Predictions of slag formation, flow behaviour, and refractory interactions during pressurised entrained-flow gasification of woody biomass/peat mixtures

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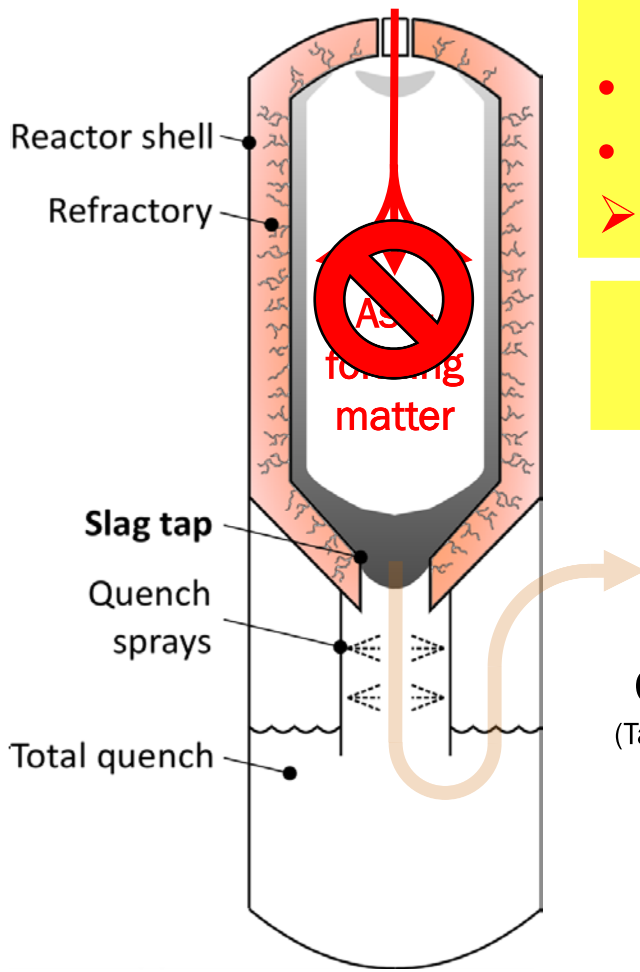
PRESSURISED ENTRAINED-FLOW GASIFICATION

- Powder/liquid/ slurry fuel
- Oxy-fired
- High temperatures
- High heating rates
- Rapid conversion
- \+ Large capacity
- \+ Syngas quality

Coal ash matter:

- **Composition**
  Si, Al, Ca, Fe (minerals)
- **Contents**
  5—50 wt%
- **1200—1600 °C**
- **Flowing slag**



Ash-related problems:

- Refractory degradation
- Outlet blockage
- ➢ Costly downtimes

∴ Ash transformations are critical to the PEFG process

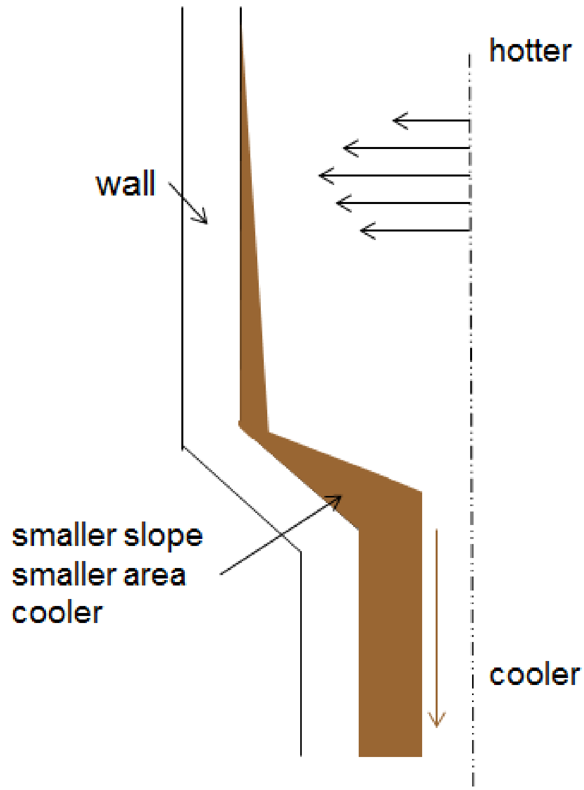
Syngas → Transport fuels, chemicals

CO, H_2,
CO_2, H_2O
(Tars, soot, C_xH_y)

Woody biomass ash:

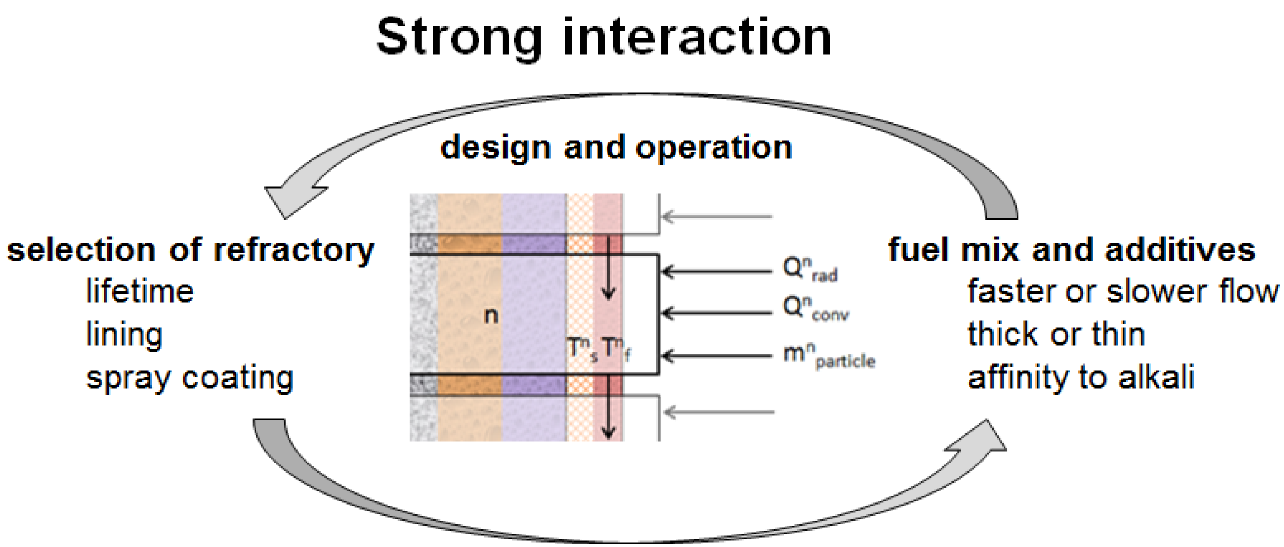
- **Composition**
  Ca, K, Si (–organic, salts)
- **Contents**
  0.1—5 wt%
- **Slag? Flowing?**

