Flexible use of biomass on PF power plants

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Background: The use of biomass for power production in Denmark

- Initial development of straw fired grate power plants around 1990
- Commercial operation: Co-firing straw (up to 20 %) and coal - Studstrup 1999
- Suspension firing of wood (with oil or coal ash) Avedøreværket Unit 2 2001 up to 800 MW_{th}
- Spring 2017: Ørsted announces that they will remove all coal from power production by 2023

Comparison of properties of coal and wood – Important for PF power plant use

Changes in fuel properties when going from coal to Wood:

- Can not be stored outside – (pellets disintegrate)
- More difficult to grind – larger particles
- Have lower volumetric heating value
- Have lower ash content rich in Cl and K
- Do have a higher fraction of volatiles

Specific conditions of PF boilers compared to fluid bed or grate boilers:

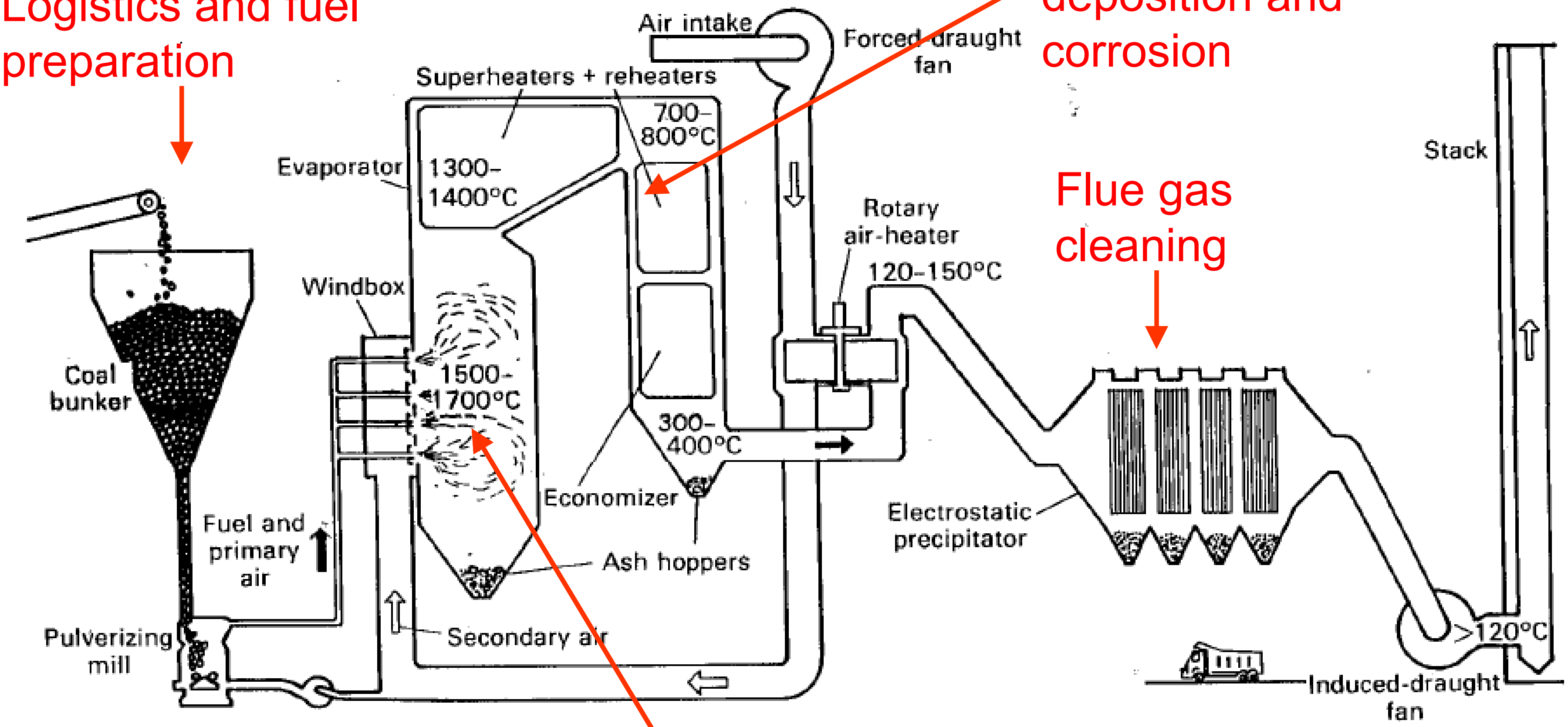
- High temperatures (up to 1600ºC) and short residence times (~5 s)
- Fuel – pelletized wood is needed
- Relatively high electrical efficiency

