Entrained Flow Gasification of Suspension Fuels – A New Modeling Approach to Investigate Processes in Burner Near Field

Manuel Haas, Sabine Fleck, Thomas Kolb

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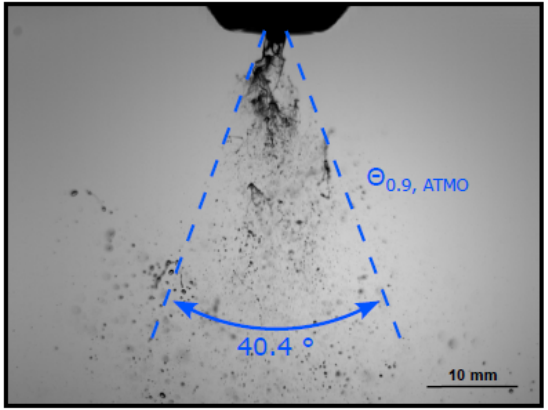

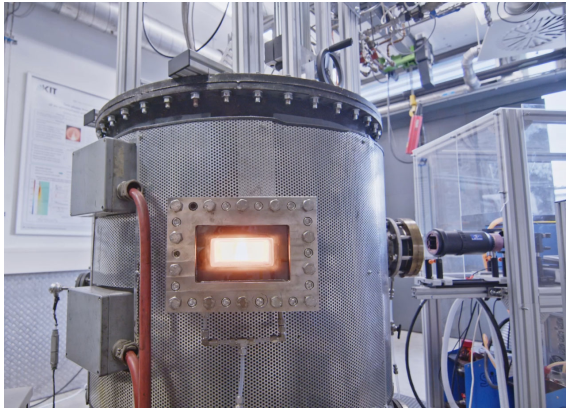

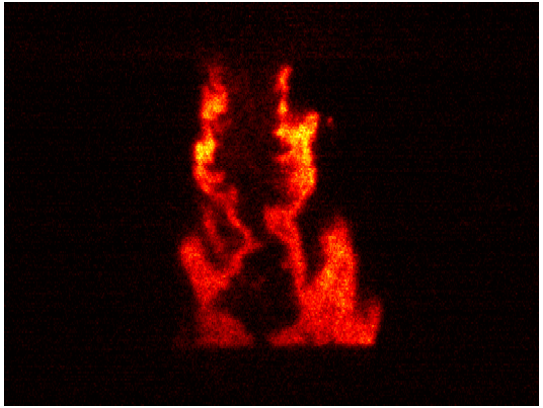

Entrained Flow Gasification of Waste Based Fuels

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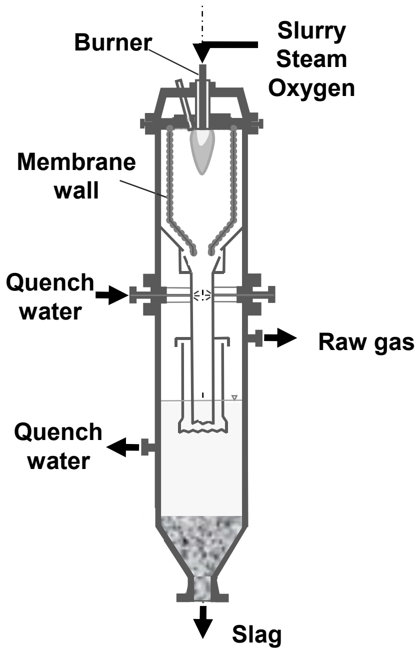
HP-EFG



Goal: Efficient Gasification Process

- High carbon conversion
- Fuel flexible operation
- Minimization of by-products: soot, tars, hydrocarbons

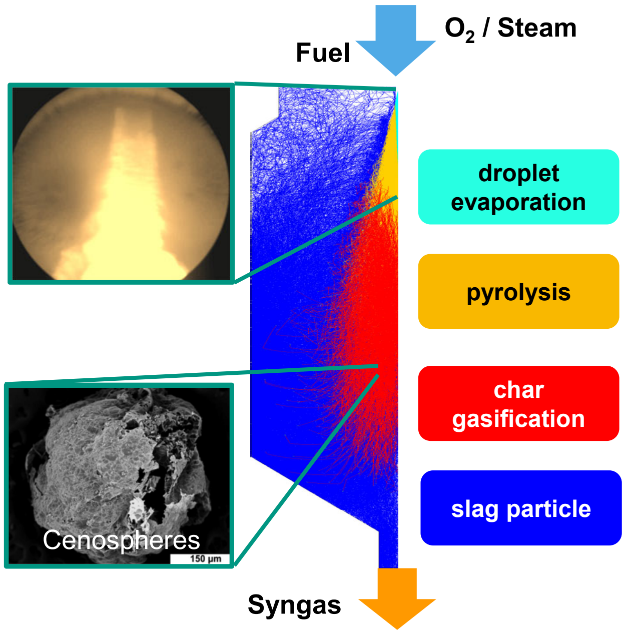
Challenge:

Fuel conversion is influenced by

- Atomization
- Fuel characteristics
- Temperature field
- Reactand mixing and flow field

→ **Importance of burner concept!**

Fuel Conversion Processes in HP-EFG



Understand and describe physical and thermo-chemical processes for modelling and operation of EFG

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HP-EFG: From Fundamentals to Technical System

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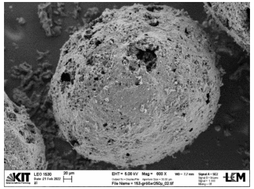
Fundamental investigations

Fuel Characterization

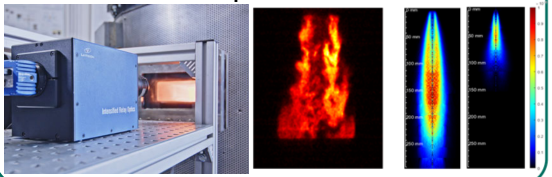
Sub processes of fuel conversion



Proof of concept

Atmospheric Gasification

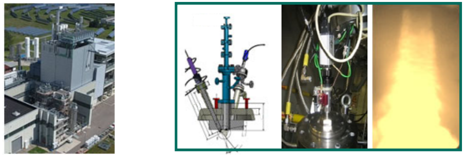
Detailed description of sub-processes for gasification of liquid and suspension fuels



Pilot scale TRL 6-7

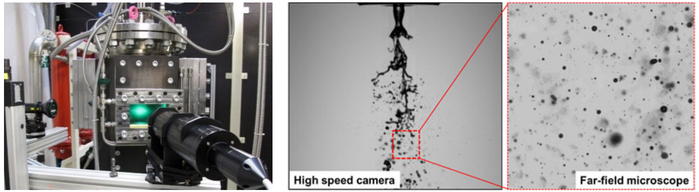
High Pressure Gasification

CCLab Entrained Flow Gasifier
Data for process optimization and validation of CFD tool



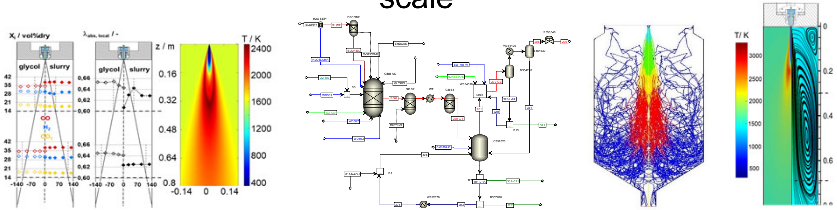
Atomization

Experimental and numerical investigation for optimized design of HP-EFG burner / Virtual Spray Test Rig



Modeling + Scale up

Process optimization and technology transfer to industrial scale



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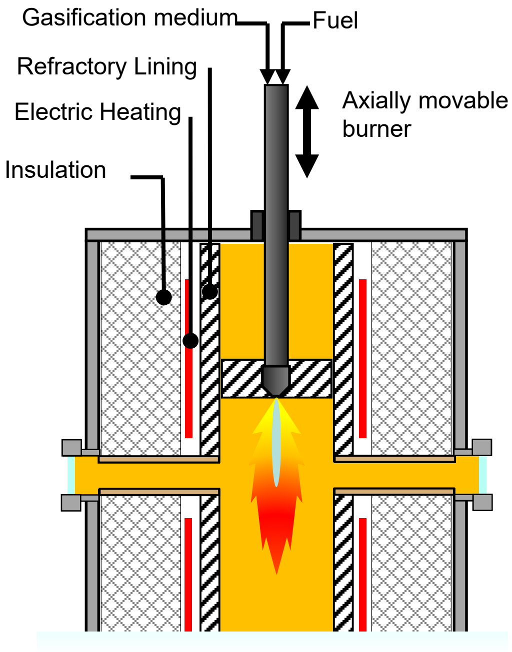
Research Entrained Flow Gasifier REGA

Research Entrained Flow Gasifier (REGA)