Slag layer thickness

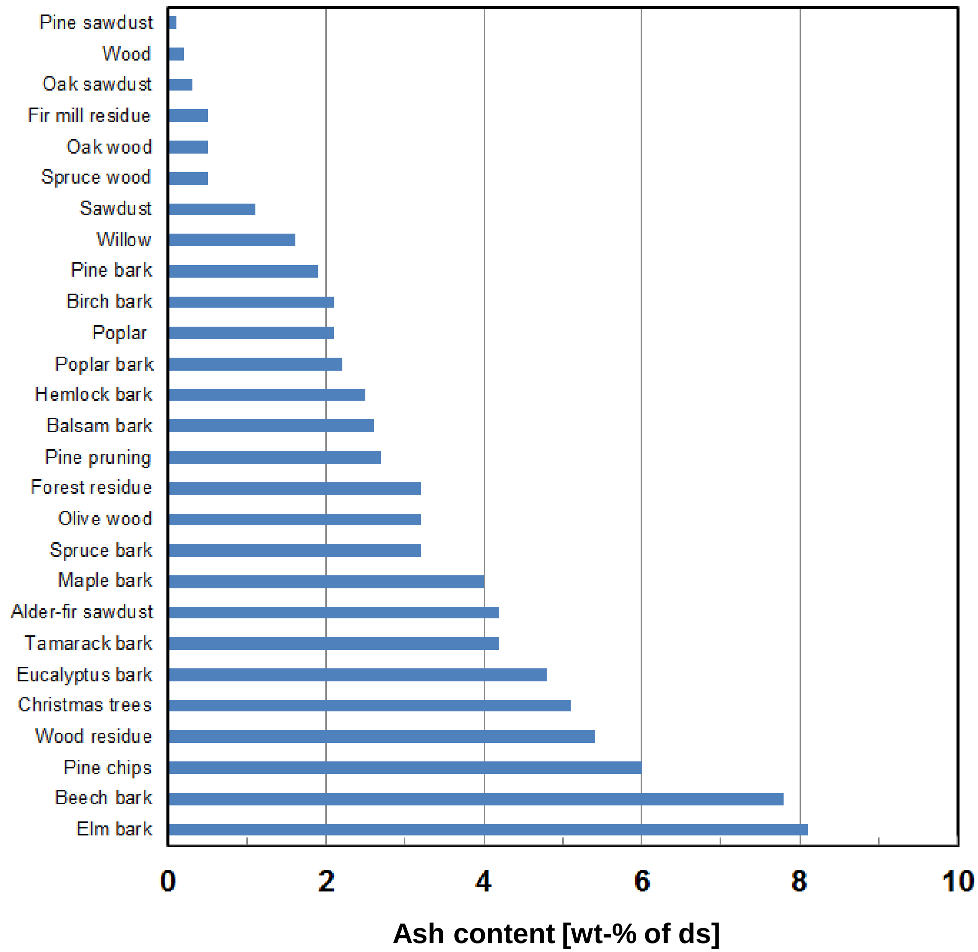


Multipurpose slag

- Transport of ash out of the reactor
  - steady state – no accumulation
- Protection of refractory against radiation
- Chemical attack on refractory
  - promote or inhibit alkali transport



Ash content of woody biomass – big variations



Data from Vassilev 2009

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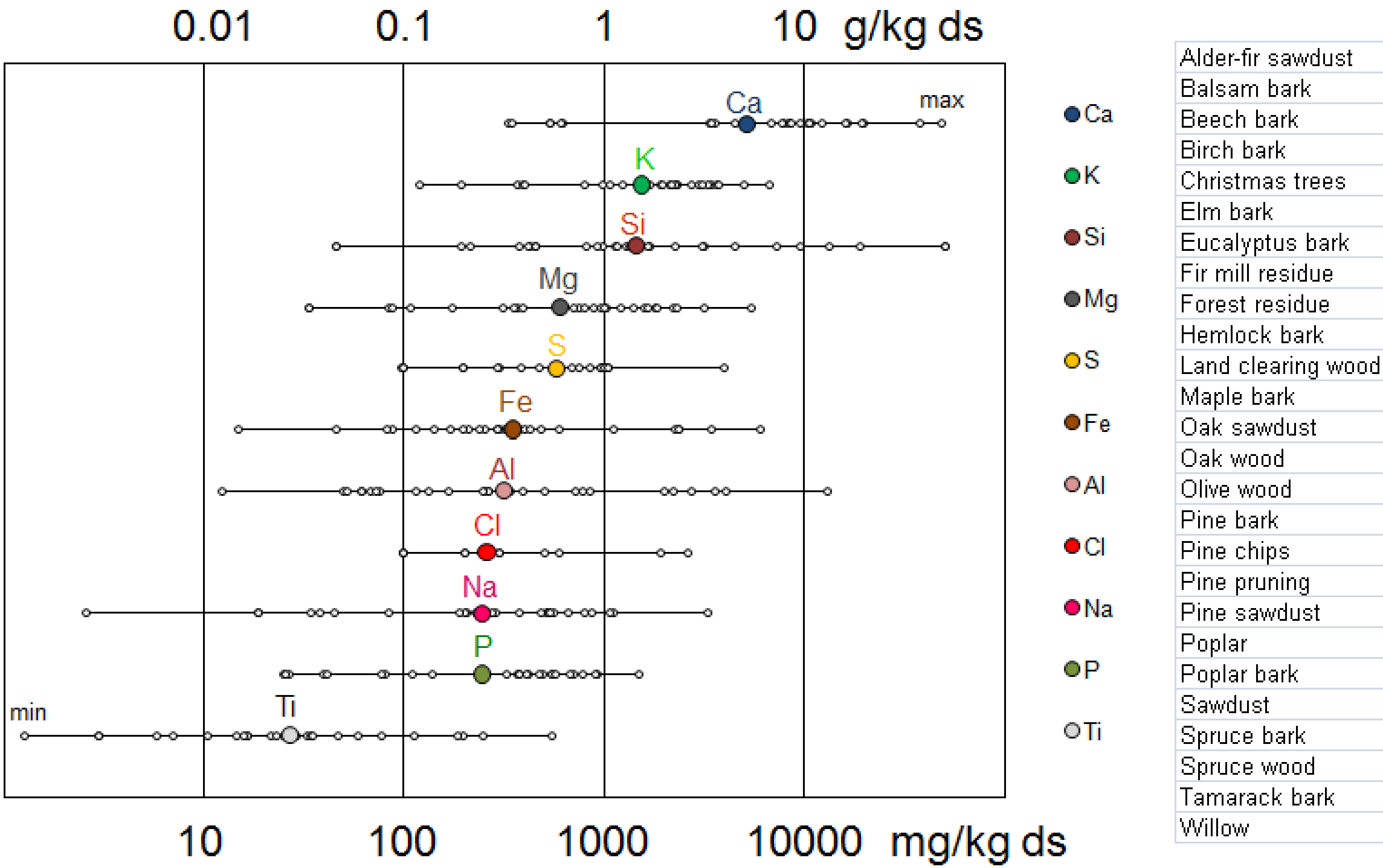
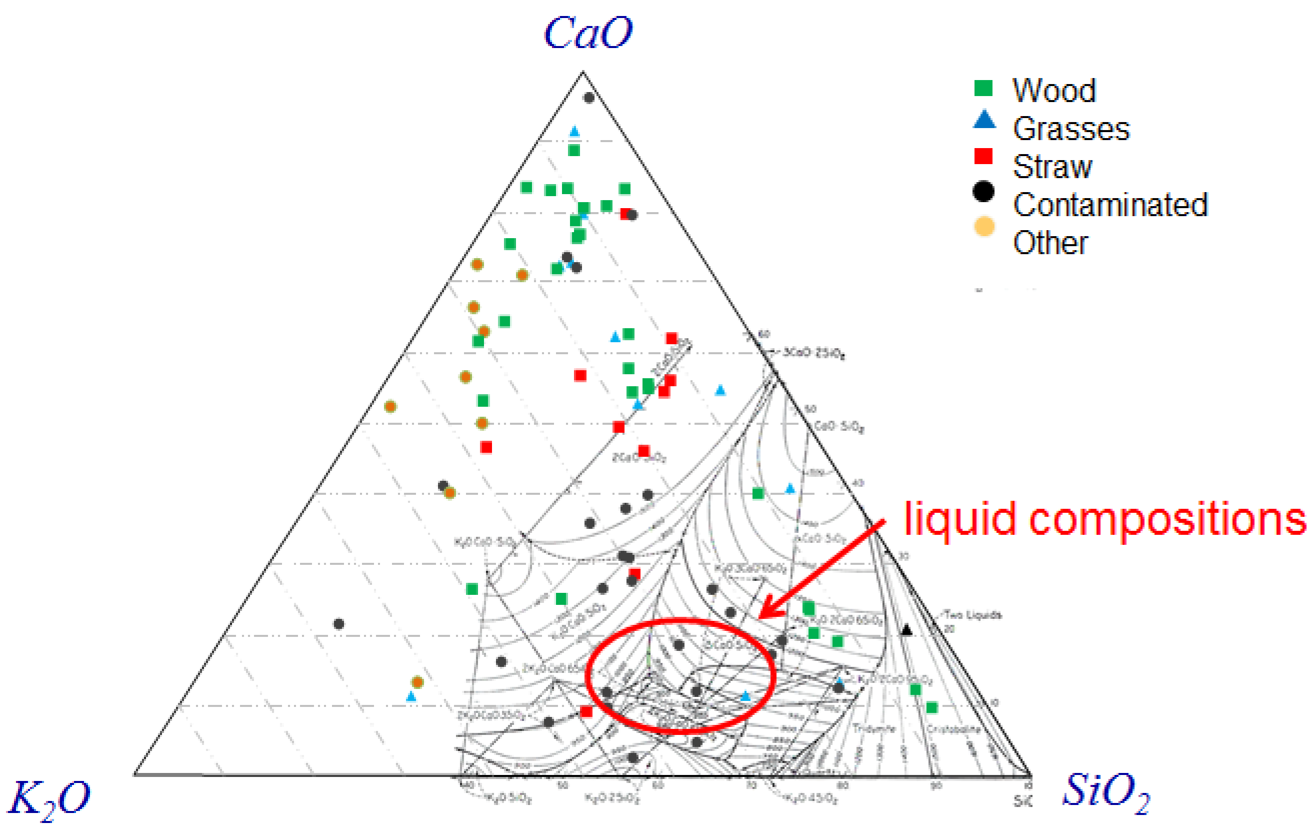
Ash composition of woody biomass – big variations