Converting a pulverized fuel power plant boiler from coal to biomass firing

Logistics and fuel preparation

Boiler ash deposition and corrosion

Flue gas cleaning

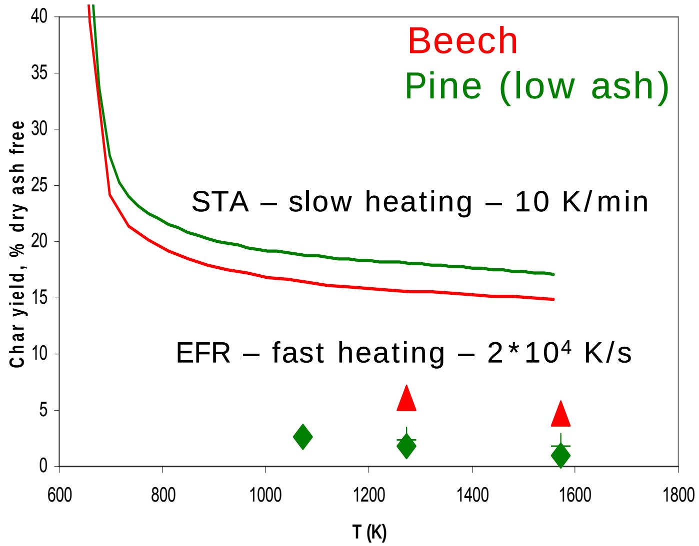


Combustion
Ash formation

Residual product utilization

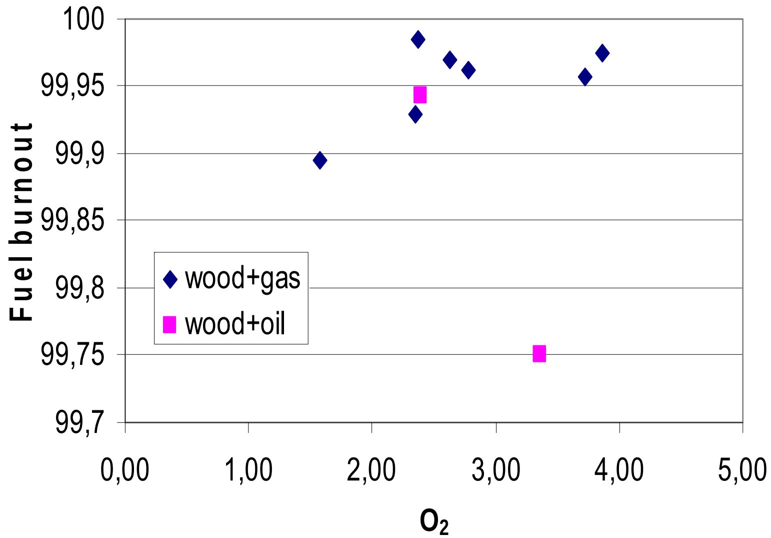
Background: Some previous research results

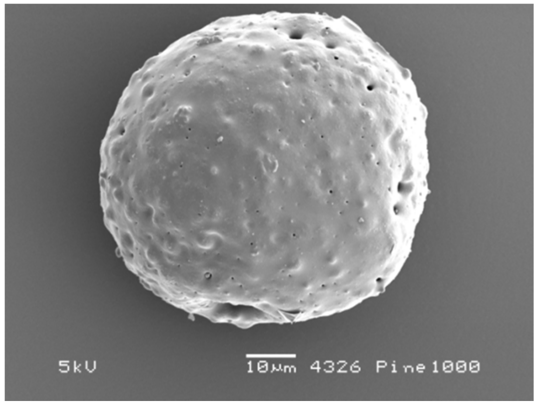
How can 1.5 mm wood particle be combusted: Wood char yield and burnout



Char yield

Burnout (full-scale)

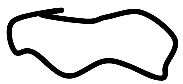




Pine char
(fast heating)

Background - The ash formation process

Fuel particles



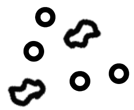
Ash forming elements in the biomass particle:

- Ionic elements
- Ash forming elements bound to the organic matrix
- Included minerals
- Excluded minerals (often soil)

Ash In furnace chamber above 1000° C

Gas phase release: Rich in elements of K, Cl, S, P, (Na):
HCl, SO_2, K_2CO_3, KOH, KCl, K_2SO_4

Residual ash: Condensed phase ash particles



Ash during the cooling process

Gas reactions: Sulfation:
$KCl+H_2O+SO_2 – K_2SO_4$ + …

Heterogeneous reactions EG. K reacts with Si rich species

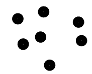
Physical processes:

- Heterogeneous and homogeneous condensation leading to aerosol formation
- Solidification of melted ash species
- Agglomeration

Exit flue gas ash species

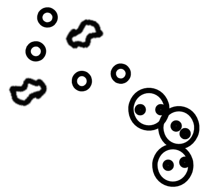
Gas phase species
HCl. SO_2

Aerosol particles, less than 1µm



Aerosols typically rich in the elements: K, Cl, S

Ash particles, larger than 1µm



Ash particles rich in Si and Ca with aerosol particles on the surface

Combustion process

Deposit formation on boiler walls

Project overview - Flexible use of biomass on PF power plants

Project duration: 2014 – 2018

Project funding: EUDP, Ørsted Bioenergy & Thermal Power A/S, DTU

Project size: Approximately 1.4 mill euro

Education of three PhD students is included

Project overview - Flexible use of biomass on PF power plants

Project objectives:

