Ash Deposition Prediction Tool for PF Boilers Fired with Coal and Biomass

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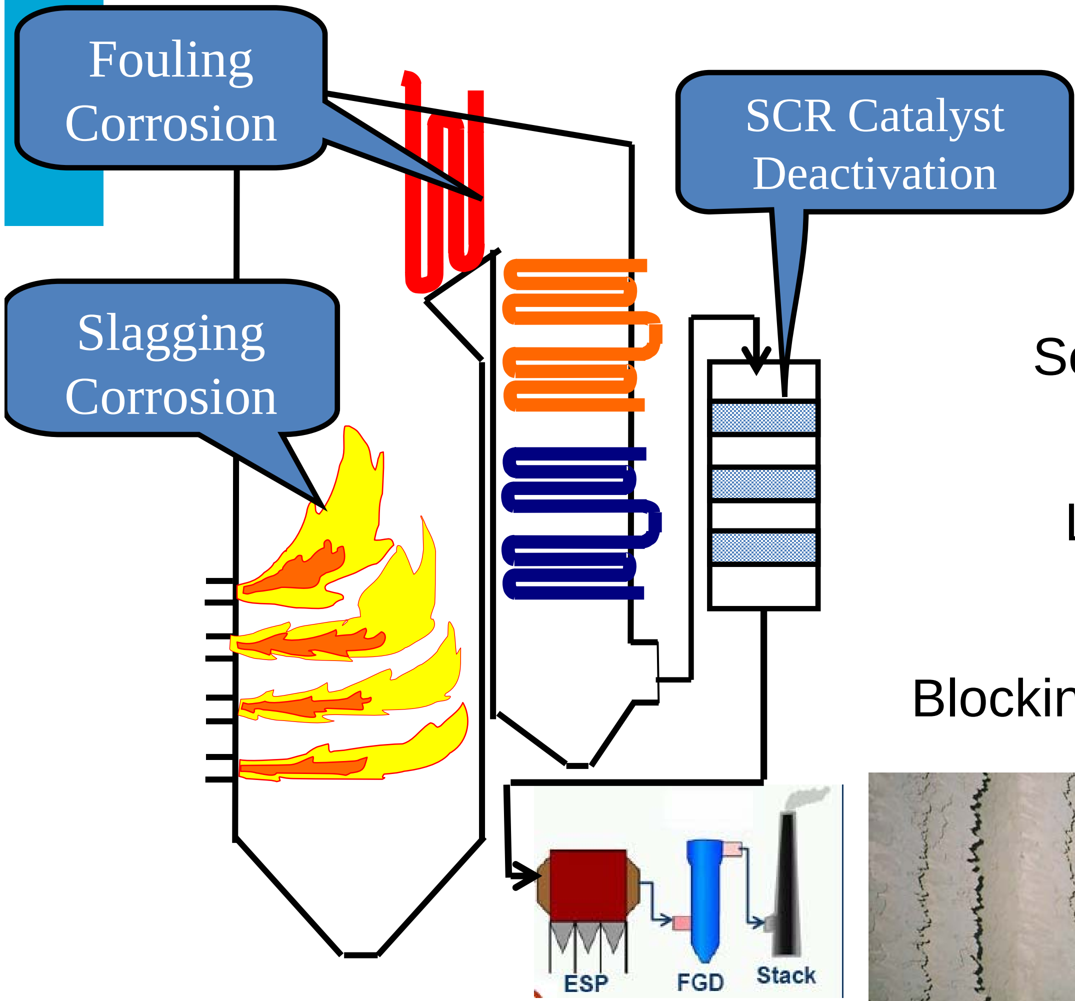
4. **Recommended Fuel Blends** -> importance of coal ash quality

Ash-releated Problems



<u>Slagging (1600-1300ºC)</u>

Molten or semi-fused ash

<u>HT Fouling (1300-900ºC)</u>

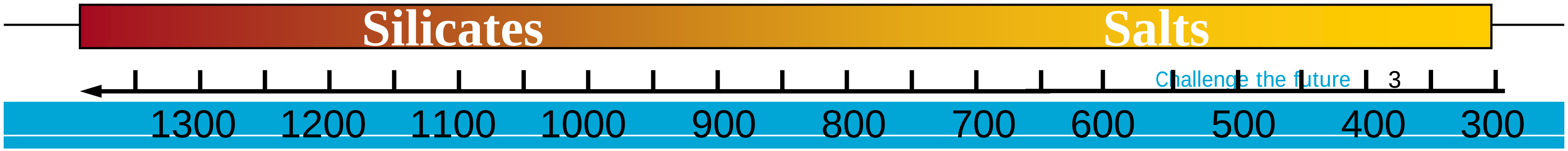
Semi-fused ash & sintered deposits

<u>LT Fouling (900-400ºC)</u>

Loose or slightly sintered deposits

<u>DeNOx Fouling&Poisoning</u>

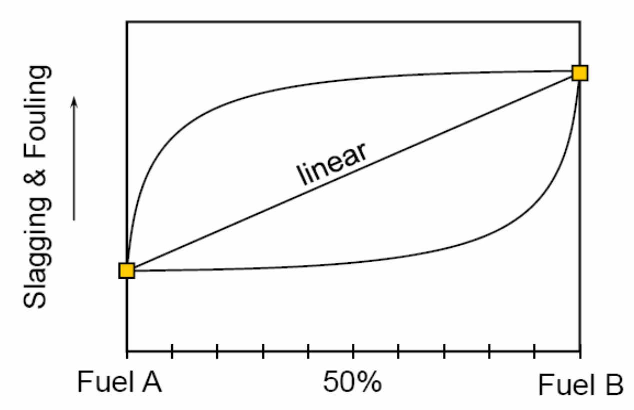
Blocking/poisoning of catalyst active sites



Current Models / Model Requirements

Slagging/fouling indices

- Mostly developed for coal combustion (limited to the range of coals)



CFD – Based models / simulators

- Time consuming, highly skilled
- Detailed ash deposition models are still under development (post-processors)

What is Needed

- Generic model => An Engineering Advisory Tool
- Easily adaptable model => various geometry and operating conditions
- Various fuel types => use of a comprehensive thermodynamic data (slag/solid/gas-phase=>FactSage)

ZONE-BASED MODEL - Temperature Profile (1D)

Boiler geometry / tube bank arrangement
Fuels data / detailed ash analysis
Firing pattern & Operating conditions

Reactive/non-reactive ash
(Chemical fractionation)

Thermal energy balance
Heat released (Fuel burnout)
Heat transfer (Ash deposition model)

Thermo-Chemical Analysis

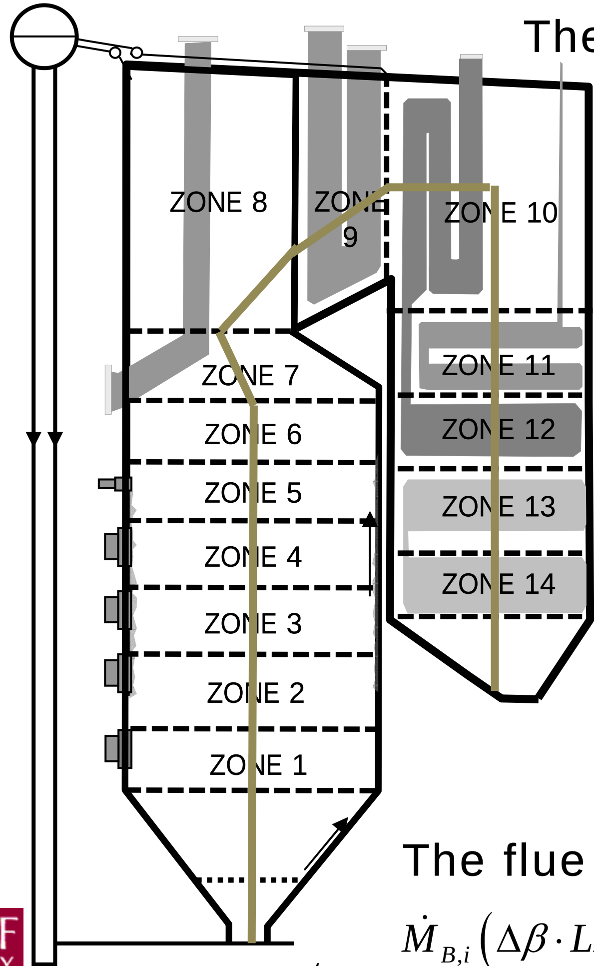
Melt phase distribution (slags + condensed alkali salts)
Deposition model (viscosity prediction + amount of molten ash)