Data from Vassilev 2009

Ash composition of biomass – big variations



Data from Vassilev 2009
Morey 1930, 1931

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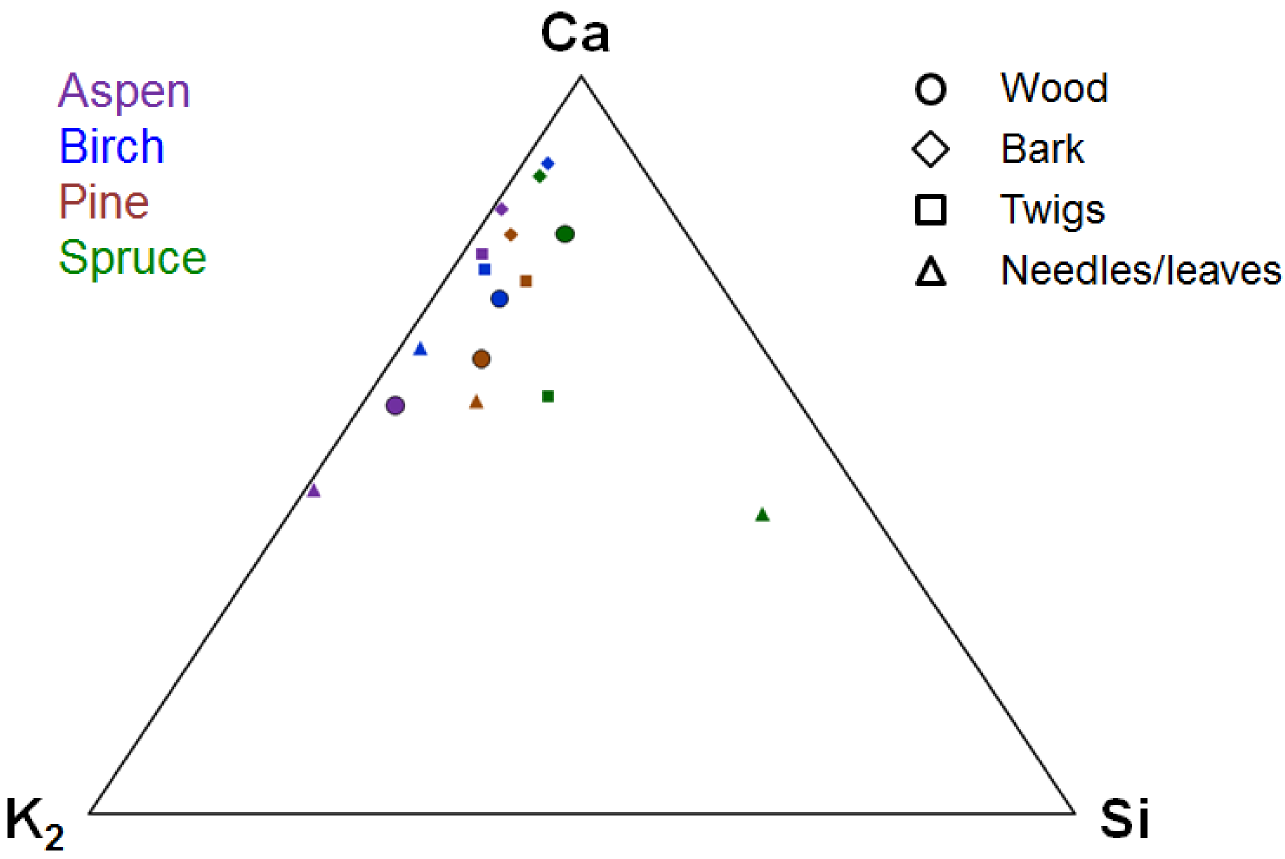
Different wood parts – different composition