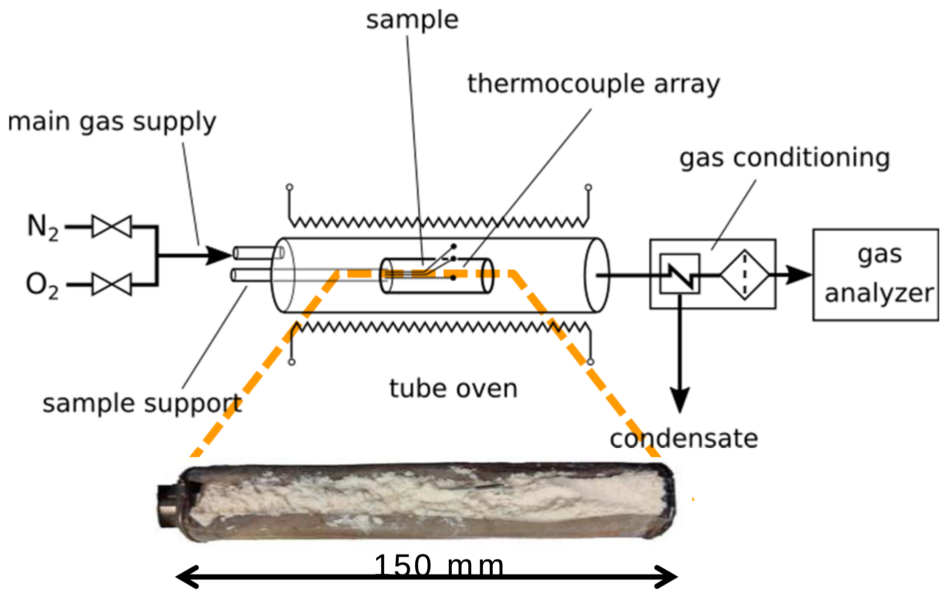
- To support an efficient and fast conversion of pulverized coal-fired power plants boilers to biomass
- To investigate key issues that insures high fuel flexibility, boiler availability and high electrical efficiency, when biomass is used as fuel on pulverised fired power plants

Project content:

- WP1. Prediction of boiler deposit formation - Fundamental data needed for deposit modelling.
- WP2.Using coal ash and other additives – Optimization of biomass and coal ash firing.
- WP3. Optimization of efficient mill operation – low temperature biomass particle ignition. Work packed leader.

