Karlsruhe Institute of Technology

Institute for Technical Chemistry

Burner Development and Optimization for High Pressure Entrained Flow Gasifiers

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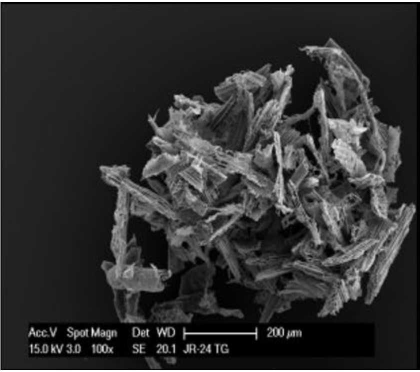
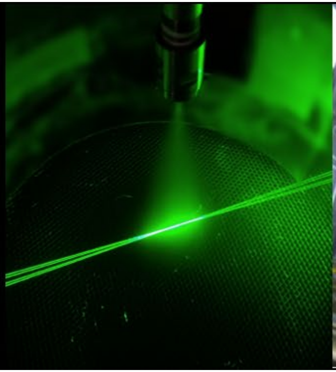
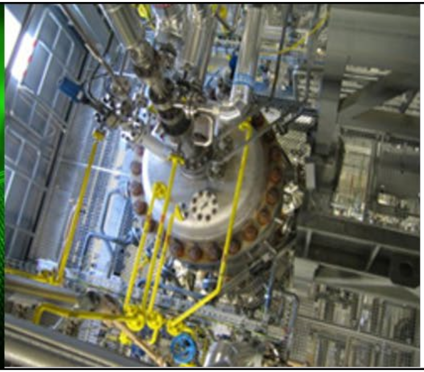
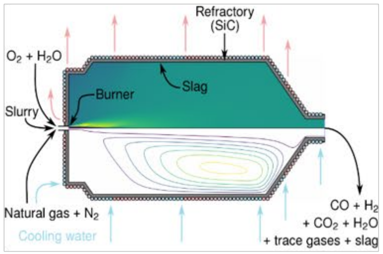
11th International Freiberg Conference 24.-29.09.2023









Entrained Flow Gasification
Key process for Circular Economy

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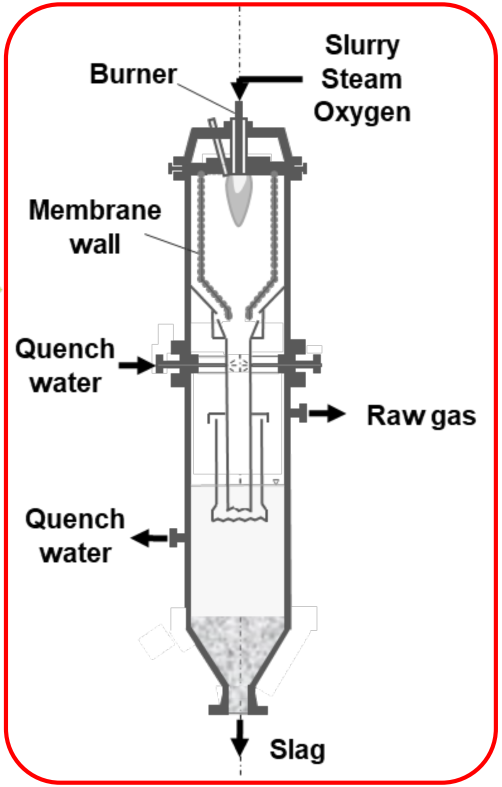
Biomass Residues

Waste

Mechanical Pre-treatment

Pyrolysis / Liquefaction



Gas Treatment

H_2-Addition

CO_2-Separation

Fuels

Basic Chemicals

Electricity / Heat

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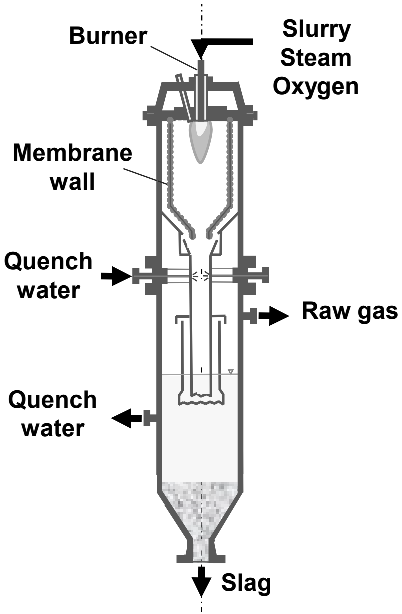
5 MW HP-Entrained Flow Gasifier



5 MW
$\dot{M}_{liq} \leq 1000$ kg·h^{-1}
p = 40 bar
T > 1200 °C

Goals:

- High carbon conversion at minimum temperature
- Minimum amount of by-products: soot + tar + hydrocarbons
- Allow for efficient and feedstock flexible operation of the gasifier

