis is mostly based on the actual data of 2013 from the German electricity system. The 2013 data will be scaled to larger shares of RES in the electricity production up to the 100% case where RES generate as much electricity as consumed during a year. The 100% case is then analysed according to the proper mix of wind and PV power, the extent of installed power, the remaining residual back-up power, the dynamics of the back-up system, the size of storage, the conditions for demand-side-management (DSM), the CO2-reduction in comparison to other supply forms and finally with regard to some cost issues. Similar results are presented for some European countries so that a rough picture emerges on the viability of RES in a European frame. Specifically, the necessary interconnection capacity is addressed.

Discussion

Electricity production from wind and solar radiation is easily possible in a society which agrees to the corresponding use of land, accepts the impact on its cultural landscape, and finances the necessary infrastructure. RES require, however, large power installations. The necessary investments can be reduced if the proper mix of wind and PV power is considered. Under peak conditions, this generating power is nearly capable of meeting the EU demand. For a total supply by intermittent sources, about 74% can be directly used; the rest is surplus which would be, in case of Germany, sufficient to supply Poland. A back-up system fills the low-power periods of RES. The power savings in this technology is about 12 %. Large storage capacity both in energy and power handling capability is necessary collecting surplus and replacing the back-up system of thermal power stations. The 100%-case operated completely CO2 free requires a storage, which seems to be beyond any chance of realization. A strong reduction of specific CO2 release for electricity production can be achieved by the application of RES. The technical effort is, however, tremendous if the release level of those countries should be met, whose electricity supply mix consists of nuclear and hydro power. The conditions for DSM are unfavourable. Owing to the PV contribution, surplus incurs during the day whereas the high-cost period can be expected for the night. The most consequent application of DSM is to expand the economic activities into the weekends. The replacement of the national RES supply field by a European one is beneficial because the requirements in back-up power, surplus handling and storage capacity drop notably. Specifically the intermittency of wind is smoothed in this case. The interconnection has to increase, however, much above the present realisations which might be a challenge specifically for those countries which are needed in an EU-wide supply system but do not much benefit from it.

Conclusions and/or Outlook

Because of their limitations and shortcomings, the most obvious question will be whether and how an electricity system based on variable sources can be improved or replaced. This will be a question classically posed to research and engineering because these disciplines have found the ways in the past to liberate mankind from the imponderabilities and perils of nature.

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European Energy Policy and Global Reduction of CO_2 emissions

J.Ongena, *Energy Group of the EPS*
C.J.H.Watson, *Energy Group of the EPS*

Abstract

We will present an analysis of the current EU energy policy to reduce greenhouse gas emissions. Current energy policies often ignore the underlying difficulties of an energy system that is dominated by renewable sources, originating from their inherent intermittency and low energy density. Often huge amounts of energy are produced that cannot be consumed near to where it is generated, resulting in a need for a large storage capacity, and/or for large additional interconnecting power lines to distribute power from regions with excess to those with insufficient power. Furthermore, during periods where there is insufficient direct solar irradiation or wind, a large backup capacity (evidently non-renewable, thus nuclear or fossil) is needed to cover the missing power. Thus an electric power system dominated by renewable sources needs to include backup and/or storage, at a level which at least matches peak consumption.

Such a system should also be efficient in reducing CO_2. The converse of the intended reduction often results from a combination of a dismissal of the use of nuclear power and a merit order that favours the use of energy produced from renewables at zero cost. The net effect is that gas plants, which are efficient and have reduced CO_2 production, are in most cases completely outperformed on the market, and are increasingly replaced by coal fired plants. This can paradoxically result in an increase in the net CO_2 production, contrary to the desired result, despite massive investments in renewable power plants.

An additional point is that it is mainly the electricity sector, which contributes only between 20-30% of total energy consumption, which is considered when planning a transformation into a green system. The result is that the amount of CO_2 that is saved is insignificant and completely overwhelmed by increasing emissions elsewhere in the world. This raises the question whether the current energy plans in Europe are really able to tackle the problem they wish to address.

Unfortunately, the general public is in most cases only very partially informed on such matters. This leads to difficult and very politicised discussions, where the facts are not fully taken into account or are used very selectively. Often protests or actions are then undertaken that are noble in themselves, but are very naïve, because they ignore some of the basic underlying facts that govern the complex process of making an energy transition to a greener system. The authors are of the opinion that there is an urgent need to provide factual data in a neutral way to the general public and to decision makers, so as to arrive at a correct discussion, and a realistic energy policy.

The paper will document these and other questions with data from recent years from various EU countries. Recommendations are then formulated, aimed at rendering the energy discussion and policy in Europe more balanced.

Residential urban structure and solar PV potentials in the context of Dhaka city, Bangladesh

M.Sc Sujit Kumar Sikder, *Department of Urban Planning and Land Management, University of Bonn, sujit.sikder@uni-bonn.de*
Prof. Dr.-Ing Theo Koetter, *Department of Urban Planning and Land Management, University of Bonn, theo.koetter@uni-bonn.de*

Keywords: Urban structure, Energy, Solar PV, Dhaka city

Introduction

There is a widely accepted argument is that the development of any country is synonymous with the level of energy consumption. With such a view energy is a critical input parameter for national economic development. Another way, there has been huge discussion in the light of climate change and energy consumption for advancing towards a low carbon growth of urban structures. Although Bangladesh is still suffering from energy constraints in comparison to many other countries but there are plenty of opportunities to integrate some the advance energy technologies for both energy efficiency and generation. In the scope of this study, the Solar PV potentials for contributing to urban energy balance at a residential context of Dhaka city have discussed.

Discussion

Bangladesh is already known to the world for success stories in solar PV home systems installations on island-based approach for electricity supply. But still there is not much visible effort to un-tap urban potentials where more than 50% electricity is consumed by residential sector alone. However, we calculated the solar photovoltaic potentials on the building rooftop in the residential urban structure of Dhaka city in consideration of conservative approach. Besides, neighborhood level domestic electricity use was also discussed on total annual consumption yield. More over, energy use for residents' working mobility factors was also calculated to introduce a discussion of future energy balance scenario especially e-mobility future.

Conclusions and outlooks

The study found that there are huge potentials to make a significant contribution for local energy balance in the context of residential urban structure of Dhaka city. There are many supportive factors such as metrological condition, energy demand but the challenges have to be tackled for example building regulations, grid integration, energy storage techniques, structure of governance, regulatory adjustments and some few more.

Acknowledgement: This research is supported by a doctoral study grant from the Catholic Academic Exchange Service (KAAD), Germany and field research travel grants from Institute of Geodesy and Geo-information (IGG) at University of Bonn, Germany.

GIS-optimized modelling of sustainable biomass potential from forests in Germany and North West Europe

__Dr. Ahssem Almehasneh__, Dr. Christine Rösch, Institute for Technology Assessment and Systems Analysis, Karlsruhe Institute of Technology, ahssem.almehasneh@kit.edu

Keywords: Forest, Biomass potential, Modelling, GIS, North West Europe

Introduction

Forests as a renewable resource provide numerous ecosystem services that are crucial for ecology, economy and society such as the supply of wood for timber, paper and energy production or spaces for the protection of biodiversity and recreation. In densely populated countries like Germany multifunctional forestry is challenged by an increasing demand for biomass from forests as feedstock for heat, electricity and fuel production [1]. In this context KIT-ITAS has developed an optimized Geographic Information System (GIS)-based model to assess present and future potentials of forest biomass for selected regions in Germany and North West Europe. Thereby, all relevant biomass categories from forestry residues and wood wastes are analysed. The theoretical and sustainably feasible forest biomass potentials are calculated considering specific ecological and techno-economical restrictions. The programming language Python and the software ArcGIS and GS+ (Geostatistics for the Environmental Sciences) have been applied for the calculations. The data used derive from national forest inventories, e.g. the second (2002) and third German national forest inventory (2012).

Results and Discussion

In Germany, the total theoretical biomass potentials of forest trees sum up to almost two billion tons or 134 t/ha, whereby the sustainable potentials for energy purposes are 508.3 TJ of forest area. The spatial resolution of the result reveals significant differences in the biomass potential at the NUTS level 1, 2 and 3. Regarding the distribution between the states of North Rhine-Westphalia (NRW), Rhineland-Palatinate (RP) and Saarland (SL) the highest potential is located in RP with 33.4 TJ/ha, followed by NRW 25.4 TJ/ha and SA with only 5.2 TJ/ha. The sustainable biomass potentials for energy purposes for other countries in North West Europe are in general lower when compared to the forests in Germany. In the Netherlands it is 13.2 TJ/ha, in France it sums up to 27.3 TJ/ha, Belgium and Luxembourg account for 18.2 TJ/ha, and in the United Kingdom are 12.5 TJ/ha available for energy purposes. The differences between the calculated potentials arise from varying forest sizes, management plans, forest types and usages of forest areas. **Figure 1** shows the spatial distribution of the forest potential TJ/ha in NRW and Zuid Nederland. Considering natural regional and local restrictions in NRW 25.4 TJ/ha and in Nederland 13.2 TJ/ha could be used for energy purposes.

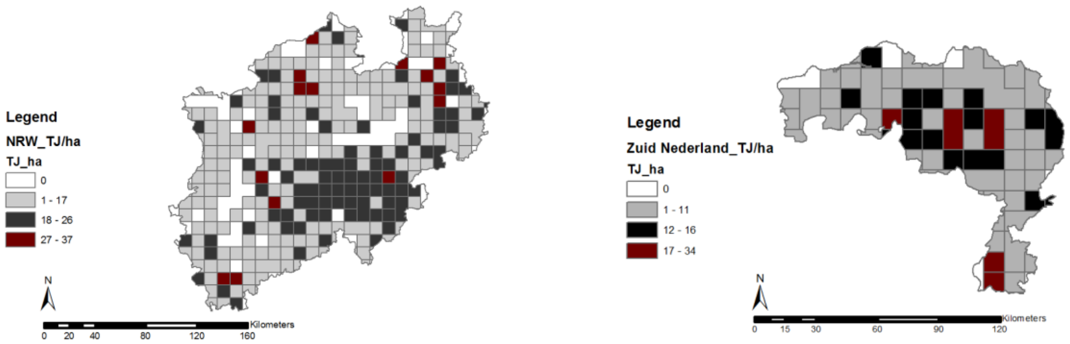

Figure 1: Spatial distribution (10 km x 10 km grid cells) of forest biomass potentials in NRW (left) and Zuid Nederland (right) in TJ/ha and year

Conclusion

The application of the developed GIS-optimized model shows new possibilities for a high-resolution estimation of spatially distributed biomass in forests and will play a major role in the design and assessment of renewable energy scenarios for North West Europe at different scales.

Acknowledgement: This work is part of the BioenNW project funded by INTERREG IVB North West Europe Program. The authors wish to acknowledge the BioenNW project partners for their contribution to their research.

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Coherent Brownian Motion for Sustainable Energy: Dream or Reality?

Jean-Selva Rattinacannou, Member of the European Physical Society, jsrtncn@free.fr

Keywords: Sustainable energy, Resonator Brownian motion, Nanoresonators, MEMS, Mechanical resonance

Permanent in-phase Brownian motions (or simply: coherent Brownian motion) are possible owing to a resonance which occurs in mechanical interactions between a macroscopic structure, the plate, and a very large number of microscopic ones, the nanopillars. This new phenomenon allows energy to be extracted from Brownian motion without the impossibility of such an extraction stated by the Principle of Microscopic Reversibility [1,2].

Let us consider a square array of nanopillars comprising a huge number of them: 10^8, 10^{10}, 10^{12}, or more. Their bases lie on a plate such as a silicon wafer (**Figure 1**), their tops are free to vibrate. Nanopillars are tiny resonators, and the considered vibration is a bulk wave one, directed along their axis, called "length mode".

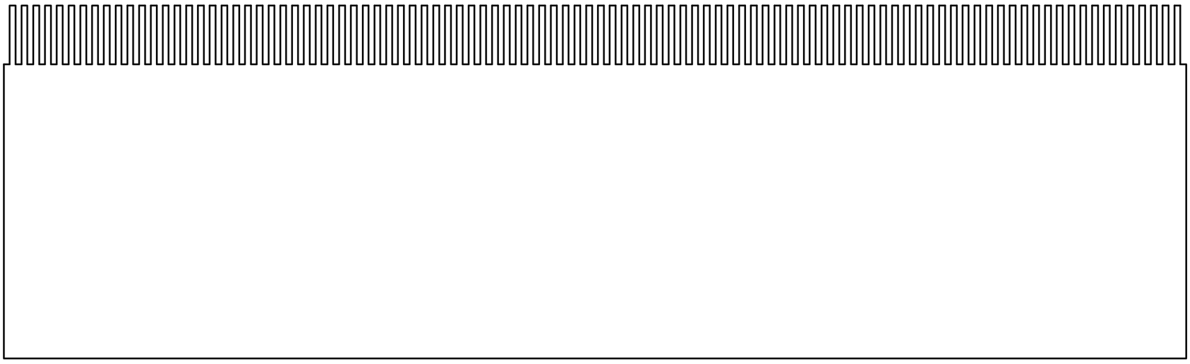

Figure 1: Schematic cross section of the nanopillars and the plate (scale not respected)

The Brownian motion of a resonator is a quite constant vibration at its resonance frequency ω_0 [3-5]. The time history of this vibration looks like a sine wave of slowly varying amplitude and phase [6]. In this array, the nanopillars vibrate at the same frequency, but with random phases. Even if at a given time all pillars vibrated in phase, this would not last, because of the varying phase of Brownian motion. Then, the question is to maintain one phase throughout the array.

For this purpose, the plate is taken to be a macroscopic resonator, with a thickness compression mode, a harmonic of which has the same frequency as the pillar length mode. Then, as soon as the pillars vibrate in phase (a way to get this will be given), they will induce a large resonance of the plate. In its turn, the plate, by its vibrating big mass, will impose one single phase to the small pillars.

The result of this new phenomenon is a constant vibration of the plate, driven by the in-phase Brownian motions of the pillars. If the plate is made of a piezoelectric material, with an electrode on each side, there will be a permanent alternating voltage at the electrodes. Then, electrical power can be extracted from this device, coming from Brownian motion. At absolute temperature T, the mean energy of the pillar Brownian motion is k_BT, the value of thermal energy (k_B: Boltzmann's constant). If the pillar number n and frequency ω_0 are sufficiently high, the product $n\omega_0$, exceedingly large, will counterbalance the thermal energy value ($n\omega_0 \approx (k_BT)^{-1}$), and the device power will be large enough to become of use, because the energy of an array of n pillars is nk_BT, but the device power, as it will be explained, is proportional to both n and ω_0.

This theoretical study shows that extracting energy from Brownian motion is no longer a dream, but in order to become a true reality, the need is still to build the device.

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Renewable Fuel from One-pot Reaction of Jatropha Oil using Core-shell Catalysts

Vorachit Umnuayporn, *The Petroleum and Petrochemical College, Chulalongkorn University, vorachit@hotmail.co.uk*
Dr. Siriporn Jongpatiwut, The Petroleum and Petrochemical College, Chulalongkorn University; Center of Excellence on Petrochemical and Materials Technology, siriporn.j@chula.ac.th
Dr. Suchada Butnark, PTT Research and Technology Institute, PTT Public Company Limited, suchada.b@pttplc.com
Mr. Chaiwat Tachakritikul, PTT Research and Technology Institute, PTT Public Company Limited, chaiwat.ta@pttplc.com

Keywords: Core-shell, Biojet, Hydrodeoxygenation, Hydrocracking

Introduction

The burning of fossil fuels contributes to global warming, which is a major problem in our world today. Biojet fuel from nonedible oil is the solution because it is environmental friendly and promising source of energy to replace petroleum-based aviation fuels. Biojet fuel is obtained by hydrodeoxygenation of triglycerides followed by hydrocracking and hydroisomerization reactions. In our previous studies, the catalysts were Pd/TiO_2 and Pt/HY respectively. In this research, the two catalysts were combined into a core-shell catalyst and tested for activity and selectivity for biojet fuel production in a continuous flow packed-bed reactor. Using core-shell catalyst can reduce utilities, number of reactors, and processes, thus lowering the total cost of production significantly. The catalysts were characterized by XRD, TEM, SEM, TPR, TPD, TPO, AAS and BET.

Discussion

Transmission Electron Microscope (TEM) was utilized to capture images of catalysts and determine shell thickness. **Figure 1** shows TEM image of Pt/HY-Pd/TiO_2 (57% Pd/TiO_2). The dark dot represented Pt/HY and the lighter was the Pd/TiO_2 covering the Pt/HY. From the image the shell thickness was approximately 5 nm. **Figure 2** shows effect of LHSV on the product yield from one-pot reaction of jatropha oil over Pt/HY-Pd/TiO_2 (44% Pd/TiO_2) at operating condition: 310 °C, 500 psig, H_2/feed molar ratio of 30, TOS of 2 h, and LHSV of 0.5 h^{-1} and 0.9 h^{-1}. Both LHSVs exhibited 100% conversion, however at LHSV of 0.9 h^{-1} the products are mainly diesel. When the LHSV reduced to 0.5 h^{-1} the products were much lighter and yielded higher jet fraction because the feed had longer time to crack and diffuse in and out of the core-shell catalyst.

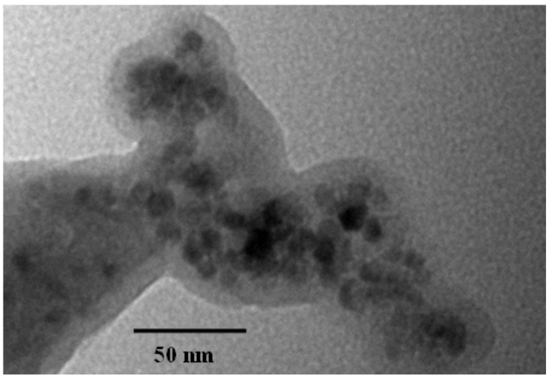

Figure 1 TEM image of Pt/HY-Pd/TiO_2 (57% Pd/TiO_2).

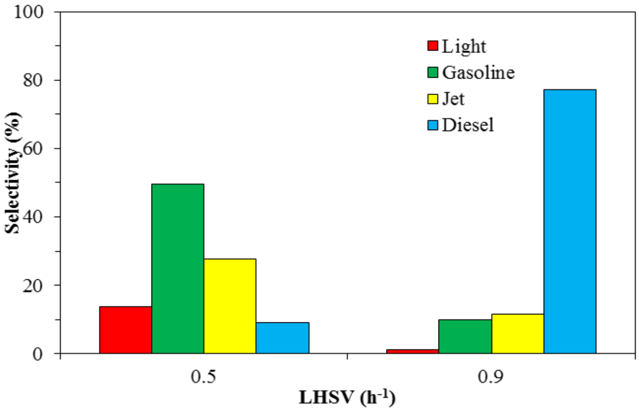

Figure 2 Product yield from one-pot reaction of jatropha oil over Pt/HY-Pd/TiO_2 (44% Pd/TiO_2) at operating condition: 310 °C, 500 psig, H_2/feed molar ratio of 30, and TOS of 2 h.

Conclusions and Outlook

The Pt/HY^{core}-$PdTiO_2^{shell}$ catalyst was successfully synthesized and it has converted triglycerides to hydrocarbons. At LHSV of 0.5 h^{-1}, up to 27.6% jet fuel yield was obtained. Nevertheless, shell composition and operating condition has to be optimized to obtain the highest jet fuel yield.

Acknowledgement: The Petroleum and Petrochemical College, Chulalongkorn University, Center of Excellence on Petrochemical and Materials Technology, Chulalongkorn University, PTT Public Company Limited.

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Properties and characterization of biodiesel from selected microalgae strains

Dr. Nikolaos C. Kokkinos, *Hephaestus Advanced Research Laboratory, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, nck@teikav.edu.gr*
MSc. Anastasia Lazaridou, Department of Petroleum and Mechanical Engineering, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, lazaridoua@yahoo.gr
Dr. Ioannis Tzovenis, Ecology & Systematics Laboratory, Department of Biology, University of Athens, itzoveni@eexi.gr
Dr. Nikolaos Stamatis, Hellenic Agricultural Organization-DEMETER, Fisheries Research Institute, nikstam@inale.gr
Dr. Sotiris Orfanidis, Hellenic Agricultural Organization-DEMETER, Fisheries Research Institute, sorfanid@inale.gr
Dr. Athanassios Mitropoulos, Hephaestus Advanced Research Laboratory, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, amitrop@teikav.edu.gr
Dr. Nikolaos Nikolaou, Department of Petroleum and Mechanical Engineering, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, nik.a.nikolaou@gmail.com
Dr. Achilleas Christoforidis, Hephaestus Advanced Research Laboratory, Faculty of Engineering, Eastern Macedonia and Thrace Institute of Technology, achrist@teikav.edu.gr

Keywords: Microalgae, chlorophytes, biodiesel properties

Introduction

The demand for alternative fuels has increased in the past several years [1]. Biofuels are gaining importance as significant substitutes for the depleting fossil fuels. The fact that biofuels are renewable fuels with very low emissions of CO2 in the lifecycle offers them a competitive advantage [2]. However, the first produced biodiesel derived from edible oil seed crops (first generation feedstocks), lurking a serious risk of disturbing the overall worldwide balance of food reserves and safety. The second generation feedstocks for biodiesel production obtained from non-edible oil seed crops, waste cooking oil, animal fats, etc., but these feedstocks are not sufficient to cover the present energy needs. Recent focus is on microalgae as the third generation feedstock [3].

Discussion

Microalgae do not compete for land, but they can grow in salty (sea), brackish (lagoons) and fresh (lakes) water. Moreover, microalgae have high photosynthetic efficiency using solar energy, water and carbon dioxide to produce higher quantities of biomass than other feedstocks. In the present research work, two indigenous fresh water and two marine Chlorophyte strains have been cultivated successfully under laboratory conditions using commercial fertilizer (Nutrileaf 30-10-10, initial concentration=70 g/m^3) as nutrient source. The produced biodiesel from the microalgae biomass achieved a range of 2.2-10.6% total lipid content and an unsaturated FAME content between 48 mol% and 59 mol%. The properties of the ultimate biodiesels were determined, based on the compositions of the various substrates, and compared with the specifications of petroleum diesel and EN 14214.

Conclusions

Gas chromatographic analysis data revealed that microalgae biodiesel obtained from Chlorophyte algae strains biomass were composed of fatty acid methyl esters. Also, the ultimate fuel properties of algae biodiesel show that biodiesel from Chlorophyte algae were comparable in quality with that of other conventional biodiesel.

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Kinetic Study of Algerian *Cuminum cyninum* L. essential oil isolated by conventional and microwave techniques

R. MEKAOUI[1] , F. BENKACI-ALI[1], G. SCHOLL[2] , G. EPPE[2]*

[1]University of Sciences and Technologies Houari Boumediène, Faculty of Chemistry, Laboratory of Organic and Functional Analysis, U.S.T.H.B, B.P. 32 El Alia, Bâb Ezzouar, Algiers, Algeria, tel/fax: 00213(0)21247311, radjamek@yahoo.fr, benkaciaf@yahoo.fr
[2]Laboratory of Mass Spectrometry, L.S.M, University of Liege, Allée du 6 Août, Bât B6c, 4000 Liege (Sart-Tilman), Belgium

Keywords: Cuminum cyninum L., Hydrodistillation, Microwave, Steam distillation and GC- MS

Abstract

Kinetic extraction of essential oil from seeds, *Cuminum cyninum* L. growing in Algeria (Biskra) has been conducted by three different procedures: steam distillation assisted by microwaves (SDAM), hydrodistillation assisted by microwaves (HDAM) and conventional hydrodistillation (HD).

The first method gives the best yields (3.4%) with reduction of extraction time (25 min), energy (0.07KWh/g) and high amount of oxygenated fraction (44.06%) compared to HDAM (45 min) and HD (150 min) with (36.68% and 40.21% of oxygenated fraction respectively).

The composition of the volatile oil of *Cuminum cyninum* L. extracted by SDAM as a function of the time of extraction has been investigated by GC and GC-MS methods and compared with those obtained by HDAM and HD. The main constituents of the volatile oil obtained by SDAM were cuminaldehyde (21.16%), p-cymene (14.19%), γ-terpinene (12.35%), γ-terpinen-7-al (12.01%), β-pinene (9.72%), α-terpinen-7-al (7.01%) and The HDAM and HD volatiles oil showed the same major components detected in SDAM with (20.91%, 18.2%, 15.45%, 12.72%, 9.53% and 4.67%) and (18.64%, 15.59%, 15.7%, 11.15%, 11.2% and 6.94%) of cuminaldehyde, p-cymene, γ-terpinene, β-pinene, γ-terpinen-7-al and α-terpinen-7-al respectively.

The SDAM method yields an essential oil with higher amounts of more valuable oxygenated compounds, and allows substantial savings of costs, in terms of time, energy and plant material. SDAM is a green technology and appears as a good alternative for the extraction of essential oils from aromatic plants.

Air Conditioning by Sunlight Co-Utilization: Monitoring Results

Prof. Dr. Flavio Horowitz, *Institute of Physics, Fed. Univ. Rio Grande do Sul, flavio.horowitz@ufrgs.br*
Prof. Dr. Marcelo B. Pereira, Institute of Physics, Fed. Univ. Rio Grande do Sul, marc1637@gmail.com
Eng. Roberto S. Ribeiro, Institute of Physics, Fed. Univ. Rio Grande do Sul, spinato@if.ufrgs.br
M.Sc. Jamuare A. Strauss, Graduate Program on Materials Science-PGCIMAT/UFRGS, jamuare@gmail.com
Arch. Giovani B. de Azambuja, HABILIS Architecture Ltd., arqgiovani@terra.com.br

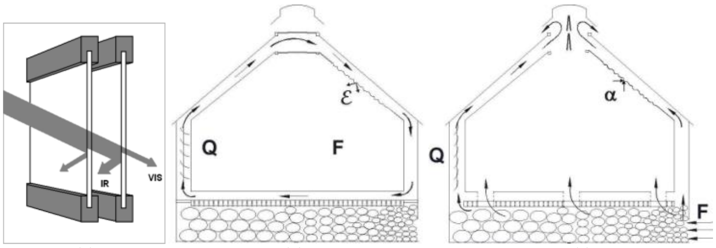
Keywords: Solar Energy, Thermal Comfort, Cooling, Illumination, Co-utilization

Introduction

Double glazings have been increasingly used in contemporary buildings, since they provide thermal insulation with small losses of natural illumination. However, in summer, much compressed air conditioning may be needed to keep interior comfort, with consequent financial and environmental costs. A spectrally selective, heat mirror coating can be added to keep out the non-illuminating infrared, but then solar energy is wasted that could be useful for heating in wintertime. This is achievable with a Trombe Wall, but at the expense of natural illumination. In this context, a double-glazed solar window that combines a passive heat mirror coating on glass with active control of natural illumination was developed, allowing co-utilization of sunlight by means of the reflected infrared for either cooling or guided heating [1], and monitoring results of the resulting CasaE (E-House) thermal performance are presented.

Results and Discussion

The smart window concept and its integration into the building envelope structure are shown in **Figure 1**. Solar radiation, after transmission through the first glazing, is divided in the second by spectral selectivity. This is produced by a metal-dielectric coating, described in [1], which transmits most of the visible light to maintain natural illumination and reflects the infrared. The radiation energy thus trapped between the two glazings heats up Venetian blinds (active control of illumination) and produces air flow by convection. This is guided, during winter mode in a closed system configuration – from which the clerestory is kept isolated - to the shadowed area in the house interior, where the sub-ceiling exchange surface enhances functionality, and from there to the over-floor channel, which completes the heating cycle. In the summer mode with an open system configuration, the hot air exit through the clerestory produces a superior region of lower pressure, which induces entrance of air from the shadowed region, via rock sub-corridors and floor windows by natural convection, thus cooling the house interior. Monitoring results from air convection by co-utilization of infrared sunlight, where cooling was prioritized for (sub)tropical climates, are exemplified in **Figure 2**. Here temperature values are shown, in rock corridor and in shaded external areas, after measured every one hour and averaged over 24 hours for each value.



(a) (b) (c)

Figure 1: Building schemes of E-house, showing (a) concept of spectrally selective window and its operation in: (b) winter closed system and (c) summer open system configurations, where Q = heat source (sunny side); F = cold source (shadowed side).[2]

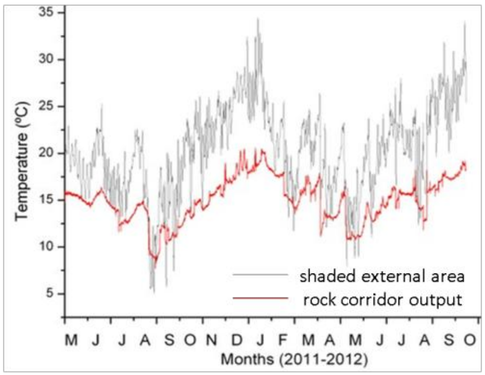


Figure 2: Temperature evolution for 19 months.

Daily and seasonal fluctuations are much smaller for the rock corridor, between 8 and 20°C due to its higher thermal inertia, whereas the external air variation lies between 5 and 35°C. Daily average difference is maximum in typical summer days, then reaching around 10°C. A corresponding average house interior cooling of 5°C, obtained from measurements in the living room, has been attained.

Conclusions and Outlook

Clear evidence of significant cooling by natural convection, induced by a double-glazed solar window with an infrared reflective coating that allows active control of natural illumination, was shown in CasaE for the (sub)tropics. This co-utilization concept of sunlight may also be used for heating of buildings at higher latitudes.

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[2] CasaE-UFRGS: Microcosmos of Solutions; http://www.ufrgs.br/casae/; Porto Alegre-RS, Brazil.

Title:

Amorphous Biological molecule in the Human Eye with the unsuspected intrinsic property to split the water molecule.

Authors: Arturo Solís Herrera, MD. PhD. María del Carmen Arias Esparza, MD. Ruth Isabel Solís Arias, MD.

Human Photosynthesis® Research Center. comagua2000@yahoo.com

Abstract

During a study about the three main causes of blindness initiated in 1990, we found a substance in human eye that in presence of light and water, produce electricity during hundred years.
This molecule is quite stable, is non-toxic, very friendly with environment, so it is a completely sustainable way to produce energy.

The finding of a molecule normally present in living beings to be able to transform light energy into chemical energy (without chlorophyll) represents a conceptual revolution, which provides the scientific basis for a new way to generate energy from sunlight.

Photograph of an LED luminaire energized with melanin and Water.

The certainty of our finding has been confirmed by other researchers and by patents granted by European Union, USA[1], Russia, Japan, Australia, New Zealand, México and Canada among others countries.

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[1] Solís-Herrera A. Photo-electrochemical method of separating water into hydrogen and oxygen, using melanins or the analogues, precursors or derivatives thereof as the central electro-lysing element. US patent No.: US 8,455,145 B2, Date of patent: June 4, 2013.

Poster Presentations

Energy Efficiency

Cryogenic Material Testing in CryoMaK

***Dr. Klaus-Peter Weiss**, Institute for Technical Physics, Karlsruhe Institute of Technology, klaus.weiss@kit.edu*
Dr. Nadezda Bagrets,Institute for Technical Physics,Karlsruhe Institute of Technology,nadezda.bagrets@kit.edu
Dr. Reinhard Heller, Institute for Technical Physics, Karlsruhe Institute of Technology, reinhard.heller@kit.edu
Dr. Walter H. Fietz, Institute for Technical Physics, Karlsruhe Institute of Technology, walter.fietz@kit.edu

Keywords: Cryogenic Material Tests, Structural Materials, High-Temperature Superconductor, Fusion

Introduction

Superconducting Technology can be used for numerous energy efficient components, e.g. for the power grid transfer cables, fault current limiters or transformers. In the field of particle accelerators or Fusion, superconductor magnet technology is essential. Within this growing field of cryogenic applications, there is an increasing demand on cryogenic material characterization. The Cryogenic Material Test Facility Karlsruhe CryoMaK was established to cover a wide variety of basic material tests from room temperature down to 4.2 K. The facility has a long-standing tradition in cryogenic testing going back to 20 years in the Institute of Technical Physics at the Karlsruhe Institute of Technology (KIT). The experimental skills and test possibilities available at CryoMaK facility are summarized, highlighting recent results obtained on different materials for cryogenic application.

Discussion

To allow an optimized design of cryogenic components, the materials to be used need to be characterized at operational temperatures from RT down to 4.2 K.
Materials under investigations are technical superconducting tapes and cables, structural materials e.g. austenitic steels or aluminium alloys and insulation materials taking composite materials into account. Beside of the basic materials the mechanical performance of joining techniques like soldering, brazing and welding are investigated Main test methods are mechanical measurements like tensile, torsion, bending, fracture toughness, impact, and fatigue crack growth test. Main test methods are mechanical measurements like tensile test, fracture toughness and fatigue crack growth test. To allow an efficient use of the dedicated facilities multi specimen fixtures are used to allow tests of more than one specimen per cool down. This minimizes the cool down costs per specimen, which is essential looking on the recent increase of the Helium cost worldwide

Figure 1: Tensile specimen equipped for Poisson measurement

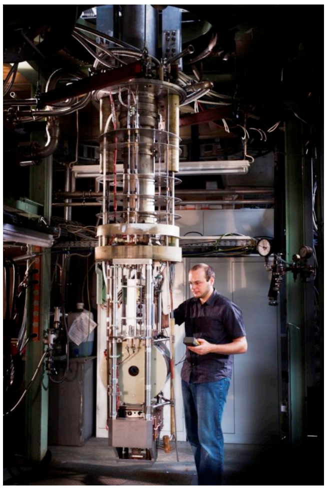

Figure 2: Superconducting cable test facility with 12 T magnet

Beside of the mechanical properties, physical characteristics as thermal expansion, conductivity or heat capacity are of interest for the materials in use. For magnet applications in addition magnetization or susceptibility is analysed. This helps to investigate functional materials like neutron shield structural steel installed to reduce the neutron flux for the Fusion magnets. For systematic approach to the explanation of the behaviour of the materials under investigation, microstructure analysis like SEM, EBSD or x-ray diffraction is applied.

Within the on-going conceptual design of future Fusion magnets, high temperature superconductors are used for current leads and are an option for the toroidal field coils of a TOKAMAK. Several layouts exist to realize high current superconducting cables to reach the necessary magnetic field to confine the plasma. A special test rig simulating the conditions for such cables within a coil is used. With currents up 10 kA, external magnetic field up to 12 T perpendicular to the current and an applied axial force up to 100 kN, the hoop stress and Lorentz force existing in large magnetic coils can be simulated to check the critical current performance of superconducting cables.

Conclusions

The existing experimental skills and the large variety of test possibilities available in CryoMaK, offers a unique test bed to examine structure materials and superconductors at temperatures down to 4.2 K.

The Reprocessing and Activation of Advanced Tritium Breeder Pebbles

Mr Oliver Leys, Institute for Applied Materials, Karlsruhe Institute of Technology, oliver.leys@kit.edu

Dr Keisuke Mukai, Institute for Applied Materials, Karlsruhe Institute of Technology, keisuke.mukai@kit.edu

Dr Regina Knitter, Institute for Applied Materials, Karlsruhe Institute of Technology, regina.knitter@kit.edu

Dr Pavel Pereslavtsev, Institute for Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology, pavel.pereslavtsev@kit.edu

Keywords: Fusion, Tritium, Breeder Blanket, Reprocessing, Activation

Ceramic pebbles composed of lithium orthosilicate with additions of lithium metatitanate, are fabricated using a melt-based process at the Karlsruhe Institute of Technology. The pebbles are to feature in the form of pebble beds in the walls of future fusion reactors. Due to their high lithium content, this material produces tritium when exposed to neutron irradiation, which is then relayed back into the reactor and used as a fuel for the fusion reaction. By producing enough tritium onsite, the reactors will be self-sufficient. The pebbles are designed to be used for 3 years, after which a waiting period will be held until the material reaches acceptable radiation levels for handling. Thereafter, it is intended that the pebbles are reprocessed by re-melting the pebbles using the standard fabrication process while simultaneously replenishing the lithium burn-up.

In order to prove the viability of melt-based reprocessing, a series of experiments was performed. Firstly, pebbles with ultra-pure starting powders were produced and subsequently characterised. The remaining pebbles were then filled back into the production crucible and reprocessed using the standard process parameters. Again, a sample was taken for characterisation and the remaining pebbles were reprocessed until the material was reprocessed a total of 4 times. It was observed that the only accumulation of impurities resulted from the metals used in the melting-crucible alloy. In addition to this, other pebble properties were not affected by the reprocessing. Secondly, pebbles with a lithium deficit (representing expected levels after 3 years' use) were produced. It was shown that the lithium levels could be replenished by reprocessing the pebbles with additions of LiOH.

In parallel to the practical experiments, computer simulations were performed to determine the effect of impurities on the time to reach both the remote-handling level (10 mSv/h) and the hands-on level (10 mSv/h) after use in the reactor wall. After storing the pebbles until they reach the remote handling level, the pebbles will be reprocessed and filled back into the reactor wall. Based on the extrapolated curves from the impurity accumulations mentioned above, the activation properties of the breeder pebbles were investigated for up to 15 recycling loops. The results indicated that the pebbles can still be reused after an acceptable storage period even after the 15 recycling steps. The calculation results identify influential impurities in the current breeder pebble composition and give future recommendations for minimising the waiting periods.

Globus-M plasma physics research the way to the fusion power application

Dr Gleb Kurskiev*, Division of Plasma Physics, Ioffe Institute, Gleb.Kurskiev@mail.ioffe.ru*
Dr Vasily Gusev, Division of Plasma Physics, Ioffe Institute, Vasily.Gusev@mail.ioffe.ru
Dr Nikolay Sakharov, Division of Plasma Physics, Ioffe Institute, Nikolay.Sakharov@mail.ioffe.ru
Dr Vladimir Minaev, Division of Plasma Physics, Ioffe Institute, Vladimir.Minaev@mail.ioffe.ru
Dr Yuriy Petrov, Division of Plasma Physics, Ioffe Institute, Yu.Petrov@mail.ioffe.ru
Dr Michael Patrov, Division of Plasma Physics, Ioffe Institute, Michael.Patrov@mail.ioffe.ru
Dr Friedrich Wagner, Max-Planck-Institut für Plasmaphysik, Greifswald, friedrich.wagner@ipp.mpg.de

Keywords: spherical tokamak, fusion, neutron source

Introduction

The idea of developing a fusion neutron source (FNS) for fusion-fission hybrid reactor applications has been debated for decades. In addition such a source of fast neutrons can be used for transmutation of elements and nuclear fuel production that can also increase the efficiency of the present fission reactors. The spherical tokamak (ST) concept is considered as a promising source of fast fusion neutrons. In comparison with traditional tokamaks, the ST has a set of advantages such as using the toroidal magnetic field with much higher efficiency, and the possibility to realize a more compact and cheaper device. However a few important issues like the achievement of steady state regimes have to be accomplished. This presentation is devoted to ST research at the Ioffe Institute focusing on ST physics and technology problems which are planned to be solved within the Globus-M2&3 strategy framework.

Discussion

In the context of a fusion neutron source and a fusion-fission hybrid facility development, production and good confinement of fast ions are mandatory because the tails of supra-thermal ion distributions determine the neutron yield and the energy spectra of neutrons. In addition, fast ion confinement is essential for the non-inductive current generation with neutral beams. Experiments in Globus-M suffered from high fast ion losses which initiated intensive numerical modeling using the standard NUBEAM code and a recently developed code which uses alternative modeling principles. Of particular interest are investigations of MHD instabilities in Globus-M, which lead to additional non classical losses. In the Globus-M experiment the neutron rate decrease is caused by the onset of Alfvèn eigenmodes (kinetic MHD instabilities). In fusion devices of larger size kinetic MHD instabilities may be a serious problem for good fast ion confinement.

Pioneering research has been carried out on Globus-M in the field of noninductive current generation using a concept proposed by theory of the Ioffe institute . The first experiments carried out in Globus-M using poloidal instead of conventional toroidal LH wave excitation demonstrated the possibility of current drive in spherical tokamaks. The noninductive current drive efficiency achieved in recent experiments was close to the one of conventional concepts, which is an important step for steady state operation of spherical tokamaks.

Plasma – wall interaction is another crucial issue for all kinds of fusion devices. At Globus-M focus was on Scrape-of-layer (SOL) physics and first wall material (mostly tungsten) interaction with plasma flows. The SOL width, determining the heat load to the divertor, is especially critical for STs because of their reduced wetted area. It was found to vary inversely with plasma current as was recently found for conventional tokamaks. Divertor tungsten tiles facing the main power flow in Globus-M are loaded by rather high power fluxes up to ~2.5 MW/m^2. But even with such high flux the FNS like conditions could not be created in the experiment due to the short pulse duration. To overcome this difficulty the tiles were preliminary damaged by electron beam and plasma jet pre-treatment providing the surface destruction equivalent to 100 - 2000 ELM-like ITER events. The analyses show that a loose layer with reduced thermal conductivity is formed beneath the tile surfaces. Such an impact is critical, since it can prevent successful heat flux removal from the first wall by the coolant in the next step devices with higher wall loads.

Conclusions

The research performed on the Globus-M spherical tokamak lead to a significant increase in non-inductive current drive efficiency and higher fast particle confinement and the recognition that the overall plasma performance will be improved if magnetic field and plasma current will rise as it is planned for the upgrade, Globus-M2 [1]. Extensive numerical simulations performed for the Globus-M2 conditions (1T and 500 kA) confirmed this conclusion. A brief description of the Globus-M2 construction status will be given.

References:

[1] V.K. Gusev, E.A.Azizov, A.B.Alekseev, et al., Nucl. Fusion, vol. 53, 093013, (2013)

Energetic and economic analysis of a plus-energy building with electric heating

Claudia Weißmann M.Sc., *Institute of Concrete and Masonry Structures, Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität (TU) Darmstadt, weissmann@massivbau.tu-darmstadt.de*

Keywords: Renewable Energy, Photovoltaic, Electric Heating, Buildings, Life Cycle Costing

Introduction

The plus-energy building in Lüneburg was designed as a passive house complemented by a photovoltaic (pv) system for reaching the plus-energy building status. The building was subsidized by the former Federal Ministry of Transport, Building and Urban Development as fulfilling all requirements of the German plus-energy building standard [1]. One remarkable aspect of this building is the heating system which is operated with electric energy. Electric heating systems were criticized in the past as all the electricity had to be provided by the public grid. In the plus-energy building Lüneburg the electric energy is partly provided by the pv system. Hence the combination of both systems might be an efficient solution. Therefor the aim of this paper is to analyse the energetic concept of the building in detail as same as its economic quality.

Discussion

For evaluating the energetic concept the monitoring data of one year (see **Figure 1**) has been analysed. Within the German plus-energy standard only the yearly overall production and consumption are being compared. However it is important that the produced energy can be directly used for the building energy demand instead of high fed-in rates into the public grid. Therefore the energy production and consumption were compared on an hourly base which shows that only 30 % of the total energy demand was covered by the pv system. One reason for that is the heating demand which is high in winter when the pv production is low. Also in the summer season the daily total energy demand cannot be covered completely by renewable energy as there is always a demand peak in the evening.

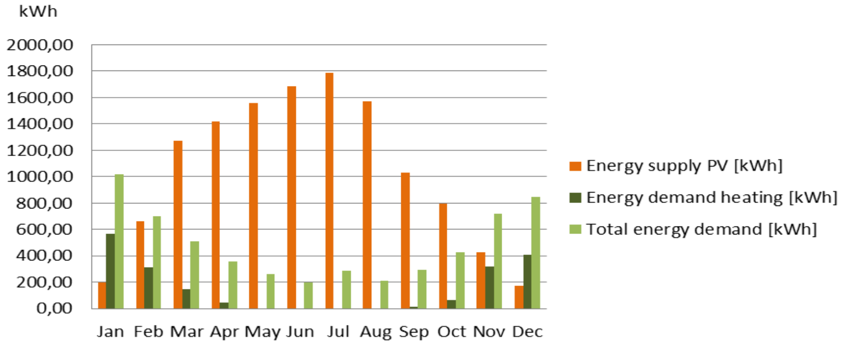

Figure 1: Energy monitoring – Plus-energy building Lüneburg

The economic quality of the building has been assessed with the Life-Cycle-Costing (LCC) methodology. The analysis shows that the discounted costs of the building are about 1.800 €/m^2 (over 50 years) which is low regarding the innovative building elements. Apart from that the investment in the pv system is amortised after 15 years. Assuming a system lifetime of about 25 years this leads to a financial benefit of 8.000 €.

Conclusions and Outlook

The LCC assessment shows that the building concept leads to financial advantage for the investor. The analysis of the energy monitoring data shows that the building produces about 6.000 kWh more than it consumes. However, the concept still hast to be criticized as the main energy demand peaks during winter season cannot be provided by renewable energy. Furthermore the high energy surplus in summer time has a negative impact on the public grid which should be assessed in further research.

Acknowledgement: The author would like to thank Mr. Jürgen Molt for his full contribution to the research project. Financial support was provided by the DFG in the framework of the Excellence Initiative, Darmstadt Graduate School of Excellence Energy Science and Engineering (GSC 1070).

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Experimental evaluation of a structural element's thermal transmittance

***Danai Georgiadou**, Dep. of Environmental Engineering, Democritus Univ. of Thrace, danaigeorgiadou@gmail.com*
Prof. Dr. Stamatis Zoras, Dep. of Environmental Engineering, Democritus Univ. of Thrace, szoras@env.duth.gr
Prof. Dr. Panos Kosmopoulos, Dep. of Environmental Engineering, Democritus Univ .of Thrace, pkosmos@env.duth.gr

Keywords: Heat flux, Thermal transmittance, In-situ

Introduction

The present work deals with a research of the thermal behaviour of a masonry wall and is carried out at the "Papageorgiou General Teaching Hospital" in Thessaloniki, Greece, in compliance with ISO 9869. This sustainable design building was picked, not only for its environmental friendly design features, including naturally shaded exterior spaces, increased insulation, ceiling fans, but also its incessant function.

Measurements and analysis

The experimental data was obtained from a 60cm width wall, which is sited on a south-eastern aspect and is consisted of five layers, including an air cavity. Two weather trackers have measured indoor and outdoor prevailing conditions. Three temperature sensors were mounted inside the wall. The heat flux plate was fixed to the inner wall surface, in a representative place with no thermal bridges vicinity, with specific conductive mastic, in order to abridge the heat flux leak around it. All measurement equipment was connected to a portable data logger, which scanned every half minute and acquired the data every ten minutes, 24 h per day during the experimental period of eight months. Thermal transmittance (U-value) was estimated to be 0.51 $W/(m^2{\cdot}K)$ by the calculation method provided in ISO 6946 according to the appropriate design thermal resistances of the materials, regarding the monitoring wall as consisted of thermally homogeneous layers and 0.48 $W/(m^2{\cdot}K)$ containing also inhomogeneous layers (combined method). Analysing the measured magnitudes with progressive average methodology by ISO 9869, the experimental thermal transmittance was 0.58 $W/(m^2{\cdot}K)$. Dynamic thermal characteristics were evaluated by the ISO 13786, but dynamic analysis method by ISO 9869 was decided not to be necessary because the test duration was extended and in the larger part there was a high temperature variation. In **Figure 1**, it is observed the difference between the heat fluxes calculated by theoretical U-value and existing temperature differences and the measured heat fluxes by HFM.

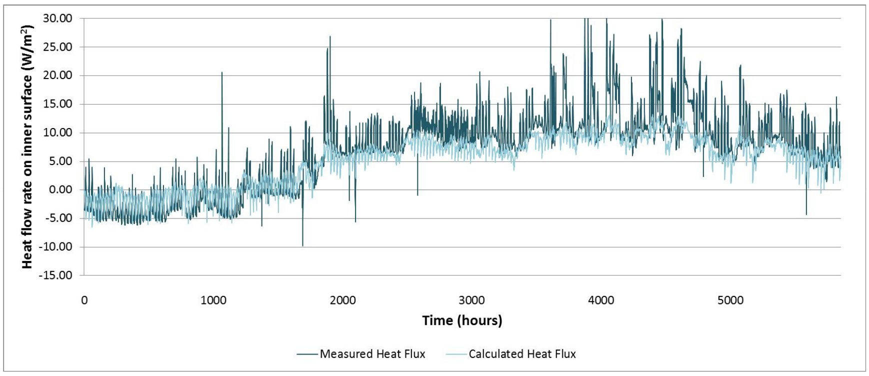

Figure 1: Comparison of measured and calculated heat flux

Conclusions

Several factors can explain the differences between measured and calculated values. Firstly, although standard procedures were used, measurements of heat flow indicated unevenly results mainly during the summer period where the temperature was lower than the limit of 10° C. The non-uniformity observed during the rest period, probably was developed due to the presence of the air layer just before the last layer, where the heat flow sensor is positioned in and of the employees, who intervened to the thermic system. Furthermore, the exact allocation of construction layers is quite vulnerable, although the endoscope method was applied, while there are a number of factors, such as cavity width, ageing of materials, moisture related phenomena and variety of materials' thermal conductivity.

References:

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Simulated and experimental thermal characterization of advanced reflective and PV glazings

N. Skandalos*, E. Vardoulakis, D. Karamanis*
Department of Environmental & Natural Resources Management, University of Patras,
**nskandalos@upatras,gr, dkaraman@upatras.gr*

Keywords: Energy savings, glazing technologies, Semi-transparent PV, building

Introduction

Window glazing is a determinant factor of energy savings and high quality standards of life in modern buildings. Glazing has become a global design tendency and concerns even higher percentage of outer building surface. Window technology is during the last 10 years under intense progress. By far, testing of the energy achievements of windows is performed by different set up variations and methods. From full scale mock-up model, entire building façade, building rooms, calorimetric hot box and chambers or ventilated PV facades.

Discussion

In the frame of the COOL-NANO project, optical and thermal investigation for various glazing types is being performed. In this work, extensive simulations along with experiments in micro and macro scale of two representative identical offices were performed to compare experimental and numerical results. Samples of conventional and innovative PV systems were initially characterized by UV/VIS/NIR spectrophotometry and solar simulator irradiation in a benchtop wind tunnel of controllable environmental conditions. Subsequently, the prototype glazings with different g and U-values, created in WINDOW 6 software were inserted to the dynamic thermal simulation environment of TRNsys in order to predict their thermal effects on two representative identical University's offices. The results of the simulations were related to the air temperature and thus office's needs for heating or cooling. Furthermore, surface temperature and heat fluxes were determined for a) a conventional double glazing, b) with external integrated reflective aluminum film and c) semi-transparent a-Si PV window systems and validated through monitoring from the macro-scale experimental set-up. Preliminary results indicate lower office temperatures when using semitransparent PV and glazing with reflective film. Max temperatures differences found to be 1.16 ºC for the PV (**Figure 1**), and 2.7 ºC for full reflective film. As expected, the higher heat fluxes through the a-Si PV were observed during the middle of the day where the solar radiation reaches its maximum value. Simulation validation was performed by comparing experimental and simulated office and glazing temperatures for the glazing with the reflective film. In **Figure 2**, a good agreement between simulated and experimentally measured data has been achieved.

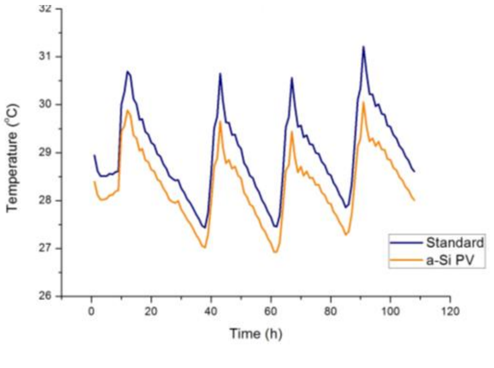

Figure 1: Hourly office temperature variation for a) standard glazing and b) semitransparent a-Si PV.

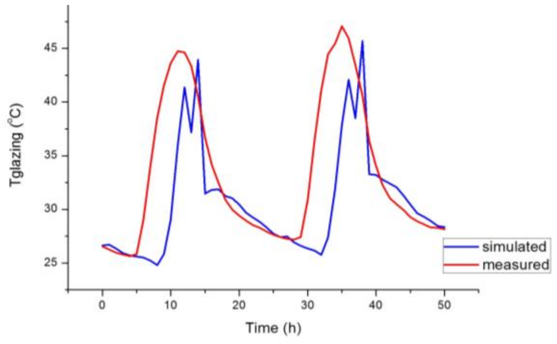

Figure 2: Validation of simulated and experimentally measured glazing temperature.

Conclusions

In conclusion, simulations and experimental measurements proved that by replacing standard glazing system with the above mentioned, cooling load of the office are reduced. Therefore, effective saving in the energy used for air-condition systems increases the energy efficiency of the building in general. Furthermore, increasing the glazing area of innovative systems like PV, the cooling load needs are further decreased. Further research for the optimum configurations are in progress.

Acknowledgement: This work is supported by the COOL-NANO (733) project under the "ARISTEIA" Action of the "OPERATIONAL PROGRAMME EDUCATION AND LIFELONG LEARNING" (co-funded by the European Social Fund (ESF) and National Resources).