Data from Werkelin 2006

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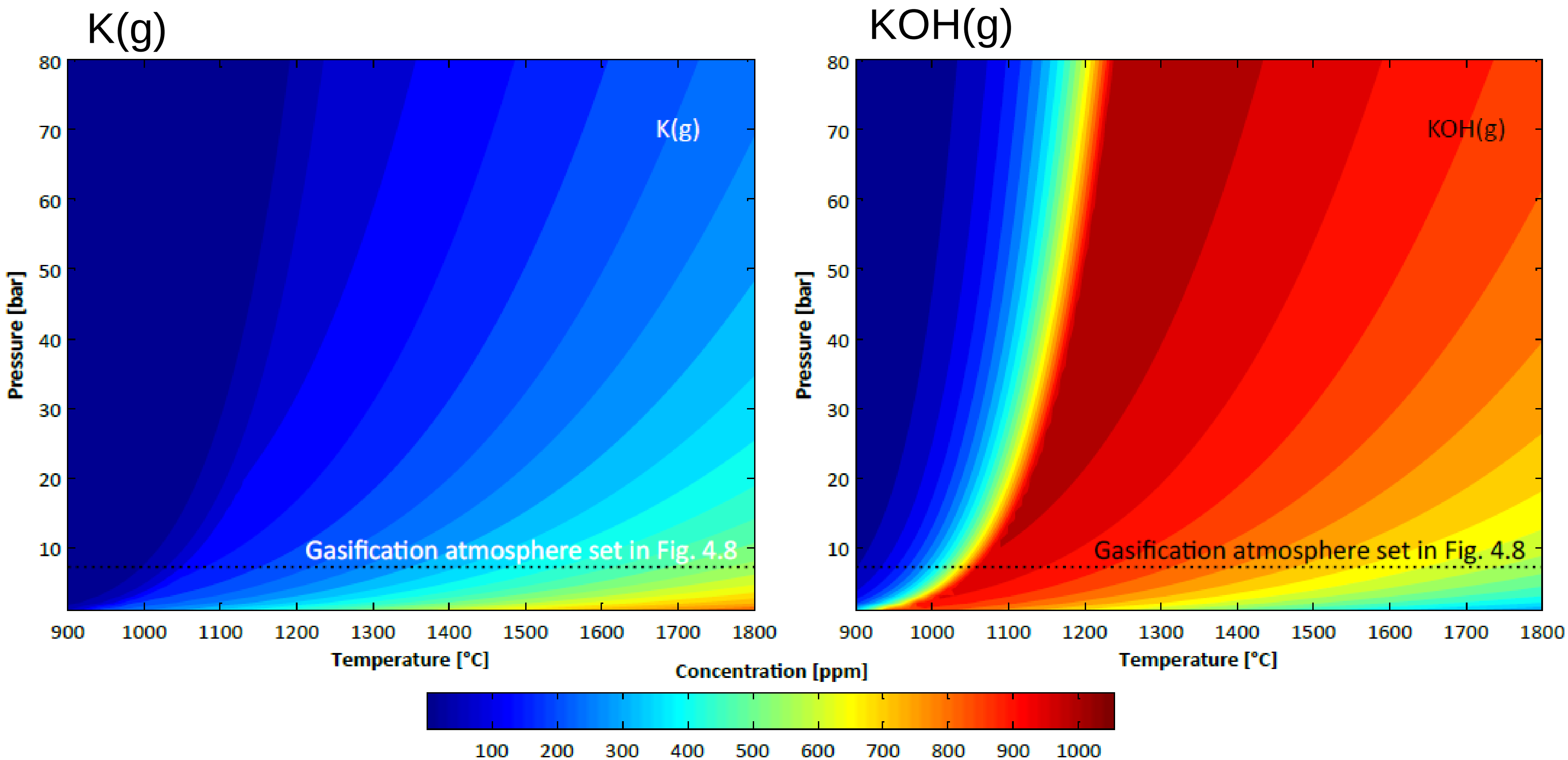
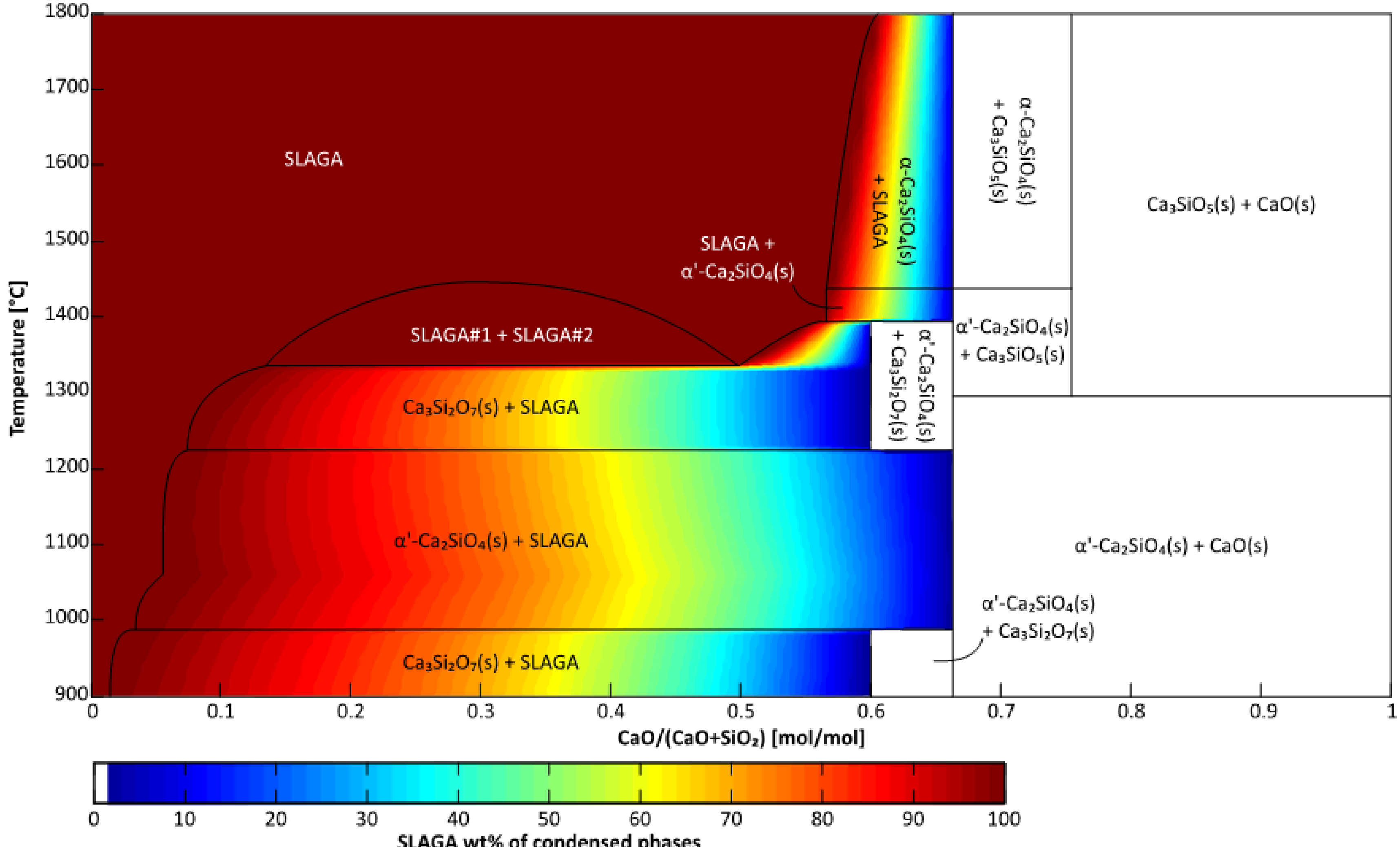
Concentrations of gaseous potassium wood gasification



Ma 2017

Slag formation wood gasification



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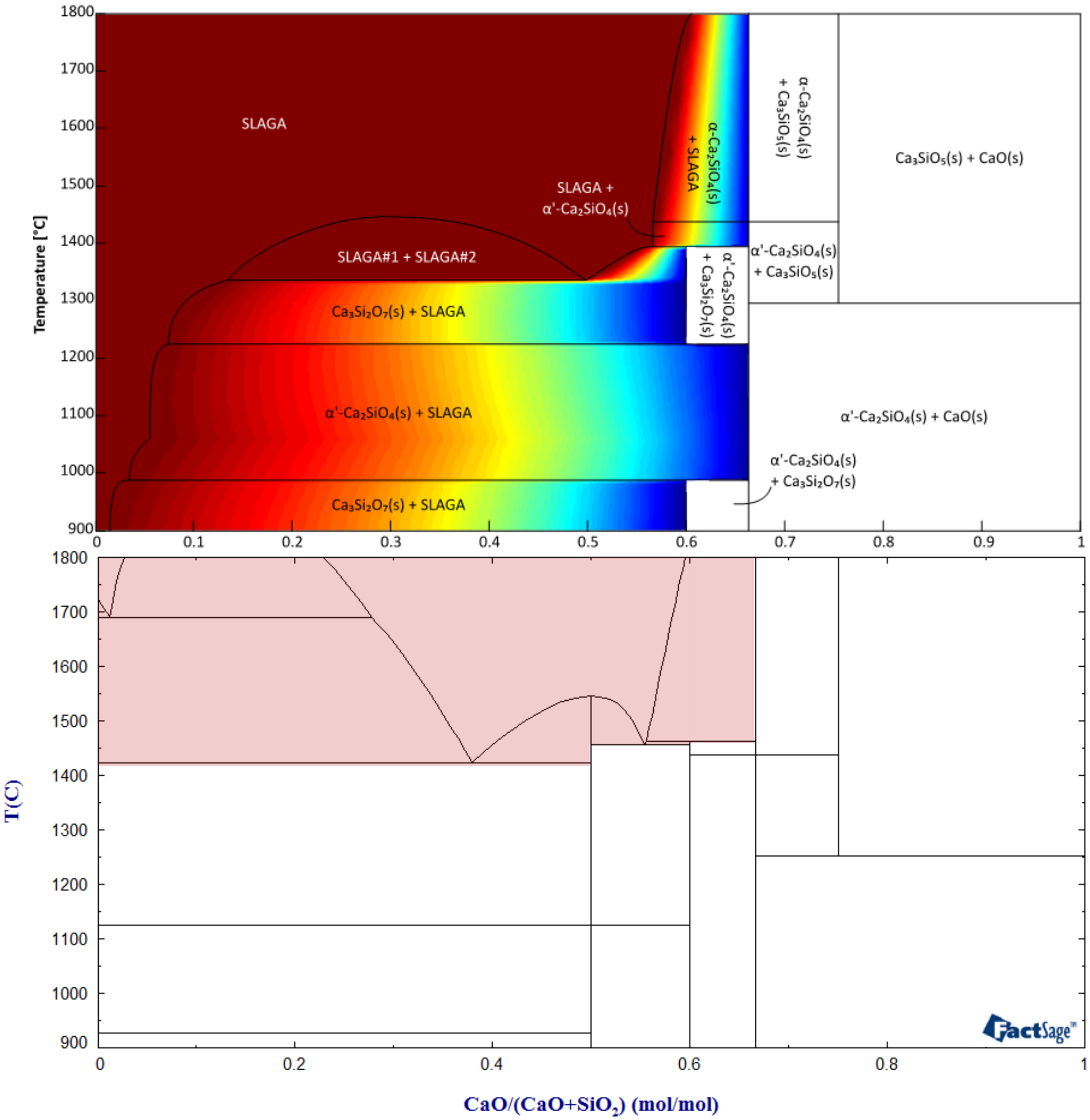
Slag formation wood gasification