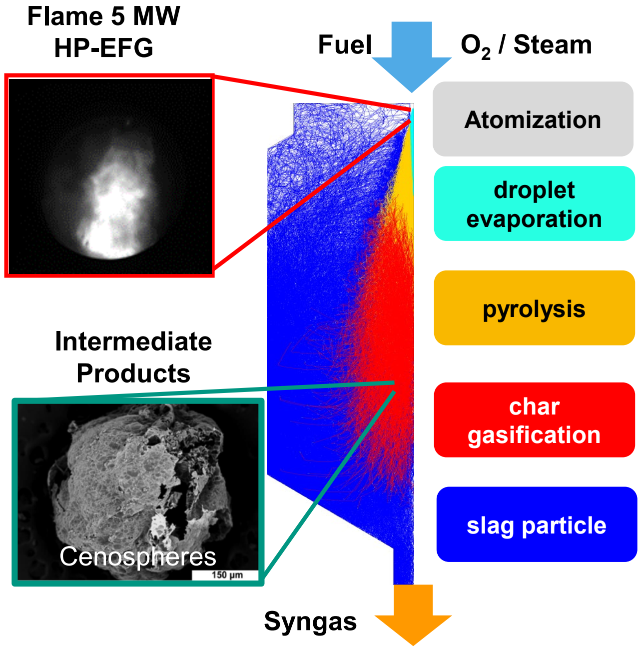
➔ Otpimize burner-design and operation

Challenges:

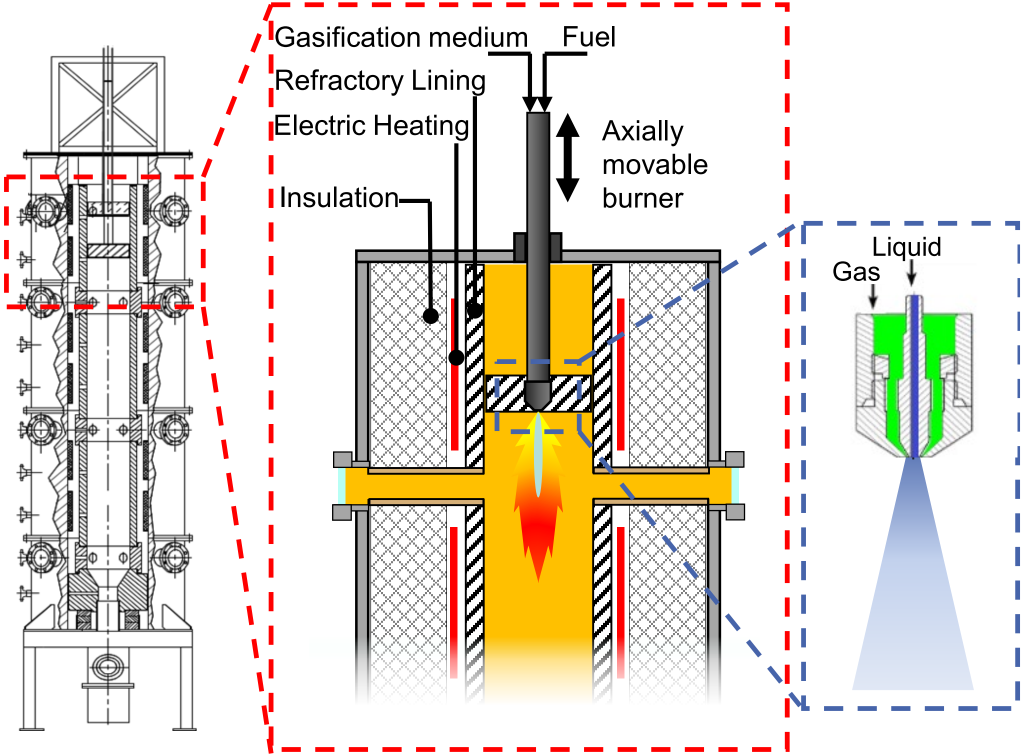
- Reacting System at high temperature and pressure
- Wide range of fuel viscosity up to 1000 mPa·s
- Atomization media serves as reactant

➔ interaction of burner operation and stoichiometry

Thermo-Chemical Processes in HP-EFG



Research Entrained Flow Gasifier – REGA



Technical Data

- Reactor length: 3 m
- Inner diameter: 0.28 m
- Wall temperature: 1200 °C
- Pressure: 1 atm
- Gasification medium: O_2/N_2 ($x_{O2,max}$ = 80 v%)