POTENTIAL BOILER INDICATOR

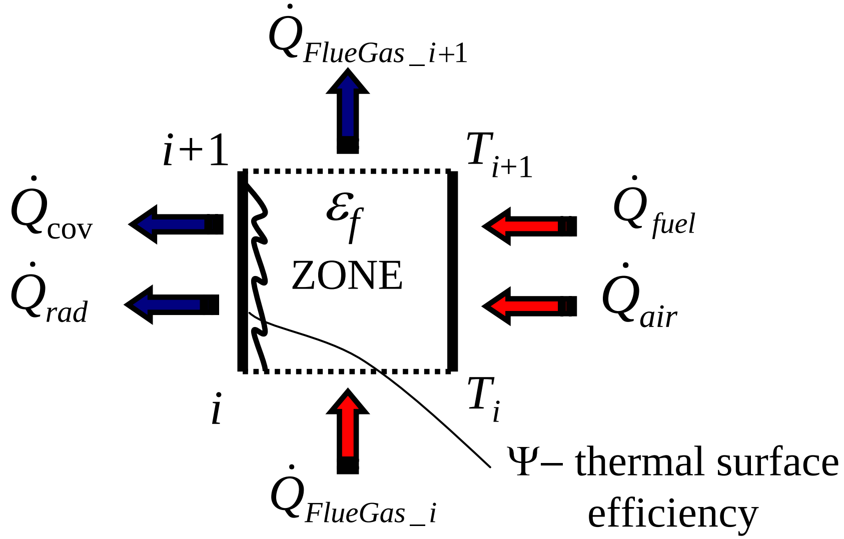
- **SLAGGING**
- **FOULING**
- **Boiler Efficiency**
- **Boiler's operational parameters**

Simulation of deposit build-up
Direct impact of deposition on boiler performance

Zone-based Model



Thermal energy balance of a zone in the furnace:

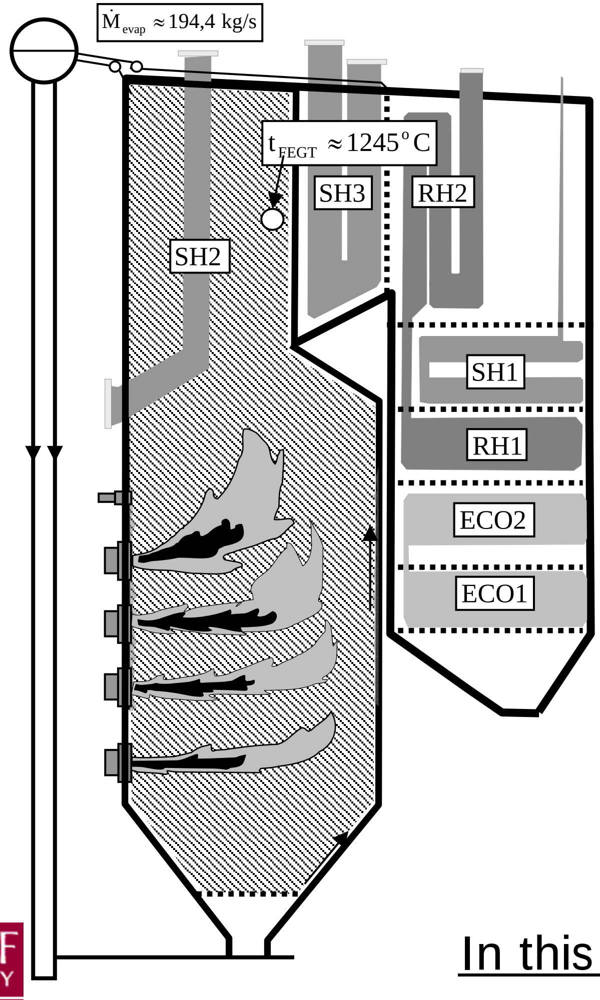


$$\dot{Q}_{FlueGas\_i} + \dot{Q}_{fuel} + \dot{Q}_{air} - \dot{Q}_{rad} - \dot{Q}_{cov} - \dot{Q}_{FlueGas\_i+1} = 0$$

The flue gas temperature at the outlet of the furnace:

$$t_{i+1} = \frac{\dot{M}_{B,i}\left(\Delta\beta \cdot LHV + i_f\right) + Q_{Air,i}}{\dot{M}_{B,i+1}VC_{i+1}} + \frac{\dot{M}_{B,i}VC_i}{\dot{M}_{B,i+1}VC_{i+1}}t_i - \frac{\sigma_0\varepsilon_f}{\dot{M}_{B,i+1}VC_{i+1}}\left[0.5\left(T_i^4 + T_{i+1}^4\right)\right]\times(\Psi F)$$

Case study: 230MWe PF Boiler



The coal burned was a blend of

- South African
- Australian
- Colombian Coal

Secondary fuels considered for co-firing

- Sawdust -> up to 60th%
- Straw -> up to 30th%
- Olive Residues -> up to 30th%
- Sewage Sl. -> up to 10th%

In this study no biomass fuels mixtures were investigated!

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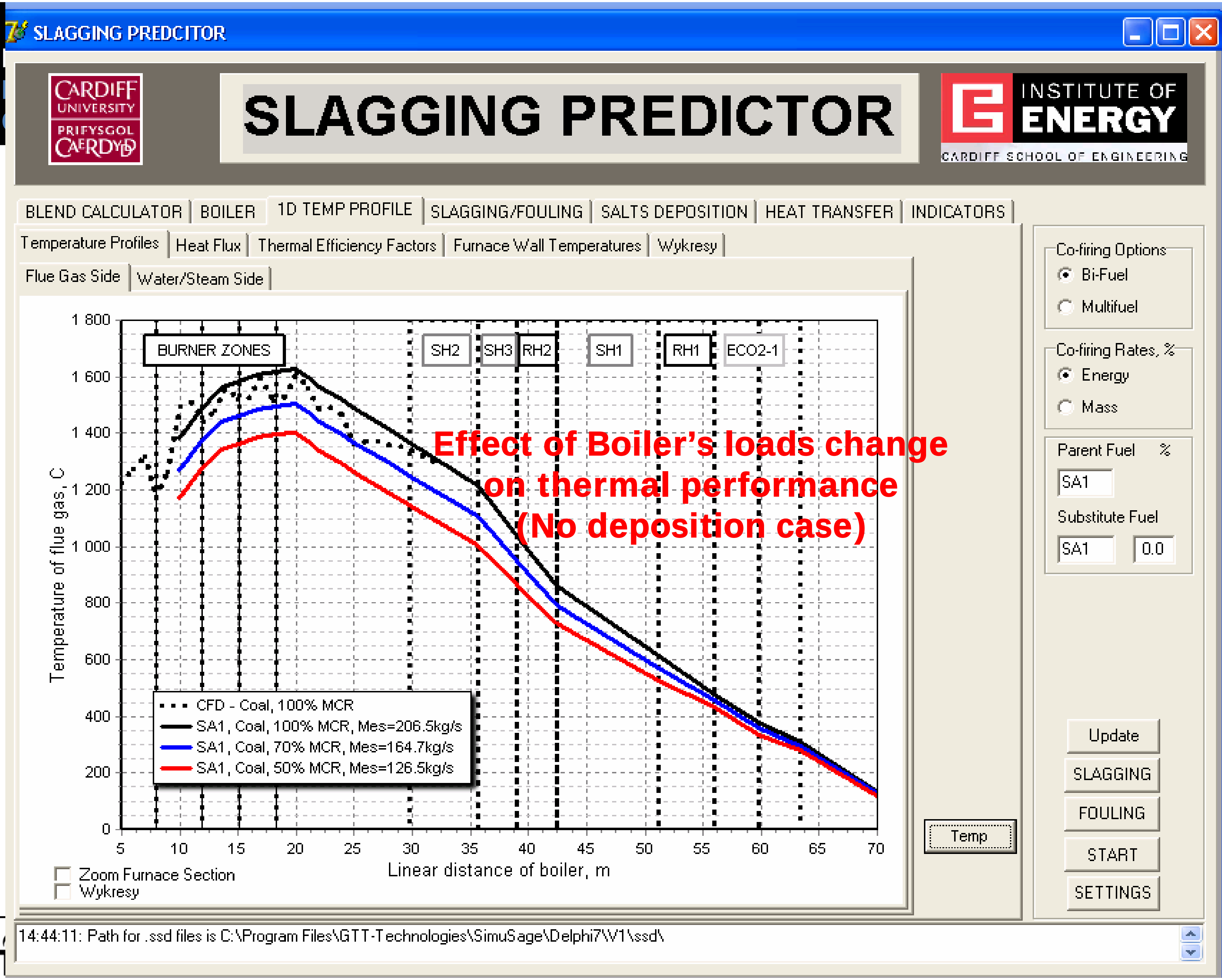
Investigated Fuels