Connecting electric mobility to the energy management of blocks of flats

M.Sc. Stephan Diekmann, *Institute for High Voltage Technology and Electrical Power Systems, Technische Universität Braunschweig, s.diekmann@tu-braunschweig.de*
M.Sc. Jan Mummel Institute for High Voltage Technology and Electrical Power Systems, Technische Universität Braunschweig, j.mummel@tu-braunschweig.de
M.Sc. Lorenz Soleymani, Institute for High Voltage Technology and Electrical Power Systems, Technische Universität Braunschweig, l.soleymani@tu-braunschweig.de
Prof. Dr.-Ing. Bernd Engel, Institute for High Voltage Technology and Electrical Power Systems, Technische Universität Braunschweig, bernd.engel@tu-braunschweig.de
Prof. Dr.-Ing. Michael Kurrat, Institute for High Voltage Technology and Electrical Power Systems, Technische Universität Braunschweig, m.kurrat@tu-braunschweig.de

Keywords: Energy Management, Electric Mobility, ICT

Introduction

The future energy system increasingly consists of decentralized energy resources. This development requires a paradigm change. The energy production can no longer follow the consumption due to the volatility of wind and sunshine. Prospectively the consumption has to follow the energy production.

Information and communication technologies (ICT) are one of the key factors to make this modification possible. By connecting production and consumption the ICT are the basis of any energy management.

The increasing number of electric vehicles which are a significant load at household level requires the consideration in the energy management process.

Discussion

The rising electrification of our society leads to a permanent increase in energy demand. This is a challenge particularly due to the political and social intended targets (80 percent renewables in electricity generation until 2050 in Germany) and the concomitant volatility in energy production. Consequently, a grid friendly consumption is becoming more important.

The change in the mobility sector (1 million electric cars on German roads until 2020) on the one hand leads to an increasing demand for electrical energy, but on the other hand the installed batteries offer opportunities to store volatile energy. This abstract describes a concept which is being developed at the Institute for High Voltage Technology and Electrical Power Systems at TU Braunschweig to meet these challenges.

The mentioned opportunities are available only through targeted integration of vehicles into the energy system. This task is handled by the energy management, which according to the VDI 4602 intends to continuously reduce the amount of energy consumption and related costs.

Rising energy costs as well as environmental and comfort aspects are the motivation of people to use these technologies. Especially own consumption in conjunction with own renewable generation plants plays an important role to reduce costs because of the reached grid parity. The intention to charge electric vehicles with own green energy and to live in a comfortable smart home increase the acceptance.

The development and implementation of this concept is carried out within the framework of the research projects BASIS (Building Automation with a Scalable and Intelligent System) [1] and Fleets Go Green. In BASIS several flats are equipped with an energy management module developed by TU Braunschweig which harmonises production and consumption. Considering the available information on load and generation capacity an ICT networked charging infrastructure contributes to achieve the optimization targets such as maximizing own consumption.

In particular for the energy management in blocks of flats or housing associations synergy effects are anticipated from the project Fleets Go Green whose goal is to integrate electric vehicle fleets into the existing power grid. Using the system elias [2] developed by TU Braunschweig, the electric vehicles are charged locally as well as on balance sheet produced energy from renewable energy sources. Furthermore, the available charging capacity is determined by the actual load data of the power grid.

Conclusions and Outlook

The combination of electric mobility and energy management at the household level helps to meet future challenges. Future developments and trends like dynamic electricity tariffs, standardized Smart Meter and Smart Meter Gateway (BSI TR-03109) as well as intelligent and bidirectional charging (ISO 15118) facilitate the positive effects and are already considered in the research.

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Control opportunities for occupants – a key to energy efficiency

***Dr. Marcel Schweiker**, Building Science Group, Karlsruhe Institute of Technology, marcel.schweiker@kit.edu*
Prof. Andreas Wagner, Building Science Group, Karlsruhe Institute of Technology,wagner@kit.edu

Keywords: Sufficiency, Energy efficiency, Occupant behaviour, Indoor climate control

Introduction

The energy consumption of a building is for a great part driven by the comfort requirements of its occupants and depends significantly on their behaviour. The variation in the energy consumption of identical buildings due to the occupants' behaviour can differ by factors between 3 and 10 [1, 4]. In the future, the relative importance of the individual's behaviour will increase with improved building envelopes or advanced building systems [3]). One solution in order to increase the energy efficiency of buildings might be the reduction of control opportunities by the occupants through the advancing automation of buildings. The occupants' behaviour is driven however for a great part by the comfort requirements of the occupants ([5]). Theories related to thermal comfort state the perceived level of control as an important influencing factor on the perceived level of thermal comfort [2]. The objective of this paper is to investigate the benefits and drawbacks of measures related to the reduction of control opportunities for the occupants on the energy efficiency of office buildings.

Project Outline and Results

For this study, the effect of a ceiling fan on the perceived thermal comfort and energy demand was analysed, because it is - compared to others - a rather cheap investment which could be applied easily during refurbishing projects of buildings. The usage of the ceiling fan was observed through experimental studies conducted in a climate chamber, which has operable windows and provides a normal work environment for the subjects. The usage profile of the ceiling fan was analysed using logistic regression analysis. In addition, the operative temperatures preferred by the subjects with and without the opportunity to use the ceiling fan were analysed. The comfort range obtained is 25.1°C ± 2K without and 26.6°C ± 2K with the ceiling fan.

These ceiling fan usage model and comfort range were taken as input to dynamic building simulations. This revealed that the elevated comfort range due to the ceiling fan nearly halved the hours with temperatures above the comfort range. In the chosen case study, the resulting hours above the comfort level are with more than 800 hrs still above an acceptable number of around 260 hrs (= 3% of a year as denoted in DIN EN 15251). The reduction of hours outside the comfort range comes through a relatively easy measure.
The installation costs of a ceiling fan could be estimated depending on the situation between 150€ and 500€ per office. The running electricity cost for each ceiling fan can be calculated to be in average 893 hrs/a x 100 W x 0.25ct/kWh = 22.3 €/a.

Conclusions

Experimental study and simulation suggest, that a higher number of effective control opportunities does not only improve thermal comfort of occupants, but can also be a cost effective measure resulting in a lower cooling demand. Further, building concepts using naturally ventilation will work in a wider range of climate conditions when a ceiling fan is provided.

Acknowledgement: This project is funded by the German Federal Ministry of Economics and Technology (BMWi) with the project ID: 0327241C. The test facility LOBSTER was funded by the German Federal Ministry of Economics and Technology (BMWi) with the project ID: 03ET1035B and supported by industrial partners. The authors are indebted to the Baden-Württemberg Stiftung for the financial support of this research project by the Eliteprogramme for Postdocs.

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Experimental assessment of thermal performance of roof materials

Sun Kyu, Bang, Department of Architecture, Chung-Ang University, snicv@naver.com
Ho Min Kim, Department of Architecture, Chung-Ang University, popc2005@hanmail.net
Dr. Min Hee Chung, Department of Architecture, Chung-Ang University, mhloveu@hotmail.com
Prof. Dr. Jin Chul Park, Department of Architecture, Chung-Ang University, jincparke@cau.ac.kr
Prof. Dr. Eon Ku Rhee, Department of Architecture, Chung-Ang University, ekrhee@cau.ac.kr

Keywords: Thermal Performance, Urban Heat Island, Cool Roof, PCM Tile

Introduction

Materials used in the roof of buildings play a very important role in the urban heat island. The solar energy absorbed by the roof of buildings heats their surface by several degrees above the ambient temperature, and also an increase in the heat flux incoming through them, especially in cooling season[1]. High reflective roof materials reflect solar radiation, and would result in decreasing the heat penetrating into the building and decreasing the ambient air temperature[2]. The present paper compares 5 types of roof materials in an artificial environment. The types of roof materials are grey waterproofing mortar, green urethane waterproofing, cool paint, tile with PCM, and tile. The most common roof materials in Korea are grey water proofing mortar and green urethane waterproofing. This study used measurements from scale-model buildings to quantify the reductions in roof surface temperature and interior temperature of scale model in an artificial environment. From this comparison we characterized the thermal performance of roof materials.

Discussion

The artificial environment makes the lamps with visible and infrared light to simulate summer solar radiation. The test measured for 24 hours and scaled models are heated for 11 hours. On average, total isolation was 5,100W/m^2, comparing the typical summer isolation of June 24 is 5,240 W/m^2. Laboratory temperature maintains for 28 to 32 °C. The peak surface temperature were grey waterproofing mortar 76.9°C, green urethane waterproofing 72.2°C, normal tile 62.7°C, cool paint 53.5°C, and PCM tile 52.9°C, respectively. Existing roof materials' surface temperatures has fluctuate sensitively by controlling lamps. On cooling hours, grey waterproofing mortar kept the hottest temperature, this means the heat reradiated during night times and contributed to increase the urban temperatures. Interior chamber air temperature were grey waterproofing mortar 37.3°C, green urethane waterproofing 35.3°C, normal tile 31.8°C, cool paint 31.4°C, and PCM tile 30.9°C, respectively. PCM tile's interior air temperature maintained the lowest temperature and fluctuated a little.

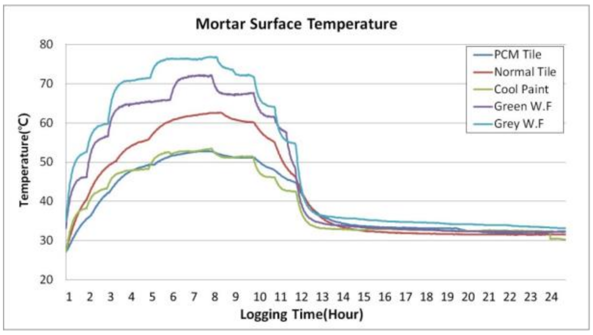

Figure 1: Surface temperature

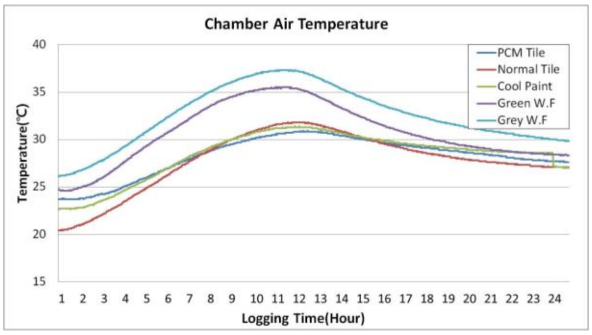

Figure 2: Interior chamber air temperature

Conclusions and/or Outlook

PCM tile reduced surface and interior chamber temperatures and fluctuated little compared other roof materials. PCM tile is the most efficient to reduce surface temperature and to keep cool inside the room. This would mitigate urban heat island and reduce peak cooling demand and annual cooling energy consumption. These savings would reduce annual greenhouse gas emissions from power plants.

Acknowledgement: This is research was supported by a grant (14CTAP-C078014-01) from Infrastructure and transportation technology promotion research program funded by Ministry of Land, Infrastructure and Transport of Korean government.

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Hybrid heating system for open-space office/laboratory

***Ph.D. student Christian Brembilla**, Department of Applied Physics and Electronics, Umeå University,*
christian.brembilla@umu.se
Dr. Mohsen Soleimanni-Mohseni, Department of Applied Physics and Electronics, Umeå University,
mohsen.soleimanni-mohseni@umu.se
Prof. Thomas Olofsson, Department of Applied Physics and Electronics, Umeå University,
thomas.olofsson@umu.se

Keywords: Open office, Hybrid heating system, Step response test, Error analysis

Introduction

Open-space office/laboratory are quite common in Scandinavia and they are usually designed for multipurpose work. There are office area where is possible to work standing up and in the same time to work at the desk. For this purpose a hybrid heating system made by electric convectors and panel radiators is investigated. Two step response tests of the hybrid heating system are performed at the laboratory of Umeå University. The first test is executed during the week, disturbances from heat sources degrading the quality of the results. The second test is performed during week-end. The error analysis shows a maximum discrepancies of +0.6 °C between measured and simulated data. However, a thermal time constant of the room can be deducted and use it for controlling purposes.

Experiment and results

The laboratory has a volume of about 200 m^3 and it is positioned in contact with the ground. The room faces to the outside environment for only one surface while all the other walls and the ceiling are adjacent to other heated zones. Two electric convectors are positioned in the room, the first at the left corner, the second in the middle of the room. The electricity heats up a resistance which in turn heats up the air. The electric convectors are set-up at the power of 3000 W each. At the opposite side of the first electric convector a system of five panel radiators is attached to the wall. The panel radiator system has a nominal power of 1500 W at the standard condition of 55/45/20 ˚C [1]. The indoor air temperature is tracked every 15s by thermocouples TT and recorded on computer.

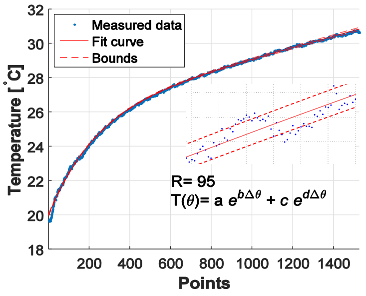

Figure 1: Step response with fitted curve

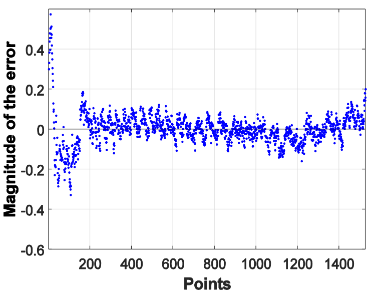

Figure 2: Error analysis

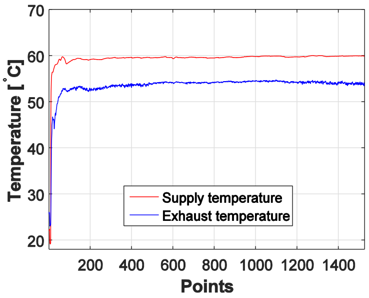

Figure 3: Supply and exhaust heat flow

Figure 1 shows the fitted curve of the indoor air. On the x-axis there is the time. The time between each point detected is 15s. The blue spots are the measured data. The red solid line is the fitted curve shown in the equation. The red dash lines represent the bounds at 95% interval of confidence. **Figure 2** shows the magnitude of the error between the fitted curve and measured data. **Figure 3** shows the temperature of supply and exhaust flow of the radiator system during the experiment.

Conclusions and Outlook

The fitted curve does not shows good accuracy with the measured data in the first hour of the test. This because the electric convectors and panel radiators take time to heat up themselves and them to transfer the heat to the air. The process of step response of the room underlines that, the system can be considered as one storage element with dead time. A thermal time constant of the room can be deducted and use it for controlling purposes.

Acknowledgement: The author wish to thank Lars Bäckström for his support and assistance during the experiment set-up.

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Energy Efficiency of Household Appliances and Awareness Modeling

Meltem Ucal, Kadir Has University, Turkey, msengun@khas.edu.tr and meltem.sengun@gmail.com

Keywords: Energy efficiency, Climate Change, Awareness, Household Appliances, Econometrics Model, Logit Model

Abstract

It is obvious that with limited resources and increasing of energy consumption from day to day, increase in amount of greenhouse gases in the atmosphere will increase risk of climate change. The objective of "Raising Awareness in Energy Efficiency of Household Appliances and Climate Change" paper is to make the connection between climate change and energy saving to be understood. First of all, research and evaluation aiming improvement of women's behaviors of purchasing and using household appliances and also educate next generations who will be faced risks of climate change, with their mothers will be done.

The research and paper are designed to seek answers to research questions related directly to the education, energy efficiency and climate change. The dataset is formed by the responses of 1323 women over 18 to the survey conducted 23 May through 15 June 2014 in three metropolitan provinces of Turkey –İstanbul, Bursa, Kocaeli. The sample projection before the survey involved a total of 1300 respondents, of which 900 being housewives and 400 being university students. The actual sample involves a total of 1323 respondents, of which 918 housewives and 405 university students. The post-survey check is undertaken at the field and over the phone from the headquarters. The field team consists of 32 employees, of which 6 is supervisor and 26 being surveyor. Binary and ordinal logit models are used for the econometric analysis in this paper for finding out of relationship among education, awareness and energy efficiency.

Shape Memory Alloys for Solid State Micro-Cooling

Hinnerk Ossmer, *Karlsruhe Institute of Technology, IMT, hinnerk.ossmer@kit.edu*
Prof. Dr. Shuichi Miyazaki, University of Tsukuba, Division of Materials Science, miyazaki@ims.tsukuba.ac.jp
Prof. Dr. Etienne Patoor, ENSAM, Laboratoire LEM3, etienne.patoor@ensam.eu
Prof. Dr. Manfred Kohl, *Karlsruhe Institute of Technology, IMT, manfred.kohl@kit.edu*

Keywords: Solid state cooling, elastocaloric effect, pseudoelasticity

Introduction

Solid-state cooling has been recognized as a promising alternative to conventional vapor-compression cooling technology due to its potential to save energy and minimise green house gas emission in macroscopic applications as well as due to its potential for down-scaling.The elastocaloric effect in shape memory alloys (SMAs) appears to be particularly promising as SMAs undergo a stress-induced first-order phase transformation, associated with a large latent heat [1]. The use of these properties in miniature devices enables fast heat transfer and high cycling frequencies allowing for innovative cooling devices. Applications are, for instance, temperature control of electronic components and novel lab-on-a-chip systems in bio-analytics or medical technology. In this study, we evaluate the cooling performance of three pseudoelastic foil and wire samples with low cross-section.

Results

Samples are prepared from (1) cold-rolled textured $Ti_{50.5}Ni_{49.1}Fe_{0.4}$ foils (thickness t = 30 µm), (2) cold-drawn textured Ti-Ni-wires (diameter d = 254 µm) and (3) single crystalline Cu-Al-Be wires (d = 400 µm) produced by the Czochralski process. The critical temperatures and latent heat L of the phase transformation are determined by differential scanning calorimetry (DSC). The elastocaloric effect is investigated by strain-controlled uniaxial tensile tests [2]. Fig. 1 shows a compilation of superelastic stress-strain characteristics for the different samples revealing the elastic modulus E_A, the critical stress σ_{crit} and work input for a full transformation cycle ΔW. Monitoring the surface of the samples during tensile test at high strain rate (>0.1 s^{-1}) by infrared thermography reveals the adiabatic temperature changes ΔT_{load} and ΔT_{unload} due to release (loading) and absorption of latent heat (unloading). The experimentally determined material properties are summarized in Table 1. For all three samples, the critical force is about 20 N. However, the surface-to-volume ratio, the mechanical performance and the elastocaloric effect size differ. Ti-Ni-based wires and foils both show a significant cooling effect of -18.6 K and -17.2 K, respectively, and low accumulation of remanent strain below 0.6% within the first 10 cycles. The Ti-Ni-Fe foil sample shows the smallest transformation strain of about 5% and lowest work input of 8.2 J m^{-3} resulting in a large coefficient of performance COP. The foil-geometry also provides the best surface-to-volume ratio with a time constant of 1.46 s for heat absorption. The single crystalline Cu-Al-Be wires, on the other hand, have the lowest critical stress and are good thermal conductors, which favours heat transfer. However, due to the small latent heat, the COP is lower than that of TiNi-based samples. The obtained results are important for the design of novel SMA-based solid-state cooling devices, where material specimens should fulfil the compromise of large effect size, low work input and long-term stability.

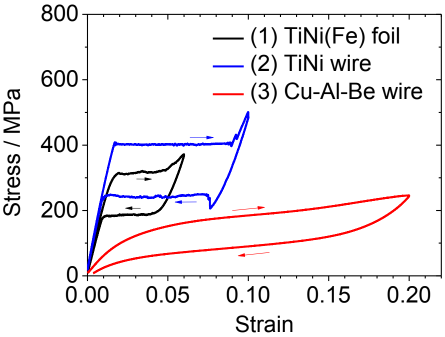

Figure 1: Stress-strain characteristics of superelastic SMA foil and wire samples as indicated determined under quasi-static loading conditions.

	(1)	(2)	(3)
E_A / GPa	20	24	6
σ_{crit} / MPa	315	400	145
ΔW / MPa	8.2	29.7	17.3
ΔT_{load} / K	21.5	24.7	8.8
ΔT_{unload} / K	-17.2	-18.6	-5.5
L / $J.g^{-1}$	17.2	R-phase: 3.8	2.2
A_f / °C	9.3	4.2	-74.1
τ / s	1.46	3.0	1.37
COP	6.0	1.8	0.9

Table 1: Thermo-mechanical properties of pseudoelastic foil and wire materials: (1) Ti-Ni-(Fe) foil, (2) Ti-Ni wire, (3) Cu-Al-Be wire.

Acknowledgement: The authors gratefully acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG) within the priority program SPP1599 (www.ferroiccooling.de).

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The New MAX Infrared Technology for Efficient Industrial Solutions

***Weber Jürgen**, Heraeus Noblelight GmbH, Kleinostheim, Germany, juergen.weber@heraeus.com*

Keywords: Heating Efficiency, Infrared, Fast Processes, Flexible Geometries

Introduction

For heating up highly reflective metals or highly transparent glasses respectively, state-of-the-art technologies are not efficient enough. Up to 90% of the energy input is not usable due to reflection or transmission losses. Thanks to the new MAX-Infrared(IR)-Technology, for these applications it is possible now to reach an energy efficiency up to 90% depending on the application and the corresponding furnace design.

Numerous tests with various customers in our application center showed impressive results. In comparison to conventional electrical heating methods, the heating process was three times faster for metals or 15 times faster for glasses respectively, but both showed five times less energy consumption simultaneously.

Discussion

The particular properties of the MAX-IR-Technology are due to the process chamber which is completely made of a special quartz quality which acts as a perfect diffuse reflector. The IR emitters heat the product directly and the radiation is reflected diffusely on the walls until it hits the product. The hot air generated in the process contributes to the heating gradient strongly. Due to the excellent thermal shock resistance of quartz the process chamber can be heated up to 900°C maximum very fast and easily. Cooling down to room temperature is possible within minutes. Therefore, in comparison to conventional furnace technology, the total process time is reduced significantly by some hours [1].

The MAX-IR-furnace is supported by own construction capabilities and will be fitted to individual optimized customer solutions. Different geometries with LxWxH from 300x300x150mm^3 up to 4000x2000x300 mm^3 were designed already. The design phase is efficiently supported by numerical simulations like ray tracing [2].

The applications go far, beginning with thermal cleaning and tinning of endless copper metal sheets for automotive, vapour deposition of graphen on copper coils for semiconductor, enameling of steel parts for the chemical industry und the sintering of metal inks on glass for decors.

At the Glasstec exhibition in Düsseldorf this year we proudly presented a new gold ink melting at low temperature in coincidence to the MAX technology. The burn-in of gold on glass substrates for decors and printed electronics applications is extremely energy efficient and fast [3]. The new technology is protected worldwide by patents.

The new MAX-IR-Technology works particularly energy efficient. Conducted mathematical deviations result in an easy formula to calculate the energy efficiency very clearly. The empirical verification by experiment proved the results. Therefore, highly reflective Aluminum (R=90% approx.) or highly transparent technical glasses (T=90% approx.) were heated up to 400°C approx. both. An energy efficiency conversion rate of 90% (!) is evident due to the special process chamber combined with infrared heating.

Energy consumption is reduced by a factor of five at permanent operation. Simultaneously the heating rate increases by a factor of three to 25, depending on the product dimensions and material properties. Due to the very fast heating, continuous processes allow a furnace length cut up to a factor of three at the same web speed as before. Otherwise, if the furnace length is kept constant, the production capacity can be tripled.

The heating homogeneity is very high due to the diffuse reflection. This is proved by numerical simulation and verification by experiment. The heating process itself is directly observable through a furnace opening. Process time is reduced up to a factor of three, because time for heating and cooling is shortened significantly. The furnace can be cooled down within minutes by forced air cooling as well as the heating up can be done in minutes again.

Conclusions

Due to possible energy cost savings usually the furnace with the new MAX-IR-Technology will be amortized in two years latest. Due to the huge energy savings, the production of CO_2 is reduced significantly. As explained before, necessary production space will be reduced strongly and production capacity will increase significantly.

Acknowledgement: Many thanks to the whole team supporting this important project: Michael Tittmann (Construction), Frank Diehl (Application Center), Jörg Wöll, Dietmar Schier, Frank Niese-Anke (Sales all) and last but not least Dr. Marie-Luise Bopp (Marketing) and all the others I forgot to name them here.

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Application of an open modelling architecture for micro-CHP systems based on Rankine technology

Márcio Santos, Faculty of Science and Technology, University of Coimbra, marcio.santos@dem.uc.pt
Dr. Jorge André, Faculty of Science and Technology, University of Coimbra, jorge.andre@dem.uc.pt
Sara Francisco, Faculty of Science and Technology, University of Coimbra, sara.francisco@dem.uc.pt
Dr. José M. Baranda, Faculty of Science and Technology, University of Coimbra, jose.baranda@dem.uc.pt

Keywords: micro-CHP, Energy, Model, Calibration

Introduction

The ultimate aim of this project is to design an innovative micro-CHP (Combined Heat and Power) gas boiler based on Rankine Technology that satisfies the hot waters and central heating domestic needs and produces electricity that can be consumed at home or sold back to the public grid. The use of combined heat and power (CHP) systems is increasing rapidly due to their high potential of reducing energy consumption, cost and carbon dioxide emissions. The objective of this work is to aid the design and control of the evolving prototypes of the micro-CHP by affording an adequate engineering understanding of the physical phenomena affecting their performance.

Discussion

The construction of a general modular modelling architecture was made in order to simulate the quasi-steady behaviour of any prototype of the micro-CHP. This architecture include realistic models of industrial units for the different components (e.g. pump, evaporator, heat exchanger and expander), ranging from purely empirical (e.g. manufacturer's or ad hoc characteristic curves of the expander or the pump) to more or less complex semi-empirical models (e.g. condenser heat exchanger and evaporator) and includes a robust and versatile solver of systems of non-linear equations of medium dimension (n<100). This work grants a complex, however versatile, modelling interconnecting of empirical data, or semi-empirical models, available on the various components of the ORC, very useful to optimize the configuration, to select the appropriate working fluid the adequate components and the best operating conditions and to define control strategy of ORCs.
Figure 1 shows the representation of the architecture of a general modular model applied to a CHP system. Given the burner load (Qc0), the pump (Np10) and expander (Nt), rotation speed the model will solve simultaneously all the equations that describe the behaviour of the different components of the system until converge to a stable solution. Notice that the mass of the system must be equal to working fluid system charge and this variable produces the system closing equation.

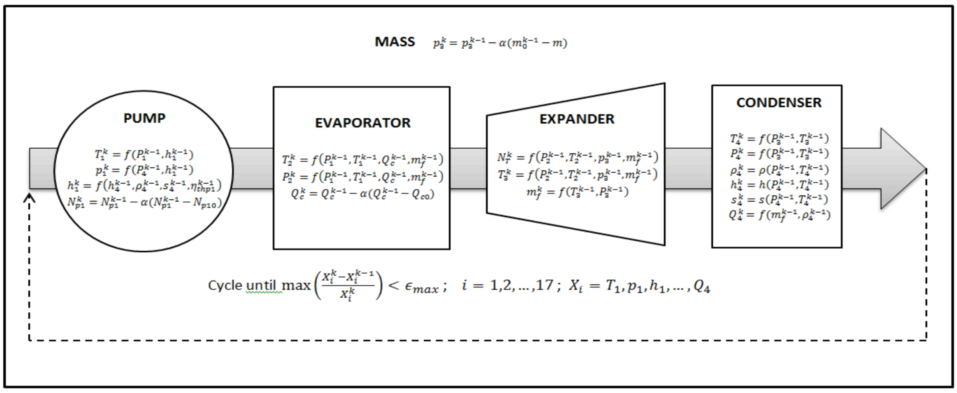

Figure 1: General modular model summary

Conclusions and/or Outlook

A particular effort was put in the construction of a general modular modelling architecture hopefully capable of describing the quasi-steady behavior of any prototype of the boiler/micro-CHP. A good and satisfactory agreement was obtained between experimental results and computational outputs of sub-models which allow simulating with some confidence other different conditions. According to these good sub-models results, a good prediction in the global model is expected.

Acknowledgement: This research is partially sponsored by FEDER funds through the program COMPETE – Programa Operacional Factores de Competitividade under the contract QREN QREN-POFC-COMPETE-23101.

Flow Optimization in a Hierarchical Plate Heat Exchanger for an Adsorption Heat Pump

Dipl.-Phys. Emmerich Tempfli*, Institute of Fluid Machinery (FSM), Karlsruhe Institute of Technology (KIT), emmerich.tempfli@kit.edu*
Dr. F. P. Schmidt, Institute of Fluid Machinery (FSM), Karlsruhe Institute of Technology (KIT), ferdinand.schmidt@kit.edu

Keywords: topological optimization, hierarchical, adsorption heat pump

Introduction

Adsorption heat pumps are operated through a periodic temperature swing process of the adsorber(s), and energy release and uptake during the adsorption/desorption sequence is highly unsteady. One goal persued in the development of adsorption heat pumps is to increase the volume specific cooling power through intensification of heat and mass transfer in the adsorber. With regard to the heat transfer, the heat transfer resistance to the fluid cycle and the thermal mass of the adsorber element (i.e. heat exchanger) have to be minimized, while keeping the pressure drop in the fluid cycle below an upper limit. To meet these requirements a biomimetic heat exchanger design with two hierarchy levels is being developed (see **Figure 1**).

Results

In a hierarchical plate heat exchanger the uniformity of the flow distribution over the active heat exchanging plane is a key issue with respect to formation of hot spots during the process and overall pressure drop, and thereby with respect to the efficiency of the system.
Here we present a design optimization method for the hierarchy levels I and II respectively (cp. **Figure 1**) by means of stationary 3D CFD calculations. The main goal of the optimization is the uniformity of the flow distribution to the respective perpendicular, parallel channel network which is visualized by means of the Probability Density Function (PDF) (see **Fig. 2**). The ideal case of perfectly uniform distribution of the flow to the parallel channel network would be a delta distribution. Due to the complexity of the flow, simple calculations based on the assumption of piecewise laminar, fully developed flows does not lead to proper channel shapes (orange distribution in **Fig. 2**). However with a *two-step* shape optimization (opt. step 1 and opt. step 2 in **Fig. 2**) a significant improvement can be achieved. Whereas **Figure 2** displays the improvement for the hierarchy level II, similar improvements can be achieved also for the hierarchy level I.

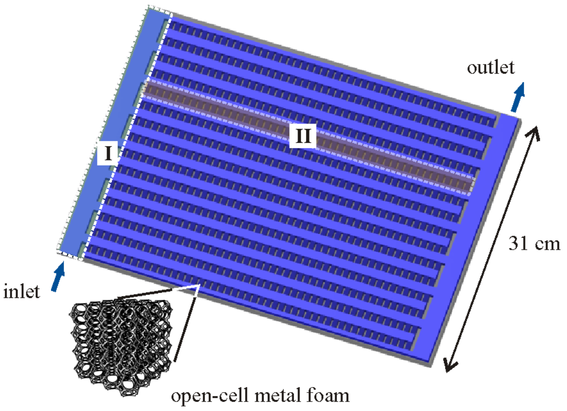

Figure 1: Sketch of the hierarchical heat exchanger with hierarchy levels I and II. The channels of level II are connected with open-porous cannels.

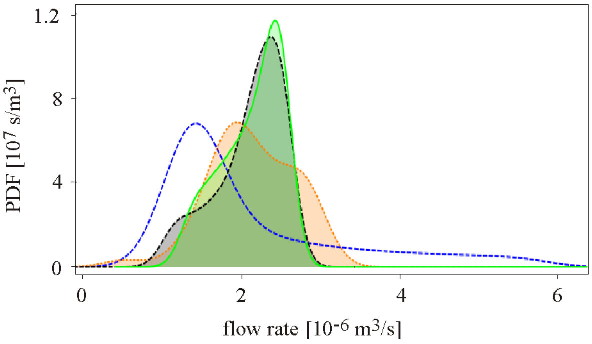

Figure 2: Flow distribution to the open-porous parallel channel network of level II characterized by PDF. (blue) rectangular limiting shape; (black) optimized shape (opt. step 1); (green) optimized shape (opt. step 2); (orange) optimal shape for the approximation of laminar, fully developed flows.

From the computational point of view an improvement of the performance of the optimization procedure can be achieved with the two-step optimization methodology. In the first optimization step (opt. step 1), a linear polynomial-shape is optimized, which initializes the second optimization step (opt. step 2), where a cubic polynomial-shape is further optimized.

Conclusions

With the shape-optimization a significant improvement of the flow distribution can be achieved. By employing this a more uniform heat removal from the heat releasing surface can be obtained. The optimal shape basically differs from the channel shape, which is achieved by the assumption of laminar, fully developed flows and gives considerably better results. Therefore optimization with 3D CFD calculations are essential to obtain the optimal channel shapes for a hierarchical plate heat exchanger.

Transient model of a panel radiator

***Ph.D. student Christian Brembilla**, Department of Applied Physics and Electronics, Umeå University, christian.brembilla@umu.se*
Dr. Mohsen Soleimanni-Mohseni, Department of Applied Physics and Electronics, Umeå University, mohsen.soleimanni-mohseni@umu.se
Prof. Thomas Olofsson, Department of Applied Physics and Electronics, Umeå University, thomas.olofsson@umu.se

Keywords: Transient model, Multiple storage elements, Heat emission, Exhaust flow, Step response

Introduction

This paper shows a detailed transient model of a panel radiator considered as a system of multiple storage elements. The experiment records the temperature surface of the panel in the process of heating up. The qualitative results of the experiment suggest the more appropriate technique for modelling this technology. The transient model performs the modelling with horizontal thermal capacitances connected in series. This model calculates the temperature of exhaust flow, heat emission towards indoor environment, temperature gradient on panel surface, dead and balancing time identified numerically on the chart.

Experiment

The aim of the experiment is to investigate how the panel radiator performs the charging process at the step of supply flow. Lenhovda MP 25 500 is the panel radiator adopted for this test [1]. **Figure 1** shows clearly the qolitative results of the charging process. The panel is charged from right to left with this type of connections of supply and exhaust flow. However, it is visable a hot area in the lower part of the radiator. This means that, a fraction of supply flow recirculates inside the panel due to some residual air that does not let the correct charging of the unit.

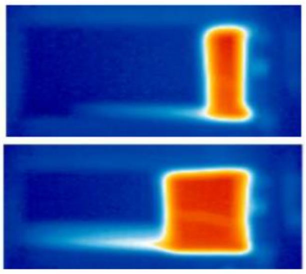

Figure 1: Experiment results

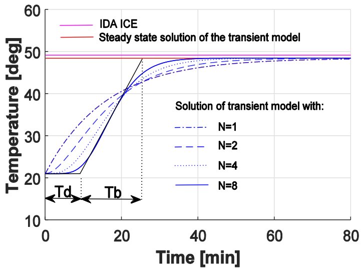

Figure 2: Temperature of exhaust flow

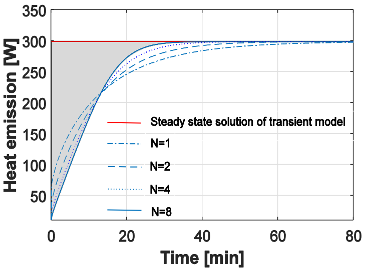

Figure 3: Radiator heat emission

Model

The model simulates the response of the radiator to the step of supply flow in terms of heat emission and temperature of exhaust flow. The transient model is based on the heat balance between the water side, the heat stored in the thermal capacitances and its heat emission. The modelling divides the radiator in equal elements. The elements, or radiator capacitances, are connected in series and the supply temperature of the following capacitance is the exhaust temperature of the previous one. Newton-Raphson method is the solver used for resolving the system of differential equations [2]. **Figure 2** shows the temperature of exhaust flow of the panel in the transient phase when the radiator is modelled with 1, 2, 4 and 8 capacitances, its static and IDA ICE solutions. Dead and balancing time (T_d ,T_b) are identified for the model with 8 capacitances. **Figure 3** shows the heat emission of the radiator modelled as previously. The grey area is the amount of energy overestimated from the steady state models. This area is about 50 Wh.

Conclusions and Outlook

Radiator performance is an essential information in order to obtain better model of heat emission towards the indoor environment. The modelling of a panel radiator with several heat capacitances linked in series achieves a temperature gradient of the supply heat flow, an accurate heat emission during the transient phase, dead and balancing time. This information is essential for controlling purposes and it is the first step for the modelling of ventilation radiators.

Acknowledgement: The author wish to thank Anders Strömberg for his support and assistance during the experiment set-up.

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Energy Saving Impacts of Solar Radiative Properties of Roof Materials in Humid Continental Climates

Dr. Min Hee Chung, Department of Architecture, Chung-Ang University, mhloveu@hotmail.com

Keywords: Solar Radiative Property, Energy Saving, Cool Roof, Detached house

Introduction

An urban heat island (UHI), referring to a warmer urban temperature than its surrounding rural areas, has increased in most urbanized cities. Many cities are taking action to reduce UHIs using the following main strategies: 1) increasing green area, 2) using cool pavements, and 3) increasing the overall albedo of the city [1]. For hot and mild climates, cool roofs are an effective strategy to reduce absorbed heat from the sun, whereas for cold climates, cool roofs can be disadvantageous, as the heating penalty is higher than the cooling savings. The objective of this study was to quantify the energy use by the solar radiative properties of building surface materials in humid continental climate. Attention was paid to building type than an existing detached house. The materials with various solar radiative properties were applied for energy simulations. A parametric study was conducted on the effects of the solar radiative properties of roof materials considering the energy demand.

Discussion

In this study, the energy performance of buildings was assessed using difference in solar reflectacne (SR) and thermal emissivity (TE). The calculations were focused on a detached house with flat roofs. The building load profiles varied with the building types, especially in humid continental climate. In this study, the annual energy consumption in Seoul, S. Korea was analysed by varying the solar radiative properties of the roof materials. The maximum difference in the cooling energy by TE and SR is 18.31 kWh/m^2. The lower SR indicates the more difference in the cooling energy by TE. Increasing SR with present TE can reduce the cooling energy up to 22%. In humid continental climate, cool roof should be carefully selected in the planning stage, because the heating load is greater than the cooling load. Increasing heating energy penalty of the cool roof might be greater than the saving cooling energy. The maximum difference (31.28 kW h/m^2) in the heating energy by TE and SR was greater than the cooling energy's difference. To decrease the annual heating energy, the roof materials with a lower SR and TE are suitable. However, these roof materials adversely affect the UHI. The total annual energy consumption' pattern is similar to the annual heating energy, but the difference in the TE and SR decreases. The maximum difference annual energy in SR and TE was 12.98 kW h/m^2. The annual energy-increasing penalty of 2% was satisfied by applying the roof materials with the cool roof standard of the California Title[2], SR, and TE of 24, 0.63, and 0.75, respectively. Furthermore, the roof with the highest SR and TE had 5% increased requirement of the total energy demand than the present condition. Another solution is a cool roof with an improved insulation level. The annual energy consumption of an improved insulated detached house was decreased of heating penalty. The roof materials with a SR of 0.65 and a TE in the range from 0.1 and 0.4 are the most suitable materials for energy saving and the mitigation of the UHI.

Conclusions and/or Outlook

The urban heat island phenomenon increases the temperature in the urban area. The cool roofs with increasing SR and TE are currently being emerging as one of the important strategies to decrease the peak ambient temperature and save energy at a relatively low cost. Cool roof are an appropriate solution for hot climate; however, in the cold or humid continental climate, cool roof should be carefully selected, because they can reduce the useful heat gain through the roofs. Increasing SR and TE reduced the cooling energy and increased the heating energy. Therefore, the total annual energy consumption increased up to 5%. Cool roofs are a good mitigation strategy; but, they consume more energy, causing greenhouse gas emission, and this might increase the UHI. However, an improved insulated house reduces the heating penalty. The roofing with the highest SR and TE increased only 1.41 kW h/m^2 of the total energy consumption than the roofing with the present level of SR and TE.

The results of this study may be useful for the potentiality of cool roofs in the humid continental climates. Furthermore, future studies regarding various building types as well as to monitor actual buildings or estimate the mitigation of urban temperature with cool roofs will be conducted.

Acknowledgement: This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning (no.2014R1A1A1004131)

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Capability of mobility systems to meet future CO2 savings targets

Wolfgang Koeppel, *DVGW-Research Station at the Engler Bunte Institue of KIT, koeppel@dvgw-ebi.de*
Prof. Dr. sc. techn. Thomas Koch, Institut für Kolbenmaschinen (IFKM), K.I.T, thomas.a.koch@kit.edu

Keywords: Energy, Storage, Mobility, CO2 savings

Introduction

The target for 2050 of the Federal Ministry of Germany is to achieve 80 – 95 % CO2 reductions when compared to 1990. The reductions are also envisioned to be uniform across all sectors. However, many studies have suggested that such a target is not realistic in the industry sector which means that the other sectors must compensate for the industrial sector with savings that are above the targeted range. Studies also show that for a uniform overall savings of 80 %, the mobility sector on its own must have at least 95 % savings in CO_2 which further means that the mobility sector must almost entirely run on renewable energy resources. This brings hydrogen, gas, liquid-fuels, electricity and other regenerative energy forms back in focus. Discussions must also involve studies regarding the available infrastructure or building new infrastructure for this purpose. The availability, transportability, cost and most importantly the efficiency of the regenerative technologies must also be analysed and also optimized in-order to arrive at realistic strategies to achieve the targets.

Discussion

In this study, the efficiency and potential of different fuels are compared. The different process chains that are needed for the fuels to be produced, transported and supplied at different fuel stations must also be considered along with their propulsion-potential. This implies that concepts must also involve various propulsion systems and their working cycles. Propulsion systems that are power based like Plug-in-Hybrid technologies therefore must be analysed along with other new advances in heat engines and fuel cells. In-order to do this, as a first step, various propulsion concepts are categorised according to different usage patterns. As a second step, the propulsion systems are tested and graded for different scenarios (for example; city only, city and outskirts, long drive scenarios etc.) and their respective fuel demands are then analysed. As a final step, these fuel demands are coupled with the supply chain to model the entire process from the production till the supply of fuel to the end users and their usage of energy (for different scenarios).

Simulation based planning processes for the integration of inductively charged vehicles into public transportation services

Dipl.-Ing. Tamas Kurczveil, Institute for Traffic Safety and Automation Engineering, TU Braunschweig, kurczveil@iva.ing.tu-bs.de
Dr.-Ing. Lars Schnieder, Institute of Transportation Systems, German Aerospace Center (DLR), lars.schnieder@dlr.de
M. Sc. Felix Burmeister, Institute of Transportation Systems, German Aerospace Center (DLR), felix.burmeister@dlr.de

Keywords: inductive charging, public transport, transportation planning

Introduction

Economy and reliability are requirements that innovative vehicle concepts for public transport operations need to fulfil. In the context of inductive charging, the interdependency between the dimensioning of power electronics and drive aggregates of the vehicles and the charging infrastructure need to be taken into consideration.

Problem – Complexity in the planning of the operation of electrically powered vehicles

Due to the long duration of usage, correct positioning and dimensioning of infrastructure is essential. Furthermore, life-cycle costs of stationary infrastructure and compatible vehicles need to be reflected. The battery significantly determines the investment and the vehicle weight. This has to be weighed up against the required high level of operational availability. The planning process of the introduction of electrically charged vehicles aims for the maximization of operational availability. An increased up-time can be achieved through the energetic optimization of drive-cycles and traffic flow as well as the improvement of energetic performance of the vehicle. Due to the limitations of available energy storage systems in capacity, electrical vehicles need to be recharged repeatedly throughout the day. These charging times represent the major element of down-time for public transport vehicles. Down-time can be reduced by synchronizing charging times with already occurring standstill periods (traffic signals, regular stops and rest periods of drivers).

Approach - Simulation-based planning utilizing traffic-, energy-consumption-models and empirical data

The evaluation of the application of novel energy-supplies and drive concepts requires a tool that combines several systems and aspects. These include transportation scheduling, the influence of and the interaction with general traffic and also kinematic models. Such a tool may utilize simulated traffic scenarios based on circulation-data of traffic and public transport. The open source software SUMO (Simulation of Urban Mobility) from the German Aerospace Centre (DLR) can be applied [2]. As for the kinematic model, each vehicle can be simplified as a mass point. It possesses a varying amount of rotational, kinetic and potential energy. For the amount of energy needed to cover a specific distance, driving resistances need to be considered as well as specific efficiencies in the powertrain and the power consumption of different vehicle systems. Real operational data from vehicles that are currently in service allows appropriate model calibration.

Application – Operational planning for the introduction of inductively charged buses

In Brunswick (Germany), the line M19 was taken into consideration for the electrification with inductively charged buses [1]. With inductive charging the charging-process can be initiated automatically without a physical connection to the infrastructure. It therefore decreases the time needed for charging, relieves the driver of any necessary actions and does not obstruct passenger service. For the project, it had to be proven though, whether the vehicle batteries could last for a whole route-cycle with varying passenger occupancy and traffic conditions. Other questions were, if charging periods could be integrated into regular driving schedules and if two optimal positions could be found for additional charging periods on the line run. The simulation-based approach could find answers to all these questions. The simulation clearly showed that not only varying traffic conditions have to be reflected, but also the passenger occupancy. The energy consumption of a single drive-cycle varies by about 20 % for the measured cycles and might vary by about 40 % in for theoretical passenger rates. The capacity of available batteries proved sufficient, though. The project proves that results of traffic flow simulations with an integrated energy consumption model are useful for operational planning prior to the start of operation of busses with alternative power trains (full electric, hybrid, conventional).

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Impact of future electric vehicle saturation on the electricity grid

***Dr Björn Illing**, Fraunhofer IOSB - Advanced System Technology (AST), bjoern.illing@iosb-ast.fraunhofer .de*
***Steffi Naumann,** Fraunhofer IOSB - Advanced System Technology (AST), steffi.naumann@iosb-ast.fraunhofer .de*
***Nikolas Dahn**, Fraunhofer IOSB - Advanced System Technology (AST), nikolas.dahn@iosb-ast.fraunhofer .de*
***Oliver Warweg**, Fraunhofer IOSB - Advanced System Technology (AST), oliver.warweg@iosb-ast.fraunhofer .de*

Keywords: electric vehicle, prediction, multi-agent system, demand load, electricity grid

Introduction

The energy transition (German: Energiewende) is one of the central terms in the current energy policy of several countries, including, among others, Germany, the United Kingdom and Japan. In order to eventually abolish non-renewable energy sources like fossil fuels a major goal is the establishment of smart energy grids and markets to support electric vehicles (EV). The current goal for Germany, set by the European Union, is to have around 150.000 public charging stations and around 1 million EVs by 2020 [1]. This creates unprecedented challenges for grid operators, as well as car manufacturers. Grid operators use statistic models to forecast the distribution of electric loads in their respective area, but at the time of writing no sufficient model exists to do the same for the dynamic loads arising from EVs.

Discussion

Therefore the Fraunhofer IOSB - Advanced System Technology (AST) developed the *Electric Load and Vehicle Simulator* (ELViS) to simulate loads from EVs with varying utilization. Current approaches are unable to model the energy demands arising from the highly dynamic EV utilization with sufficient accuracy. To combat this, ELViS uses a multi-agent system to simulate a large pool of EVs following one or more global behaviour models with individually randomized parameters (resulting in individual vehicle utilization). The following parameters are necessary for a simulation:

- EV pool parameters (EV count, battery capacity, maximum speed, driving range, etc.)
- Charging station parameters (available power, global and/or individual grid restrictions, etc.)
- Behaviour model
- Map consisting of zones with optional constraints

The simulation consists of the EVs performing trips according to their behaviour model. Over the course of a simulation ELViS records various parameters, among others energy consumption and the load arising at charging stations when vehicles reach them. By varying the simulation's input parameters (e.g. map size, location of charging stations, trip probabilities or grid restrictions) a vast amount of scenarios can be modelled.

In this work a total amount of 8 scenarios are discussed, showcasing the effects EV might have on the electric grid. To parameterize the EVs' battery capacity and reach the forecast of the NPE (Nationale Plattform Elektromobilität) for 2020 is used with a pool size of 1 million EV. The EVs' behaviour is based on the study "Mobilität in Deutschland 2008" [2]. Scenarios differ in terms of pool composition (different shares of battery capacities – 16, 22 and 60 kWh) and power available at home charging stations (3.7 and 11 kW) and public charging stations (11 and 22 kW).

Results and Conclusion

The results of this work showcase the possible impact of several EV pools with a fixed pool size of 1 million EVs and varying battery capacity compositions and charging station availabilities on the annual grid load curve. The effects of these variations is analyzed and evaluated for the German electricity grid. This paper further evaluates power plant utilization in the context of the described scenarios. We will also assess whether an improved integration of renewable energy sources is accomplished and therefore the goals of the energy transition are met.

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Assessment and classification of the soft magnetic material cores for EMI filter application

M.Sc. Illia Manushyn, Institute for Power Electronics, TU Darmstadt, imanushyn@srt.tu-darmstadt.de
Prof. Dr.-Ing. Gerd Griepentrog institute for Power Electronics, TU Darmstadt, griepentrog@srt.tu-darmstadt.de

Keywords: Electromagnetic comparability, Soft magnetic materials, EMI passive filters, Common mode, Differential mode

Today the number of regenerative energy sources is increasing significantly. Among them photovoltaic panels and wind generators play the main role [1]. One of the biggest disadvantages of the regenerative power sources is the impossibility of direct connection to the general power grid. They always demand an installation of additional power converters. The purpose of the power converters is to feed energy into the grid with desirable voltage and frequency level, independently of wind speed and sun brightness. Besides useful and intended power transformation, all types of converters produce electromagnetic interference (EMI). EMI produced by converters can negatively affect or even incapacitate the other devices connected to the same power grid. Equipment connected to the Smart Grid must have an especially high level of compatibility and reliability. Therefore EMI have to be limited to the sufficient level by applying of passive EMI filters. The performance and the size of the EMI filters are becoming more and more important, due to increasing of power density. The biggest contributors into the filter performance are inductive components, namely common (CMC) and differential mode chokes (DMC), whereas the damping characteristics of CMC and DMC depend on the core material. Currently on the market are available a huge number of soft magnetic materials, suitable for the inductive components design. Unfortunately for electrical engineers become an issue to understand the all diversity of soft magnetic materials. Consequently, this leads to a slow implementation of the new materials science developments in the field of power electronics. There are a very few sources, which compare all soft magnetic materials by the same set of parameters [2, 3]. Soft magnetic materials suitable for using in EMI filter inductive components can be divided into four main groups, depicted on the **Figure 1.** All subgroups of soft magnetic materials which can be used for implementation in inductive components of the EMI filters listed on the same figure (in yellow rectangles). In this classification are being considered materials capable to keep the properties in the frequency range 10 kHz – 30 MHz.

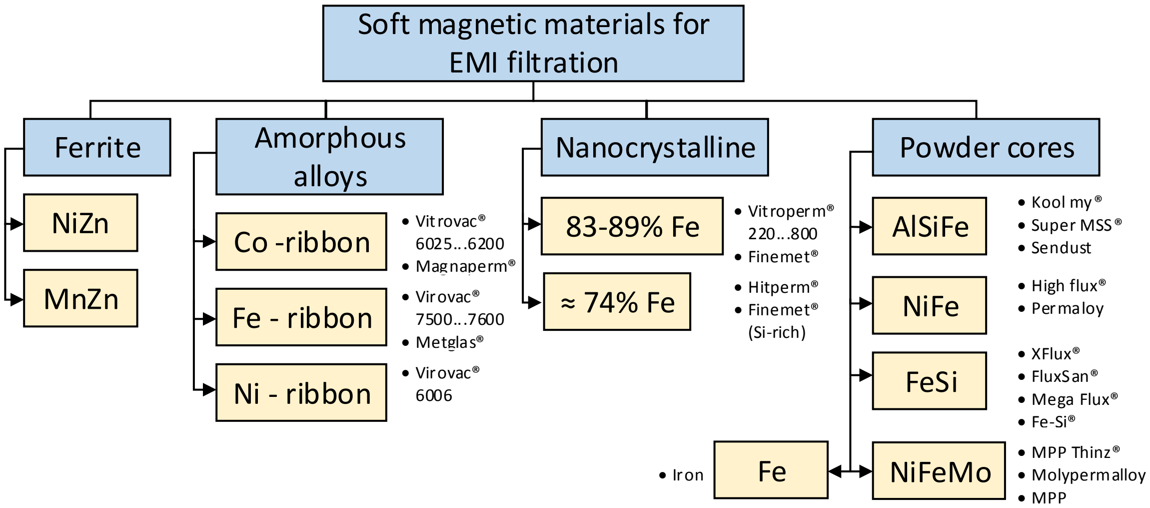

Figure 1: Types of soft magnetic materials for EMI filter applications

Electrical, mechanical and economical parameters are extracted for each material type and an assessment has been conducted in accordance with these parameters. For the correct evaluation of materials these parameters are brought to one denominator. Samples of common mode and differential mode chokes based on cores made of evaluated materials have been made and tested in laboratory. The obtained damping characteristics clearly show the benefits and shortcomings of the each material type. Based on requirements for ideal CMC and DMC core materials, the outlook on future trends and the prediction of the development directions had been given.

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Creep characterization of the SOFC ceramic anode substrate

Jianping Wei, IEK-2, Forschungszentrum Jülich GmbH, j.wei@fz-juelich.de
Dr. Goran Pećanac, IEK-2, Forschungszentrum Jülich GmbH, g.pecanac@fz-juelich.de
Dr. Jürgen Malzbender, IEK-2, Forschungszentrum Jülich GmbH, j.malzbender@fz-juelich.de

Keywords: SOFC, Ni-YSZ, Microstructure, Creep

Abstract

The mechanical stability of solid oxide fuel cell (SOFC) components is crucial for the reliable operation of the whole stack. In order to achieve high performance, SOFC needs to operate at elevated temperatures. In this environment an effect of creep takes place, which needs to be understood and mitigated to ensure formation of a robust and durable stack. The anode substrate Ni-YSZ is the crucial material which needs to be investigated in this respect, since it should provide mechanical stability for the functional layers. Creep results of the anode substrate obtained in bending and compression loading configuration are compared. The experimental results highlight that, in addition to the Ni and YSZ ratio, the porosity is of main importance.

