Fluidized bed particle layer formation in thermochemical conversion of biomass

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  - LTU: H Hi, A Grimm, X Ji, T Hannl, G Häggström, A Validazeh
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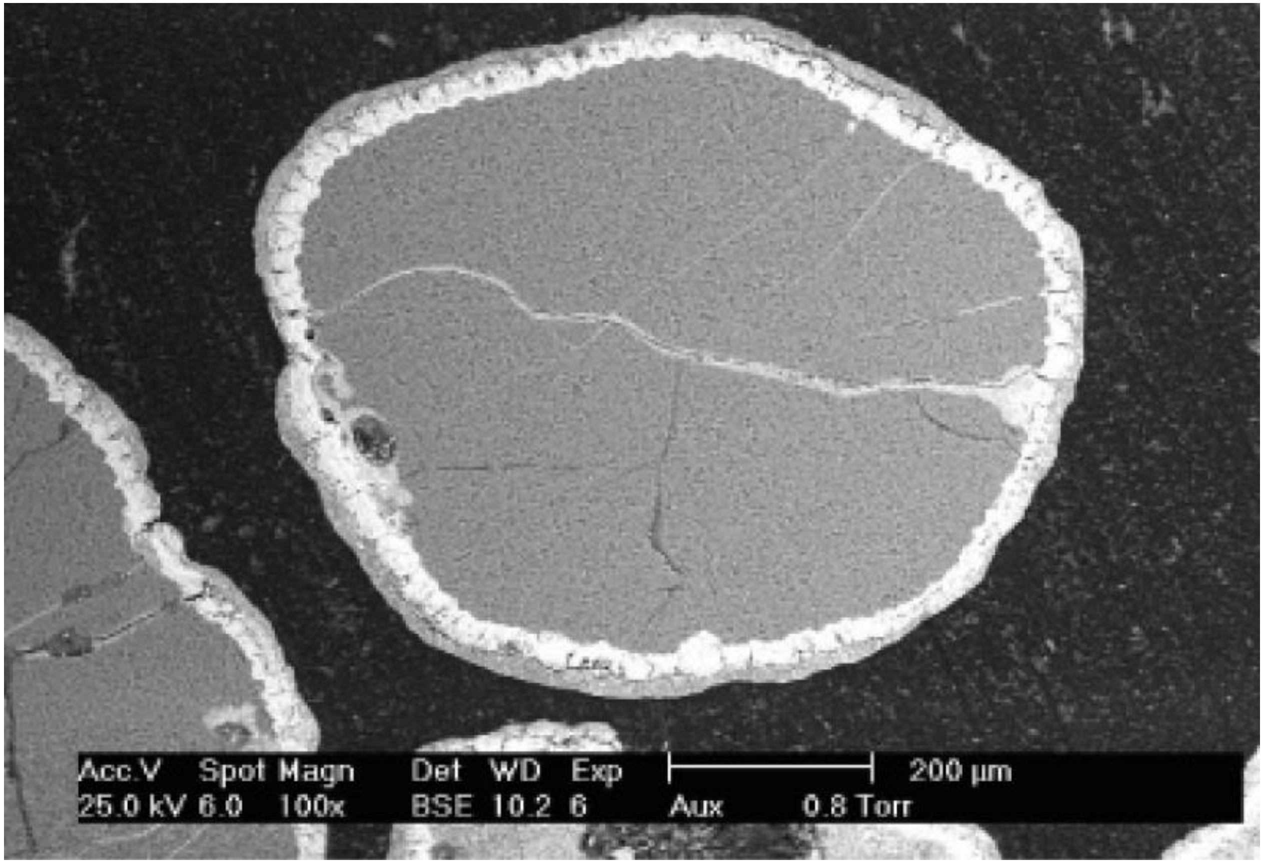
Outline of this presentation

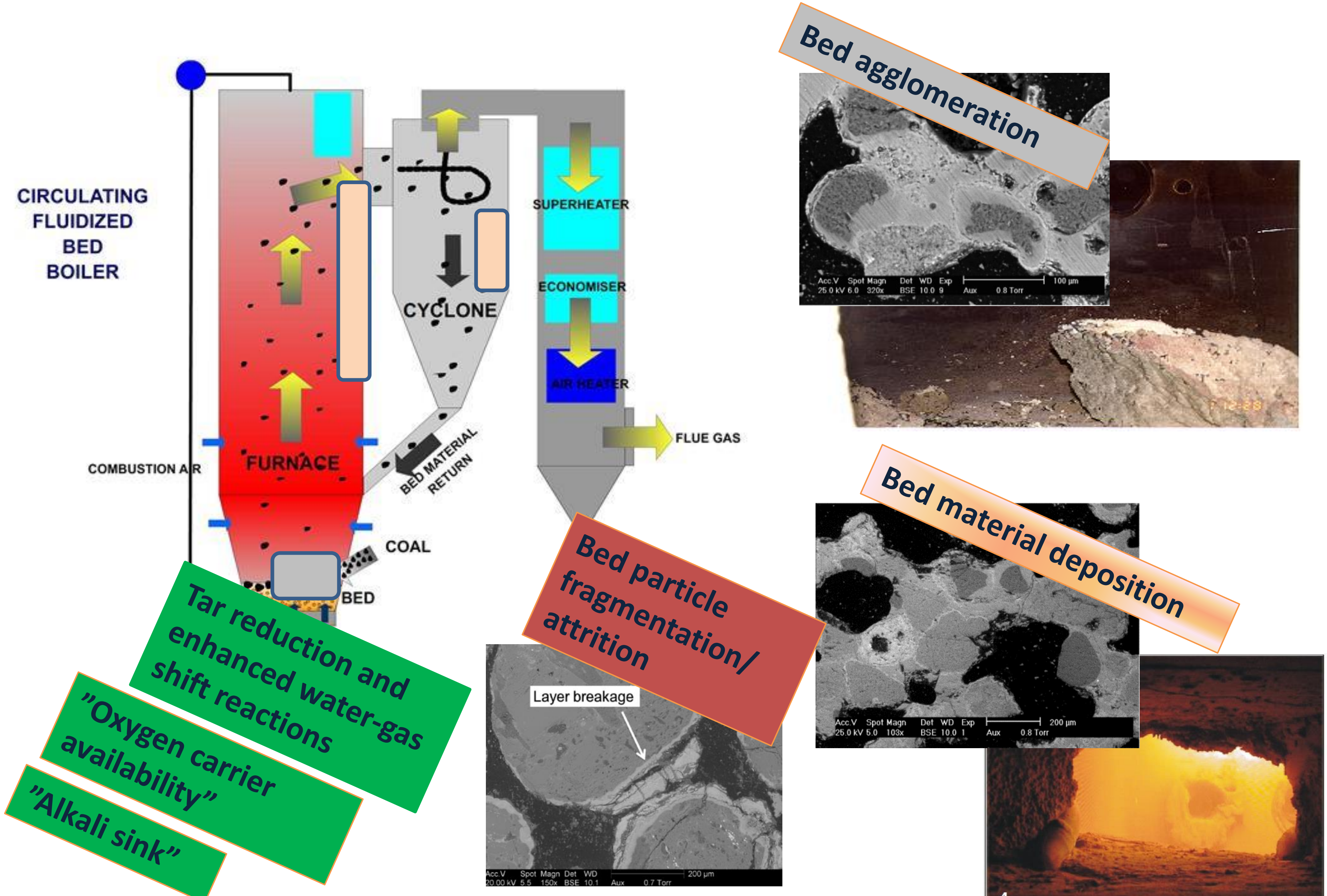
- Motivation
- Influence of fuel composition
- Influence of residence time (woody biomass)
- Compare BFBC, CFBC and DFBG (woody biomass)
- Compare different bed particles - quartz, olivine, K/Na feldspar (woody biomass)
- Compare combustion with gasification
- Summary

Typical cross-section of old quartz bed particle (33 days) taken from BFB wood combustion