WP3: Ignition in mills; ...-2018

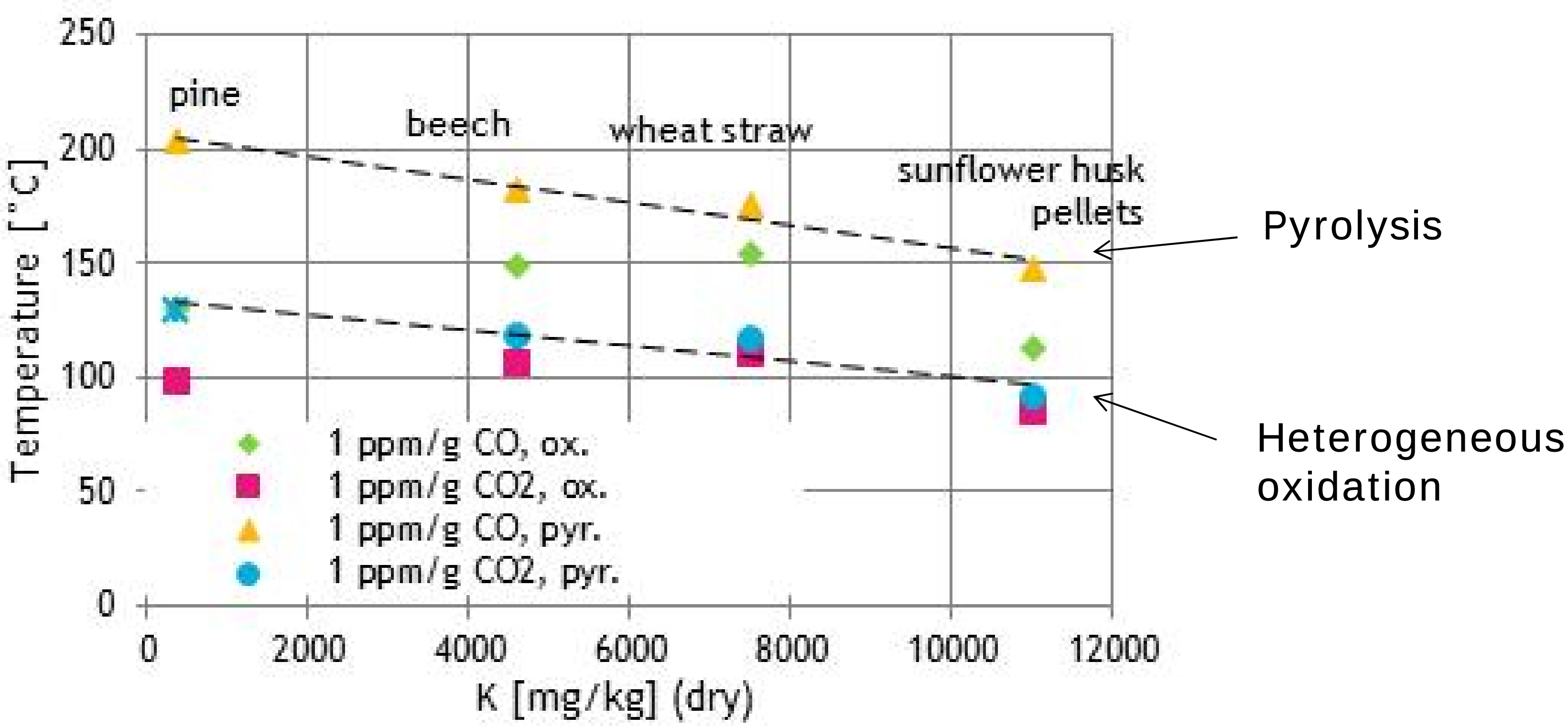
Fixed bed experiments



Objectives:
- Identifying ignition mechanisms of biomass at low temperatures
- Evaluating influences of fuel type and process parameters

Activities:
- Fixed bed experiments
- TGA experiments – pyrolysis conditions / oxidation
- Modelling

Fixed bed experiments - Onset of Reaction

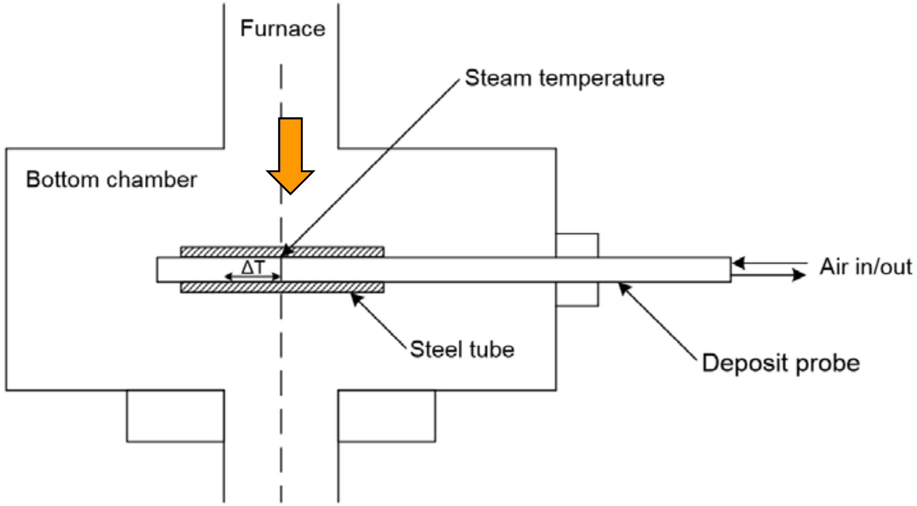


- Initial oxidation release at much lower temperatures (90 – 130ºC) than pyrolysis (150 – 200ºC)
- Presence of mineral matter and extractives possibly enhance ignition.
- Of the typical biomass constituents, lignin appears most reactive.
- Project is to some extent a detective story

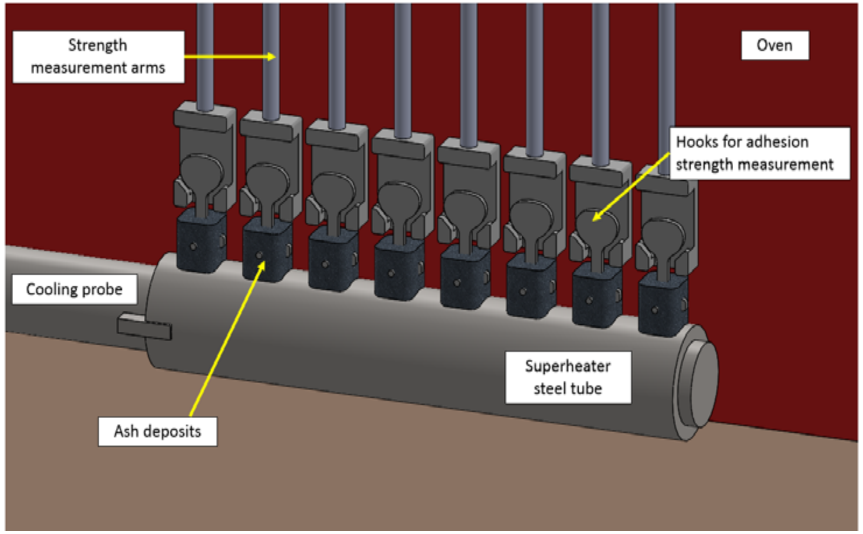
WP1: Fundamental studies for deposit modeling -