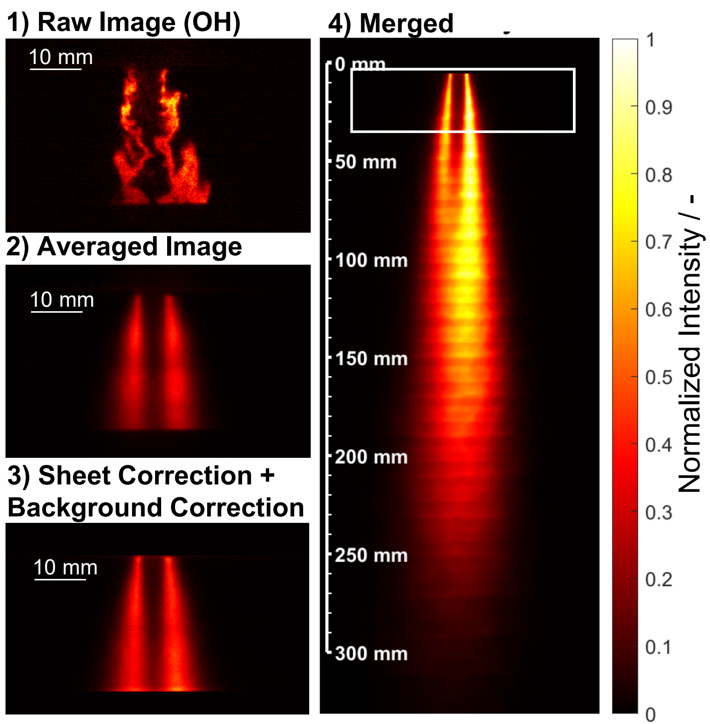
Technical Data

- p = 1 bar
- Reactor length 4m
- Inner diameter 0,28m
- T_{wall} 1200°C
- Optical access z = 0 – 330 mm

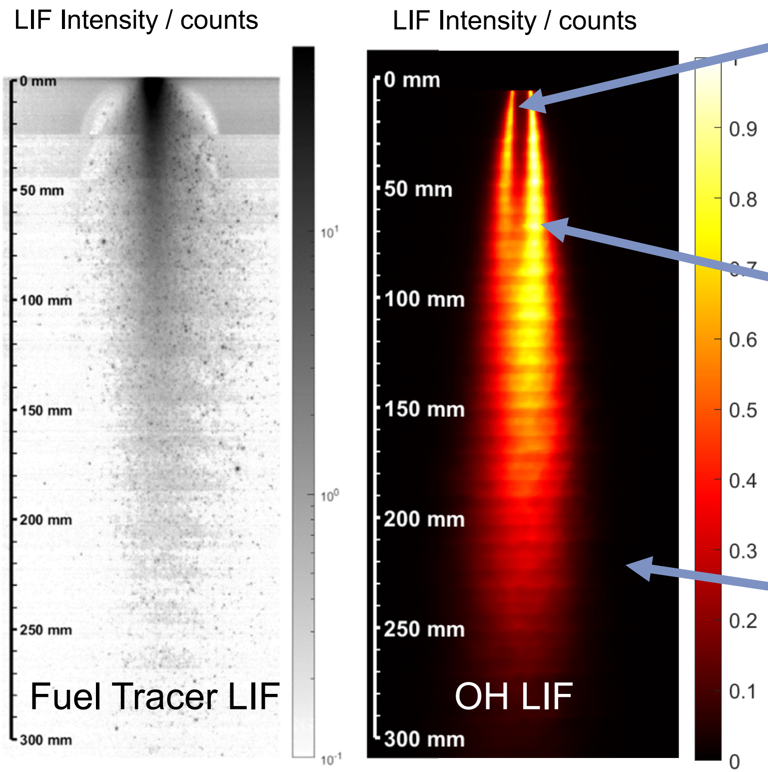
Diagnostics

- OH distribution (OH-LIF)
- Fuel distribution (Fuel-Tracer-LIF)
- T_{gas} (Thermocouples)
- y_i (extractive)
- d_{drop}, u_{drop} (PDA)

Laser Induced Fluorescence (LIF)



Flame Structure under EFG conditions



Haas et al., 2023, Fuel, https://doi.org/10.1016/j.fuel.2022.126572

Core Zone

- Only fuel, no OH radicals detected
- No oxidation reaction
- Low temperature

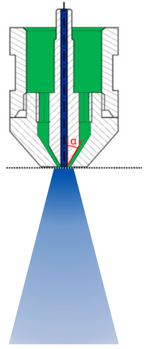
Oxidation Zone

- OH radicals detected
- Oxygen is consumed by reaction with fuel and syngas entrained from surrounding atmosphere
- High temperature