Fuel property	Colombian Coal – CO1	South African Coal – SA1	Australian Coal– AL1	Sawdust SD2/SD2wet	Olive Residue – OR3	Sewage Sludge – SL1	Danish Straw – DS2
LHV,(ar) kJ/kg	26080	24070	22160	17630 / 10480	16400	9100	14670
Proximate analysis (% as received basis)							
Volatile Matter (VM)	34.03	24.52	28.30	77.43 / 49.94	66.24	36.72	68.49
Fixed Carbon (FC)	48.17	52.58	43.70	14.85 / 9.58	14.92	2.75	13.15
Moisture	9.00	6.30	3.30	**6.98 / 40.00**	9.00	11.72	12.40
Ash	8.80	16.60	24.70	0.74 / 0.48	9.84	**48.81**	5.96
AFM Composition (g/ kg fuel)							
Si	25.42	32.51	55.65	0.74	13.31	79.63	9.47
Al	9.83	25.83	41.31	0.09	1.56	31.52	0.30
Fe	4.06	8.36	13.65	0.15	2.71	64.87	0.27
Ca	1.38	8.66	6.71	2.35	**16.37**	40.12	3.11
K	1.75	0.96	0.82	0.84	**14.16**	10.94	**14.74**
Na	0.72	0.74	0.37	0.05	3.31	3.98	0.38
P	0.08	0.00	0.54	0.1	1.46	**30.89**	0.74
Cl	0.10	0.10	0.10	0.1	**9.10**	1.0	**4.82**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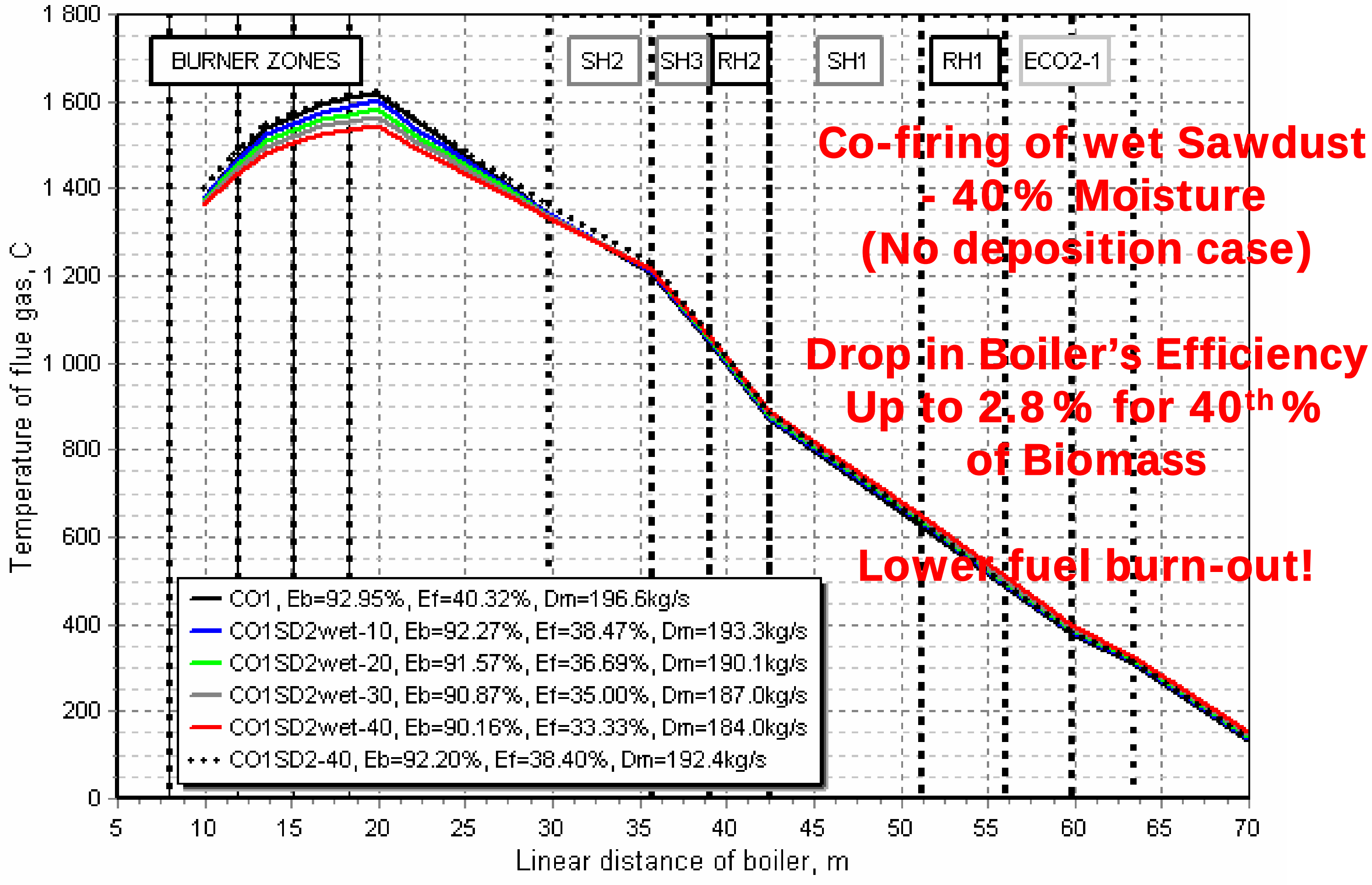
BOILER
1D TEMP PROFILE
SLAGGING/FOULING
SALTS DEPOSITION
HEAT TRANSFER
INDICATORS
Temperature Profiles
Heat Flux
Thermal Efficiency Factors
Furnace Wall Temperatures
Wykresy
Flue Gas Side
Water/Steam Side
Effect of Boiler's loads change on thermal performance (No deposition case)
BURNER ZONES
SH2
SH3
RH2
SH1
RH1
ECO2-1
Temperature of flue gas, C
Linear distance of boiler, m
CFD - Coal, 100% MCR
SA1, Coal, 100% MCR, Mes=206.5kg/s
SA1, Coal, 70% MCR, Mes=164.7kg/s
SA1, Coal, 50% MCR, Mes=126.5kg/s
Zoom Furnace Section
Wykresy
Temp
Co-firing Options
Bi-Fuel
Multifuel
Co-firing Rates, %
Energy
Mass
Parent Fuel %
SA1
Substitute Fuel
SA1
0.0
Update
SLAGGING
FOULING
START
SETTINGS
14:44:11: Path for .ssd files is C:\Program Files\GTT-Technologies\SimuSage\Delphi7\V1\ssd\

Predicted Thermal Boiler Performance



Heat transfer shifts towards the convective section of boiler

-> lower mass flows of the produced steam.