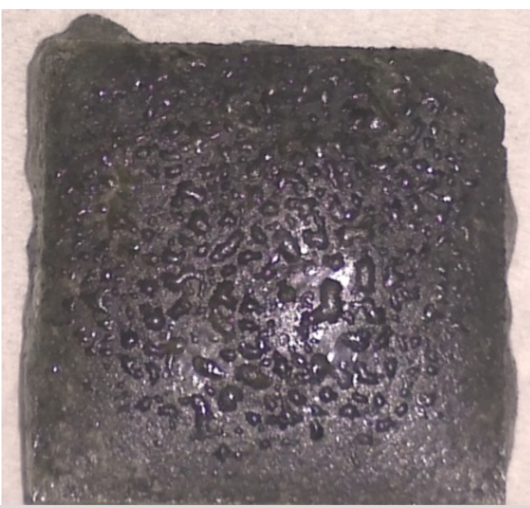


Ma 2017,
Data from Yazhenshikh 2013

Slag formation – sampling and calculations

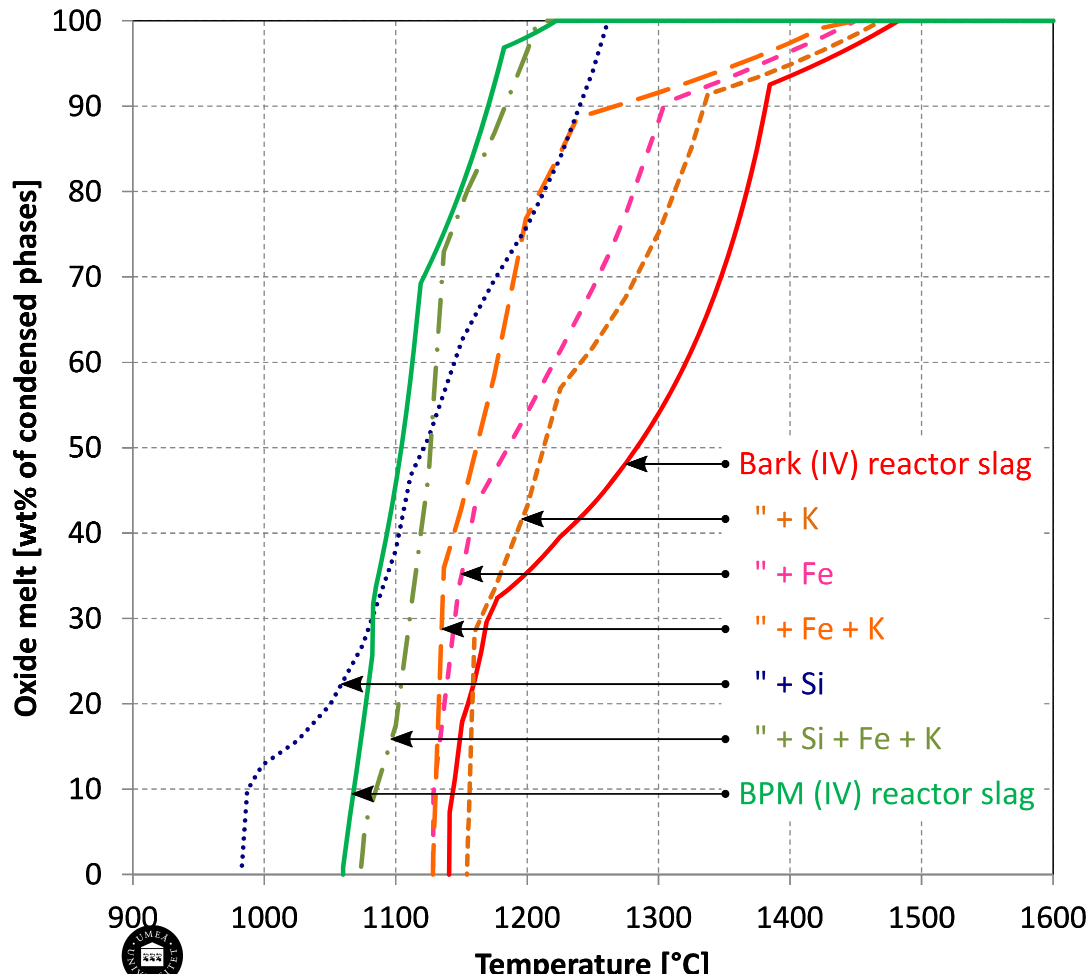
Bark (IV) – *sintered coarse particles*

+Si
+Fe
+K

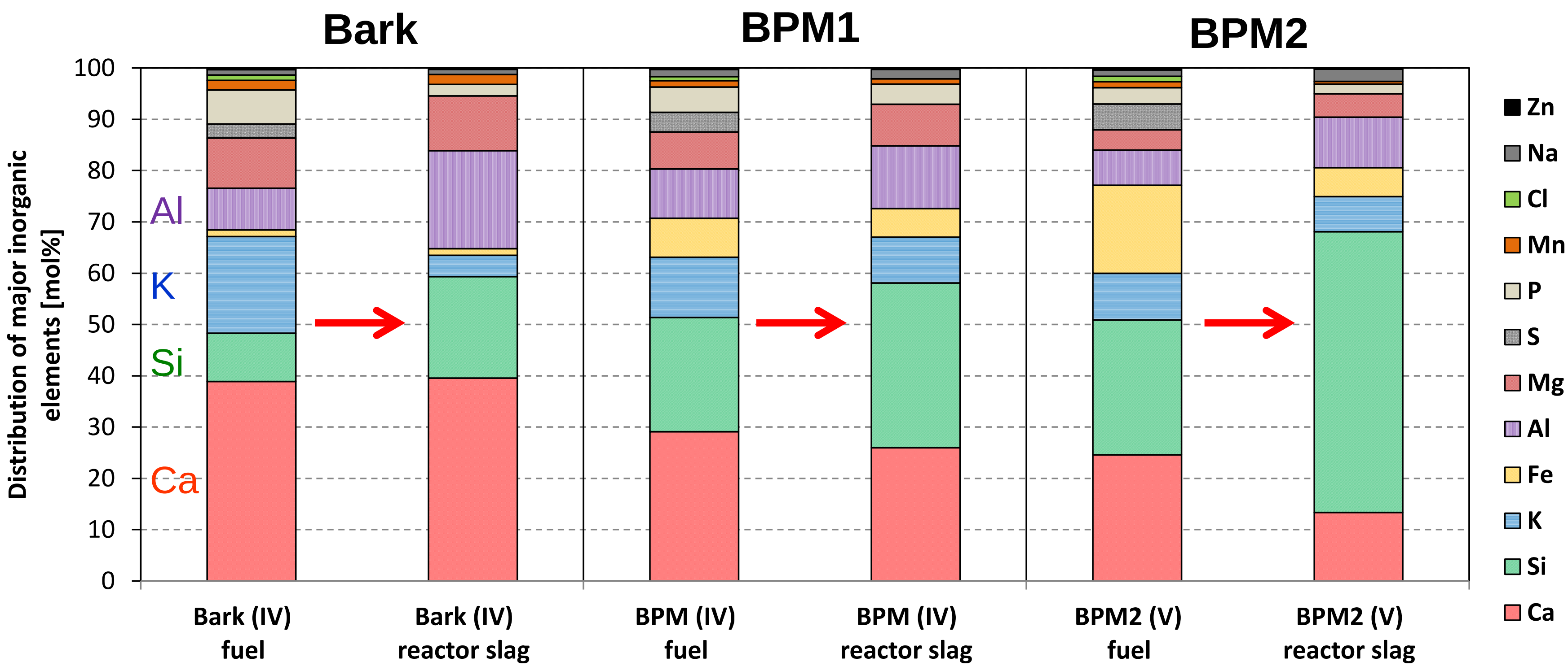


BPM (IV) – *consolidated melt*

Melt formation – thermodynamic perspective



Fuel to Slag transformation



Fuel ash → Reactor: Ash fractionation of major inorganic elements → Reactor slag

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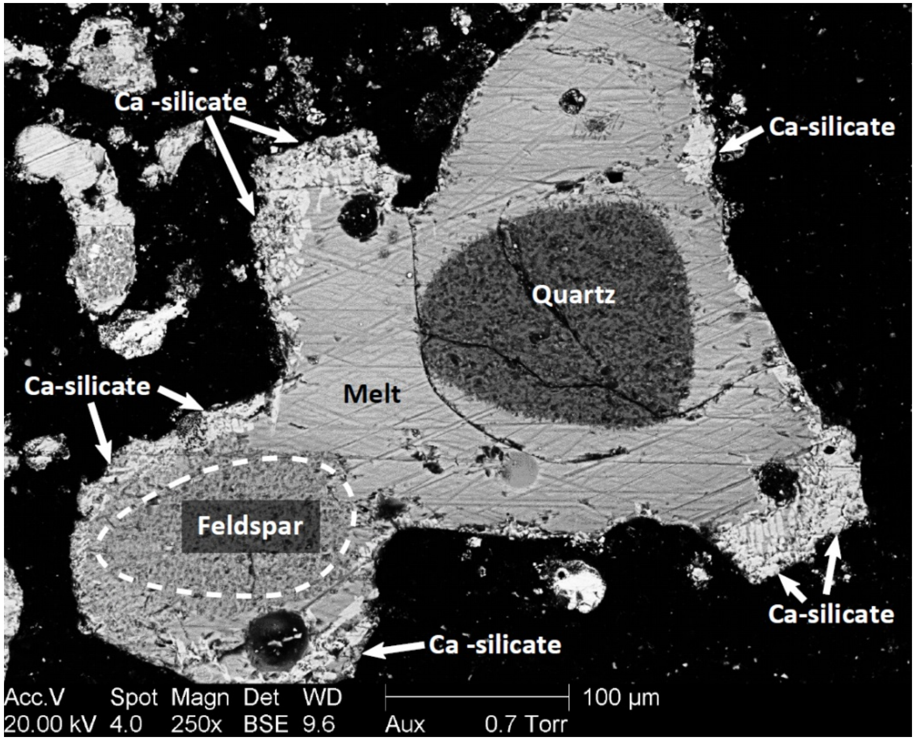