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Atom probe tomography (APT) on $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ (BSCF) and $Ba_{0.5}Sr_{0.5}(Co_{0.8}Fe_{0.2})_{0.9}Y_{0.1}O_{3-\delta}$ (BSCF10Y)

Dipl.-Ing. Lana-Simone Unger, *Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe/Germany, lana.unger@kit.edu*

Dr. Thomas Kresse, Karlsruhe Nano Micro Facility (KNMF), 76344 Eggenstein-Leopoldshafen/Germany, thomas.kresse@kit.edu

Dr. Julia N. Wagner, Institut für Angewandte Materialien (IAM), Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe/Germany, julia.wagner@kit.edu

Dr.-Ing. Stefan F. Wagner, Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe/Germany, stefan.wagner@kit.edu

Dr.-Ing. Wolfgang Menesklou, Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe/Germany, menesklou@kit.edu

Prof. Dr.-Ing. Ellen Ivers-Tiffée, Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe/Germany, ellen.ivers@kit.edu

Keywords: Oxygen separation, Mixed ionic-electronic conductor, Perovskite Oxides, Phase-Analysis

Introduction

Mixed ionic-electronic conducting perovskite oxides (ABO_3) are used for ceramic high temperature (700 °C – 900 °C) oxygen-transport membranes (OTMs). $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ (BSCF) has outstanding oxygen-permeation properties and is the most promising candidate for such an OTM. Its superior ionic and electronic transport performance is only given in its cubic phase [1,2], which is stable above 840 °C [3]. Below this temperature limit detrimental secondary phases occur, preferably on the grain boundaries [4]. By skillful B-site doping with, e.g., yttrium, the cubic-phase stability can be expanded to lower temperatures [5]. With the help of atom probe tomography (APT), which generates an atomic three-dimensional (3D) reconstruction of the chemistry of a perovskite ceramic, the exact phase-composition in the vicinity of the grain boundaries can be investigated [6].

Experimental

Ceramic bulk samples of BSCF and $Ba_{0.5}Sr_{0.5}(Co_{0.8}Fe_{0.2})_{0.9}Y_{0.1}O_{3-\delta}$ (BSCF10Y) were prepared and annealed at 800 °C for 10 d in ambient air. Then the samples were quenched down to room temperature. To analyze the element distribution in the grain boundaries by APT, tips with diameters between 50 and 200 nm were cut out by the focused ion beam (FIB) technique.

Results and Discussion

APT was used to analyze the nanoscale chemistry of BSCF and BSCF10Y before and after aging with respect to a chemical element analysis of the grain boundary regions. By comparing the doped and undoped BSCF the influence of yttrium on the formation of the hexagonal phase can be determined.

Acknowledgement: Financial support from the Helmholtz Association of German Research Centers through the portfolio topic MEM-BRAIN is gratefully acknowledged.

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Processing and Characterization of Nanoscaled Ni/YSZ Anodes for Solid Oxide Fuel Cells

Julian Szász, *Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruhe Institute of Technology (KIT), julian.szasz@kit.edu*
Dr. Dino Klotz, Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruhe Institute of Technology (KIT), dino.klotz@kit.edu
Dr. Heike Störmer, Laboratorium für Elektronenmikroskopie (LEM), Karlsruhe Institute of Technology (KIT), heike.stoermer@kit.edu
Prof. Dr. Dagmar Gerthsen, Laboratorium für Elektronenmikroskopie (LEM), Karlsruhe Institute of Technology (KIT), gerthsen@kit.edu
Prof. Dr. Ellen Ivers-Tiffée, Institut für Werkstoffe der Elektrotechnik (IWE), Karlsruhe Institute of Technology (KIT), ellen.ivers@kit.edu

Keywords: Solid Oxide Fuel Cell, Nano Anode, Ni/YSZ Nanoparticles, Impedance Spectroscopy, TEM

Abstract

Solid oxide fuel cells (SOFC) and electrolyzer cells (SOEC) are preferable operated at temperatures of 600°C or even lower, either for improved durability or efficiency (SOEC). However, this is a challenge, as the electrode activation polarization is a thermally activated process, responsible for a steep decline of performance at lower temperatures. Anode studies report either the use of (i) new materials with enhanced reaction and transport properties, or of (ii), nanoparticles enhancing the catalytic activity within porous µm scaled electrodes. However, most options make use of expensive rare earth materials or even noble metals. In contrary, this study shows the benefit of a nanoscaled Ni/YSZ interlayer, which forms at the interface electrolyte/anode by a simple, yet efficient, in-operando treatment [1]. The fundamental processing step is based on a short-time application of a high current density in reverse direction (reverse current treatment - RCT). Transmission electron microscope (TEM) studies prove, that Nickel grains of 20 nm size are embedded in a porous YSZ network, leading to a significant increase of electrochemical active sites (triple phase boundary - TPB). Superior reaction kinetics for the electro-oxidation reaction of hydrogen reduces the area specific polarization loss when compared to µm scaled technical anodes.

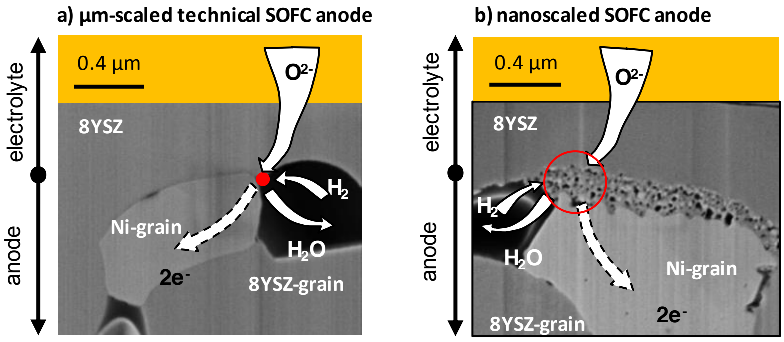
a) µm-scaled technical SOFC anode
b) nanoscaled SOFC anode

Figure 1: SEM-micrographs of a FIB polished cross-section, showing the electrochemically active region in an state-of-the-art SOFC anode: a) a µm-scaled anode and b) after applying an RCT; a nanoscaled anode.

In this contribution we evaluate the effective reaction mechanisms by means of current/voltage measurements during RCT, electrochemical impedance spectroscopy measurements and post-test analysis by TEM. Proposed mechanisms are: (i) the reduction of the YSZ electrolyte, (ii) an interdiffusion of Ni and Zr by NiXZrY phase formation, (iii) a reoxidation of NiXZrY to the former states Ni and YSZ and the building of pores.

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A new type of thermoelectric generator based on organic materials and manufactured through generative microstructuring

André Gall, *Light Technology Institute, Karlsruhe Institute of Technology, andre.gall@kit.edu*
Matthias Hecht, *Light Technology Institute, Karlsruhe Institute of Technology, matthias.hecht@kit.edu*
Dr. Siegfried Kettlitz, *Light Technology Institute, Karlsruhe Institute of Technology, siegfried.kettlitz@kit.edu*

Keywords: Energy, Heat Conversion, Thermoelectric, Organic Materials, Microstructuring

Introduction

Thermoelectric generators (TEG) transform heat to electricity without any moving parts. The physical effect (Seebeck effect) is a purely based on material properties. For decades the main focus of research was on inorganic materials. However pricy raw materials, complex manufacturing processes and recycling problems have so far impeded a commercial success of TEGs. The discussed design is based on earth-abundant organic semiconductor materials, which can be easily processed in large scale printing machines. The electric power of such a TEG lies in the range of micro- to milliwatts and is therefore suitable for energy autonomous sensors and actuators of applications in the field of Wearables, the Internet of Things and Industry 4.0.

Scalable manufacturing process

The production of the discussed TEG design is fully based on generative processes, which allow to obtain structures with lateral orientation in micro-scale. For this purpose a roll-to-roll printing process is used to apply the organic semiconductor materials on thin plastic foils. For the organic semiconductor materials a derivative of PEDOT is used. These materials already allow efficiencies, that are about half of the efficiency of commercially available inorganic materials [1][2]. With regard to the temperature range, the upper bound for this type of material is 200° Celsius.

Effective design with unique electrical, thermal and mechanical properties

The thermoelectric effect is reversible and only takes place in the active semiconductor material. The irreversible heat flow in the plastic foil (passive material) cannot be used for energy conversion. Therefore an effective TEG design aims to optimise the volume ratio of active and passive materials. The active materials of state of the art roll-to-roll processed TEG designs have a 1% filling degree of the device by volume [3]. The discussed design has improved this ratio by the factor of 50 in comparison to the next best approach. This improvement was achieved by using plastic foils of thickness 1.4 µm, which leads to a 50 % filling degree by volume.

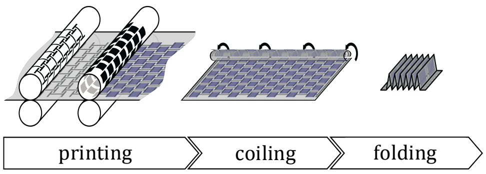

Figure 1: Manufacturing process

After printing the active material on the substrate, a coiling and folding process (Figure 1) leads to the microstructur of the TEG. As a result, the density of thermocouples is as high as 2.500 thermocouples per square centimetre, which is an improvement by two orders of magnitudes compared to published approaches based on PEDOT [4][5]. In practice a device based on the discussed design was able to produce 1 Volt at a temperature difference of 30 Kelvin (between a finger and an ice cube in Figure 2).

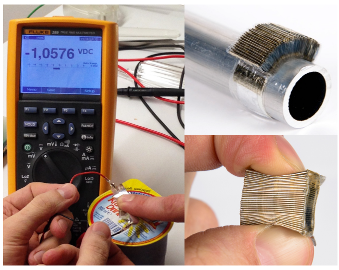

Figure 2: Electrical and mechanical properties

To reach the optimal thermal configuration of a setup, the thermal resistance of the TEG has to be specifically adapted to the heat source of an application. Regarding the discussed design, this can be achieved by a simple modification of the printing layout which affects the thickness of the device. Therefore the design is so far the only approach that can be optimally adapted to various kinds of applications in an easy manner.

Apart from the electrical and thermal properties the final device has also unique mechanical characteristics. Containing organic polymer materials, the whole structure of the devices is flexible and elastic. Not only leads this to a high robustness against mechanical and thermal stress. It also allows bending the device and therefore adapting it to curved surfaces like pipes (Figure 2).

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Crystallization Phase Diagram of *m*- and *p*-Chloronitrobenzene: Effects on Seeding

Jatuporn Kanuengnuek, *The Petroleum and Petrochemical College, Chulalongkorn University, jatuporntuk@gmail.com*
Dr. Pramoch Rangsunvigit, The Petroleum and Petrochemical College, Chulalongkorn University, pramoch.r@chula.ac.th
Dr. Santi Kulprathpanja, UOP, A Honeywell Company, Des Plaines, USA, santi.kulprathipanja@uop.com

Keywords: Adsorption, Crystallization, Isomeric substances, Phase diagram

Introduction

In the separation process, chloronitrobenzenes (CNBs), isomeric substances, consisting of *o*-, *m*-, and *p*-CNB, are used as an important starting material in chemical production of manufacture of azo and sulfur dyes, rubber, photograph film, pharmaceuticals and industrial agent. Most isomeric mixtures are difficult to separate and usually end up requiring an elaborate and expensive technique [1]. Therefore, we used the crystallization technique to separate CNBs liquid mixture, because its boiling point is very close, which is quite difficult to distillate. Crystallization, the last general process of the chemical purification of product mixture, consumes less energy consumption and produces high product purity. In addition, the melting points of CNBs are difference; thus, it is able to separation. In this work, *m*- and *p*-CNB were used as seeds to investigate their effects on the crystallization phase diagram of *m*- and *p*-CNB.

Discussion

From **Figure 1(a)**, the addition of *p*-CNB seed into the mixture CNB results in the change in phase diagram of *m*- and *p*-CNB. The crystallization temperature decreases and the eutectic composition increases. It may be explained that the seeding acts as impurity, which results in the change in the boundary between the stable zone and metastable zone [2]. Moreover, there is no significant change in the phase diagram when the *p*-CNB is used instead of *m*-CNB, as shown in **Figure 1(b).**

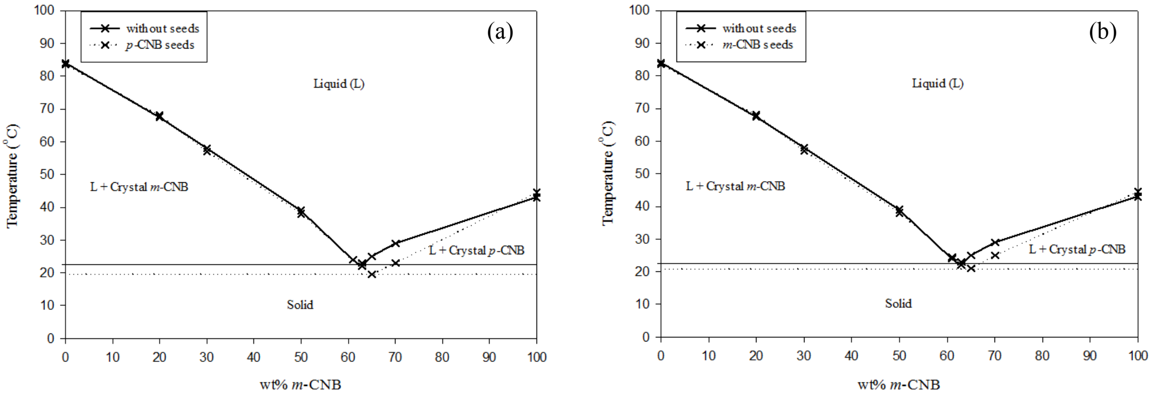

Figure 1: Binary phase diagram of *m*- and *p*-CNB with the presence of the *p*-CNB seed (a) and *m*-CNB seed (b)

Conclusions

Adding the seeds into the crystallizer does not significantly change the solid formation composition. However, at the eutectic point, the crystallization temperature slightly decreases whereas the composition of *m*-CNB increases. The feed compositions before and after adding the seeds are almost the same regardless the particle size and type of the seeds.

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Optimization of thermal plasma process for the particle fabrication system

***Mr. Byungkwon Kim**, Thermal Fluid System R&BD Group, Korea Institute of Industrial Technology, KITECH, Mechanical Engineering, University of Yonsei, greatrox@kitech.re.kr*
Mr. Dong-Yeol Chung, Thermal Fluid System R&BD Group, KITECH, dy77k96@kitech.re.kr
Dr. Dongho Park, Thermal Fluid System R&BD Group, KITECH, senna@kitech.re.kr
Dr. Prof. Jungho Hwang, Mechanical Engineering, University of Yonsei, hwangjh@yonsei.ac.kr
Dr. Jeong-Yeol Kim, Thermal Fluid System R&BD Group, KITECH, esperant@kitech.re.kr

Keywords: Thermal plasma, Nanoparticle, Particle fabrication, Energy efficiency, Optimization

Introduction

Nanoparticle is widely used in industrial area. The thermal plasma process is one of the advanced materials processing technique, which has successfully been applied for the nanoparticle fabrication [1]. There are a lot of ways to generate thermal plasmas, such as AC and DC high current discharges, RF discharges, and microwave discharges [2]. In relation to high efficiency technology for energy conservation, an optimization design of thermal plasma process has improved the energy efficiency of thermal plasma system. In this study, the optimization procedure for improving the energy efficiency was investigated using the calculation of heat and mass transfer in thermal plasma process. And the transferred DC plasma discharge was compared with other method to generate thermal plasmas.

Discussion

The schematic diagram of thermal plasma process for the calculation of heat and mass transfer is shown in Fig. 1. The input energy of thermal plasma is the electric power to generate the arc plasma. And the output energy of thermal plasma is consists of three parts. One is a cooling part by using cooling water in plasma torch and anode. Another is gas parts which are pilot gas, shield gas and quenching gas of plasma torch. And the other is material part. Material part includes the chemical reaction energy. The output energy was compared with the input energy to calculate the plasma temperature.

Fig. 2 shows that the plasma temperature was increased without particle injection. The energy consumption to the particle production was decreased with high plasma power in the same process temperature. The energy consumption to the particle production was sharply reduced from 5.5 to 2.6 kWh/kg.

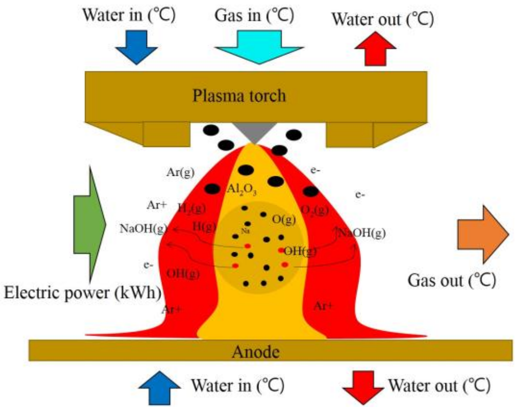

Figure 1: Schematic diagram of thermal plasma process

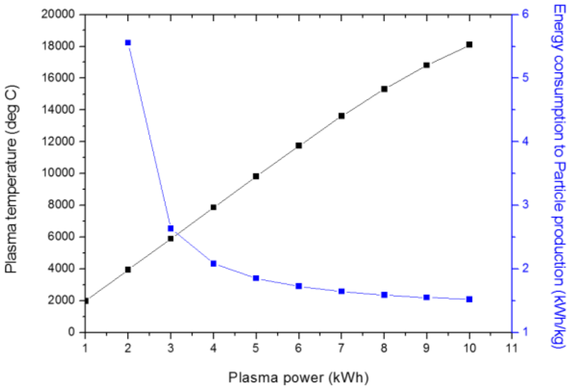

Figure 2: Power consumption curve of the particle production

Conclusions

The thermal plasma process was optimized using the calculation of heat and mass transfer analysis. Optimization was carried out to improve the power consumption efficiency of particle production using comparison with energy transfer. The results showed that the high plasma power reduced the energy consumption to particle production in the same temperature and increased the plasma temperature without particle injection.

Acknowledgement: This work was supported by the project "Next generation energy production system against climate change (Project number : EO-15-0006)"" funded by KITECH in South Korea Agency

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Efficient low temperature N_2O decomposition from HNO_3-exhaust streams over K-$Cu_xCo_{3-x}O_4$ catalysts

M. Sc. Tanja Franken*, Institut für Technische und Makromolekulare Chemie, RWTH Aachen University, tanja.franken@rwth-aachen.de*
Prof. Regina Palkovits, Institut für Technische und Makromolekulare Chemie, RWTH Aachen University, palkovits@itmc.rwth-aachen.de

Keywords: Energy, Climate, Greenhouse gases, N_2O Decomposition, Spinel

Introduction

To reach the climate goals it is not alone constructive to reduce CO_2 emissions but also emissions of other greenhouse gases. N_2O is a very strong greenhouse gas, which is mainly produced during HNO_3 production in industry. Nowadays, strategies to decompose N_2O into N_2 and O_2 need additional energy due to heating of the tail gases for complete removal of N_2O emissions. Therefore, it is highly necessary to introduce new catalysts with high performance in the exhaust conditions of the HNO_3-tail gases avoiding additional heating of these gases. An industrially applied catalyst is Fe-ZSM-5 which achieves 50 % conversion at a temperature ($T_{50\%}$) of 430 °C [1]. Compared to the average temperatures of the tail gases (T = 250 – 500 °C) the activity is still too low for quantitative conversions without energy input. Herein, we present a promising catalyst with high activities at temperatures below 500 °C applying realistic process conditions.

Discussion

As Co_3O_4 shows promising results for efficient N_2O decomposition into N_2 and O_2 [2] varying amounts of Co atoms in the spinel phase were exchanged by Cu. During the use of these materials as catalysts a strong dependency of the catalytic activity on the degree of exchange of Co by Cu was found. The integration of Cu into the unit cell highly increases the catalytic performance compared to Co_3O_4. Reducing the amount of Cu from x = 1 to 0.25 in $Cu_xCo_{3-x}O_4$ increases the performance even more. In the next step a promotion with trace amounts of K was able to increase the catalytic activity and decrease the temperatures for full N_2O conversions to 330 °C. In the presence of H_2O and O_2 the necessary decomposition temperatures increases only slightly, while the presence of NO has a strong influence (**Figure 1**). But still, at a high GHSV of 54000 h^{-1} and in the presence of all inhibitory gases (NO, O_2, H_2O) present under realistic reaction conditions, the catalyst K-$Cu_{0.25}Co_{2.75}O_4$ shows full conversions at temperatures as low as 490 °C. Stability tests in real exhaust gas conditions emphasise stable activities and no further inhibition during a reaction time of at least 60 h. Even an increase of the gas flow rates leads only to minor changes of the conversions.

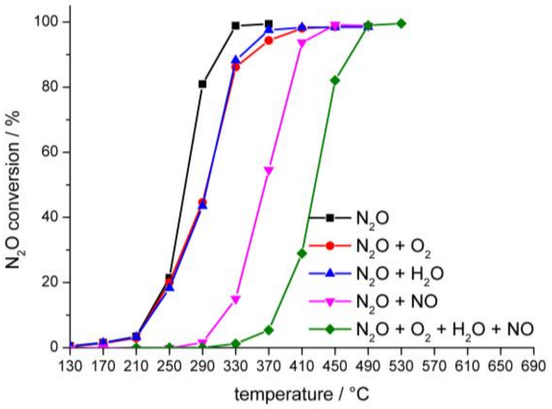

Figure 1: Performances for N_2O decomposition of K-$Cu_{0.25}Co_{2.75}O_4$ in the presence of NO, O_2 and H_2O.

Conclusions

The introduced catalyst shows high activities in the conditions of exhaust gases of HNO_3 production. Introducing this catalyst after the $DeNO_x$ unit could enable operating temperatures of the DeN_2O stage as low as 330 °C. Overall, this development facilitates a more environmentally benign production of HNO_3 with minimum energy requirement for treatment of the exhaust gases.

Acknowledgement: We acknowledge financial support by the Max-Buchner-Foundation.

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Materials research for energy supply at Karlsruhe Institute of Technology

Dr. Regina Krüssmann*, Institute of Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology, regina.kruessmann@kit.edu*

Tim Gräning, Institute for Applied Materials, Karlsruhe Institute of Technology, tim.graening@kit.edu

Daniel Janda, Institute for Applied Materials, Karlsruhe Institute of Technology, daniel.janda@kit.edu

Dr. Sebastian Ruck, Institute of Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology, sebastian.ruck@kit.edu

Daniel Schneider, Institute for Applied Materials, Karlsruhe Institute of Technology, daniel.schneider@kit.edu

Luis Strassberger, Institute for Applied Materials, Karlsruhe Institute of Technology, luis.strassberger@kit.edu

Dr. Pavel Vladimirov, Institute for Applied Materials, Karlsruhe Institute of Technology, pavel.vladimirov@kit.edu

Dr. Mariya Yurechko-Hussy, Institute for Applied Materials, Karlsruhe Institute of Technology, mariya.yurechko@kit.edu

Keywords: Materials Research, efficiency, HGF-Portfolio, enhanced heat transfer, ODS steel

The German “Energiewende” has the objective to base the energy supply of Germany as far as possible on renewable energy sources in the nearest future. A key factor for its success are innovative materials. These should allow higher temperatures in power conversion systems to enhance the efficiency of the process regardless of its type.

To support research on advanced materials, the German research organization Helmholtz-Gemeinschaft launched a program called “Portfolio - Materials Research for Future Energy Supply”. Partners are several research institutions in Germany, among them the Karlsruhe Institute of Technology (KIT). The objective is to bring together materials research, simulation, experimental characterization and application and to shorten time to market.

At KIT, the focus is mainly on composite materials; in particular on a variety of oxide dispersion strengthened steels (ODS). In several sub-projects, different aspects of fabrication, characterization and testing of this material are investigated:

- A new austenitic ODS-steel is under development. Austenitic steels have a higher ductility and better creep characteristics than ferritic steels, which makes them attractive for use at higher temperatures. First probes in laboratory scale are available. Research on manufacturing semi-finished products is under way.
- It is assumed that creep resistance depends mainly on the Y-Ti-O nanoclusters formed during mechanical alloying. Their morphology and thermal stability are investigated by atom-probe tomography (APT).
- Simulations of the grain boundary and grain growth during the development of the crystalline structure shall help to clear up how the oxide particles interfere with the grain boundary movement.
- The elasto-viscoplastic behavior of this new austenite, but also of ferritic ODS-steel is analyzed by monotonic and cyclic creep and relaxation tests to find the parameters that fit the Chaboche model.
- Further, the mechanical properties are also experimentally investigated in corrosive environment, either by running tests in liquid metal (Lead or Lead-Bismuth-eutectic) or in hot Helium. Both fluids are candidates for coolants of conventional and nuclear power stations at elevated temperatures.
- For this purpose, also a small Helium loop is built (operating at 6 bars, 750 °C and with a mass flow up to 10 g/s) to investigate semi-finished parts made from the new materials and close the gap to applications in industry.
- Finally, service life and efficiency of components could be expanded by enhanced heat transfer. Structured surfaces are investigated experimentally and by simulation.

Phosphate based ceramics as solid electrolyte for high temperature lithium ion batteries

***Yuantao Cui**, Karlsruhe Institute of Technology, Institute for Applied Materials – Applied Materials Physics,*

Yuantao.cui@kit.edu

M. Rohde, M. M. Mahmoud, C. Ziebert, H. J. Seifert

Keywords: LAGP, Solid electrolyte, LIB, All-solid state battery

Introduction

A Li-ion battery with liquid electrolyte may suffer from security risks such as inflaming or short circuits. A solid electrolyte made of ion conducting glass-ceramic is thermally more stable. If a battery could use the ion conducting ceramics as combined electrolyte and separator, the battery will be safer.

Experiments

LAGP ($Li_{1+x}Al_xGe_{2-x}(PO_4)_3$) was investigated as a candidate for solid electrolytes in Li ion batteries. LAGP glass samples were produced using the melt-quench-method. Samples were produced using powder compaction by pressure less sintering or by direct heat treatment of the glass. Their ionic conductivities were measured with impedance spectroscopy. Dilatometer measurements, X-ray diffraction and scanning electron microscope analysis were also carried out. The thermal properties like crystallization temperature, heat capacity and thermal conductivity were measured with differential scanning calorimeter and Laser-Flash apparatus. The relationship between the process parameters, the microstructure and ionic conductivity of the solid electrolyte was studied.
The ionic conductivity of LAGP sample reaches $3\cdot10^{-4}$ S/cm at room temperature and increased to $1\cdot10^{-2}$ S/cm at 150°C.
All-solid test cells were fabricated using LAGP ceramic as solid electrolyte. Magnetron sputtering, spark slasma sintering and furnace sintering were used to produce the anode-electrolyte-cathode multilayer tablets. The tablets were assembled in swagelok-cells and tested between 100°C and 200°C.
In the cells with Li metal as anode it was found that there is a side reaction between the Li metal and the LAGP solid electrolyte at the interface. The Ge^{4+} in LAGP was reduced. The reaction products were investigated with XRD and chemical analysis.
This side reaction can be avoided by using $Li_4Ti_5O_{12}$ as anode. However the cells still show large internal resistance. The resistance could be attributed to the effect of space-charge layer or due to the insufficient contact between the electrodes and the solid electrolyte. The internal resistance will be investigated with complex impedance spectroscopy.

Conclusions and Outlook

The ionic conductivity of LAGP at about 150°C is comparable with the liquid electrolyte. However the Ge^{4+} is easy to be reduced, which prevents the usage of Li metal and graphite anode. To take advantage of the large capacity of Li metal anode, some protection mechanisms need to be developed. Furthermore the interface resistance is also a limiting factor. A buffer layer or an interface modifier could help to solve this problem.

Limitation of Diagnostic Methods for Single Core XLPE-Power-Cable and Requirements for Future Developments

***Dipl.-Ing. Tobias Maier**, Department of Electric Energy Systems and High-Voltage Technology,*
Karlsruhe Institute of Technology, tobias.maier@kit.edu
Prof. Dr.-Ing. Thomas Leibfried, Department of Electric Energy Systems and High-Voltage Technology,
Karlsruhe Institute of Technology, thomas.leibfried@kit.edu

Keywords: energy efficiency, diagnostic, power-cable, cost of cable failure

Introduction

Electrical energy is an important recourse today. Failures in the energy systems will lead to problems in the delivery stabilisation and in the worst case to blackouts. To prevent such problems diagnostic methods are used to investigate the state and the possible remaining life-time of the components. On the basis of the remaining life-time a strategy of changing worn parts is feasible. The changing strategy allows minimizing system failure rate and therefor financial costs.

In this paper the focus is on the diagnostic investigation of XLPE-Single-Core-Power-Cable. XLPE-Cables are used in the power delivery since 1970 and the state of art in medium- and high-voltage rates today.

Discussion

Diagnostic tools are subdivided in destructive and non-destructive methods. In this paper the main focus is on the non-destructive techniques. These methods are separated in time and frequency domain analysis [1, 2]. One example for the time domain analysis is the Time-Domain-Reflectometry (TDR). The TDR method is well-established and a common analyse technique. However, the TDR needs a short circuit or great impedance skip to recognize and localise a defect, especially there precise location. A dielectric change of the insulation material gives only insufficient information about the cable and isn´t measurable with this technique. A possible technique to evaluate the insulation material is to measurement the dissipation-factor ($\tan\delta$) [1 - 3]. The $\tan\delta$ measurement is variable in frequency- and voltage-rate as well as in time- and frequency-domain. The measurement technic is well known for the detection of water-trees and aging processes in older or strongly aged XLPE-cables [2]. But for new XLPE-cables the measurement system is not practicable yet, because the changing in the insulation is very small and the measurement result is depending on different parameters (for example: temperature, moisture, frequency, cable producer, …) [2, 3]. New XLPE-cables are higher manufactured and used since the last 20 to 30 years and normally they haven´t the problem of water-trees as the first XLPE-cables. The $\tan\delta$ diagnostic measurement is an integral measurement and gives an arithmetic average over the cable. Therefore, localization of a failure is not possible. Other and only frequency domain measurements systems are the Frequency-Domain-Reflectometry (FDR), the Line-Resonance-Analysis (LIRA), the Joint-Time-Frequency-Domain-Reflectometry (JTFDR) and the Axial Tomography [1, 4].

In this paper the focus is on FDR and the LIRA, because these diagnostic systems are very similar and more practicable for diagnostic measurements. The FDR and LIRA investigate the impedance change in the cable and allow to predict there position along the cable. The LIRA is more sensitive as the FDR and measures additionally phase and magnitude of the input impedance. Another positive effect of the LIRA is the resonance-frequency-analyse. A possible evaluation algorithm is using the Fast-Fourier-Analyse at the resonance frequency. The problem of both techniques (FDR and LIRA) is that small changes in the impedance across the cable are difficult to detect and to localize. The LIRA isn´t a common technique and there function and capabilities isn´t well-understood today.

Conclusions and Outlook

A lot of different diagnostic measurements are available and feasible for diagnostic evaluations. But all different systems face a challenge when they have to detect a failure with small impedance or dielectric change. Hence, future deeper investigations of this diagnostic measurement are necessary. The LIRA isn´t well known and raises a lot of question about their feasibilities. Based on this more fundamental studies according the LIRA are required.

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Low temperature Carnot Engine

Prof. Dr. Manfred Wilhelm, *ITCP, Karlsruhe Institute of Technology (KIT), manfred.wilhelm@kit.edu*
Stefan Horn, Economics and Management, KIT, stefan.horn@student.kit.edu
Dr. Ingo F.C. Naue, Mechanical Engineering, KIT, ingo.naue@kit.edu
Wolfgang Arbogast, Chemistry and Biosciences, KIT, wolfgang.arbogast@kit.edu
Daniel Winter, Mechanical Engineering, KIT, daniel.winter@student.kit.edu

Keywords: mechanical energy at small temperature difference, shape memory alloy, heat exchanger,

Introduction

Conventional power plants gain energy out of burning hydrocarbons like gas, oil or coal to CO_2 and water. The released combustion enthalpy is used to get the highest possible temperatures. During the primary circuit evaporated water drives a turbine and afterwards a connected generator. After this process, the steam needs to be condensed so that the water can evaporate again. The condenser is cooled by a second circuit. In this circuit the temperature is generally too low, to generate further electricity by using conventional engines. At the ITCP we develop a so-called ‘Entropy Wheel’ to use small temperature difference e.g. in cooling water of power plants.

Discussion

The operating principle is based on a shape memory effect and a contraction of springs as a function of temperature. To illustrate the construction one could conduct a gedankenexperiment: We replaced the spokes of a wheel with shape memory springs that contracts through heat. An eccentrically arranged source of energy (e.g. hot water) heats the spokes. Thus, the heated spokes shrink. The wheel is non-deformable, therefore the center moves and the center of mass of the outer wheel moves, too. Finally the center of mass is moved above or sideways of the rotation axis of the hub, resulting a moment of tilt. This leads to a continuum rotation, because warm spokes are displaced out of the thermal energy source and will cool, cold spokes will be heated up [1].

Figure 1: First powerful ‘Entropy Wheel’ construction developed at the ITCP (KIT) can move a car, 10W mechanical power using hot water at a temperature of 80°C

We tested different materials, the best material are shape memory alloys (SMA) out of a nickel titanium copper alloy. Actuator made out of these special metal alloys are very powerful at low volumes and weight. In addition the heated springs contracts. An essential improvement of the efficiency is based on the application of an adaptable eccentric between the outer wheel and the center [2].

Conclusions and Outlook

The next step is to implement several technical improvements. We will increase the efficiency **(1)** by optimizing the design and the construction of Entropy Wheel, **(2)** by improvements of the heat transfer, and **(3)** by adapting the shape and geometry of the actuator. **(4)** Meanwhile we will evaluate the different possibilities of designing products based on this technology. To achieve our goal for the next 3 years we search for cooperation with different companies, who could develop the SMA or build the construction based on our requirements.

Acknowledgement: We thank Prof. A. Albers and the past and present employees of the ‘Working Group Wilhelm’, in particular Mr. Logel, Mr. Schadel, Mr. Heilmann, Mr. Kranz, Mr. Powelske, Mr. Becker, Mr. Zimmermann and Mr. Arbogast and the workshop of our institute.

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Optimization for Improving Energy Efficiency of an Axial-Flow Fan

***Dr. Prof. Jin-Hyuk Kim**, Thermal Fluid System R&BD Group, Korea Institute of Industrial Technology (KITECH), Energy System Engineering, University of Science and Technology (UST), jinhyuk@kitech.re.kr*
Mr. Sung Kim, Thermal Fluid System R&BD Group, KITECH, ks2928@kitech.re.kr
Mr. Dong-Yeol Chung, Thermal Fluid System R&BD Group, KITECH, dy77k96@kitech.re.kr
Dr.Jong-Hyeon Peck, Thermal Fluid System R&BD Group, KITECH, pjh6240@kitech.re.kr
Dr. Prof. Young-Seok Choi, Thermal Fluid System R&BD Group, KITECH, UST, yschoi@kitech.re.kr

Keywords: Energy, Efficiency, Optimization, Axial-Flow Fan, Blade

Introduction

In relation to high efficiency technology for energy conservation, optimization techniques with computational fluid dynamics (CFD) have recently become promising tools for the design of high performance turbomachinery [1]. Applications of these techniques to turbomachinery design have reduced the cost and time required for experimental tests. This paper presents an optimization procedure for improving the energy efficiency of an axial-flow fan used for refrigeration and air-conditioning.

Discussion

The flow field in the computational domain was analyzed by solving three-dimensional steady incompressible Reynolds-averaged Navier-Stokes (RANS) equations with a shear stress transport turbulence model through a finite-volume solver, the commercial code ANSYS-CFX 11.0. An optimization process based on a radial basis neural network model (RBNN) was performed with two design variables that define the setting angles at hub and shroud of the blade. Total efficiency was selected as the objective function for optimization. The objective function was numerically assessed at design points selected by Latin hypercube sampling in the design space. Three-dimensional mesh plot for the RBNN model is shown in Fig. 1. The optimum point located at (71.31%) on the three-dimensional surface is clearly shown in this figure. Figure 2 shows the total pressure and efficiency performance characteristic curves for the reference and optimum designs. The optimization yielded a maximum increase in efficiency of 3% at the design point compared to a reference design. Considerable improvements in the efficiency curves through optimization were observed for flow rate regions higher than about 150 CMM, whereas the efficiency values for the reference and optimum designs are almost the same in the region of the low flow rate region.

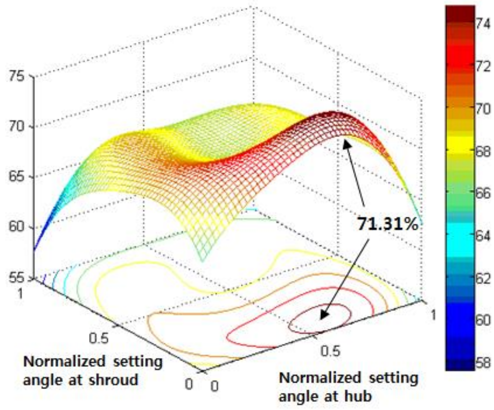

Figure 1: Three-dimensional plot for RBNN model

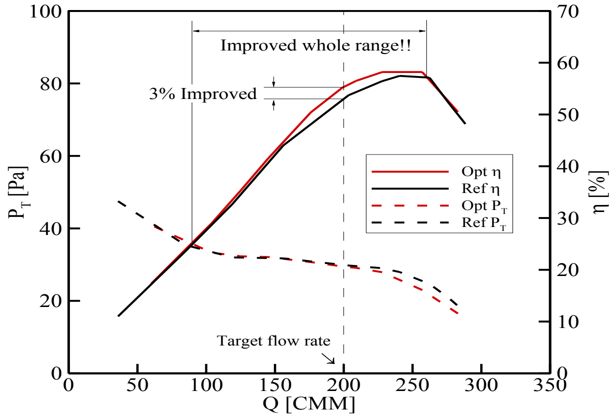

Figure 2: Performance characteristic curves

Conclusions

An axial-flow fan design was optimized using an RBNN model with three-dimensional RANS analysis. Optimization was carried out to enhance the total efficiency of the axial-flow fan with two design variables defining the setting angles at hub and shroud of the blade. The results of the design optimization showed that the efficiency for the optimum design was improved by 3%, and the efficiency curve was significantly improved in the high flow rate region, as compared to the reference design. This result elucidates how the axial-flow fan's efficiency was improved as a result of the present optimization.

Acknowledgement: This research was supported by the Korea Institute of Industrial Technology Evaluation and planning (ITEP) grant funded by the ministry of Trade, Industry and Energy (No. 10049090).

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Poster Presentations

Systems, Storage and Grids

Electrochemical evaluation of electrodes for Microbial Fuel Cells

M.Sc. *Bolong Jiang, Prof. Ulrich Kunz, Institute of Chemical and Electrochemical Process Engineering, Clausthal University of Technology, bolong.jiang@tu-clausthal.de*

Key words: Microbial fuel cell, Current-voltage Characteristics, Microorganism, Start-up behavior

Introduction

Recently, the use of microbial fuel cells (MFC) has attracted worldwide interest as they can generate energy from renewable feedstock and contribute to wastewater purification [1]. However, MFC is still in its infant and the majority of work has been focused on its technical feasibility and fundamental characteristics. Two MFC were set up and start-up behavior was evaluated. Characteristic potential-current curves and optimal power densities of the two MFCs were studied. The electrodes were made of carbon-polymer composites with different surface roughness.

Discussion

Two MFC were built, the electrodes were made of the same carbon polymer composite. They had a flat geometry with a channel across the electrodes. The dimensions of the electrodes were 25cm*14cm. As a membrane Nafion 117 was used. By two pumps waste water (using NaAc as additional nutrition for the microorganism) was fed through the cathode and the anode compartment. The cathode water was enriched with air by bubbling air through the catholyte reservoir. **Figure 1** shows the trend in power development as a function of time (left). Each symbol in the figure is the maximum power which was reached with time. This value was derived by the measurement of a current voltage characteristic (right). After this measurement the load current was adjusted to the current density in the maximum. By this procedure it can be seen that during the whole test period, the optimal power density rises with time of operation. As the microorganism on the electrodes grow slowly it takes several days to weeks to reach high power levels. Fluctuations in power can be explained by changing substrate (NaAc) concentrations caused by irregular feeding of the microorganism and by different development of the biofilms on the electrodes. The highest power density is 48 mW/m^2 for the MFC with a rough electrode surface. The MFC with a not roughened electrode surface could not reach this power density. That means that the microorganism settlement on the electrodes depends strongly on the surface properties of the electrodes.

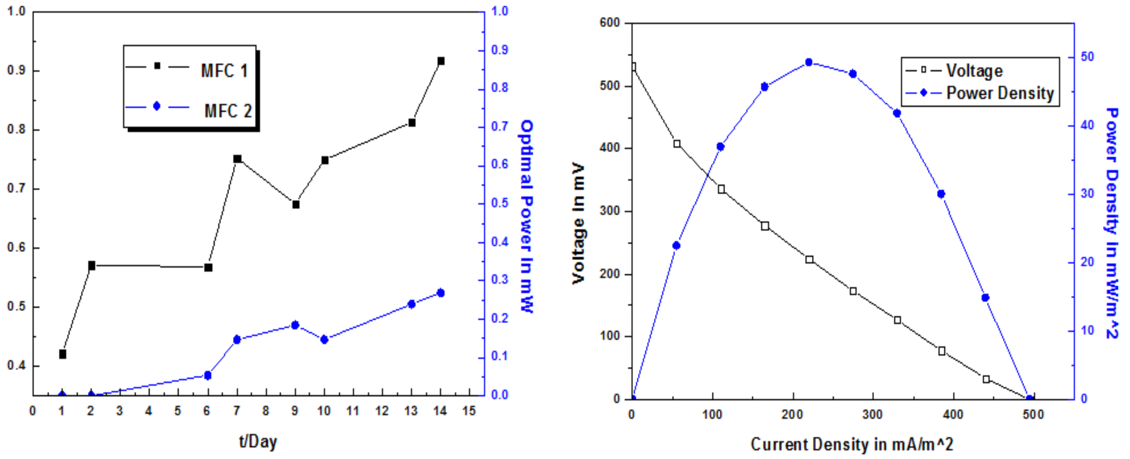

Figure1: Start-up behavior of two MFCs with different electrode roughness with time (left)
Voltage and power density as a function of current density (right)

Conclusions and Outlook

The optimal power development of MFC depends strongly on the electrode surface properties. This leads to the result that for the improvement of MFCs not only the electrode material but also the surface roughness is of great importance. For the development of better MFCs not only material testing is necessary but also investigations on the surface properties of the electrode materials.

Acknowledgement: The authors thank BMBF for funding this project (WTER0219813).

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Influence of particle shape on MSMD modelling of Li-ion batteries

Dipl.-Ing. Philipp Seegert*, Institute of Thermal Process Engineering, Karlsruhe Institute of Technology, philipp.seegert@kit.edu*
Dipl.-Ing. André Loges, Institute of Thermal Process Engineering, Karlsruhe Institute of Technology, andre.loges@kit.edu
Prof. Dr.-Ing. Thomas Wetzel, Institute of Thermal Process Engineering, Karlsruhe Institute of Technology, thomas.wetzel@kit.edu

Keywords: Li-ion batteries, numerical simulation, multi-scale multi-dimensional, particle shape influence

Introduction

The performance as well as the lifetime of Li-ion batteries strongly depend on the thermal behaviour of the cells. For the improvement of battery performance and the development of sophisticated thermal management systems in electric vehicles accurate thermal characterisation of the cells is necessary. A commonly used method to describe the behaviour of Li-ion batteries is the numerical simulation. The multi-scale multi-dimensional (MSMD) modelling approach used in this contribution has the advantage to describe the energy and charge balance of the cell as a function of the local physical processes of the electrochemical reaction and thereby identifying the inhomogeneous heat development and ageing of the cell dependent on the temperature distribution inside the battery.

Discussion

The MSMD modelling approach is based on the division of the battery cell in three coupled computation levels with different length scales (multi-scale): particle, electrode and cell domain [1]. The separation by scale is illustrated in **Figure 1**. The three domains are connected in the superordinated MSMD structure but can operate independently, which allows a high level of detail for each domain, while also significantly reducing the computational effort compared to a single level model.

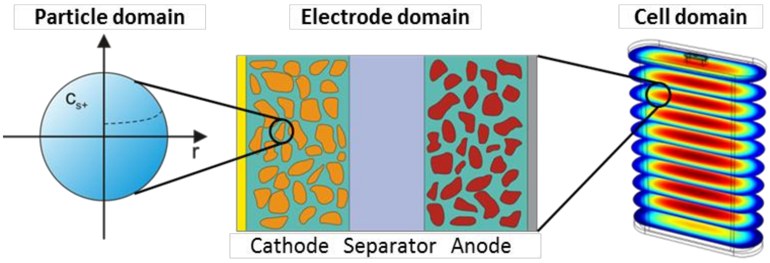

Figure 1: Structure of the multi-scale multi-dimensional model of a prismatic Li-ion battery

A commonly used simplification for the display of the electrode particles is the assumption of spherical shaped particles with isotropic properties. Especially in the case of the graphite based anode material, this is a significant deviation from the actual layer structure of graphite and the typically non-spherical shape of graphite particles. The goal of the project is to determine systematically the influence of these special particle properties on the coupled electro-thermal behaviour of a Li-ion battery cell. Therefore different parametric single particle models with generic non-spherical particle shape (e.g. ellipsoid shape) and anisotropic properties were developed and compared to a spherical shaped particle model with isotropic properties.

Conclusions and Outlook

The basic structure of the built MSMD model of a prismatic Li-ion battery as well as the first results of the single particle models encompassing the particle shape influence of the anode materials on the battery behaviour will be presented in this contribution. Future work will concentrate on the development of electrode models based on the single particle models.

Acknowledgement: The authors would like to thank the Friedrich and Elisabeth Boysen foundation for the financial support of the research project.

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Titanium doped $LiCoMnO_4$: High-Voltage Spinels as cathode materials for Li-Ion Batteries

Christoph Dräger, *Institute for Applied Materials – Energy Storage Systems, Karlsruhe Institute of Technology,*
Christoph.Draeger@kit.edu
Sylvio Indris, *Institute for Applied Materials – Energy Storage Systems, Karlsruhe Institute of Technology,*
Sylvio.Indris@kit.edu
Aiswarya Bhaskar, Institute for Applied Materials – Energy Storage Systems, Karlsruhe Institute of Technology,
Aiswarya.Bhaskar@kit.edu
Helmut Ehrenberg, Institute for Applied Materials – Energy Storage Systems, Karlsruhe Institute of Technology,
Helmut.Ehrenberg@kit.edu

Keywords: Li-Ion Battery, high-voltage cathode, high-power, spinel, in situ synchrotron diffraction

Abstract

Besides the layered oxides, spinels are the most commonly used cathode materials for lithium-ion batteries. Their high rate capability as well as good cycling stability result in high power densities of up to 1200 Wkg^{-1}, which are required for the application of lithium-ion batteries in hybrid electric vehicles (HEVs). Nevertheless, the use of spinels as cathode material for the application in electric vehicles (EVs) is restricted due to their low energy density (800 $Whkg^{-1}$). Furthermore, spinels show poor thermal stability. In order to improve the energy density we investigate lithium-cobalt-manganese spinels doped with titanium. In comparison to the commonly used nickel, cobalt shows a higher oxidation and reduction potential and therefore the cobalt containing spinel has a higher theoretical energy density. Additionally, replacing manganese with titanium leads to better thermal stability and to a better cycling performance due to the higher redox-stability of Ti^{4+}.

Modification of Graphitization and Surface for Electrodes in all-Vanadium Redox Flow Batteries

Langner, Joachim, *Institute for Applied Materials (IAM-ESS), Karlsruhe Institute of Technology, Joachim.Langner@kit.edu*
Zils, Susanne, Freudenberg New Technology
Scheiba, Frieder, Institute for Applied Materials (IAM-ESS), Karlsruhe Institute of Technology
Ehrenberg, Helmut, Institute for Applied Materials (IAM-ESS), Karlsruhe Institute of Technology
Roth, Christina, Freie Universität Berlin, Fachbereich Biologie, Chemie, Pharmazie

Keywords: all-Vanadium Redox flow Battery, Electrode Material, Raman spectroscopy, Electrochemistry

Each year redox flow batteries (RFB) receive more and more attention. This is driven by the need to build large scale energy storage systems balancing the increasing fraction of renewable energy in the electrical grid. RFBs appear especially attractive for this purpose due to their rather safe chemistry, their precious metal free construction and their independent scalability of capacity and power.
Carbon based fibres, made out of synthetic or natural precursors like rayon or polyacrylonitrile (PAN), are widely used as electrode material. Those fibres are processed to carbon nonwoven or paper by carbonization or partly graphitization and are used in flow-through or flow-by cell geometries, respectively.

Since the half-cell reactions occur at the interface between the fibre and the electrolyte, the surface area and surface chemistry are the key parameters to improve the electrochemical activity of the electrode. For the latter parameter it is well known that oxygen containing surface groups also reduce the overpotentials, and in particular for the negative half-cell reaction. This mechanism is still not completely understood. In addition, the fibre surface mainly consists of graphitic and amorphous carbon, which is directly influenced by the graphitization degree. This is important since the graphitization degree has a significant impact on the aging and degradation behaviour of the electrode as well as on side reactions, such as hydrogen evolution.

In this work we investigated differently graphitized carbon based nonwovens (Figure 1), which were later oxidized by heat treatment to create different amounts of oxygen functional groups on their surface. The changes of the atomic structure and surface chemistry caused by the thermal treatment and ageing were investigated by Raman spectroscopy and XPS. Cyclic voltammetry (Figure 2) and electrochemical impedance spectroscopy were applied for the electrochemical characterization of the positive and negative half-cell reactions.

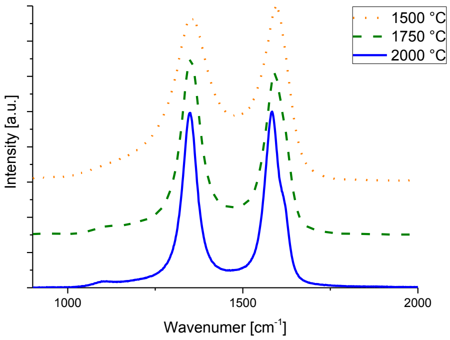


Figure 1: Raman spectra of the electrode materials graphitized at 1500, 1750, 2000 °C under Argon.

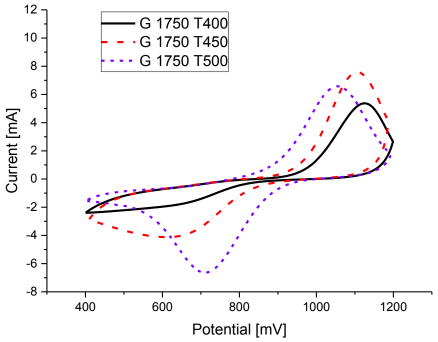


Figure 2: Cyclic Voltammetry of $V^{4+/5+}$ reaction on electrode materials oxidized thermally at different temperatures.

Acknowledgement: The financial support of the BMFB within the project "Flow 3D" (03EK3011D) is gratefully acknowledged.

Controlled formation of nanostructured silicon as potential anode material for lithium ion batteries

MSc.,Nastaran,Hayati-Roodbari,Materials Science and Physics,University of Salzburg, nastaran.hayati@sbg.ac.at
Dr., Michael S., Elsaesser, Materials Science and Physics, University of Salzburg, michael.elsaesser@sbg.ac.at
Univ.-Prof. Dr., Nicola, Hüsing, Materials Science and Physics, University of Salzburg, nicola.huesing@sbg.ac.at
Dr., Joong-Hee, Han, Electric Drive Technology, Mobility, Austrian Institute of Technology, joong-Hee.Han@ait.ac.at
Dipl.-Ing. Philipp, Hans, X-ray Center, Vienna University of Technology, philipp.hans@tuwien.ac.at
Dr., Klaudia, Hradil, X-ray Center, Vienna University of Technology, klaudia.hradil@tuwien.ac.at

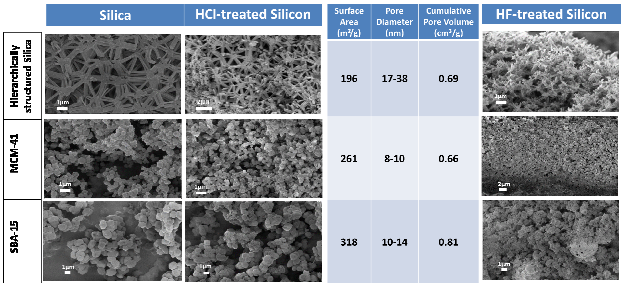
Keywords: Nanostructures, Silicon, Magnesiothermic reduction

Introduction

Lithium (Li) ion batteries attracted much interest in recent years due to their manifold applications, including portable electronics, but also electric vehicles with increased operating distances. Major research effort has been dedicated to the preparation of novel electrode materials. One way to achieve Lithium ion batteries with improved energy and power density is the selection of suitable anode materials providing high capacities and facilitated diffusion of lithium ions, combined with high cycle stabilities. Silicon (Si) is considered as one of those high performance anode materials because of its high theoretical specific capacity, its earth-abundance, cost-effectiveness and well-established commercial history [1].One major disadvantage of Si is its strong volume expansion during lithium insertion (~400%) typically resulting in rapid capacity fading. To overcome this problem, the preparation of nanosized active materials is discussed.