Gasification Zone

- No OH radicals detected, oxygen is no longer present
- Fuel droplets converted by slow gasification reactions
- Moderately high temperatures

Burner nozzle



2-Phase Free Jet Model (2-Ph-FJM)

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EFG Flame structure

- Fuel spray converted in inverse diffusion flame of oxidizer (jet medium) and surrounding atmosphere (syngas)
- Reaction zones determined by jet mixing and spray dynamics

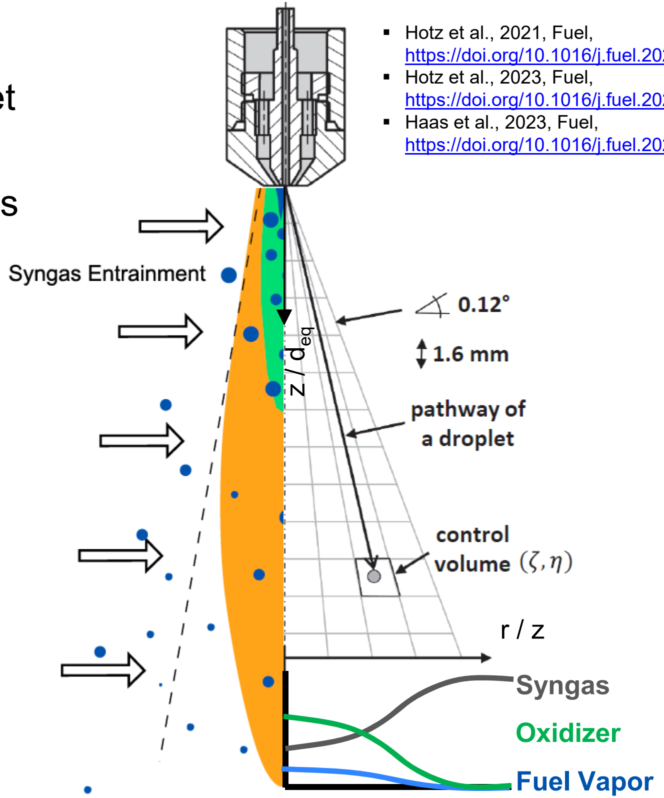
Model Principle

- Gas free jet theory expanded to 2-phase jets
- Coupling of mixing with droplet and reaction sub-models
- Independent variation of process parameters (spray properties, stoichiometry, …) and sub-models (evaporation, heterogeneous reaction, …)

► **Influence of sub-process models on fuel conversion**

► **Detailed process understanding**

- Hotz et al., 2021, Fuel, https://doi.org/10.1016/j.fuel.2021.121392
- Hotz et al., 2023, Fuel, https://doi.org/10.1016/j.fuel.2022.126912
- Haas et al., 2023, Fuel, https://doi.org/10.1016/j.fuel.2022.126572



Manuel Haas, Institute for Technical Chemistry, Department Gasification Technology, ITC vgt

Impact of Spray on Reaction Zone Structure?

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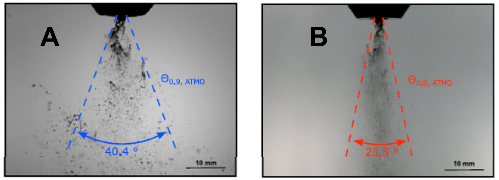
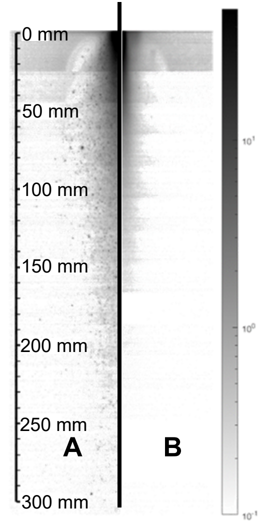
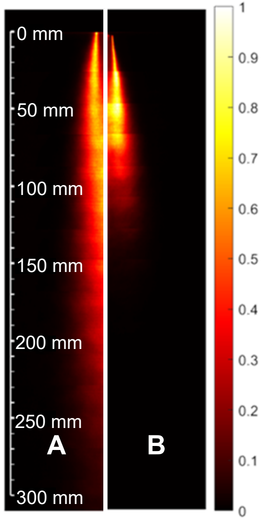
Ambient Spray Characterization