Optical Measurement

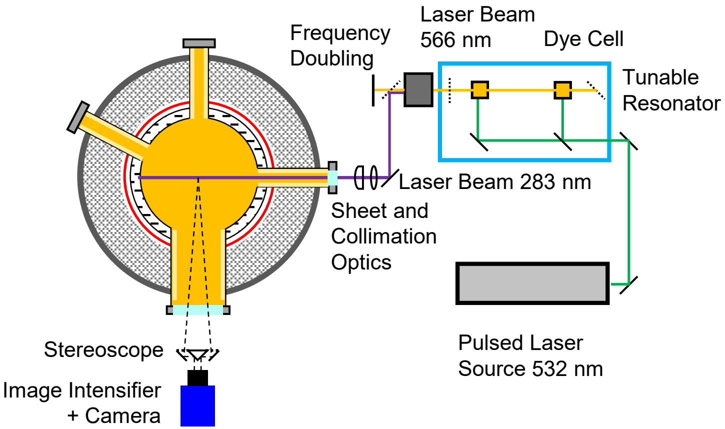
- Optical access ports on 4 levels
- Axially movable burner
- Accessible area: z = 0 – 300 mm

Probe Measurement

- T, y_i, Particles

Reaction Zone Analysis

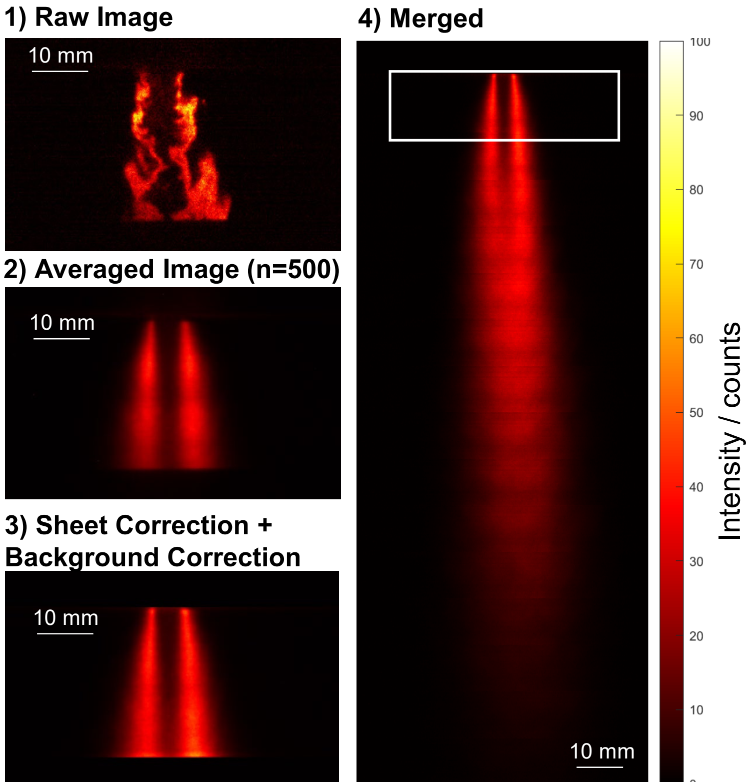
Laser Induced Fluorescence (LIF)



- Laser beam is expanded to a sheet
- Flame intermediates excited by laser pulse
- Detection of fluorescence by camera

→Instantaneous, 2D spatially resolved detection of OH

→**Flame front imaging**



Reaction Zone Analysis Model Fuel (λ = const.)

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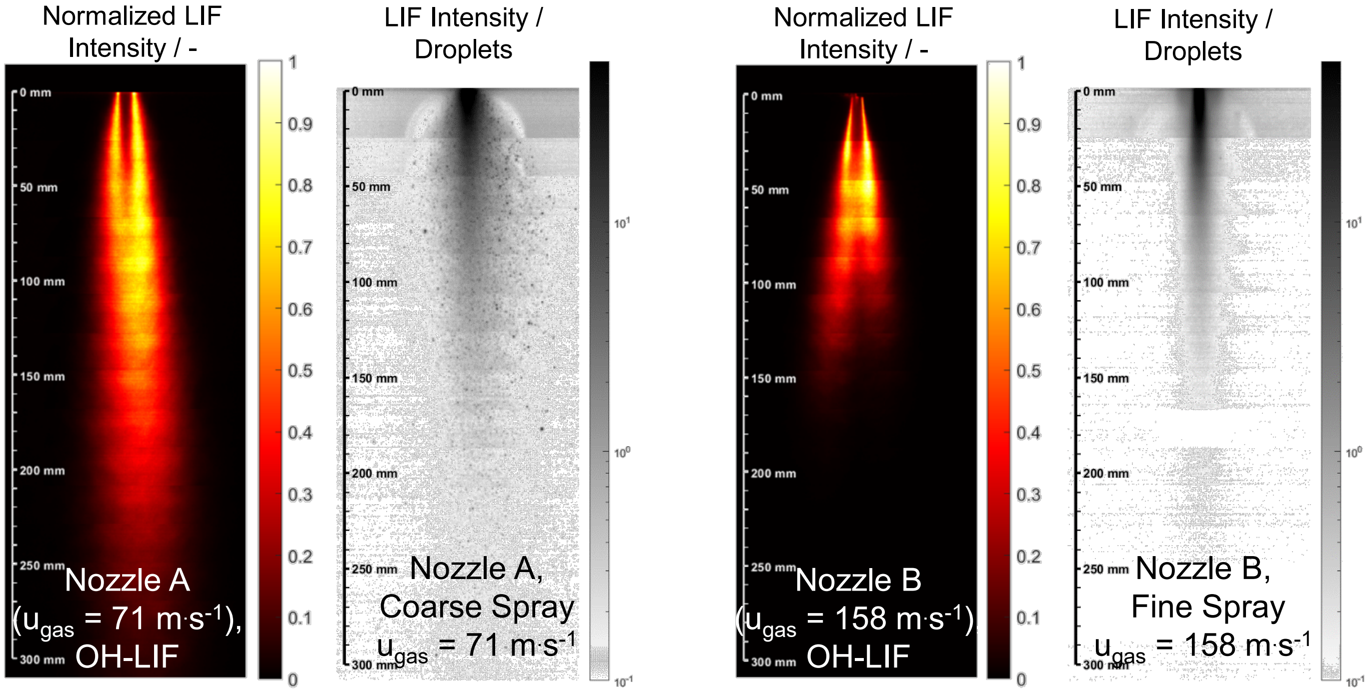


