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Influence of Additive Sintering on Fine Particle Formation during Biomass Pulverised-Fuel Combustion

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Session: Alternative Fuels

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Outline

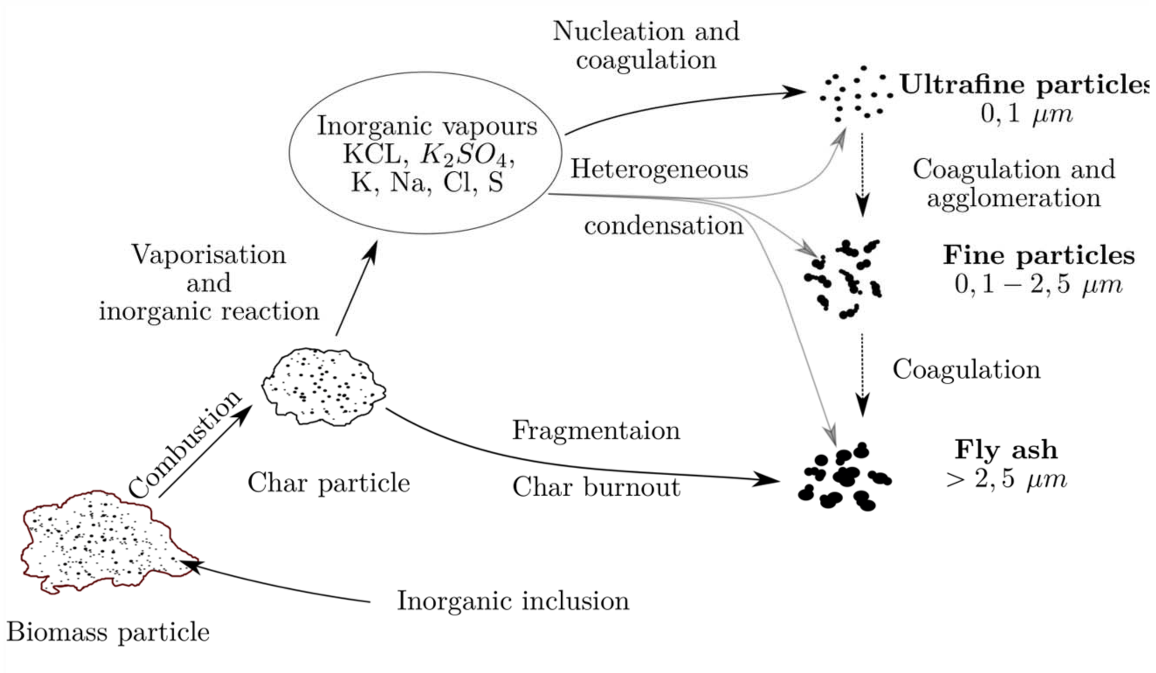
1. Motivation – Why Burning Biomass?
2. Introduction
3. Additives – Coal Fly Ash and Kaolin
4. Kaolin Sintering Experiments in Furnace Test rig
5. Pulverised-Fuel Combustion of Biomass with Additives at BoCTeR
6. Summary
7. Future Work

1. Motivation – Why Burning Biomass?

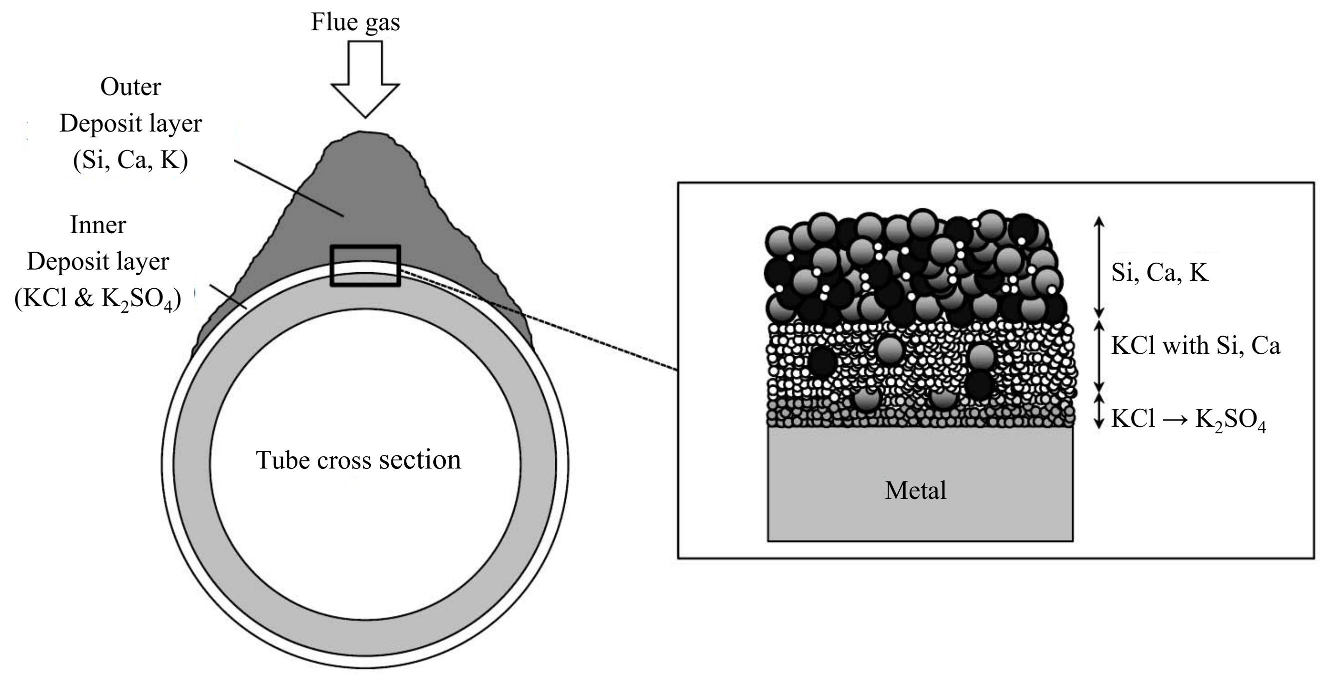
- „CO_2-neutral“ fuel for heat and power supply.
- Negtive Emissions possible using BECCS.
- Possibility to replace hard coal in chp plants (retrofitting).
- Which fuels? Wood, forestal residues, bark, straw and other agricultural residues.
- Advanatage of pulverized-fuel combustion are higher steam parameters and higher flexibility regarding load changes compared to fluidized-bed and grate firing.

2. Introduction
Fine Particles ⇒ Deposits (slagging/fouling) ⇒ Corrosion

- High alkali concentrations cause high fine particle concentrations.
- Large shares of alkalies and chlorine are causing ash-related challenges.
- Decreased efficiency due to deposits and higher corrosion rates.