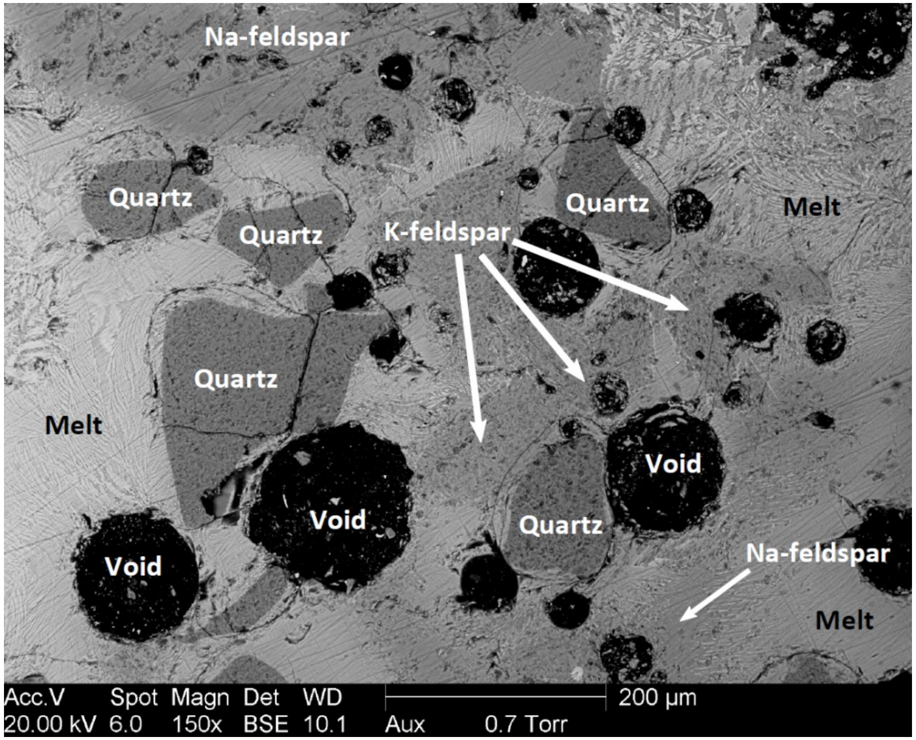
Reactor slags: composition and morphology



Bark reactor slag aggregates



PMDR consolidated reactor slag

Si-rich components dominate slag:
melt, quartz (SiO_2), & feldspar ($(K,Na)AlSi_3O_8$) particles
Mg, Ca, Al, Si, and K prominent in reactor slags (> 80 mol%)
Melts: alkali contents 10 – 20 mol%

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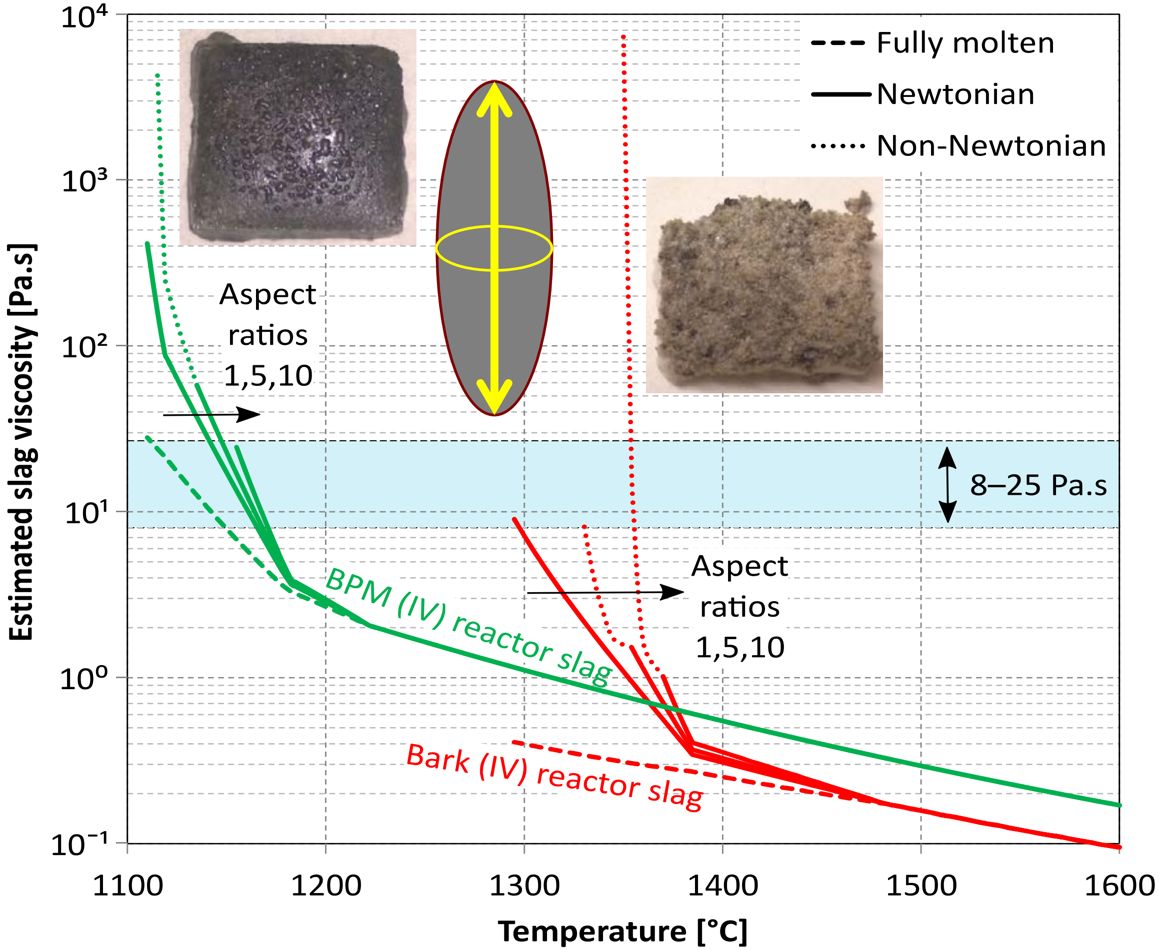
Viscosity estimation