➔ **Different OH-distribution observed for different drop sizes and spray angles**

➔ **Larger Droplets: Significant portion of fuel converted outside the hot zone**

➔ **Spray affects reaction zone, temperature field and fuel conversion**

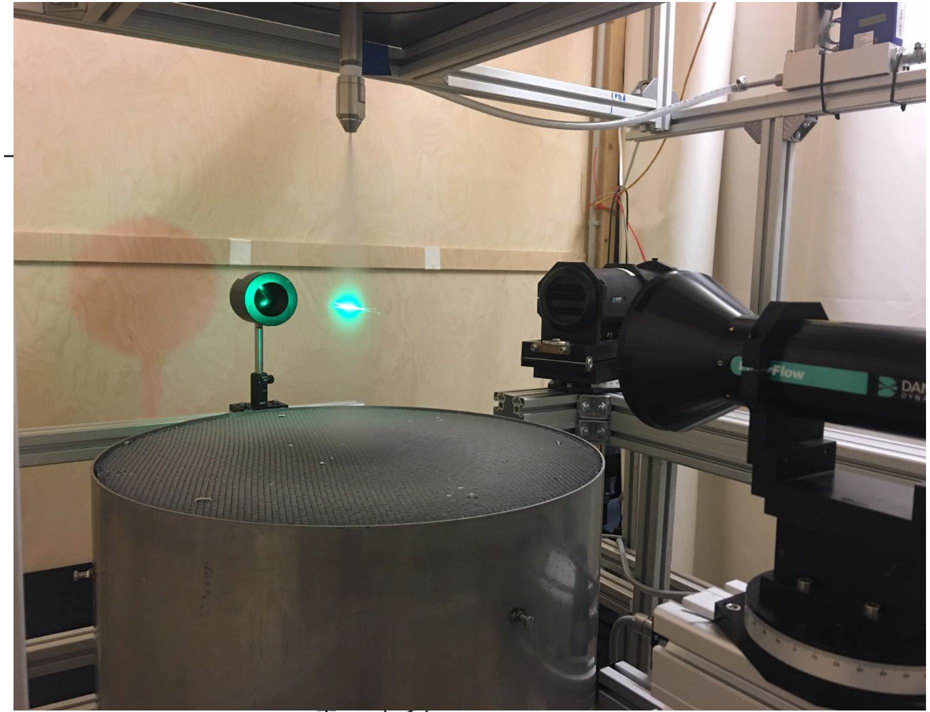
➔ **Experiments at $\dot{M}_{liq}$ = 15 kg·h^{-1} – 5 MW HPEFG operated at 1000 kg·h^{-1} ➔ Burner Scaling!**

➔ **Correlations reported mostly at $\dot{M}_{liq}$ ≤ 20 kg·h^{-1} ➔ not applicable for a 1000 kg·h^{-1} burner**

[1] M. Haas et al., Entrained flow gasification: Impact of fuel spray distribution on reaction zone structure; Fuel 334 (2023)

Atmospheric Spray Test Rigs – ATMO & BTR

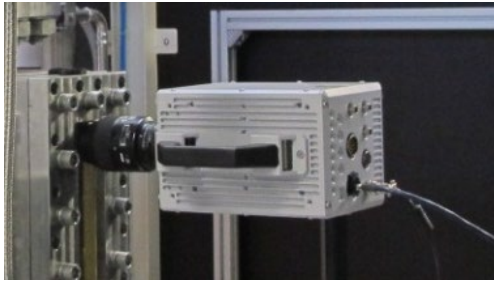
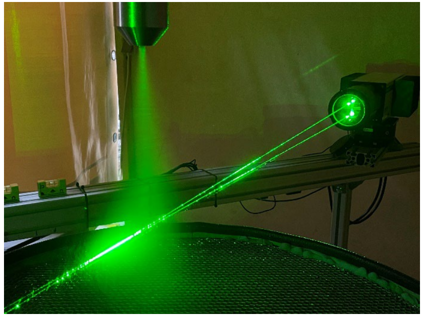
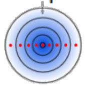
ATMOspheric Spray Test Rig (ATMO)