- Study on deposit formation – ash particle sticking propensity
- Fundamental data on deposit adherence
- Modeling of deposit formation and removal

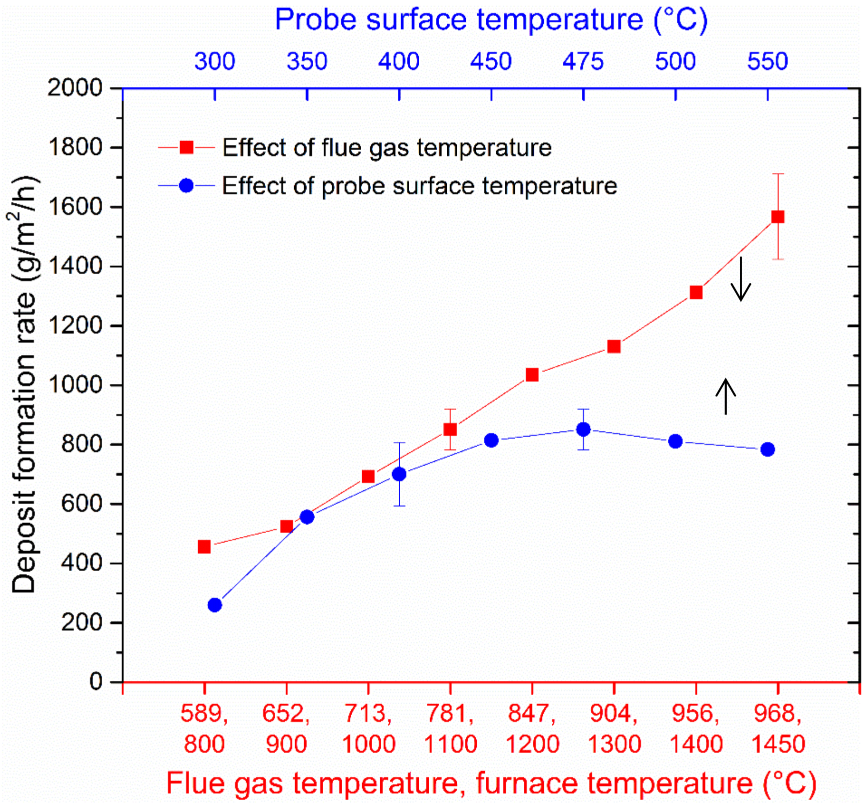
Deposit formation: Ash particle deposits formation EFR probe tests

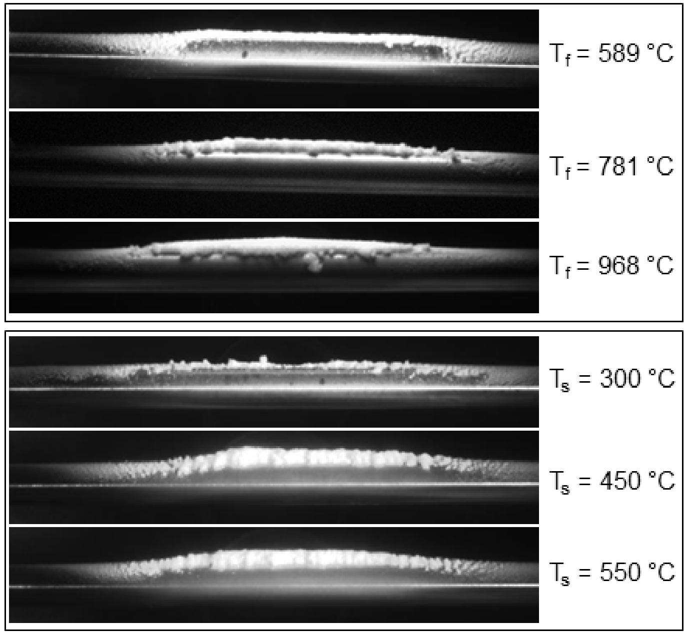


Deposit removal: Oven for ash adherence strength tests



Deposit formation: $K_2Si_4O_9$ particles impacting on probe - Effect of temperature