Discussion

Magnesiothermic reduction [2] is one of the standard methods to reduce silica to silicon. In this study we could show that it is possible to reduce different meso and meso/macroporous silica sources to porous Si, while retaining the macroscopic morphological features of the starting silica to a large extent (only for fine powders, agglomeration was observed, Figure-1). The specific surface area decreased for the highly porous silica precursor materials (i.e. from 797 to 318 $m^2g^{-1}$for SBA-15), due to a change in the mesoscopic pore size regime. First investigations indicate crystallite sizes of the silicon nanostructures in the range from 11 to 30 nm, which strongly depend on the heating procedure during magnesiothermic reduction. Heat release indicators ($BaCO_3$, $SrCO_3$) showed that the reaction temperature did not reach more than 1300 °C, since both carbonate salts are still present after the reduction. Silicon-based cells were assembled and electrochemically investigated. First results showed that the cell with Si from MCM41-silica exhibits average discharge capacity of 1000 mAh/g and coulombic efficiency of 97% after 52 cycles. The analysis of the X-ray diffraction diagrams revealed the expected strong amorphisation of the particles.



	Surface Area (m^2/g)	Pore Diameter (nm)	Cumulative Pore Volume (cm^3/g)
Hierarchically structured Silica	196	17-38	0.69
MCM-41	261	8-10	0.66
SBA-15	318	10-14	0.81

Figure 1:SEM images and N_2-sorption results for HCl-treated silicon, on the right side images after HF treatment.

Conclusion and outlook

The synthesized porous Si materials are build-up from nano scale silicon crystallites, which again are aggregated to larger highly porous structures. With that they offer a high surface to volume ratio, thus resulting in an increased number of active sites for Li storage, from which an increased rate capability could result, besides a better diffusion of the lithium ions through the porous matrix. In case of Li-ion batteries, the influence of the silicon morphology on the cell capacity was investigated, suggesting that the changes of the Si-particles' porosity and dimensions can effectively reduce the problematic volume changes associated during lithiation/ de-lithiation. Currently, investigations are underway, which aim at a chemical insertion of Li in porous Si by thermal and mechanical treatment. The use of pre-lithiated anode material might lead to improved control of the Si volume expansion during electrochemical activity. Moreover, electrochemical performance tests as well as scale up strategies will be considered. Investigations of the short-range order within the particles may also help to deduce important properties from their structures.

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Novel Electrolytes for Li-Ion Batteries with Improved Safety Issues

***Dr. Andreas Hofmann**, Institut für Angewandte Materialien - Werkstoffkunde, Karlsruher Institut für Technologie; andreas.hofmann2@kit.edu*
Prof. Dr. Thomas Hanemann, Institut für Angewandte Materialien - Werkstoffkunde, Karlsruher Institut für Technologie ; Institut für Mikrosystemtechnik, Universität Freiburg; thomas.hanemann@kit.edu

Keywords: Energy storage, Lithium-ion battery, Safety, Electrolytes

Introduction

Electrolytes are one of the key components in lithium ion batteries because of their interaction with all materials inside the lithium cell. Usually, they consist of mixtures of organic carbonates as solvents, lithium containing conducting salts, and various additives. In dependence of the electrode material, which is used inside the cell, individual electrolyte formulations are necessary for best results of the cell performance and stability. Currently, electrolyte mixtures are commercially available with the focus on high performance and a broad functional range with respect to the temperature. Unfortunately, such electrolytes cannot be used for extended periods of time at high potentials (> 4.5 V vs. Li/Li+). Additionally, one component of commercial electrolytes are organic linear carbonates with very low boiling points and flash points (e.g. dimethyl carbonate, bp = 90°C, fp = 14°C; ethylmethylcarbonate, bp = 107°C, fp = 23°C) for achieving sufficient lithium mobility during the charging and discharging periods (high performance of the Li-ion cell). Therefore, such electrolytes exhibit a high risk of flammability if any process of temperature rise occurs (e.g. a defect or short circuit of the cell).

Discussion

In this study we developed novel electrolyte formulations with high flash points (>140°C) composed of well-known conducting salts ($LiBF_4$; lithium bis(trifluoromethanesulfonyl) azanide, LiTFSA; lithium bis(oxalato) borate, LiBOB) which can be used at room temperature up to C-rates of >1.5 C in current cell configurations (e.g. NMC|C). These mixtures remain liquid below -10°C, which is proven in DSC measurements. Thus, the electrolyte mixtures have excellent safety properties which are significantly improved compared to standardly used electrolyte formulations (e.g. EC/DMC + 1M LiPF6, fp = 31 °C). The mixtures are analysed by standardly used physic-chemical methods and characterized according to viscosity, lithium mobility, density, electrochemical window and conductivity. Exemplarily, the electrochemical window of the electrolyte mixtures is demonstrated to be >4.5 V vs. Li/Li^+ (Pt as working electrode) and the conductivity of all mixtures is larger than 4 mS/cm. It is shown based on coin cells (CR2032), that discharge capacities of ~125 mAh/g can be delivered at 1 C (discharge rate) at room temperature (25 °C) in C|NMC cells (commercial electrode materials, C/10: ~150 mAh/g) (Figure 1).

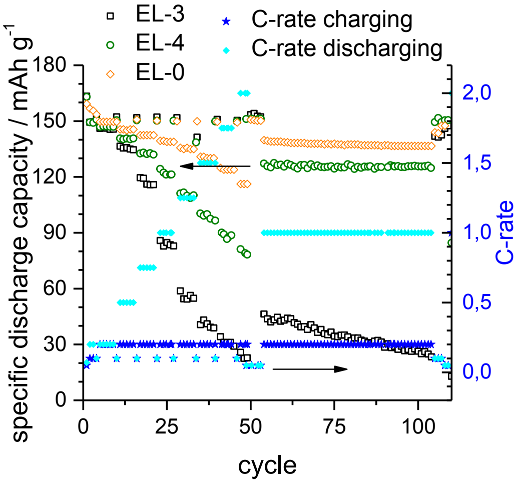

Figure 1: Performance of two different electrolytes (EL-3 and EL-4) compared to EC/DMC+1M $LiPF_6$ (2032 coin cell, 25 °C, NMC|C)

Conclusions and Outlook

Novel electrolyte formulations are presented with a special focus on the combination of safety and cell performance. The cell safety is enhanced by increasing the flash points of the electrolytes to above >140 °C. It is proven that the electrolytes can be used at moderate C-rates up to 1-2 C. Further, it is demonstrated that an electrolyte mixture based on LiTFSA and LiBOB is able to retain the specific capacity excellently without the need of additional additives. Based on the choice of the conducting salt, temperatures higher than 60°C could be achieved without electrolyte damage.

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In-Situ SANS Analysis of Lithium Sulphur Cells

***Dr. Charl Jafta*[1]**, *Helmholtz Zentrum Berlin, charl.jafta@helmholtz-berlin.de*
Dr. Sebastian Risse[1], Dr. Yan Yang[1], Anika Juhl[3], JProf. Simone Mascotto[2], Dr. Boris Ufer[2], Prof. Michael Fröba[2], Prof. Matthias Ballauff [1]

[1]Institute of Soft Matter and Functional Materials, Helmholtz-Zentrum Berlin (HZB)
[2]Institute of Inorganic Solid State Chemistry and Material Science, University of Hamburg

Keywords: in-situ, lithium sulphur battery, SANS, UV/vis

Introduction

Due to their high theoretical electrochemical capacity of 1675 mAhg-1 Lithium/Sulphur (Li/S) batteries are subjects of intense research [1]. However, there is still a loss of capacity with the number of charging cycles and the complicated processes within the Li/S battery are still not understood. Here we present an in-situ setup (Figure 1) that allows us to analyze the cathode of the Li/S cell with five different measurements.

Discussion

The small angle neutron scattering (SANS) measurement gives information about the macroscopic formation of the solid sulfur phase (S_8) that is present at the end of each charge cycle. The contrast matching method was used to match the elemental sulphur phase in the electrochemical cell. Simultaneous performance of electrochemical impedance spectroscopy (EIS) and UV/vis spectroscopy enables the access to kinetic processes at the solid electrolyte interface as well as the composition of the electrolyte. The cell temperature of the electrochemical cell is also monitored during the cycling process.

Figure 1: In-situ SANS cell

Conclusions and/or Outlook

The use of a monolithic carbon cathode material and the non-application of a separator layer make this cell design a model system for Li/S batteries. The authors have also developed an operando setup for X-ray radiography with the same parallel performed characterization methods. The results of the SANS measurement extend the view into the formation process of elemental sulphur to smaller length scales.

Acknowledgement: The SANS measurements were performed at PSI (SANS II) in Villingen, Switzerland and at MLZ (KWS-II) in Garching, Germany.

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Lithium-Air Battery Cathode Modification via an Unconventional Thermal Method Employing Borax

M.Sc. ***Fiedler Andy****, IAM-Energy Storage Systems, Karlsruhe Institute of Technology, andy.fiedler@kit.edu*
Dr. Vogt Andrew P., Macromolecular chemistry group, KIT, christopher.barner-kowollik@kit.edu
Dipl.-Phys. Pfaffmann Lukas, IAM-ESS, KIT,lukas.pfaffmann@kit.edu
Dipl.-Ing. Trouillet Vanessa, IAM-ESS, KIT, vanessa.trouillet@kit.edu
Breukelgen Jörg T., Staatliche Majolika Manufaktur Karlsruhe GmbH, J.Breukelgen@majolika-karlsruhe.com
Dr. Köppe Ralf, Institute of Inorganic Chemistry, KIT, ralf.koeppe@kit.edu
Prof. Dr. Barner-Kowollik Christopher, Macromolecular chemistry group, KIT, christopher.barner-kowollik@kit.edu
Dr. Scheiba Frieder, IAM-ESS, KIT, frieder.scheiba@kit.edu

Keywords: Energy, Lithium-Oxygen-Batteries, Carbon, Cathode

Introduction

The lithium/oxygen battery is an attractive candidate for a new generation of batteries due to its high theoretical energy storage density of 5200 Wh/kg^{-1} [1]. Due to its light weight, high conductivity and high surface area, carbon is the preferred material for the air-electrode in lithium-air-batteries. We investigated the difference in the electro reduction of oxygen by using an unconventional thermal method to improve carbon cathodes employing borax.

Discussion

Carbon felt electrodes were subjected to a thermal treatment by sealing them together with different amounts of borax under high vacuum. A roughening and pitting of the carbon fiber surface could be observed after the heat treatment which increased with the added amount of borax. Similarly the electrochemical activity of the carbon fibers toward oxygen reduction increased. Characteristic regions of the carbon fibers before (a-c) and after electrochemical cycling (d-f) are shown in **Figure 1**. The pits on the fiber surface appear slightly elongated and aligned along the carbon fiber direction. After the electrochemical cycling larger crystals can be found at the surface for the samples treated with 15 and 30 mg of borax. The 15 mg sample is covered with a layer of small plates and needles (**Fig 1e**), which stand vertically on the fiber, having only a narrow interface with the fiber surface. This is in stark contrast to the general opinion that a closed Li_2O_2 film is formed on the carbon surface and that the increasing film thickness is limiting charge transfer and eventually stops the electrochemical reaction. Another interesting observation is, that the morphology of the deposits is changing for the electrode treated with the highest borax content. For this sample fewer but larger mostly rhombic crystals can be observed. The crystal shape matches with the hexagonal crystal structure of Li_2O_2, suggesting that the deposits are indeed Li_2O_2.

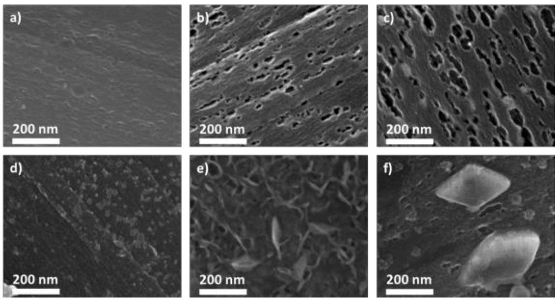

Figure 1: InLens SEM images of the carbon cathode surfaces after employing a) 5 mg, b) 15 mg, and c) 30 mg of borax in the kiln. The images a) – c) show the surfaces before cycling, whereas d) – f) show the same samples after discharge.

Conclusion

A commercially available carbon felt cathode was modified by an unconventional thermal method employing borax within a closed quartz ampule under high vacuum in a pottery kiln at 800 °C for the use in lithium-air batteries. The resulting cathodes performed more effective than the original material, which can be attributed to an increased carbon surface created by the borax treatment. Two different growth modes were observed for the deposition of Li_2O_2 crystals, plate-like and rhombic, which gives new insight in the deposition mechanism of the discharge product in lithium-air batteries.

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Nano-structured lithium manganese phosphate via solvothermal reaction and anion substitution

Lars Esmezjan, *Institute for Applied Materials-Energy Storage Systems (IAM-ESS), Karlsruhe Institute of Technology (KIT), lars.esmezjan@kit.edu*
Sylvio Indris, Institute for Applied Materials-Energy Storage Systems (IAM-ESS), Karlsruhe Institute of Technology (KIT)
Maximilian Kaus, Institute for Applied Materials-Energy Storage Systems (IAM-ESS), Karlsruhe Institute of Technology (KIT)
Vanessa Trouillet, Institute for Applied Materials-Energy Storage Systems (IAM-ESS), Karlsruhe Institute of Technology (KIT)
Murat Yavuz, Electrochemical Energy Storage, Helmholtz Institute Ulm (HIU), Institute for Applied Materials-Energy Storage Systems (IAM-ESS), Karlsruhe Institute of Technology (KIT)
Helmut Ehrenberg, Electrochemical Energy Storage, Helmholtz Institute Ulm (HIU), Institute for Applied Materials-Energy Storage Systems (IAM-ESS), Karlsruhe Institute of Technology (KIT)

Keywords: Lithium ion battery, $LiMnPO_4$, solvothermal, substitution, electrochemical behaviour

Abstract

Nano-structured $LiMnPO_4$ was synthesized via solvothermal reaction in diethylene glycol (DEG). Various parameters like precursor, pH-value and temperature treatment were controlled during synthesis. The products were characterized by SEM and XRD. To obtain phase pure $LiMnPO_4$ with uniform size distribution (100-300 nm) the precursors $Mn(CH_3COO)_2$, $Li(CH_3COO)$ and H_3PO_4 were used. Initial heating of $Mn(CH_3COO)_2$ in DEG for several hours enhanced the particle size uniformity. After solvothermal reaction the as-prepared materials were coated with carbon and annealed at 650 °C for 4 h. Electrochemical tests showed specific discharge capacities of 50 mAh/g at 0.02 C and a capacity fade of 10 % after 10 cycles. Furthermore, partial substitution of the phosphate anion (PO_4^{3-}) in the olivine-like structure was carried out with oxometallates. For silicate SiO_4^{4-} and titanate TiO_4^{4-} the substitution on the P-site was successful, but for vanadate VO_4^{3-} Mn-site substitution occurred. The occupations were determined by Rietveld refinement and through the oxidation states of the substituents which were determined from XPS measurements. The electrochemical performance was tested. All samples with anion substitution showed enhanced discharge capacities. The values were 104 mAh/g, 96 mAh/g and 59 mAh/g for $LiMnPO_4$ for vanadate, titanate and silicate, respectively. Moreover, the cycling stability was improved for the material with silicate and capacity retention of 97 % over 10 cycles was reached.

New approach to evaluate EASA of carbon electrodes using OsO_4

Dipl. Phys. Lukas Pfaffmann*, Energy Storage Systems (ESS), KIT, Lukas.Pfaffmann@kit.edu*
Dr. Frieder Scheiba, ESS, KIT, Frieder.Scheiba@kit.edu
Prof. Helmut Ehrenberg, ESS, KIT, Helmut.Ehrenberg@kit.edu

Keywords: Lithium-Ion Battery, Osmium Tetroxide, SEM

Introduction

The demands on the life time, capacity and power of portable energy storage systems such as lithium-ion batteries have increased significantly over the last decade. In addition to its high specific capacity of 372 mAh/g, carbon is inexpensive and lightweight. These advantages make it the negative electrode material of choice for most commercial applications. However, due to the anisotropic structure of graphite, lithium ions cannot intercalate in each direction. Therefore, only a fraction of the surface is active for lithium intercalation. This is generally addressed by the concept of the electrochemically active surface area (EASA) [1]. In this work, the EASA of two artificial graphite materials, differing in particle size, and an amorphous carbon material is investigated. For this purpose a new experimental technique based on osmium tetroxide staining is used.

Discussion

Due to its low scattering contrast visualization of lithium and lithium compounds in the electron microscope is highly challenging. Moreover, lithium cannot be detected by Energy Dispersive X-Ray (EDX) spectroscopy. Therefore, other means for lithium visualisation are necessary. Previously, it was sown that osmium tetroxide fume reacts strongly with Li and Li compounds [2] and its reaction product is stable under the electron beam. The significantly higher electron density of osmium eases visualisation by Energy selective Backscatter detector (EsB) or EDX in the electron microscope. It turned out that the reaction can also be used to extract lithium which is intercalated into carbon. Since the osmium containing reaction product can only form where lithium can effuse out of the graphite particle, it was used to mark intercalation sites on the carbon particle surface. The thickness of the reaction layer depends on the stored Li in the graphite, hence on the State Of Charge (SOC). It is well established that lithium can diffuse only parallel to the graphene layers in graphite [3]. Hence, lithium cannot intercalate into the particle where the graphene layers are parallel to the surface. This means that the parts where the graphene layers are parallel to the surface are not part of the EASA. As a consequence no Li-Os-O-compounds will be found on these parts of the surface (compare **Figure 1**). Consequently the EASA is reflected by the area covered by Li-Os-O-compounds. Three different carbon electrodes were studied: electrodes with coarse graphite (particle size 20 microns), fine graphite (particle size 9 microns) and an amorphous carbon. The electrodes were stained with OsO_4 at an SOC of 10 %. After the treatment, Ar-ion cross-sections were formed and examined in the scanning electron microscope using backscattered electrons. The evaluation of the image data gave the following EASA to surface ratio: coarse graphite 33 %, fine graphite 36 % and the amorphous carbon 72 %. The higher value of the EASA for the amorphous carbon is in agreement with its disordered structure, which leads to a more homogeneous distribution of entry sites on the particle surface.

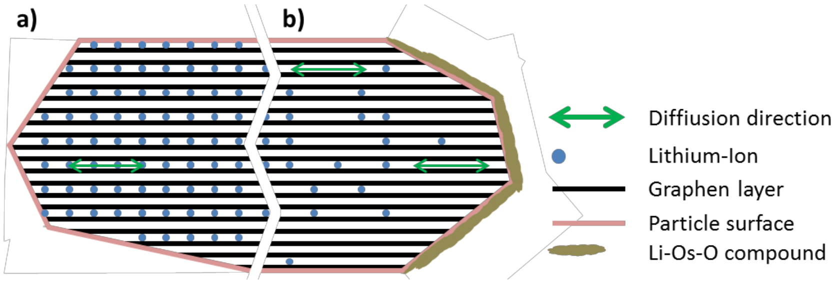

Figure 1: Sketch of a graphite particle a) before and b) after the osmium tetroxide staining.

Conclusions

The visualization of lithium intercalation sites on carbon anodes in the SEM was demonstrated using osmium tetroxide staining. With this technique it was possible to visualize the areal distribution of intercalation sites on carbon anodes and to determine the ratio of the electro-chemical active surface area in respect to the overall electrode surface.

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Nafion Coated Sulfur Electrode for High Performance Lithium-Sulfur Batteries

Xin-Hui Ma, *Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, PRC, r02524094@ntu.edu.tw*
Dr. Chia-Nan Lin, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, ROC, d98524016@ntu.edu.tw
Dr. Nae-Lih Wu, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, ROC, nlw001@ntu.edu.tw

Keywords: Li-S batteries, Self-discharge, Nafion, Transmission X-ray microscopy

Abstract

Electrical energy storage is one of the most critical needs for the 21st century. Li-ion batteries have proven successful in large-scale energy storage. Therefore, new systems are being sought for the next-generation batteries to provide much higher energy density and less cost. Lithium-sulfur (Li-S) battery is a promising electrochemical system. This study aims at significantly raising the Li-S performance from the viewpoints of morphology modification and coating of the electrode material.

A novel composite consisting of sulfur-activated carbon nanocomposite particles coated with a Nafion polymer film was prepared via a liquid mixing method as a cathode material for Li-S batteries. When measured under the rate of 0.1C, the reversible specific capacity of the Nafion coated electrode reaches 1100 mAh g^{-1}. It also shows improved cycle performance and Coulombic efficiency of Li-S cell. Self-discharge is also efficiently suppressed with Nafion coating. The dynamics of S and Nafion-coated S during electrochemical lithiation of Li-S cell have for the first time been revealed by in-operando TXM analysis. The Nafion polymer coated exhibits a core-shell interior structure that not only allows penetration of lithium ions transmission but also effectively prevents polysulfide anions transporting in the electrolyte. It is demonstrated from an in-operando measurements that the Nafion layer is effective in reducing shuttle effect and enhancing the stability and the reversibility of the electrode.

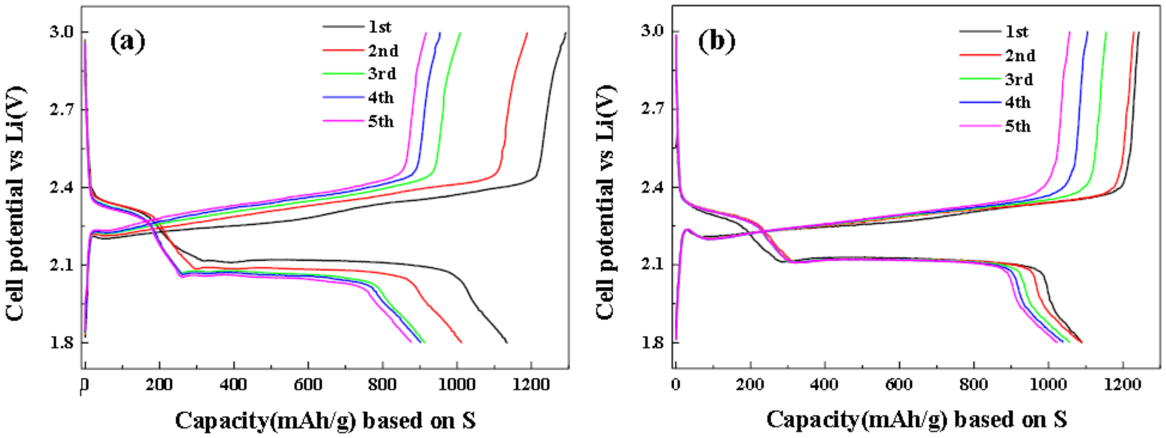

Figure 1: The voltage-versus-capacity plot for the charge/discharge profiles at 0.1C (a) nanocomposites of sulfur and carbon without Nafion coating, and (b) nanocomposites of sulfur and carbon with Nafion coating.

Acknowledgement:
This work is supported by the Ministry of Science and Technology, Taiwan, under the contract number: NSC 101-2221-E-002 -160 -MY3

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Novel Electrolytes for Batteries

Dr. Thomas J.S. Schubert*, IoLiTec Ionic Liquids Technologies GmbH, Heilbronn, Germany, info@iolitec.de*
Dr. Bettina Blumenröder, IoLiTec Ionic Liquids Technologies GmbH, Heilbronn, Germany, info@iolitec.de
Dr. Frank Endres, TU Clausthal, Clausthal-Zellerfeld, Germany, frank.endres@tu-clausthal.de

Keywords: Energy, Batteries, Ionic Liquids, Electrolytes

The efficient storage of electric energy delivered by renewable sources is one of the major challenges nowadays. Within the turnaround in energy policy a lot of research has been conducted to achieve an environmentally sound, reliable and affordable energy supply. One approach is the targeted development of rechargeable metal-air-batteries with high energy density based on readily abundant resources. Reducing the cost of raw materials using common and easy-to-apply elements such as aluminum, silicon or zinc instead of the rarer lithium which in addition requires dry room conditions for the large scale production is an important factor for more sustainable energy storage.

In this context, ionic liquids (ILs) based electrolytes became more and more important in the last years and thus part of many investigations due to their beneficial combination of properties, [1], [2] such as tunable viscosities and conductivities, chemical and thermal stability as well as large electrochemical windows (ECW) (**Figure 1**).

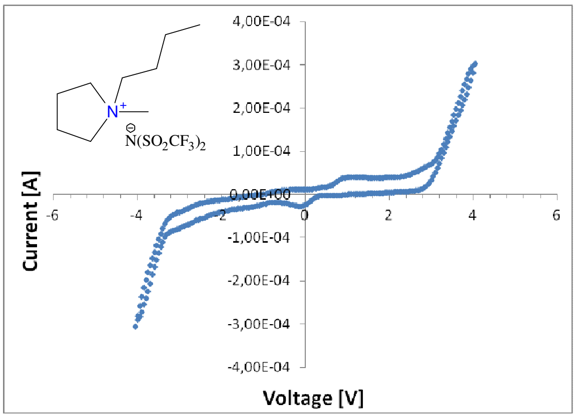

Figure 1: Electrochemical window (ECW) of BMPyrr BTA

We will report on recent developments in IL-technology. The focus is on the synthesis and characterization of novel lead structures of ionic liquids for this application. Furthermore, we will present also novel insights in the relation between structure and performance of ionic liquids.

Acknowledgement: We thank the BMBF (Federal Ministry of Education and Research) for funding.

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Function integrated machine module for the production of cell stacks

Dipl.-Ing. Manuel Baumeister, wbk, Karlsruhe Institute of Technology (KIT), manuel.baumeister@kit.edu
Prof. Dr.-Ing. Jürgen Fleischer, wbk, Karlsruhe Institute of Technology (KIT), juergen.fleischer@kit.edu

Keywords: Cutting, handling, cell stacking

Introduction

In Germany, we are currently experiencing a change of climate policy, mainly driven by cabinet decisions of the Federal Government of 6 June 2011 regarding the energy transition law. For this reason, the electrification of the powertrain and the establishment of stationary battery storage devices to complement wind turbines and photovoltaic systems are increasingly moving into the focus of German companies and research facilities. The biggest challenge in both application fields is the development of powerful and cost-effective battery cells [1]. In order to reach the cost objectives demanded by the industry, it is necessary to improve the technologies used to assemble the battery cells.

Discussion

Regarding the whole assembly process for lithium-ion pouch-cells, building up the cell stack by using single sheets represents the most critical process step. Thereby, the material web for the anodes and cathodes which were coated in a previous step are processed to become single sheets by mechanic or laser cutting. Afterwards, they are stacked on top of each other with separator sheets in a repetitive sequence by pick and place processes [2]. In response to this task, the wbk Institute of Production Science at KIT (Karlsruhe Institute of Technology) is working on an approach for developing a functional integrated machine tool **(Figure 1)** with low investment and running costs which cuts and deposits single electrode sheets with high precision. The core of this machine module is a stamping tool with an integrated vacuum gripper. At the moment of cutting, the orientation of the electrode is retained by the gripper and the sheet is guided to the bottom of the machine module where it is deposited with high accuracy inside a shaft magazine for the subsequent stacking process. In contrast to other state of the art machines, no expensive sensors for the detection of the electrode's position and no aligning of the sheets by additional machine axis is necessary, due to the integrated vacuum handling system.

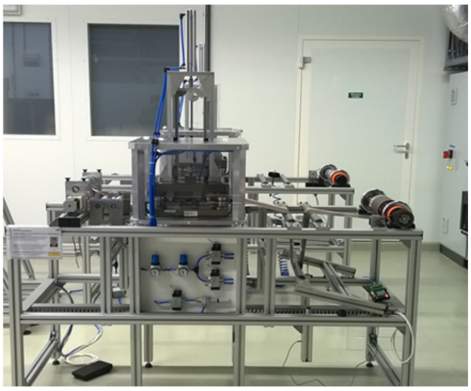
Figure 1: Machine module

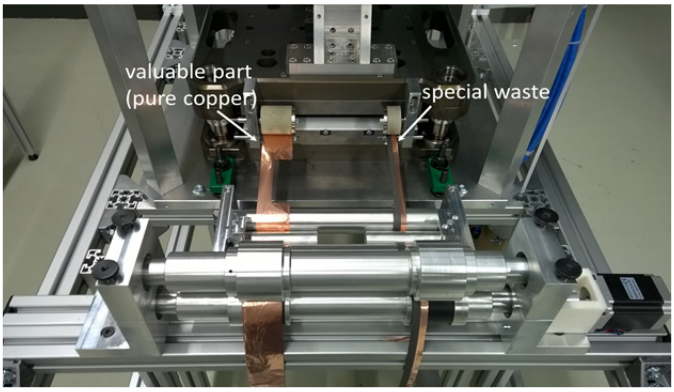

Figure 2: Separation of the cutting residue

Furthermore, one reason for low running costs is the fact that the cutting residue is removed after leaving the stamping tool by separating the valuable part from the waste that needs to be disposed at the operators expense **(Figure 2).** This is done by using circular blades, which are arranged directly at the outlet orifice of the tool.

Outlook

Contemporary, the above described machine module is used to fill shaft magazines which later have to be transported manually to the subsequent cell assembly steps. In the future, two machine modules, one for the anodes and one for the cathodes, may be connected and supplemented with a separator machine to produce complete cell stacks automatically.

Acknowledgement: This work has been funded as part of the project 'Competence E'. We thank the board of the KIT for the support.

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Continuous folding process for the assembly of lithium-ion cells

Sebastian Haag, wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT), sebastian.haag@kit.edu
Prof. Dr.-Ing. Jürgen Fleischer, wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT), juergen.fleischer@kit.edu

Keywords: Lithium-ion battery, production science, manufacturing

Introduction

Cell manufacturing is unmistakably the main cost driver of the current production process of lithium-ion cells [1]. For achieving a breakthrough in lithium-ion technology in stationary applications and electro-mobility, it is fundamental to reduce costs in cell manufacturing. This reduction can be achieved through cost efficient assembly processes and by increasing the production yield. A significant process in cell manufacturing is the stacking of electrodes and separator foils. State of the art stacking and assembly processes are either complex and time-consuming or they have a lower energy density. Therefore, the development of an advanced cell stacking technology is required.

Discussion

Current state of the art stacking technologies for lithium-ion battery cells can be divided into two categories: continuous and discontinuous stacking processes [2]. Discontinuous procedures involve single sheet stacking and z-folding with single sheets. Continuous processes include z-folding and winding. Discontinuous technologies have a high energy density but consist of complex production steps with many single steps such as cutting the single sheet, cleaning the sheets of cutting particles, handling and positioning of every single sheet. In contrast, the continuous technologies do not contain as many process steps but have a lower energy density due to the material arrangement or its unsuitability for thickly coated materials. Thus, continuous processes have a high potential based on the cost-efficient and robust production process. Consequently, a new continuous process with a high energy density and the possibility of handling thickly coated materials has been developed at the KIT. With this new process, called “Helix”, an endless prismatic stack can be built. In this process, no cutting and no gripping is needed. The materials used for this process are two continuous separators, an intermittent anode coated on both sides and an intermittent one-side coated cathode. The two separators and the anode will be processed together. These materials will be folded in the coating gap of the anode. The cathode is arranged in a 90° angle to these three materials. The cathode is placed above the three sheets: separator, anode and second separator, and after positioning the cathode, the three-material-line is folded over the cathode. For realising, analysing and optimisation purposes, a pilot assembly is built. This pilot plant for the continuous folding of electrodes and separators at the KIT is shown in **Figure 1**.

Figure 1: Pilot plant for the continuous folding process

The folding of the materials is of vital importance for this continuous process, since the folding process determines the accuracy of the stack and the cycle time of production as well as the energy density. In the bending zone, it is not possible to have a coated electrode. In order to optimise the energy density, it is necessary to minimise the bending zone.

Conclusions and Outlook

The presented new folding process for the stacking of electrodes and separators now allows to realise cost-efficient manufacturing of lithium-ion cells. To achieve the objectives such as high positioning accuracy for each layer, gentle handling of material and short cycle times, a parameter variation and the detection of interaction will be investigated with the specially-built pilot plant at the KIT. This will offer the opportunity to optimise the folding process.

Acknowledgement: This work has been funded as part of the project ‘Competence E’. We thank the Karlsruhe Institute of Technology for the support.

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Sodium-ion batteries for low cost electrochemical energy storage

Christoph Vaalma[ac], *Luciana Gomes Chagas*[abc], *Daniel Buchholz*[abc], *Liming Wu*[abc] *and Prof. Dr. Stefano Passerini*[ac]

a) Helmholtz Institute Ulm (HIU) Electrochemistry of Batteries, Helmholtzstrasse 11, 89081 Ulm, Germany
b) Institute of Physical Chemistry, University of Muenster, Corrensstrasse 28/30, 48149, Muenster, Germany
c) Karlsruhe Institute of Technology (KIT), PO Box 3640, 76021 Karlsruhe, Germany.
E-Mail: christoph.vaalma@kit.edu, luciana.chagas@kit.edu, daniel.buchholz@kit.edu, liming.wu@kit.edu, stefano.passerini@kit.edu

Keywords: Cost study, sodium-ion battery

Introduction:

Sodium-ion batteries (SIBs) record an increasing scientific and commercial interest within the recent years and are considered as a promising low-cost technology for large-scale stationary energy storage.[1] SIBs have a lower ability to provide high power needed for transportation as well as high energy needed for electric vehicles compared to lithium-ion batteries (LIBs), but enable the use of aluminium (sodium is not alloying with it [2]) as anode current collector instead of the heavy and expensive copper. This aspect is additionally underlined by the high abundance, uniform distribution and low-cost of sodium-ion raw materials. However, detailed studies about the cost of SIBs are still missing.

Discussion:

Herein, we present a detailed study and cost evaluation for the most commonly used materials and cell components in SIBs. The cost advantage of SIBs is demonstrated although it has to be taken into account that we could regard the raw material cost only. The substantial cost savings are anchored to the use of cheap, abundant and environmentally friendly elements like carbon, manganese, magnesium and iron. The cost per kWh on the cathode side for example can be reduced to 40%, if $Na_{0.67}Mn_{0.5}Fe_{0.5}O_2$ and $LiMn_2O_4$ are compared (Table 1).

Material	Molar mass	Capacity (Ah/kg)	Av. Potential vs. Li or Na (V)	Cost [1] ($/kg)	Cost[1] ($/kAh)	Cost[1] ($/kWh)
Graphite (Li)		330		3.52	10.7	
Hard Carbon (Na)		300		2.52	8.4	
$LiNi_{0.33}Co_{0.33}Mn_{0.33}O_2$	96	175	3.8	14.24	81.4	21.4
$LiMn_2O_4$	181	100	4.1	2.75	27.5	6.8
$Na_{0.67}Ni_{0.22}Co_{0.11}Mn_{0.66}O_2$	103	140	3.3	7.75	55.4	16.8
$Na_{0.67}MnO_2$	102	175	2.7	1.69	9.6	3.6
$Na_{0.67}Mg_{0.2}Mn_{0.8}O_2$	96	150	2.7	1.60	10.7	4.0
$Na_{0.67}Mn_{0.5}Fe_{0.5}O_2$	103	175	2.9	1.38	7.9	2.7

Table 1: Cost of active materials, derived from publicly available prices (not including energy, processing, labour etc.)

Conclusion:

Our cost analysis proves the assumed but never verified conjecture that SIBs can provide significant cost advantages compared to LIBs. The commonly used active materials, but also the current collectors and conductive salts in SIBs are cheaper and more price stable. Taking into account that material processing and cell manufacturing is similar to LIBs, SIBs can be regarded as a complementary battery technology. Attractive applications are those in which cheap and cost-efficient energy storage is the critical issue.

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Influence of substrate material and annealing process on phase and crack formation of LIB electrodes in the system Li-Mn-O

M. Strafela[a], *J. Fischer*[a], *N. Arikan*[a,b], *H. Mozaffari-Jovein*[b], *H.J. Seifert*[a], *S. Ulrich*[a]

[a]*Karlsruhe Institute of Technology (KIT), Institute for Applied Materials – Applied Materials Physics (IAM-AWP), Hermann-von-Helmholtz-Platz 1,*
76344 Eggenstein-Leopoldshafen, Germany

[b]*Furtwangen University (HFU), Faculty of Industrial Technologies, Campus Tuttlingen, Kronenstraße 16, 78532 Tuttlingen*

Abstract

Lithium-ion batteries (LIB) have become one of the most used energy storage units. They have not only revolutionized the portable electronics market, but also attracted a great deal of attention in the automotive industry. Compared to the commercial $LiCoO_2$ cathode material $LiMn_2O_4$ has become an important alternative as a cathode material since Manganese is environmentally friendlier and non-toxic and production costs are lower. Magnetron sputtering is a powerful method for materials development and produces homogenous and dense films without any additives and can be applied in mass production for all solid state thin film LIB.

In this work Li-Mn-O thin film cathodes have been deposited onto Silicon, oxidized Silicon and stainless steel substrates by non-reactive r.f. magnetron sputtering from a ceramic $LiMn_2O_4$ target. The sputtering pressure was 7 Pa and r.f. power was 100 W. Film thickness was about 1.5 µm The as-deposited films were annealed in vacuum in a temperature range from 300 °C to 700 °C for one hour to induce crystallization. The microstructure of the films was characterized by X-ray diffraction (XRD) and by unpolarized micro-Raman spectroscopy at room temperature. Surface characterization of the films was carried out by scanning electron microscope (SEM) and atomic force microscope (AFM). Correlations between substrate materials and annealing process on phase and crack formation are discussed in detail.

Optimal flow rate and load sharing control for flow batteries

Sebastian König, *Prof. Dr. Thomas Leibfried, Institute of Electric Power Systems and High Voltage Technology, Karlsruhe Institute of Technology, sebastian.koenig@kit.edu*

Keywords: Flow batteries, battery management, stationary storage

Introduction

Flow batteries are very promising for grid-scale storage, because of the independently scalable energy and power rating, low toxicology and intrinsic fire and explosion protection. However, these systems have a higher grade of complexity, compared to other battery types because of the combination of electric and hydraulic circuits. In terms of operation, this disadvantage can be resolved by optimal control strategies which can be embedded in a flow battery management system (FBMS). The presented control strategies cover a pumping control for the electrolyte and an optimal load sharing between the battery strings which requires a sophisticated idle management for the non-used strings, to prevent self-discharge.

Optimal pumping strategies

For a single-stack test system, flow rate optimization has been reported in [1]. Here we adapt their approach to a string with six-stacks, a rated power of 54 kW and a complex hydraulic circuit. The main loss mechanism involved in this study is pumping losses. Furthermore, concentration over-potential has to be considered as well, which occurs because of limited mass-transfer in the diffusion layer around the electrodes, as well as cells' state of charge (SOC) which differs from tank SOC. Both concentration over-potential mechanisms as well as a model of the hydraulic circuit to determine pumping losses have been implemented in our multi-physical model. The theoretically required electrolyte volumetric flow rate can be derived from Faradays first law of electrolysis and therefore depends on battery SOC and power. If a constant flow rate is used, it has to fulfil the requirements of the extreme operations points, i.e. charging of the nearly full battery or discharging of the nearly empty battery, both with rated power, where the largest flow rates occur. This leads to an oversupply of electrolyte during times where less power is required or the SOC is in the middle range. Finally very low efficiencies under partial load conditions do result, where variable flow rates perform much better, see **Figure 1**. All efficiencies have been averaged over the SOC. The flow factor (FF) scales the theoretically required volumetric flow rate, which is kept variable and therefore varies with SOC and load current.

Optimal load sharing and idle management

Under partial load conditions, it is not reasonable to dispatch all battery strings equally. In fact the simulatively derived string efficiency curves (**Figure 1**) can be used to obtain an optimal distribution of the system power to the battery strings. The strings which are not required during low-load times are separated from the hydraulic circuit by the idle management system. Thereafter, the energy conversion system extracts the energy which is still stored inside the deactivated stacks. Before reactivation of a string it has to get resupplied with fresh electrolyte before charging or discharging operation is supposed to start. The optimal load distribution as well as the idle management leads to a large efficiency gain under partial load conditions, see **Figure 2**.

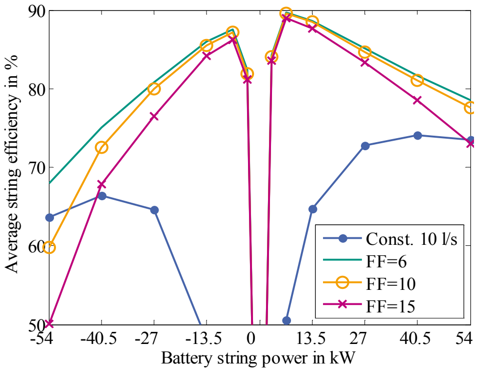

Figure 1: Efficiency for constant and variable volumetric flow rate.

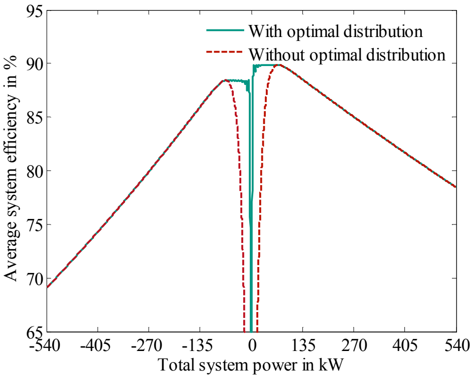

Figure 2: Optimal and non-optimal load sharing in a 540- kW-system, comprising ten 54-kW-strings

Acknowledgement: This work is supported by the Initiative and Networking Fund of Helmholtz Association, in the frame of the Helmholtz Energy Alliance.

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Solid state thin film electrolyte for fluoride ion batteries

Le Zhang, *Helmholtz Institute Ulm (HIU), Electrochemical Energy Storage, le.zhang@partner.kit.edu.*
Dr. M. Anji Reddy, Helmholtz Institute Ulm (HIU), Electrochemical Energy Storage, munnangi.reddy@kit.edu.
Dr. Maximilian Fichtner, Helmholtz Institute Ulm (HIU), Electrochemical Energy Storage; Karlsruhe Institute of Technology (KIT), Institute of Nanotechnology (INT), maximilian.fichtner@kit.edu.

Keywords: Fluoride ion battery, thin film battery, solid state electrolyte, tysonite structure, fluoride ion conductor

Introduction

Since the solid state bulk-type fluoride ion batteries (FIB) were reported [1], this type of new energy storage system can be considered as an interesting battery system due to its high theoretical energy density [2,3]. However, the capacities do not reach its theoretical values and fade quickly during the cycling. Large improvements are needed concerning the performance of the electrodes and the electrolyte, in particular for the ionic conductivity of the solid electrolyte [4]. In case of bulk-type FIB, the thick electrolyte layer leads to a high internal resistance. At the same time, a high contact resistance can be produced due to an insufficient contact at the interface of electrode/electrolyte. Thus, thin-film battery may be a potential solution to improve the performance of solid-state battery, because of its short ion diffusion length and its good contact between electrode and electrolyte.

In the previous work [1, 4 - 6], $La_{0.9}Ba_{0.1}F_{2.9}$ has been demonstrated as an optimal composition for the electrolyte for FIB, due to its high ionic conductivity. And $La_{0.9}Ba_{0.1}F_{2.9}$ thin film electrolyte was also fabricated through a spin-coating method [7]. Although the overall ionic conductance of the thin film was greatly improved, because of the reduced thickness, the conductivity was still below that of the bulk type electrolyte. The porous structure of the films was identified as a major reason. To improve the conductivity, it would thus be necessary to make denser films.

Discussion

In this work, the dense films of $La_{0.9}Ba_{0.1}F_{2.9}$ electrolyte were obtained through modifying the temperature and time of preparation. The films were characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and electrochemical impedance spectroscopy (EIS). It was shown that the films that were sintered at 400 and 450 °C kept the tysonite structure. At 500 °C, an impurity of LaOF was formed. From the SEM images, it was found that, in principle, higher temperature and longer sintering time resulted in dense films. According to the EIS data, the film which possessed the highest conductivity was prepared at 450 °C for 4 h. The value of the conductivity at 170 °C was 1.6×10^{-4} S cm^{-1}, which was similar with the bulk-type electrolyte [5]. Moreover, the specific conductance was greatly improved. The results demonstrated that the optimal condition for the preparation of dense film electrolyte is at 450 °C for 4 h.

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Lithium ion transport kinetic in ultrafast laser structured $LiFePO_4$ composite electrodes

***Melanie Mangang*, Karlsruhe Institute of Technology, IAM – AWP, melanie.mangang@kit.edu**
Dr. Petronela Gotcu-Freis, Karlsruhe Institute of Technology, IAM – AWP, petronela.gotcu-freis@kit.edu
Prof. Dr. Hans Jürgen. Seifert, Karlsruhe Institute of Technology, IAM – AWP, hans.seifert@kit.edu
Dr. Wilhelm Pfleging, Karlsruhe Institute of Technology, IAM – AWP, wilhelm.pfleging@kit.edu

Keywords: LiFePO4, Ultrashort laser ablation, Galvanostatic intermittent titration technique, cyclic voltammetry

Abstract

Since its discovery by Padhi et al. [1], lithium iron phosphate ($LiFePO_4$) is a promising candidate as cathode material for lithium-ion batteries due to its cost efficiency, environmental compatibility and structural stability. Nevertheless, $LiFePO_4$ has a low rate capability. In order to overcome this drawback, electrical conductivity and lithium-ion kinetic have to be improved. A common and very well investigated approach for increasing the electrical conductivity is to coat $LiFePO_4$ particles with conductive graphite [2]. The lithium-ion transport kinetics can be enhanced by increasing the active surface area of $LiFePO_4$ particles, which can be realized by reducing the particle size. However, a reduction of the particle size leads to a decrease of the active particle packing density [3]. Another method to increase the lithium-ion transport kinetic is the generation of three dimensional microstructures in the electrode surface using ultrafast laser ablation. It was shown for lithium cobalt oxide ($LiCoO_2$) and lithium manganese oxide ($LiMn_2O_4$) thin film and composite electrodes that the capacity retention and cycle stability were enhanced due to the laser generated surface microstructures [4,5]. By using ultrafast laser pulses, the thermal-induced material modifications can be reduced. Furthermore it was shown, that ablation efficiency can be significantly increased.
A quantitative approach for a better understanding of the lithium-ion transport rate in electrodes with laser generated microstructures is the determination of the diffusion coefficient. For this purpose, electrochemical methods such as cyclic voltammetry (CV) and galvanostatic intermittent titration technique (GITT) have been applied. As an example, **Figure 1** shows the cyclic voltammograms of a cell (Swagelok$^{®}$ cell type using lithium metal as anode material) with an unstructured $LiFePO_4$ composite cathode and a $LiFePO_4$ composite cathode structured with ultrashort laser pulses. The peak current increases and the shift of the current peaks decreases due to the laser generated surface structures. As a consequence, the lithium-ion diffusion kinetic was improved and thus the cell polarization decreased.

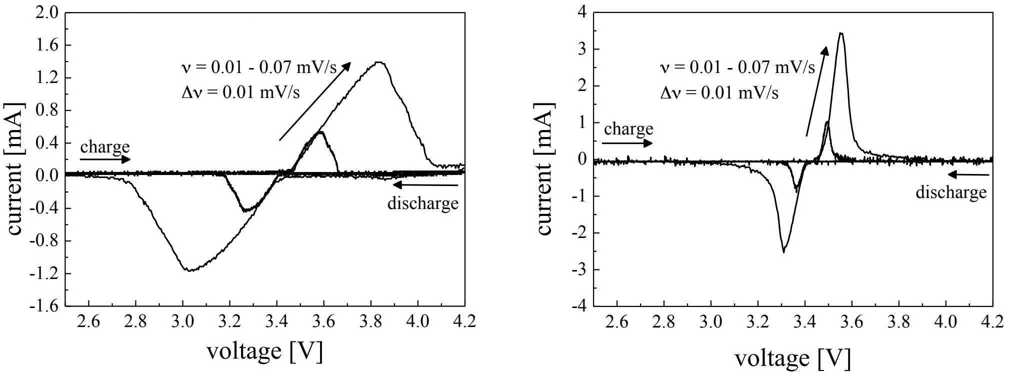

Figure 1: Cycle voltammograms of a cell with an unstructured $LiFePO_4$ cathode (a) and a $LiFePO_4$ cathode which was structured with ultrashort laser pulses (b).

Furthermore, as a result of the three dimensional structures, the capacity retention and the cycle stability were improved.
The diffusion coefficient values of a cell with an unstructured cathode and a cell with a laser structured cathode obtained by CV were compared. The results determined by CV are supported by the results obtained by the GITT measurements.

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Multi-dimensional thermal modelling of prismatic Li-ion batteries

***Dipl.-Ing. Daniel Werner**, Institute of Thermal Process Engineering (TVT), Karlsruhe Institute of Technology (KIT), daniel.werner@kit.edu*
Dipl.-Ing. Philipp Seegert, Institute of Thermal Process Engineering (TVT), Karlsruhe Institute of Technology (KIT), philipp.seegert@kit.edu
Prof. Dr.-Ing. Thomas Wetzel, Institute of Thermal Process Engineering (TVT), Karlsruhe Institute of Technology (KIT), thomas.wetzel@kit.edu

Keywords: Thermal modelling, numerical simulation, Li-ion battery

Introduction

The storable energy of automotive battery packs for hybrid and full electric driven vehicles has to be used as extensively as possible and high power throughput and maximum utilization of the nominal capacity are key development goals. Nevertheless, safe operation is limited to a certain temperature range. This makes operation of Li-ion batteries in automotive applications without reducing the battery's life span and without exceeding recommended temperatures a challenging task. At low temperatures the output power is significantly reduced [1,2] and high charging rates cannot be applied. One of the reasons behind that restriction is the deposition of metallic lithium at the anode, which reduces the available capacity irreversibly and may even cause internal short circuits. However, charging at low temperatures can occur in case of recuperation with a cold battery pack. Elevated temperatures support parasitic irreversible (electro)chemical reactions inside the battery. Only batteries in adequate thermal state facilitate a high power output because of reduced ohmic resistances and raised diffusion coefficients inside the battery cell, respectively. The identification of the adequate temperature range und the according temperature inside the battery cells is essential for the design of batteries and their thermal management systems. Thermal modelling with adequate numerical techniques is an effective and efficient way in the development process of such systems.

Discussion

In this contribution a comparison of thermal models for prismatic Li-ion batteries with different levels of details will be presented. Some numerical models for batteries, e.g. those addressing ageing mechanisms or those integrated into comprehensive car models, require fast thermal simulations with a sufficient accuracy for long-timescale simulations within an acceptable computational time. Others require high spatial resolution of temperature for relatively short timescales or for representative driving cycle sections. Coupled electro-thermal simulations with an underlying complex 3D model of a reference battery cell have been used to identify the principal heat flow paths, thermal capacities and their geometrical equivalents. Based on these results, multi-dimensional thermal models consisting of 1D, 2D, and pseudo-3D type have been built up to cover different levels of detail and computational effort. **Figure 1** shows the principal paths and magnitude of heat flow in a prismatic cell, cooled using the bottom surface of the case, as an example.

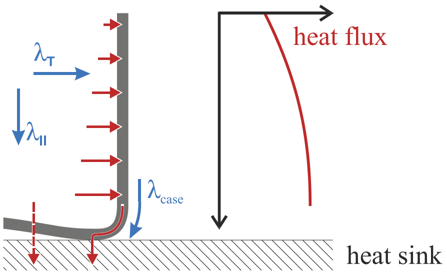

Figure 1: Principal heat flow paths, heat flux and thermal conductivity of a prismatic hardcase cell

Conclusion

An outline of representative electro-thermal simulations with automotive boundary conditions of the battery cells is presented to demonstrate the capabilities of each thermal model.

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In situ detection of Lithium plating on Graphite by pulse-relaxation and optical microscopy

***Christian Uhlmann**, Institut für Werkstoffe der Elektrotechnik, Karlsruhe Institute of Technology, christian.uhlmann@kit.edu*
Dr.-Ing. Moses Ender, Institut für Werkstoffe der Elektrotechnik, Karlsruhe Institute of Technology, moses.ender@kit.edu
Dr.-Ing. Jörg Illig, Bosch Engineering GmbH, Robert-Bosch-Allee 1, D-74232 Abstatt, joerg.illig@kit.edu
Prof. Dr. Rolf Schuster, Institut für Physikalische Chemie, Karlsruhe Institute of Technology, rolf.schuster@kit.edu
Prof. Dr.-Ing. Ellen Ivers-Tiffée, Institut für Werkstoffe der Elektrotechnik, Karlsruhe Institute of Technology, ellen.ivers@kit.edu

Keywords: Lithium-ion batteries, lithium plating, electrochemical modeling, in-situ optical investigations

Introduction

Lithium plating describes the deposition of metallic Lithium onto the anode surface. This phenomenon takes place in conditions of high current and/or low temperatures, due to several kinetic limitations. The principle reason is the slow solid-state diffusion of Lithium ions within the graphite, which depends on temperature and the Lithium content. In the case of high currents, the resulting overpotential causes the anode surface potential to undergo 0 V versus Li/Li^+ [1,2]. At this point the formation of metallic Lithium is thermodynamically permissible.

The aim of this study is to increase the understanding of Lithium plating *in-operando*. It is hoped this will lead to a suitable visualization. For that purpose, experimental graphite half-cells were investigated combining optical and electrochemical measurements.

Discussion

Measurements were performed under different current rates, varying from 1 C to 10 C, while gauging the voltage course during current pulses and the subsequent period of potential relaxation. The pulse lengths (1-10 min) were adjusted with the current rates, so that every current pulse transported the same amount of charge, guaranteeing the same final SoC (state of charge). The relaxation phases can therefore be directly compared to each other. When plating occurs, a distinctive plateau can be recognized within these relaxation phases.

To investigate the influence of temperature, these measurements were done in the range of 0-25 °C, plating is more pronounced at lower temperatures.