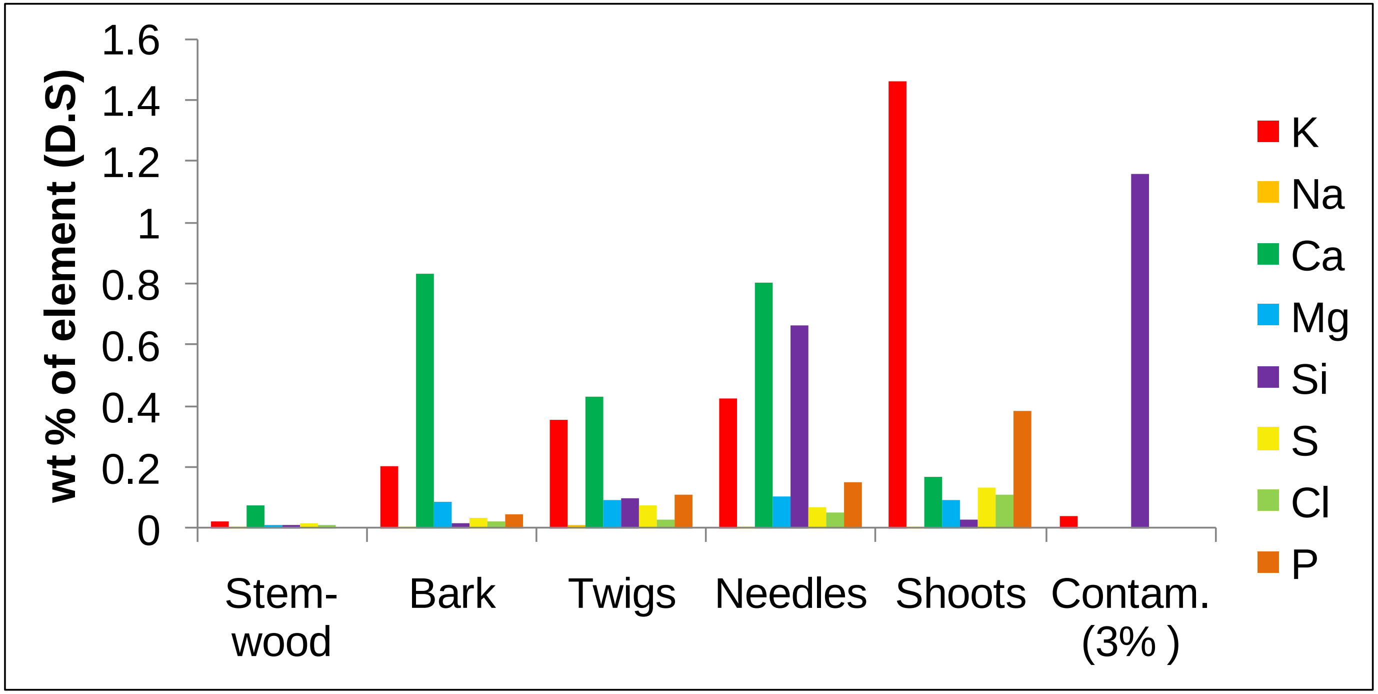
Brus, E., Öhman, M., Nordin, A. Mechanisms of bed agglomeration during fluidized bed combustion. Energy&Fuels, 2005, 19, 825-832

Motivation – Challenges & Opportunities



Influence of fuel composition (I)

Main ash forming elements in Norway Spruce

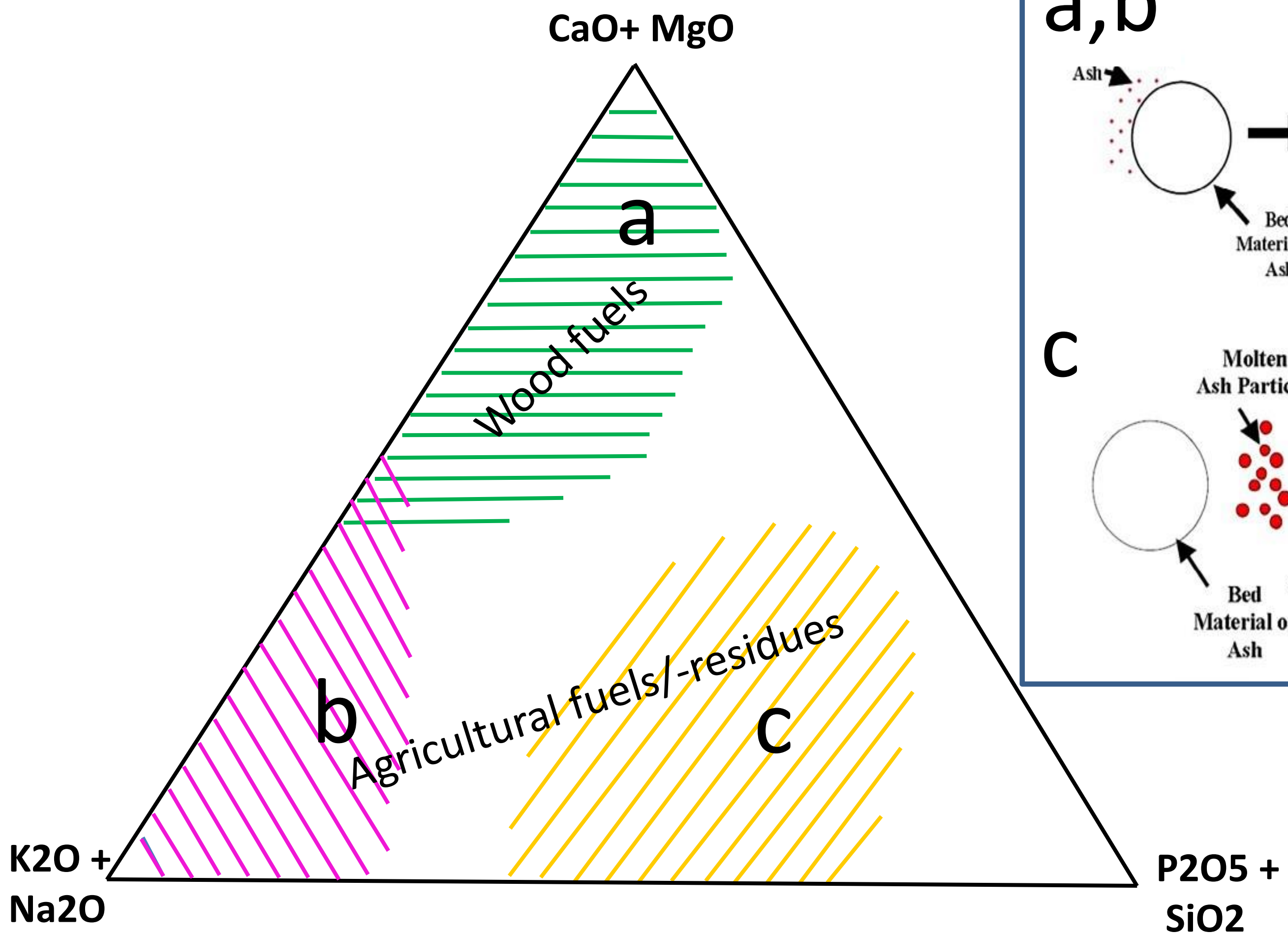


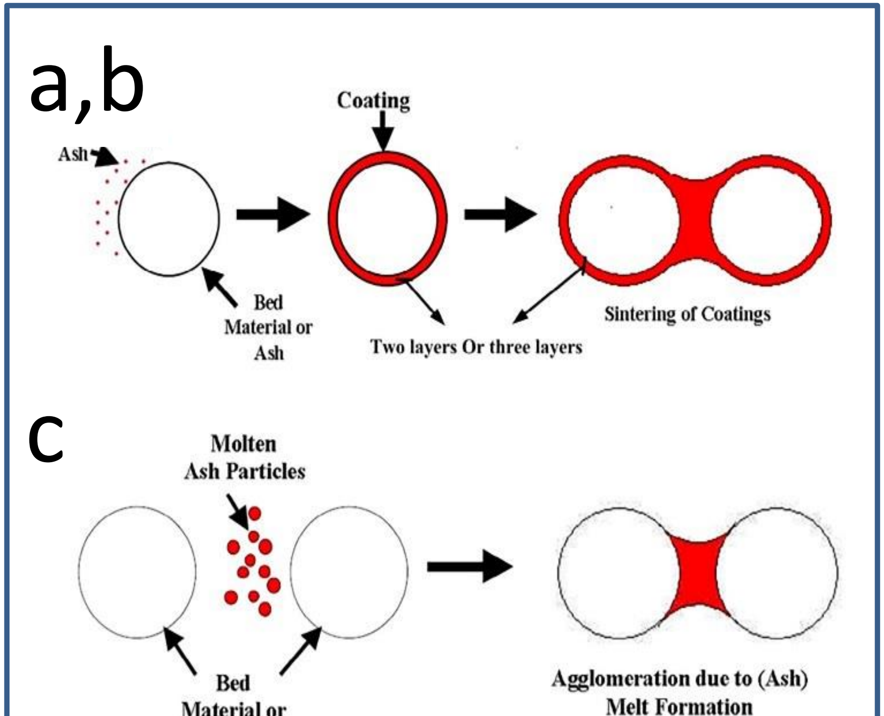
Ash forming elements in Norwegian spruce and Birch: Werkelin J, Thesis, 2008, Åbo Akademi University

Ca, K, (Si) – Wood fuels

K, Si, P, Ca – Agricultural fuels/-residues

Influence of fuel composition (II) – overall layer formation mechanism





Visser, H. J. M. et al 2001

Influence of fuel composition (III) – dominating layer formation mechanisms in quartz bed combustion