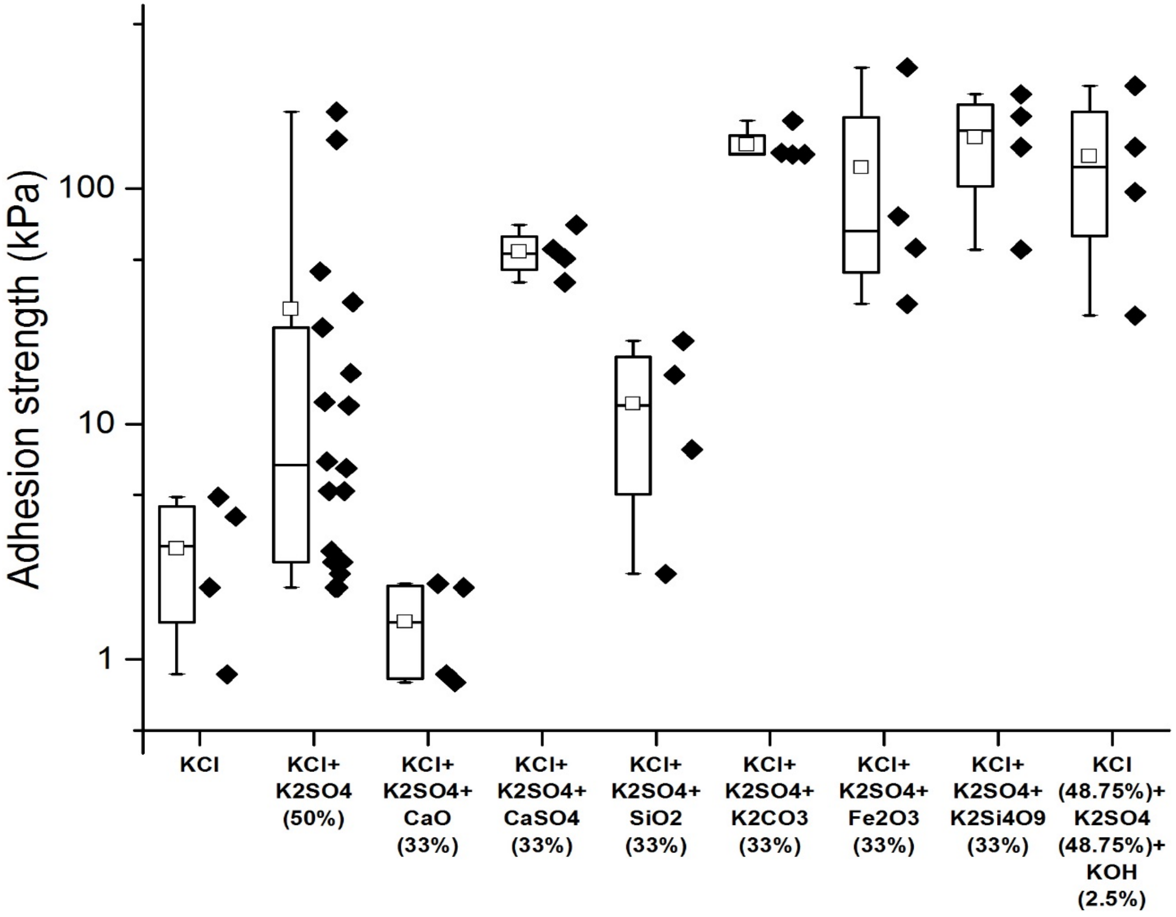


T_f = flue gas temperature, T_s = steam temperature

- Increasing flue gas temperature → decreasing particle viscosity → stickier particles
- Increasing probe surface temperature → decreasing viscosity of deposit surface → stickier deposit surface

*Standard conditions

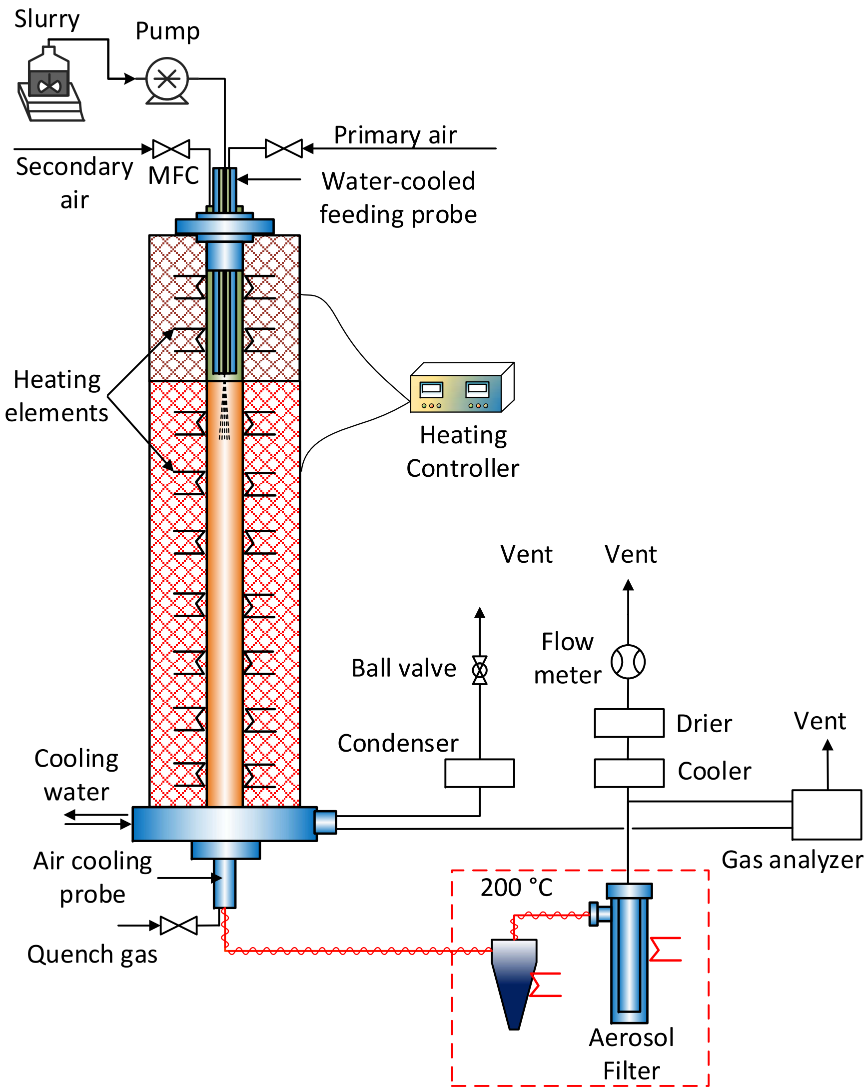
Deposit removal: Laboratory study: Adherence strength of different ash species on boiler tubes