A new test-cell design was developed for observing Lithium metal plating in operando by using a confocal microscope. This setup allowed us to study the kinetics of Lithium metal plating and dissolution at the surface of individual graphite particles at room temperature.

Combining both optical and electrochemical in-situ investigation methods, the occurrence of Lithium plating could be confirmed as being directly correlated to the formation of a plateau in the potential relaxation curves after a charging pulse. This plateau was interpreted as mixed potential resulting from the interplay of Lithium intercalation and the dissolution of the reversible part of the deposited metallic Lithium on the graphite surface [3].

Outlook

A direct correlation of the potential trends in both cell setups cannot be done at present, since the here presented optical cell possesses no reference electrode. However, an improved setup utilizing a reference electrode will be presented in the near future.

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Influence of driving cycles on Li-ion cells studied by electrochemical-calorimetric measurements

***Dr. Carlos Ziebert,* carlos.ziebert@kit.edu**
Dr. Andreas Melcher, **andreas.melcher@kit.edu**
Dipl.-Ing. Boxia Lei, **boxia.lei@kit.edu**
Dr. Magnus Rohde, **magnus.rohde@kit.edu**
Prof. Dr. Hans Jürgen Seifert, **hans.seifert@kit.edu ,**

All authors: Institute of Applied Materials - Applied Materials Physics, Karlsruhe Institute of Technology

Keywords: Li-ion cell, calorimetry, electrochemical testing, driving cycle, thermal management

Introduction

It is important to understand the temperature evolution of lithium ion cells, since both are closely related to battery performance and safety issues. In this study commercial 20 Ah pouch cells with $LiFePO_4$ (LFP) cathodes were cycled using the ARTEMIS Urban driving profile [1] under isoperibolic (30 – 50 °C) and adiabatic conditions in an Accelerating Rate Calorimeter (ARC, THT Company) with a maximum 1C discharge rate in the State of Charge (SOC) window of 90% to 10%. The maximum temperature increase has been determined for both conditions.

Discussion

Under isoperibolic conditions the temperature of the calorimeter chamber is kept constant, while the temperature change of the pouch cell is recorded. This simulates a single cell under constant environmental temperature. Adiabatic tests simulate the worst-case scenario of a battery pack without any cooling. In this case the temperature of the calorimeter chamber is controlled by a main surface thermocouple fixed on the surface of the pouch cell. The calorimeter temperature follows immediately any increase of the cell temperature preventing any heat exchange with the surroundings. Under isoperibolic conditions the temperature increase of the 20 Ah LFP pouch cell cycled at a max. discharge rate of 1C is about 0.5° C at an environmental temperature of 40° C. Under adiabatic conditions the temperature increase for the same maximum discharge rate rises to about 9° C for T_{start} = 43° C after a time of 60 h as can be seen in Figure 1.

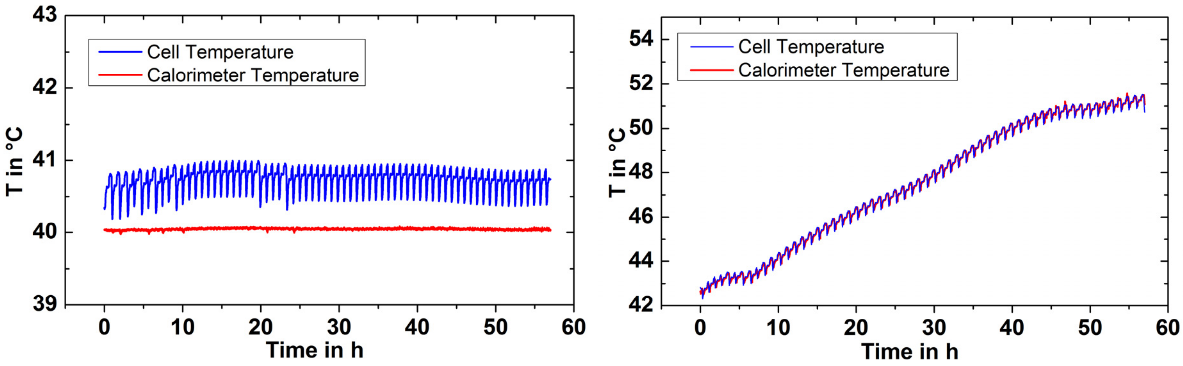

Figure 1: Comparison of isoperibolic and adiabatic cycling of a LFP pouch cell with ARTEMIS Urban Profile at max. 1C discharge rate.

Conclusions and Outlook

The results shown in this work will help to improve thermal management of Li-ion batteries, because they help to improve the understanding of the processes that lead to heat generation during charging and discharging. The next steps will be to calculate the heat effects from the measured temperatures and to compare the presented experimental results with simulation results coming from an equivalent circuit model that has been implemented in Matlab®/Simulink®/ Simscape^{TM}.

Acknowledgement: This R&D project is partially funded by the Federal Ministry for Education and Research (BMBF) within the framework "IKT 2020 Research for Innovations" under the grant 16N12515 and is supervised by the Project Management Agency VDI | VDE | IT. Additional funding was granted by the Helmholtz program Science and Technology of Nanosystems (STN) and by the Helmholtz Portfolio Project "Electrochemical Storage in the System – Reliability and Integration Aspects".

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Table-driven Li-Ion Battery Cell Model for a BMS Development Platform

Dr. Andreas Melcher[1]*, andreas.melcher@kit.edu*
Dr. Carlos Ziebert[1]*, carlos.ziebert@kit.edu*
Dipl.-Ing. Matthias Gulbins[2]*, matthias.gulbins@eas.iis.fraunhofer.de*
Dipl.-Ing. Thomas Markwirth[2]*, thomas.markwirth@eas.iis.fraunhofer.de*
Dipl.-Ing. Thomas Uhle[2]*, thomas.uhle@eas.iis.fraunhofer.de*
Dr. Joachim Haase[2]*, joachim.haase@eas.iis.fraunhofer.de*

[1] *Institute of Applied Materials - Applied Materials Physics (IAM-AWP), Karlsruhe Institute of Technology*
[2] *Fraunhofer-Institute Integrated Circuits, Design Automation Division (Fraunhofer IIS/EAS Dresden)*

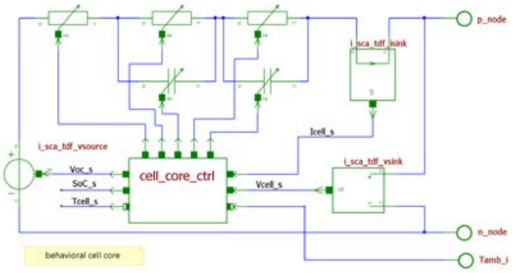
Keywords: System Simulation, Equivalent Circuit Models, Li-ion Batteries

Introduction

As part of the IKEBA project [1], we have created a prototype of a virtual design platform. This platform allows to verify the suitability and the interaction between selected hardware components (Li-Ion batteries and semiconductor circuits for battery monitoring), and of the software of a battery management system (BMS) by simulation. A table-driven Li-ion battery cell model based on an equivalent circuit model approach is used in this platform in order to describe battery packs. Enabling the investigation and comparison of a large number of BMS hardware and software versions requires efficient models and simulation algorithms. Therefore, special effort is necessary in order to increase the efficiency of the cell model evaluation.

Discussion

The basis of the virtual design platform is the design environment COSIDE® for the development of electronic systems. COSIDE® is a tool that can be used to model and simulate highly complex electronic and heterogeneous systems along with software running on those systems [2]. To this end, the hardware components are modelled with the hardware description languages SystemC and SystemC AMS [3]. This approach allows to take into account the characteristics of the batteries, circuits to balance unequal states of charge (charge balancing), and load profiles. In addition, it enables a detailed integration of the components of the battery monitoring integrated circuits (BM ICs) with respect to the characteristics of the A/D converters, delay times etc. and the communication interface (specifically SPI) between BM ICs, and a battery management controller at high simulation speed. The electrical equivalent circuit model of the Li-ion cell has been implemented as electrical linear network (ELN) using SystemC AMS. In order to ensure a quick model evaluation, we developed a special technique yielding a linear problem for each time step. The network model consists of the internal resistance of the cell and of two parallel RC elements in series. The values of these elements depend on the state of charge (SOC) and the temperature and are represented by lookup tables (LUT). The table values were determined by current interruption technique (CIT) measurements [4]. The LUTs approximate the real behaviour by interpolation and extrapolation during the simulation of the BMS.



Conclusions and Outlook

Regarding future work, we intend to include potential faulty behaviour of the components in the models in order to investigate fulfilment of safety requirements of the BMS. Based on a SystemC/SystemC AMS description, an executable virtual prototype can be generated. Therefore, our approach allows for a transition to real-time simulation hardware and thus the application in hardware-in-the-loop testing.

Acknowledgement: This R&D project is partially funded by the Federal Ministry for Education and Research (BMBF) within the framework "IKT 2020 Research for Innovations" under the grants 16N12515 and 16N12440 and is supervised by the Project Management Agency VDI | VDE | IT.

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Parameter Identification For Equivalent Circuit Models Of Li-Ion Batteries Using The Current Interruption Technique

***Dr. Andreas Melcher**, andreas.melcher@kit.edu*
Dr. Carlos Ziebert, , carlos.ziebert@kit.edu
Dipl.-Ing. Boxia Lei, boxia.lei@kit.edu
Dr. Magnus Rohde, magnus.rohde@kit.edu
Prof. Dr. Hans Jürgen Seifert, hans.seifert@kit.edu

All authors: Institute of Applied Materials - Applied Materials Physics (IAM-AWP), Karlsruhe Institute of Technology

***Keywords:** Parameter Identification, Equivalent Circuit Models, Li-ion Batteries, Current Interruption Technique*

Abstract:

The phenomenological modeling of Li-ion batteries can be realized by Equivalent Circuit Models (ECM), where the electrical behavior of the battery is described by a passive electrical network consisting in general of passive electrical elements like resistors, capacitors, inductors and voltage- resp. current sources [1].

In this work based on experimental measurements [2] in an Accelerating Rate Calorimeter (ARC) using the Current Interruption Technique (CIT) such an ECM model will be derived and the corresponding parameters i.e. resistors, capacitors, voltage soures and relaxation times will be identified.

The CIT-based ECM will be expressed in terms of a system of nonlinear ordinary differential equations for the corresponding inner voltages u_i, $i = 1, \dots n$, where n denotes the number of the relaxation mechanisms in the cell, extended with two linear differential equations for the State Of Charge (SOC) and the overall temperature T of the battery and an algebraic equation for the terminal voltage u_L of the battery [3].

It is assumed in this modeling that the system parameters i.e. resistors R, capacitors C, voltage sources etc. are functions of SOC and T respectively. Unfortunately this depencence of the parameters is not explictiy known in general, but with the help of the CIT measurement technique it is possible to identify these parameters for several known values of the SOC and T in terms of lookup-tables. The unknown nonlinear functions for the parameters can then be approximated by interpolation and extrapolation from the lookup-tables [4]. Furthermore from these measurements the corresponding relaxation mechanisms can be identified by the determining the relaxation distribution function from a Fredholm equation of the first kind in the time domain. The correct determination of the dominating relaxation mechanisms is the most import issue in the parameter identification because the underlying mathematical problem described by the Fredhom integral equation of the first kind is from its nature a mathematical ill-posed problem with incomplete and noisy data in general. To solve this problem special regularization procedures based on the method of Tichonov are needed.

The lookup-tables will then be used to build up an Matlab/Simulink simulation model based on the nonlinear ECM system using the Simscape environment[1] for the simulation of real current load profiles of the battery. This approach will be applied to different Li-ion batteries with different chemistries and simulation results for different load profiles will be presented. Finally an outlook is given to the possible extension of this approach for aging or abuse mechanisms.

Acknowledgement:

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Electrochemical-calorimetric studies on different lithium-ion cells

Dipl.-Ing. Boxia Lei, *boxia.lei@kit.edu*
Dr. Carlos Ziebert, *carlos.ziebert@kit.edu*
Dr. Andreas Melcher, *andreas.melcher@kit.edu*
Dr. Magnus Rohde, *magnus.rohde@kit.edu*
Prof. Dr. Hans Jürgen Seifert, *hans.seifert@kit.edu* ,

All authors: Institute of Applied Materials - Applied Materials Physics, Karlsruhe Institute of Technology

Keywords: Li-ion cell, Accelerating rate calorimeter, Thermal camera, electrochemical measurements

Introduction

The lithium-ion batteries used in current electric vehicles evidently have reserves. If the capacity in each cell was optimally utilized, more energy could be put in and delivered again. Thus, the driving range of electric vehicles could be significantly increased. In the project IKEBA, funded by the Federal Ministry for Education and Research, researchers are working together with partners from industry to find solutions for this task.
In this work, commercial 18650 lithium ion cells (1.6Ah) with $LiMn_2O_4$ cathodes, 20Ah pouch cells with $LiFePO_4$ cathodes as well as 40Ah pouch cells with NMC cathodes were cycled at varying C-rates under isoperibolic and adiabatic conditions in an Accelerating Rate Calorimeter (ARC) with internal or external battery cycler to investigate their performance and their thermal behavior. A thermal camera was also used to investigate the heat effects and the local temperature distribution during cycling in more details.

Discussion

Different factors that have influence on the performance of energy storage, such as the ambient temperature, the charging/discharging current, and the state of charge (SOC) have been studied. The isoperibolic investigations were performed at specific temperatures in the range from 25 to 60 °C. Both isoperibolic and adiabatic tests were performed at different charging/discharging rates in the range from C/4 to 3C.

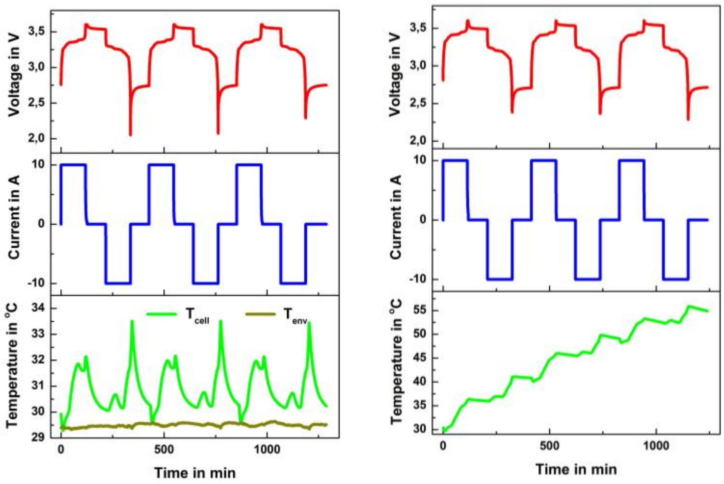

Figure 1: Comparison of isoperibolic and adiabatic cycling of a LFP 20Ah pouch cell at C/2 discharge rate.

Conclusions and/or Outlook

The results show a considerable temperature rise with increasing rate. Comparing the isoperibolic and the adiabatic measurements for the three cell types examined, it can be stated that the differences between the maximum temperature rises under isoperibolic conditions are low. Under adiabatic conditions, the NMC pouch cell showed the highest value. Moreover the applied environmental temperature did not largely influence the cell thermal behavior. Additionally, the heat capacities and calorimeter constant were determined to calculate the total generated heat during cycling. The resulting information from the IR images could be correlated to the results of measurements with the calorimeter. It could be also used to identify temperature gradients and “hot spots” on the surface of the cell.
Based on this work, the project partners will elaborate a new virtual design platform to develop reliable microelectronic circuits and improved battery management software.

Acknowledgement: This R&D project is partially funded by the Federal Ministry for Education and Research (BMBF) within the framework “IKT 2020 Research for Innovations” under the grant 16N12515 and is supervised by the Project Management Agency VDI / VDE / IT.

The Liquid Organic Reaction Cycle – Thermochemical Energy Storage using Liquid Organic Hydrides

Dipl.-Ing. Christin Wagner*, Institute for Micro Process Engineering, KIT, christin.wagner@kit.edu*
Dipl.-Ing. Martin Cholewa, Institute for Micro Process Engineering, KIT, martin.cholewa@kit.edu
Dipl.-Ing. Ulrich Ulmer, Institute of Nanotechnology, KIT, ulrich.ulmer@kit.edu
Prof. Dr.-Ing. Peter Pfeifer, Institute for Micro Process Engineering, KIT, peter.pfeifer@kit.edu
Prof. Dr.-Ing. Roland Dittmeyer, Institute for Micro Process Engineering, KIT, roland.dittmeyer@kit.edu

Keywords: Energy, Storage, Conversion, LOHC, Dehydrogenation, Hydrogenation,

Introduction

To enhance the use of renewable energy resources, storage technologies are needed to guarantee a continuous supply. Thermochemical storage systems that combine reversible endothermic and exothermic chemical reactions to convert, store and transport solar thermal energy, have been proposed and studied intensively in the last decades [1]. A new approach of converting thermal into chemical energy is the so called “Liquid Organic Reaction Cycle” (LORC) which combines the dehydrogenation of Methylcyclohexane with the hydrogenation of Toluene to store and retrieve thermal energy respectively.

Discussion

Figure 1 shows the generalized structure of the LORC. In the charging step the highly endothermic dehydrogenation of Methylcyclohexane is used to convert thermal to chemical energy. The produced hydrogen will be stored in solid metal hydrides. Toluene can be easily stored within conventional liquid tanks. To discharge the storage and recover the thermal energy Toluene is hydrogenated back to Methylcyclohexane and the cycle is closed. Advantages of this storage system are the relatively high theoretical energy density (0.6 $\mathrm{kWh/kg_{Toluene}}$) and the possible long-term storage without additional losses. The system efficiency strongly depends on the process design of each step. Dehydrogenation is performed at 300-400°C and elevated pressures to deliver a reasonable hydrogen partial pressure for hydrogen intermediate storage. Hydrogenation is conducted at temperatures above 300°C, therefore the pressure is raised up to 30 bars to avoid thermodynamic limitation. For both processes active and selective catalysts were developed for the unusual but required reaction conditions. Further both reactions are characterized by high reaction enthalpies (±204 kJ/mol), so that microstructured reactor concepts offer great potential for process intensification. Regarding dehydrogenation process intensifycation can be sup-ported by separating the produced H_2 via a Pd-membrane directly from the reaction zone. This allows a shift of thermodynamic conditions for dehydrogenation. First test modules already proofed the concepts beneficial effect.

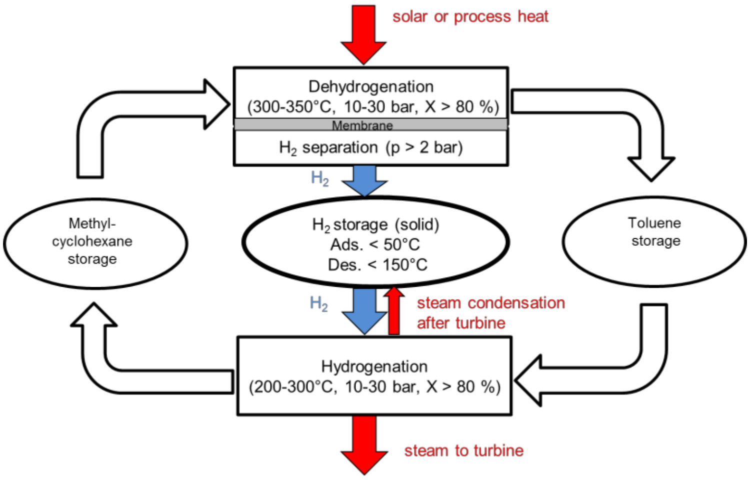

Figure 1: Schematic structure of the Liquid Organic Reaction Cycle [2]

Conclusions and Outlook

A new system for thermochemical energy storage via reaction enthalpies of de-/hydrogenation of liquid organic hydrides is suggested and possibilities for process intensification using micro structured reactors are presented.

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Chemical Heat Storage by the Dehydrogenation of Methylcyclohexane in Microstructured Reactors

Martin Cholewa, *Institute for Micro Process Engineering, KIT, martin.cholewa@kit.edu*
Christin Wagner, *Institute for Micro Process Engineering, KIT, christin.wagner@kit.edu*
Prof. Dr. Peter Pfeifer, *Institute for Micro Process Engineering, KIT, peter.pfeifer@kit.edu*
Prof. Dr. Roland Dittmeyer, *Institute for Micro Process Engineering, KIT, roland.dittmeyer@kit.edu*

Keywords: Energy storage, dehydrogenation

Introduction

With more fluctuating renewable energy sources, higher storage capacities are necessary. One system to store waste or solar thermal energy is the Liquid Organic Reaction Cycle (LORC). By the endothermic dehydrogenation of methylcyclohexane (MCH) the system is charged. The released hydrogen is stored near ambient temperature as a solid metal hydride. Toluene and MCH can be kept in conventional liquid tanks. For discharging toluene is hydrogenated again, generating heat at comparable temperature level as used in the dehydrogenation reaction. A high charging efficiency is required, thus separating the produced H_2 via a Pd-membrane directly from the reaction zone is thermodynamically required in the dehydrogenation step.

Discussion

With regard to hundreds of cycles in the storage system a good stability and selectivity of the catalyst as well as improved heat management is necessary for the highly endothermic dehydrogenation of MCH. Regarding this, microstructured reactors have great advantages because of their high specific inner surface area and provide intensified heat transport conditions, resulting in high system compactness and isothermal reaction conditions. First tests for catalyst screening in a stacked reactor showed a strong deactivation of the catalyst. In the following a more stable 1 wt.-% Platinum on Alumina catalyst was developed by Kreuder et al. [1].

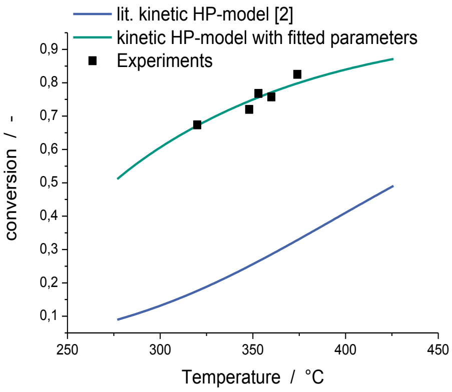

Figure 1: Fit of the kinetic with experiments at 1 bar and $\tau_{mod} = 250\ kg\ s\ m^{-3}$

To improve stability of the catalyst and intensify the process, a planar membrane test module with microstructures for reaction was further developed. Via in-situ selective hydrogen removal reaction equilibrium is shifted to the product side in this system.

The planar test module operates stable at high conversions and pressure up to 12 bars. A reasonable hydrogen separation is achieved and no organic contaminations were detected. This indicates that pure hydrogen is subtracted. Further the back mixing of H_2 towards the reactor entrance applying pure hydrogen conditions on the permeate side greatly suppresses deactivation by coke formation and therefore is an additional benefit for the catalyst.

A further optimization of the microstructured membrane reactor construction will be performed by a MATLAB® simulation. Therefore parameters of literature kinetics [2] were already fitted to the applied catalyst properties (see Figure 1). Specifically, an improved membrane surface to catalyst volume ratio ensuring high H_2 separation is aimed. Finally, a sensitivity analysis of system performance with pressure and temperature will be performed.

Conclusions and Outlook

The concept of microstructured reactor with integrated membrane shows good potential for the usage in the LORC storage system. Further steps, beside the optimization of the reactor, are the integration of membranes which allow higher pressures and thereby also higher separation factors with less membrane surface area.

References:
[1] Kreuder H, Müller C, Meier C, Gerhards U, Dittmeyer R, Pfeifer P; Catalyst development for the dehydrogenation of MCH in a microstructured membrane reactor-For heat storage by a Liquid Organic Reaction Cycle; Catalysis Today; 262; 2015
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Energy storage and transportation by solar irradiation-aided CaO-looping

Dipl.-Ing. Jonas Obermeier, *Institute of Separation Science & Technology, University of Erlangen-Nuremberg*
Dr.-Ing. Karsten Müller, Institute of Separation Science & Technology, University of Erlangen-Nuremberg, Karsten.Mueller@fau.de
Prof. Dr.-Ing.Wolfgang Arlt, Institute of Separation Science & Technology, University of Erlangen-Nuremberg

Keywords: Energy Carrying Compounds, thermochemical energy storage, renewable energy, CaO-looping,

The efficient usage of surplus renewable energy is an important aspect for the energy supply in the future. In this contribution a trans-regional energy storage, transportation and distribution concept is introduced. The process is based on the concept of Energy Carrying Compounds (In German “Energie Tragende Stoffe”, ETS) using a material system which could exist in an energy-lean and energy-rich state [1]. The cheap, available and non-toxic components calcium oxide (CaO) and calcium carbonate (CaCO3) have been identified as suitable materials for the storage and trans-regional transportation of solar energy [2].

The handling and performance of the reactants are well investigated. The energy storage reaction (R1) represents the classical lime burning process and the calcination reaction (R2) is demonstrated in several projects concerning flue gas purification and CO_2 sequestration. The high storage density ($0{,}86\ kWh_{th}/kg_{CaO}$) and the high temperature of energy release reaction are important for a high efficiency of the process performance.

$$\begin{array}{lclll} CaCO_{3(s)} & \rightarrow & CaO_{(s)} + CO_{2(g)} & \Delta^R h^+ = +178\ kJ\ mol^{-1} & T > 800\ °C \qquad (R1) \\ CaO_{(s)} + CO_{2(g)} & \rightarrow & CaCO_{3(s)} & \Delta^R h^+ = -178\ kJ\ mol^{-1} & T < 800\ °C \qquad (R2) \end{array}$$

The concept scheme is shown in **Figure 1**. On the site of high solar intensity (SSI, e.g. Southern Europe), high temperature heat generated by a concentrated solar irradiation system is used in a solar calcination reactor for the decomposition of $CaCO_3$ to CaO and CO_2. The CaO represents the energy-rich state of the ETS and is transported (e.g. with a bulk carrier) to the site of high energy demand (SED, e.g. Central Europe). With the help of a CO_2 source the energy release reaction is introduced and the high temperature heat can be used in an existing power plant for heat and power supply [3]. The energy-lean $CaCO_3$ is transported back to the SSI and the cycle is closed.

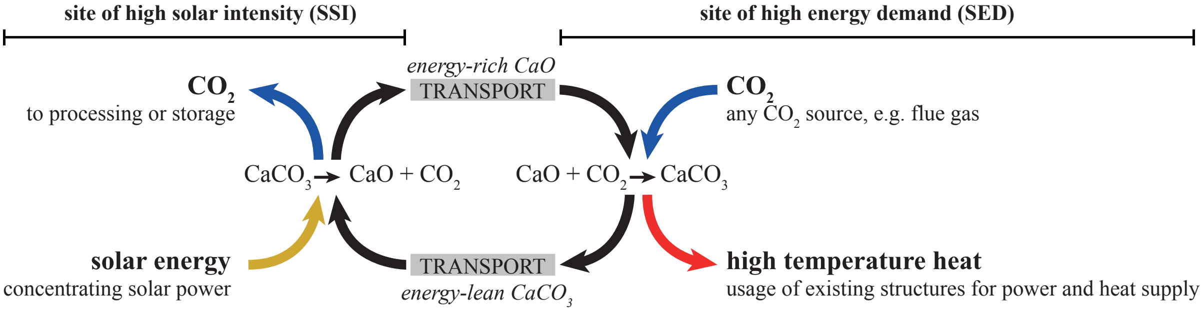

Figure 1: Process design of a trans-regional energy storage and transportation concept based on solar irradiation-aided CaO-looping

In this contribution the aspects of material selection, material synthesis and different process designs are discussed. Besides the evaluation of CO_2 sources on the SED and possibilities of CO_2 recycling on the SSI, process simulations and efficiency calculations are presented.

Acknowledgement: This project on which this contribution is based on is funded by the Federal Ministry of Education and Research with the reference number 03SF0466 and was done within the framework of the Energie Campus Nürnberg.

References:
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One-step synthesis of liquid fuels in microchannel reactors

M.Sc. Chenghao Sun, *Institute for Micro Process Engineering (IMVT), Karlsruhe Institute of Technology (KIT), chenghao.sun@partner.kit.edu*
Prof. Peter Pfeifer, Institute for Micro Process Engineering (IMVT), Karlsruhe Institute of Technology (KIT), peter.pfeifer@kit.edu
Prof. Roland Dittmeyer, Institute for Micro Process Engineering (IMVT), Karlsruhe Institute of Technology (KIT), roland.dittmeyer@kit.edu

Keywords: Fischer Tropsch synthesis, hydrocracking, microchannel reactor, one-step synthesis

The generation of synthetic diesel-like fuels from synthesis gas via Fischer Tropsch synthesis (FTS) receives new attention due to the depletion of crude oil reserves. Modular microchannel reactors, which have excellent heat and mass transfer properties, provide a possible way of FTS intensification. However, a cracking of the higher molecular weight FTS product is needed to maximize the fuel productivity. To simplify the process for decentralized applications, integration of the hydrocracking (HC) into the FTS microchannel reactor could be beneficial.

For the above mentioned purpose, four integration patterns of FTS and HC were discussed for arranging the catalysts on the microchannel walls: double catalyst layers, opposite catalyst layers (equivalent reactor type II in **Figure 1**), subsequent catalyst layers (equivalent reactor type I in **Figure 1**) and layers containing a catalyst mixture.

As the optimal temperature for HC (~320 ℃) is usually higher than that for FTS (~220 ℃), different temperatures are preferred to enhance the performance of each process. Two types of microchannel reactor were designed (**Figure 1**) and the FEM calculation showed good temperature separation between the FTS and HC catalyst sections. The simulation results also confirmed that HC needs higher temperature to obtain the desired hydrocarbon fraction.

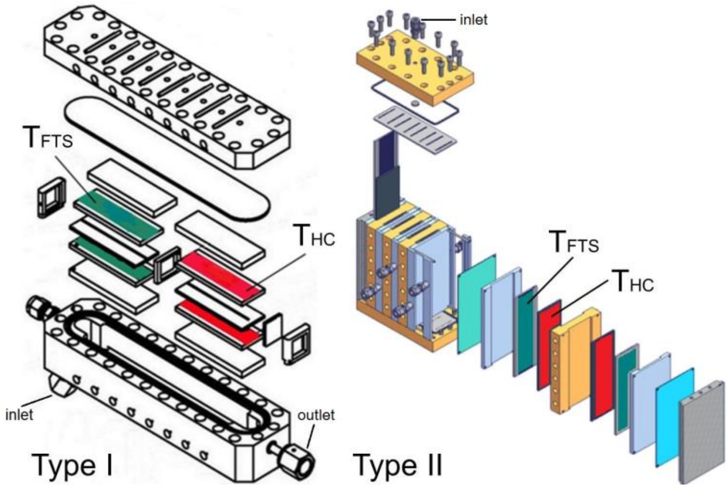

Figure 1. Microchannel reactors with individual temperature control

Both FTS (Co/Al_2O_3) and HC (Pt/ZSM-5) catalyst were prepared by washcoating followed by impregnation of active metals and fine catalyst layers were obtained. Apart from in microchannel reactors, the integration process was also carried out in subsequent reactors (a micro packed bed for FTS and a tubular fixed bed for HC) for comparison. The operating conditions will be optimized in future to maximize the yield of the desired fraction with the help of accompanied modelling.

Techno-economic Assessment of the Utilization of CO_2 to Produce Liquid Fuels by Electrolysis and Fischer-Tropsch Synthesis

***Daniel H. König**, Institute of Engineering Thermodynamics, German Aerospace Centre, daniel.koenig@dlr.de*
Nadine Baucks, Institute of Engineering Thermodynamics, German Aerospace Centre, nadine.baucks@dlr.de
Dr. Antje Wörner, Institute of Engineering Thermodynamics, German Aerospace Centre, antje.woerner@dlr.de

Keywords: Power-to-Liquid, Process simulation, CO_2 utilization

Introduction

The conversion of CO_2 and renewable energy into high quality fuels is one way to provide a sustainable and secure energy supply in the future. The “Power-to-Liquid” technology is an approach to produce these synthetic hydrocarbons not being based on fossil resources. The German Aerospace Centre (DLR) asses the technical and economic performance of production processes based on renewable energy and CO_2.

Discussion

The process concept proposed (**Figure 1**) is based on CO_2, which reacts with H_2 from electrolysis via the reverse water gas shift reaction (rWGS) to synthesis gas (CO and H_2). Synthesis gas is then converted to liquid hydrocarbons in the Fischer-Tropsch (FTS) reactor. A downstream product separation and upgrading section allows the production of defined fractions for specific applications.

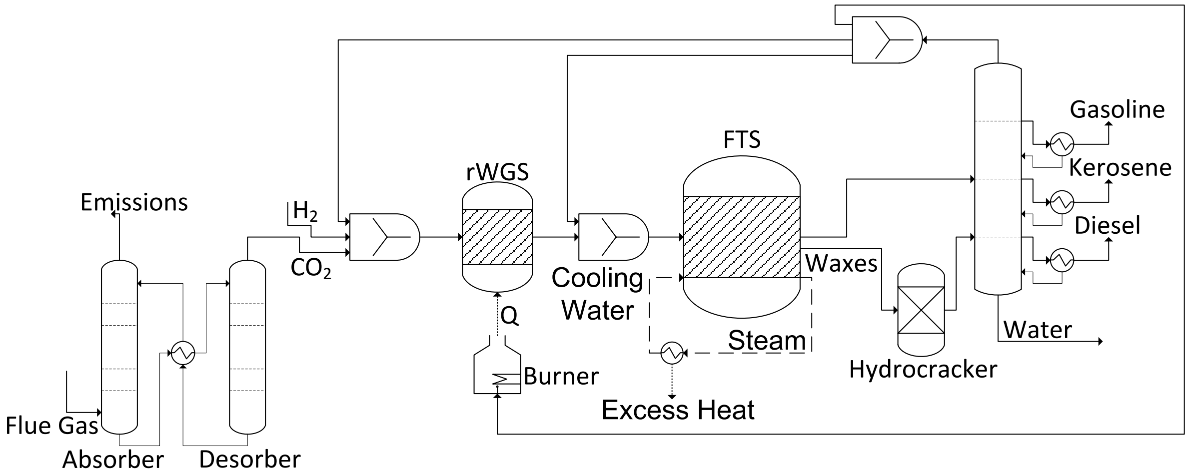

Figure 1: Flowsheet of a process to produce synthetic fuels from H_2 and CO

The proposed process was modelled with the flowsheeting simulation tool Aspen Plus. The capacity was set to a feed of 100 MW_{LHV} (LHV basis) of H_2, corresponding to 33,368 Nm /h. The base case model comprises the rWGS reformer, the FTS reactor, the product separation step and a hydrocracker. A recycle stream network was implemented to increase the conversion. Further compressors, pumps and blowers were modelled to account for pressure changes and losses. A total amount of 5.5 t/h (67.2 MW_{LHV}) liquid hydrocarbons was generated. A feed of 22.8 t/h of CO_2 was required and 21.8 MW of steam at 225°C and 20 bar was generated as excess heat. The carbon conversion and the “Power-to-Liquid” efficiency, which describes the process performance and is defined as the fraction of the electrical energy chemically bound into liquid hydrocarbons, were identified as the parameters to evaluate the overall process. The CO_2 separation process was included into the process model to investigate a combined heat and material integration of the CO_2 separation from industrial sources. It could be shown that the excess heat of the synthesis process satisfies the heat demand of the CO_2 separation. Additionally, the effect of various operation conditions was investigated by sensitivity analyses. Increasing the chain growth probability, using oxygen generated by electrolysis in the burner and preheating the supply air of the burner were identified as measures to increase the overall efficiency of the process. The capital and operational costs were estimated on the basis of the developed flowsheet and the results of the process simulation. The effect of the capital costs of the electrolyser on the production costs was investigated.

Conclusion

The option to use hydrogen from electrolysis and CO_2 from industrial flue gas to produce synthetic hydrocarbons was investigated. The “Power-to-Liquid” efficiency of the presented base case arises to 43% and the carbon conversion is 73%. The application of efficiency increasing measures could increase the efficiency to 48% and the carbon conversion rate to 81%.

Acknowledgement: This work is part of the Helmholtz Energy Alliance “Synthetic liquid hydrocarbons”.

Coil Wound Heat Exchangers for Molten Salt Applications

M. Sc. Rosiel Millan Elias, Linde AG, Engineering Division, rosiel.millan.elias@linde-le.com
Dipl.-Ing. Konrad Braun, Linde AG, Engineering Division, konrad.braun@linde-le.com
Dr.-Ing. Markus Weikl, Linde AG, Engineering Division, markus.weikl@linde-le.com

Keywords: heat exchanger, molten salt, direct and indirect thermal energy storage

Abstract

Heat exchangers for direct or indirect Thermal Energy Storage (TES) systems using molten salt as storage medium are investigated. The thermal and mechanical design challenges heat exchangers are facing due to the special nature of the molten salt and the different operating modes of TES processes are therefore analysed.

The main features of coil wound heat exchangers, for instance, compactness, higher heat transfer efficiency and high mechanical flexibility are shown in order to emphasise the advantages of this technology. Those advantages enable a cost-effective and innovative solution for molten salt applications. An exemplary comparison between shell-and-tube and coil wound type for indirect TES in a parabolic trough plant employing synthetic oil as heat transfer fluid is presented.

Poster Abstract: Development of an innovative heat storage system for combined heat and power plants (CHP)

Dr. Sascha Merkel, Boris Epple, Akin Simsek, Dr. Hans-Peter Kollmeier, *Fraunhofer Project Group ICT/IWM New Drive Systems (NAS),* ***Wilhelm Eckl, Sandra Pappert**, **Peter Elsner*** *Fraunhofer Institute for Chemical Technology ICT, sascha.merkel@ict.fraunhofer.de*

Keywords: Energy efficiency, CHP, heat storage

Introduction

In times of climate change it is necessary to put more effort on reducing the worldwide CO_2 –emissions. In this context taking the focus off from fossil-resources (e. g. crude oil) plays an important role. About 30 percent of the secondary energy in Germany is used by domestic-households, primarily for room and water heating. Combined heat and power plants (CHP) offer a great potential in meeting future requirements regarding the reduction of CO_2 – emissions and the protection of resources. To increase the efficiency and to decrease the runtime due to the required durability of the CHP-unit the target is to store electrical and thermal energy.

Discussion

Sorption-storages are expected to be suitable for the use in an intelligent CHP-system. Due to their large storage density as well as their good ageing resistance zeolites are of special interest with regard to sorption storage-systems for higher temperature levels. To investigate the behaviour of different zeolites which have been characterized in the ICT-laboratory before a down-scaled vacuum-reactor with an integrated fin-heat-exchanger was developed and built up.

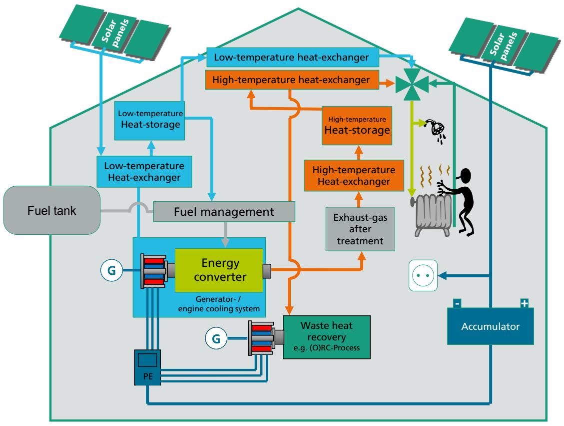

Figure 1: Innovative heat-storage system for Mini-CHP-units

The heat which was stored on a higher temperature level could be used for the operation of a bottoming Rankine cycle [1]. The heat on lower temperature level is stored in a water buffer storage to heat a building and generate warm water. Phase-change-materials (PCM) offer potential to increase the heat capacity of a water buffer storage. To investigate this aspect a special test stand was built up to reconstruct a heating system similar to one in a building. First investigations done in the ICT-laboratory show respectable results to increase the heat capacity of a water buffer storage with added PCM. So it is possible to increase the efficiency of the CHP-system due to a shorter engine-runtime.

Conclusions/Outlook

Heat storage systems offer a high potential to increase the efficiency of combined heat and power plants. Therefore test stands were built up to investigate zeolites and phase change materials for an application in such heat storage systems. In the first step the materials were characterized in the ICT-laboratory. In the next step the preselected materials are qualified in a down-scaled vacuum reactor (zeolites) respectively in a water buffer storage (PCM) under real boundary conditions.

Acknowledgement: This work was founded by the Friedrich-und-Elisabeth-Boysen-Stiftung

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Experimental Determination of Heat-Dynamics of a Zeolite Bedding

B.Eng. Hakspiel, Fabian, Fraunhofer Institut Chemische Technologie (ICT), Pfinztal,
fabian.hakspiel@ict.fraunhofer.de
Dipl. Ing.(Fh) Sandra Pappert, Fraunhofer Institut Chemische Technologie (ICT), Pfinztal,
sandra.pappert@ict.fraunhofer.de
Prof. Dr. -Ing Teipel, Ulrich,Technische. Hochschule Nürnberg, Partikeltechnologie, Nürnberg,
ulrich.teipel@th-nuernberg.de
Dipl.-Phys. Wilhelm Eckl' Fraunhofer Institut Chemische Technologie (ICT), Pfinztal,
wilhelm.eckl@ict.fraunhofer.de

Keywords: Thermo-chemical heat storage, Zeolite Bedding, Adsorption, Desorption, Heat dynamics

Residual heat usage of stationary and mobile thermal processes forces its storage. To design effective systems, a high level basic physical and chemical knowledge on the used materials and involved processes like diffusion, heat and mass flow is necessary. Zeolites as thermo-chemical storage materials combine excellent properties like reversible dehydration, lossless energy storage, environmental safety and perfect cycle stability. Fraunhofer ICT investigates zeolites to get detailed knowledge on applicability, temperature ranges and dynamics of charging and discharging. Therefore a flow reactor was designed and developed at a size exceeding lab scale (fig. 1). In this reactor thermal efficiency and adsorption behavior of zeolite beddings can be experimentally determined. The bedding is streamed with defined air atmospheres varying its volume flow, humidity and temperature.

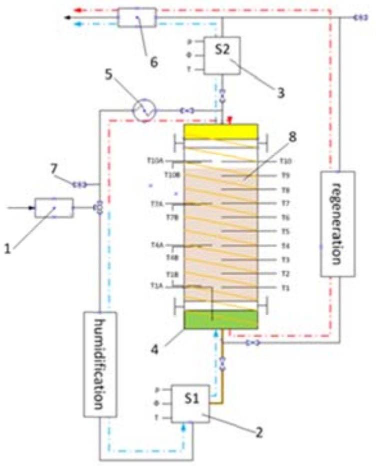

Figure 1, Process plan flow reactor, 1: Mass flow controller, 2-3: Sensormodul: pressure, temperature, rel humidity 4: Reactor, 5: Air heater, 6: Mass flowmeter, 7: Overpressure value, 8: Reactor bedding, -·→ Discharching/ Desorption, - - → Charging/ adsorption, T1-10 Thermal sensor

In-situ measurement of resulting temperature profiles along the direction of the airflow in the packed bedding enables the registration of the progress of the charging front and the related energy flux (fig. 2). The presented investigations show the dynamics of the adsorption processes of 3A-zeolite bedding depending on the air flow loading conditions.

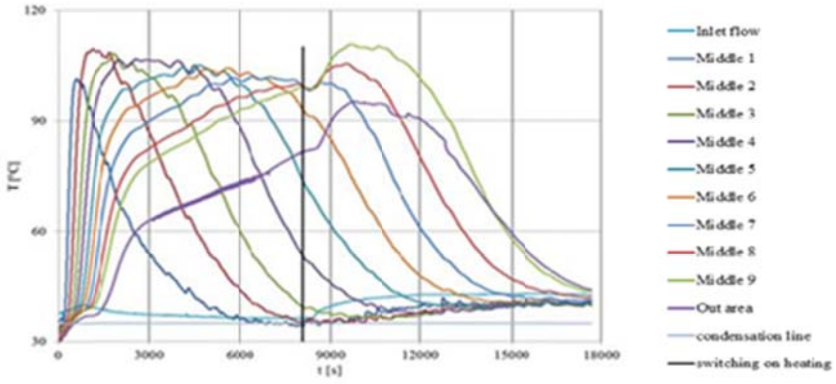

Figure 2, Temperature profiles along the flow direction of the bedding

A Study on Transient Heat Transfer of Thermal Insulation with Latent Heat Material

Mr. Dong-Yeol Chung, *Thermal Fluid System R&BD Group, Korea Institute of Industrial Technology (KITECH), Graduate School, Chonbuk National University, dy77k96@kitech.re.kr*
Mr. Byungkwon Kim, Thermal Fluid System R&BD Group, KITECH, greatrox@kitech.re.kr
Dr. Dongho Park, Thermal Fluid System R&BD Group, KITECH, senna@kitech.re.kr
Dr. Jong-Hyeon Peck, Thermal Fluid System R&BD Group, KITECH, pjh6240@kitech.re.kr
Dr. Jeong-Yeol Kim, Thermal Fluid System R&BD Group, KITECH, esperant@kitech.re.kr

Keywords: Latent Heat Material, Insulation, Time Lag, Decrement Factor

Introduction

It is important to control the temperature for saving energy consumption of building. One of the ways is to use thermal insulation having low thermal conductivity. . Recently, thermal insulation included latent heat material (LHM) has been studied for the enhancement of thermal insulation [1-2]. In this study, it is investigated for stabilized the temperature and evaluated time lag and decrement factor by numerical analysis of thermal insulation with LHM. We calculated transient heat transfer on 1-dimension by COMSOL Multyphysics 4.5 for the numerical analysis.

Discussion

We selected for n-octadecane as LHM and insulation (extruded polystyrene form) which has been widely used in common. The thermal properties of heat of fusion and thermal conductivity were measured by differential scanning calorimeter (DSC6000, PerkinElmer) and heat flow meter (HFM436, Netzsch) respectively. On heating and cooling periodically (360 minutes) under variable load conditions (50, 75, 100, 150 W/m^2), the thickness ratio of the LHM in more than 50% was studied for the time lag and decrement factor by followed equations [1]:

$$\text{Time lag } \Phi=T_{in,\,max}-T_{out,\,\mathrm{max}},\ \text{Decrement factor } \lambda=A_{out}/A_{in}$$

Where, $T_{\mathrm{in,max}}$ and $T_{\mathrm{out,max}}$ are time on maximum temperature of input side and on minimum temperature of output side respectively, and A_{out} and A_{in} are amplitude difference of output side and input side respectively. Variation of time lag and decrement factor is shown in Figure 1.Ttime lag and decrement factor increased in the range of time constant of 0.003 to 0.005. However decrement factor was relatively low at the heat flux 150 W/m^2 because the LHM had already been melt and could not storage the heat.

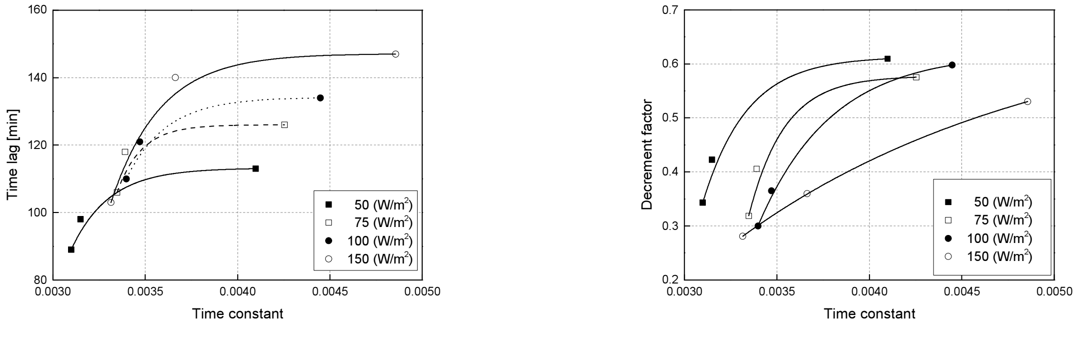

Figure 1: Variation of time lag (left) and decrement factor (right) according to time constant

Conclusions

The LHM of the thermal insulation affected to control the temperature. And it was possible to design optimization for the thermal insulation on various conditions (heat flux, thickness ratio of the LHM, thermal properties) by numerical analysis.

Acknowledgement: This research was supported by the Technology Innovation Program (No. 10049090) funded by the Ministry of Trade, Industry and Energy (MI, Korea).

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The Feasibility Study on Solar Greenhouse with Latent Heat Materials

Mr. Dong-Yeol Chung*, Thermal Fluid System R&BD Group, , Korea Institute of Industrial Technology (KITECH), Department of Mechanical Engineering, Chonbuk National University, dy77k96@kitech.re.kr*
Mr. Byungkwon Kim, Thermal Fluid System R&BD Group, KITECH, greatrox@kitech.re.kr
Dr. Jeong-Yeol Kim, Thermal Fluid System R&BD Group, KITECH, esperant@kitech.re.kr
Prof. Chaedong Kang, Department of Mechanical Engineering, Chonbuk National University, ckang@kitech.re.kr
Dr. Jong-Hyeon Peck, Thermal Fluid System R&BD Group, KITECH, pjh6240@kitech.re.kr

Keywords: Latent Heat Material, Solar Energy, Greenhouse, Energy-Saving, Thermal Storage

Introduction

Latent heat materials (LHMs) absorbing or releasing heat during phase changing process have been well known as one of the thermal storage materials. The main advantage of using LHMs is to store irregular and unstable energy (*i.e.* solar energy, waste heat, etc.). Applications of LHMs have been studied for the high energy-efficiency [1-2]. In this study, the heating load in greenhouse was calculated [3]. And then, the greenhouse including thermal storage system was designed and evaluated the performance of energy saving.

Discussion

The schematic of greenhouse with LHMs is shown in Figure 1. LHMs used three different types of melting temperature; 20 °C, 25 °C and 27 °C. Thermal properties of LHMs were measured by a differential scanning calorimeter (DSC6000, PerkinElmer). The nucleating agent was added in LHM with melting temperature of 27 °C to remove the supercooling behaviour.

Figure 2 shows solar radiation and the temperature of inside and outside greenhouse during a day in Korean winter. Inner temperature of greenhouse remained over 5°C at night. The calculated result of heating load was 157,000 kcal and the thermal storage system was stored the heat of 165,395 kcal.

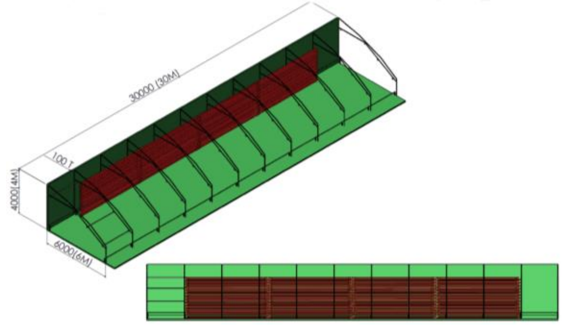

Figure 1: Schematic of greenhouse using LHM

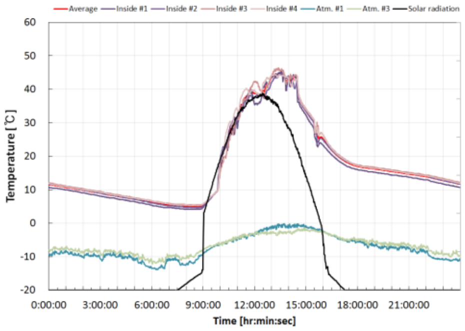

Figure 2: Test result for 1 day (December, 2-3, 2014)

Conclusions

It was designed and evaluated the solar greenhouse with LHMs. The results of test showed the inner temperature of the solar greenhouse had been maintained over limited temperature for farming without additive energy. It is possible to save the energy to apply the thermal storage system with LHMs.

Acknowledgement: This work was supported by the project "Development of total solution platform technology for energy installation (Project number : JA-15-0022)"" funded by KITECH in South Korea Agency

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Test method of thermal conductivity during phase change processes with the HotDisk-technique

Burkhard Krüger, *Heiko Lohmann, Maria Tyukavina, Dr. Barbara Zeidler-Fandrich*
Fraunhofer Institute for Environmental, Safety and Energy Technology,
burkhard.krueger@umsicht.fraunhofer.de

Keywords: HotDisk, thermal conductivity, phase change materials, sample holder

Introduction

A growing importance of renewable energy sources and a better efficiency in industrial processes is the objective in the current energy transition in Germany. An effective approach is the exploitation of intermittent occurring waste heat in these processes by energy storage systems. For energy storage systems sensible heat, latent heat or thermochemical heat of materials can be used. Phase change materials (PCM), using the latent heat of the phase change, are the most effective material class to obtain a high energy storage density at low temperature differences. In order to design energy storage systems both thermal conductivity and energy storage density of materials have to be measured. The transient plane source method allows the fast and precise measurement of thermal conductivity [1]. The HotDisk instrument bases on the transient plane source method and utilises a sensor, which is both heat source and temperature sensor. Typically, the sensor is placed between the plane surfaces of two solid sample pieces (Figure 1).

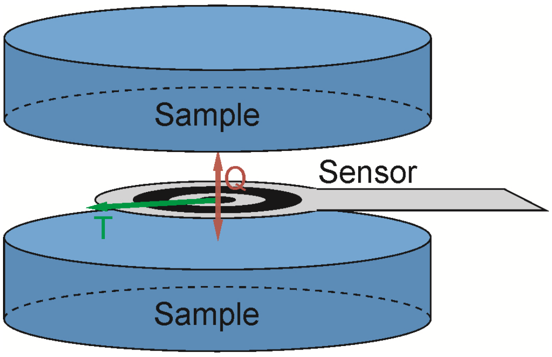

Figure 1: Sketch of the HotDisk-configuration for the measurement of a solid sample

For each phase state (gas, fluid and solid) of a material, a specific measuring device already exists. Sample devices, providing measurements through phase changes in the specific temperature range, are not commercially available yet. For this reason, a sample device was developed at Fraunhofer UMSICHT, enabling such measurements.