FactSage 7.1 + Mader´s two-phase model



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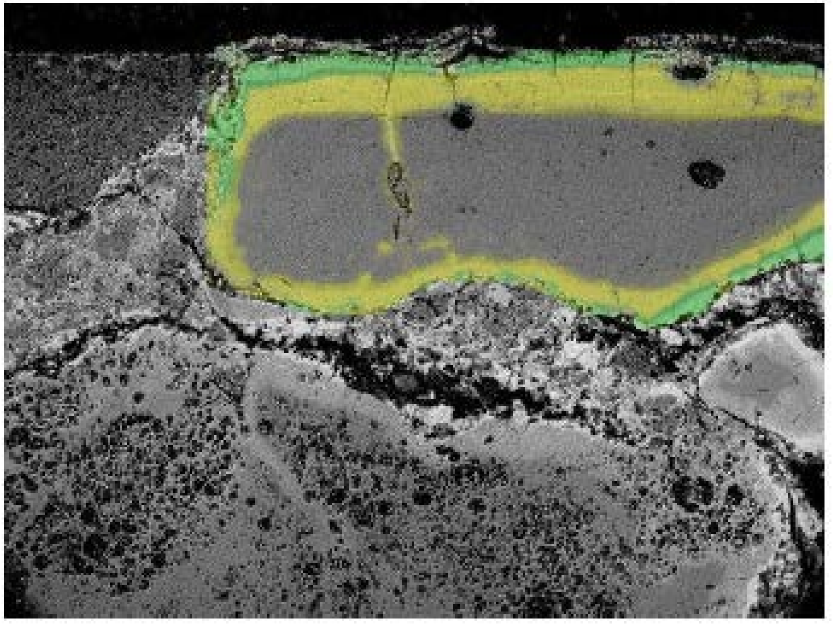
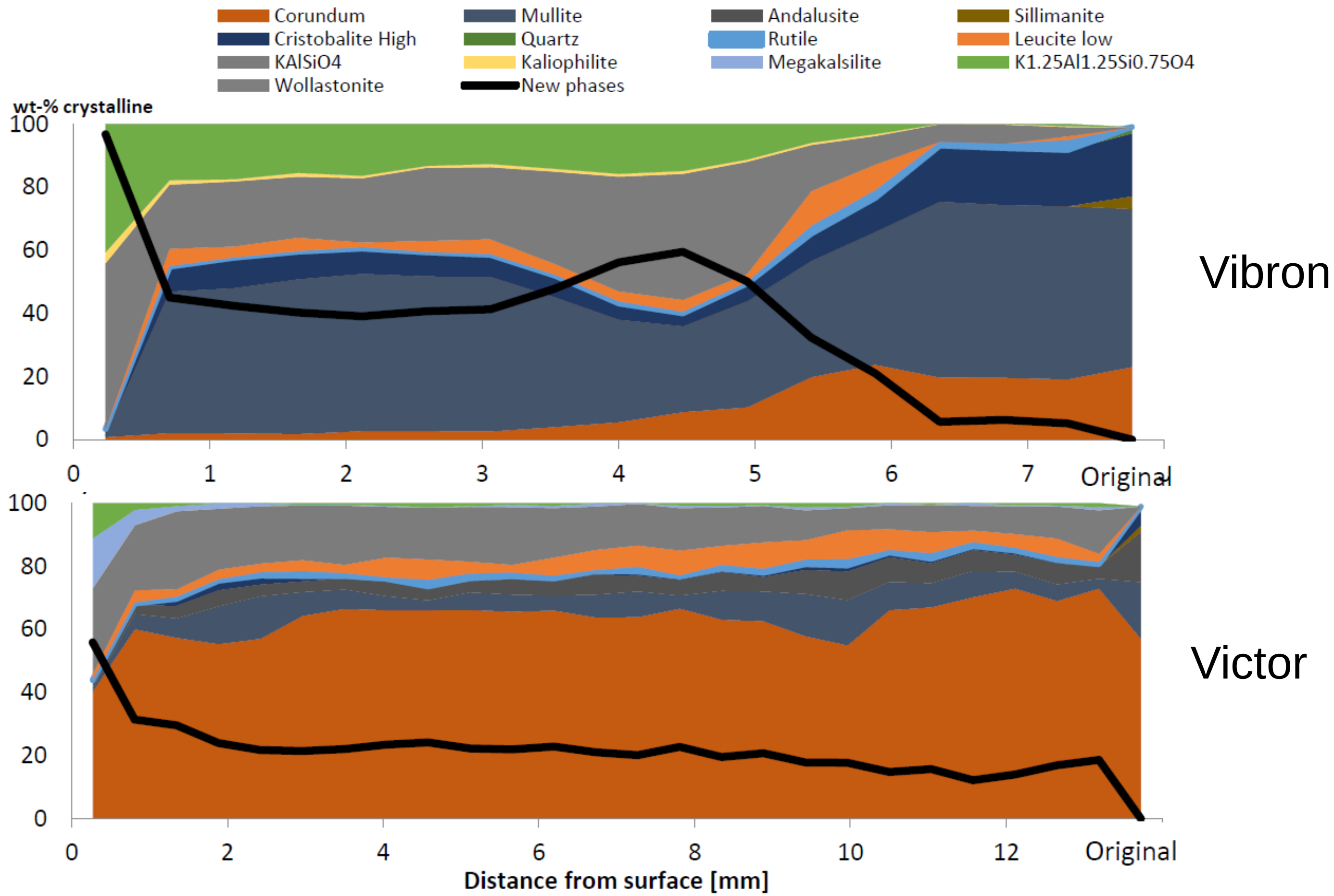
Chemical attack on refractory

Exposure tests at 1000°C: Potassium reacts with mullite grains.



Depth of penetration mullite based refractory

Exposure at 1000ºC K_2CO_3, XRD



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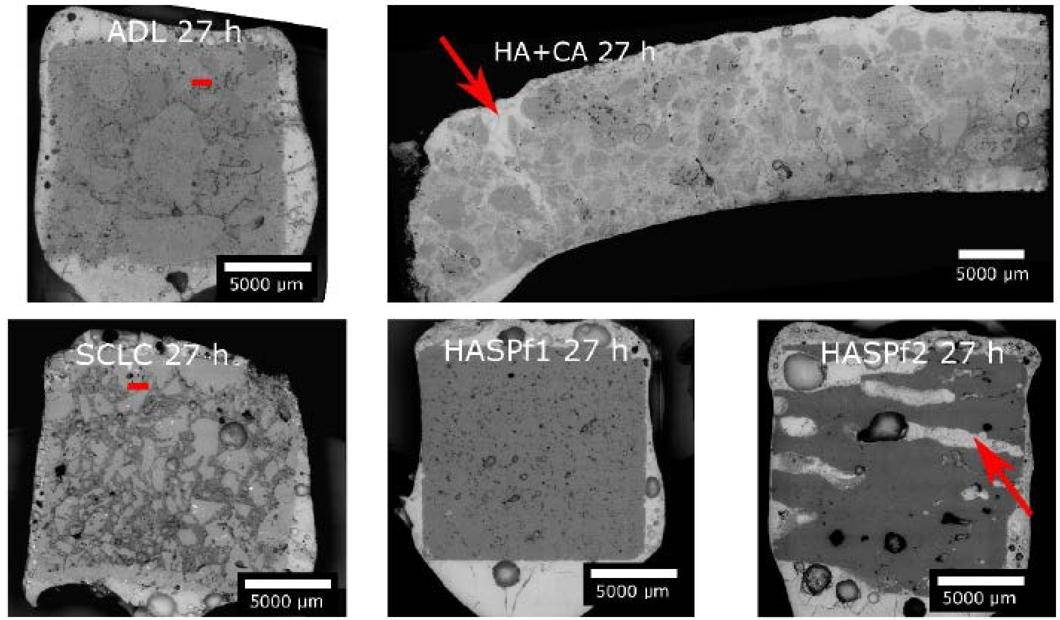
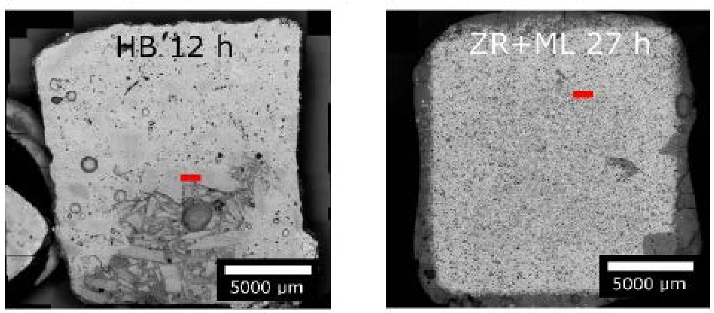
Carlborg 2013