- Sulphation → Increased strength
- Inert compounds with high melting point → decreased strength
- Compounds which increase melt fraction → increased strength

Deposits sintered at 650° C for 4 hours, measured at 600° C, steels pre-oxidized for 24 hours. All compositions in wt %

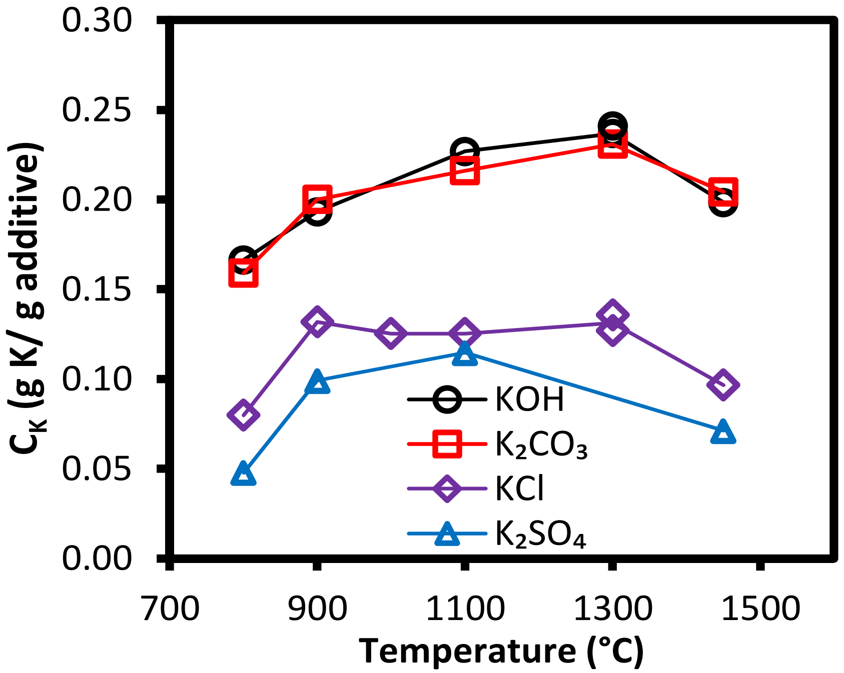
WP2: Use of additives to reduce bio-ash induced problems



- EFR based studies of the reaction between alkali salts and kaolin
- EFR based studies on the reaction between gas phase alkali and coal ash additives
- Modeling: Equilibrium predictions and particle conversion model

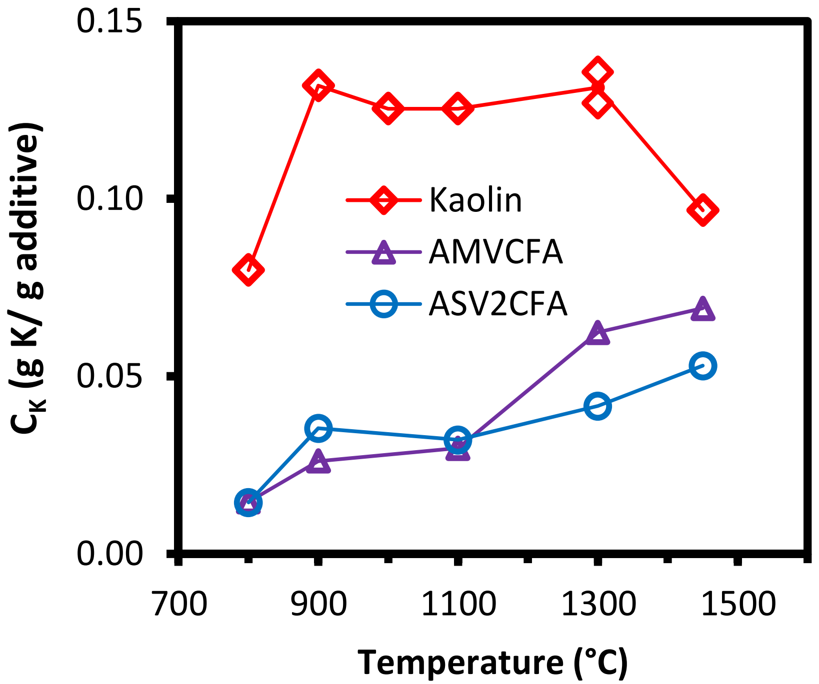
Use of additives to reduce bio-ash induced problems