(a) Coating-induced layer formation through attack by K-compounds in gas or aerosol phase and diffusion of calcium, forming Ca rich silicates (typical for woody fuels)

(b) Direct attack by K-compounds in gas or aerosol phase, forming low-melting silicate layers (typical for alkali-rich fuels)

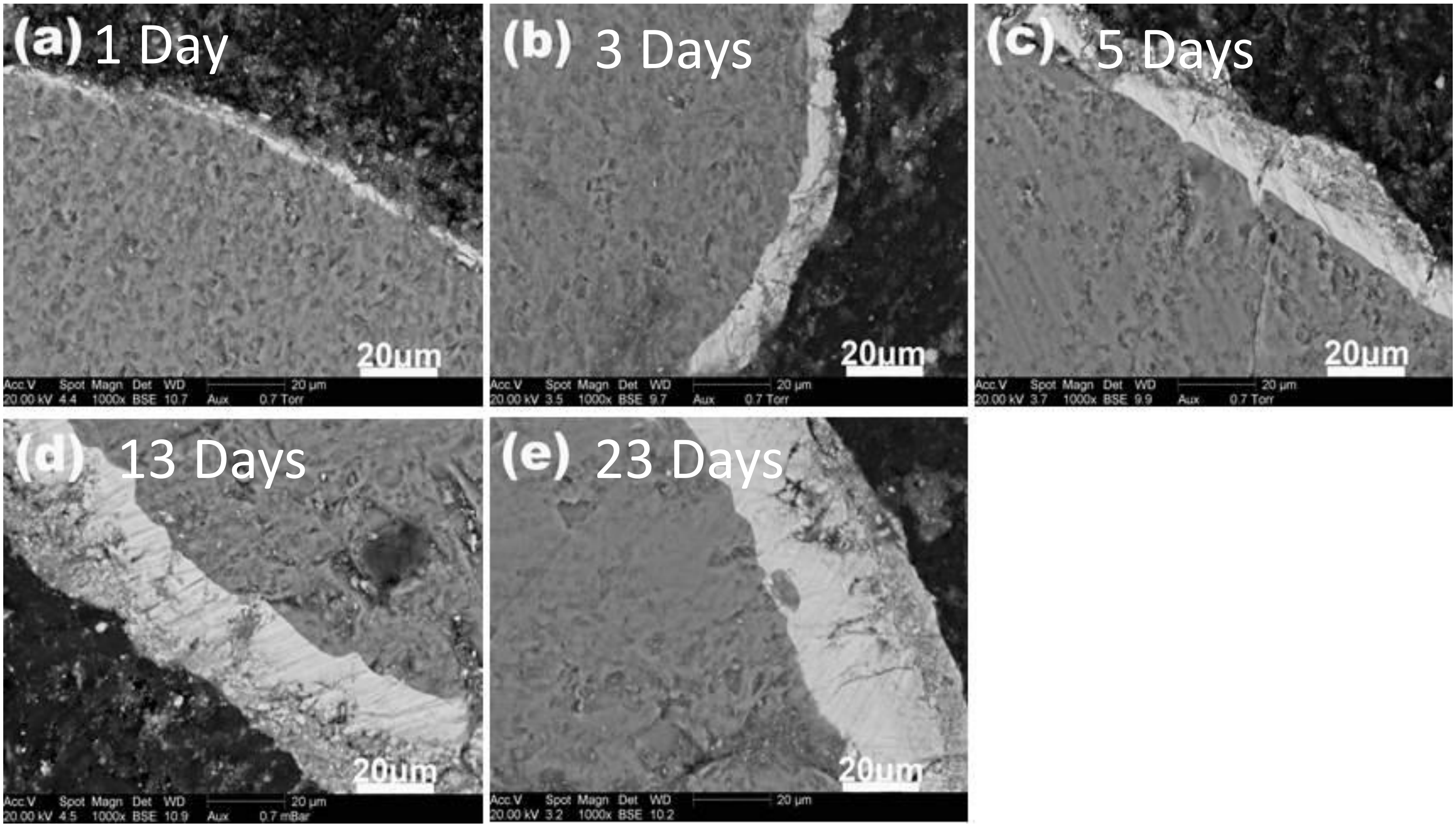
(c1) Direct adhesion by partly melted ash-derived potassium silicate particles/droplets (for K- and Si rich fuels e.g. straw fuels)

(c2) Direct adhesion by partly melted ash-derived potassium rich phosphate particles/droplets (for K- and P rich fuels e.g. some agricultural fuels)

(a-c) Brus, E., Öhman, M., Nordin, A. Mechanisms of bed agglomeration during fluidized bed combustion. Energy&Fuels, 2005, 19, 825-832

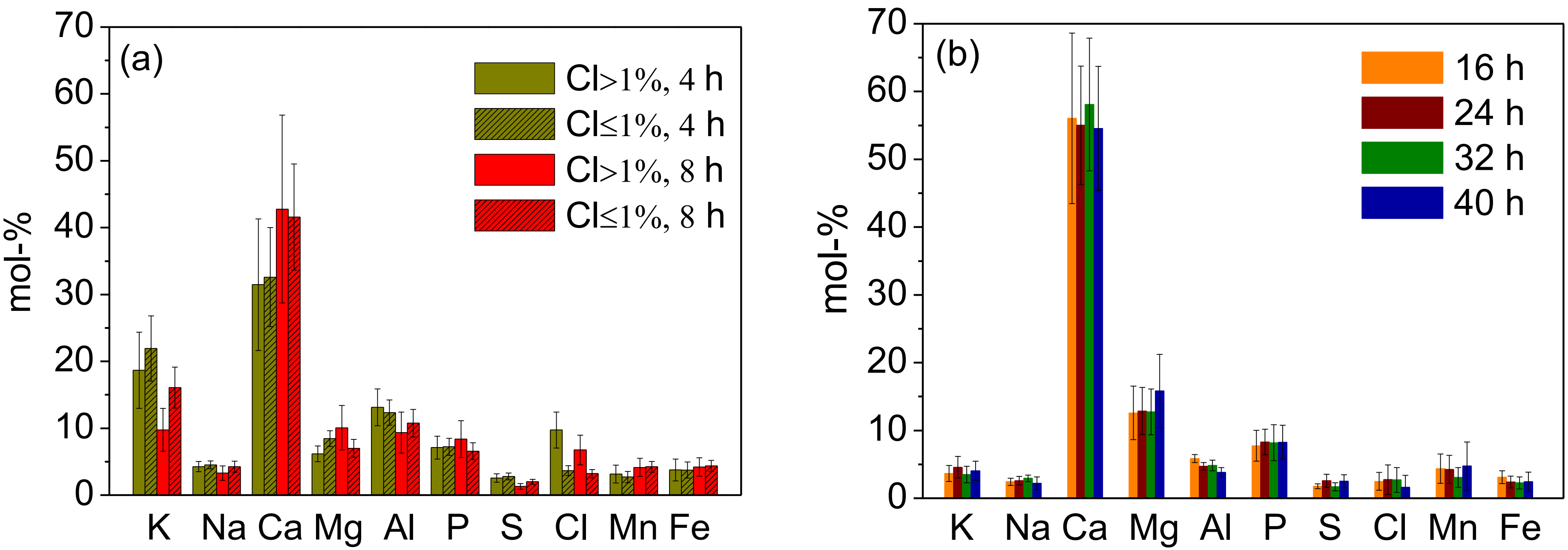
(c2) Grimm, A., Skoglund, N., Boström, D., Öhman, M. Bed agglomeration characteristics in fluidized quartz bed combustion of phosphorus rich biomass fuels. Energy&Fuels. 2011, 25, 937-947

Influence of quartz bed particle age on layer characteristics in BFB (30 MW) wood combustion



Hanbing, H., Boström, D., Öhman, M. Time Dependence of Bed Particle Layer Formation in Fluidized Quartz Bed Combustion of Wood-Derived Fuels. Energy Fuels 2014, 28, 3841−3848

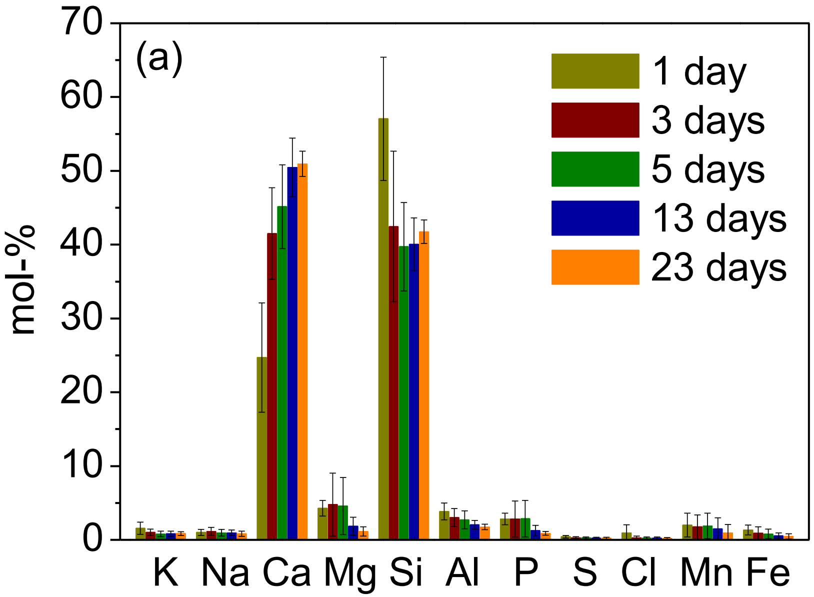
Influence of quartz bed particle age on layer characteristics in BFB (5 kW) wood combustion