Melt penetrates into refractory
atmospheric pilot runs 27h, 12h





ADL: Andalusite based castable
HA+CA: Tabular corundum based castable
SCLC: Silicon carbide, low cement
HASPf1: Fused-cast high alumina spinel
HASPf2: Fused-cast high magnesia spinel
HB: Hibonite, Al2O3 > 90%
ZR+ML: Isopressing zirconia with mullite

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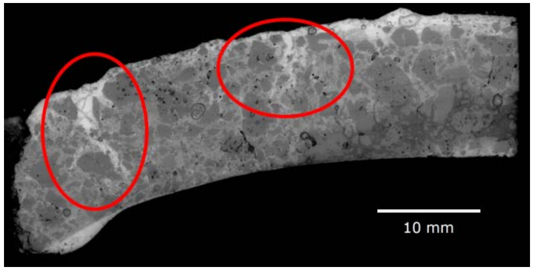
Estimated viscosity of infiltrated slag

metod according to Besmann

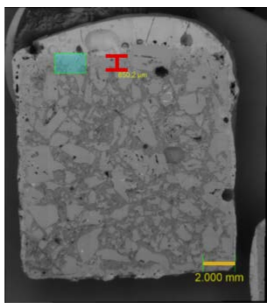


HA+CA

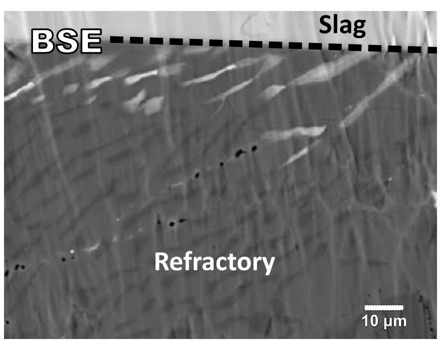
Impact of viscosity upon infiltration:

$$\text{Infiltration rate} \propto \frac{1}{\text{Viscosity}}$$

New phases: anorthite, melilite

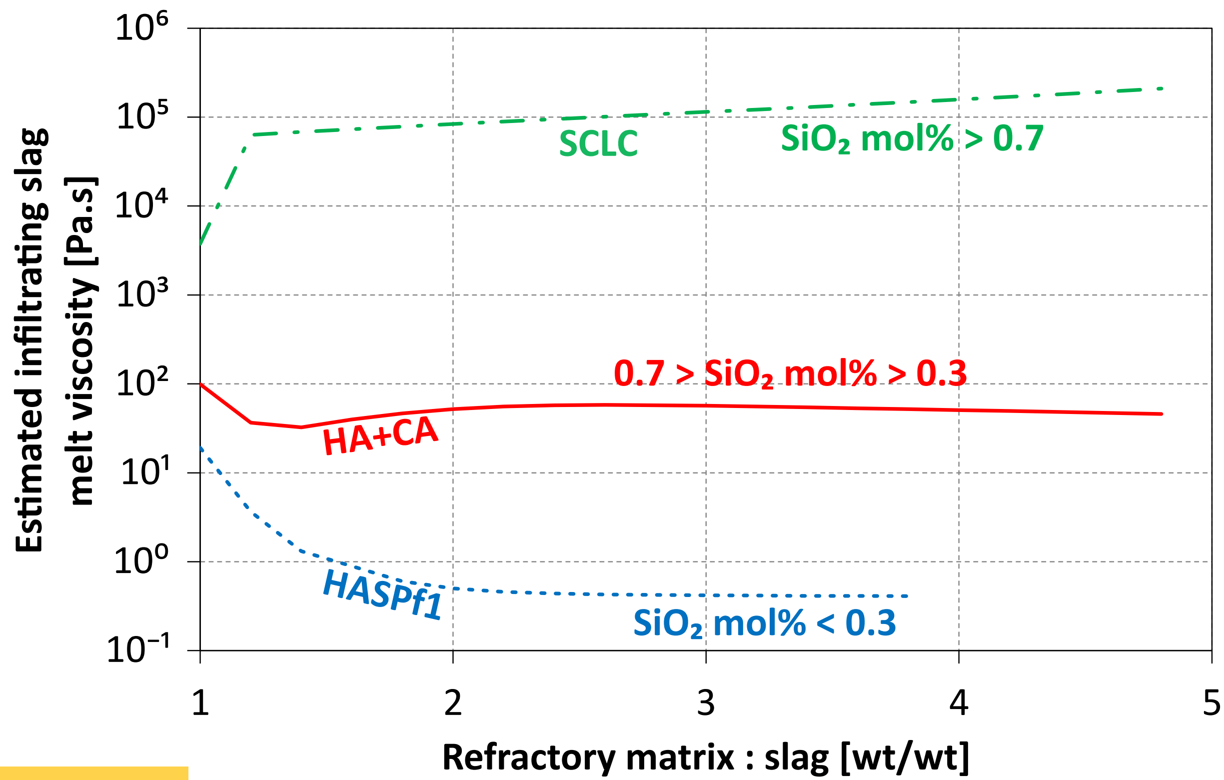


SCLC



HASPf1

No new phases



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CONCLUSIONS – SLAG FORMATION

Ash fractionation in PEBG campaigns

- Reactor slags enriched in Si compared to fuel ash compositions
- K and Cl likely volatilised out of the reactor

Slag formation and melting

- K-rich gasification atmosphere and Si thermodynamically important
- Si addition to bark reactor slag was most important in melt formation

Slag flow behaviour

- No flowing slag was produced from PEFG of the pure bark
- Blending bark with Si-rich peat produced reactor slag with bulk flow behaviour
- Estimations of slag viscosities were qualitatively consistent with observations

CONCLUSIONS - ASH/REFRACTORY INTERACTIONS

PEBG experience

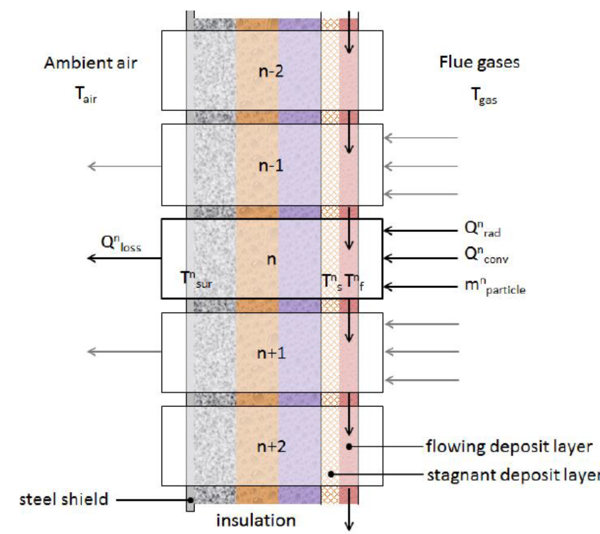
- Ash-induced dissolution of the PEFG reactor wall occurred

Refractory exposure campaigns

- Slag that degraded test refractories primarily via infiltration into the matrix
- SiC, hibonite, zirconia, and spinel grains were most resilient

Development of models

- useful generic models are emerging
- slag design possible in near future



STILL NEEDED

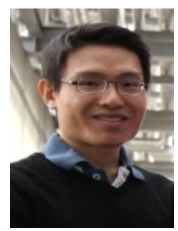
- Release of ash components
- Particle transport to the wall
- Crystallisation (kinetics, shapes, sizes)
- Viscometric studies
- Effect of carbonate formation
- Effect of surface tension
- Estimation of deposit temperatures and gradients

Recommended literature

DOCTORAL THESIS

Aspects of Ash Transformations in Pressurised Entrained-Flow Gasification of Woody Biomass

Pilot-scale studies



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http://www.diva-portal.org/smash/get/diva2:1087214/FULLTEXT01.pdf

Recommended literature

Wood-ash interaction with mullite based lining in entrained flow gasification

Carlborg, M.[1*], Boström, D.[1], Backman, R.[1], Öhman, M.[2]

[1]Thermochemical Energy Conversion Laboratory, department of Applied Physics and Electronics, Umeå University, SE-901 87 Umeå, Sweden

- Ma, C., Carlborg, M., Backman, R. & Öhman, M. "Slag formation during pressurized entrained-flow gasification of woody biomass – a thermochemical study". Conference proceedings: Impacts of Fuel Quality on Power Production, Snowbird, Utah, U.S.A., 26th–31st Oct. 2014.

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