Discussion

The device consists of two metal plates with sufficient milled volume, where sample can be filled for measurements. The sensor is fixed between these plates. The device was successfully tested for different phase changes. When the HotDisk is placed in a furnace, measurements can be carried out at defined temperature up to 200°C. This measuring system is suitable for samples with high volatility property and its pressure tight atmosphere can hold pressure up to 4 bar. The poster will show details regarding the sample device, filling and measurement procedure, as well as first test results of commercially available paraffin.

Conclusions and Outlook

The measurement of the thermal conductivity of phase changing materials is significantly simplified by the developed sample holder. Special emphasis will be put on the measurement of phase change materials and the characterization of gaseous compounds released by thermochemical materials.

Acknowledgement: We thank the German Federal Ministry of Education and Research for financial support in the project (03EK3023)

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Phase Change Analysis of PCM with simultaneous Cooling and Heating

***Donggyu Lee**, Department of Mechanical Engineering, Chonbuk national University, Korea, ldg3246@jbnu.ac.kr*
Sechang Park, Graduate School, Chonbuk National University, Korea
Jong-Hyeon Peck, Thermal & Fluid Sytem R&BD Group, Korea Institute of Industrial Technology (KITECH), Korea
Chaedong Kang, Department of Mechanical Engineering & Geothermal Energy Technology Research Center, Chonbuk National university, Korea, ckang@jbnu.ac.kr

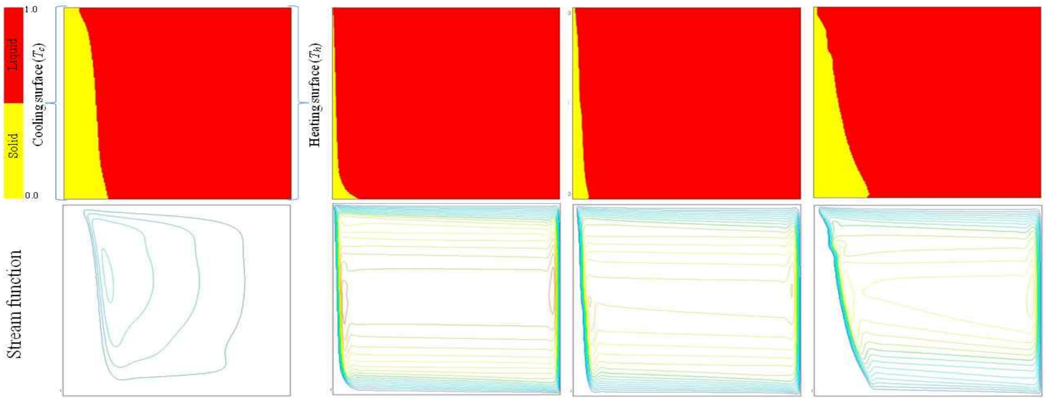
Keywords: Phase-Change Material(PCM), Solidification, Melting, Computer Fluid Dynamics(CFD)

Introduction

Some applications of high temperature industrial sewage came in industrial heat pumps. PCM can be applied to a heat source which collect and store waste heat and supply stable heat. However, in order to store and utilize the waste heat effectively on inevitable piping structure, thermal intervention between working fluids and PCM should be reduced, as possible. In this study, the behavior of PCM during phase change was analyzed and compared with different simultaneous heating-cooling, which is related to heat source of evaporator in high-temperature heat pump. And fundamental data of design for PCM storage tank can be obtained from the result.

Results

In order to analyze the interference of heat transfer by using ANSYS FLUENT®, an organic PCM(NMP:78°C) was given to 2-D square cavity(50mm×50mm), which is insulated to both of top and bottom boundary and heated from a vertical wall and cooled to another wall simultaneously. Four patterns of two-wall temperatures are applied to PCM(T_i=80°C) in the cavity. During phase change, natural convection occurs to temperature difference between vertical wall and initial temperature of liquid PCM. Figure 1 shows a different solidifying behavior of liquid PCM to each wall temperature after 1 hour from initial state. Among (b), (c) and (d), the growth amount of solid layer of (c) is smaller than others. It should be related to natural convection due to temperature difference of wall. It shows thermal intervention retards to solidification, compared to (a) with small natural convection. And the shape of PCM solid was influenced on natural convection.



(a) $T_c = 73$℃ / T_h = adiabatic (b) $T_c = 73$℃ / $T_h = 93$℃ (c) $T_c = 63$℃ / $T_h = 93$℃ (d) $T_c = 63$℃ / $T_h = 83$℃

Figure 1: Stream function and liquid volume fraction according to cooling and heating condition after calculation elapse 3600s

Conclusions

Simultaneous heating-cooling in PCM provokes thermal intervention and influences to the solidification rate of PCM by using ANSYS FLUENT. And well-conditioned temperature difference can improve the performance of heat releasing of PCM.

Acknowledgement: This research was supported by Industrial Strategic Technology Development Program through Ministry of Trade, Industry and Energy Republic of Korea. (10049090).

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Production and regeneration of paraffin based Phase Change Slurries

***Dr. Lucian Hanu**, Tobias Kappels, Dr. Clemens Pollerberg,*
Fraunhofer Institute for Environmental, Safety and Energy Technology,
lucian-george.hanu@umsicht.fraunhofer.de

Keywords: Thermal energy storage, Phase Change Slurries (PCS), latent heat, paraffin/water dispersion

Introduction

Thermal Energy Storages (TES) based on phase transition of the storage medium (PCM - Phase Change Materials) outmatch conventional water buffer tanks in many applications. The latent heat storage can store additionally energy as latent heat, enabling a higher heat density compared to sensible heat storage for a defined temperature range [1]. A drawback of PCM is its poor thermal conductivity. Dispersing the paraffin in a continuous phase (water), with stabilizing emulsifiers, assures a large surface to volume ratio and a considerable increase of the heat exchange compared to bulk paraffin. The so called Phase Change Slurry (PCS) combines the advantages of the good heat exchange behavior of water, with high heat capacity of PCM. The PCS remains liquid even when the paraffin is solid, can be pumped and used directly as storage medium and heat distribution fluid. That offers the possibility for many different applications, like space cooling or thermal control of sensitive electronic devices. A challenge in the development of the paraffin based dispersions is their stability during the repeating charging-discharging process. The aim of this work is to investigate the emulsifying and re-emulsifying process of the PCS directly into the test rig by only using the energy of a frequency regulated centrifugal pump and a static mixer as dispersing tool.

Discussion

The premix of 30 wt.-% hexadecane, 3 wt.-% mixture of emulsifier (polyethylene glycol fatty acid ester with HLB value 12) and water is filled into the tank. The sample can be pumped with a centrifugal pump over a dispersing tool (static mixer) or only through the bypass [2]. The test rig is s depicted in Figure 1. The specific process temperature is controlled using a thermostat. The samples are characterised by means of particle size. After several cycles through the static mixer a decrease of the particle size is observed from a mean value of 45 µm to 1.5 µm.

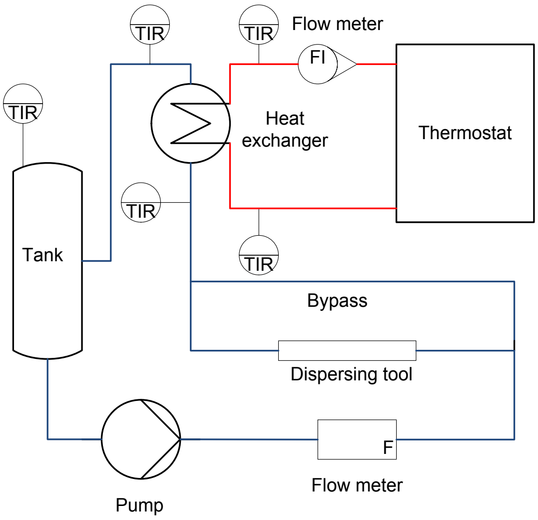

Figure 1: Schematic of the test rig

Conclusions and Outlook

The investigations on manufacturing paraffin/water dispersions using a static mixer show convincing results. Small droplets of paraffin with sizes between 1 and 10 µm are obtained under specific conditions of temperature, dispersing time and flow volumes. The regeneration of a broken dispersion was also successfully investigated at temperature above the melting point of the paraffin.

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Effect of Hollow Silica/Activated Carbon on CH_4 Hydrate Formation

Rawipreeya Suesuan, *The Petroleum and Petrochemical College, Chulalongkorn University, rawipreeya.s@hotmail.com*
Dr.Pramoch Rangsunvigit, The Petroleum and Petrochemical College, pramoch.r@chula.ac.th
Dr.Santi Kulprathipanja,UOP, A Honeywell Company, Des Plaines, USA, santi.kulprathipanja@uop.com

Keywords: Methane (CH_4), Storage, Hydrate, Hollow silica, Activated carbon

Introduction

Gas hydrates are an interesting technology for gas storage and transportation as they were discovered to accommodate large amount of gas. The slow formation rate and low conversion of water to hydrates hinder the production of gas hydrate storage and transportation of gas in industry. The porous medium in the gas hydrate system was discovered to enhance the gas hydrate formation, both thermodynamically and kinetically. Both hollow silica and activated carbon are attractive porous medium because of their high specific area, high porosity, and high adsorption capacity. In this work, the gas hydrate formation and dissociation in the presence of hollow silica and activated carbon were compared.

Discussion

Formation of gas hydrate is noticed by the increase in the temperature, at the same time, with lowering of pressure. **Figures 1(a) and 1(b)** show the formation of methane hydrate in the presence of hollow silica and activated carbon at 8 MPa and 4°C. The hydrate randomly forms in both cases. In the presence of activated carbon, the temperature of all thermocouple rises abruptly referring to the hydrate formation in different locations almost the same time and continue to grow until reach the limit of hydrate formation. But multiple spikes of the temperature in hollow silica indicate multiple hydrate nucleations, which is different from the system with activated carbon that shows only one spike of temperature [1]. The amount of gas uptake with hollow silica increases rapidly because of gas hydrate formation, while, in the presence of activated carbon, the increase in the gas uptake is affected by the adsorption of gas into the pores before the gas hydrate formation.

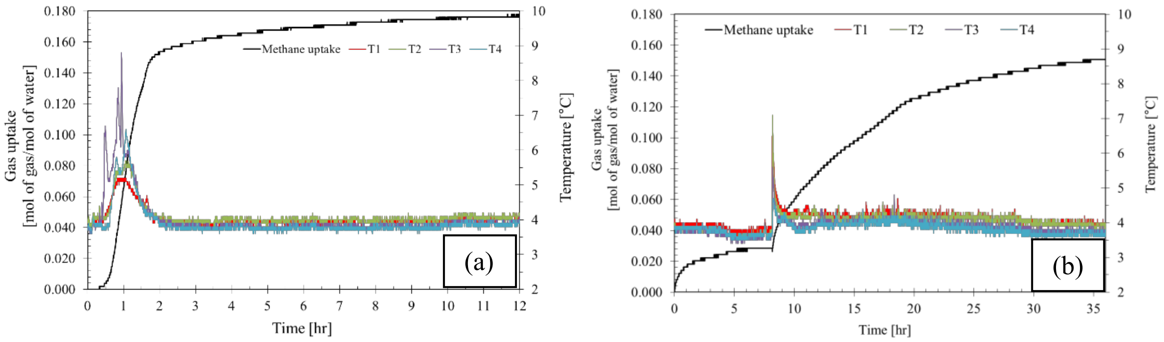

Figure 1: Formation of methane hydrate at 8 MPa and 4°C with the presence of (a) hollow silica and (b) activated carbon.

From **Figure 1**, the amounts of gas uptake with the presence of hollow silica and activated carbon are about 0.18 and 0.15 mol of gas/mol of water, respectively. The hydrate formation is completed in 12 hr in the system with hollow silica but 35 hr with the activated carbon.

Conclusion

The results of methane gas uptake and methane hydrate formation rate in the presence of hollow silica and activated carbon at 8 MPa and 4°C are different. It implies that the type and characteristics of porous medium play a significant role in the methane hydrate formation.

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Zero-emissions power plant for chemical energy storage as well as power and heat generation

Dipl.-Ing. Can Yilmaz, *Division Energy Conversion and Processing, Energy Research Centre of Lower Saxony, can.yilmaz@efzn.de*
Prof. Dr.-Ing. Robert Güttel, Institute of Chemical Engineering, Ulm University, robert.guettel@uni-ulm.de
Prof. Dr.-Ing. Thomas, Turek, Institute of Chemical and Electrochemical Process Engineering, Clausthal University of Technology, turek@icvt.tu-clausthal.de

Keywords: chemical storage, material cycle, Power-to-Gas, sustainable power plant, synthetic natural gas

Introduction

The “Energiewende” and the related further development of volatile renewable energies within the energy system are expected to cause an increasing demand for energy storage systems. A promising possibility to store energy for medium to long (hours to months) periods of time on a large scale is the so-called Power-to-Gas (PtG) technology, which utilizes the storage medium methane. However, a fact that is often neglected with regard to this concept is the requirement of extensive carbon sources for the synthesis of methane. The present paper introduces an innovative PtG concept that facilitates a way to store energy without a continuously fed carbon source.

Discussion

The processes water electrolysis, methanation and combustion of methane with pure oxygen (oxyfuel combustion) form, neglecting losses, a closed material cycle, which is simplified shown in **Figure 1**. This cycle can be used to store electrical energy in the form of synthetic methane (SNG) and to later supply electricity and/or heat (Power-to-Methane-to-Power = PtMtP).

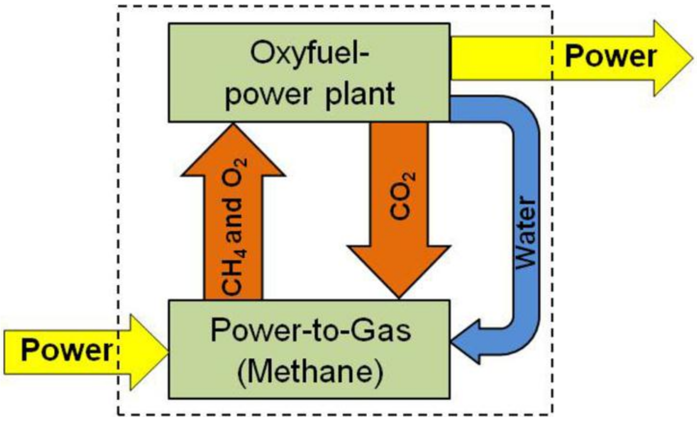

Figure 1: Simplified illustration of the closed material cycle for the PtMtP process.

In addition to an electrolyser, a methanizer and an oxyfuel power plant gas storage capacity is needed in order to decouple the operation modes of charging (PtM) and discharging (MtP) the storage system. Within the present paper, appropriate technologies for the necessary components are selected and each of them as well as the entire process chain is critically discussed regarding its state of the art and progress of technology development based on the Technology Readiness Levels (TRL) [1]. Furthermore, an overall efficiency of the whole PtMtP process is estimated using data from the literature.

Conclusions and Outlook

An innovative energy storage concept based on the principle of PtG utilising the storage medium SNG is described, which can produce electrical energy as well as heat without emitting any greenhouse gases. From the authors’ point of view, the proposed PtMtP concept is theoretically feasible. However, overall storage efficiencies of about 33 % (power-to-power) are calculated and the total process is to be assigned a TRL of 2. As a next step towards a realisation of a PtMtP plant, the components being at an early stage of development should be further investigated. Moreover, an economic efficiency analysis and a detailed process modelling quantifying losses should be carried out.

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CO_2 Neutral Fuels

Dr. ***Adelbert P.H.Goede****, Dutch Institute for Fundamental Energy Research, PO Box 1207, 3430 BE Nieuwegein, NL, a.p.h.goede@differ.nl*

Dr. Waldo A.Bongers, FOM-Institute DIFFER, PO Box 1207, 3430 BE Nieuwegein, NL, W.A.Bongers@differ.nl

Mr. Martijn F.Graswinckel, FOM-Institute DIFFER, PO Box 1207, 3430 BE Nieuwegein, NL, M.F.Graswinckel@differ.nl

Prof. Dr. Richard M.C.M van de Sanden, FOM-Institute DIFFER, PO Box 1207, 3430 BE Nieuwegein, NL, M.C.M.vandeSanden@differ.nl

Dr. Martina Leins, Institute of Interfacial Process Engineering and Plasma Technology, Univ. Stuttgart D 70569 Stuttgart, Germany, martina.leins@igvp.uni-stuttgart.de

Dr. Jochen Kopecki, IGVP, Univ. Stuttgart, D 70569 Stuttgart, Germany, jochen.kopecki@ ipf.uni-stuttgart.de

Dr. Andreas Schulz, IGVP, Univ. Stuttgart, D 70569 Stuttgart, Germany, schulz@ipf.uni-stuttgart.de

Dr. Matthias Walker, IGVP, Univ. Stuttgart, D 70569 Stuttgart, Germany, walker@igvp.uni-stuttgart.de

Keywords: Renewable Energy Storage, Power to Gas, Carbon Capture and Utilisation

Introduction

The need for storage of renewable energy (RE) generated by photo-voltaic, concentrated solar and wind arises from the fact that supply and demand are ill-matched both geographically and temporarily. This already causes problems of overcapacity and grid congestion in countries where the fraction of RE exceeds the 20% level. A system approach is needed, which focusses not only on the energy source, but includes conversion, storage, transport, distribution, use and, last but not least, the recycling of waste. Furthermore, there is a need for more flexibility in the energy system, rather than relying on electrification, integration with other energy systems, for example the gas network, would yield a system less vulnerable to failure and better adapted to requirements. For example, long-term large-scale storage of electrical energy is limited by capacity, yet needed to cover weekly to seasonal demand. This limitation can be overcome by coupling the electricity net to the gas system, considering the fact that the Dutch gas network alone has a storage capacity of 552TWh, sufficient to cover the entire EU energy demand for over a month.

Discussion

This paper explores energy storage in chemicals bonds. The focus is on chemicals other than hydrogen, taking advantage of the higher volumetric energy density of hydro-carbons, in this case methane, which has an approximate 3.5 times higher volumetric energy density. More importantly, it allows the ready use of existing gas infrastructure for energy storage, transport and distribution. Intermittent wind electricity generated is converted into synthetic methane, the Power to Gas (P2G) scheme, by splitting feedstock CO_2 and H_2O into synthesis gas, a mixture of CO and H_2. Syngas plays a central role in the synthesis of a range of hydrocarbon products, including methane, diesel and dimethyl ether. The splitting is accomplished by innovative means; plasmolysis and high temperature solid oxygen electrolysis. A CO_2 neutral fuel cycle is established by powering the conversion step by Renewable Energy and recapturing the CO_2 emitted after combustion, ultimately from the surrounding air to cover emissions from distributed source. Carbon Capture and Utilisation (CCU) coupled to P2G thus creates a CO_2 neutral energy system based on synthetic hydrocarbon fuel. It would enable a circular economy where the carbon cycle is closed by recovering the CO_2 emitted after reuse of synthetic hydrocarbon fuel. The critical step, technically as well as economically, is the conversion of feedstock CO_2/H_2O into syngas rather than the capture of CO_2 from ambient air.

Outlook

On the basis of experiments carried out on a 10kW RF powered CO_2 plasmolysis machine, design parameters for a 100 kW demo reactor will be derived.

The gas network as a controlling factor in the electricity net

Wolfgang Koeppel, *DVGW-Research Station at the Engler Bunte Institue of KIT, koeppel@dvgw-ebi.de*
Prof. Dr.-Ing. Thomas Leibfried, Institute für Elektroenergiesysteme und Hochspannungstechnik (IEH), K.I.T, thomas.leibfried@kit.edu

Keywords: Energy, Conversion, PowerToGas, Storage

Introduction

The load requirements for the '*Energiewende*' (Energy-Transformation), is high on the electricity grid. A potential scenario that could arise due to such a situation is that the surplus renewable energy produced would have to be used immediately after production to prevent wastage. To counter this restriction, implementing innovative technologies on the gas network is a possible solution. On implementation of such technologies, the existing gas network would not only act as a control element but also as a storage system to store the surplus energy produced in the electricity net. This means that, the gas network would not only produce surplus energy (in the form that it is needed) to supply the power grid when the power grid is energy deficient but also store the surplus energy from the power grid when surplus power is produced.

Discussion

The surplus energy (gas) produced by the gas net can be used to power CHP systems (both small scale and large scale) which in turn produce electricity that could be fed into the power grid. When the power grid produces surplus energy, it could be fed back into the gas grid using a bi-directional coupling mechanism. This involves PowerToGas (PtG) plants that convert the surplus electricity to gas which could be stored in the gas net, used to power the CHP plants or provide fuel for electro-mobility. This strategy however involves the preparation of the power grid, the gas network and all the bi-directional coupling technologies so that the concept becomes feasible. This contribution involves the analysis of possibilities and potential control strategies that would enable the gas network and the electricity grid to be integrated into a common energy system**.**

Comparison of Biological and Catalytic Methanation for Power-to-Gas Applications

***Manuel Götz, Amy McDaniel Koch, Dr. Frank Graf**, DVGW Research Center at the Engler-Bunte-Institut of the Karlsruhe Institute of Technology (KIT)*

Keywords: Biological methanation, methanation, Power-to-Gas, SNG, Substitute Natural Gas

Introduction

Germany has set a goal that by 2030, 30 % of its gross final energy consumption and at least 50 % of its power supply will be provided by renewable energy sources such as wind or solar energy. Nevertheless, these energies are fluctuating and intermittent and will need to be balanced for electric grid stability purposes. Electricity storage via Power-to-Gas (PtG) technology is a promising solution to tackle this issue. This process links the power grid with the gas grid by converting this surplus power into a grid compatible gas via a two-step process: H_2 production by water electrolysis and H_2 conversion with an external CO or CO_2 source to CH_4 via methanation. Both biological and catalytic methanation could be used for the methanation step (Figure 1). The resulting synthetic natural gas (SNG) can be injected into the existing gas distribution grid.

Discussion

Catalytic methanation means the conversion of H_2 and CO_2 at about 300 - 550 °C usually with nickel-based catalysts. Catalytic methanation processes can be realized in several reactor concepts. Mainly, these can be subdivided by the nature of the support (e. g. honey combs or pellets), the temperature control (e. g. isothermal or adiabatic) or the phases involved in methanation (two phase vs. three phase reactions).

Another approach is the biochemical conversion. A microorganism serves as biocatalyst. The bioprocess takes place in aqueous solutions at temperatures between 40 - 70 °C. The limiting step is the transfer of hydrogen from gas phase into the liquid phase. Hence, there are several reactor concepts under development aiming to reduce these mass transfer limitations. So far the stirred reactor (CSTR) is the mostly used reactor.

Mainly due to the higher process temperature and the resulting higher reaction rate, catalytic methanation requires much lower reactor volumes for a certain feed gas flow compared with biochemical methanation. However, full CO_2-conversion in a single step catalytic methanation reactor is difficult to achieve due to thermodynamic equilibrium limitations.

Both catalytic and biochemical methanation processes will be figured in the presentation. The main characteristics of the processes with advantages and challenges will be discussed as well as the state of development.

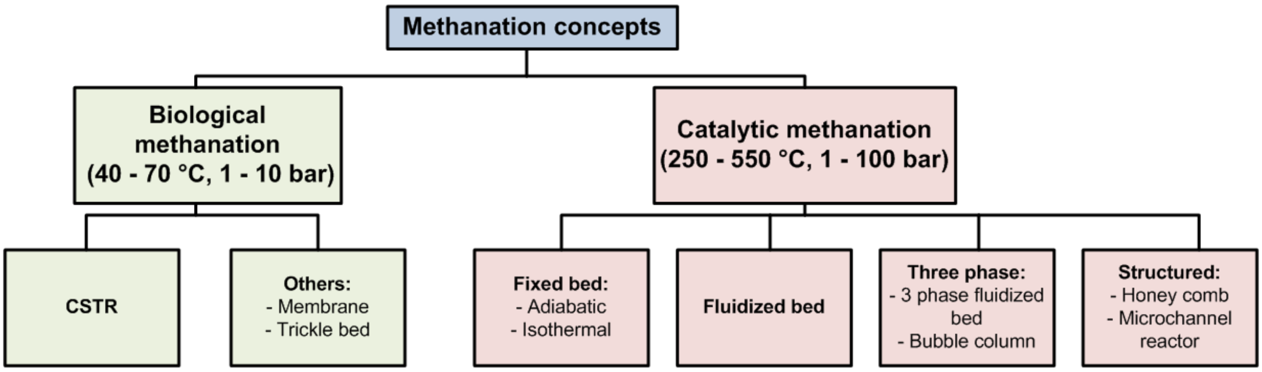

Figure 1: Methanation concepts for the production of SNG

Conclusions

The PtG process is a promising way to transform electricity from renewable energy sources and store it as chemical energy carriers. The methanation reaction can be performed in biological and catalytic reactors. Biological methanation is an attractive option for small plants and impure gas feeds. On the other hand, catalytic methanation is attractive for its high reaction rates resulting in small apparatuses. Moreover, the high temperature level of catalytic methanation results in more options for process integration and waste heat usage, which yields more efficient processes. However, PtG economics are not yet assured because of the high costs related to the H_2 production.

Selective Adsorption of Methane over Carbon Dioxide on Activated Carbon

Pantipa Pranudomrat, *The Petroleum and Petrochemical College, Chulalongkorn University, aepantipa@gmail.com*
Dr. Pramoch Rangsunvigit, The Petroleum and Petrochemical College, Chulalongkorn University, pramoch.r@chula.ac.th
Dr. Boonyarach Kitiyanan, The Petroleum and Petrochemical College, Chulalongkorn University, boonyarach.k@chula.ac.th
Dr. Santi Kulprathipanja UOP, A Honeywell Company, Des Plaines, USA, santi.kulprathipanja@uop.com

Keywords: Hydrophobicity, Methane Adsorption, Activated Carbon

Introduction

In recent years, the interest in natural gas (NG) has grown rapidly because of the increase in the price of petroleum and stringent environmental regulations. There has been a significant increase in the production of NG as an efficient and environmentally clean fuel supply. However, the big disadvantage of NG is its low energy density. An interesting method is to store NG as an adsorbed phase in porous materials and low pressure resulting in safety advantages. In this study, activated carbon treated with alkali solution (KOH and NH_4OH) and silane coupling agent (MTES) as a hydrophobic promoter was investigated for the selective adsorption between methane (CH_4) and carbon dioxide (CO_2).

Discussion

Figure 1 shows CH_4 adsorption capacity and selectivity on the adsorbents at 298 K and atmospheric pressure with CH_4:CO_2 = 50:50. The adsorption capacity of CH_4 increases after the alkali treatment, especially with NH_4OH, because some oxygen functional groups are neutralized resulting in the hydrophobic extent on the surface [1]. MTES also decreases the CO_2 adsorption due to the lower hydrophobic on the surface but the CH_4 adsorption also decreases because some micropores of adsorbent might be blocked by MTES. The pore size distribution of activated carbons was obtained by Horvath-Kawazoe (HK) method indicates that almost all micropores an around 3.6 Å. As the kinetic diameter of CH_4 (3.8 Å) is larger than CO_2 (3.3 Å), so it is possible that CH_4 can adsorb in the mesopores more than the micropores, where CO_2 preferential adsorbs.

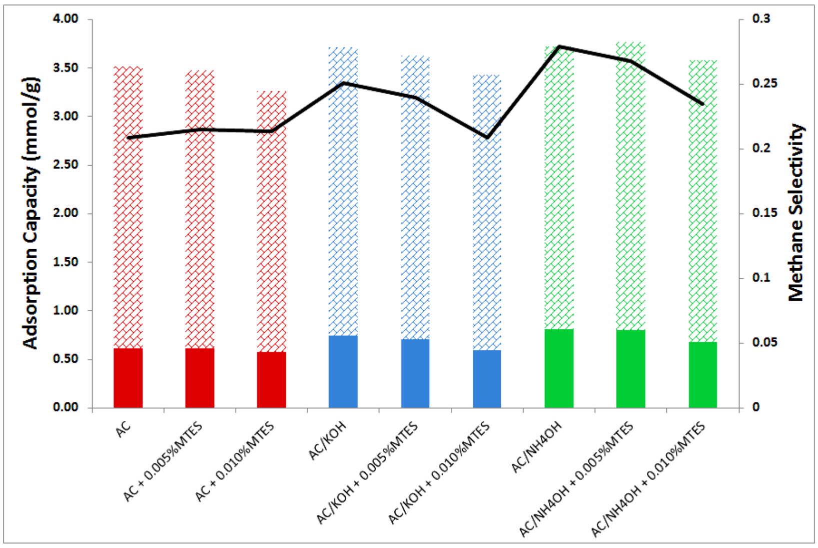

Figure 1: Adsorption capacity and selectivity of CH_4/CO_2 on modified activated carbon.

Conclusions

The adsorption capacity of CH_4 can be increased on the hydrophobic adsorbents. In contrast, the treatment may block the micropores of activated carbon that affect the CH_4 adsorption capacity.

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High-pressure Hydrogen Vessel Simulations with the Computational Fluid Dynamics Code GASFLOW

Dr. J.R. Travis*, Engineering & Scientific Software, Inc., 2128 S. Ensenada Circle, Rio Rancho, NM 87124, USA*
jack_travis@comcast.net
Dr. D. Piccioni Koch, Steinbuch Centre for Computing (SCC), Karlsruher Institut fu¨r Technologie (KIT), Postfach 3640, 76021 Karlsruhe, Germany, daniela.piccioni@kit.edu

Keywords: Cryo-compressed hydrogen (CcH2) vessels, Hydrogen Storage, Bonfire test simulations, Loss of Vacuum, Hydrogen Refuelling

Hydrogen represents one of the most favorable gases as a future alternative energy source. However, in the automotive field, several challenges must be overcome before the introduction of hydrogen fuel cell vehicles on a large scale can become possible. One key hurdle is the development of efficient and safe hydrogen storage technologies and, in particular, the realization of high-pressure hydrogen vessels for long term viability.
The Computational Fluid Dynamic (CFD) code GASFLOW was used to simulate cryo-compressed hydrogen (CcH2) vessel systems for vehicular applications and, in particular, to model Al-liner carbon-fiber/epoxy tanks of Type III.
Three main studies are presented:

- Bonfire Test Simulations
- Cryogenic Tank Loss of Vacuum Scenarios
- The HySIM Hydrogen Refuelling Benchmark

The GASFLOW simulations show good agreement with previous simulation results and with data.

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Hydrogen Energy System (H_2ES) as Grid Management Tool for Renewable Energy Systems in Hawaii

Dr. Mebs Virji, Hawaii Natural Energy Institute, University of Hawaii, mvirji@hawaii.edu
Dr. Guenter Randolf, GRandalytics, g.randolf@grandalytics.com
Mitch Ewan, Hawaii Natural Energy Institute, University of Hawaii, ewan@hawaii.edu
Dr. Richard Rocheleau, Hawaii Natural Energy Institute, University of Hawaii, rochelea@hawaii.edu

Keywords: Hydrogen, Renewable Energy, Grid Management, Battery

Introduction

In Hawaii, high penetration levels of intermittent renewable energy sources such as wind and solar are causing challenges in regulation of grid frequency, and as the percentage of these intermittent resources increases can result in their curtailment. Similar to a battery, the optimized use of an electrolyzer as a variable load can help regulate grid frequency and increase the penetration of renewable energy resources on the grid. The use of an electrolyzer in this way provides an "ancillary service" to the grid that can be assigned a monetary value. This monetary value can be used to offset the cost of hydrogen production. The hydrogen in turn can be used in high value applications such as a transportation fuel.

Discussion

The Hawai'i Natural Energy Institute (HNEI) is conducting research to assess the technical potential and economic value of using an electrolyzer-based hydrogen production and storage system as a demand response tool for grid management. A 65 kg/day hydrogen energy system (H_2ES) has been purchased and will be installed at the Hawaii Natural Energy Laboratory Hawaii Authority to demonstrate long-term durability of the electrolyzer under cyclic operation required for frequency regulation on an island grid system. A secondary objective is to supply hydrogen for fuel-cell battery buses to be operated at Hawai'i Volcano National Park and by the County of Hawai'i Mass Transit Authority. The H_2ES (Figure 1) consists of a 65 kg per day Proton HOGEN PEM electrolyzer, 35 bar buffer tank, 450 bar compressor, and chiller systems. The hydrogen will be transported from the production site by tube trailers to two dispensing sites. This test shall demonstrate whether the electrolyzer has the capability to effectively mitigate the impacts of intermittent solar and wind power on the grid, while continuously generating 90-80% of its designed hydrogen production capacity.

A comprehensive test plan has been developed to characterize the performance and the durability of the electrolyzer under dynamic load conditions. A main objective of the test plan is to determine the operating envelope and dynamic limits of the electrolyzer and the overall H_2ES. A long-term study shall evaluate the H_2ES performance under a load profile developed from a fast acting Battery Energy Storage System (BESS) that is currently in use as grid management tool on the Big Island grid. Figure 2 shows a 20 minute cyclic load profile from the BESS and a smoothed set point profile for the electrolyzer, generated by a 0.02 Hz low pass filter. The low pass frequency is based on the electrolyzer's ramp rate of 10% to 90% in 1 minute and power amplitude of 10%.

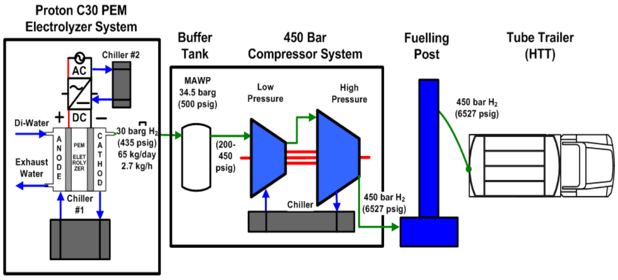

Figure 1: Overview of the main components of the GM H_2ES

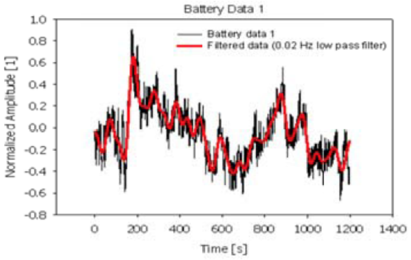

Figure 2: Cyclic load profile derived from the BESS data

Conclusion

The paper will describe the H_2ES configuration, plans for operation in the field, and results of initial tests to determine the dynamic response of the electrolyzer and overall system.

Voltage- and State-of-Charge-managed storage integration for grid stabilization

Dipl.-Phys. Dirk Pietschmann, *Department of Transportation, Energy and Environment, Fraunhofer Institute for Transportation and Infrastructure Systems IVI, dirk.pietschmann@ivi.fraunhofer.de*
Dipl.-Ing. Richard Kratzing, Department of Transportation, Energy and Environment, Fraunhofer Institute for Transportation and Infrastructure Systems IVI, richard.kratzing@ivi.fraunhofer.de
Dr.-Ing. Ulrich Potthoff, Department of Transportation, Energy and Environment, Fraunhofer Institute for Transportation and Infrastructure Systems IVI, ulrich.potthoff@ivi.fraunhofer.de

Keywords: Energy, Storage, Grid, Stabilization, Voltage, State of Charge (SoC)

Introduction

The integration of decentralized renewable energy sources can significantly influence the low voltage grid – especially if the energy supply is not coordinated or if there is no storage available for taking in excess energy. On the other hand, controlling the energy supply for grid safety can imply the disconnection of renewable energy sources, which interferes with their intended use. In addition, existing storages are not available for grid stabilization, as they are in most cases used for private consumption and to reduce local energy costs. This results not only in the fact that expensive storage is used inefficiently, but also in voltage fluctuation and increased costs for a sustainable energy transition.

Discussion

For a more efficient use of the grid and a significant impact on the grid quality, the battery-based electrical storage system should be controlled with respect to grid voltage and frequency as well as to the State of Charge of the storage itself. This approach will additionally reduce the general grid load and finally the costs for grid operators and consumers. One very important variable of this approach is the grid voltage U. This value, its limits and history are used to calculate the power exchange between battery and grid in combination with a calculated future trajectory of the SoC, named SoC_{set}. **Figure 1** shows different regimes where the grid voltage (U) in combination with the calculated $SoC_{set}(t)$ controls the power exchanged with the grid.

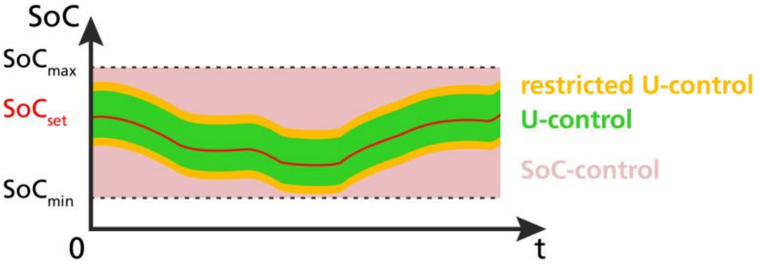

Figure 1: SoC_{set} in dependence of the time and the regimes for U-control and SoC-control

Beside the SoC_{set}, a surrounding range of tolerance, based on the voltage history of the specific grid node the storage is connected to, is also calculated by the algorithm. This leads to the effect of balancing the low voltage grid to reduce over- and under-voltages as well as increasing the possible energy transfer rate to the grid.
All algorithms have been developed and implemented with Matlab/Simulink and tested with measured voltage data. We differentiate the voltage history in urban grid nodes without photovoltaic power plants (PV) and rural grid nodes with PV systems.

Conclusions

It was possible to implement efficient and complete autarkic use cases for decentralized battery storage systems as support for grid nodes, particularly low voltage grids, with a new control approach based on SoC level, grid voltage and frequency. The impact of this system on the grid and its quality is inherently coupled with and limited by the battery capacity.

Acknowledgement: I would like to thank the supervisors Richard Kratzing and Dr. Ulrich Potthoff for providing the possibility to develop the algorithm. I would like to express my very great appreciation to Liya Ma who integrated and improved most of the algorithms and ideas. Assistance provided by Phuong Tran and Michael Beyer was greatly appreciated.

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Reserve Capacity Provision through Flexible CHP and Power-To-Heat Technology in Industrial Applications

Dr. Hans Schäfers, *Center for Demand Side Integration, Hamburg University of Applied Sciences (HAW Hamburg), hans.schaefers@haw-hamburg.de*
Dipl.-Geogr. Philipp Wellbrock, DFGE – Institute for Energy, Ecology, Economy, Wellbrock@dfge.de
Dipl.-Ing. (FH) Johannes Braunagel, Center for Demand Side Integration, Hamburg University of Applied Sciences (HAW Hamburg), Johannes.braunagel@haw-hamburg.de

Keywords: Energy, Industry, Demand Side Management, Power-to-heat, Reserve Capacity

Introduction

All along the North Sea, the transition towards renewables has led to large capacities of wind power, which at times produce more electricity that needed and challenge grid stability. Large industrial consumers in the region could help to absorb surplus amounts of wind energy by flexibly adjusting their power demand, using demand side management and power-to-heat technologies. Within the project “e-harbours”, partners have investigated cases in which these solutions can be implemented successfully in the current energy market environment, identifying economic potentials as well as regulatory and organizational barriers.

Discussion

Highlighted showcase in Hamburg is a chemical company with high steam and power demand, which uses a combined heat and power plant (CHP), coupled with gas boilers for peak demand. A techno-economic analysis was carried out to investigate feasibility, revenues and additional costs for the provision of negative reserve capacity.
Using a model for flexible operation of the CHP (7 MW_{el}), the available load size within the operation boundaries, it was determined that negative secondary reserve capacity of 2.5 MW could be offered for the first scenario, which implies regulating down the CHP whenever negative reserve capacity is demanded, and generate steam with existing gas boilers. As a second scenario, a retrofit with 5 MW electric boilers to substitute the CHP was assessed, which triples the available amount of negative reserve capacity.

To investigate revenues and costs for both options, a simulation was carried out based on energy market data series, the company’s demand and individual price components. Results show that both scenarios are profitable, with the second scenario generating net profits of almost 20% of baseline energy costs (see **Figure 1**). While the Power-to-heat option largely increases the possible revenues, costs increase disproportionately due to depreciated investments, grid fee increase and other regulatory implications. Still, the additional investment for electric boilers will amortize after approximately two years, given 2013 market data.

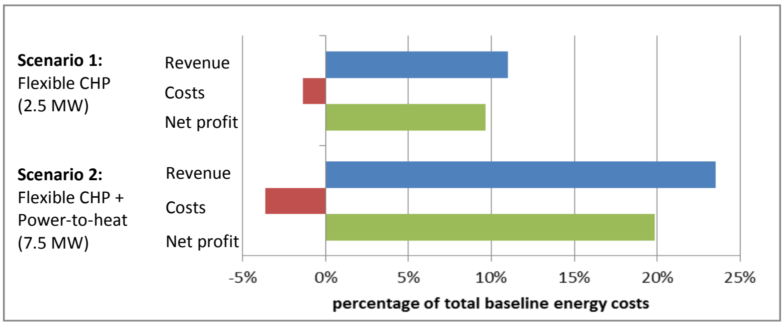

Figure 1: Costs and revenues of both scenarios; inlcluding investment, excluding reserve capacity market transaction costs

Conclusions and Outlook

The investigations have shown that reserve capacity provision using large CHPs can be profitable, and that additional Power-to-heat devices can largely increase possible revenues, at a moderate investment amount. However, several factors are still weakening the business case: Adverse regulations, but also costs and risks of the reserve capacity market. These factors may prevent companies from investing in such solutions. Since exploiting demand side integration is seen as a key factor of the energy transition, HAW Hamburg has consulted the Federal State of Hamburg in the development of a subsidy scheme for industrial demand side flexibility, which will become effective in 2015.

High-Temperature Superconductor Current Leads as Energy Efficient Current Feeders for Superconductor Applications

Dr. Walter H. Fietz, Institute for Technical Physics, Karlsruhe Institute of Technology
Dr. Reinhard Heller, Institute for Technical Physics, Karlsruhe Institute of Technology
Dr. Klaus-Peter Weiss, Institute for Technical Physics, Karlsruhe Institute of Technology

Keywords: Power Transmission, Superconductor Application, High-Temperature Superconductor

Introduction

Due to the zero resistance at sufficient low temperature, superconductors can transfer currents very efficiently. As a consequence they are used to operate large magnets e.g. for NMR or in accelerator science. Another application is the efficient transfer of very high currents in the 20 kA to 200 kA range for applications like aluminium production. One of the problems to be solved for a wide use of superconducting high current cables in science and industry is the efficient transfer of current from room temperature down to low temperature in the range of 4 K to 77 K (approx. -270°C to -196°C) and back to room temperature. This transfer is done by current leads, which have to bring the current to low temperature to allow a connection to a superconductor. The necessary electrical insulation with a parallel optimization of current transport and a minimization of thermal conduction gives challenging boundary conditions for a current lead.

The poster will introduce the field and give examples for current leads in the range of 20 kA to 80 kA.

Discussion

Conventional current leads are made of Cu or Al with a current carrying material combined with a heat exchanger. Cold gas e.g. He at 4 K is injected at the low temperature end and cools the current lead when passing the heat exchanger (see fig. 1, left hand side). The efficiency of such current leads is low because of the power needed to recool the cooling gas to low temperature.

The use of High-Temperature Superconductors (HTS) allows to operate the conventional heat exchanger only between room temperature and approx. 60 K. From that temperature down to 4 K, the HTS material transfers the current with no Joule heating (see fig. 1, right hand side). The thermal transport from 60 K to 4 K is massively reduced by the smaller cross section of the superconductor and by using optimized material with lower thermal conductivity. This results in an energy saving by a factor of 3 to 5 compared to conventional current leads. The Institute for Technical Physics of KIT has designed, constructed and tested prototypes and series HTS current leads in the range of 20 kA to 80 kA. Fig. 2 shows a current lead that was built for the stellerator W7-X currently under commissioning in Greifswald (Germany).

The poster will outline the basic design used for these current leads and show the actual development.

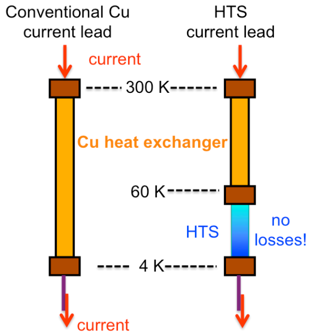

Figure 1: Function principle of conventional and HTS current leads

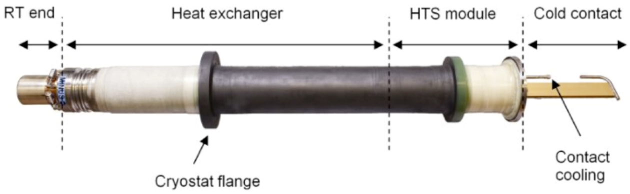

Figure 2: 18.2 kA HTS-current lead for W7-X

Conclusions

For an energy efficient use of superconductors for high current transfer, an optimized current lead that minimizes losses at low temperature is indispensible. HTS materials reduce the losses massively and allow an efficient transfer of current to low temperature and back.

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Optimization of Large Scale Smart Grids

Francesca Jung, Center for Industrial Mathematics (ZeTeM), University of Bremen, fjung@math.uni-bremen.de
Arne Berger, ZeTeM, University of Bremen, a.berger@uni-bremen.de
Prof. Dr. Christof Büskens, ZeTeM, University of Bremen, bueskens@math.uni-bremen.de
Dr.-Ing. Michael Schollmeyer, IAV GmbH, Gifhorn, michael.schollmeyer@iav.de
In cooperation with the TU Clausthal.

Keywords: Smart Grid, Optimization, Reactive Power

Introduction

To reach the climate targets there have been a massive sponsorship from the German government for the renewable energies, for example for solar panels and wind turbines. As a result, the number of decentralized power plants in the private sector increased a lot. All these power plants are connected to the public electricity grid and if there is an surplus of energy, they will feed it into the grid. The grid is not designed for these processes. At first the supply of energy in all grid levels is new. Normally the producer are in the highest level and most of the consumer in the lowest level. The second change is the high amount of fluctuating energy supply due to the renewable energies. For these reasons the German electricity grid is in a phase of transition at the moment. In addition to the expansion of the grid there are possibilities to extend the efficiency of the existing grid. Some of these possibilities should be modelled and analysed in our current work. The focus is on the optimization of the current electricity grid without a high investment in additional sensors and control variables.

Discussion

We integrated the model of a electricity grid in the optimization method WORHP ('We Optimize Really Huge Problems') from our working group 'Optimization and Optimal Control' at the University of Bremen. This optimization method is specialised for high dimensional non linear problems with sparse structures.
The first step has been the inclusion of the static load flow calculations. For the optimization method these are normal constraints. Without an objective function the method only has to satisfy the constraints and therefore satisfy the equations from the load flow. To develop a very flexible model, it is not specified in general, which parameters will be optimized. Therefore different variables can be given on different nodes. Possible optimization variables are:

- absolute value of voltage $|U|$,
- phase angle of voltage φ,
- active power P,
- reactive power Q
- and additional parameters for the stability of the optimization.

There are box constraints for every optimization variable: $x_l \leq x \leq x_u$.
Calculating the load flow for example, the active and reactive power are given and the corresponding voltage should be calculated, except for the infeed node. Therefore the left and right constraint for the power values are the same and the other variables will be calculated by WORHP.
Having integrated the model of an electricity grid, different objective functions can be analysed.
One objective function, which has been tested on a IEEE bus system with 14 nodes (IEEE14), is a function which measures the difference between the actual voltage and the nominal voltage. The reactive power at the generators are the optimization variables. As expected, the result shows that the distribution of the voltages at different nodes is more smoothly with this optimization. This objective function can be expanded by a weight for every generator, which reflects the coast for the usage. Thus economic calculations can be performed and saving potentials can be analysed.
Due to the high flexibility of our model, a lot of different objective functions can be tested. These are only two of many objective functions, which will be presented and discussed in the presentation.
After the validation on the IEEE14 example we applied the method to more realistic data, which results in a higher dimension of the problem. Nevertheless, the same analyses can be performed as before and the advantages of WORHP became clear.

Conclusions and Outlook

We integrated the model of a electricity grid in the optimization algorithm and solved different optimization problem. The next step will be to expand the model by dynamic components to integrate time dependent processes.
A long term target is the calculation of the optimal control of the reactive power in extreme situations. For example when there is a grid overload due to too much wind, hopefully less wind turbines have to be forced to switch off and the voltage can be regulated by reactive power instead.

Advanced algorithm for the energy optimization in Microgrids - laboratory testing and experimental results

Matteo Rossini, *Università degli Studi di Milano, matteo.rossini1@studenti.unimi.it*

Diana Moneta, *Energy Systems Development Department, RSE Ricerca sul Sistema Energetico SpA, diana.moneta@rse-web.it*

Gianluca Alimonti, *INFN, Università degli Studi di Milano, gianluca.alimonti@mi.infn.it*

Keywords: Distributed Energy Resources, Renewable Energy Resources, Storage

Introduction

Decarbonisation of Europe power system goes through increasing targets for the exploitation of renewable energy sources (RES), together with energy savings and improved market schemes. *Microgrids* are studied among the possible solutions to further increase RES penetration, guaranteeing at the same time a proper level for the quality of service.

Microgrid are electricity distribution systems containing loads and distributed energy resources DERs, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded. This architecture supports the self-consumption of RES generation, usually adopting an overall energy optimization including both electricity and heat.

Discussion

The optimization algorithm, to be integrated into the SCADA (Supervisory Control And Data Acquisition) system of the microgrid, has to guarantee firstly proper voltage and current values in all nodes and branches of the microgrid. Secondly it has to permit the fulfilment of further goals.

For the scope of this activity, the algorithm VoCANT (Voltage Controller for Active NeTworks) [1] is adopted. It computes the set-points of the distributed energy resources (generators, loads, storages) according to specified economic and technical objectives. It can be used for both offline analysis of different scenarios (generation, load, characteristics and cost of resources) and for online real time control. It is already under testing as a voltage controller in large Medium Voltage networks with high penetration of RES [2].

The experimental phase is carried out on the Distributed Energy Resources Test Facility (DER-TF) in RSE. It is a three-phase LV Microgrid consisting of several generators with different technologies (renewable and conventional), controllable loads and storage systems. The microgrid is connected to the distribution grid through a 23kV/0.4kV transformer. It allows to test the single components, the communication aspects, and different optimization algorithms on fully configurable topologies.

This paper focus mainly on modelling of DERs in terms of their energy behaviour, with respect to the optimization goals. In particular, a micro-turbine in co-generative configuration is included: since it has to follow the thermal load, the controller can request only a little displacement from the actual active power value, guaranteeing the energy production on a given horizon. Also managing storage devices need to handle a multi period optimization: setpoints cannot be calculated considering the single time period but analysing the overall horizon. This allows to identify the 'best' periods for charging/discharging them, but at the price of further input data (forecast profiles) and increased calculation effort. Proper models for storage devices, in order to take into account cycle efficiency and consumption of auxiliary systems, are furtherly described.

Examples of optimization procedure in the offline case and on the real test facility are then reported.

Conclusions and Perspectives

Several benefits are expected from microgrids: higher quality of service, increased reliability and flexibility, reduced costs for energy purchasing from the grid, reduced Green House Gases emissions. Their economic attractiveness relies on proper optimization procedures, able to compose complex constraints.

In perspective, microgrids could provide ancillary services to the electricity distribution network, in terms of scheduled profiles and/or requested modulation of energy at the interface (point of common coupling).

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A Modelling Language for Energy Consumption Management of Transport Networks: the case study of Karlsruhe

***Ellishia Owens Cruz**, SIANI, University of Las Palmas de Gran Canaria(ULPGC), ellishiaowens@siani.es*
Dr. Jose Juan Hernández Cabrera, SIANI, ULPGC, josejuanhernandez@siani.es
Dr. José Évora Gómez, SIANI, University of Las Palmas de Gran Canaria, joseevora@siani.es
Dr. Enrique Kremers, EIFER, Enrique.Kremers@eifer.uni-karlsruhe.de

Keywords: Transport Networks, Facility Management, Energy Consumption Management, SmartCities, Modelling Languages

Introduction

During the last centuries our societies have grown and evolved rapidly. This growth has resulted in the uncontrolled consumption and waste of energy to keep providing services to citizens. Nowadays, our present society is facing a new challenge, becoming eco-friendly and respectful with our environment, as well as supplying efficient transportation infrastructures that meet the needs of the population.

To tackle these requirements the key is facility management. Policymakers and managers need valuable information of the reality and a defined decision making process based on predictive analysis. For this analysis to be as accurate as possible, the main concern is to have a good representation of the reality and simulation mechanisms. To achieve it, transport network models must not simplify a very complex reality.

Discussion

The objective of this paper is to make a contribution in transport system modelling languages for energy consumption analysis. In short, the work consists of designing and developing a Domain Specific Language (DSL) that assists on modelling tasks. A DSL provides a notation tailored towards an application domain and is based on the relevant concepts and features of that domain [1].

Domain-specific languages are usually declarative. Consequently, they can be viewed as specification languages[2]. These languages are restricted to a specific domain and therefore, they trade generality for expressiveness in the specific domain. They offer substantial gains in expressiveness and ease of use compared with general-purpose languages (GPL), for the domain in question [3].

In this paper, we present a DSL that is able to represent the transport system structure itself, how people are using this system and the impact on energy consumption. The calibration of this behavioural model must be made using historic series concerning the usage of the public transport in different aspects, for example, the usage of the lines, directional flows of people, occupancy of the vehicles at a given time, and so on. This involves a new conception in which not only is the static view of the reality modelled but also the dynamic view. Moreover, one of the main focuses is to analyse and comprehend the evolution of the Transport Network in the area and its energy incidence.