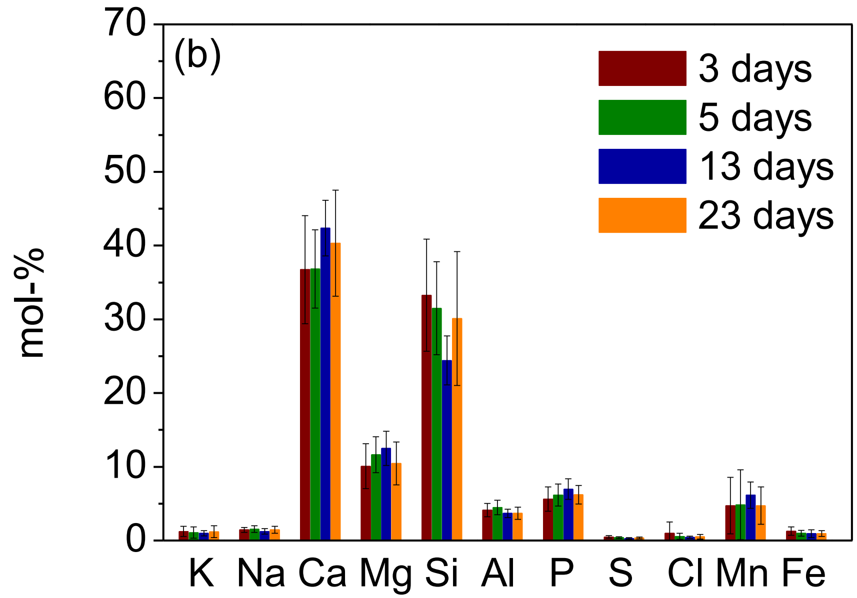
Hanbing, H., Boström, D., Öhman, M. Time Dependence of Bed Particle Layer Formation in Fluidized Quartz Bed Combustion of Wood-Derived Fuels. Energy Fuels 2014, 28, 3841–3848

Influence of quartz bed particle age on layer characteristics in BFB (30 MW) wood combustion

Inner layer



Outer layer

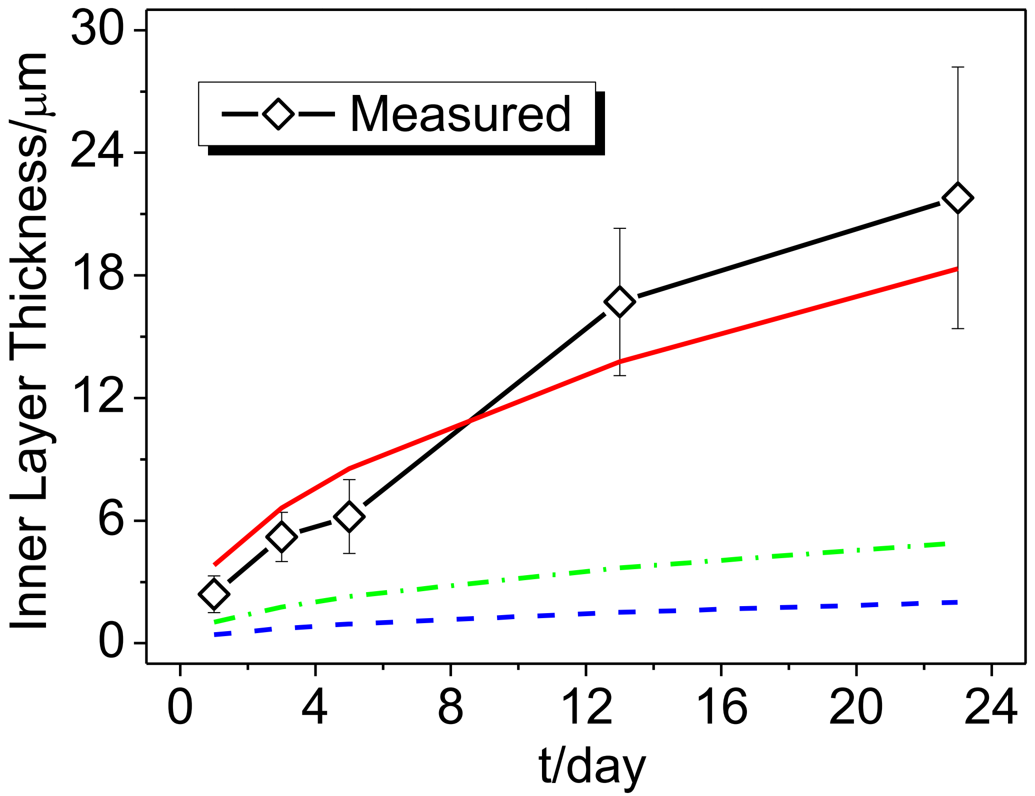


1 day → 23 days

$CaSiO_3$ Ca_2SiO_4 Ca_3SiO_5

Hanbing, H., Boström, D., Öhman, M. Time Dependence of Bed Particle Layer Formation in Fluidized Quartz Bed Combustion of Wood-Derived Fuels. Energy Fuels 2014, 28, 3841−3848

Diffusion-controlled inner layer growth (quartz bed, BFB 30 MW, wood)



Diffusion of Ca^{2+} at 850 °C in

Ca_2SiO_4

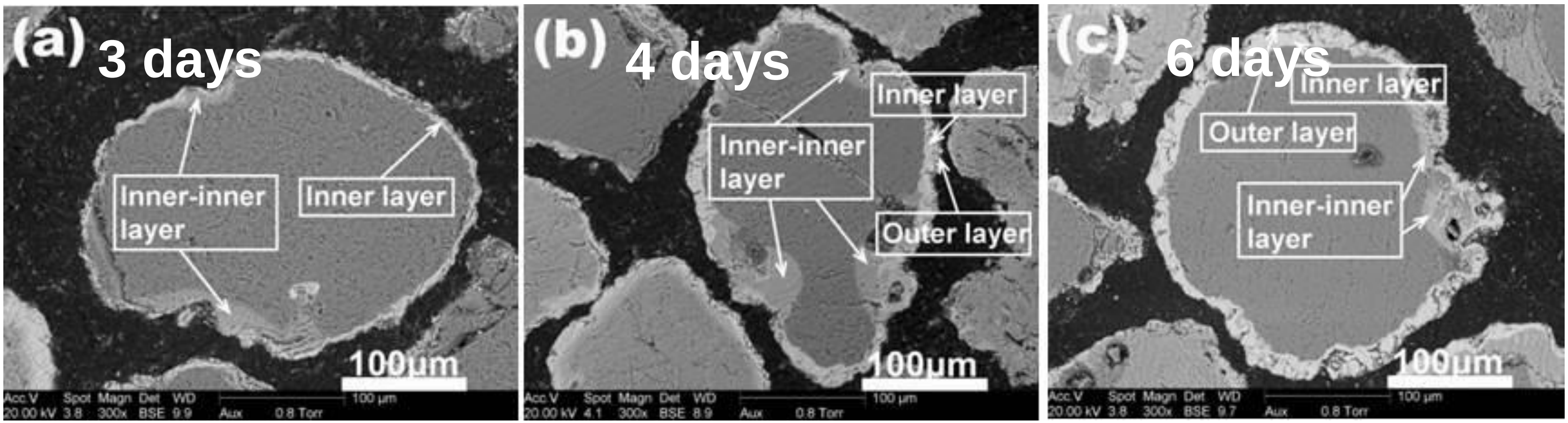
Ca_3SiO_5

$CaSiO_3$

He, H., Ji, X., Boström, D., Backman, R., Öhman, M. Mechanism of Quartz Bed Particle Layer Formation in Fluidized Bed Combustion of Wood-Derived Fuels, Energy Fuels, 2016, 30 (3), pp 2227–2232