Reaction of kaolin with different gas phase potassium salts – influence of temperature



- Different Si/Al/k species are formed when different salts are present

Coal ash and kaolin reaction with KCl – influence of temperature



- Indication: coal ash melting properties influence K capture

The main lessons learned – This project

- We have improved our capability to understand and predict both ash formation and ash removal
- Improved understanding of additive behavior and provision of recommendations for optimal additive use
- Still some way before biomass ignition well predicted

The main lessons learned – About PF firing

- Focus areas when converting from coal to biomass: sustainable wood pellets supplies, fuel storage, milling, burners for biomass particle combustion, handling deposit formation and corrosion, operation of de-NOx process, deposal of residual products.
- Optimization potential: Prevention of storage and mill fires, improve burners (larger fuel span), manage corrosion and increase electrical efficiency, optimize additive use, improved SCR catalysts.

Status of the biomass PF firing technology

- A relatively mature technology today
- Most attractive if existing PF plants are available and that a high electrical efficiency is wanted
- Can provide a sustainable supplement and electrical load adaption supplement to a power system with high wind and solar contributions

Main challenges (research areas):

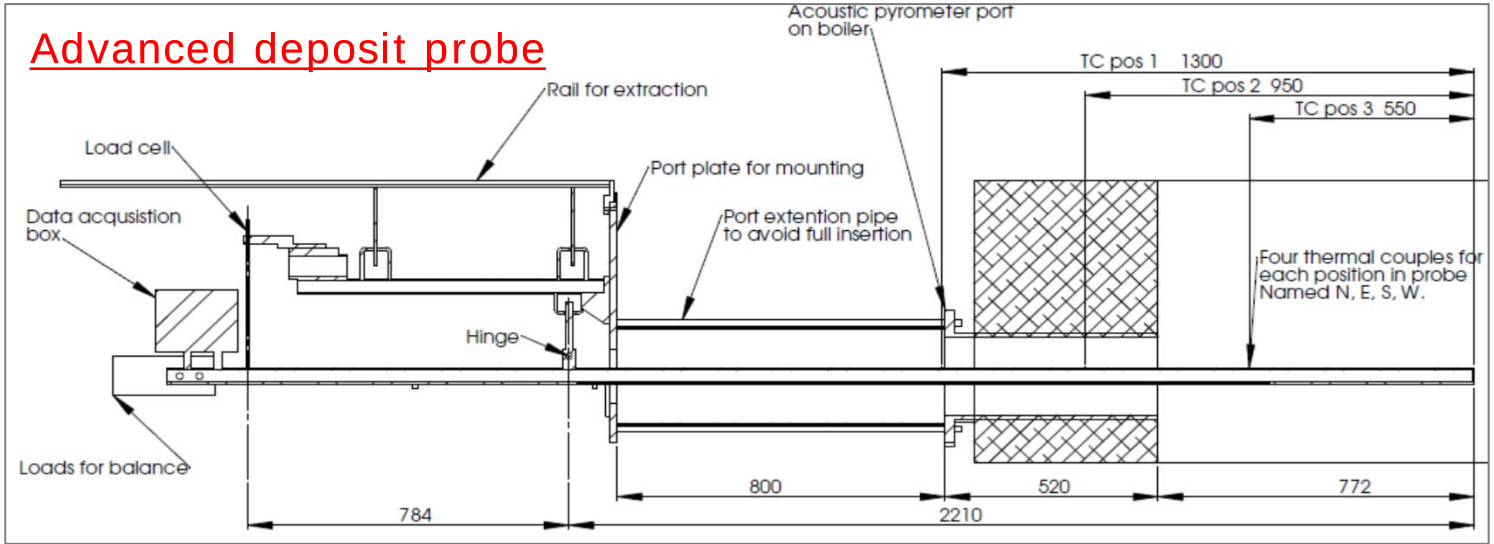
- Ensure sustainable wood pellets supplies
- Application of a broader fuel spectrum
- Prevent fires during biomass storage
- Prevent ignition in mills and provide efficiently small particles to the flame
- Understand the particle combustion process – to make optimal burner design possible
- Understand the ash induced issues: Ash formation, deposit formation, corrosion, de-activation of SCR de-NOx catalysts
- Understand the use and optimization of additives and provision of alternative additives.

EU funded project: Bioefficiency: Highly-efficient biomass CHP plants by handling ash-related problems

Activities planned (DTU)

- Full scale boiler probe measurements at PF power plants: Avedøre and Studstrup
- Lab Fly ash formation study – on EFR
- Development of biomass fly ash formation model

Advanced deposit probe



- Participants: TUM, Ørsted, DTU – VTT, VAL, ABO, NTUA, ECN, MHPSE, LAB, MET
- Duration: 2016 - 2019

Thank you for the attention