Burner Test Rig (BTR)

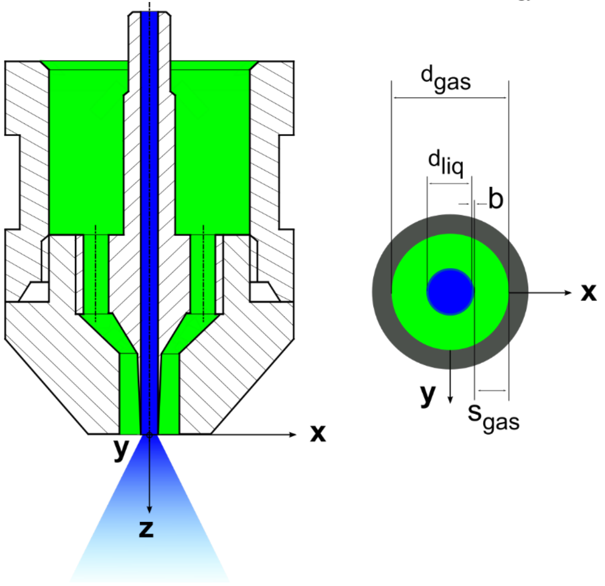
- full optical access

Applied Measurement Techniques

	High-speed camera (HSC)	Phase Doppler anemometer (PDA)
		
Set up:	1 MP 3600 Hz	561 nm 1st order refraction
Measurement:	2000 images Nozzle tip & measuring plane	50,000 droplets or 60 s 1 full profile + 2 half profiles
Postprocessing:	Nozzle: Breakup morphology and lenght Measuring plane: Max droplet size	 $Id_{32,m} = \frac{\sum_{i=1}^{N} d_{30,i}^{3} \cdot \dot{m}_i \cdot A_i}{\sum_{i=1}^{N} d_{20,i}^{2} \cdot \dot{m}_i \cdot A_i}$

Approach for Mass-Flow-Scaling

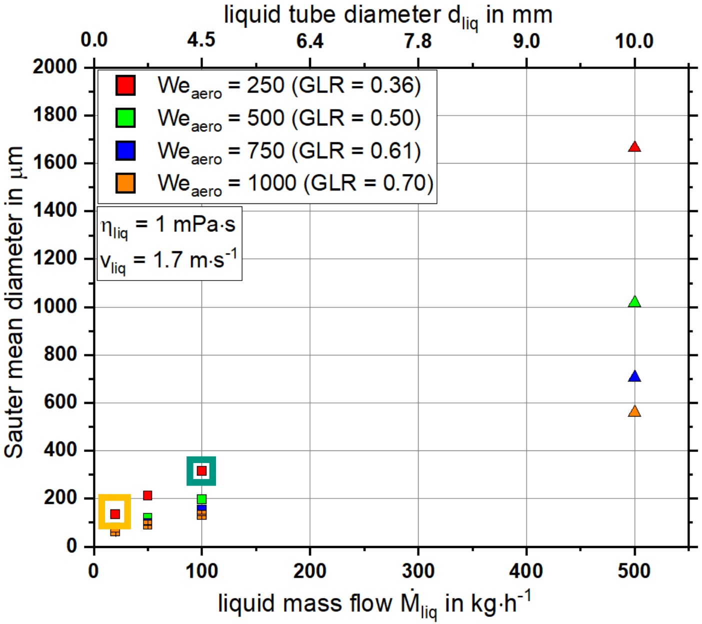
- v_{liq} was kept constant ($1.7\ m{\cdot}s^{-1}$) while increasing $\dot{M}_{liq}$
  - ➔ Requires an increase of d_{liq}
- GLR = const. (as process relevant parameter)
  - ➔ $\dot{M}_{gas}$ must be increased with $\dot{M}_{liq}$
  - ➔ Adaption of geometry in terms of d_{gas} and s_{gas}
- Being the most relevant char.-Number in terms of atomization We_{aero} is kept constant
  - ➔ requires a decrease in v_{gas} for increasing d_{liq}
- **4 Nozzles:** $\dot{M}_{liq}$ = 20 / 50 / 100 / 500 $kg{\cdot}h^{-1}$



$$We_{aero} = \frac{(v_{gas} - v_{liq})^2 \cdot \rho_{gas} \cdot d_{liq}}{\sigma_{liq}}$$