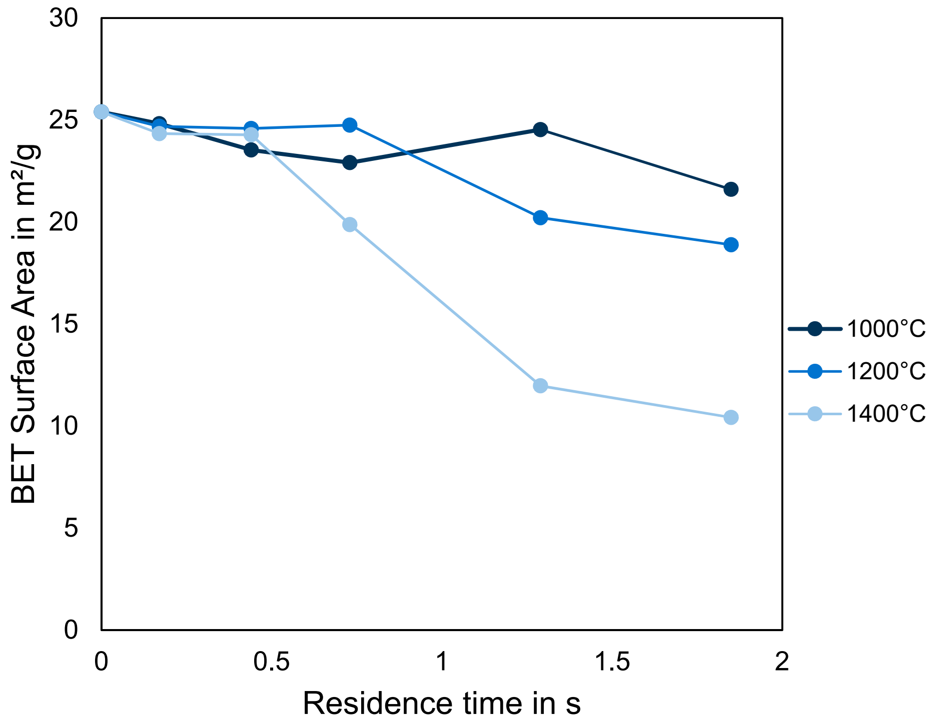
Adapted from: van Loo, Kaltschmitt and Frandsen



Adapted from Balan et al.

3. Additives – Coal Fly Ash and Kaolin

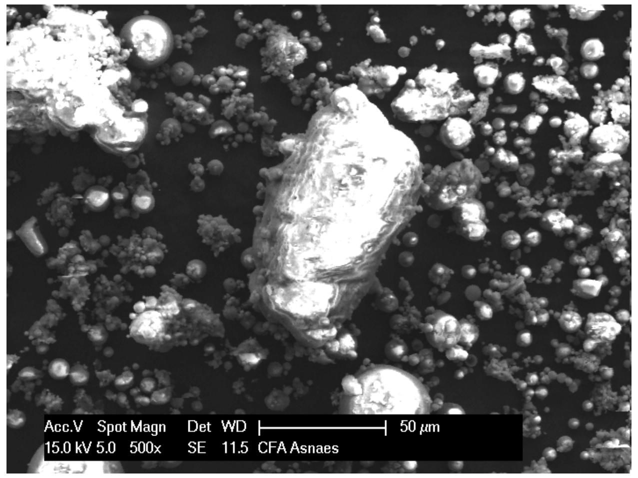
- Aluminium Silicate-based additives used for capturing gaseous Alkali species.
- Reduced number of fine particles and change in chemistry of fine particles.
- Capturing reactions of Alkalis:
- $Al_2O_3 \cdot 2\ SiO_2(s) + 2KCl + 2H_2O(g) \rightarrow K_2O \cdot Al_2O3 \cdot 2\ SiO_2(s) + 2\ HCl(g)$.
- The use of Coal fly ash as additive is already state of the art at industrial scale (Ørsted, Studstrup and Avedøre)
- Two Phase changes of Kaolinite: 450°C to Metakaolinite and from 1100°C change to Mullite.
- Sintering effects reduces the active surface area of the additives for capturing alkali species.