Conclussions – No deposition cases

Effect of the high moisture and low/high ash load on thermal boiler performance

SAWDUST

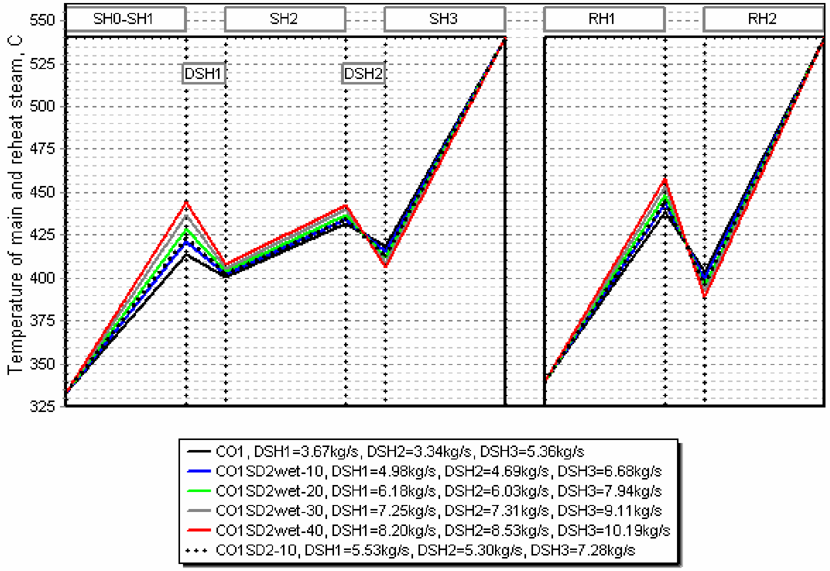
- Co-firing high percentages of wet sawdust may lead to significant drop in boiler efficiency, lower steam generation, and higher steam parameters variations -> resulting in steam overheating and increased spray-water injections into DSH

SEWAGE SLUDGE

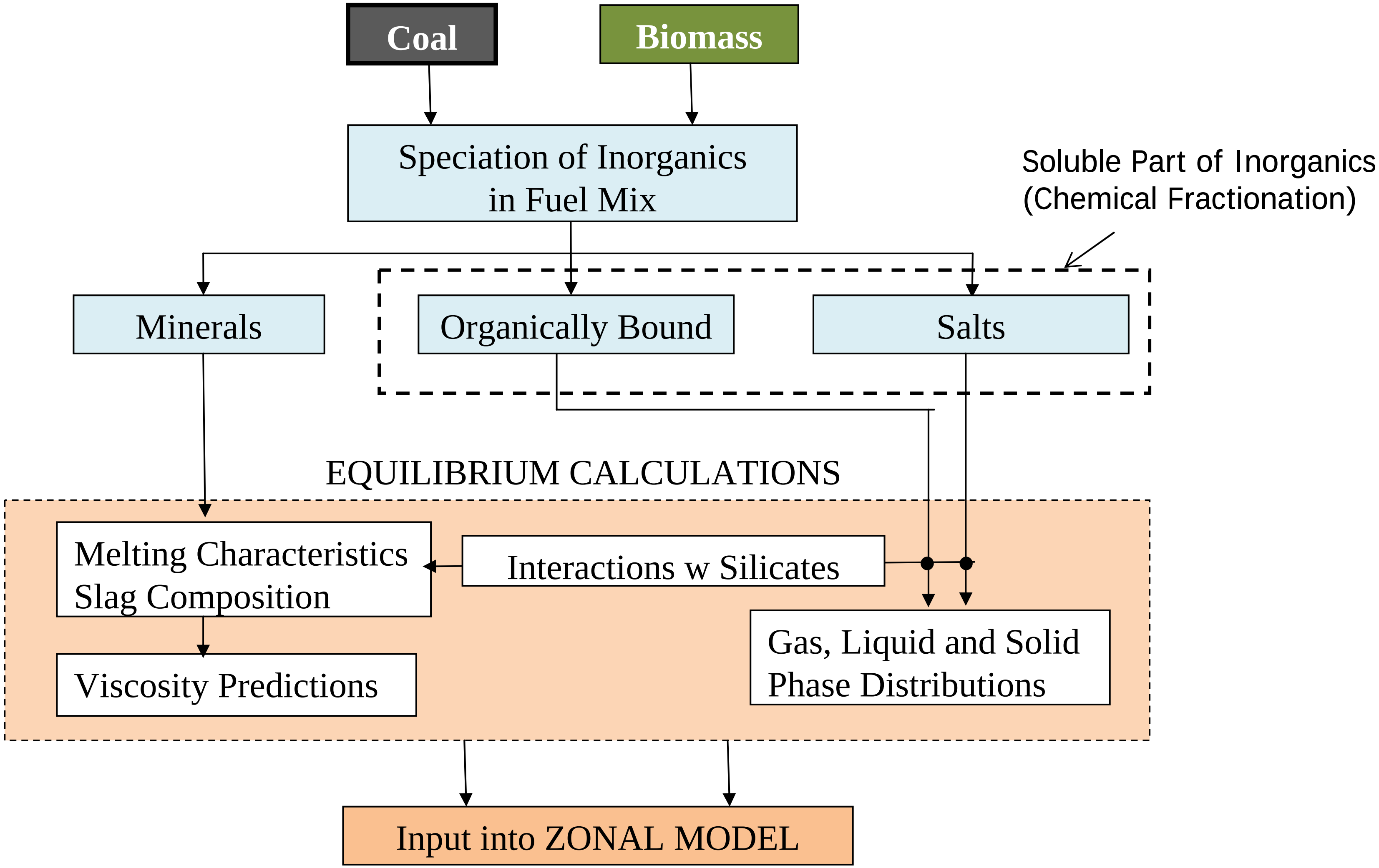
- Co-firing low percentages (up to 3th%) of high ash, dried sewage sludge may improve radiative heat transfer in the furnace, and thermal boiler performance! -> ash deposition?

NEXT -> ASH DEPOSITION CASES

Steam parameters variations
Sawdust Co-firing

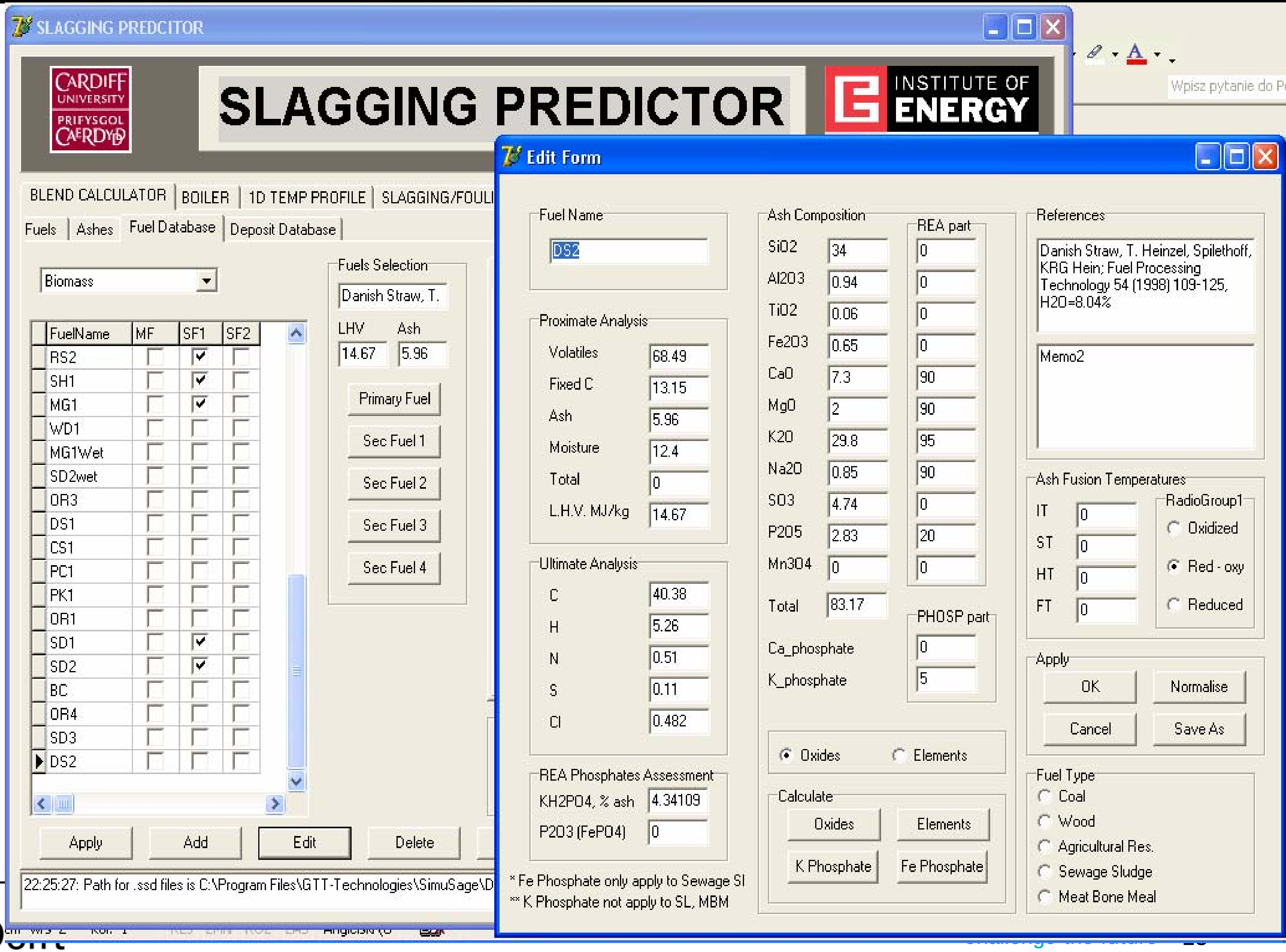


Ash Termochemical Deposition Module



Ref. Adapted and modified from: V. Doshi et all, *Fuel Process. Tech.*, Volume 90, Issue 9, 2009

