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MALEG

Machine Learning for Enhancing Geothermal Energy

Increasing the Efficiency of Geothermal Power Plants by Coupling with Artificial Intelligence

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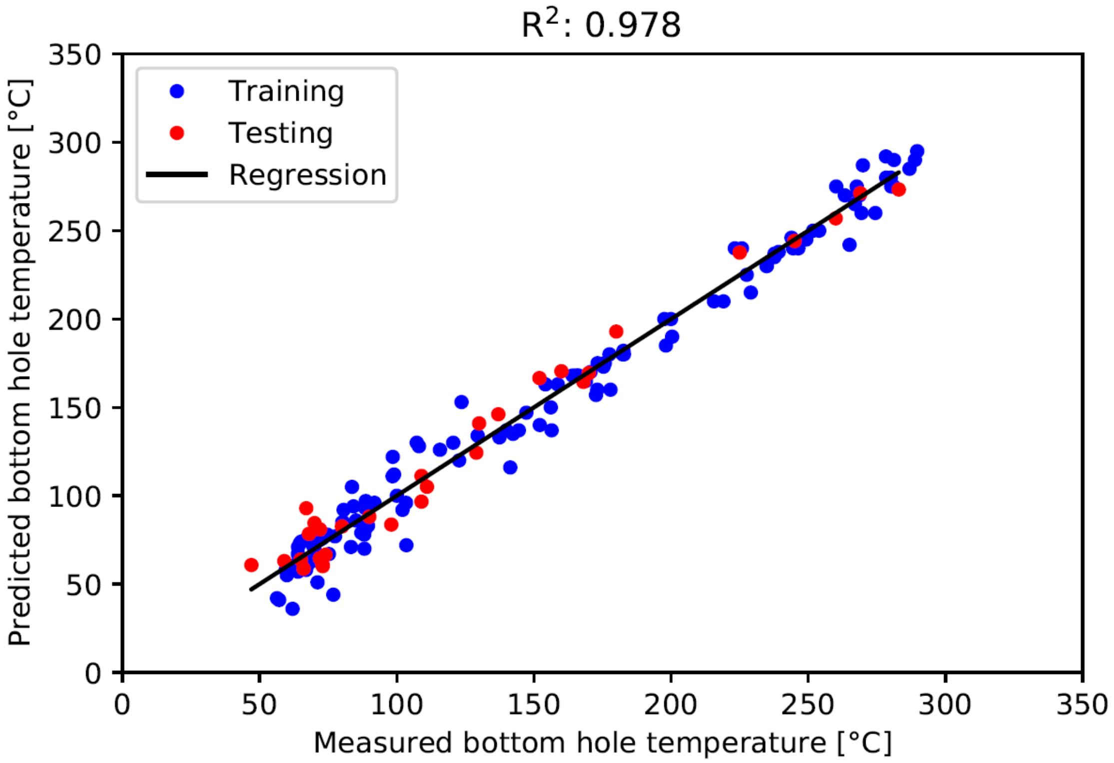
Motivation - Machine learning for exploration

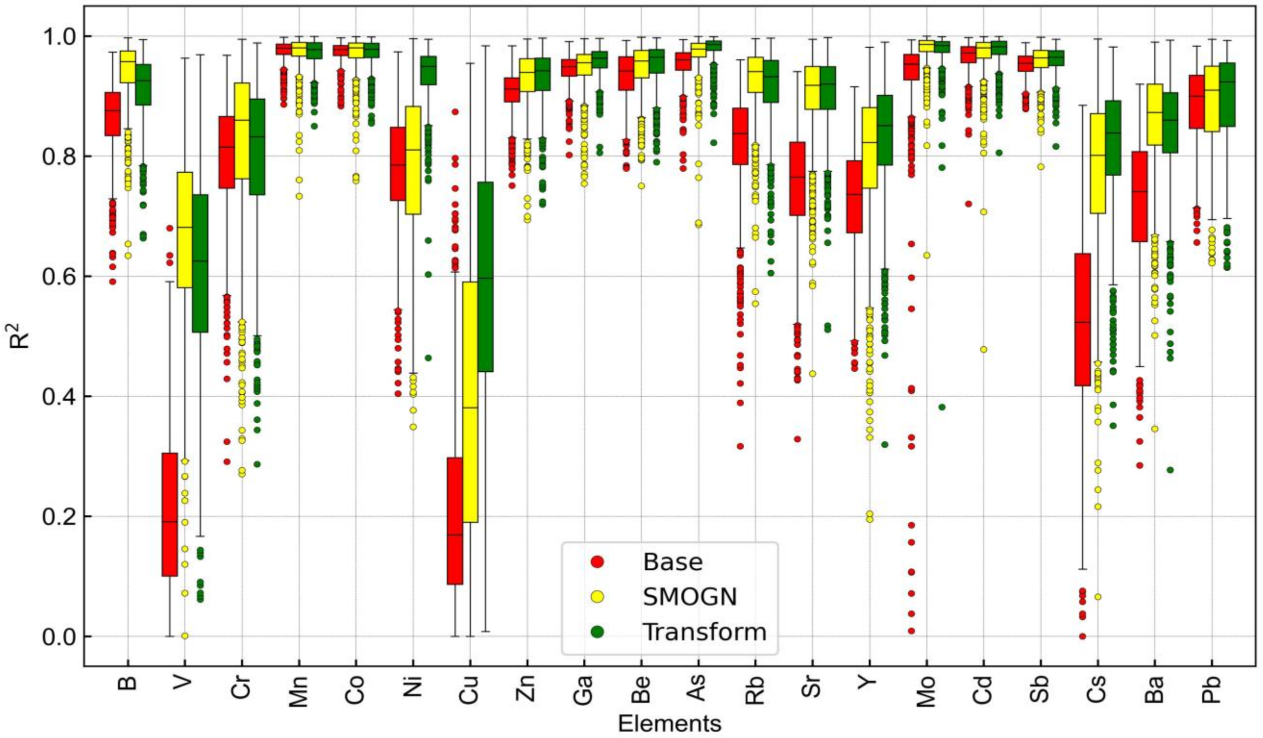
- Example of reservoir temperature estimation
  - Based on geochemical fluid parameters
  - Hydrochemical composition used for multi component geothermometer
  - Proofed that small data sets of 80 entries are sufficient



YSTROEM, 2023

Motivation - Machine learning for exploration

- Development from a single element prediction (Li) to a multi prediction tool
- Prediction of geothermal fluid composition with focus on trace elements
- Major Cat- and Anions and pH used as input variables
- Concentration of trace elements as output variables



DASHTI ET AL., (UNDER REVIEW)

Motivation – From exploration to application

- **What we learned so far:**
- Data quality reflects model quality
  - Comprehensive hydrochemical data sets are expensive and require a lot of effort to generate
  - Usually only a portion of the chemical system is investigated
- Data processing is more important than model tuning
- Datasets with 75 entries can be sufficient for machine learning in geochemistry
- Data set distribution becomes very important when handling small data sets