Measured BET Surface Area of Kaolin under entrained-flow conditions

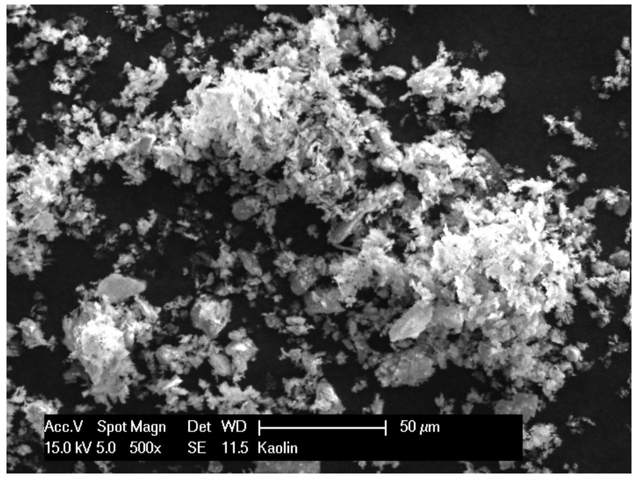
Adapted from Kerscher et. al

Additives – Coal Fly Ash and Kaolin



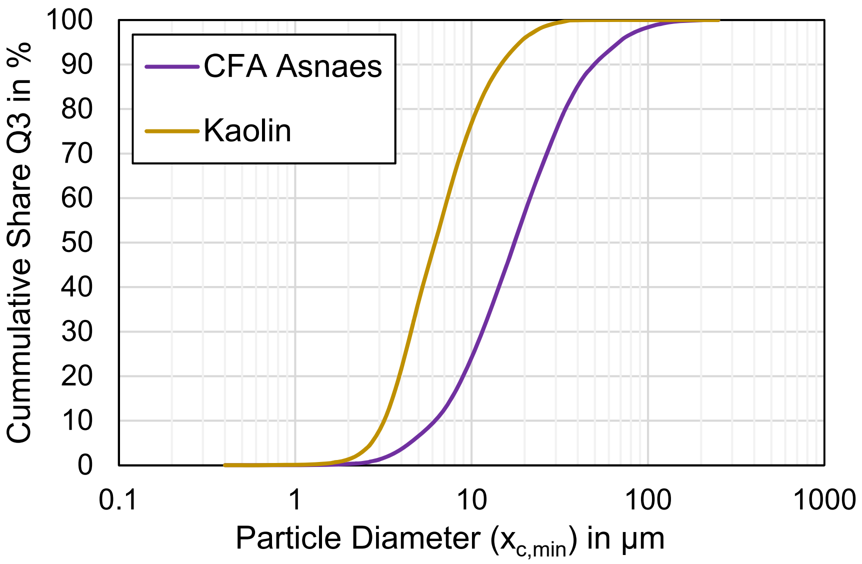
Coal Fly ash

BET Surface Area = 0.72 m^2/g



Kaolin

BET Surface Area = 10.84 m^2/g

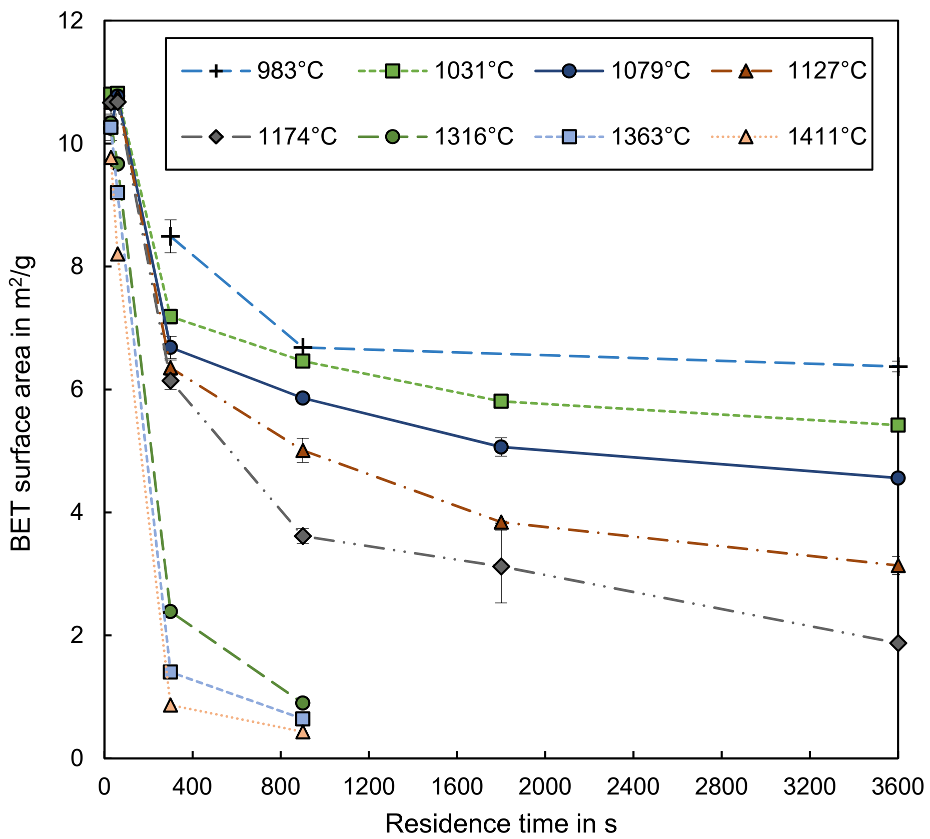


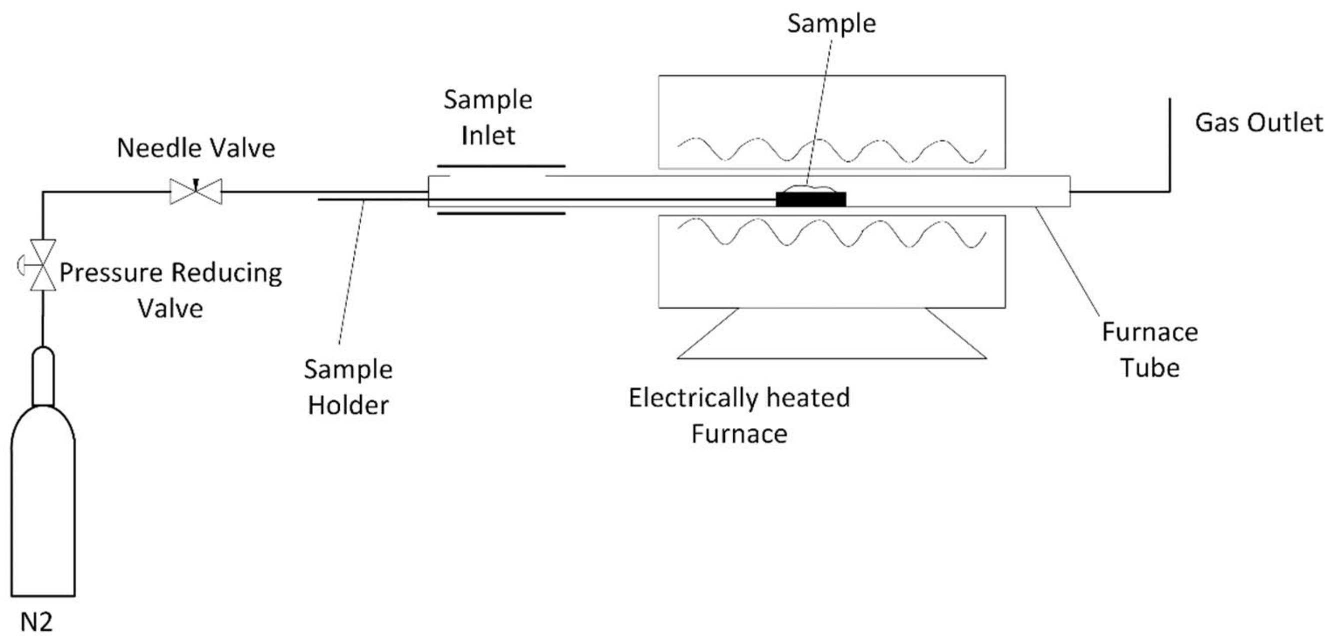
Analysis	Unit	Coal Fly Ash	Kaolin
Moisture	[wt.-% ar]	1.19	1.15
MgO	[wt.-% in ash]	1.29	1.64
Al_2O_3	[wt.-% in ash]	25.56	39.14
SiO_2	[wt.-% in ash]	51.12	40.18
SO_3	[wt.-% in ash]	0.75	0.02
K_2O	[wt.-% in ash]	1.12	2.80
TiO_2	[wt.-% in ash]	1.31	0.18
Fe_2O_3	[wt.-% in ash]	4.17	1.82
ZnO	[wt.-% in ash]	0.01	0.01
SrO	[wt.-% in ash]	0.01	0.06

	Coal Fly Ash	Kaolin
d_{10}	6.2 µm	3.2 µm
d_{50}	17.5 µm	6.2 µm
d_{90}	49.4 µm	14.7 µm

4. Kaolin Sintering Experiments in Furnace Test rig

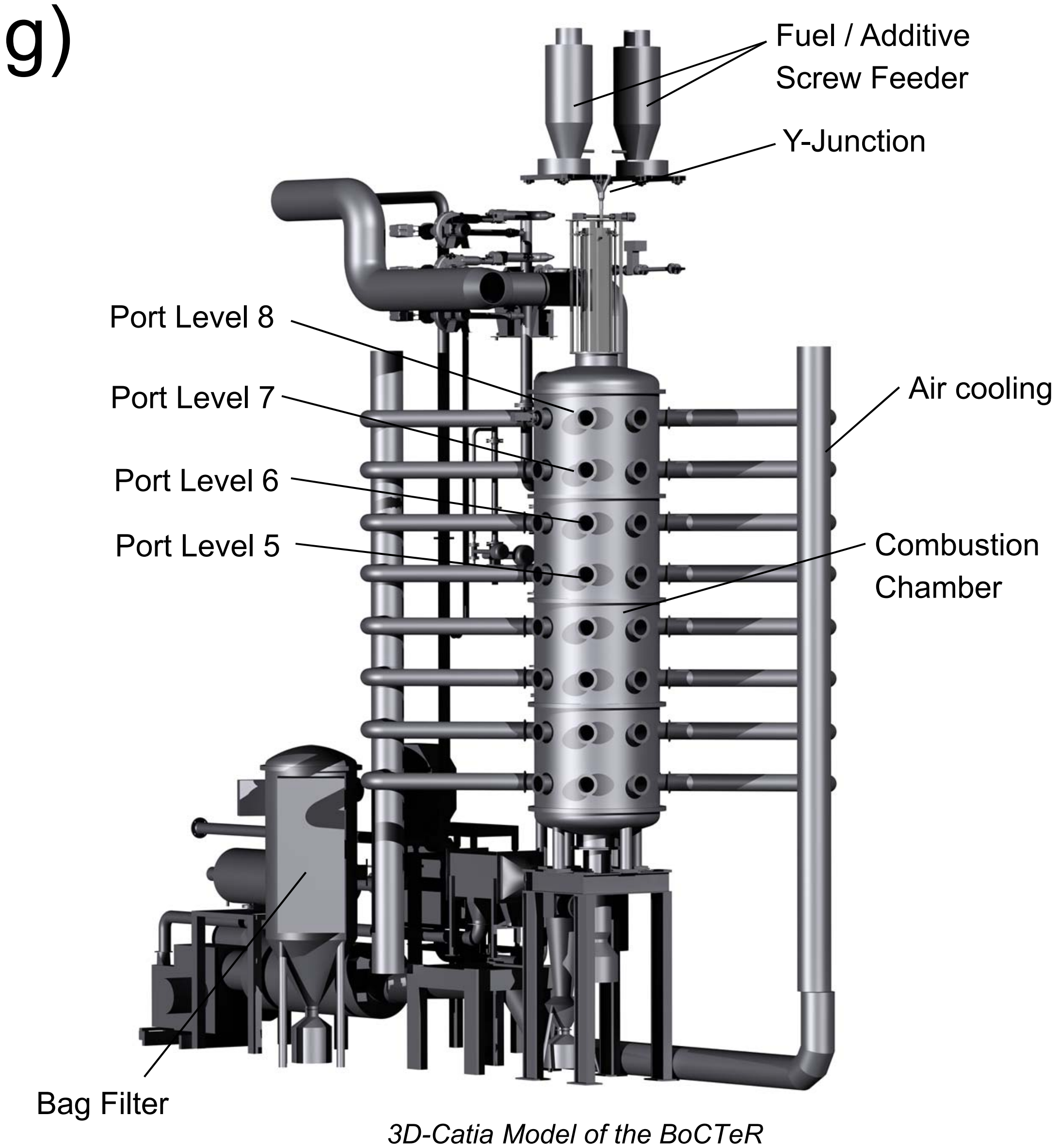
- Sintering of kaolin powder measured by BET analysis with nitrogen (3 g)
- Experiments with temperatures 980 – 1400 °C
- With residence times from 30 – 3600 s