Fuels Selection and Data Input Module



Mechanistic Model

- Deposition of sticky ash particles -> inertial impaction

$$\dot{m}_d = u_f \cdot C_{ash,I} \cdot \frac{A_{tube}}{A_{total}} \cdot \theta \cdot p_{stick} \qquad [kg/m^2 s]$$

u_f – the bulk gas velocity

$C_{ash,I}$ – the mass concentration of ash particle

p_{stick} – the sticking probability coefficient

A_{total} – the total flow area

A_{tube} – the cross-sectional area of the tubes perpendicular to the flow direction

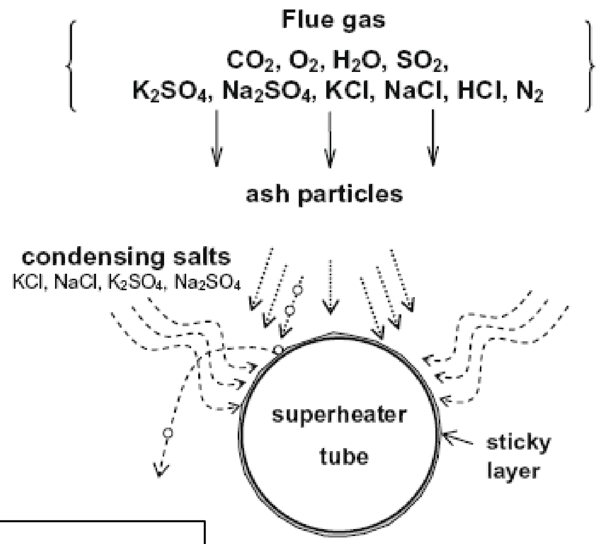


Fig. 2. Schematic presentation of ash particles deposition.

Thermo-chemical Equilibrium Analysis

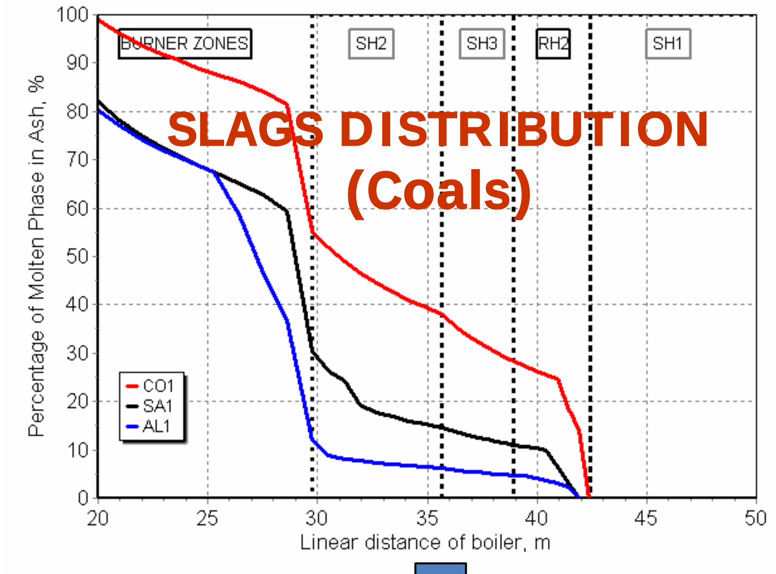
- **Percentage of the molten phase in the approaching to the tube ash particles**

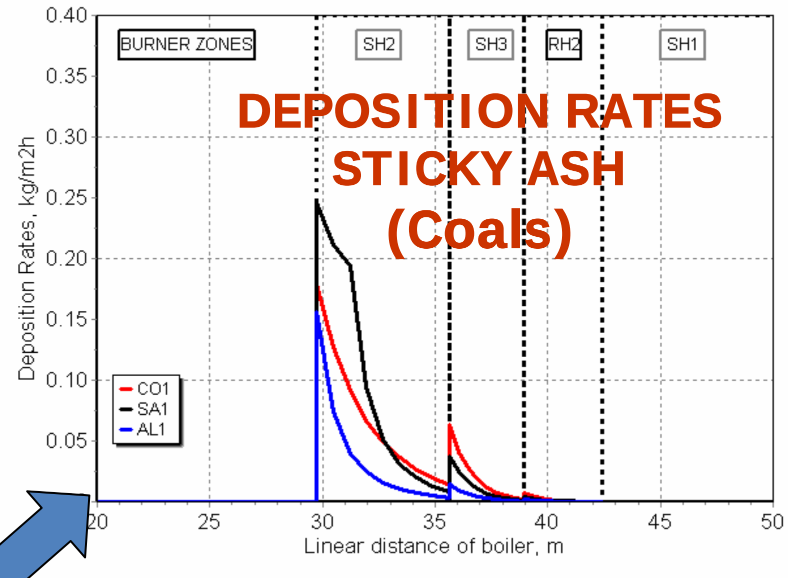
$$\theta = \frac{m_{slag}}{m_{solid} + m_{slag}} \cdot 100\,[\%]$$

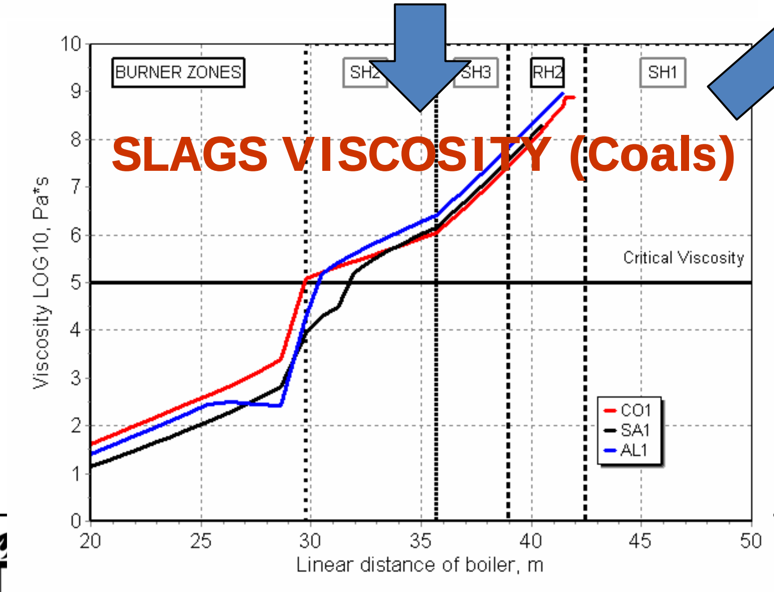
- **Sticking probability of the molten phase**

$$p_{stick} = \begin{cases} \frac{\eta_{ref}}{\eta} & \eta > \eta_{ref} \\ 1 & \eta \le \eta_{ref} \end{cases} \Rightarrow \quad \eta_{ref} \approx 10^3 - 10^5 \; Pa \cdot s$$