Experimentally, in order to validate the DSL, we chose the case study of Karlsruhe because the area has a well developed infrastructure where multiple means of transport are present, for instance: trains, light trains, trams, buses, taxis and private cars as well as bicycles. Besides, the amount of data available is enough for developing the models. Ensuring that we cover all the information calls for careful analysis of all the available data collected from the KVV, openstreetmaps and CityGML of EIFER Institute of Karlsruhe. Lastly, since the evolving situation of the transport infrastructures is a requirement for this analysis, Karlsruhe city is an interesting case due to its current transportation master plan which is transforming the city infrastructure.

Conclusions and/or Outlook

There is a significant lack of modelling languages which not only focus on one aspect of transportation but on several of them, as well as the inclusion of social factors such as the impact on the population. The approach presented and the introduction of the expressive modelling language enable us to develop a complex, rich and accurate model of the transport network. The next steps would be to create several scenarios where Key Performance Indicators are calculated in order to assist in the decision making and ultimately optimizing the energy consumption which is an essential issue in Smartcities.

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Addressing the complexity of modeling building energy dynamics using a component-based approach

***Muhammad Anas Munir**, Chair for Software and Systems Engineering, Technische Universität München, anas.munir@tum.de*
Georg Hackenberg, Chair for Software and Systems Engineering, Technische Universität München, hackenbe@in.tum.de

Keywords: building modeling, interface modeling, component-based modeling

Abstract

Efficient building energy management is becoming increasingly important. Existing building energy management approaches range from classic optimal control techniques [1] to dedicated control architectures [2, 3]. Optimal control techniques [1] typically include some form of building energy dynamics modeling, while the models usually are represented by sets of nonlinear state equations or differential equations. This model representation allows precisely to describe the interactions between the physical variables (e.g. room temperature and heat exchange), but with increasing building complexity managing the variables and interactions can become difficult. Control architectures [2, 3], on the other hand, focus on the structure of respective controller systems, e.g. using a three-layered approach including device drivers (e.g. for washing machines), prevention measures (e.g. circuit breaker activation) and anticipation strategies (e.g. user demand forecast and weather forecast). Together, optimal control techniques and control architectures already provide powerful tools for efficient building energy management. However, existing approaches typically are limited to a single form of energy (i.e. electricity or heat) [1, 2] and are restricted in complexity due to the underlying model representation. In this paper we address these problems using a component-based approach for modeling of buildings (see **Figure 1**), which can be combined with existing model representations for expressing building energy dynamics. The approach allows one to model not only the building, but also the surrounding infrastructure (e.g. the power grid and district heating) and the environment using respective components with heat, power and information interfaces. Furthermore, the building can be decomposed into the roof, floors and rooms with supporting heat, power and communication infrastructure components. Finally, the rooms contain air and device components, while devices interact with the air as well as infrastructure components. We evaluate the presented approach with respect to comprehensibility and completeness. To evaluate comprehensibility we perform a user study asking for advantages and disadvantages of the presented approach. To evaluate completeness, on the other hand, we map the features of existing building models to the features of the proposed approach. We conclude that the component-based approach indeed provides a comprehensive and complete building model with focus on energy dynamics.

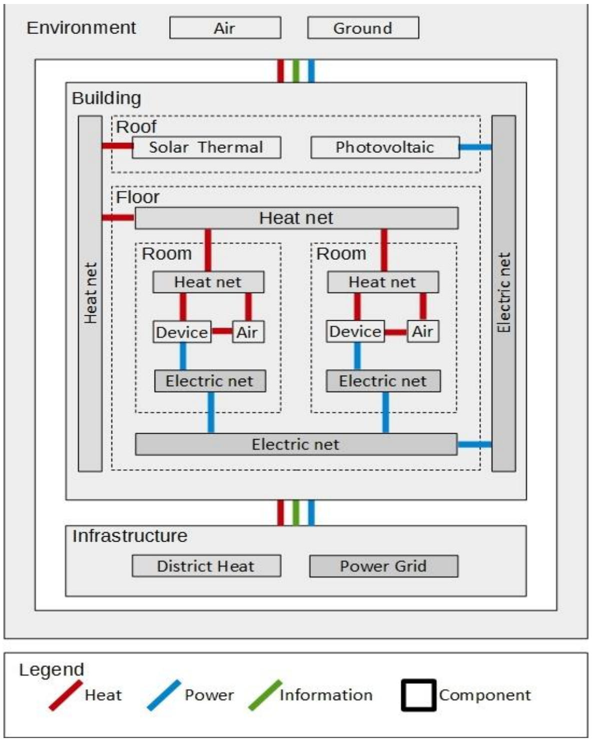

Figure 1: Overview of the component-based modeling approach including building, infrastructure and environment components as well as heat and electricity interfaces.

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Study on Enhanced Energy Density of Organic Active Carbon-Based Supercapacitors

***Jen-Hao Chien**, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, r03524039@ntu.edu.tw*
Dr., Prof. Nae-Lih Wu, Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan, nlw001@ntu.edu.tw

Keywords: Supercapacitor, Conductivity, Percolation, Capacitance

The demand of energy storage devices has recently increased substantially due to the advancements of various electronic devices. As a result, research has been devoted to the development of energy storing devices that possess low cost, long durability, high capacity, and environmental friendly properties. In view of power density and energy density, supercapacitor can be regarded as an energy storage device between a battery and a ceramic capacitor. General speaking, supercapacitor has a greater storage capacity which is thousands times larger than conventional ceramic capacitor. Moreover, the power density of supercapacitor is around 20-100 W/kg, which is ten times more than a battery. Therefore, it can provide powerful energy to electronic devices.

Depending on different charge storage mechanism, there are two types of supercapacitors, electric double-layer capacitor (EDLC) and pseudocapacitor. Owing to electrochemical stability and low cost, carbon-based EDLCs with large specific surface area are still the major choices for electrode materials. Based on the advantage of large surface area (2632 m^2/g), active carbon is used as the active material of the electrode in this study. Composite electrodes which consist of active carbon and a conductive carbon black (CB) have been studied for the capacitance properties in organic $LiPF_6$ electrolytes. It is shown that there exists an CB threshold, above which the capacitance of the composite electrode is limited by the surface area of the active material and below which the electronic resistance of the electrode turns out to be the limiting factor. As a result, it is shown that the maximum capacitance exists at a threshold composition which the percolation networks are constructed.

For further capacitance enhancement, the active carbon electrode is impregnated with MnO_2 within the porous structure by adopting a solution reduction process. It is shown that the charge-storage behaviour of the C-Mn oxide electrode depends strongly on the subsequent heat treatment conditions, including temperature and atmosphere.

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Electrochemical characterisation and abuse tests of first FSBW-Supercapacitors

Dr. N. Baltes, *Fraunhofer Institute for Chemical Technology, Pfinztal/Germany,*
norman.baltes@ict.fraunhofer.de
J. Frohberg, Fraunhofer Institute for Chemical Technology, Pfinztal/Germany
F. Geier, Fraunhofer Institute for Chemical Technology, Pfinztal/Germany
M. Krampfert, Fraunhofer Institute for Chemical Technology, Pfinztal/Germany
M. Joos, Fraunhofer Institute for Chemical Technology, Pfinztal/Germany
R. Speck, Fraunhofer Institute for Chemical Technology, Pfinztal/Germany
P. Kitzler, Fraunhofer Institute for Manufacturing Engineering and Automation, Stuttgart/Germany,
peter.kitzler@ipa.fraunhofer.de
M. Cudazzo, Fraunhofer Institute for Manufacturing Engineering and Automation, Stuttgart/Germany
S. Hellstern, Fraunhofer Institute for Manufacturing Engineering and Automation, Stuttgart/Germany

Supercapacitors are becoming increasingly important in many transport and automotive technologies, e.g. pallet transporter, transport systems, automated guided vehicle systems or rack feeders. They have attracted considerable attention in the last decade because they can provide a higher power density than batteries and a higher energy density than conventional dielectric capacitors. In order to enhance the energy density, a new hybrid type pseudocapacitor is developed in the course of the FastStorage (FSBW) project.

An increased production of electric cars is followed inevitably by a larger number of rare but potentially dangerous incidents. Thus, quality and safety standards are distinguishing features and demand preliminary and defined abuse tests. Our Battery Test Group focusses on the generation of battery safety data and analytics. Here, we present first thermal, mechanical and electrical abuse tests of FSBW-I supercaps as well as qualitative and quantitative investigations into the gases released.

The maximum energy/capacity also depends on the properties of the (active) electrode material, which was fabricated by means of elaborated vacuum filtration or dry coating processes. In order to gain information concerning the size of the specific surface and electrochemical characteristics adsorption measurements as well as galvanostatic cycling measurements have been performed.

The actual FSBW-II project is supported by the *Ministerium für Finanzen und Wirtschaft Baden-Württemberg* and represented by members of the Fraunhofer IPA&ICT, the University of Stuttgart (EEP, IFSW, ISW), the Karlsruher Institute for Technology (KIT), the Centre for Solar Energy and Hydrogen Research Baden Würtemberg (ZSW) and industrial partners from Varta Microbattery GmbH, Festool, SEW Eurodrive, Viastore Systems and Freudenberg & Co KG.

Roles of Polybenzoxazine Functionalization on CO_2 Adsorption

***Katipot Inkong**, The Petroleum and Petrochemical College, Chulalongkorn University, i.katipot@gmail.com*
Dr. Pramoch Rangsunvigit, The Petroleum and Petrochemical College, Chulalongkorn University pramoch.r@chula.ac.th
Dr. Thanyalak Chaisuwan, The Petroleum and Petrochemical College, Chulalongkorn University, thanyalak.c@chula.ac.th
Dr. Santi Kulprathipanja, UOP, A Honeywell Company, Des Plaines, USA, santi.kulprathipanja@uop.com

Keywords: CO_2 Adsorption, Activated Carbon, Polybenzoxazine

Introduction

Carbon dioxide (CO_2) is the major greenhouse gas that contributes to global warming phenomenon. Various processes have been proposed to reduce CO_2. The adsorption process is one of interesting processes because of low energy consumption, non-corrosive problems, and easy regeneration. The amine-functionalized adsorbents have been used to overcome the limitation of classic adsorbents in the CO_2 adsorption field by synergistic effects of physical and chemical adsorption [1]. Polybenzoxazine (PBZ) is a very attractive polymer for the CO_2 adsorption due to more amine functional group [2]. In this work, activated carbon (AC) was functionalized with benzoxazine via ring-opening polymerization of the benzoxazine monomer, which was synthesized from phenol, paraformaldehyde, and triethylenetetramine.

Discussion

The initial concentrations of benzoxazine monomer (BZ) solution was varied in the range of 0.1-0.5 g/l. Higher concentration of the BZ solution increased the amount of impregnated PBZ as a result of the increased driving force of diffusion in the impregnation step. After PBZ was impregnated on AC, the surface area, pore volume and pore diameter of the samples decreased as the PBZ loading amount increased. This confirms that PBZ was successfully introduced onto the AC. The effect of PBZ loading on CO_2 adsorption is shown in **Figure 1**. CO_2 adsorption capacity of 0.13 wt% and 0.49 wt% PBZ/AC was higher than the AC due to chemical reactions between the amine group of PBZ and CO_2 and synergistic with the physisorption to increase the CO_2 adsorption capacity. However, 0.54 wt% PBZ/AC had lower CO_2 adsorption capacity than the AC because it decreased the surface area, hence, the extend of the physical adsorption. **Figures 1a)** and **1b)** show the effects of adsorption temperature on the CO_2 adsorption of PBZ-functionalized AC and AC. When the adsorption temperature increases, the CO_2 adsorption capacity decreases. This may indicate that the effects of chemisorption were shadowed by the physisorption on grafted the AC.

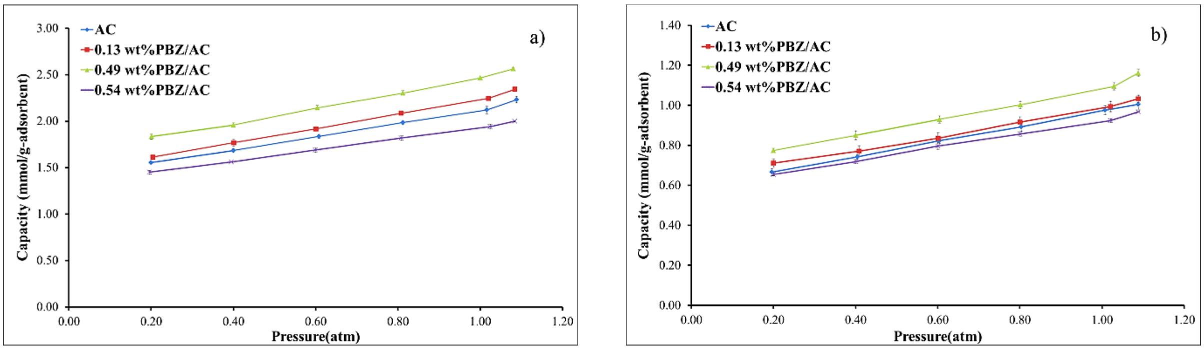

Figure 1: CO_2 adsorption isotherms of the AC and PBZ/AC at a) 35°C and b) 75 °C.

Conclusion

The functionalization of PBZ improved the CO_2 adsorption capacity due to the synergistic effects between physical and chemical adsorption. The increase in adsorption temperature reduces the CO_2 adsorption capacity decreases due to a strong influence of physisorption.

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Measurement of Minimum Miscibility Pressure of CO_2 in Thai Crude Oil. Effect of gas impurity

Supanut Jirarattanawanna, *The Petroleum and Petrochemical College, Chulalongkorn University, supanut273@hotmail.com*
Chintana Saiwan, The Petroleum and Petrochemical College, Chintana.sa@chula.ac.th
Farshid Torabi,University of Regina, Regina, Canada, farshid.torabi@uregina.ca

Keywords: Enhanced oil recovery, Minimum miscibility pressure, Pressure decay technique

Introduction

A demand of energy from fossil fuel is continuously increased every year, the petroleum production worldwide becomes difficult and requires new developments in technology, especially to assist oil recovery. A tertiary recovery of petroleum using carbon dioxide injection (CO_2) becomes an interest and alternative challenge for Thailand. CO_2 is the greenhouse gas that leads to the global warming. Capture and storage (injection) of CO_2 become a significant and important process to reduce the CO_2 emission into the atmosphere. CO_2 reacts with the reservoir rock and fluids to improve the oil mobility, such as oil viscosity and interfacial tension reduction, oil swelling, and extraction of lighter components. Minimum miscibility pressure (MMP) is a key parameter for screening and operating for CO_2 injection in the tertiary recovery. Several methods to measure MMP are slim-tube apparatus and rising bubble apparatus. Previous work used a modified pressure decay technique to measure MMP of CO_2-Thai crude system, where MMP was measured at the maximum pressure drop of the plot of total pressure drop against initial pressure. This research will measure MMP of CO_2 in Thai crude oil and study effect of gas impurity (N_2) in CO_2 by the modified pressure decay technique. Each sample will be tested at two different temperatures and nine different pressures.

Discussion

The effect of temperature is shown in Figure 1a for n-decane, crude (API 63.9), and oil sample at 20 ºC. The MMP values are 825psi, 775 psi, and 725 psi, respectively. At 775 psi, the MMP of crude oil at 30 ºC is 850 psi. The MMP value at 30 ºC is higher than at 20 ºC. Increase temperature of the system increases the MMP because the solubility of CO_2 in the samples is decreased when temperature is increased and thus, requires higher CO_2 pressure to achieve the miscibility. The effect of molecular weight is shown in Figure 1b. The results show that increasing molecular weight of samples increases the MMP values due to the increase of sample viscosity. At 20 ºC, n-decane (MW=142.28) has the highest MMP among the oil studied.

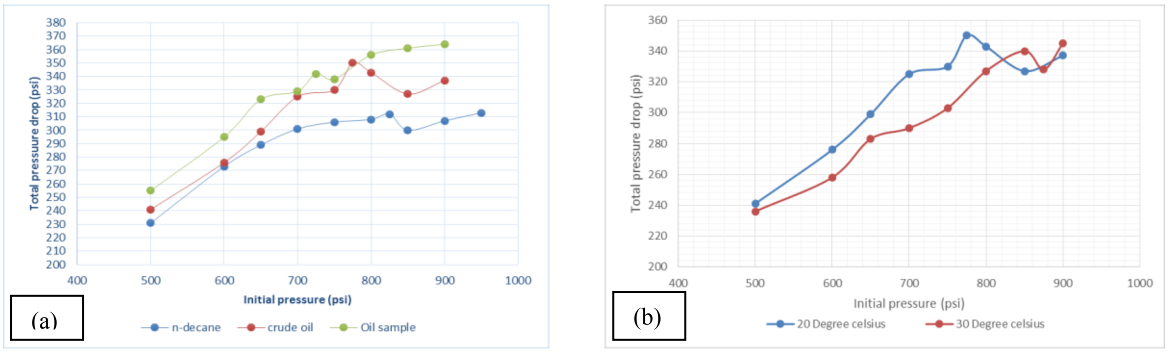

Figure 1: MMP of CO_2-oil systems. (a) Effect of molecular weight at 20 ºC (b) Effect of temperature

Conclusion and Outlooks

The effect of temperature on MMP of the CO_2—crude oil system at 20 and 30ºC showed that MMP is increased with increasing the temperature of system. Similarly, the effect of molecular weight on MMP of the CO_2—crude oil system at 20 ºC, increase with the molecular weight of samples. For the effect of impurity gas (Nitrogen) in CO_2 on MMP will be presented.

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Extraction of Degradation Products in Monoethanolamine Absorption Solution Used in Carbon Dioxide Capture

Wallapa Krajangpit, *The Petroleum and Petrochemical College, Chulalongkorn University, k.wallapa@hotmail.com*
Dr.Chintana Saiwan, The Petroleum and Petrochemical College, chintana.sa@chula.ac.th
Dr.Teeradet Supap, University of Regina, Regina, Canada, teeradet.supap@uregina.ca

Keywords: MEA degradation products, MEA, Extraction, CO_2 *capture*

Introduction

The combustion of fossil fuel for energy from coal used in power plants produces high concentration of carbon dioxide (CO_2) in flue gas stream. Carbon dioxide (CO_2) emission is the largest composition of all the greenhouse gases (GHG) emitted into the atmosphere. Thus, there are a lot of attempt to drive the development of technologies for CO_2 capture. Chemical absorption with aqueous amine solutions is a current and the most attractive technologies for separation and capture of CO_2 from flue gas streams. Monoethanolamine (MEA) is the most extensively used solvent due to high reactivity to CO_2 in the absorption process. However, significant disadvantage from degradation products of MEA occurs due to undesired side reaction of active amine with oxygen (O_2) and other contaminants. MEA degradation products have no ability to absorb CO_2 and must be removed from the MEA solvent because it reduces the efficiency of MEA absorption process. A commercial removal process of MEA degradation products is distillation, which requires large quantity of energy. A solvent extraction technique is a low energy consumption process. The purpose of this research is to use solvent extraction to separate neutral MEA degradation products (imidazole, N-acethylethanolamine, 2-oxazolidone and N-(2-hydroxyethyl)-succinimide). The extraction efficiency of neutral MEA degradation products was investigated under various experimental conditions including temperature and CO_2 loading.

Discussion

The extraction efficiency was calculated by percentage of extraction of neutral MEA degradation products from the aqueous phase. The effect of temperature on extraction efficiency at 25, 40 and 60°C is shown in Figure 1. The percentages of extraction efficiency of all degradation products increased with increasing the extraction temperature. At the same extraction temperature, N-(2-hydroxyethyl)-succinimide was the most extracted, follow by 2-oxazolidone, imidazole and N-acethylethanolamine.

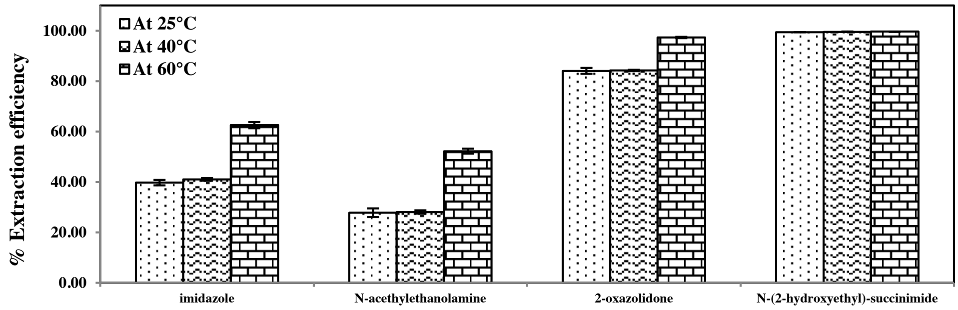

Figure 1 Effect of temperature on extraction efficiency of neutral MEA degradation in aqueous solution without MEA.

Conclusion

The extraction efficiency of neutral MEA degradation product increased with increasing the extraction temperature.

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Natural Fiber Adsorbents Treated by Amines for Carbon Dioxide Adsorption

Andaman Taechatada, *The Petroleum and Petrochemical College, Chulalongkorn University, Andaman.tc@gmail.com*
Assoc. Prof. Chintana Saiwan, The Petroleum and Petrochemical College, chintana.sa@chula.ac.th
Dr.Rattanapol Mongkolrattanasit, Rajamangala University of Technology Phra Nakhon, rattanaphol.m@rmutp.ac.th

Keywords: CO_2 Adsorption, Natural fibers, Amine, Polyethylene imine

Introduction

Carbon dioxide (CO_2) emission from industrial sources is the most significant contributor to global warming. CO_2 capture using adsorption process has always gained interest because it offers low cost and energy penalty. The advantage of impregnating amines on adsorbents is to improve selectivity and CO_2 adsorption capacity. Nevertheless, high concentration of amine on the general porous adsorbent, such as activated carbon, zeolite and mesoporous silica may cause pore blockage, and thus, there is less benefit gained from high surface area of adsorbent to increasethe adsorption efficiency. In this work, natural fibers (NFs), i.e. silk, cotton, kapok, and borassus were used as adsorbent due to low cost. The objective was to modify NFs by chemical modification method and further impregnation with 50 wt% of polyethyleneimine (PEI) for CO_2 chemical adsorption applications.

Discussion

When PEI-50wt% was loaded, the adsorption capacity was improved, although the contribution of PEI was little when PEI loading was low. Beyond PEI 50 wt% loading, the adsorption capacity increased significantly because PEI being to be coated on the external surface of fibers support materials. It was 2.07 wt% for silk, 2.15 wt% for cotton, 1.54 wt% for kapok and 1.58 wt% for borassus. The results could come from the enhancement of PEI-50wt% that the impregnated cotton can load the more amount of PEI with 2.15 wt%. The sorption capacity of kapok and borassus slightly lower than cotton and silk since the morphology of kapok surface was smooth results in decreased possibility of PEI coating.

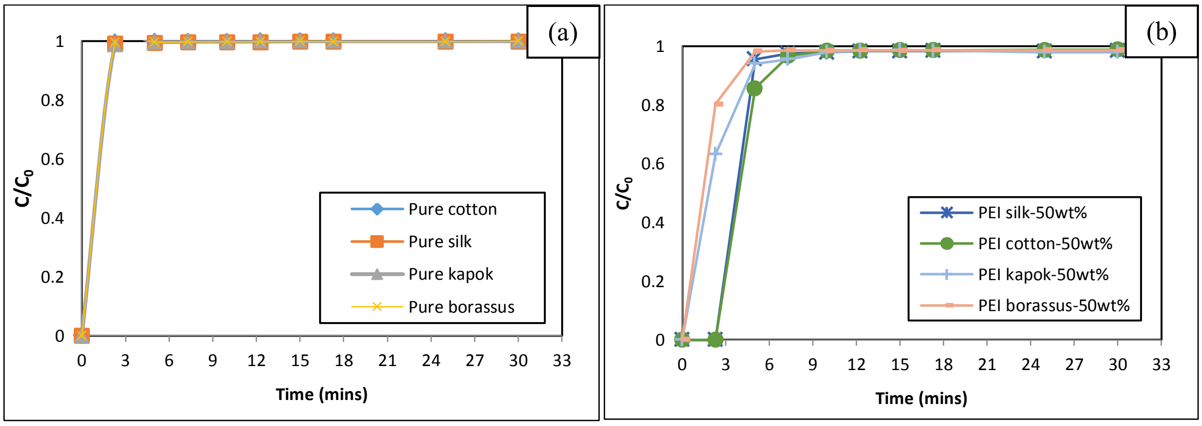

Figure 1: Breakthrough curves of (a) the unimpregnated silk, cotton, kapok and borassus at pressure 14.7 psi 25°C. and (b) the impregnated silk, cotton, kapok and borassus at 14.7 psi 25°C

Conclusion

The results showed that modified adsorbents adsorption capacity enhanced after impregnated with 50wt% of polyethylene imine. When PEI loading was 50wt%, the loaded PEI coated on the external surface of fibers.

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CO_2 Absorption: Effect of Glycols on CO_2 Solubility of 2-Amino-2-Methyl-1-Propanol (AMP)

***Mr. Puttipong Jaroenthai**, Petroleum and Petrochemical College, Chulalongkorn University,*
Deer_zuza@hotmail.com
Assoc. Prof. Chintana Saiwan, Petroleum and Petrochemical College, Chulalongkorn University,
Chintana.Sa@chula.ac.th
Prof. Paitoon Tontiwachwuthikul, Clean Energy Technologies Institute, University of Regina, Regina, Canada
Paitoon.Tontiwachwuthikul@uregina.ca
Dr. Teeradet Supap, Clean Energy Technologies Institute, University of Regina, Regina, Canada
Teeradet.Supap@uregina.ca

Keywords: CO_2 capture, AMP, Glycols, CO_2 loading

Abstract

The solubility of carbon dioxide in 4 M solutions of 2-amino-2-methyl-1-propanol (AMP) was determined at 25, 40 and 60 ˚C and CO_2 partial pressures ranging from approximately 5 to 100 kPa by studying at atmospheric pressure. The results showed that at 25˚C and 9.81 kPa CO_2 partial pressure, the 4M AMP solution has the solubility of CO_2 0.676 and decreased with the increase of temperature. Effect of additives on the CO_2 solubility was studied by blending the AMP solution with ethyleneglycol (EG), diethyleneglycol (DEG) and triethyleneglycol (TEG). Each additive concentration range was 1 to 10 wt %. At 25˚C and 9.81 kPa CO_2 partial pressure, the blending of 5% EG in 4M AMP solution gave the CO_2 solubility of 0.748 accounted for 10.72 percent higher than the AMP solution alone while DEG and TEG gave almost the same CO_2 solubility as the AMP solution alone. For the effect of mixed glycols, the EG concentration was varied from 1 to 5 wt % while keeping DEG and TEG concentrations at 1 wt %. The results showed that at 25˚C and 98.14 CO_2 partial pressure the CO_2 solubility of mixed glycol additives gave 4.23 to 9.50 percent lower than that of 5% EG alone. The CO_2 solubility in AMP solutions blended with ethanol and methanol solutions at 10 wt % were also determined. The results showed that it gave the same CO_2 solubility as the AMP solution alone.

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Evolutionary Multi-Objective Optimization of Micro Grids

***M.Sc. Alexander Wanitschke**, Reiner Lemoine Institut (RLI) gGmbH, alexander.wanitschke@rl-institut.de*

Keywords: Energy, Multi-Objective Evolutionary Optimization

Introduction

In order to design and simulate energy micro grids, a new simulation environment called SMOOTH (Simulation Model for Optimized Operation and Topology of Hybrid energy systems) is being developed at RLI. It allows the simultaneous simulation of integrated energy production units (e.g. photovoltaic, small scale wind turbines) as well as electric storage units and consumption loads (e.g. electric vehicles) throughout the year with variable time resolution. An integral part of establishing SMOOTH as an effective planning tool is to develop an approach for optimizing a micro grid's design parameters regarding objectives, such as cost minimization or maximization of sustainability. Evolutionary algorithms (EA) are population based meta-heuristic optimization techniques based on the principles of Darwin's Theory of Evolution (recombination, mutation, and selection). Because EAs were found to be along the most useful and promising methods in hybrid energy system design [1,2], they are chosen as the principle optimization approach for SMOOTH. The micro grid model in SMOOTH can be characterized as a mixed-integer, non-linear, multi-modal, high-dimensional, and non-separable optimization problem with multiple objectives and various equality and inequality constraints. While existing EAs for hybrid energy systems optimization are capable of dealing with some of SMOOTH's characteristics, none of them can treat all characteristics simultaneously. For instance, all of the existing EA approaches so far have failed at handling constraints while working on a mixed-integer parameter space. Thus, it was necessary to compose a new multi-objective evolutionary algorithm (MOEA) to meet the requirements of SMOOTH.

Discussion

Past and current research in the field of evolutionary optimization was reviewed with regard to the requirements of the optimization problem formulated in SMOOTH, so that for each of the three main steps in the EA heuristic (recombination, mutation and selection) two candidate subroutines could be identified. Along with a newly developed approach for speeding up convergence of the optimization process, called tail band, the subroutines were cross-combined to form 16 MOEA variants. For comparison, a bi-objective test problem with SMOOTH's characteristics was formulated. It represents an optimization problem in which 12 design parameters of a set of photovoltaic generators supplying a predefined load are to be optimized in such a way as to both minimize levelized cost of energy (LCOE) and maximize the system's self-sufficiency ratio (SSR), while satisfying a set of inequality constraints. To compensate for the semi-stochastic nature of EAs a sufficient number of optimization runs was conducted, so that the algorithm variants could be compared with statistical significance regarding ultimate optimization success, speed of convergence, scope of constraint violations and diversity within the MOEA's solution population.

Conclusions and Outlook

The algorithm variant identified as having superior performance, called SMOOTH-MOEA, demonstrated effective and reliable optimization behavior on the test problem. It converged the solution to a sensible tradeoff curve between the objectives of minimized LCOE and maximized SSR while satisfying the constraints 98% of the time. Due to its selection subroutine, SMOOTH-MOEA was found to be highly parallelizable, distributing the optimization function evaluations among separate workers with a parallel efficiency of over 80%. It can be expected that SMOOTH-MOEA is a suitable optimization approach for any multi-objective optimization problem with the same or similar characteristics as SMOOTH. Its parallelizability allows reducing optimization time by a factor at the order of the number of available workers.

References:

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Load Analysis of a House with Hybrid Systems and an E-Vehicle

***Stamatia Dimopoulou**, Faculty of Supply Engineering, Ostfalia University of Applied Sciences / Faculty of Mathematics, Computer Science and Mechanical Engineering, TU Clausthal, st.dimopoulou@ostfalia.de*
Alice Oppermann, Faculty of Supply Engineering, Ostfalia University of Applied Sciences / Faculty of Mathematics, Computer Science and Mechanical Engineering, TU Clausthal, a.oppermann@ostfalia.de
Prof. Dr. Ekkehard Boggasch, Faculty of Supply Engineering, Ostfalia University of Applied Sciences, e.boggasch@ostfalia.de
Prof. Dr. Andreas Rausch, Faculty of Mathematics, Computer Science and Mechanical Engineering, Clausthal University of Technology, andreas.rausch@tu-clausthal.de

Keywords: Energy Management, Photovoltaic, Hybrid Systems, Vanadium Redox Flow Battery, Electric Vehicle

Introduction

Energy management in small-scale basis is going to constitute the core of energy reform for the upcoming years and the energy balance is going to change after the introduction of electromobility. Therefore, studying hybrid systems consisting of renewable energy sources, battery components, house and electric vehicle loads would circumscribe the possibility of maximizing the use of locally produced renewable energy, in order to avoid load fluctuations and peaks to the grid.

Discussion

In this frame two photovoltaic plants of 5,1kW and 1,02kW respectively, a Vanadium Redox Flow Battery (VRFB)of 5kW /20 kWh and a 16kWh Lithium iOn battery from a Peugeot iOn pure electric vehicle, which all exist to the facilities of the Laboratory for Electrical Engineering and Renewable Energy Systems at the Faculty of Supply Engineering in the Ostfalia University of Applied Sciences in Wolfenbuettel, along with house load profiles created according to the guideline VDI 4655 [1], were modelled and integrated all in one system. Registered data stemming from the weather station of the faculty were used for verifying and validating the developed models and simulation analysis for the consecutive years of 2011, 2012 and 2013 was performed. As shown in **Figure 1** for a typical sunny day in Germany, during the sunny hours the battery takes over the PV generation and in the afternoon the VRFB can also cover almost most of the augmented load (house and EV load) without straining the electricity grid during peak demand.

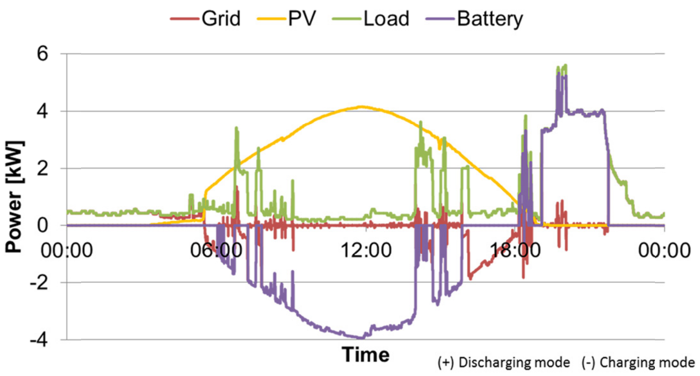

Figure 1: Power Balance on 27th June 2011

In an annual evaluation an increase above 124% was noticed to the self-consumed renewable energy when a battery system was integrated to the system.

Conclusions

The penetration of electric vehicles in the market would mean a significant escalation of the electric demand, setting energy management in the household of primary importance. Hybrid systems as examined in this paper can assure reliable and qualitative power supply provided that adequate renewable energy is locally generated.

Acknowledgement: This research was funded by the Lower Saxony Cooperative PhD Program Electromobility (Niedersächsisches Kooperatives Promotionsprogramm Elektromobilität) and the Lower Saxony Institutes of Technology (Niedersächsische Technische Hochschule, NTH).

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Impact of “Energy Turnaround” in Germany on the Nordic Power Market: A Cross-Border Energy System Modeling Approach

Mr. Behnam Zakeri, Department of Energy Technology, Aalto University, behnam.zakeri@aalto.fi
Prof. Sanna Syri, Department of Energy Technology, Aalto University, sanna.syri@aalto.fi

Keywords: Energy planning, energy system modelling, energy storage, market coupling, Northern-west EU power market, renewable energy integration.

Abstract

The European Target Model for electricity market integration aims at establishing a pan-European market with closer connecting of individual power markets. In February 2014, Nordic power market together with three other cross-border power exchanges launched the North-Western Europe (NWE) day-ahead price coupling project, which coupled the day- ahead markets across Great Britain, Central Western Europe (CWE), the Nordic countries, the Baltic countries, and the link between Sweden and Poland. The recent dramatic growth in installed capacity of variable renewable energy sources (RES) in Germany, as a result of energy turnaround (Energiewende), has offered new opportunities and challenges that also affect connecting power markets, like Nordic countries. For example, Norway and Germany are to build an interconnector of 1400 MW (NordLink), which is expected to be completed by 2018. This is in addition to the recent improvement of 700 MW in DC interconnector between Norway and Denmark (Skagerrak 4) in Nov 2014, which ultimately enhances the power exchange between Nordic power market and Germany. The analysis and investigation of impact of such changes calls for cross-border energy models with adequate details. Hence, to address this need, we model the Nordic energy system in addition to their interdependencies with Germany, on an hourly basis. The model offers the capability to capture the details of each energy system including interconnection of power, heat and transport sectors. We examine the interrelation of Nordic power market coupled with Germany to demonstrate the consequences of Germany’s energy turnaround on the power and energy systems of the Nordics. The results illustrate how such market couplings can influence the predicted revenues in one country, by the energy policy of other neighboring countries.

Modelling of Cross-Border Energy Systems — Towards EU-Wide Electricity Markets

Mr. Behnam Zakeri, Department of Energy Technology, Aalto University, behnam.zakeri@aalto.fi
Prof. Sanna Syri, Department of Energy Technology, Aalto University, sanna.syri@aalto.fi

Keywords: Energy planning, energy system modelling, energy storage, EU energy market, Nordic power market, renewable energy integration.

Abstract

One of the key energy policies of the EU has since 1990s been the creation of open, unified European energy markets. Concerning electricity markets, the goal was to have a European integrated market by 2014. Yet the goal is not achieved as national-based market mechanisms, such as RES support and capacity mechanisms are currently counteracting this goal. On the other hand, ever-increasing growth in integration of variable renewable energy sources (RES) is a motivation for different countries to expand their power markets to wider areas to tackle with intermittency and uncertainty of renewable- based electricity. Accordingly, national energy planning and development of future energy policy is not a domestic setting anymore, but a dynamic, complex and multinational modelling environment. To this end, we introduce a cross-border energy system model that is capable for addressing this need by simultaneous modelling of a group of countries and their interdependencies. On an hourly basis, the proposed model captures the required details of an energy system including heat, power, transportation and industry sectors, as well as linkage between these sectors in each country. Then, energy systems of a group of interconnected countries are modelled to quantify the amount of power that is offered to the common electricity market in each hour of the year. This way, the cross-border model demonstrates the consequences of changes in one country's energy policy on power exports, power prices, and other neighbouring energy systems. The case of Nordic countries, including Norway, Sweden, Finland, and Denmark is further examined as a proper example of such interrelations. The results illustrate how the predicted revenues of future RES scenarios in one country can be deteriorated by similar plans in other countries, in high-RES scenarios.

Stabilizing offshore wind farm power feed-in via power to gas storage systems

Yassin Bourraaman, *Department of Electrical Engineering - Sustainable Energy Concepts, University of Paderborn, Yassin.bouyraaman@upb.de*
Jörg Bendfeld, *Department of Electrical Engineering - Sustainable Energy Concepts, University of Paderborn, joerg.bendfeld@upb.de*
Stefan Balluff, *Department of Electrical Engineering - Sustainable Energy Concepts, University of Paderborn, Stefan.balluff@upb.de*
Prof. Dr.-Ing. Stefan Krauter, *Department of Electrical Engineering - Sustainable Energy Concepts, University of Paderborn, Stefan.krauter@upb.de*

Keywords: Storage system strategy, offshore wind farm, energy management, Power to Gas technology

Introduction

In times of globalization and fast growing demand for energy, a secure, independent and ecological energy supply is getting more and more important for the economic success of an industrial nation. Energy prices go up, amongst other things due to a shortage of fossil resources. The European Council decided that the European Union has to enter a clear and independent commitment. It has to increase the renewable energy by 20% compared with the base year 1990. This is why the endeavours of the German Federal Government shall lead to installing 25GW offshore wind energy in German territorial waters until the year 2030.

Discussion

This leads to the question how an offshore wind park, with a built-in power of more than 400MW, can be embedded into the conventional system of generating stations. Even with the help of weather forecasts a volatility of this kind of renewable energy supply cannot be determined clearly. To guarantee a reliable energy supply the energy fluctuations have to be minimized. Moreover, sometimes wind power generation exceeds the limit that the electrical grid can safely transmit and then wind farms have to be disconnected. The shutdown of wind farms during high generation but low demand periods is an important cause in the decrease of the penetration of renewable energies into the grid and then in the CO 2 emissions increase.

The objective of this investigation is to provide two storage strategies to control the feed-in fluctuations of 400MW offshore wind farm by Power to Gas storage technology. The basic idea is to minimize the occurring differences, which are the deviations between the real performances of a wind farm and the corresponding predicted values by storing a surplus energy and recovering it when needed.

Conclusions and/or Outlook

The used calculation model is based on current research in the field of offshore wind farm and storage systems. The wind farm behaviour is calculated based on real measurements. The wind power feed-in calculations are based on changes in wind speed and variable wake effects of the turbines, caused by changes of wind direction.

Gaining insight into meso-level behaviour around collaboration behaviour in the energy storage field within the Dutch heat and cold chain.

Jorick Weijers (BSc.),*Delft University of Technology, j.w.f.weijers@student.tudelft.nl, jorickweijers@gmail.com*
Dr. Gijsbert Korevaar (PhD, MSc), Delft University of Technology, g.korevaar@tudelft.nl

Keywords: Heat and cold, Storage, collaboration behaviour, IAD Framework, Q-methodology.

Introduction

Heat and cold storage networks can have a significant contribution to saving CO_2 and creating a more environmental friendly energy market in the Netherlands. Their benefits could contribute to lower emission targets of the Dutch government as partly set by European directive 2009/28/EC (Intelligent Energy Europe, 2011). Also necessity for heat and cold storage stems from the European energy efficiency directive on the obligation to perform national heat and cold potential mapping before the end of 2015. Currently only at a local level leading edge technological innovations are implemented, mainly as individual and stand-alone initiatives, but these are not yet largely implemented throughout the Netherlands. This study tries to find an answer to the question: *"Which are the most important drivers for collaboration behaviour of stakeholders in the Dutch heat and cold energy storage field?"* This is done by performing a literature research based on the Institutional Analysis and Development framework. As a second step the factors resulting from the IAD research study will be used for a research with the Q-methodology technique. A discussion and comparison with market parties should lead to applicable factors that drive or obstruct the collaboration around energy storage in the Dutch heat and cold chain. This serves also as a test for the factors found in literature to their applicability to elucidate about collaboration behaviour (Bennett, 1997).

Methodology

By performing a literature research several factors are found to have influence on collaboration behaviour between stakeholders. Rather than to have a long list of factors that could be applicable for multiple fields, a set of factors for the Dutch energy storage are used. To ensure the applicability of these factors, it is important to keep a 'systems perspective' into account. The Institutional Analysis and Development framework (IAD) proposed by Ostrom et al. (1994) is used for this part of the research. The IAD framework is an institution driven tool that enables the researcher to develop a systems perspective on the Dutch heat and cold energy storage field. In short the IAD framework can be divided into three segments, (1) the operational environment; actions and participants, while understanding (2) the underlying structure of the social system and (3) the last segment focusses on observing the interaction patterns and outcomes, given a set of criteria. Therewith the IAD framework ensures that these factors fit in the Dutch energy storage system. As second stage, this research will consist of semi-structured interviews with stakeholders in the energy storage sector. The Q-methodology theory developed by Brown (1978) will be used for this stage. This is a more specific version of the Delphi method focusing on the opinion of experts, not per se in long-term forecasting (Helmer, 1967). The factors found in the first stage are developed into the Q-set, this Q-set is than given to expert stakeholders in the Dutch heat and cold energy storage field, the P-set. In an interview, stakeholders are asked to rank the factors in the set. The result of the subject is than tested according to correlation and with a factor analysis of the subjects. The opinions on the subjects form the N-cases, if compared to normal statistical analysis. These factors are than used to explain the drivers for collaboration behaviour in the Dutch energy storage field.

Conclusions

The combination of the factor analysis from the literature research and the focus applied with the IAD framework ensures a very applicable set of factors to gain insight into collaboration behaviour in the Dutch heat and cold energy storage system. Q-methodology with these factors, is a good method to test the perception of the current small amount of collaboration and a new contribution to the literature. Herewith it also tests the validity in the market. A suggestion for policy to intervene on significant drivers for collaboration behaviour is the final result.

Outlook

A policy (framework) can be developed to combine stakeholders and to continue the development of energy storage in the heat and cold chain. As next step the model or framework can be further improved in different steps with behavioural analysis and optimization for different stakeholders. Behavioural analysis can be pursued with a complex adaptive systems approach like Agent Based Modelling (ABM) or as a first step within Modelling Agent Systems using Institutional Analysis (MAIA-model). Secondly an optimisation model could be developed which should allow the different stakeholders to adapt their strategies according to a given policy.

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Techno-economical System Optimisation and Its Application to an Energy System

***M.Sc. Mario Holl**, Chair of Fluid System, TU Darmstadt, mario.holl@fst.tu-darmstadt.de*
Prof. Dr.-Ing. Max Platzer, Department of Mechanical and Aerospace Engineering, University of California Davis, maximilian.platzer@gmail.com
Univ.-Prof. Dr.-Ing. Peter Pelz, Chair of Fluid System, TU Darmstadt, peter.pelz@fst.tu-darmstadt.de

Keywords: Pareto- Optimisation, Techno-economical system, Coefficient of Performance, System design

Introduction

Addressing the common wrong assumption that systems can be optimised by optimising their components, we present a general analytic optimisation method on system layer. This method is applied to an energy system. The energy system involves the operation of wind-propelled vessels equipped with hydrokinetic turbines so that the kinetic energy of the water flow relative to the hydrokinetic turbine is converted into electricity. This electric power then is used to split sea water electrolytically into hydrogen and oxygen. The hydrogen gas then is compressed and stored in tanks. First conceptual studies of this energy system have been made by Platzer [1]. A more detail analysis has been performed by Pelz et al. [2]. The optimisation considers energetic and economic aspects simultaneously, whereby the optimal system in design and operation can be determined.

Analytic system optimisation in method and application

First the idea of a system needs to be stated as shown in the introduction. The next step is to describe the system based on a physical model. In our example the result of the description is the vessel speed as a function of physical parameters such as the resistance force of turbine and vessel and the thrust resulting from the aerodynamic lift. The next step considers the evaluation of the system characteristics of interest, in this case energy and economy. For the purpose of evaluation, reasonable system quantities needs to be defined. All these system quantities need to converge in an optimisation function. Figure 1 shows the energetic and economic flow through the energy system. They converge in the produced hydrogen which is a quantity for the energetic efficiency and the economical revenue. The energetic description of the system is applied by using the first law of thermodynamics. As the energetic system quantity, the coefficient of performance is defined as the ratio of the turbine and available power. The economic system description is supplied by the economic profit function. The economic system quantity is the yearly profit, which is the difference between the yearly revenue and the yearly costs. Using yearly costs the discounting of capital needs to be considered. The yearly revenue is proportional to the yearly produced mass flow of hydrogen. Therefore the revenue is a function of the energetic efficiency of the system. Through the revenue the energetic system quantity and the economic system quantity converge and generate in this way the optimisation function. In the next step the system is optimised by means of the objective function to maximize the yearly profit. This optimisation is performed analytically and provides optimal system design and operation parameters. The resulting Pareto- frontier includes all optimal systems, which cannot be improved energetically without simultaneously worsening them economically.

Conclusions

The analytic system optimisation provides the optimal dimensioning and operation of components in a system with a fixed component architecture. Therefore it is a strong tool to optimise the system design process because economical and technical aspects are similarly considered. Only the consideration of economic aspects leads to reasonable component dimensioning.

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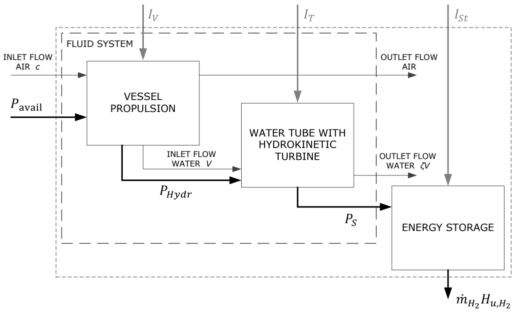

Figure 1: Block-diagram of the energy system

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In situ study of nano-CeO_2 synthesis using laboratory diffractometer

Dr Olga Narygina, *PANalytical B.V., Almelo, The Netherlands, olga.narygina@panalytical.com*
Mr Nicholas Norberg, PANalytical B.V., Almelo, The Netherlands, nicholas.norberg@panalytical.com
Dr Marco Sommariva, PANalytical B.V., Almelo, The Netherlands, marco.sommariva@panalytical.com
Dr Milen Gateshki, PANalytical B.V., Almelo, The Netherlands, milen.gateshki@panalytical.com

Keywords: nanomaterials, CeO_2, *in-situ*, XRD, PDF, SAXS

Cerium dioxide has numerous applications including use as a catalyst for petroleum refinement, as a polishing agent, in coatings and as an electrolyte material for intermediate temperature solid oxide fuel cell. Although yttria stabilized zirconia is still the preferred electrolyte material, cerium dioxide offers an alternative, enabling operation at lower temperatures (500-600 °C). The ionic conductivity of ceria is approximately an order of magnitude greater than that of yttria stabilized zirconia for comparable doping conditions, especially if it is nano-crystalline. An additional advantage of nano-crystalline ceria is the lower sintering temperature due to the high surface energy of the nanoparticles.

A key point in optimization of production and tailoring of the useful properties of any nano-material, including nano-ceria, is the understanding of the synthesis process. X-ray diffraction and scattering techniques are widely used for the characterization of structural and dimensional properties of nano-sized systems. X-ray diffraction (XRD) and small angle X-ray scattering (SAXS) provide information about the crystal structure, size, shape and orientation of nano objects. Pair distribution function (PDF) technique is a powerful probe of atomic arrangement at short and medium-large order distances. This combined approach, bridging both atomic and nano scales, allows for better understanding of nanomaterial properties. Furthermore, a particular advantage of the X-ray techniques is their easy coupling with the *in-situ* measurements enabling process monitoring in real time.

Here we present the *in situ* study of hydrothermal synthesis of nano-ceria using combination of XRD, SAXS and PDF techniques. Correlations between particle size and short order atomic arrangement have been established in a wide temperature range. A good agreement between particle size as measured by SAXS and XRD has been observed.

Scenario-Based Assessment of the Economic Feasibility of CCS Power Generation Technology in Central Europe

Dr. Subhash Kumar *FCN, E.ON ERC, RWTH Aachen University, SKumar@eonerc.rwth-aachen.de*
Tobias Brauweiler, FCN, E.ON ERC, RWTH Aachen University, tobias.brauweiler@rwth-aachen.de
Prof. Reinhard Madlener, FCN, E.ON ERC, RWTH Aachen University, RMadlener@eonerc.rwth-aachen.de

Keywords: Energy supply, CCS Technology, Least-Cost Analysis, LEAP, Central Europe

Introduction

The anthropogenic carbon emissions in the atmosphere are increasing rapidly despite of many talks and negotiations worldwide. These emissions may have to be tolerated in the near future due to short-term economic reasoning but certainly cannot be maintained forever. There is a limit to the carbon dioxide concentration in the atmosphere that can be sustained in the longer term without destructive consequences to the environment and human well-being. Many experts agree that this critical carbon content has already been achieved or will be achieved in the near term. Accordingly, as pointed out in the IPCC 5th Assessment Report [1], atmospheric carbon emissions need to be significantly limited in the near future, and thus more low-carbon technologies, potentially including carbon capture and storage (CCS), will be urgently required. By using the LEAP energy model, we have developed a regional model to estimate the least-cost scenarios for eight central European countries (i.e. Germany, Austria, Switzerland, Czech Republic, Poland, Hungary, Slovenia and Slovakia). The countries of the region covered in our study have different arguments and views on when and how to implement the CCS technology. The new optimization module added to LEAP can give insights and useful conclusions on prospects and challenges associated with expanding the diffusion of the CCS technology in the future low-carbon central European economies.

Discussion

The modelling results show the installed capacity and costs of electricity generation in various CCS deployment scenarios required in the long-term future until 2050 for all the eight central European countries investigated. In the case of Austria, 22 GW of new capacity are required in the optimization scenario until 2050, and the cumulative cost of electricity production is €3.5 bn. Similarly, an estimation has been performed for all other countries under different scenarios; the results are varying according to the policies and commitments of the countries concerned. **Figure 1** shows an example (i.e. Germany) of ten different scenarios created for the eight countries investigated. The scenarios have been compared with each other in order to find a least-cost scenario. The results show that investing in new NGCC power plants equipped with CCS will be the least-cost option for a timeframe until 2050, even though a faster gradual retrofitting of existing coal and gas plants will lead to lower cumulative CO_2 emissions. Due to a gradual renunciation of coal power and an increased focus on natural gas the optimization scenario “All New Power installation with CCS” will even cost less than the reference scenario.

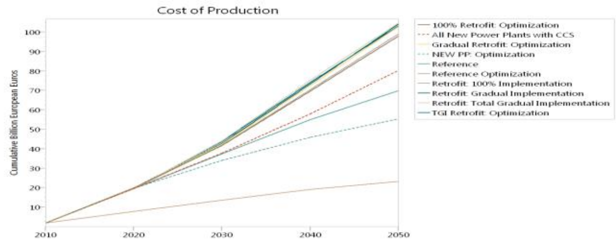

Figure 1: Cost of electricity production for different CCS implementation scenarios for Germany, 2010 -2050

Conclusions

Due to different national requirements two main policy strategies can be distinguished in order to ensure a steady electricity supply and the fulfilment of the EU climate policy targets. Switzerland, Austria and Germany aim for a nuclear-free power generation in the future and at the same time an increase in renewable power plants. In contrast, most of the eastern European countries try to reach their emission goals by enforcing nuclear power. The low costs from investing in new CCS integrated gasification power plants result from the decreasing importance of coal power plants in the future and the relatively low CO_2 emissions, capital and O&M costs from gas-fired power generation. However, it should be noted that the GHG emissions are lower in other scenarios, which could make the option of retrofitting existing power generation units economically attractive, depending on future prices of CO_2 certificates, or the introduction of more restrictive environmental targets.

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Concept study – using a hybrid vehicle as a CHP plant

Bachelor of Engineering (B.Eng.) Kessler, Andreas, Reutlingen University,
andreas.kessler@student.reutlingen-university.de
Prof. Dr.-Ing. Truckenmüller, Frank, Reutlingen University,
frank.truckenmüller@reutlingen-university.de

Hybrid vehicle, combined heat and power, CHP plant, virtual power plant, storage technology

Introduction

Decentralisation and increasing energy efficiency are factors of success of the 'Energiewende'. Sensible interlinking of various energy markets will support and speed up the energy system transformation process. This concept study looks at and discusses an innovative approach to integrate power, heat and the mobility market using hybrid vehicles. Automobile electrification is steadily rising and goes hand-in-hand with qualitative (larger energy storage options) and quantitative storage capacity (much more hybrid vehicles) [1], [8]. Further utilisation options of electrical storage units in e-vehicles for intermediate storage to compensate volatile renewable energy sources are being discussed and tested. The innovative approach of integrating future full-hybrid vehicles with the principle of 'combined heat and power' [2], [3] to supply energy to buildings is not being pursued in depth, or even at all. In this approach both the electrical and also the thermal energy produced would be used as supply sources for the building.