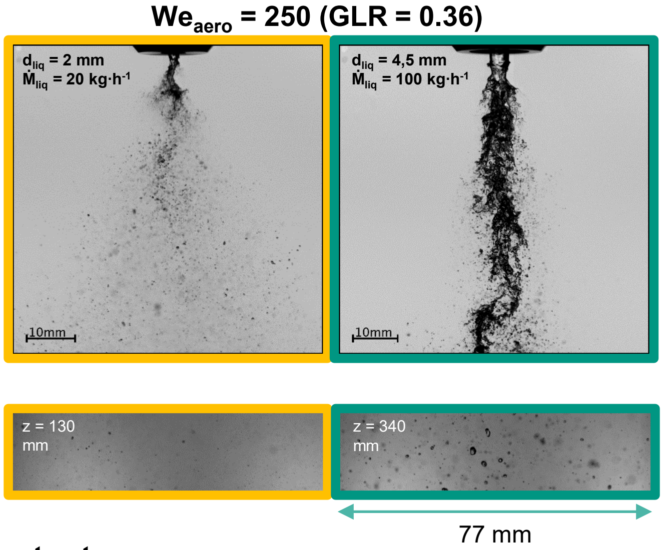
$$GLR = \frac{\dot{M}_{gas}}{\dot{M}_{liq}}$$

Sauter Mean Diameter as function of $\dot{M}_{liq}$



Measured via PDA

Image analysis (HS-Data)

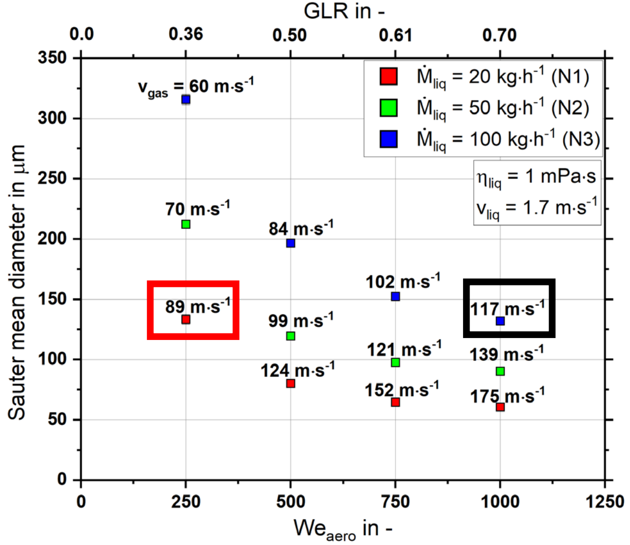


- $\dot{M}_{liq}$ ↑ (d_{liq} ↑) → **SMD ↑ for We_{aero} (GLR) = constant**
- **We_{aero} ↑ (GLR ↑) → SMD ↓ for $\dot{M}_{liq}$ (d_{liq}) = constant**

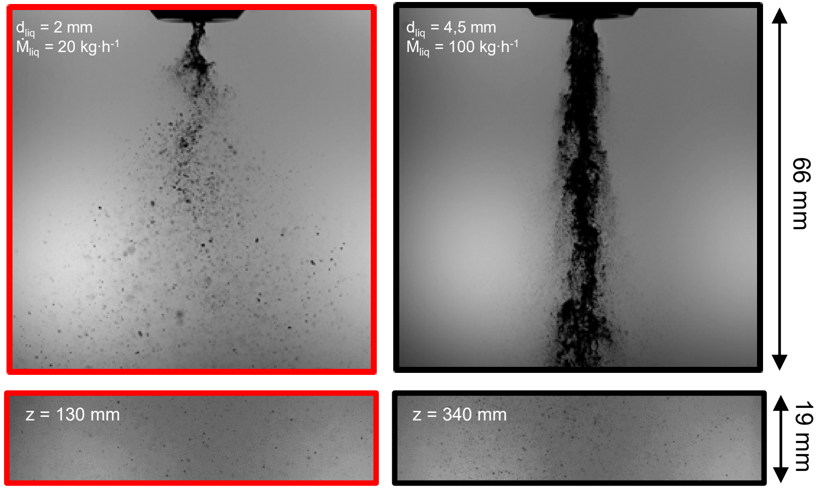
➔ Keeping We_{aero} = constant not enough to guarantee for constant drop-size

[2] Wachter, Jakobs, Kolb; Mass Flow Scaling of Gas-Assisted Coaxial Atomizers; Appl. Sci.; 2022, doi.org/10.3390/app12042123