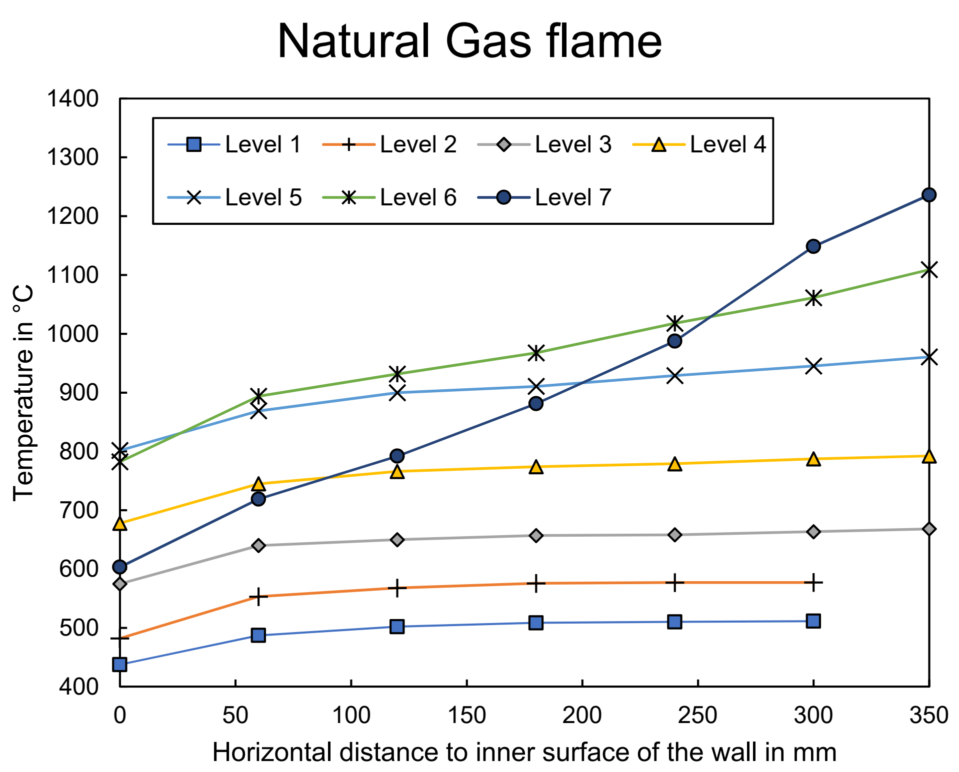
5. Pulverised-Fuel Combustion of Biomass with Additives at BoCTeR (**Bio**mass **C**ombustion **Te**st **R**ig)

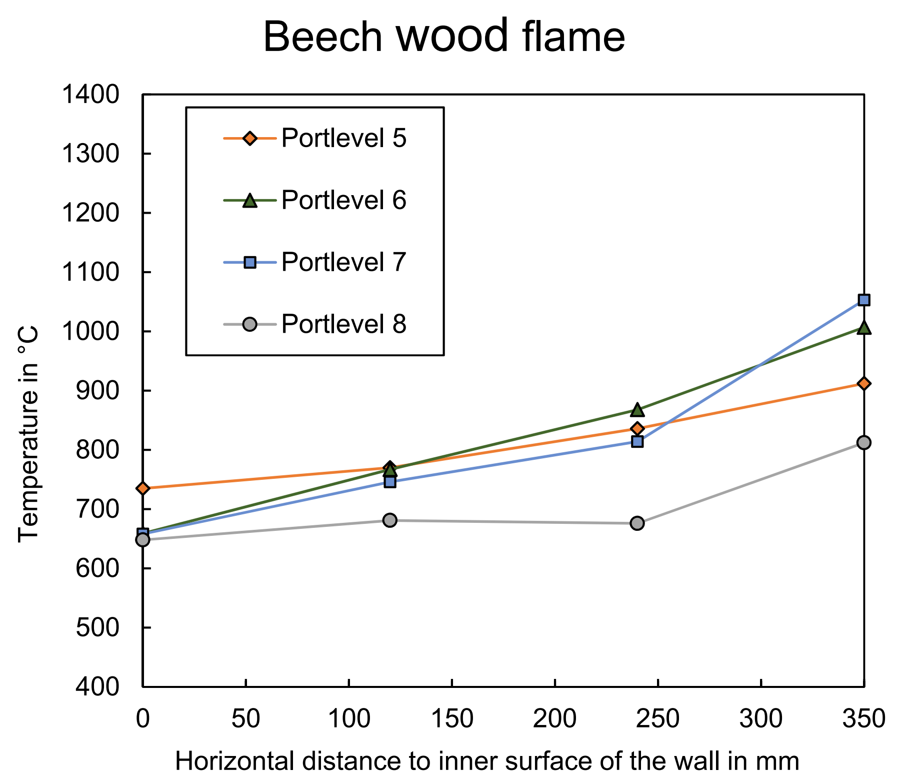
- Height of 4 m
- Inner diameter of 70 cm
- λ = 1.15 – 1.25
- Air-cooled Inner Walls
- 120 kW thermal Input
- Top-Down Swirl burner
- 8 Port levels with Access from four sites
- 50 cm axial distance between Port levels

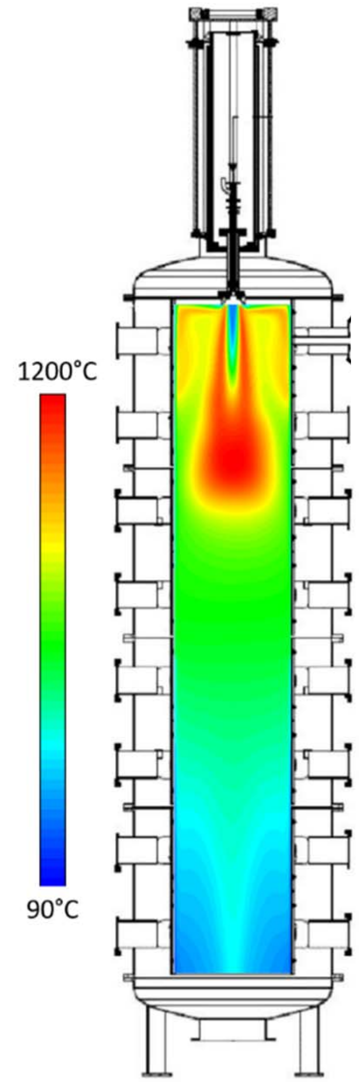


3D-Catia Model of the BoCTeR

Temperature Distribution in Combustion Chamber measured by IFRF-suction pyrometer (120 kW)