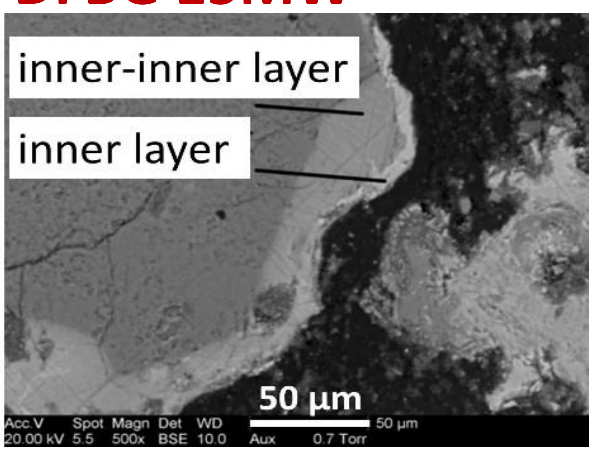
Influence of quartz bed particle age on layer characteristics in wood CFBC (122 MW) and DFBG (15 MW)

CFBC 122MW



Hanbing, H., Boström, D., Öhman, M. Time Dependence of Bed Particle Layer Formation in Fluidized Quartz Bed Combustion of Wood-Derived Fuels. Energy Fuels 2014, 28, 3841–3848

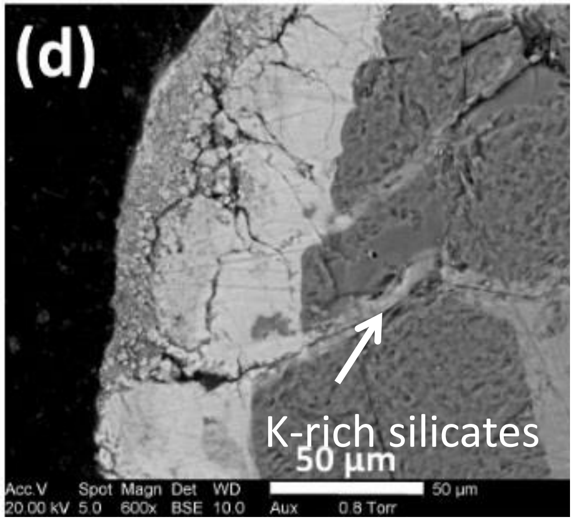
DFBG 15MW

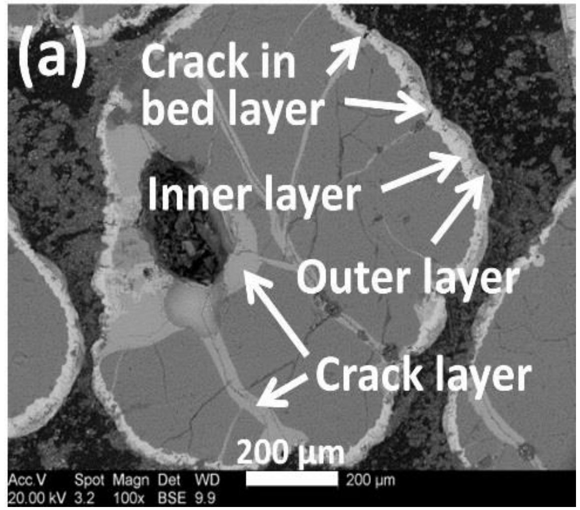


Kuba, M., He, H., Kirnbauer, F., Skoglund, N., Boström, D., Öhman, M., Hofbauer, H. Thermal stability of bed particle layers on naturally occurring minerals from dual fluid bed gasification of woody biomass, Energy Fuels, 2016, 30 (10), pp 8277–8285

Crack layer formation in quartz particle (BFB, DFBG) & bed material depositions in CFBC's

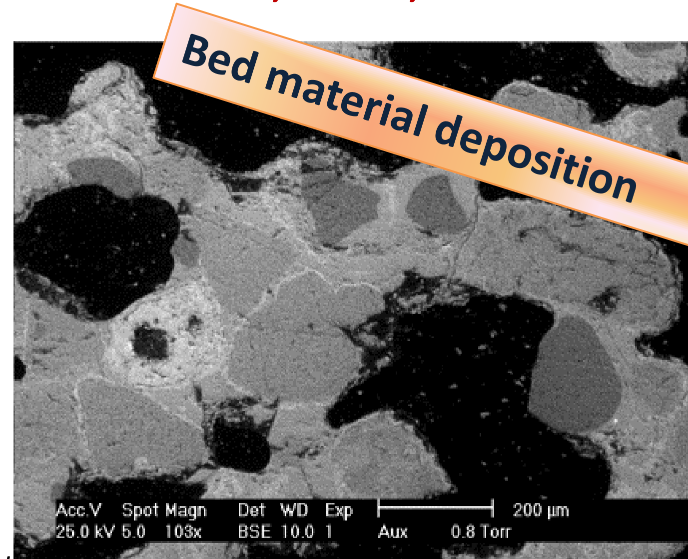
BFBC 30 MW, wood, after 23 days

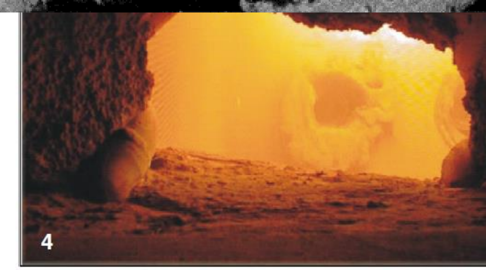




He, H., Skoglund, N., Öhman, M. Time-Dependent Crack Layer Formation in Quartz Bed Particles during Fluidized Bed Combustion of Woody Biomass, Energy Fuels, 2017, 31 (2), pp 1672–1677

CFBC 100 MW, wood, natural sand



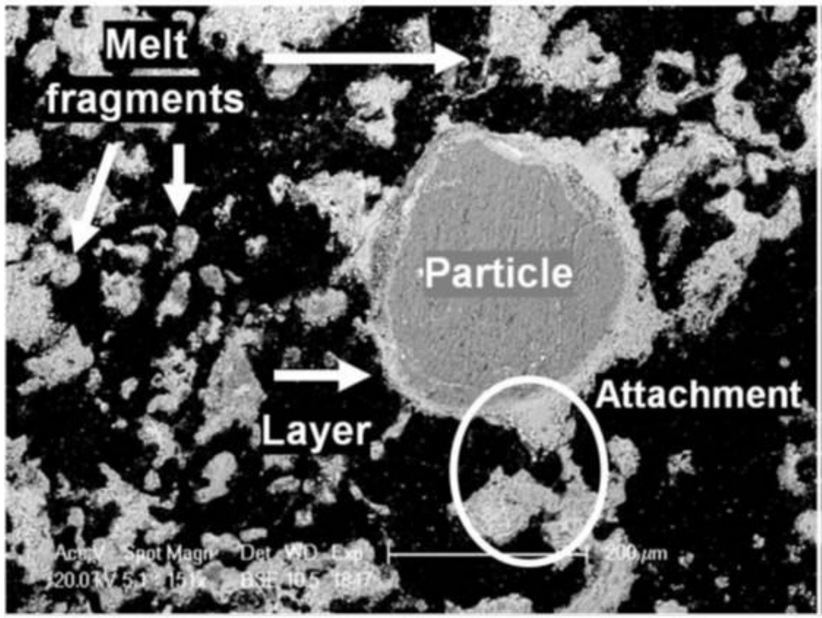


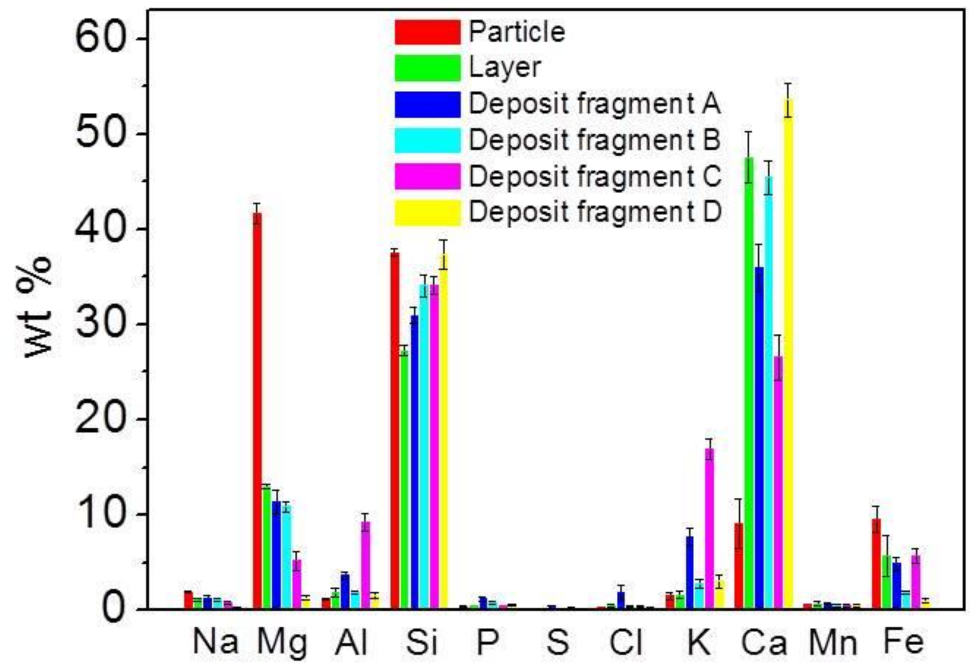
Tranvik, A.C., Öhman, M., Sanati, M. Bed material deposition in cyclones of wood fuel fired CFB's. Energy&Fuels, 2007, 21, 104-109