Sauter Mean Diameter as function of We_{aero}



We_{aero} = 250 (GLR = 0,36) | **We_{aero} = 1000 (GLR = 0,70)**

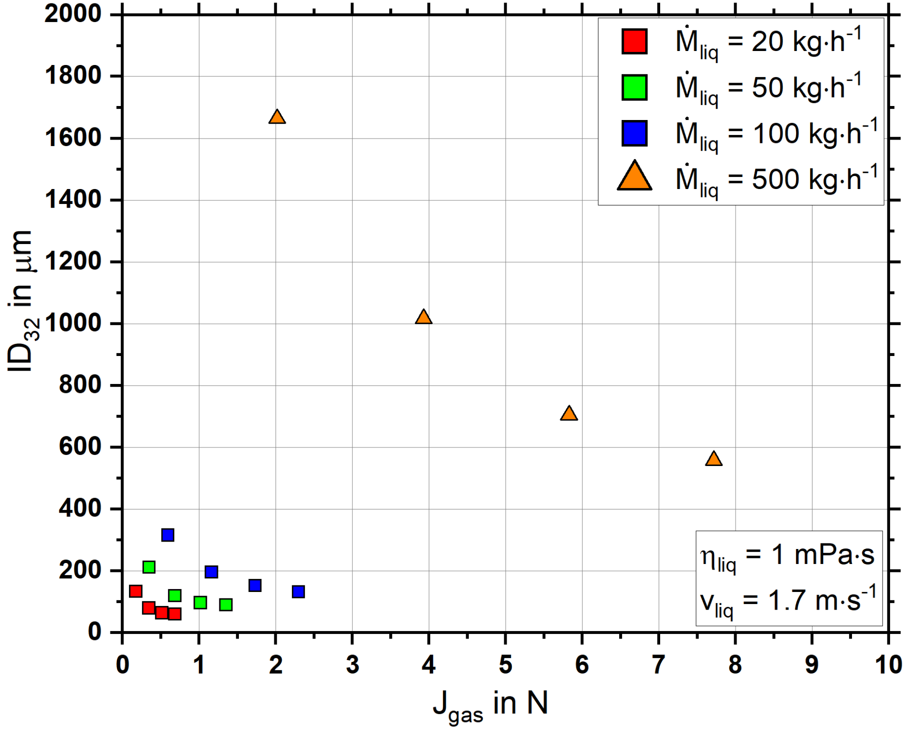


- **$\dot{M}_{liq}$ ↑ (d_{liq} ↑) → $Id_{32,m}$ ↑ for We_{aero} (GLR) = const.**
- **v_{gas} ↑ (GLR ↑) → $Id_{32,m}$ ↓ for $\dot{M}_{liq}$ (d_{liq}) = const.**

- **SMD can be kept constant for increasing $\dot{M}_{liq}$ (d_{liq}) by adapting We_{aero} and GLR (v_{gas})**
- **An increase in both parameters (We_{aero} and GLR) is covered by an increase in J_{gas}**

[2] Wachter, Jakobs, Kolb; Mass Flow Scaling of Gas-Assisted Coaxial Atomizers; Appl. Sci.; 2022, doi.org/10.3390/app12042123

Sauter Mean Diameter as function of J_{gas}



- All liquid mass flows under investigation show similar trends towards SMD and J_{gas}
- Exponential fit via least square method to cover all data

[2] Wachter, Jakobs, Kolb; Mass Flow Scaling of Gas-Assisted Coaxial Atomizers; Appl. Sci.; 2022, doi.org/10.3390/app12042123

SMD-Correlation for various Massflows

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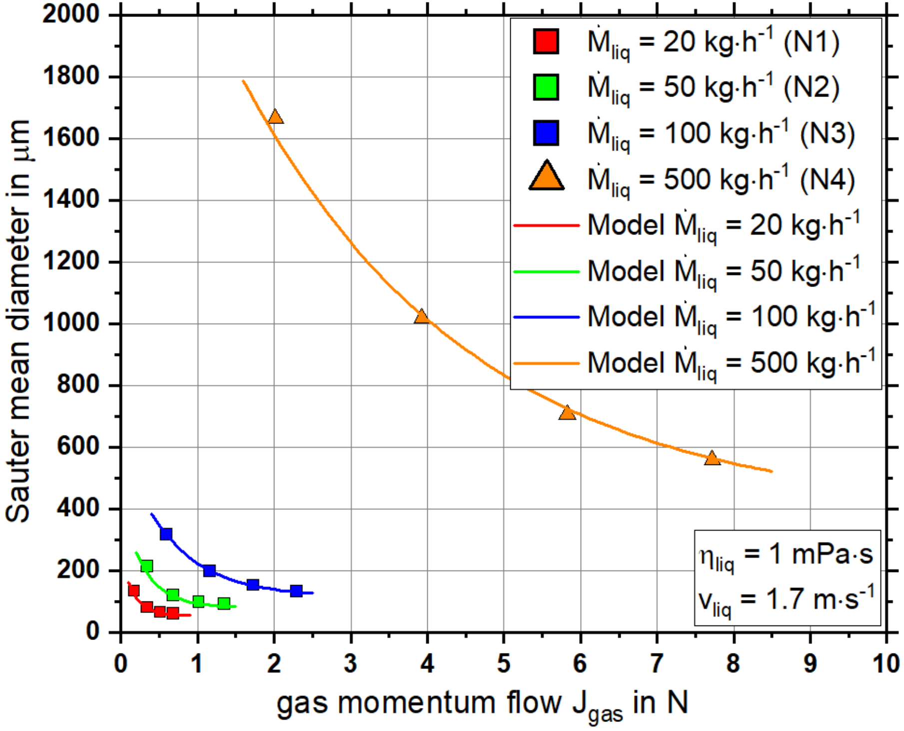