➡ Translate knowledge into operation of geothermal power plants

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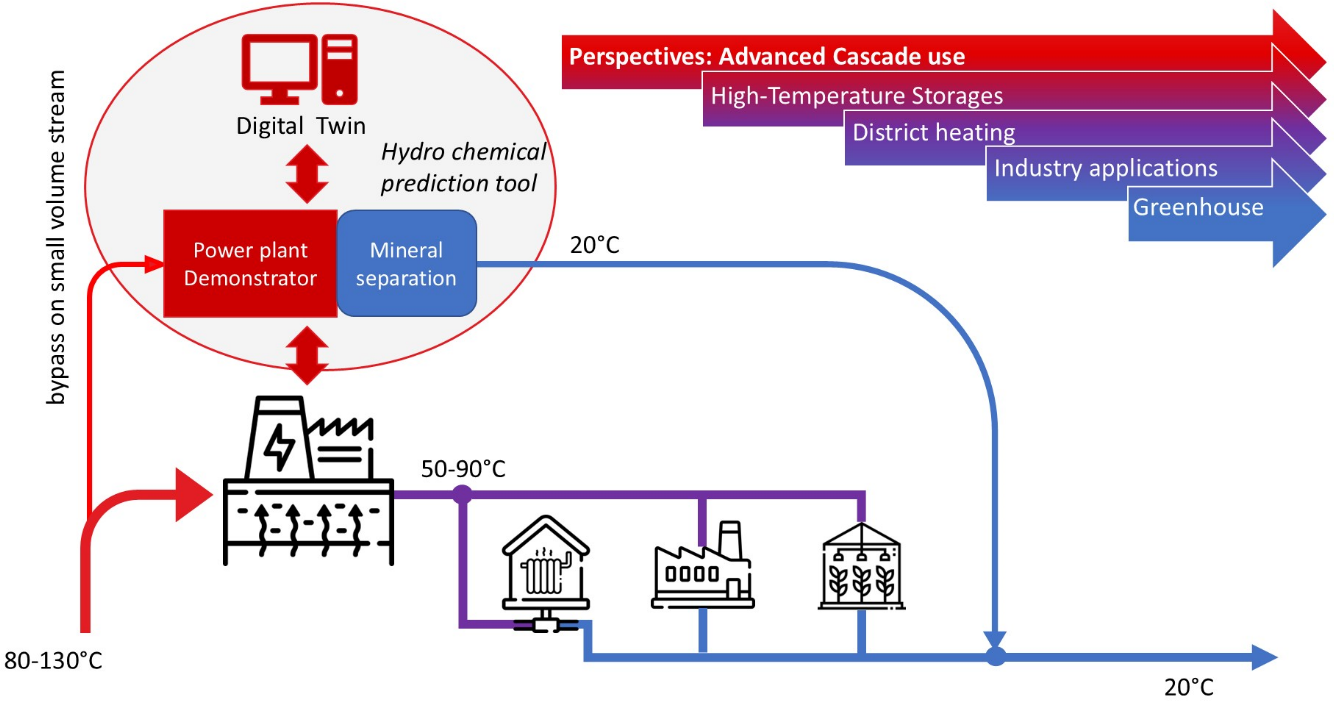
The idea

- Using AI to control the occurrence of scaling and degassing
- Increased ΔT for cascade use and heightened heat extraction efficiency
- Technological challenges with pressure maintenance in cascade use



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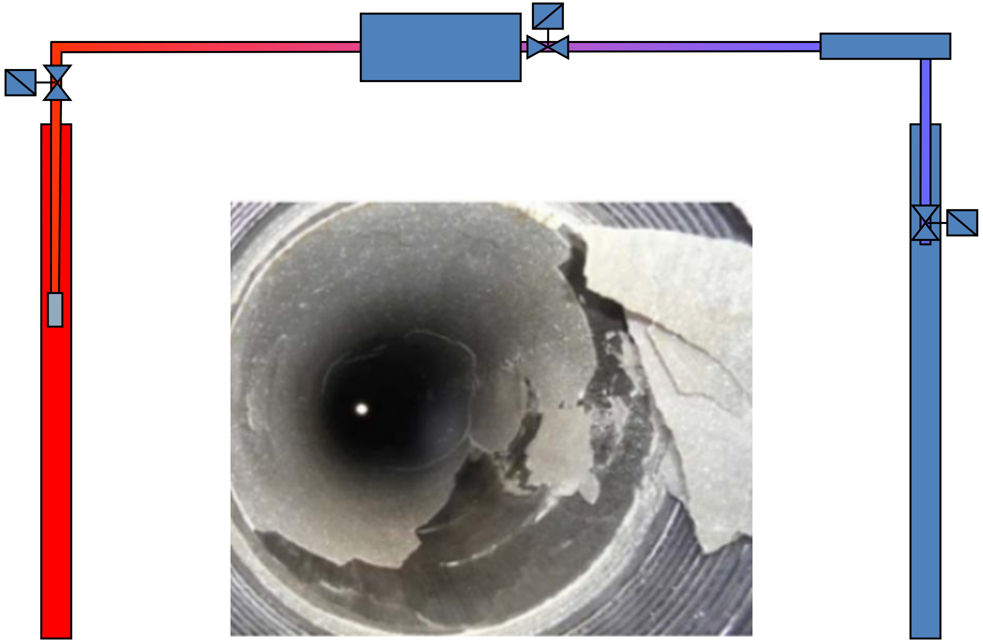
Pressure maintenance

- Pressure level maintenance throughout the power plant cycle
- Formation of a free gas phase can lead to carbonate scaling, chemical corrosion or abrasion corrosion
- The system boundaries are not clearly defined, and there is a significant security factor involved in maintaining pressure.



WANNER ET AL., 2017

Experiment locations

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Unterschleißheim, Germany

Haag am Hausruck, Austria

Gülpinar, Türkiye

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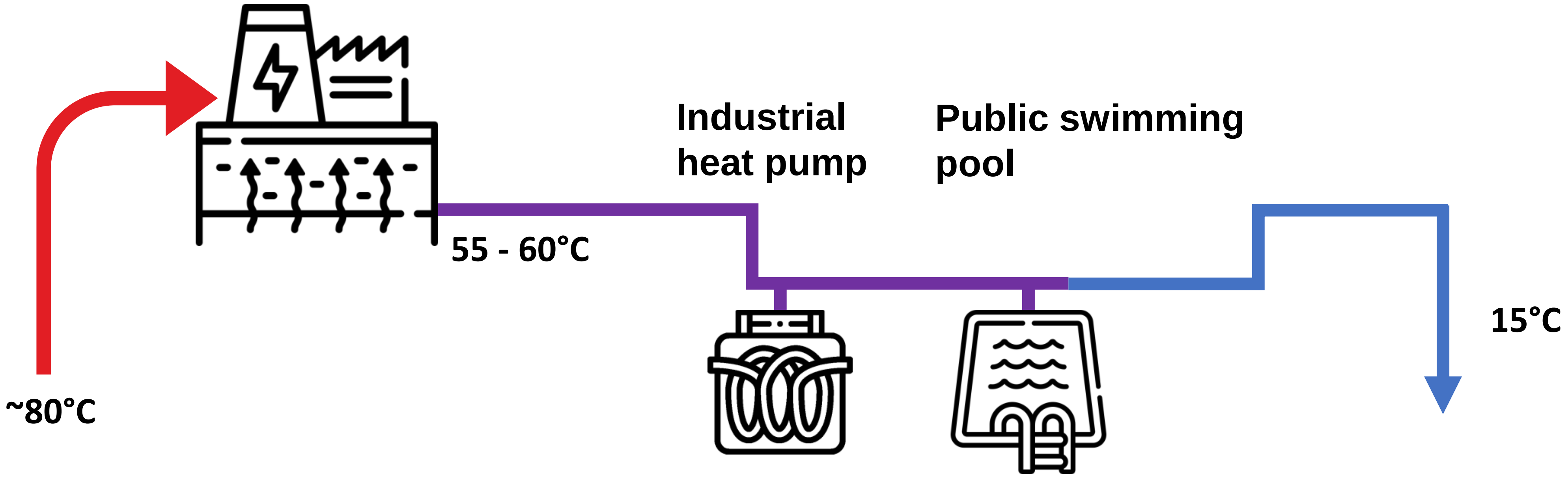
Cascade use example Unterschleißheim

Increase efficiency by implementing second heat extraction with an industrial heat pump prior to using brine in a thermal bath.