Fuel-Tracer-LIF Intensity / -



OH-LIF Intensity / -



Experimental and Model Investigation

- Experiments at bench-scale (REGA) using advanced optical diagnostics (OH-LIF, Fuel-Tracer-LIF, PDA)
- Sensitivity study using 2-Ph-FJM to separate influence of droplet size, spray angle and gas momentum

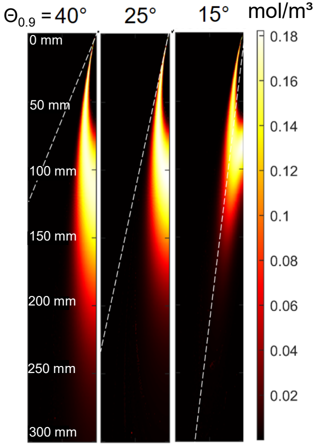
Results:

- Strong impact of spray and gas phase mixing on flame length and shape through local stoichiometry
- Fuel conversion in flame zone can be described and optimized using 2-Ph-FJM

► **Fundamental insight in sub-process interaction**

► **Application knowledge for burner development**

OH concentration (model)



- Haas et al., 2023, Fuel, https://doi.org/10.1016/j.fuel.2022.126572
- Haas et al., 2024, Chem. Eng. Sci., submitted
- Dammann 2023, PhD-Thesis

Influence of Slurry Droplets on Flame?

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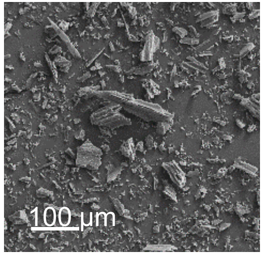
Biogenic Slurry Fuel

- 30 m-% beech-wood char, 70 m-% glycol
- $\dot{M}_{liq}$ = 12,7 kg/h
- $\dot{V}_{gas,N}$ = 7,5 m³/h
- T_{ad} = 1700 °C
- λ = 0,42