DFBG 15 MW, logging residues

Kuba, M., He, H., Kirnbauer, F., Skoglund, N., Boström, D., Öhman, M., Hofbauer, H. Thermal stability of bed particle layers on naturally occurring minerals from dual fluid bed gasification of woody biomass, Energy Fuels, 2016, 30 (10), pp 8277–8285

Deposit build-up in the post-combustion chamber in DFBG (15 MW) of logging residues in olivine bed



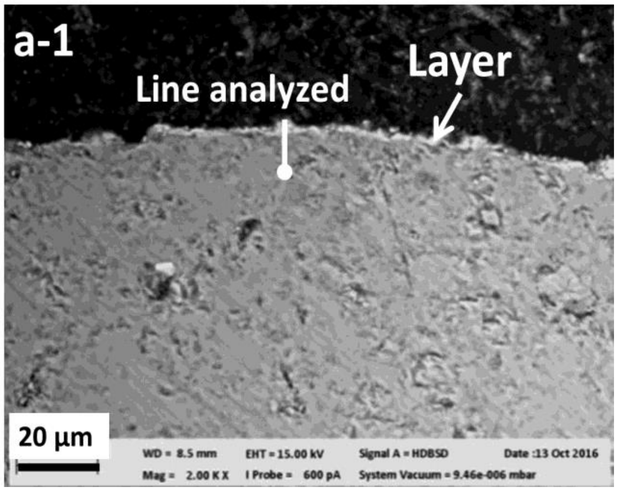


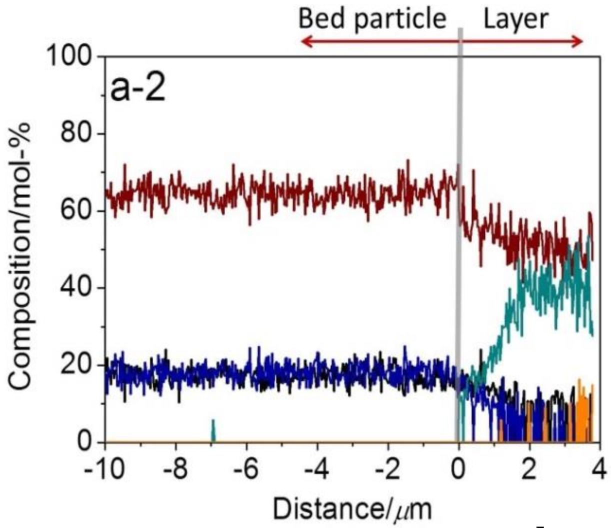
Deposit fragments C & D indicates impurity driven partial-melting process

Kuba, M., He, H., Kirnbauer, F., Boström, D., Öhman,M., Hofbauer, H. Deposit build-up and ash behavior in dual fluid bed steam gasification of logging residues in an industrial power plant. Fuel Processing Technology 2015, 139, 33–41