Hardware-Twin – on-site demonstration unit

- Demonstrator for continuous geochemical monitoring
  - Mobile unit, deployable in the field
  - Coupled directly to the power plant
  - Emulation tool for geochemical processes in a geothermal power plant
  - Controlling of temperature, pressure, pH and flow rate allow on-site degassing, scaling and corrosion experiments

Hardware-twin while testing at the Fraunhofer ISE

In-line degassing experiments

- Investigating degassing processes of the geothermal fluid under in-situ conditions
- The inlet pipe extends almost to the top within the cylinder.
- Outlet at the bottom
  - Gravity traps gas bubbles
- Observation of gas level through sight glass
- Sampling port and overpressure valve at the top

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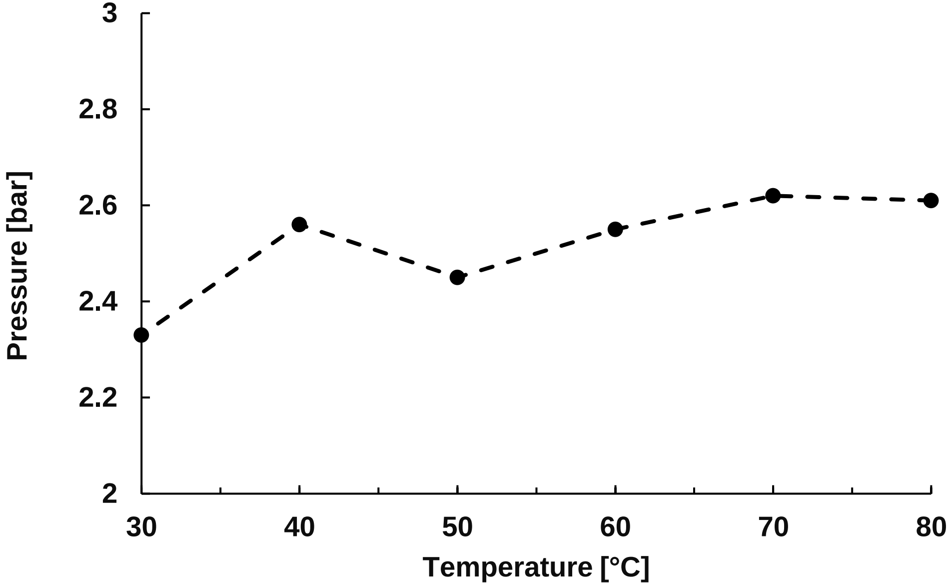
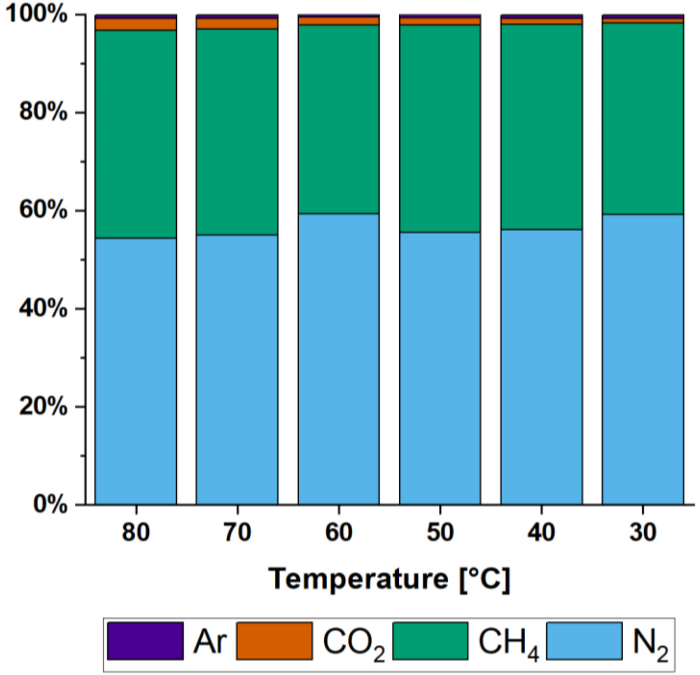
Bubble point determination in USH

- Investigating the bubble point in dependance of temperature
- Defining boundaries for the digital-twin





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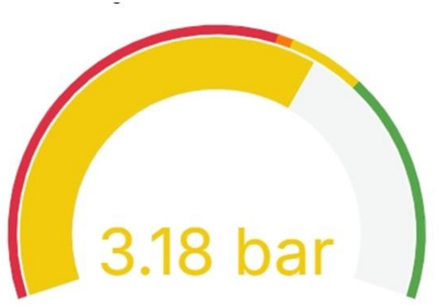
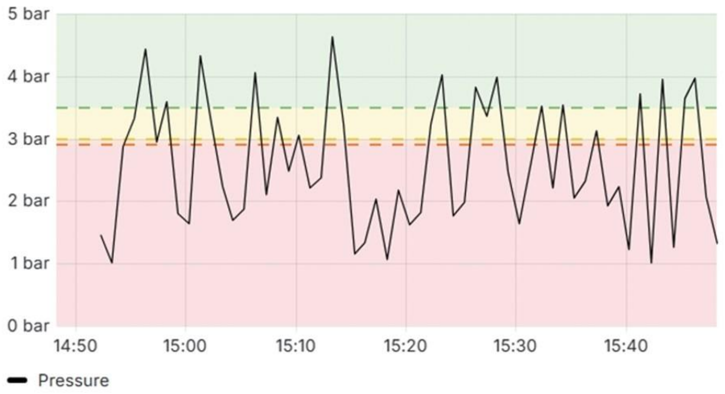
Digital twin

- Cloud based geochemical modelling environment via PHREEQC
- Data of over 50 sensors are written in real time in a cloud database
- PHREEQC scripts are run at one-minute intervals to determine the scaling and degassing potential under the current hydrochemical conditions measured by the sensors
- Depending on the modelling results, the demonstrator's flow rate and pressure can be controlled dynamically by an AI.