Main part, discussion

Triggered by statutory regulations, the increase in the electrification of vehicle technology allows new ways of thinking about how to use one's own vehicle. In addition to the central issue of increasing mobility efficiency, hybridisation of vehicle technology allows this equipment to also be used for other energy markets, e.g. to supply heat and power to buildings or to generate capacities for the electricity grid. Central factors for the efficient use of a vehicle as a source of energy are the performance of the combustion engine, the e-machine, the storage capacity, a mobile thermal storage unit that is as compact as possible and existing interfaces to feed the energy into the building network. This promising combination exists, in particular in vehicles with range extender aggregates, because there is already an electrical interface in the vehicle. For this reason, any further theoretical considerations will be based on the technical data of the BMW i3 [6], and the range extender aggregate of the KSPG AG [4]. The quantities of energy required to supply a building were determined using the VDI 4655 [5] and compared to the output that could be generated in the vehicle by both systems, on a thermal and also electrical basis. This comparison examines three system utilisation scenarios and assesses them as realistically as possible. The following comparisons are carried out: daily mileage (duration) to work; average annual mileage of the vehicle; and the flexible use-independent production of heat and power. All three scenarios afford a good and secure supply of energy. Depending on the examined case, back-up boilers also need to be considered on cold energy-intensive winter days to cover the additional thermal output.
In addition to the use of the hybrid vehicle for mobility and as a building supply source, a further business model is the participation in the Electricity Balancing Market as part of a virtual grid. Calculations using the latest figures in combination with the projected number and assumed future performance capability of hybrid and electric vehicles result in a storage capacity of 3.1GWh (approx. 7,8% of the pump-storage hydropower plant capacity of Germany) for the year 2020 and a power plant capacity via the existing range extender combustion engines of up to 40 GW (approx. 40x1000MW power plants), plus a 33.6GWh storage capacity (approx. 84%) and a power plant capacity of approx. 100GW (approx. 100x1000MW power plants) for the year 2030. In relation to188 GWh [7] required to store one production hour of the current power plant output, this results in a coverage of the total storage capacity of almost 20% for the year 2030; in the field of output supply, the capacities are already more than adequate in the year 2030. Even when only 30% of the cars are available for storage or energy production, this approach will solve the needed flexibility in storage and production to integrate the further increase of the volatile renewable energy sources for the future. With this innovative approach, the so-called 'Energiewende' can be further accelerated by improving efficiency with decentralised storage and power plant capacities through hybrid vehicles.

Conclusion and outlook

The investigation shows that significant synergies can be utilised by optimising the crosslinking of the mobility, power and thermal energy markets. The required energy volumes in detached homes or smaller apartment complexes will be more or less covered. In particular, the integration of hybrid vehicles in other energy markets will allow the efficiency of these vehicles to be increased. In a further step, the theoretical examinations can be explored and developed in greater depth by means of detailed examinations of the various energy systems, specific interface analyses and economic efficiency calculations. Finally, steps also need to be taken at the political level to create a statutory framework to combine all three energy markets.

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Comparative assessment of representative data driven modelling approaches for medium term electricity price forecasting

Nico Schweiger, *KIT B.Sc. Mathematics*, *Nico.Schweiger@eifer.uni-karlsruhet.edu*,
Dr. Atom Mirakyan, *EIFER European Institute for Energy Research*, *Atom.Mirakyan@eifer.uni-karlsruhe.de*

Keywords: Electricity price, model selection, forecasting accuracy, time series analysis

Introduction

One of key determinant in energy planning and modelling is the electricity prices. The analysis and accurate forecasting of electricity price for industry can have significant impact to the planning results and decision. In this study different data driven modelling approaches particularly univariate time series analysis and artificial intelligence are tested and the performance of different methods are compared.

Discussion

Numerous methods have been implemented and tested in different studies. A large initiative implementing and comparing diverse data driven methods is M-competition. In these initiatives, different methods are tested, and their performances [1-3] are compared. A survey of stochastic modelling approaches in energy sector is provided by [4].

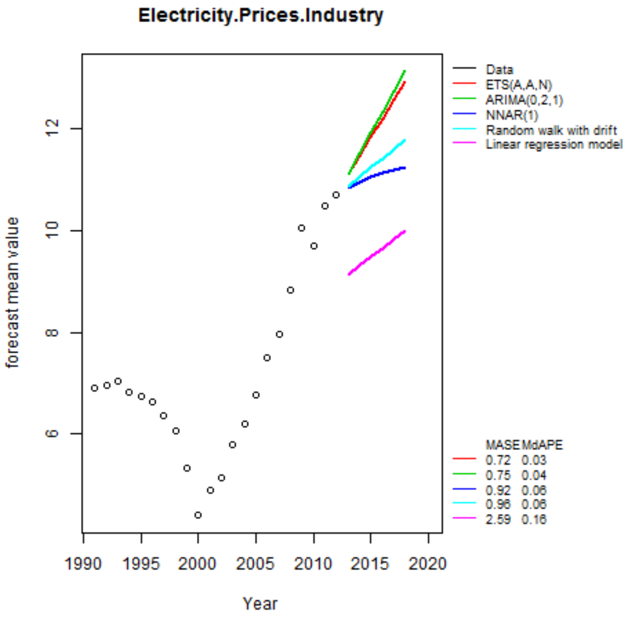

Fig. 1 Comparative assessment of methods and models for electricity price forecasting[1]

In this study, the performance of pre-selected forecasting methods like ARIMA, Neural Networks or robust trend are compared using different error measures [5, 6] for evaluation of methods performance. The results of analysis of different extrapolated methods and their performance according to error measures are presented in Fig. 1.

Conclusions and Outlook

The results of analysis shows that the lowest error measure have exponential smoothing and automatic ARIMA, the highest error measure have linear regression according to MASE and MdAPE value using annual data. However, the analysis and extrapolation have been performed without analysing and incorporating stochasticity of data. We thus plan to extend our analysis including modelling stochasticity with different methods.

Acknowledgement: This work was supported in part by (European Institute for Energy Research) and EDF (Electricité de France)

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Energy management modelling for PV-diesel off-grid power plants

Dr.-Ing. de Martel Emmanuel*, Intelligent Energy System, European Institute For Energy Research (EIFER), demartel@eifer.org*
Dr.-Ing. Az-Eddine Khalfi, EDF, Reasearch & Development, az-eddine.khalfi@edf.fr

Keywords: Off-grid, hybrid PV-diesel power plant, Energy management, LCOE

Introduction

Many off-grid villages in remote areas produce their electricity on a mini-grid by means of a diesel generator. Besides environmental effects, Levelled Cost Of Electricity (LCOE) are very high and still increase, following the cost of diesel fuel. On the other hand, investment costs for photovoltaic (PV) modules have drastically decreased during the last time [1]. However, PV panels produce a fluctuating and not well predictable energy which makes difficult to guaranty the grid stability. Moreover, the use of PV energy during the night implies the use of an expensive storage. Different patterns of energy management are currently sold by solution suppliers like SMA, Juwi or ABB. Questions rising are: is it profitable to inject PV energy in a diesel mini-grid? If yes, how much? Which energy management pattern is the most appropriate?

Discussion

Different sites with various load curves and amount of sunshine have been simulated. These simulations are based on technico-economic data provided by suppliers for EDF rural electrification projects developed in Africa and French oversea territories. Three patterns of energy management have been considered, so called "Diesel" (D), "Fuel saver" (FS) and "Hybrid" (H). More precisely 2 Diesel modes, D1 and D2, respectively with one and two diesel groups, 2 Fuel Saver modes, FS1 and FS2, respectively with low and high rate of PV and 2 Hybrid modes, H1 and H2, where electricity for the night is produced respectively by a diesel generator or stored from PV production, were calculated for several ongoing projects.

D1 is used as a reference mode. D2 gives an insight on net gains that can be achieved while using a second diesel group, thanks to reduction of specific fuel consumption. FS modes refer to direct injection of PV energy into the load curve to reduce fuel consumption during the daylight. During the night, the system works as in Diesel mode. In FS1 mode, diesel groups have to keep running during the daylight with a minimal load to ensure grid stability, therefore reducing the share of PV in the energy mix. In FS2 mode, diesel generator can be switched-off during the daylight but an additional reserve of power (e.g. fly wheels, supercondensator, battery, etc.) has to be implemented additionally. In H modes, PV is used together with a battery. The sizing of the PV field and of the battery storage is greater in mode H2 than in mode H1 to supply the nocturnal consumption.

Results show that depending on the site, increasing the share of PV energy does not lead necessarily to a reduction of LCOE because of the increase of the Capex. Indeed, higher share of PV leads to a higher complexity of the energy management system.

Conclusions

Even if the cost of a kWh of PV electricity alone has drastically fallen, it's injection in a power plant reduce also its profitability against diesel energy. On one hand storing PV energy (modes H) increases rapidly the LCOE. Moreover the cost of electronics in these modes can reach over 20% of the capex. On the other hand, using PV only for the daylight and even together with a diesel generator (FS modes) reduces the share of PV in the energy mix.

Beyond the cost of diesel fuel and the amount of sunshine, the daylight/night share of load as well as the level of power to be supply appears to be relevant parameters to evaluate the right pattern of energy management. However, the choice remains to be done by simulating the different modes in order to take into account the local parameters.

Acknowledgement: This work has been founded by Électricité de France/Direction Développement International (EDF/DDI) and Électricité de France/Systèmes Énergétiques Insulaires (EDF/SEI).

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An open-source data infrastructure for storage, analysis and visualization of city energy geospatial data

***Jochen Wendel**, European Institute for Energy Research (EIFER), wendel@eifer.org*
Alexandru Nichersu, European Institute for Energy Research (EIFER), nichersu@eifer.org

Keywords: Data infrastructure, 3D GIS, CityGML, data analysis, energy modelling

Introduction

Research in the energy domain is of high complex multidisciplinary nature and involves multiple stakeholders. Data used in city wide research projects usually differs by domain and by means of data gathering. These differences in data can be either by data resolution, data structure or data storage format which requires an intensive data integration effort. A major obstacle in this process is the current proprietary nature of major commercial software packages. The lack of interoperability between software packages makes it difficult to share and further process research results. This research focuses on the development of an open data structure which allows data storage, data exchange, data manipulation, and data visualization across different projects and domains.

Discussion

At EIFER, we have developed a data infrastructure based on an open-source database environment which allows integration of cross domain data sets, functions and models. The data infrastructure is based on a PostgreSQL database and PostGIS, a PostgreSQL extension, for spatial capabilities. All 3D building information and other spatial features are stored in the CityGML format. GityGML is an open XLM standard which allows exchange between multiple formats [1]. This open infrastructure enables connectivity of multiple spatial data sources directly to a GIS system. Multiple environments and models in languages such as Python, Matlab. R or JDBC (Java Database Connectivity) can be connected to the data infrastructure [2]. Figure 1a shows an overview of the developed data infrastructure. As proof of concept, we have developed multiple models and extensions such as an EBM (Energy Balance Model) in Python, a socio-demographic data analysis of energy user behavior in Matlab and R, a vertical solar radiation tool in Python and a plug-in free open-source 3D Web-GIS based on open JavaScript libraries and HTLM5.

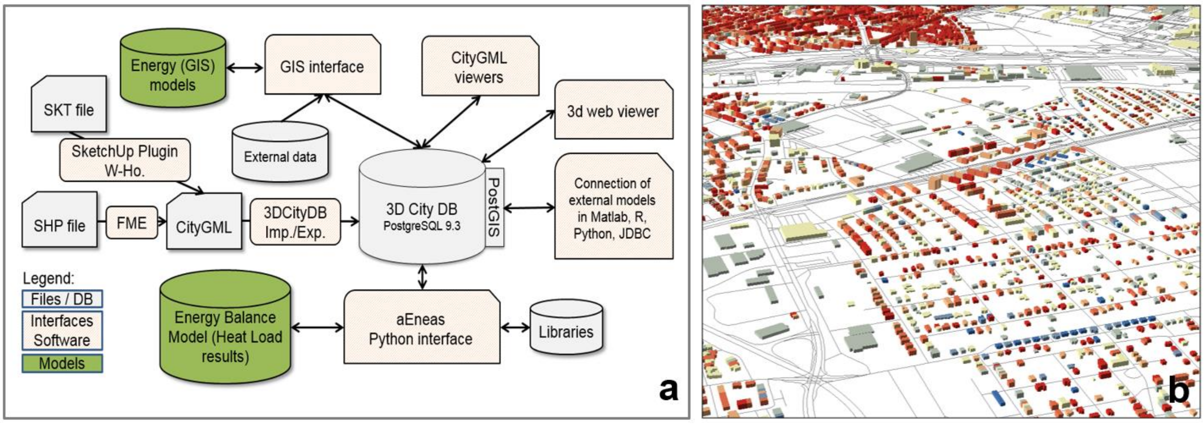

Figure 1: Open data infrastructure based on a PostreSQL and PostGIS (a). Case study of a socio demographic energy user behaviour study for the city of Karlsruhe base on the open data infrastructure which shows heating energy demand per household and associated user behaviour (b).

Conclusions

The developed open data infrastructure allowed us to implement multiple case studies ranging from energy balance models to the development of a 3D web interface. Current and future integration work focuses on the integration of micro-climatic models such as urban heat island and testing of novel visualization interfaces such as augmented reality applications (AR) and tangible touch screen applications for presentation of energy model results to stakeholders and decision makers. The presentation will cover demonstration of the open 3D web interface as well as discussion of the results from the energy user behavioral study for the city of Karlsruhe.

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Development of a Market-Based Virtual Power Plant Optimisation Model

***David Gohsen, M.Sc.**, Institute for Reactor Safety and Reactor Technology, Dept. Energy Economic Systems Analysis, RWTH Aachen University, gohsen@lrst.rwth-aachen.de*
Univ.-Prof. Dr. rer. nat. Hans-Josef Allelein, Institute for Reactor Safety and Reactor Technology, RWTH Aachen University, allelein@lrst.rwth-aachen.de

Keywords: Virtual Power Plant, Renewable Energies, Portfolio Optimisation, Balancing Markets, Pooling

Introduction

Due to the national climate policy objectives a structural change occurs for the power systems in the next few decades. Accordingly, this can only succeed with an increasing share of renewable energies that is accompanied by certain central challenges: feed-in management, grid expansion, and storage capacity requirement. Hereby, questions about the market as well as the system integration arise. Flexibility in generation and trading becomes more valuable, not only in terms of possibly increased revenues, but also by the potential of internal hedging, which is the ability to hedge against price and volume risks within their own portfolio [1]. Therefore, different compositions of a virtual power plant are compared and evaluated in this study.

Methodology and Results

In the market-based optimisation model, renewable energy systems (e.g. wind, photovoltaics, and biomass) are combined with a gas turbine as well as a storage facility to form a centrally managed virtual power plant (VPP) that provides participation in the balancing markets by the 'pooling' concept [2]. Hence, this portfolio can overcome the market entry barriers. All considered renewable energy systems are using the market premium model as part of the direct marketing and, therefore, depend on the spot prices of the European Energy Exchange (EEX). The comparison between several VPPs is shown in **Figure 1**, whereas **Figure 2** describes exemplarily the detailed distribution of negative secondary balancing power within the portfolio marketing.

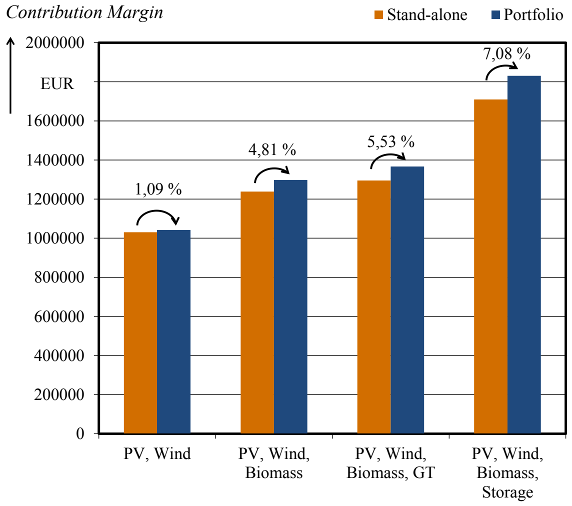

Figure 1: Contribution margin of different VPPs in an exemplary week (09.09.-15.09.2013)

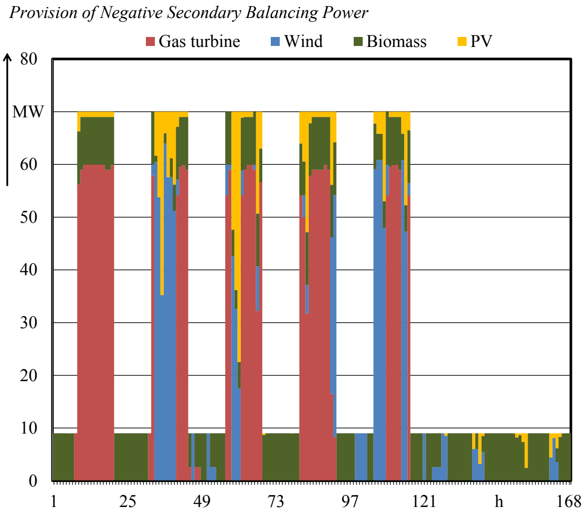

Figure 2: Provision of negative secondary balancing power within portfolio marketing

The contribution margin of the portfolio marketing is up to 7 % higher in comparison to the stand-alone marketing, which is the proper sense of such a VPP. Also, the contribution margin of different scenarios has increased significantly through biomass, gas turbine, and storage plant. These types are not dependent on weather conditions and, hence, much more controllable. Thus, a flexible demand-based and price-orientated electricity production is possible. Furthermore, the larger provision of balancing energy generates additional revenues within the portfolio. Even wind turbines and photovoltaic systems can participate temporarily in the secondary balancing market and benefit from the high remunerations of this kind of product.

Conclusion

For a safe and efficient supply transformation of the energy system, it is necessary to align the electricity production from renewables at short and long-term market signals. In addition, these renewable energy systems are forced to participate in new markets and be successively more competitive to the established fossil power plants. The bundling to virtual power plants generates additional revenues, especially at the balancing markets.

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A balanced electricity mix – the role of system costs and material requirements in renewable energy supply systems

***Dipl.-Ing. Denis Hess**, Department of System Analysis, German Aerospace Center (DLR), denis.hess@dlr.de*
***B.Sc. Manuel Wetzel**, University of Stuttgart and Chalmers University of Technology, manuel-wetzel@web.de*

Keywords: International energy system analysis, renewable energies, costs, resources, materials

Introduction

Dispatchable renewable energies (RE) (e.g. biomass, geothermal energy and concentrating solar power (CSP)) have the possibility of balancing the impacts of fluctuating RE [1] (photovoltaics, wind, run-of-river), just like fossil dispatchable energies (coal, gas) and in small amounts also nuclear energy do already today. However, dispatchable RE are capacity related more expensive than fluctuating RE [2]. The international analysis proves how and in which amounts dispatchable and fluctuating RE can balance and build a sustainable energy system with low costs and low material requirements.

Discussion

Since the occurrence of fluctuating RE is site specific and very diverse, storages and transmission lines are needed. Transportation of electrical energy requires a huge effort with high conflict potential by local protest movements or citizen initiatives [3]. Imports of dispatchable RE from different territorial levels (e.g. local, regional, national and world region level) reduce the territorial and technological dependence in favor of an efficient energy supply due to more territorial and technological supply alternatives. If a diversified renewable energy supply system is based on approximately equal energy shares of dispatchable (50%) and fluctuating RE (50%) the economic, environmental and societal burdens sink due to more balance in the system – compared to a scenario with 90% fluctuating and 10% dispatchable shares of used electricity (figure 1). High shares of RE with a balanced share of these two supply forms minimize infrastructural effort due to lower installed power plant capacities and thus lower surplus generation and its lower further use in storages and grid. Also costs are minimized in the scenarios with different shares of fluctuating and dispatchable RE but are with the underlying assumptions not the essential point, because the cost minimum is rather flat, thus costs do not play a decisive role of the design for the overall optimal long term renewable energy mix. In this analysis resources for the construction of an energy system based on renewable energies (RE share of ~95%) are therefore an important indicator [4]. The results show that a balanced mix also diversifies resources and their dependencies on imports.

Conclusions and/or Outlook

The results could lead to new energy system modelling, using not only costs but social and environmental indicators. Nevertheless, time series analysis will rest the backbone of the energy modelling methodology.

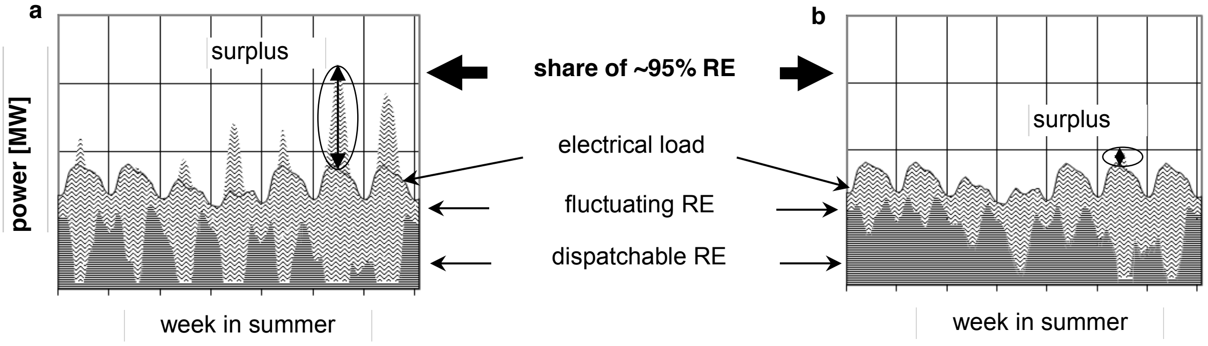

Figure 1: Extract of one week in summer in Germany of the two hourly numerical renewable supply system models with different shares of renewable technologies, both with ~95% RE share of gross electricity consumption. **a**, 90% fluctuating and 10% dispatchable share with a high surplus and high capacities. **b**, 50% fluctuating and 50% dispatchable share with a low surplus and less capacities.

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Evaluation of energy efficient wastewater treatment concepts of the future using a plant-wide modelling approach

Dr. Maike Beier, Institute for Sanitary Engineering and Waste Management, LUH, beier @isah.uni-hannover.de
Nina Manig, Institute for Sanitary Engineering and Waste Management, LUH, manig@isah.uni-hannover.de
Dr. Dieter Thöle, Ruhrverband Essen, dth@ruhrverband.de

Keywords: Wastewater treatment plant, Plant-wide modelling, Energy efficiency, Time of investment

Introduction

The ongoing changing conditions imposed by demographic change, climate change, and further purification requirements as well as rising concern over scarce energy resources present the wastewater sector with new challenges. Long-term investment planning of resource- and energy-efficient wastewater treatment plant upgrades under these uncertain future conditions is one of them. As dynamically changing conditions are not considered in the traditionally design and planning phase of plant upgrades, it is necessary to support plant operators and planners to find energy-efficient future plant concepts and, even more important, to fix the optimal time of investment. The research project “E-Klär” (started in May 2014 including 4 universities, 5 companies and the water association Ruhrverband) will address these tasks by developing a transferable evaluation concept based on a plant-wide modelling approach that is expected to assist the decision-making process in terms of process selection and properly timed investments towards an energy-efficient WWTP of the future.

Project content / methods:

Modelling and simulation of complex wastewater treatment processes became a usable tool to optimize plant operations in terms of process efficiency. In recent years, the idea of plant-wide models to simulate the interactions of various treatment facilities (e.g. Benchmark simulation model No. 2 after Jeppsson et al., 2006) becomes more and more interesting. Based on the idea of plant-wide modelling, the aim of this research project is to develop a modelling approach that integrates substance- and energy flows (based on daily average values) as well as the resulting annual costs of an entire WWTP including the optimal time of investment. The use of this holistic approach allows the evaluation of interactions and dependences of various treatment units on a mass-, energy- and cost-level. The developed evaluation model concept will be applied for three full-scale WWTPs of the Ruhrverband including Schwerte (50,000 PE), Wickede (20,000 PE), and Essen-Kupferdreh (96,000 PE) to test and evaluate the applicability of the method. Based on available full-scale data and information, the current plant concepts of these three plants will be implemented in the software package WEST (by DHI) that will be extended to include a substance flow model (addressing new wastewater treatment concepts for removal of micropollutants, Thermal Pressure Hydrolysis Process, fibre and pulp extraction, deammonification), an energy flow model, and a long and short term cost estimation model. Beside a rough overview of the project concept, the presentation will describe the basic modelling steps (including the needed model extensions) that are necessary for the specific model-based plant and scenario evaluation. Figure 1 illustrates the basic idea of the plant-wide modelling approach of the “E-Klär”-project.

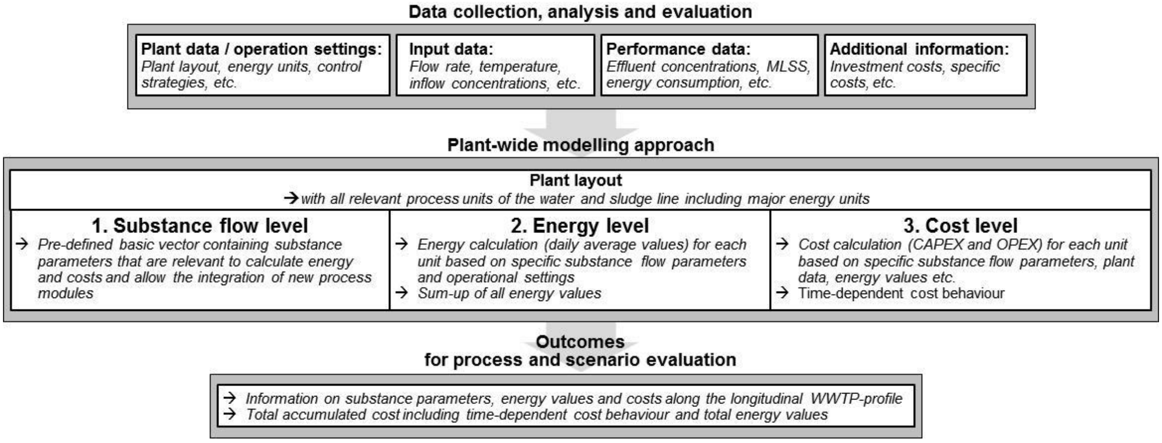

Figure 1: Overview of the basic plant-wide modelling approach

Acknowledgement: This work is supported by the cooperative project “E-Klär – Towards the energy-optimized WWTP of the future – Development and model-based integration of innovative treatment technologies for transformation processes” funded by the German Federal Ministry for Education and Research (BMBF), FKZ 02WER1319B.

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Indicators for monitoring and assessing the German energy transition

Dr. Christine Rösch, Klaus-Rainer Bräutigam, Nora Weinberger, Jürgen Kopfmüller, Patrick Lichtner, Dr. Volker Stelzer, KIT, Institute for Technology Assessment and Systems Analysis, christine.roesch@kit.edu

Keywords: Energy transition, Sustainability, Indicators, Assessment, Socio-technical system

Introduction

The objective of the energy transition adopted in Germany is to supply energy in a sustainable way and to use it efficiently. In particular, this means a nuclear energy phase-out, a continuous expansion of renewable energies, an increase in energy efficiency, a reduction of total energy use, and a reduction of greenhouse gas emissions. At the same time, the classic goal triangle of security, economic affordability, and environmental soundness of energy supply plays an important role in the energy policy debates. Nevertheless, the key shortcoming of many existing approaches to indicator-based activities to monitor the German energy transition consists in the focus on classic techno-economic and ecological aspects, and in underweighting the importance and complexity of socio-economic, socio-technical, and societal aspects.

Results

Against this background, the authors applied the Integrative Concept of Sustainability [1] to derive sustainability indicators for monitoring and assessing the German energy system and its transition. Based on this normative concept, a holistic and systematic view can be taken of the sustainability of the energy system. Following this approach around 40 core sustainability indicators were selected, complemented by additional indicators. As far as possible, spatially differentiated data were gathered for these indicators. This set includes several traditional and "standard" indicators, such as the "Share of renewable energy in total primary energy use", and indicators on energy efficiency or greenhouse gas emissions. Beyond that, ecological indicators were selected focusing on the use of natural resources (see **Figure 1**). This topic definitely needs more attention in the future since the energy transition towards increasing shares of renewables leads to an increasing demand of resources, some of which are scarce or critical. Also in contrast to established indicator approaches, the set includes indicators that suitably address the socio-technical and socio-ecological interface of the energy system and its transition. Examples are the "Acceptance of different energy technologies in the neighbourhood", being an important factor of successful transition processes, the "Number of energy co-operatives" (see **Figure 2**), which provides information about the support of the transition in society, or the "Energy expenditure of low-income households compared to their expenditure for basic energy needs", which addresses the relevant and controversial topic of "energy poverty".

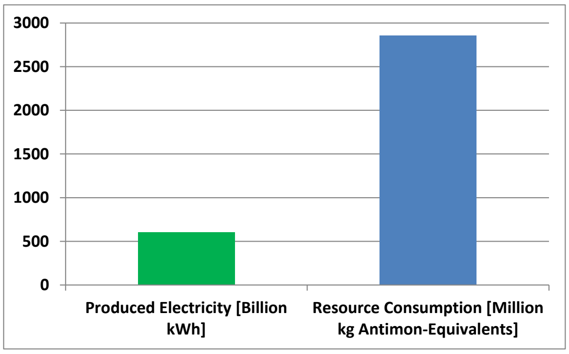

Figure 1: Resource consumption in 2013 for electricity generation in Germany

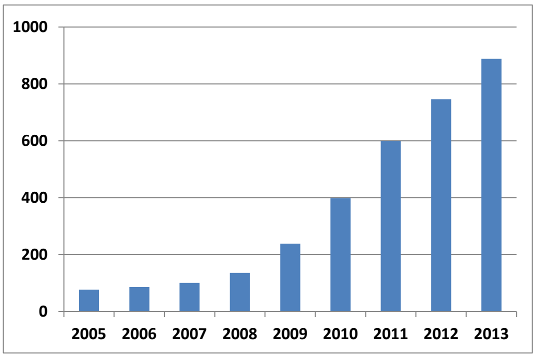

Figure 2: Number of energy co-operatives in Germany

Conclusions

The authors propose an indicator-based integrative sustainability assessment approach that helps to broaden the understanding and definition of a sustainable energy system. It was developed for the case of Germany, but should be applicable as a valid starting point for other regions as well. This approach is intended to stimulate and enrich the scientific and political discussion about visions for and pathways towards a more sustainable energy system, on the one hand, and to improve energy policy decision-making, on the other hand. In fact, the proposed indicator set overcomes some of the shortcomings of existing indicator systems. The development of this tool in an interdisciplinary process within the Helmholtz Alliance ENERGY-TRANS allowed the integration of expert knowledge in the field of social, psychological, and political sciences.

Acknowledgement: This work is part of the Helmholtz Alliance ENERGY-TRANS funded by the Helmholtz Association.

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Health-related external costs in Europe: impacts of methodological developments since 1999 for a coal-fired power plant

Jonathan van der Kamp, *European Institute for Energy Research (EIFER) and KIT, vanderkamp@eifer.org*
Dr.-Ing Till M. Bachmann, EIFER, bachmann@eifer.org

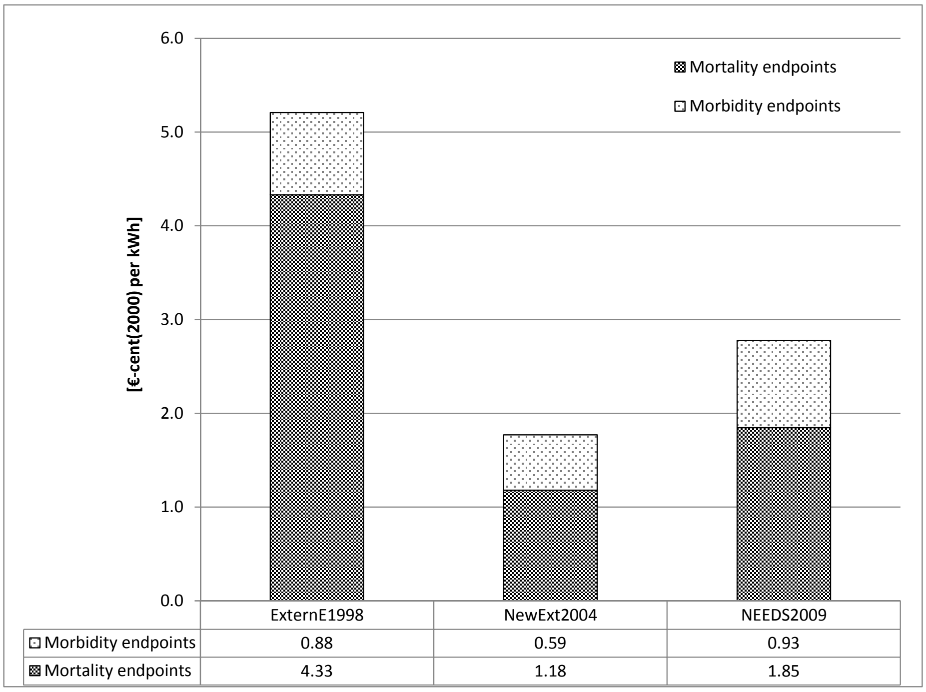
Keywords: air pollution, external cost, health risk, methodology, variability

Introduction

European air quality policies are regularly supported by scientific impact assessments, including the monetary valuation of environmental and health damages, also referred to as environmental damage costs (EDC; e.g. [1]). Since the early 1990s, related methodological developments have taken place in the Externalities of Energy (ExternE) project series and follow-up activities [2].
This study aims at looking back on about 15 years of external cost quantification in Europe and discusses the main methodological evolutions from the 1990s until recently. The focus here is on the variability of human health costs caused by classical air pollutants (mainly NOx, SO2, particulate matter).

Discussion

Using a case from the energy sector, the development of external costs is shown in **Figure 1**. In addition, major influencing parameters are identified. Changes in exposure modelling and related data lead to variations in external costs of up to 21%. Concerning risk assessment and monetary valuation, changes in assessing long-term exposure mortality risks together with assumptions on particle toxicity explain most of the observed changes in external costs. This variability and an increasing use in policy making require continued scientific efforts for a further improvement of the underlying methodology.



	ExternE1998	NewExt2004	NEEDS2009
☐ Morbidity endpoints	0.88	0.59	0.93
▨ Mortality endpoints	4.33	1.18	1.85

Figure 1: Marginal external costs of a coal-fired power plant unit, estimated with different assessment frameworks; adapted from [3]

Outlook

Future pathways concerning health risk assessment are discussed, such as the effects of a cause-specific mortality assessment compared to an all-cause mortality approach.

Acknowledgement: The support of Sonna Pelz (University of Hohenheim) in collecting and compiling data at an early stage of the work is gratefully acknowledged.

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A library and modelling approach for the simulation of holistic multi energy systems

Xiubei Ge, *European Institute for Energy Research, ge@eifer.org*
Dr. Enrique Kremers, European Institute for Energy Research, kremers@eifer.org

Keywords: multi energy library, energy system modelling, multi energy carriers, energy system analysis

Introduction

The introduction of renewable and distributed energy resources, the rapid growing demand for energy as well as the need for more sustainability are leading towards a paradigm shift in the energy sector. This change is driving towards new solutions, such as local energy systems with multiple energy carrier management. To tackle these challenges, modelling and simulation are used as tools to support decision processes on design, planning and operation of energy systems [1]. Several libraries containing energy system components have been developed to serve the need of energy modelling tasks. TRNSYS library includes components commonly found in thermal and electricity energy systems [2]. Homer helps designing hybrid micro grids, with models of both conventional and renewable energy technologies [3].

Based on its energy system modeling activities, the European Institute for Energy Research has developed a multi-energy library named EnergyLogic in the multi-paradigm modelling environment of Anylogic. This library were emphasised on model reusability, modularity and reliability, which ensures components to be easily integrated into energy system simulations and be able to communicate with other energy system models following a standardised communication protocol.

Discussion

EnergyLogic contains various model components of demand, generation and storage technologies carried by different energy carriers. As shown in Fig. 1, the library components are grouped by energy carriers, electricity, heat and biogas, and further categorized by technology domains. Intersections between groups, highlighting on CHP, HVAC system and heat pumps enables modelling on energy conversion between different energy carriers in a multi-energy system model.

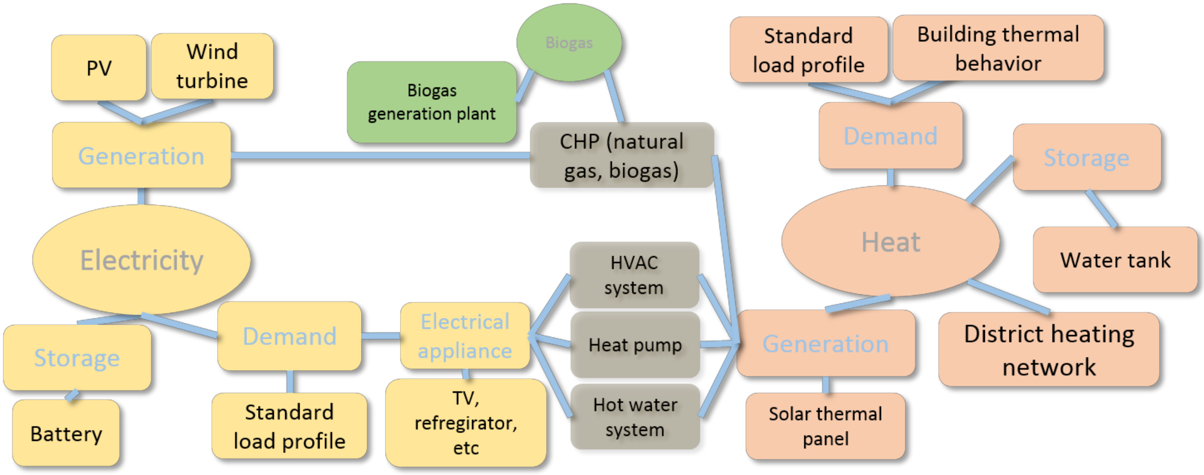

Figure 1: Grouping of library EnergyLogic

An energy system model is further developed as an application case of EnergyLogic. The system is configured with combined heat and power, photovoltaic and heat pumps to supply both heat and electrical demand. Coupling between the different carriers are regarded explicitly, enabling investigation in the synergy of local energy generation, energy conversion and the influence of system operation on utility grid. A case study is also carried out to demonstrate how the developed application case can be used for energy system analysis.

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Energy Optimization at the Baden-Wuerttemberg Cooperative State University Mannheim

M.Eng. Linda Steglich, *Prof. Dr. rer. nat. Ingo Haug, Kompetenzzentrum Nachhaltige Energiesysteme, Duale Hochschule Baden-Württemberg Mannheim, ingo.haug@dhbw-mannheim.de*

Keywords: Energy management system, Storage, Load management

Introduction

In the year 2009 a competence centre for sustainable energy systems was founded at the Baden-Wuerttemberg Cooperative State University Mannheim and since then it has been extended [1]. An experimental field of renewable energy systems has been built at the university. Using the experimental field the interaction between production and consumption are examined in practice and load management potential and storage requirements are analysed.

Discussion

The load at the Cooperative State University differs from the peak load 310 kW to the base load 52 kW. At the weekend the average peak load is only 110 kW, while during the week in semester break it is 160 kW and in lecture period 250 kW.
At the moment 66 kW of renewable energies are installed, which is already more than the base load. In spring 2014 there have been moments where the feed-in of the renewable energies has exceeded the load (figure 1). When scaling the renewable energies feed-in so that the feed-in corresponds to the daily consumption (figure 2) the feed-in exceeds the load during some periods enormously [2].

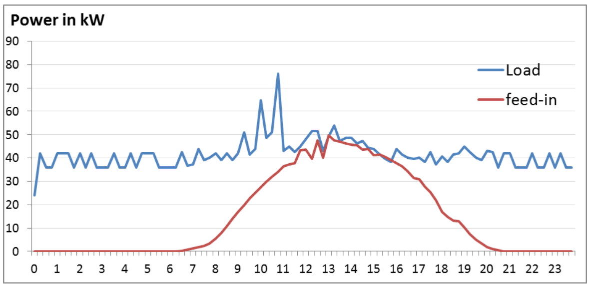

Figure 1: 4th of May 2014 with low load and high feed (real data).

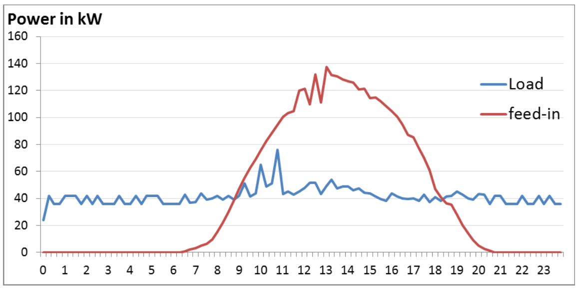

Figure 2: 4th of May 2014 with load and scaled feed-in.

A solution for this problem could be the storage of energy. The storage system must be able to charge and discharge several times a day. Such an analysis can be seen at the 3rd of May in figure 3.

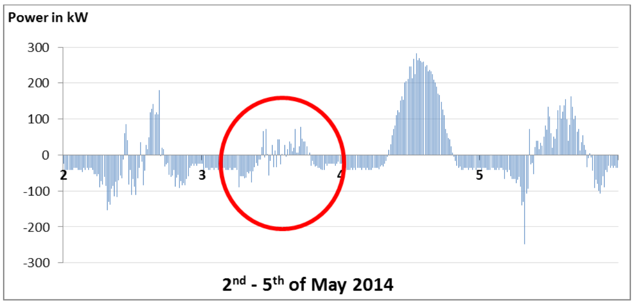

Figure 3: Need for storage, period 2nd – 5th of May 2014, load and scaled renewable energy feed-in.

Outlook

A model will be developed which allows a detailed analysis of the needed storage system. Load management potential will be identified in order to minimize the number of load cycles and to minimize the storage capacity [3].
In the poster the first results of the analysis are presented.

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Simulation of current distribution in parallel-connected cells to achieve homogeneous cell stress

Dipl.-Ing. Thorsten Grün, Project Competence E, Karlsruhe Institute of Technology, thorsten.gruen@kit.edu
Dr. Jörg Kaiser, Project Competence E, Karlsruhe Institute of Technology, joerg.kaiser@kit.edu
Dr. Kevin Stella, Project Competence E, Karlsruhe Institute of Technology, kevin.stella@kit.edu
Dr. Olaf Wollersheim, Project Competence E, Karlsruhe Institute of Technology, olaf.wollersheim@kit.edu
Dr. Andreas Gutsch, Project Competence E, Karlsruhe Institute of Technology, andreas.gutsch@kit.edu

Keywords: Energy, Storage, Modelling, Battery System

Introduction

The development of battery storage systems will play an important part in an energy supply based on 100 % renewable energy, with applications ranging from e-mobility to on- and off-grid stationary storage systems. However, in order for battery systems to enter the power supply market it is necessary to reduce their specific costs. Battery packs made up of conventional cylindrical cells could help reduce costs, but due to their small capacity it is necessary to connect several cells in parallel to achieve enough capacity for the desired application. In a parallel configuration, individual cells can experience different stress levels, so that some cells could be strained beyond their limits and battery ageing could be accelerated.

Two connection configurations forms were studied by employing simulations of their current distribution. Furthermore, experiments were carried out and compared to the simulation results. Based on this knowledge, different possible ways to connect cells to achieve a more homogenous current distribution and avoid excessive stress and early ageing of single cells shall be introduced.

Discussion

The current distribution in several parallel-connected cells depends on the connection forms of current collectors and also on the number of welding spots that connect cells with the contact strip. Based on a simple electrical-thermal battery model for single cells, an algorithm that calculates the current distribution was developed, taking into account the influence of State of Charge and temperature on the cell internal resistance.

Figure 1 shows an example of a simulation result which was compared to an experiment for validation of the assumed model. This process of simulation and experimental verification was repeated in order to obtain a more uniform current distribution across the battery pack.

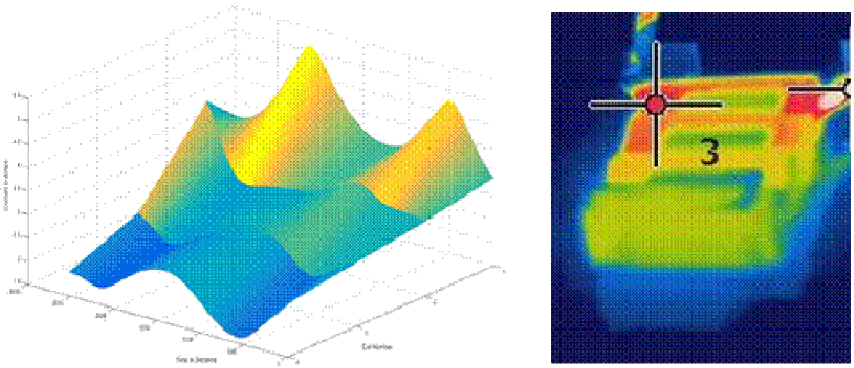

Figure 1: Simulation of current distribution (left) during a 1C charge period, compared to an infrared image (right) from an experimental study.

Conclusions and Outlook

Based on resistance measurements and observation of temperature during the experiments, it was shown that the postulated electrical-thermal model is a reasonable approximation of the real charging behaviour of parallel-connected cells. With help of the simulation results, methods were found which can be applied to homogenize the current distribution in parallel cell connections.

Battery packs for stationary or mobile applications designed with the present method lead to a better current distribution and avoid over-stressing of single cells, thus preventing early ageing. The novel approach of combining cells could allow one to use customary cylindrical cells for those applications. This leads to lower prices through decreasing the specific costs and increasing the cycle number.

ELEXTERN: transparently valuing electricity externalities

Ing. Frédéric Wertz*, Department of Nuclear Fuel Cycle, Research Centre Rez,* *frederic.wertz@cvrez.cz*
Dr. Vladimír Kočí, Faculty of Environmental Technology, Institute of Chemical Technology, *vlad.koci@vscht.cz*

Keywords: Electricity, Economic, Social, Environmental, Impact

Introduction

To reduce CO_2 emissions and fossil fuel dependency, Europe is engaged to switch from mainly coal-based to low-carbon technologies for electricity generation. Though determination of the different economic, social and environmental impacts belongs to scientists and specialists, valuing them on a unique scale is of societal matter. This paper presents ELEXTERN, a tool that clearly distinguishes physical impacts from social parameters that are scenario-dependent, to be chosen by the user. It considers electricity variable value (peak/low demand) and relative costs of each technology as well as following externalities: fossil fuel depletion, dependency to fuel or technology imports, CO_2 emissions, environmental footprint, health impact, and long-term liabilities.

Discussion

ELEXTERN considers the different stages where economic, social and environmental expenses or impacts occur in the life cycle of a power plant: Construction, Operation, Decommissioning, and Long term consequences. A discount rate R is used to levelize these costs and impacts. R = 0 means a complete neutrality of time. With higher values of R, future costs and impacts will weigh less than present ones. Electricity is not intrinsically storable, supply and consumption must match every time. Thus, power plants cannot be operated at full capacity because of variable demand and some intermittent sources. Load Factor LF is then important for the computation of Levelized Cost Of Electricity (LCOE) [1].

Economic, social and environmental impact valuation depends on how much we value our dependency to foreign technologies and resources, our health and life, our biodiversity and our capacity to manage nuclear waste storage as well as future climate change. While existing studies [2] partially compute these impacts, ELEXTERN shows in **Figure 1** that LCOE and impacts valuation is not unique. For given investment, operation and fuel costs, Load factor LF and Discount rate R can dramatically change the LCOE. Also, Value of Statistical Life (VSL) and CO_2 price affect the impacts valuation. That is why it is important to let the user adjusting its own social values of different life events. This scale may be the result of democratic debates. Transparency then supports energy policies and improve social acceptance.

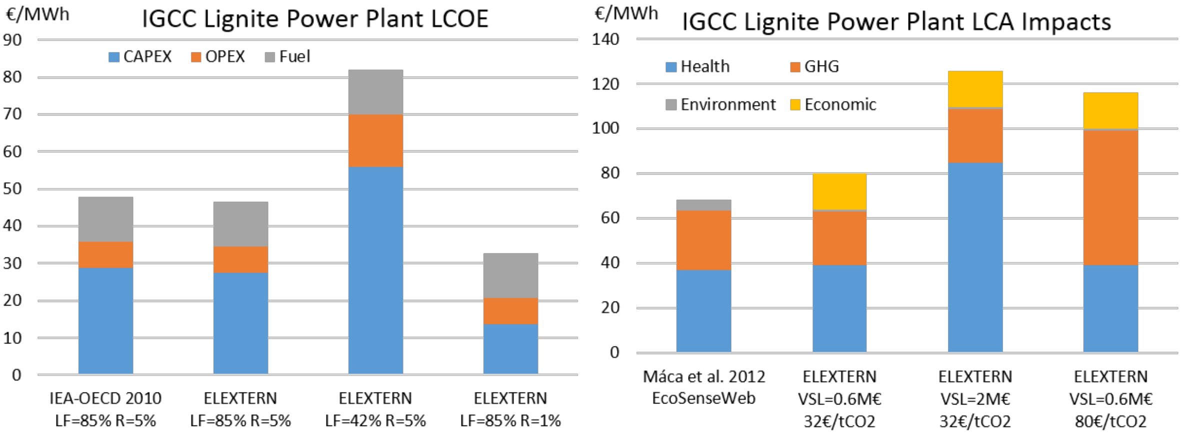

Figure 1: Czech Lignite Power Plant LCOE and LCA impacts computation for different methodologies and parameters.

Conclusions and Outlook

Because different technologies have different costs and life-cycle impacts, changing social parameters affects the technology merit order. Utilities do not use the same discount rate as would do a whole country, nor are the externalities completely internalised. Thus, authorities should compute the real social cost of different electricity technologies, then build incentives so that private actors meet social objectives in a transparent manner.

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The viability of distributed energy storage solutions for end-consumers: An assessment of regulatory and financial incentive schemes

Jan Ossenbrink*, Dep. of Management, Technology, and Economics, ETH Zurich, jossenbrink@ethz.ch*
Sveinbjörn Finnsson, Dep. of Management, Technology, and Economics, ETH Zurich, sfinnsso@ethz.ch
Dr. Catharina Bening, Dep. of Management, Technology, and Economics, ETH Zurich, cbening@ethz.ch

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Over the last two decades, the increasing share of renewable energy sources (RES) in the electricity sector of many countries has spurred a debate about whether, when and where energy storage systems will become a complement to RES to deal with their intermittent nature. Recent studies have shown that, to date, conventional power plants, industrial demand response, and cross-border electricity trade represent the least costly options to provide sufficient flexibility even for considerable RES shares. For several reasons distributed energy storage (DES) systems (e.g. PV + stationary battery / heat storage / e-vehicle) have started to gain relevance as an additional technology option [1]. So far, this development is largely driven by private investments into two end-consumer business cases, namely PV self-consumption and energy arbitrage. These applications render "behind-the-meter" storage systems an interesting solution to many end-consumers given that retail electricity tariffs rise and the dominant technologies undergo further cost decreases [2]–[4]. Depending on the operation mode that prosumers choose, DES can present an additional burden to the distribution grid infrastructure (e.g. causing higher PV feed-in gradients) or provide additional benefits (e.g. contributing to security of supply or grid investment deferral) [5], [6].

To fully leverage the technical potential of modern DES systems across the electricity value chain, considerable amendments to the current regulatory and market environment are necessary. While many governments have started to address this topic (e.g. via demonstration projects (JP), direct subsidies (DE), integrated RES + storage procurement (CA)) it remains largely unclear how proper regulatory and financial incentive schemes must be designed in order to stimulate and compensate for these additional services DES [7]. So far, nearly all of the studies on DES implicitly assume a stable regulatory environment and singular investment decision for each component (e.g. PV and battery), thereby underestimating the effect of policy dynamics and integrated technology portfolios. In addition, most of the studies neglect behavioural effects such as mental accounting which occurs when individuals assess the utility of technologies with multiple applications (e.g. e-vehicle) or when maturity comes into play (e.g. retrofitting a five year old heat pump with a new control system).

In order to address this literature gap we analyse how different incentive schemes influence the viability of distributed energy storage solutions at the end-consumer level (residential, small commercial). To shed light on this question we pursue a three-step approach. Firstly, we collect a database and conduct an in-depth review of the most important incentive schemes relevant for DES. Exploratory interviews with DES installation companies and early-adopters together with prior research on energy efficiency in buildings are used to derive archetypical technology configurations and end-consumer groups. Secondly, we conduct a techno-economic assessment to determine the critical sensitivities of potentially viable combinations between investment schemes and DES applications. Finally, we elaborate on the general diffusion potential of these energy storage solutions.

This study holds valuable insights for policy makers and administrations who try to develop effective as well as efficient, technology-neutral instruments to spur the diffusion of innovative storage technologies. Moreover, utility companies as well as other firms active in the energy domain (e.g. contractors, ICT, tech providers) will benefit from a holistic assessment of behind-the-meter storage systems and their applications in different business cases which have the potential to further disrupt the electricity sector.

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