Predicted Results for Pure Coals

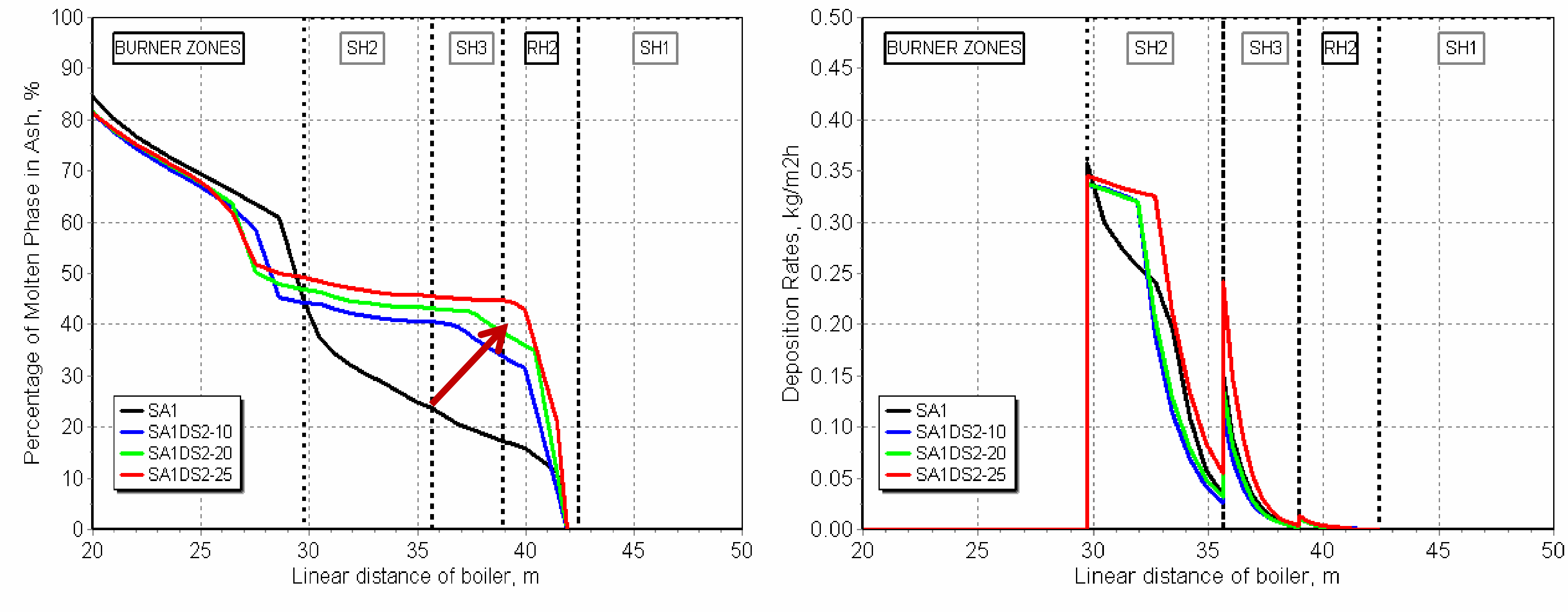






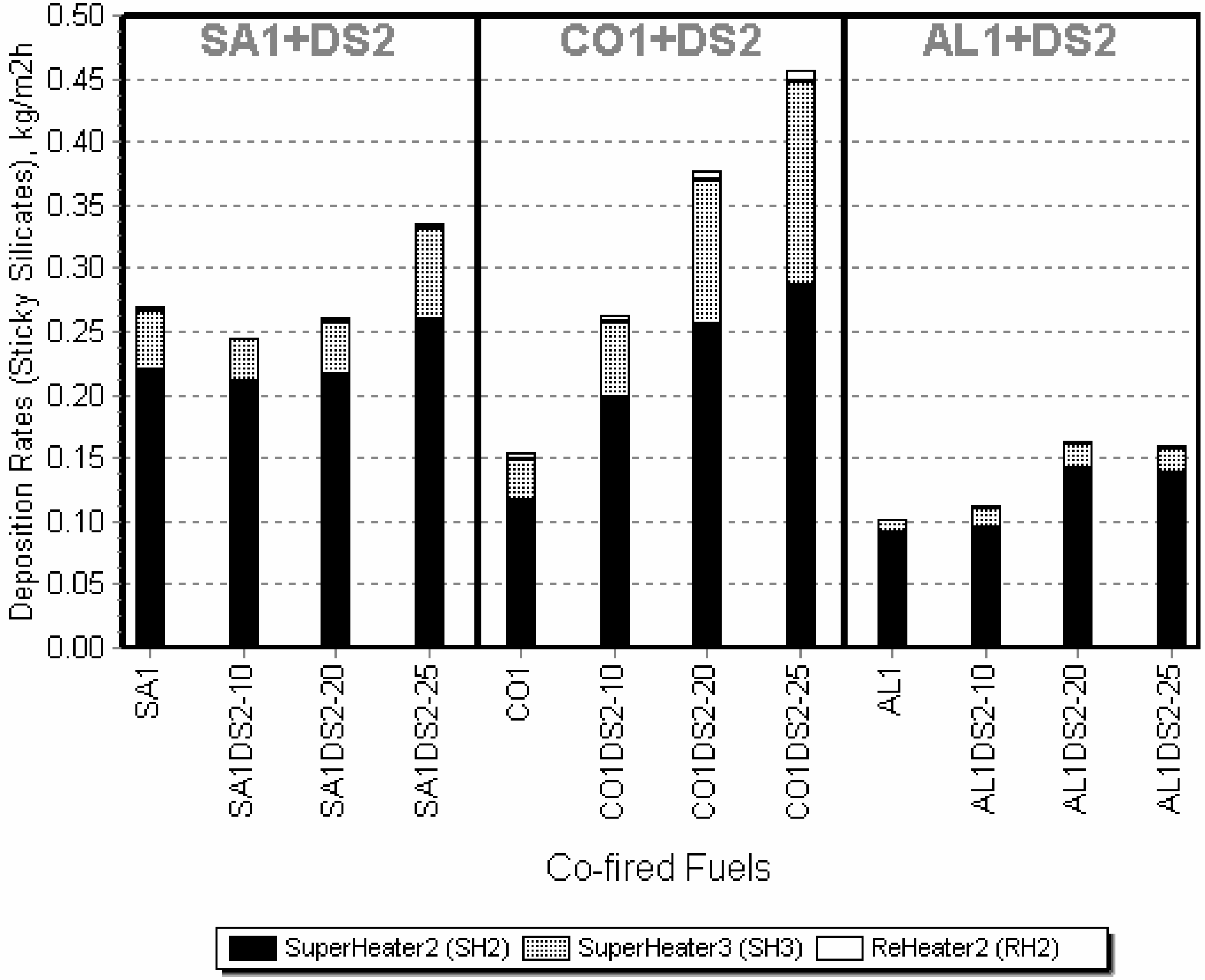
- AL1 – best ash characteristics, but high ash content (erosion)
- CO1 – twice higher potassium content in silicates /clays, but overall low ash; slag distribution extended to the furnace outlet (resulting in increased ash deposition risk in the SH3 region)
- SA1 – intermediate ash content, and slag distribution