Pressure gauge



Time series on artificial data for benchmarking



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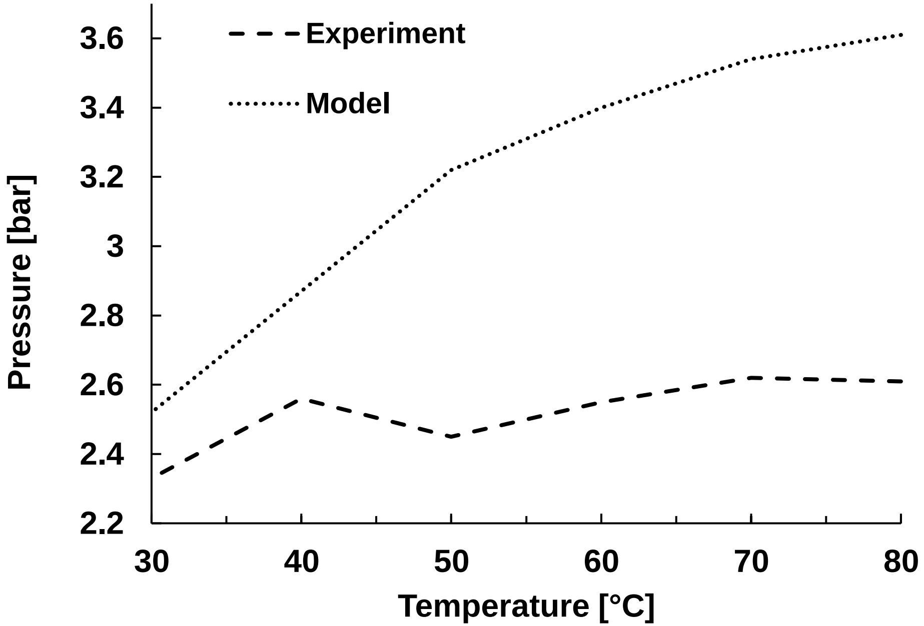
Automatization for hydrochemical big data

- Automatization of gas trap data generation
- Geochemical models do not consider all the relevant parameters
  - Biggest challenge is the data distribution across the variation of degassing controlling chemical parameters (Temp., pressure and pH)
  - 3D parameter space needs to have data spread evenly across all three dimensions to prevent the machine learning model from being biased



Summary

- Artificial intelligence can provide valuable support during the exploration phase of a geothermal power plant.
- Machine learning models struggle to grasp chemical processes since an equal amount of data is required for every system state.
- Developed a mobile tool to overcome the aforementioned challenges and generating comprehensive data sets for machine learning models to support the operation of geothermal power plants

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Thank you for your kind attention

Machine Learning for Enhancing Geothermal Energy

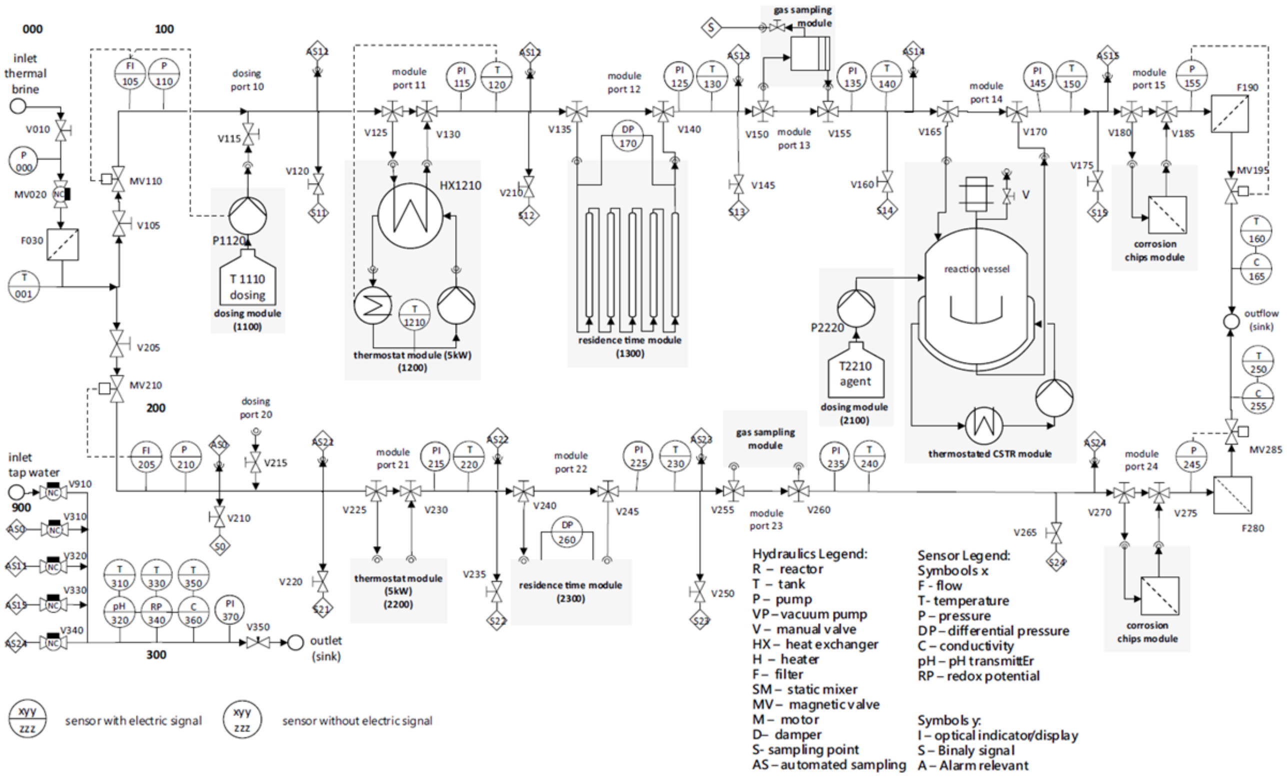
Federal Ministry for Economic Affairs and Climate Action

Locations & their issues

- **Haag am Hausruck**:
  - Clocking of filter systems at the decentral heat pumps of the customers with organic compounds followed by microbial growth
- Unterschleißheim:
  - Increasing the heat extraction rate with an industrial heat pump to cool down the brine by 5 more °C after the heat exchanger
  - Investigate the scaling potential if there is no pressure maintenance
- Gülpinar:
  - Reducing the maintenance pressure from 20 to 10 bars
  - Testing different scaling prevention methods

Hardware-Twin in the field

Hardware-Twin - Features



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Planned experiments in Gülpinar

- Degassing experiments: Investigate bubble point and gas content in dependance of temperature and flow regime

- Scaling occurence: Investigate mineral precipitation in harsh pH and temperature conditions. pH between 3 and 10 and temperature down to 30°C.

- Monitoring of major cations, sulfate and trace elements.
- Isotopes in cooperation with Hydroisotop.