Layers on K-feldspar bed particles taken from wood BFB combustion

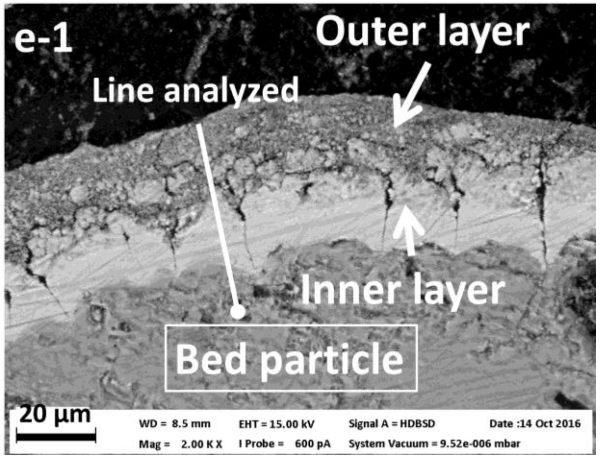
1 Day, BFB 30 MW

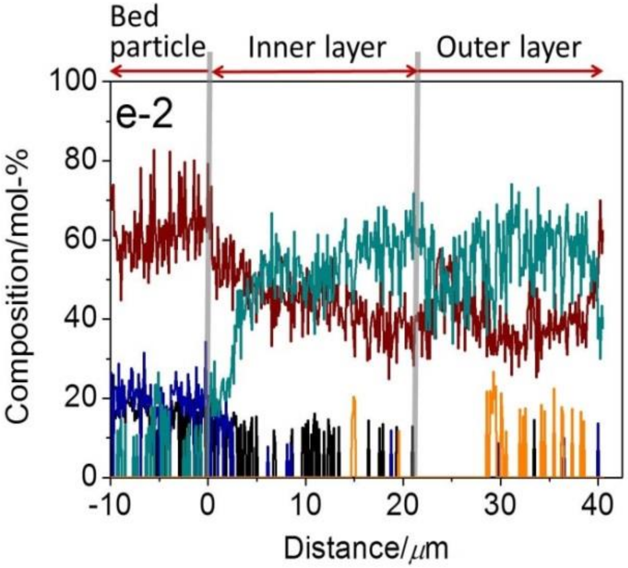




Si, K, Al, Ca and Mg

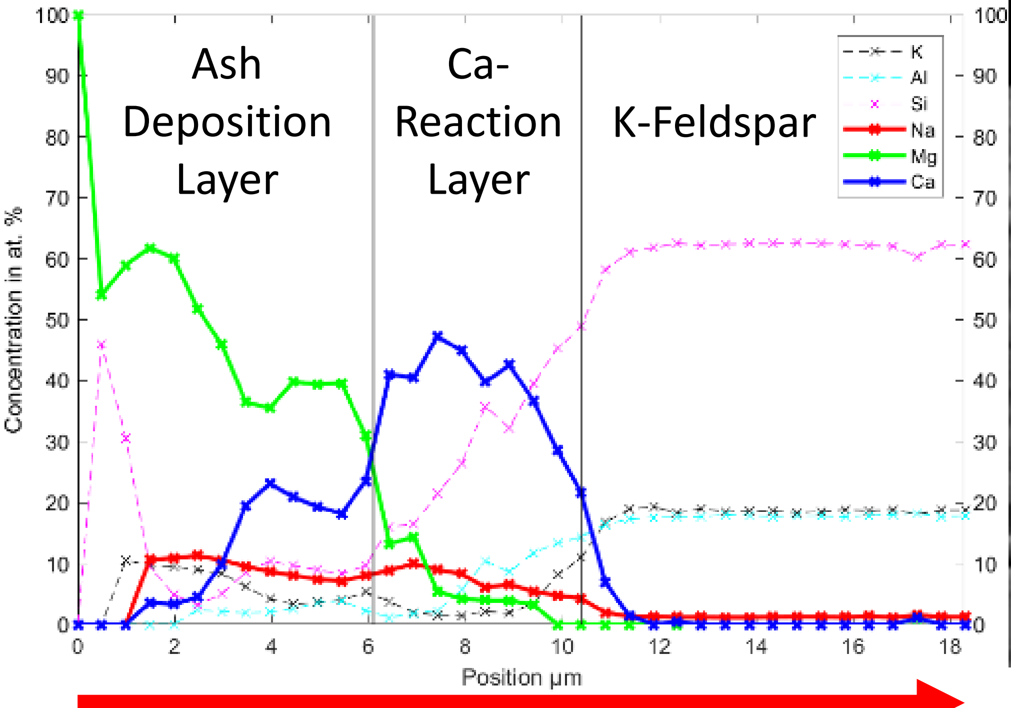
33 Days, BFB 30 MW

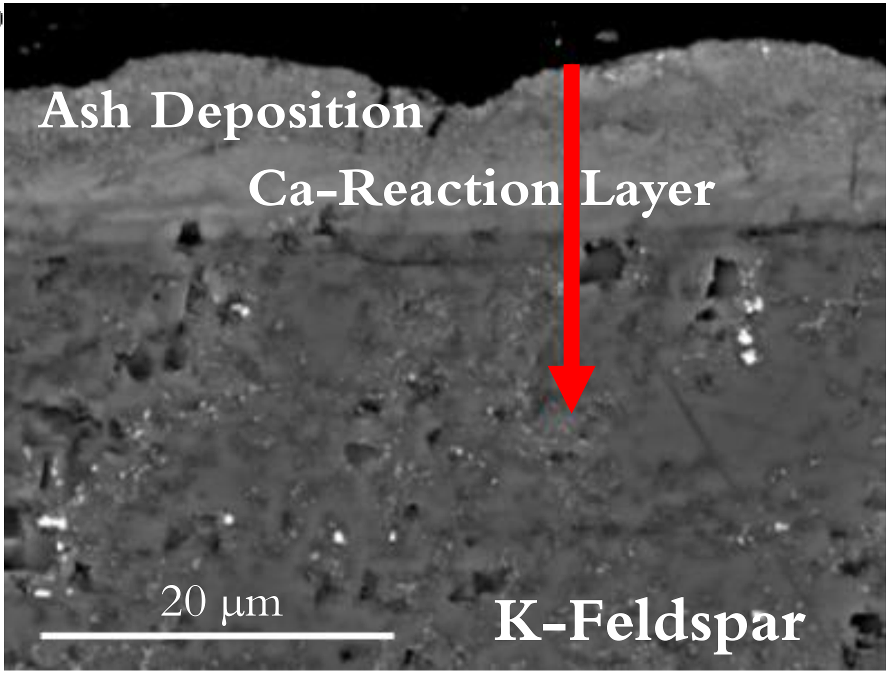




H., He, Skoglund, N. Öhman.M. Time-dependent layer formation on K-feldspar bed particles during fluidized bed combustion of woody fuels. Energy Fuels, 2017, 31, 12848–12856

Layers on K-feldspar bed particles taken from DFB wood gasification (Chalmers indirect gasification system)



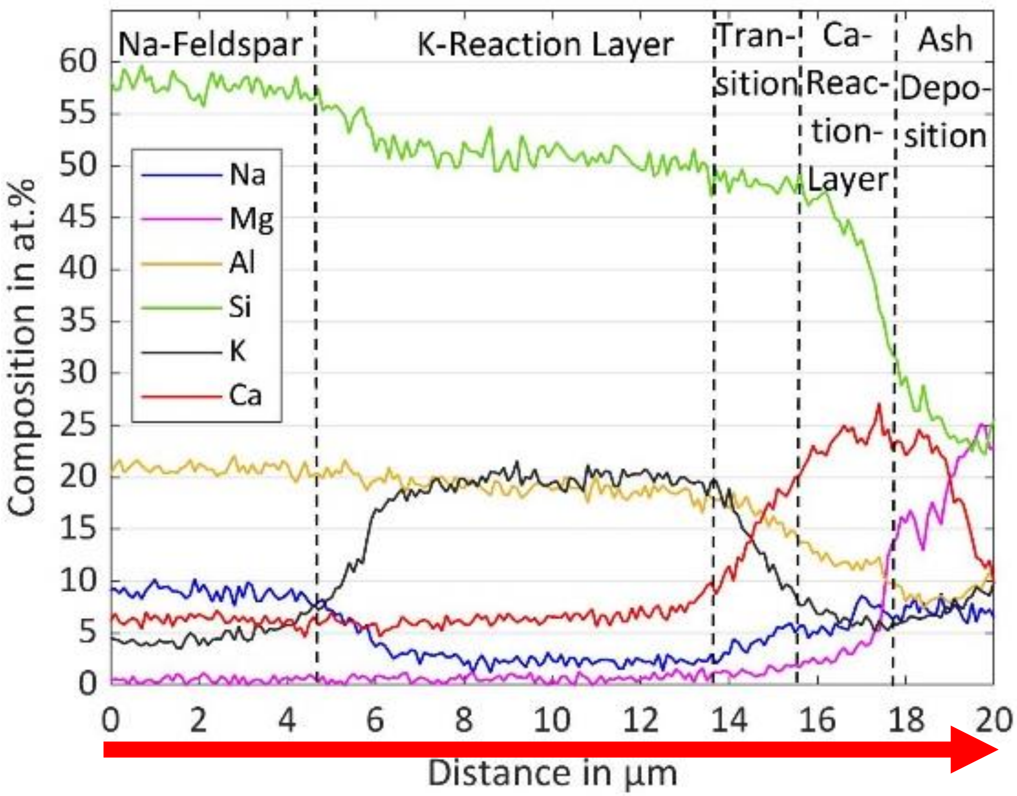


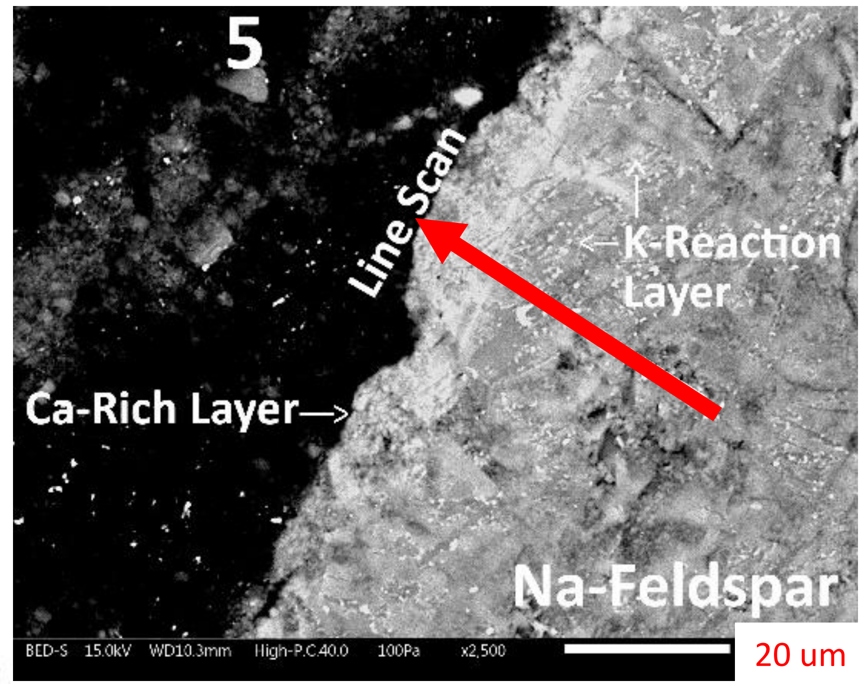
K-feldspar after **143 hours** of operation

Left: EDXS-line scan profile   Right: SEM micrograph

Faust, R., Hannl, K. T., Vilches, T. B.., Kuba, M., Öhman, M., Seemann, M., Knutsson, P. Layer Formation on Feldspar Bed Particles during Indirect Gasification of Wood. 1. K-Feldspar, Energy Fuels, 2019, 33, 7321-7332

Layers on Na-feldspar bed particles taken from DFB wood gasification (Chalmers indirect gasification system)



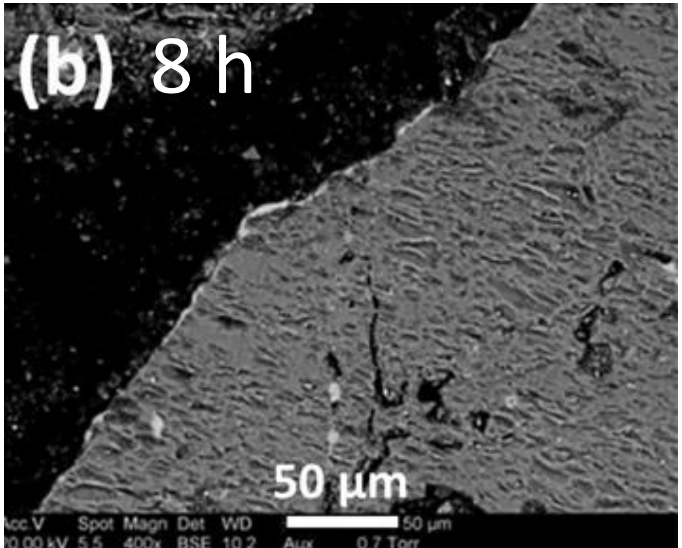


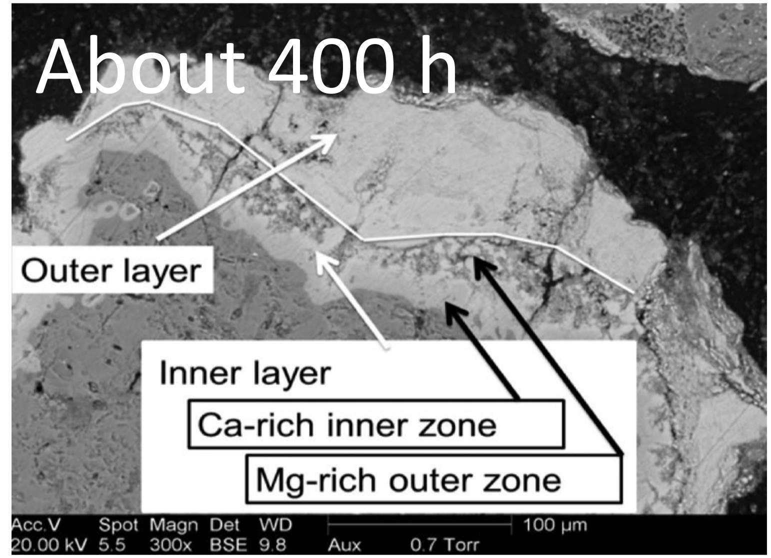
Na-feldspar after **143 hours** of operation