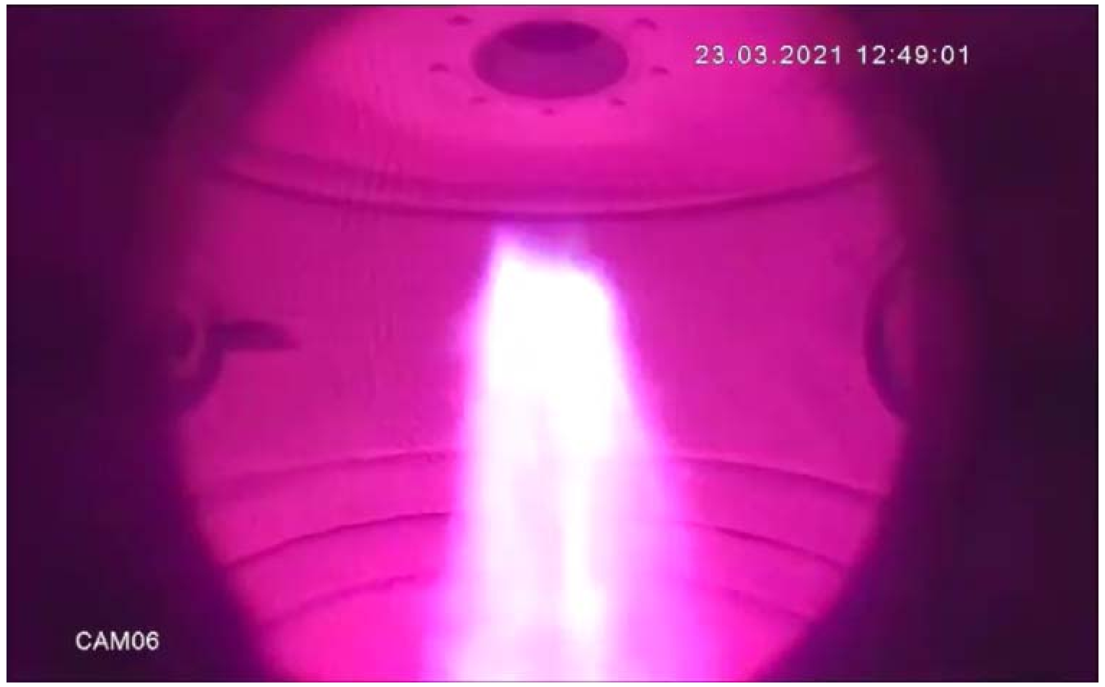


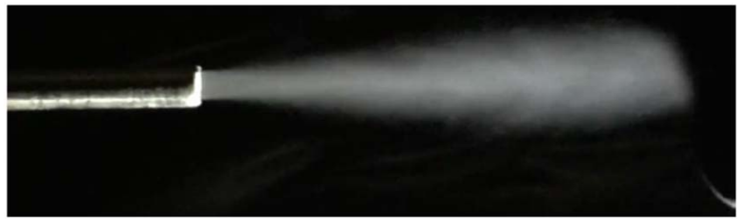




CFD Simulation of Temperature Distribution of pulverized-fuel combustion of bark, adapted from Niemelä