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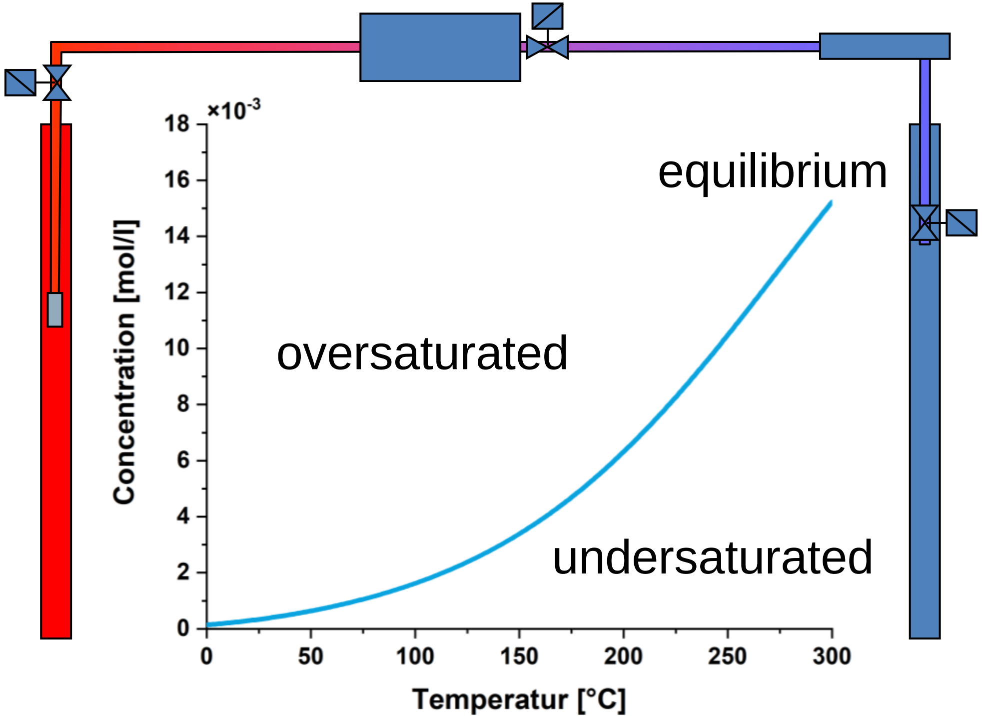
Motivation - Scaling

Solubility is dependant on:

1. pH
2. Pressure
3. Temperature
4. Salinity



Project & Partner

Karlsruhe Institute of Technology

Funded by:

GEOTHERMICA

Federal Ministry
for Economic Affairs
and Climate Action

Started in 2022 until 2025

Funding volume: 1 788000 €

Fraunhofer ISE

Karlsruhe Institute of Technology

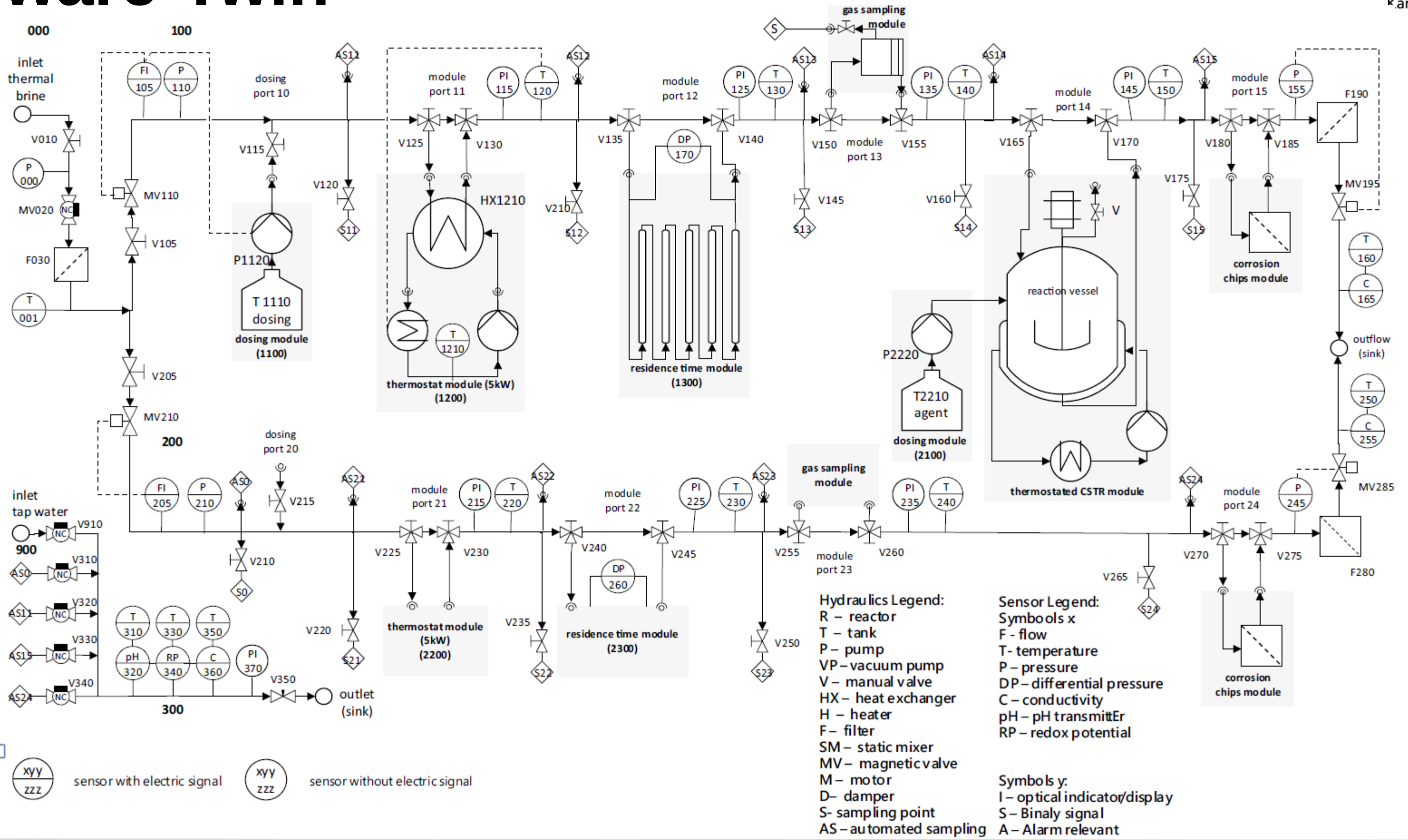
Hydroisotop

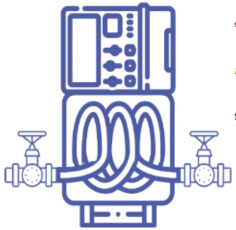
hydroFilt

Geosaic GmbH

Transmark Renewables

Hardware-Twin





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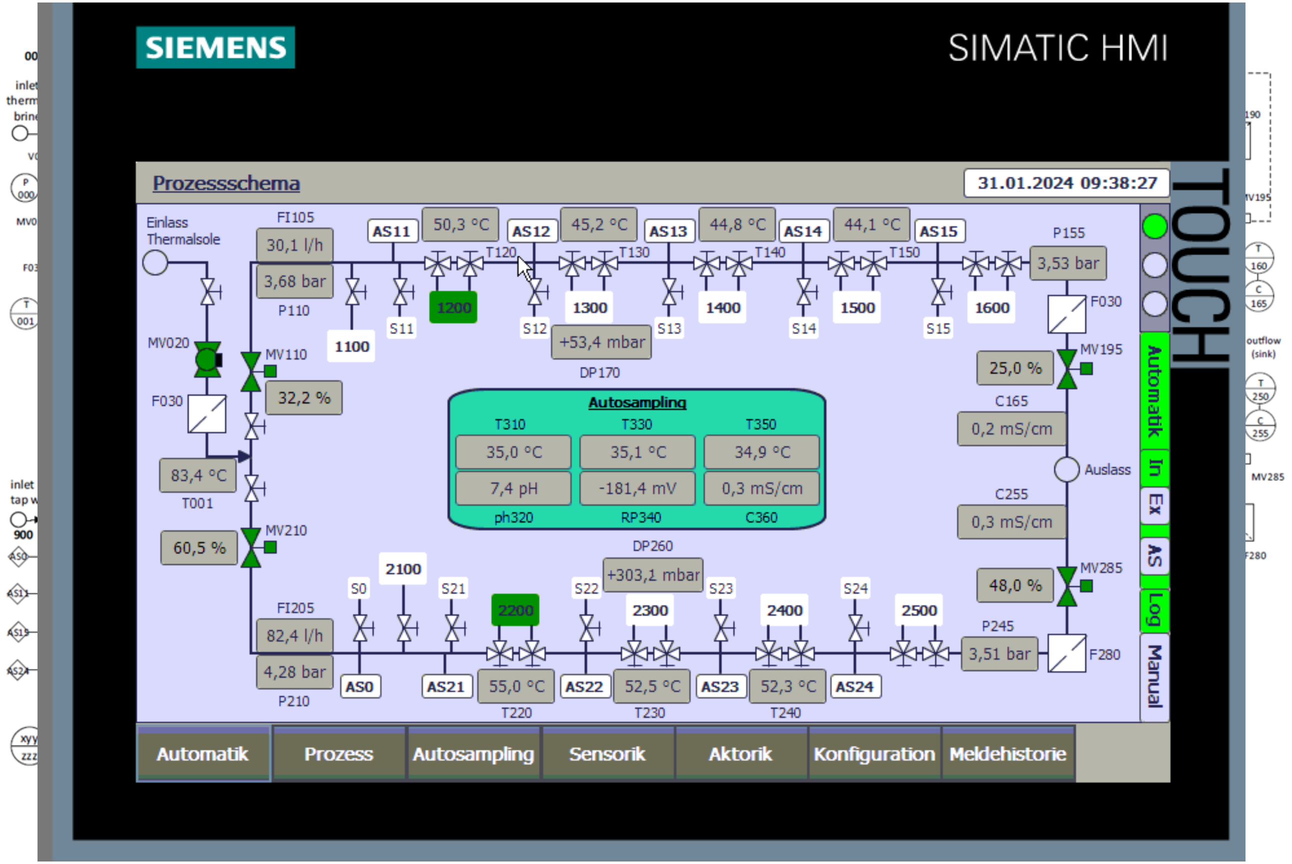
Hardware-Twin - Features



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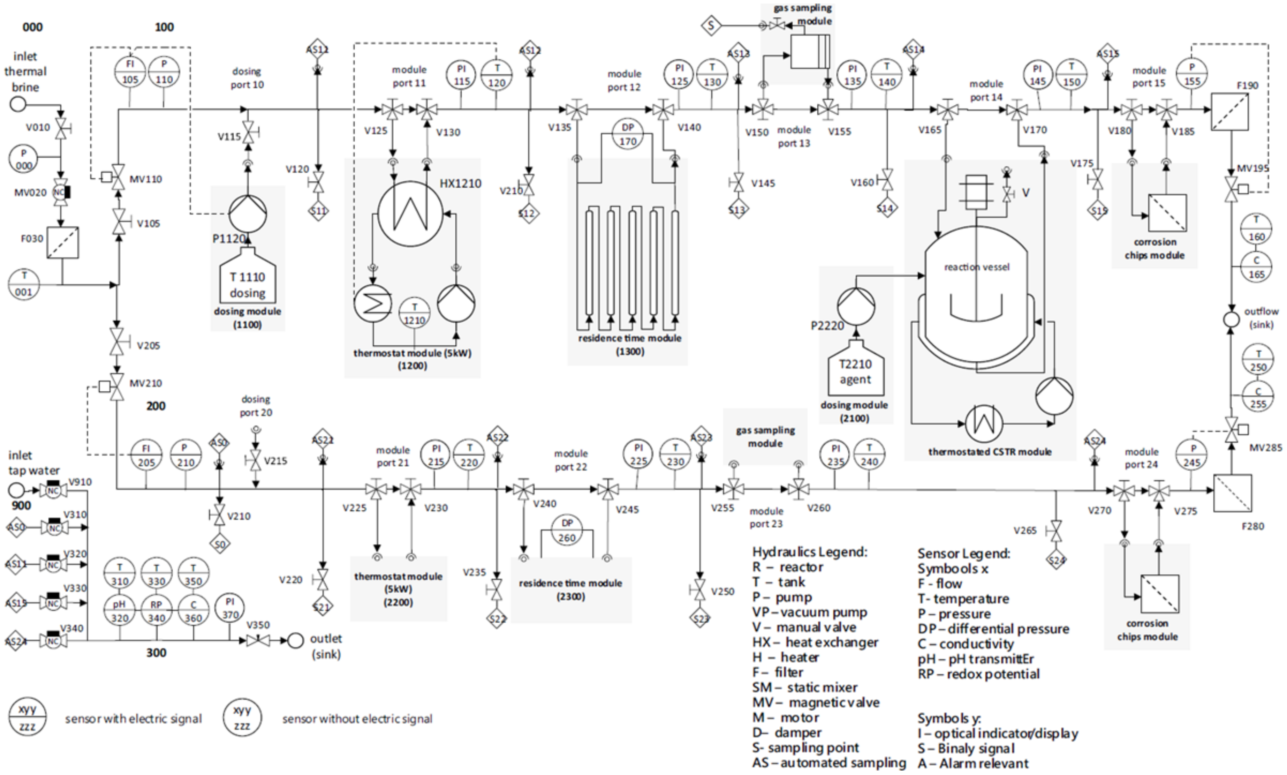
The Team

Hardware-Twin - Features



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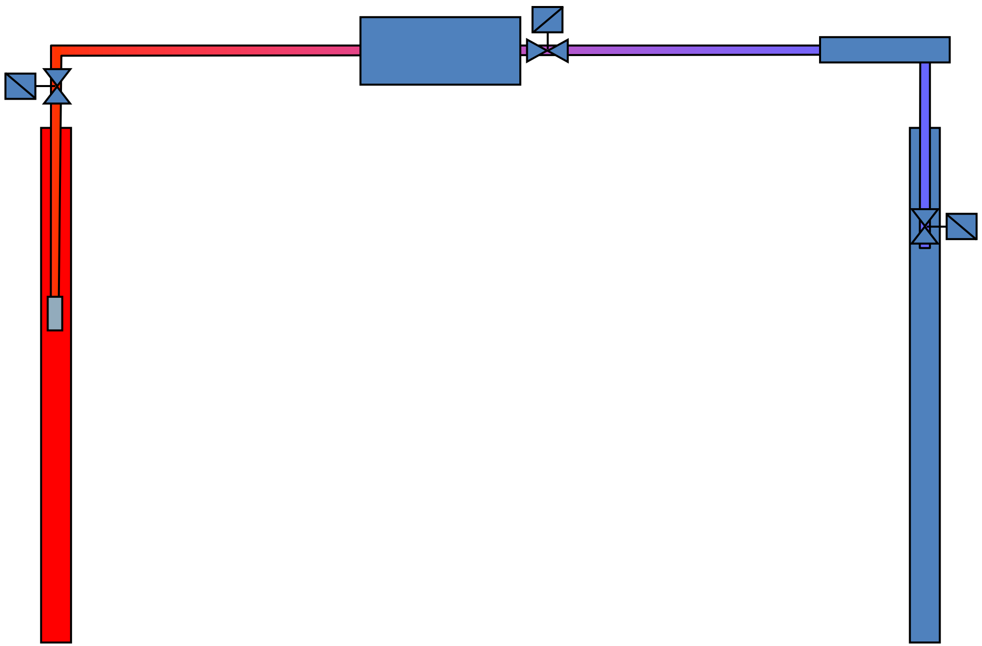
Agenda