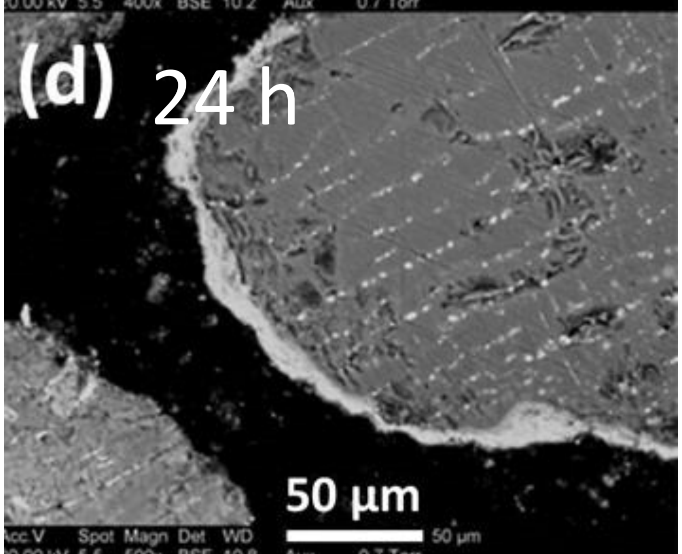
Left: EDXS-line scan profile Right: SEM micrograph

Hannl, K. T., Faust, R., Kuba, M., Knutsson, P., Vilches, T. B. , Seemann, M., Öhman, M. Layer Formation on Feldspar Bed Particles during Indirect Gasification of Wood. 2. Na-Feldspar, Energy Fuels, 2019, 33, 7333−7346

Layers on olivine bed particles taken from DFB wood gasification (8 MW)







Inner layer composition

Mg, Si, Fe, Ca, (O)

Ca, Si, Mg, Fe, (O)

Time

Kuba, M., He, H., Kirnbauer, F., Skoglund, N., Boström, D., Öhman, M., Hofbauer, H. Mechanism of Layer Formation on Olivine Bed Particles in Industrial-Scale Dual Fluid Bed Gasification of Wood. Energy Fuels, 2016, 30 (9), pp 7410–7418

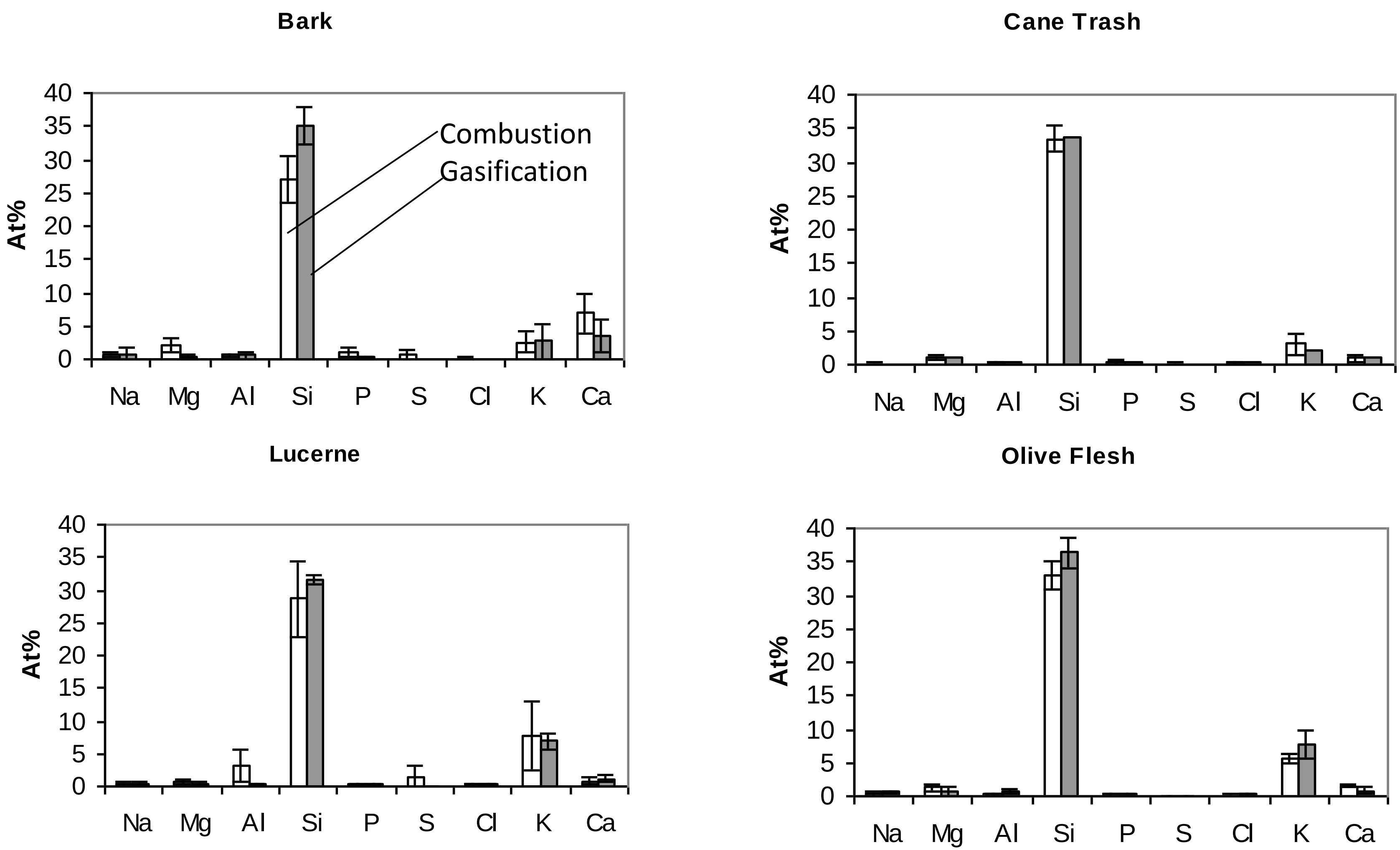
Difference in quartz layer characteristics between combustion and gasification (I)

	Bark (Ca, K)		Cane Trash (Si, K)		Reed Canary Grass (Si, K)		Olive Flesh (Si, K, Ca)		Bagasse (Si,K)		Lucerne (K, Ca, Cl, S)	
	Gasif.	Comb.	Gasif.	Comb.	Gasif.	Comb.	Gasif.	Comb.	Gasif.	Comb.	Gasif.	Comb.
Total bed particle layer thickness (µm)	2-8	2-8	2-8	2-8	2-8	2-8	4-20	4-20	-	-	3-20	1-3
Layer distribution (% of bed particles which have layers)	>90	>90	10-30	10-30	10	10	>90	>90	< 10	< 10	>90	10

Fuel ash derived material dominated as separate ash particles (Ca, K, S, P, Cl…)

Öhman, M., Pommer, L., Nordin, A. Bed agglomeration characteristics and mechanisms during gasification and combustion of biomass fuels. Energy&Fuels, 2005, 19, 1742-1748

Difference in inner quartz layer characteristics between combustion and gasification (II)



Öhman, M., Pommer, L., Nordin, A. Bed agglomeration characteristics and mechanisms during gasification and combustion of biomass fuels. Energy&Fuels, 2005, 19, 1742-1748

Summary – layer formation in thermal fluidized bed wood conversion (quartz, olivine, K/Na-feldspar)

- **Initially:**
  - Only one layer - the formation mechanism differs between particles
    - K-gaseous reaction dominated for *quartz*
    - Individual melted ash particles probably enhance reaction between Ca-compounds and the bed particle for *olivine & K-feldspar*

- **After some days:**
  - Separation in to inner- and outer (more particle rich) layer(s) (*all particles*)
  - Thinner outer layers for CFB and DFB *(all particles*)
  - Increasing Ca concentrations in the inner layer with time – the layer growth is a result of incorporation of Ca (*all particles*)
  - Cracks in inner layer are formed (*all particles*)
  - Inner-inner layers (K rich silicates) are formed in *quartz* particles in absence of “protective Ca rich silicate inner layer, CFB & DFB
  - Crack layers (K rich) in the *quartz* and *Na-feldspar* particle core starts to form – connected to cracks in the inner layer

Thanks for your attention

Marcus.ohman@ltu.se

https://www.ltu.se/research/subjects/Energiteknik?l=en