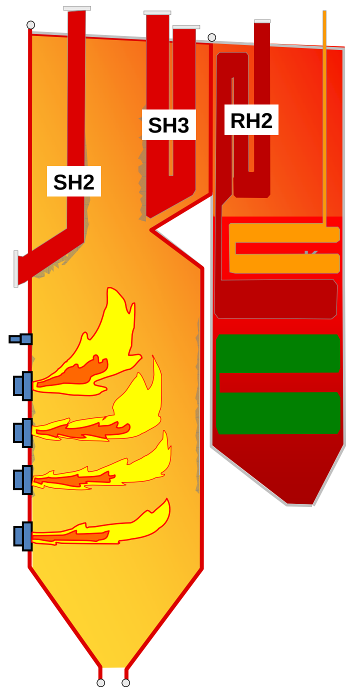
Co-firing Straw with Coal



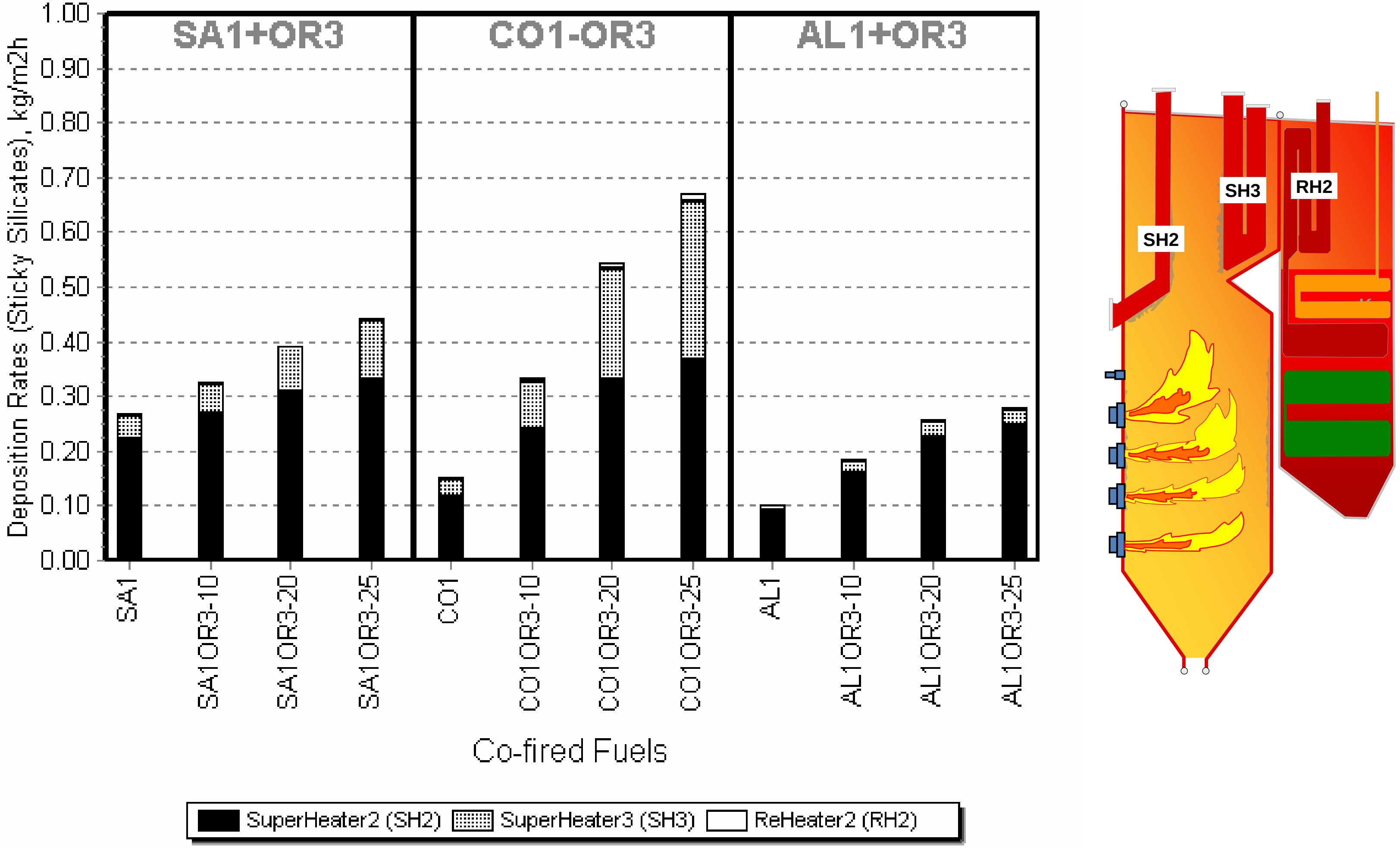
- Straw co-firing may change the melting characteristics of the viscous ash particles approaching the tube banks leading to the increase in ash deposition risk