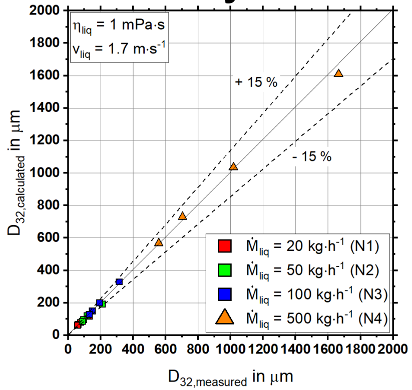
$$ID_{32,m} = A(\dot{M}_{liq}) \cdot e^{-\frac{J_{gas}}{B(\dot{M}_{liq})}} + C(\dot{M}_{liq})$$

$$A(\dot{M}_{liq}) = 4.6 \cdot \dot{M}_{liq} + 91$$

$$B(\dot{M}_{liq}) = 0.006 \cdot \dot{M}_{liq} + 0.03$$

$$C(\dot{M}_{liq}) = 0.67 \cdot \dot{M}_{liq} + 45$$

Parity Plot

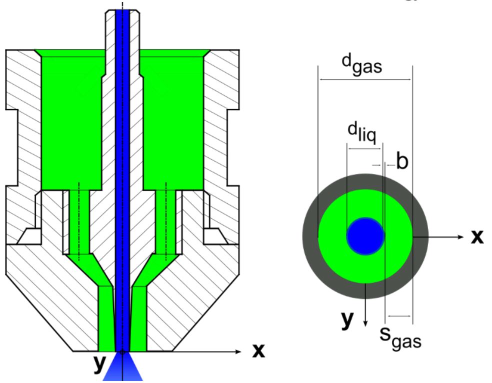


- **Empirical model fits liquid mass flow between 20 and 500 kg·h^{-1} with less than 15% deviation**

[2] Wachter, Jakobs, Kolb; Mass Flow Scaling of Gas-Assisted Coaxial Atomizers; Appl. Sci.; 2022, doi.org/10.3390/app12042123

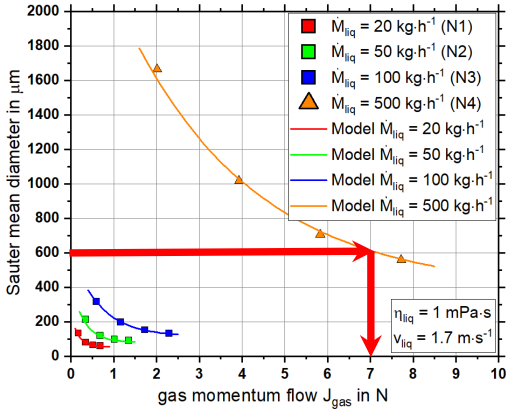
Application of the model to design a nozzle

$$ID_{32,m} = A(\dot{M}_{liq}) \cdot e^{-\frac{J_{gas}}{B(\dot{M}_{liq})}} + C(\dot{M}_{liq})$$



- **Determination of $\dot{M}_{liq}$ (v_{liq} is set to 1.7 m·s^{-1}) ➔ d_{liq}**
- **Specification of GLR (e.g. given by process conditions)**
- **Specification of target Sauter Mean Diameter**
- **Required J_{gas} for chosen SMD and $\dot{M}_{liq}$ can be calculated by the model**
- **Out of J_{gas} and chosen GLR ($\dot{M}_{gas}$) the required d_{gas} is determined**

➔ Nozzle design completed



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Summary and Outlook

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Target: Burner Optimization and Development for HPEFG

Summary:

- Spray and flame structure analysis in an atmospheric entrained flow gasifier
- Influence of fuel spray on reaction zone structure observed
- Approach for mass flow scaling of burner nozzles keeping charact. numbers constant
- Increase of liquid mass flow results in an increase in droplet size
- SMD-Correlation that allows for estimation of nozzel operating conditions / design for distinct droplet size

Outlook:

- Extend the range of investigated parameters and thus the validity range of the scaling approach
- Investigation of other burner nozzle designs
- Accompanying investigations in our 5 MW HPEFG focused on the burner near zone

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Thanks for your attention and the support of my colleagues!

5 MW HPEFG Flame

[1] Flame Structure

[2] Mass-Flow-Scaling