Gas flame without and with Kaolin Injection at Port Level 8

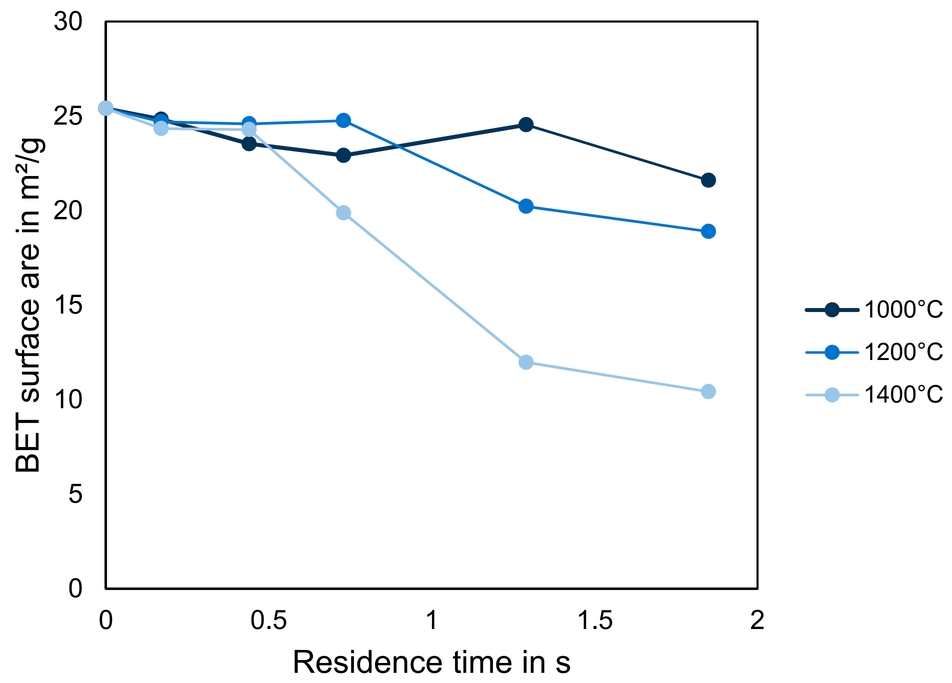


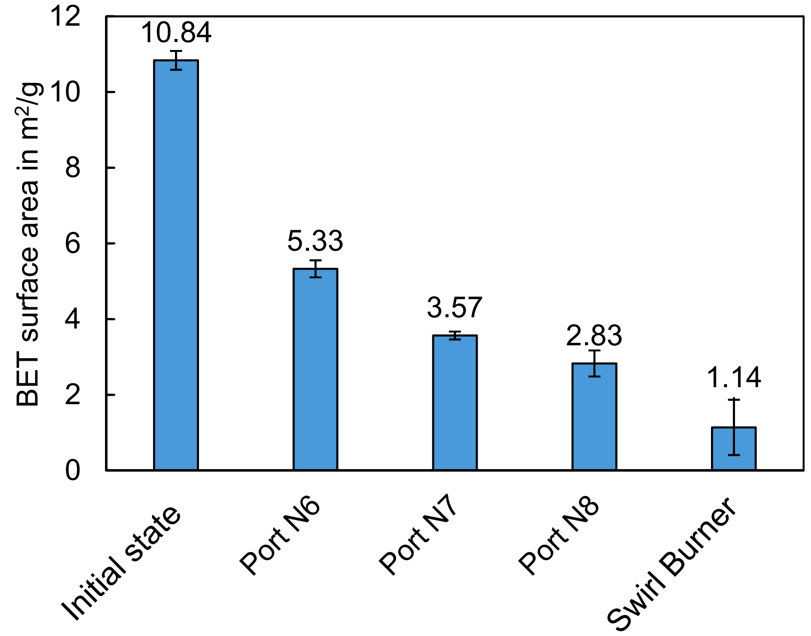


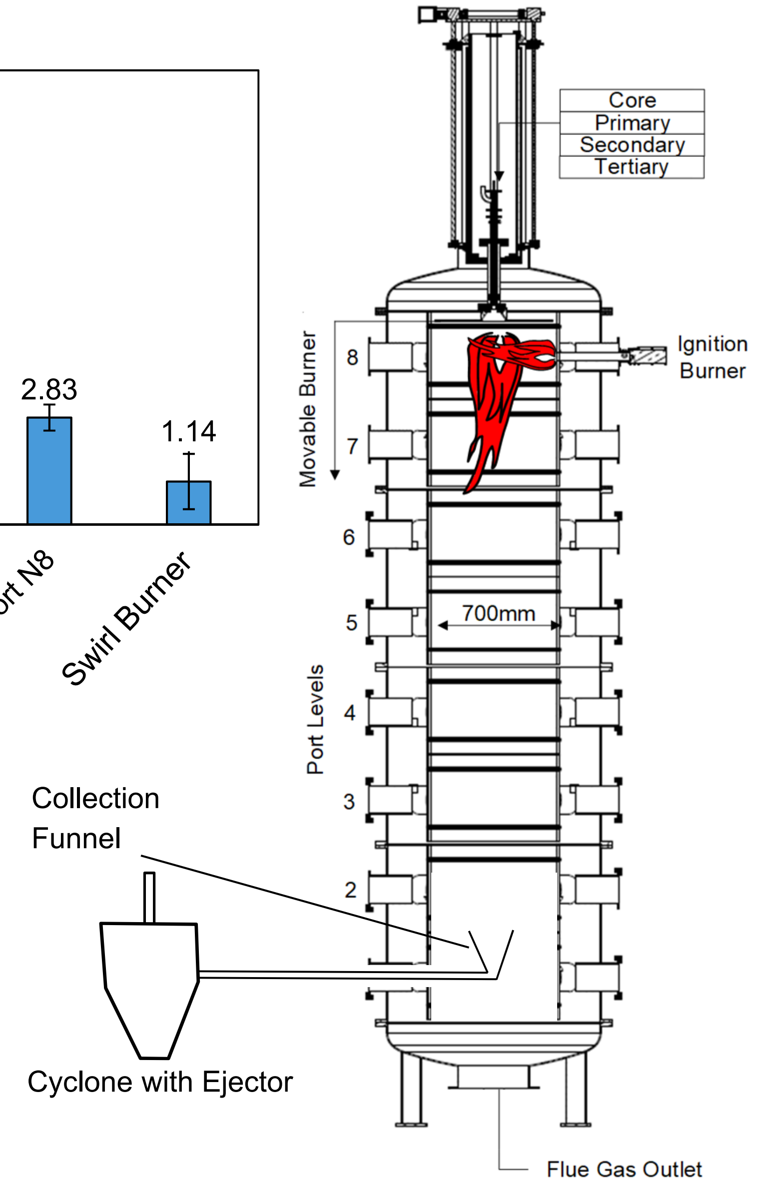
Kaolin Injection via Tube

Surface Area Development of Kaolin in Natural Gas Flame

- Collection funnel with cyclone and ejector installed at port level 1
- Collection of Kaolin samples during Injection through Burner and Port Levels 6, 7 and 8
- Clearly Sintering effects visible







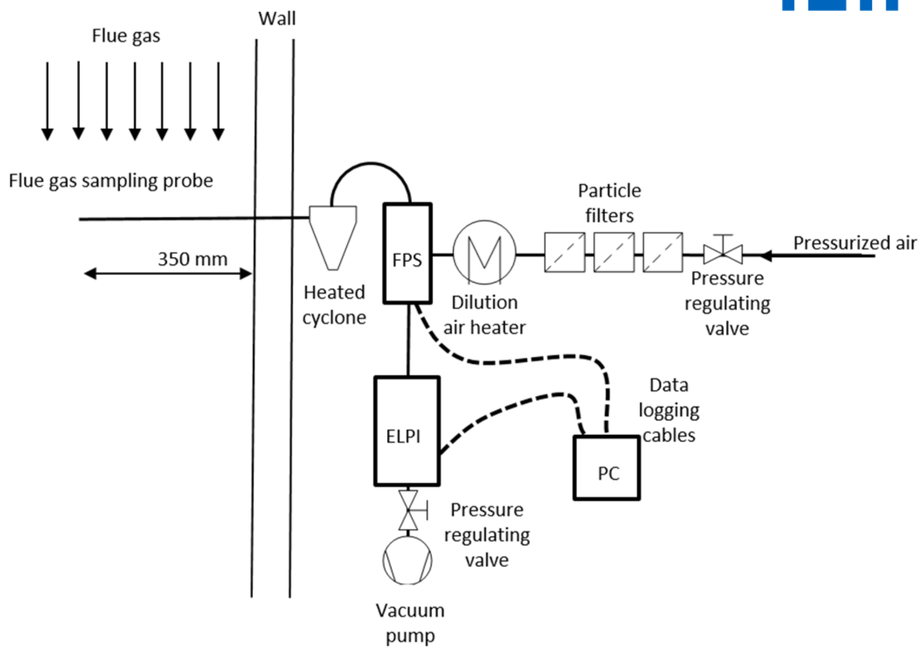
Beech Wood Properties

Analysis	Unit	Beech Wood
Moisture	[wt.-% ar]	6.01
Ash Content	[wt.-% ar]	1.01
Volatiles	[wt.-% ar]	78.61
LHV	[MJ/kg]	17.15
C	[wt.-% ar]	49.44
H	[wt.-% ar]	5.39
N	[wt.-% ar]	0.11
O	[wt.-% ar]	45.00
S	[wt.-% ar]	0.07
Cl	[wt.-% ar]	0.01
Al_2O_3	[wt.-% in ash]	2.16
CaO	[wt.-% in ash]	36.39
K_2O	[wt.-% in ash]	17.94
Na_2O	[wt.-% in ash]	0.97
SO_3	[wt.-% in ash]	3.32
P_2O_5	[wt.-% in ash]	2.66
SiO_2	[wt.-% in ash]	15.40

	Beech Wood
d_{10}	12.4 µm
d_{50}	43.6 µm
d_{90}	153.9 µm

Transition of Natural Gas Flame to Beech wood Flame (120 kW)