- Project & Partner
- Motivation
- The Idea
- Concept
- Implementation of Artificial Intelligence

Motivation – Degassing & Corrosion

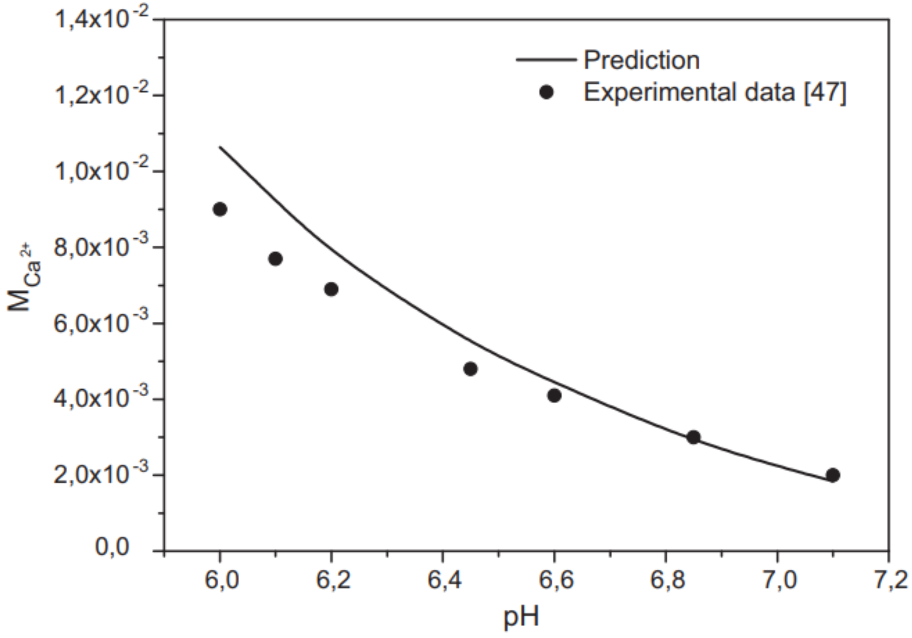
Silica scaling here!



Carbonate scaling

- Degassing results in loss of carbonic acid because it is in solution as dissolved CO_2
- A shift in the carbonate equilibrium leads to higher pH
- Calcium solubility decreases with higher pH

➡ Carbonate scalings

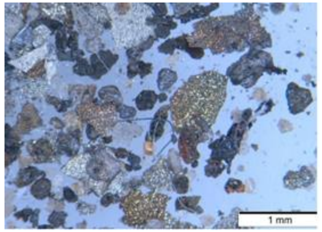


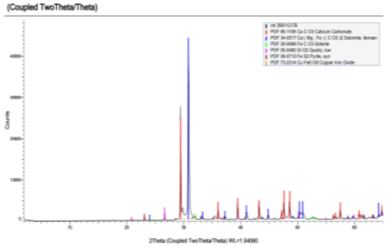
COTO ET AL. (2012)

Intensive hydrogeochemical sampling

- Hydrogeochemical sampling campaign
  - Fluid analyses of the geothermal brine include major elements, trace elements, common isotopes and gas phase
  - Solid analyses of suspended particles and scaling via SEM, XRF, XRD….

→ Hydrogeochemical data for deterministic modelling





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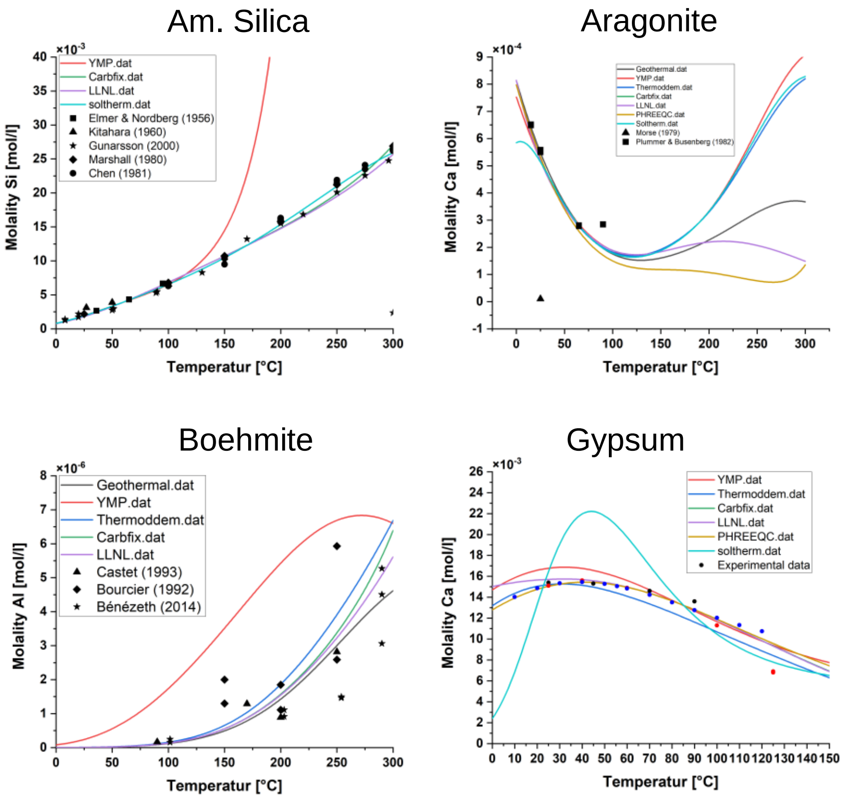
Thermodynamic databases

- Validation of thermodynamic data
  - Compilation of a valid thermodynamic database in PHREEQC
  - Comparison with literature data (Experiments and verified thermodynamic models)