Char HK08a

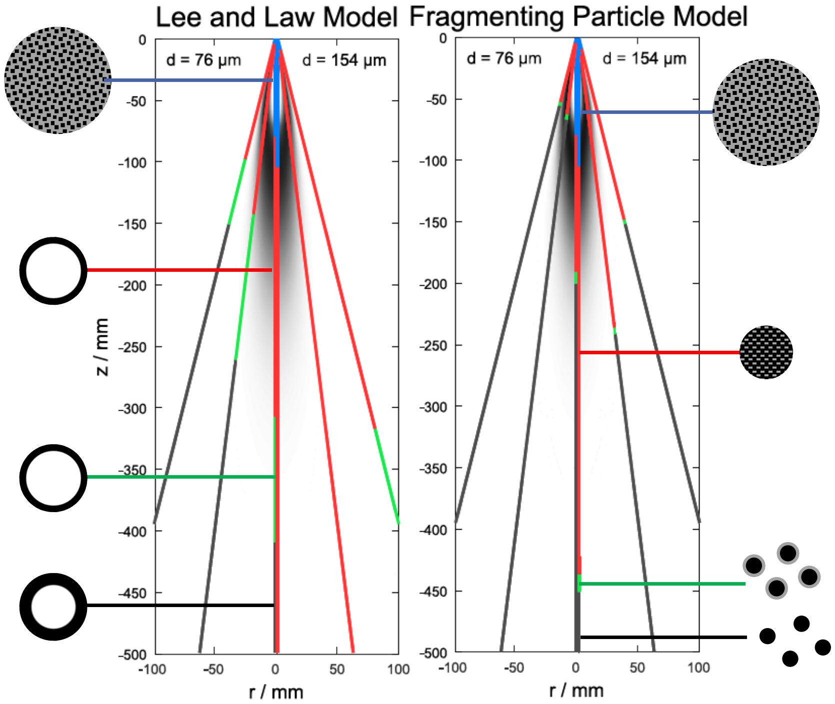


$D_{32,p}$ = 9 µm

Expansion of 2-Ph-FJM

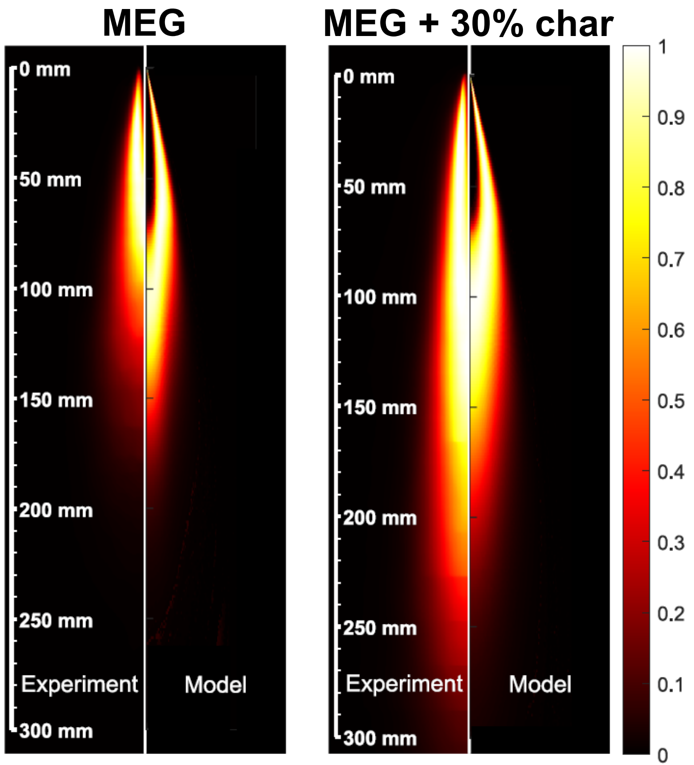
- Exchangeable slurry droplet models
- Coupling with gas phase by mass-, energy- and momentum balance
- In-house devolatilization and gasification kinetics

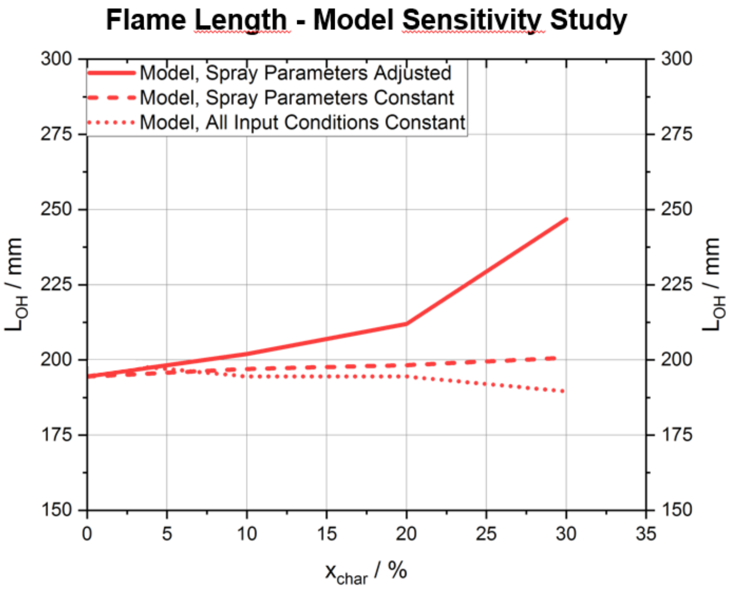
→ Investigate impact of slurry droplet model on flame and fuel conversion



Haas, 2025, PhD-Thesis

Slurry Gasification: Impact of Solid Content?





Haas, 2025, PhD-Thesis

→ Evaluate impact of single process parameters on flame and fuel conversion

Summary and Outlook

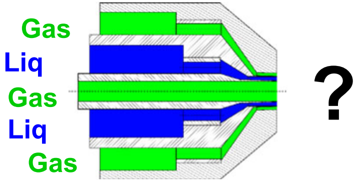
Summary

- **2-Phase Free-Jet Model: Computationally inexpensive tool to conduct parameter studies and compare sub-process models**
- Model applied to describe EFG slurry spray flame
- Experimental validation in 60 kW EFG plant
- FJM is able to explain effects observed in experiment

→ Valuable tool for burner development

Outlook

- Impact of burner concept on flame structure and soot formation?
- Influence of pressure on burner near processes?



Thank You for Your Attention!

Engler-Bunte Institute, Division of Fuel Technology (EBI-ceb)

Engler-Bunte-Ring 1,
76131 Karlsruhe

Institute for Technical Chemistry, Gasification Technology Department (ITC-vgt)

Hermann-von-Helmholtz-Platz 1,
76344 Eggenstein-Leopoldshafen

Entrained flow gasification: Impact of fuel spray distribution on reaction zone structure (Fuel, 2023)

Haas, Dammann, Fleck, Kolb

Two-phase free jet model of an atmospheric entrained flow gasifier (Fuel, 2021)

Hotz, Haas, Wachter, Fleck, Kolb