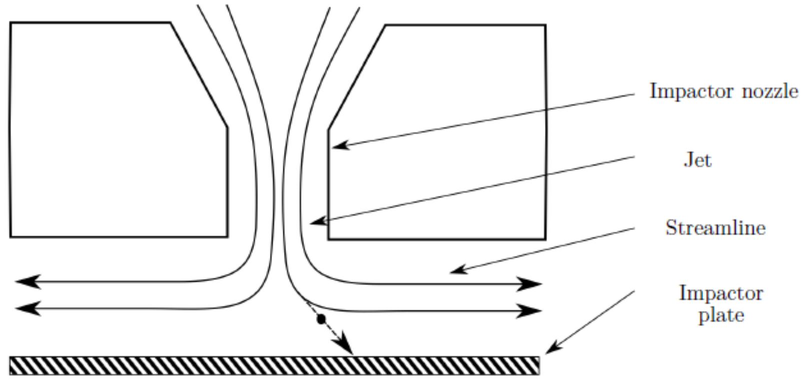
Fine Particle Measurements with ELPI



Fine Particle Sampling System at BoCTeR

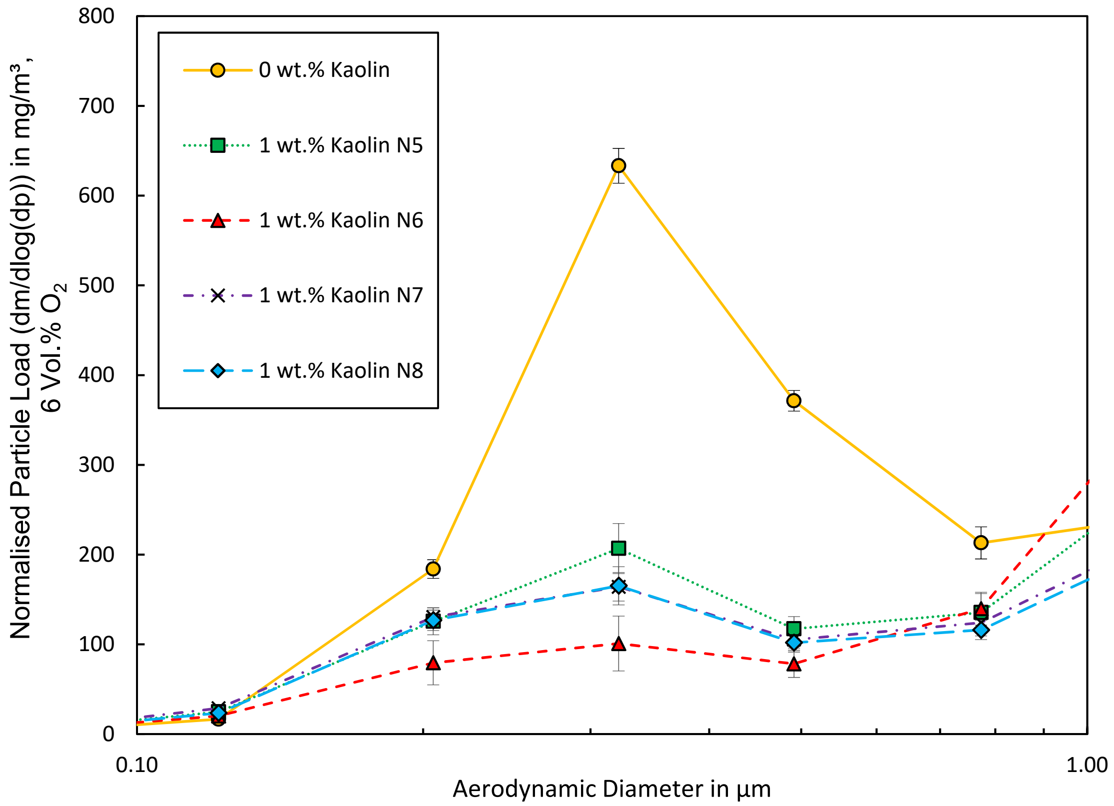
ELPI (Electrical Low Pressure Impactor)

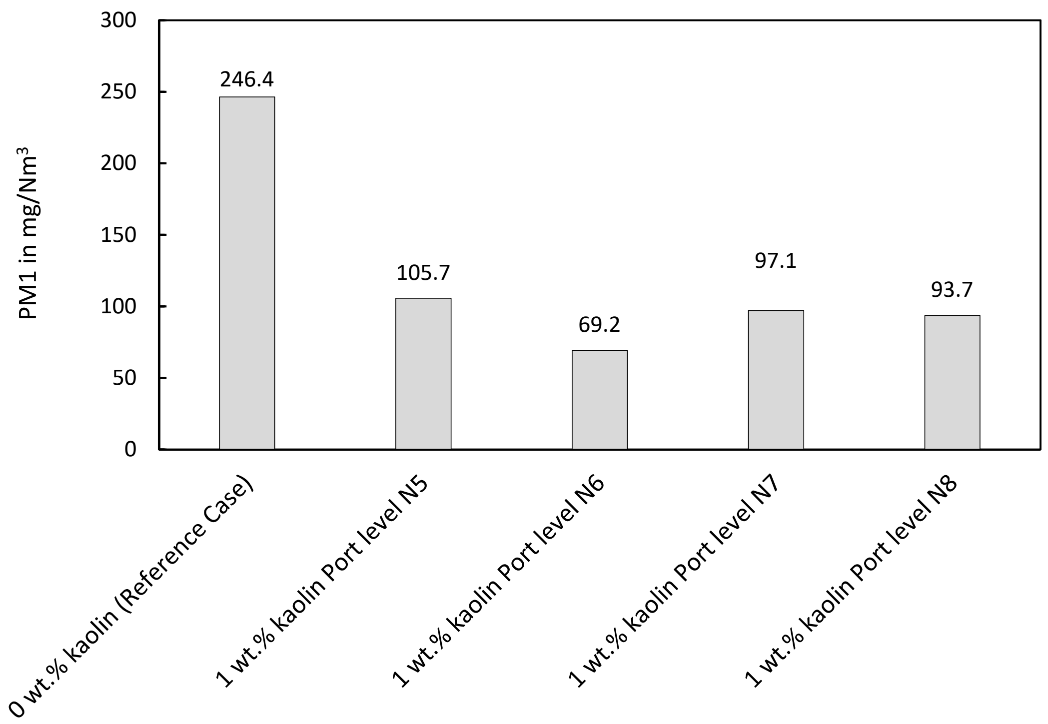
- Extraction of Flue gas with a sampling probe
- Removal of large fly ash particles > 10 µm with heated cyclone
- Dilution with Fine Particle Sampler System
- Classification and Detection of Particles in the Impactor Cascade of ELPI
- 12 Stages from 0.007 – 6 µm aerodynamic diameter
- Online Measurement possible



Impactor working principle adapted from Hinds et al.

Fine Particle Measurements with ELPI – Variation of Kaolin Injection Port





- Reference Case without Kaolin
- 1 wt.% Kaolin based on Fuel (dry/dry)
- Reduction of PM1 with minimum at port level 6
- Entrainment of kaolin particles detected by ELPI

6. Summary

- Kaolin as additive looses active surface area due to sintering in the boiler.
- Temperature and residence time are the important parameters for sintering.
- Experiments showed that the kaolin injection position important for the alkali capture efficiency.
- Potential for saving kaolin as additive when using the optimum temperature window for injection.

7. Future Work

- Evaluation of Experiments with Injection of Kaolin via the Swirl burner under same conditions.
- Validation of results in larger combustion units necessary.