Improvement of deterministic calculations and models



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Digital-Twin

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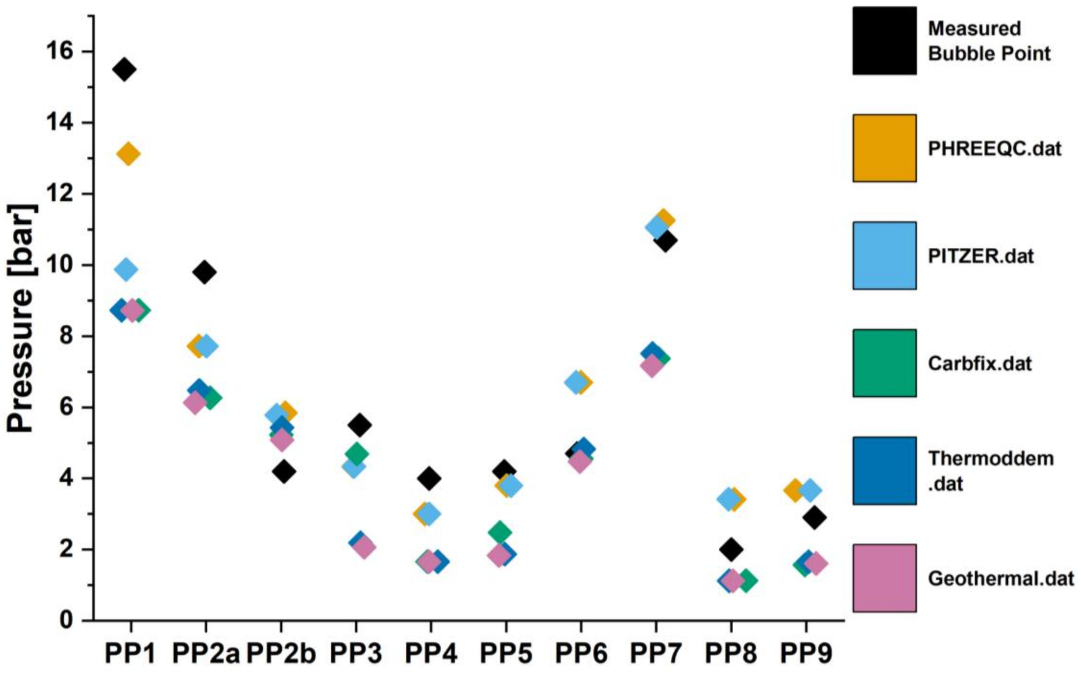
- Deterministic modelling
  - Deterministic adaptation of power plant parameters (temperature, pH, pressure)
  - Modelling of degassing, scaling, and corrosion potential

```
% For-loops of the several sensitivity analyses calculated via IPhreeqC
for bb = 1:bbb   % numbre of pressure sensitivity steps
for cc = 1:ccc   % number of steamloss/dilution sensitivity steps
for aa = 1:aaa   % number of pH sensitivity steps
    iphreeqc = actxserver('IPhreeqcCOM.Object');
    iphreeqc.LoadDatabase(['C:\Program Files\USGS\IPhreeqcCOM' ...
        ' 3.7.3-15968\database\llnl.dat']); % pathname to IPhreeqcCOM
    iphreeqc.ClearAccumulatedLines;
    iphreeqc.AccumulateLine ('SOLUTION 1');
    iphreeqc.AccumulateLine (['-units ' con]);
    iphreeqc.AccumulateLine (['-temperature ' (num2str(...
        struct.Temperature))]);
    iphreeqc.AccumulateLine (['-pH ' (num2str(struct.pH))]);
```

→ Establishment of a huge dataset to train the artificial intelligence

Bubble point modelling

- 5 thermodynamic databases (TDB)
- 2 TDBs use a special approach to exclude N_2, CH_4 and H_2S from redox reactions
- Dissolve the measured gas phase in the brine and gradually reduce the pressure until the bubble point is reached and a free gas phase is formed
- Comparison of the measured bubble point of different power plants (PP) with the modeled one from each TDB



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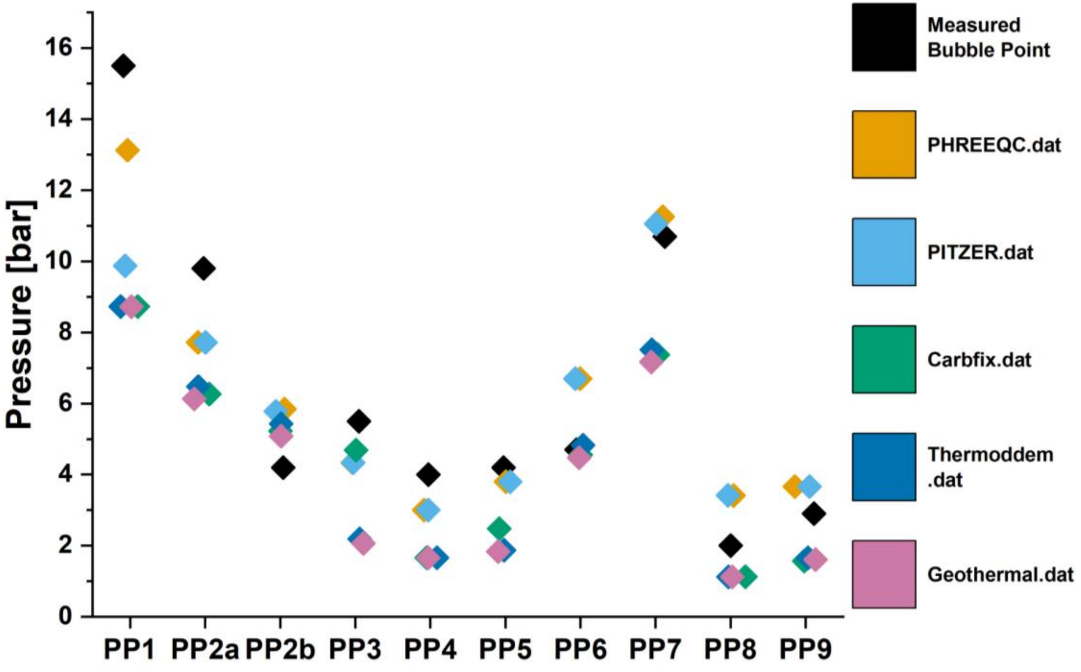
Bubble point modelling

Conclusion

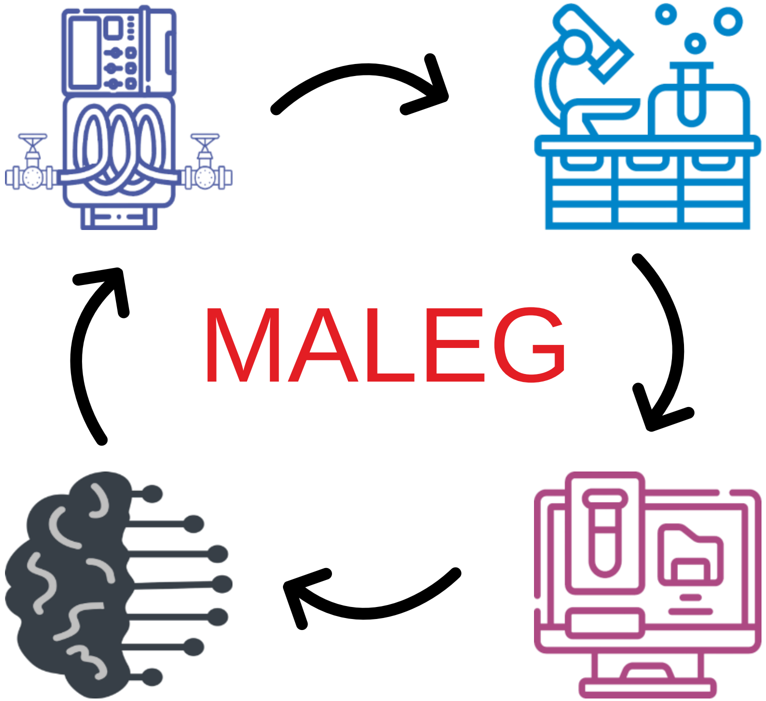
- Tendency to underestimate the bubble point in the model
- Active redox reactions of the gas-forming species reduce the bubble point
- High uncertainties in the measured data, especially the bubble point
  - The bubble point is determined by in-situ observation in a pressure vessel until the formation of gas bubble is observed.
  - Flow regime – turbulent vs laminar



Implementation of artifical intelligence

Use results to train AI

Safe analytic cost



Compare hydro-geochemistry with AI model

Model hydrogeo-chemistry with live data feed

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References

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- B. Coto, C. Martos, J.L. Peña, R. Rodríguez, G. Pastor, Effects in the solubility of CaCO3: Experimental study and model description, Fluid Phase Equilibria, Volume 324, 2012, Pages 1-7, ISSN 0378-3812, https://doi.org/10.1016/j.fluid.2012.03.020.