Supported by the
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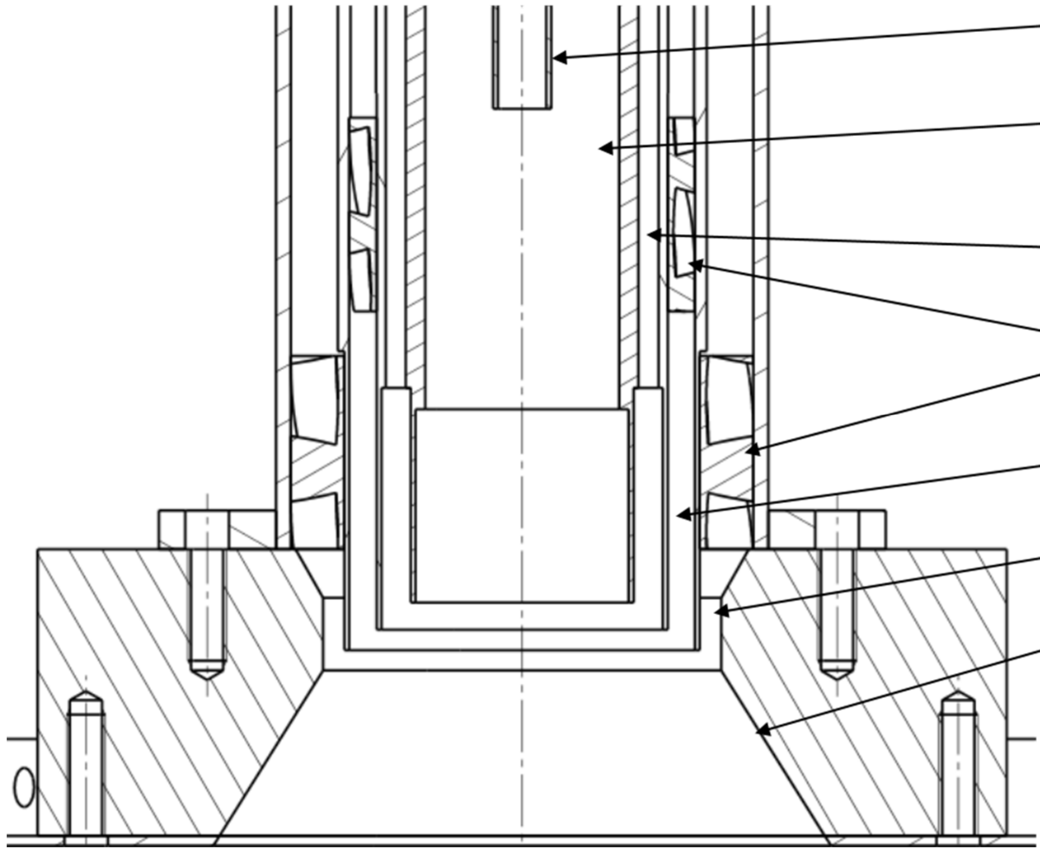
Thank you for the attention!

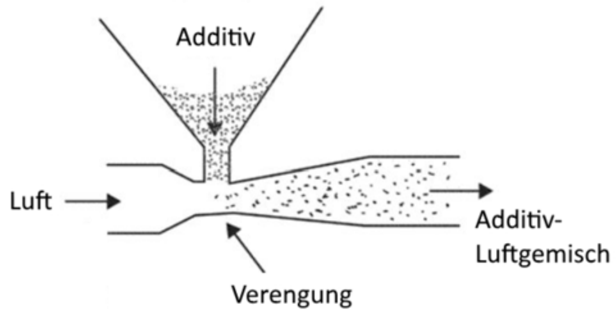
Additional Slides

Swirl Burner Design

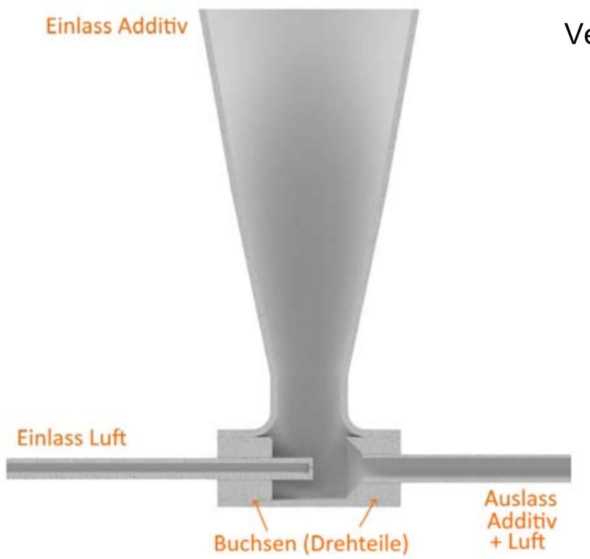


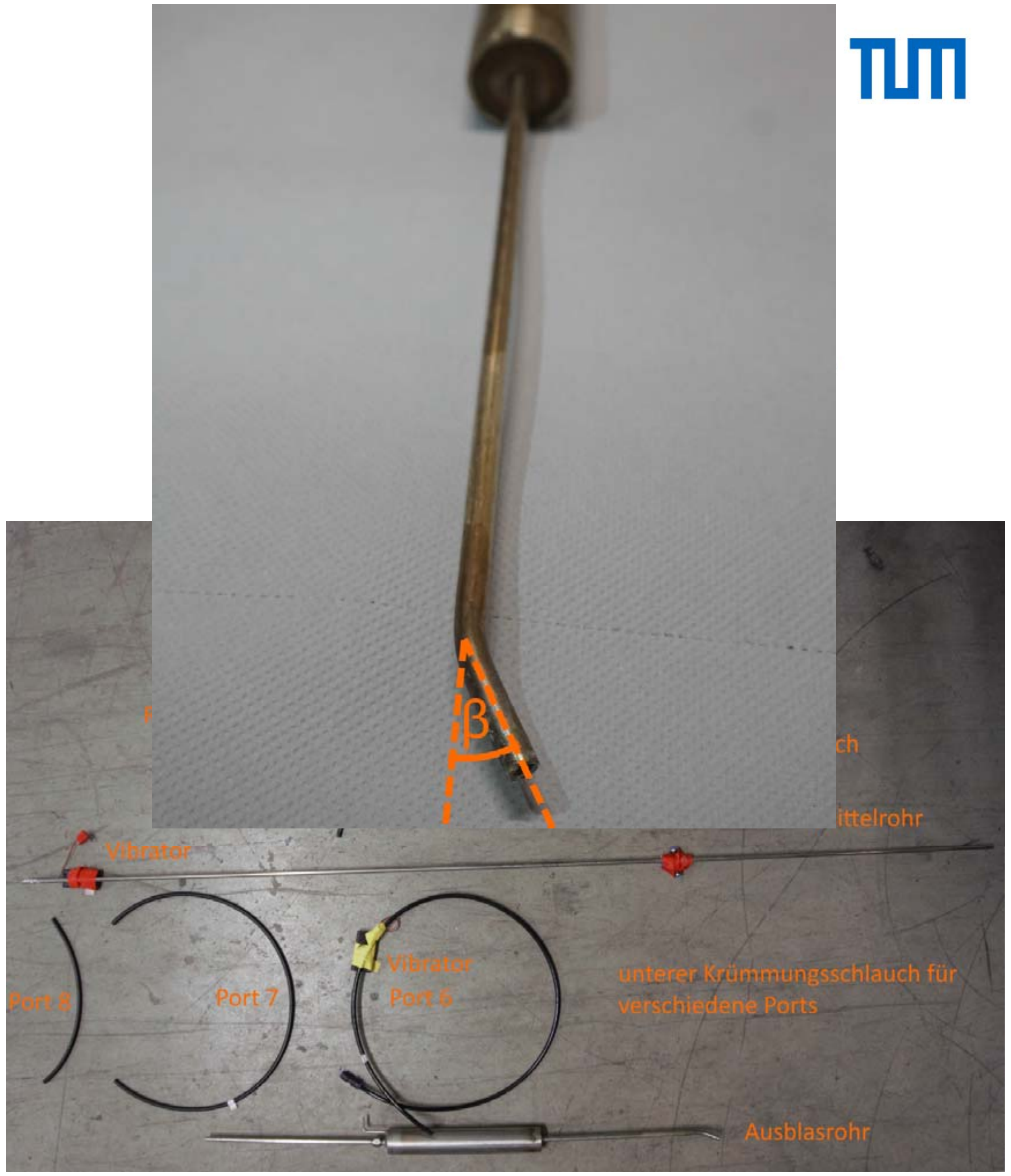
Injection System

- Gravimetric Dobble screwfeeder for dosage of kaolin powder
- Injection tube which is tangentially bent into swirl direction of burner



Venturi-Zerstäuber adaptiert von Mills et. al 2009





Source: Coperion K-Tron

Venturi Zerstäuber