Average Deposition Rates – Straw Co-firing

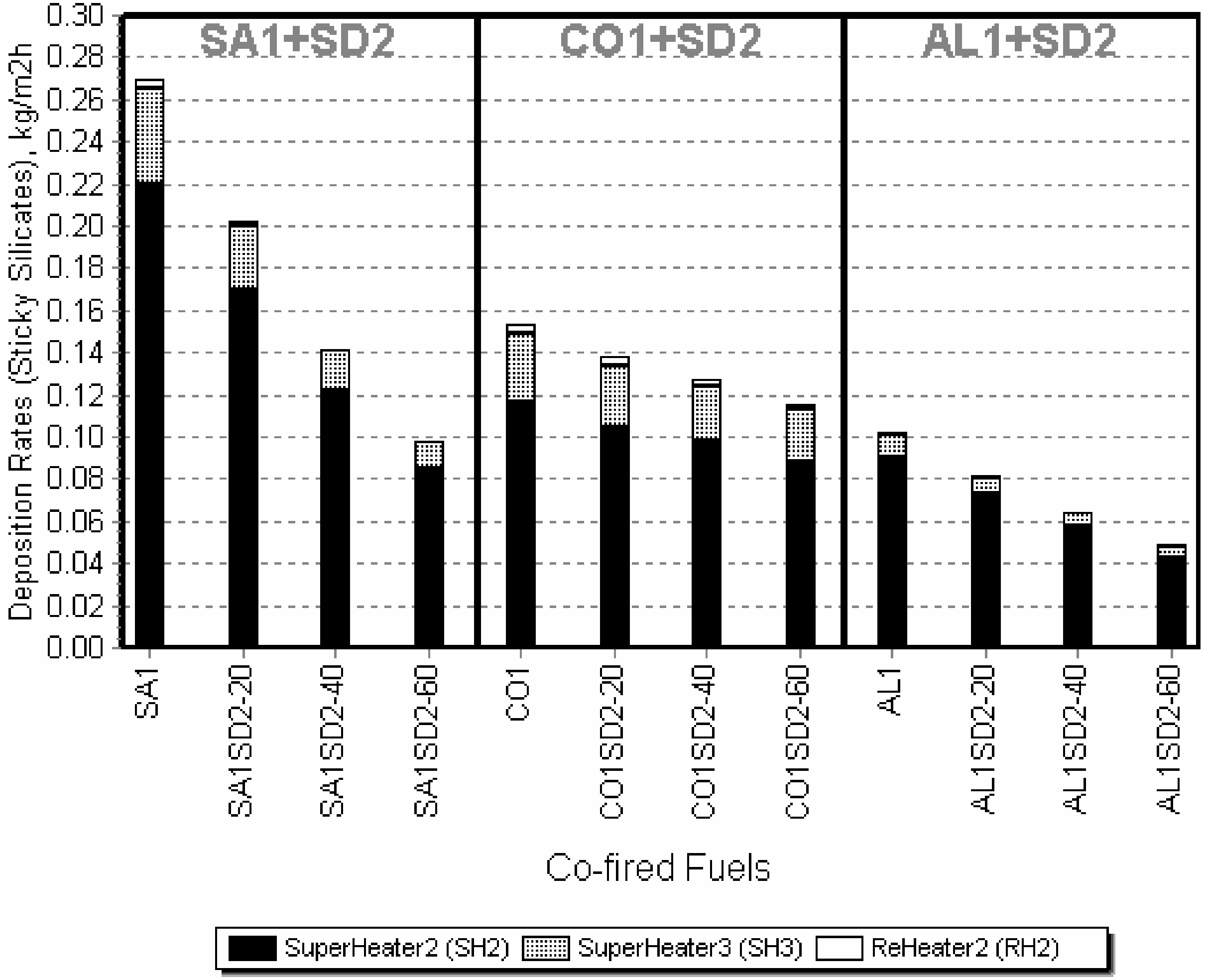


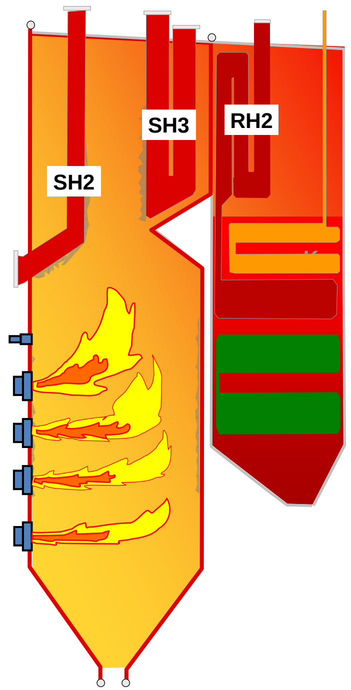


Average Deposition Rates – Olive Residues



Average Deposition Rates – Sawdust



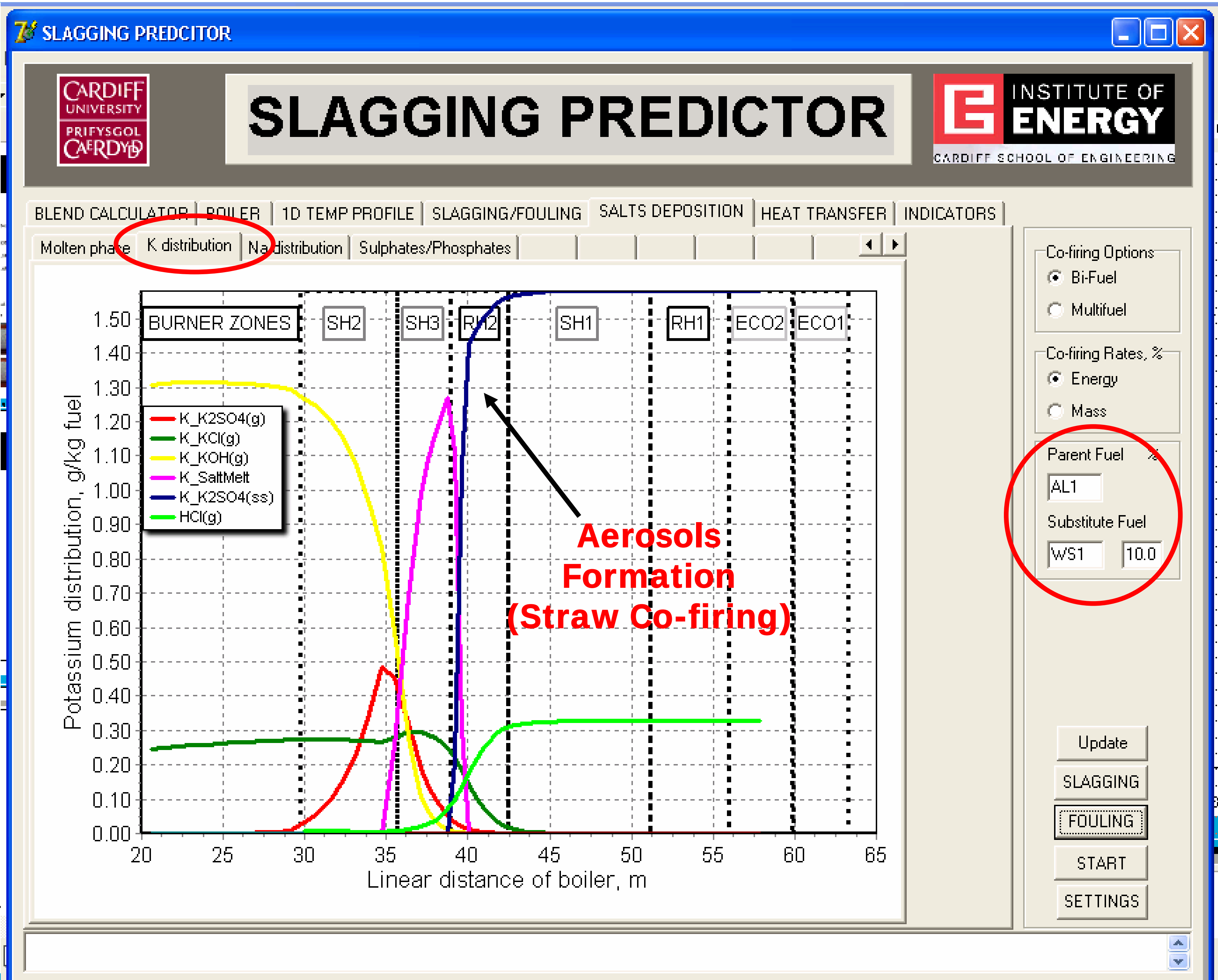


Mechanistic Model

- Salts Condensation / Deposition

An improved equilibrium model (based on FactSage data) was used to assess deposit formation risk originated from salts,

- Fate of Alkali Aerosols: Na, K (SO4/Cl)
- Formation of deposit binder - CaSO4 (s),
- Assessment of the P2O5(g), Ca3(PO4)2 (s) (phosphates)
- Risk of phosphoric acid H3PO4(liq) formation DeNOx- SCR poisoning
- HCl (g) concentration



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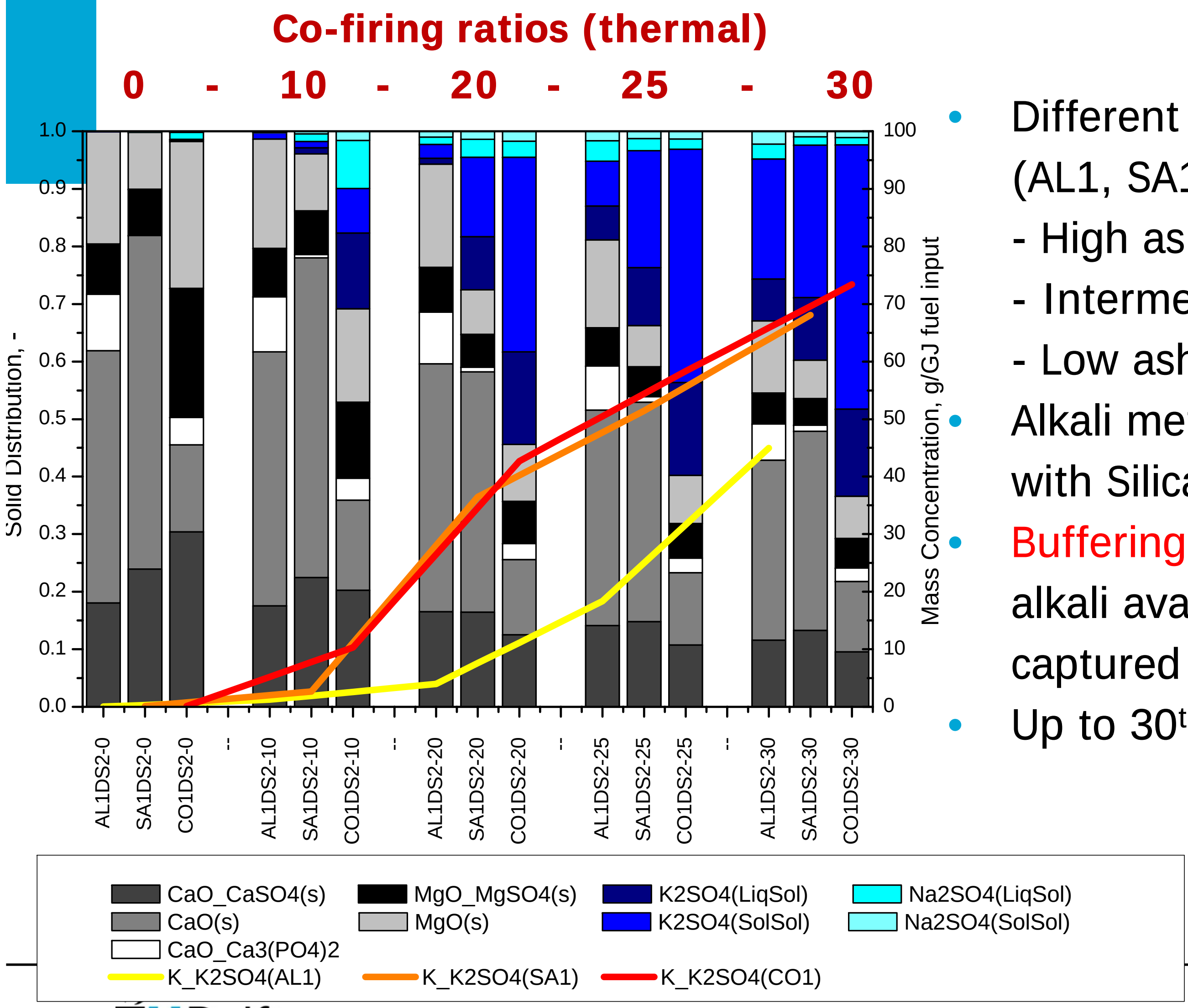
INDICATORS
Molten phase
K distribution
Na distribution
Sulphates/Phosphates
BURNER ZONES
SH2
SH3
RH2
SH1
RH1
ECO2
ECO1
K_K2SO4(g)
K_KCl(g)
K_KOH(g)
K_SaltMelt
K_K2SO4(ss)
HCl(g)
Potassium distribution, g/kg fuel
Linear distance of boiler, m
Aerosols Formation (Straw Co-firing)
Co-firing Options
Bi-Fuel
Multifuel
Co-firing Rates, %
Energy
Mass
Parent Fuel
AL1
Substitute Fuel
WS1
10.0
Update
SLAGGING
FOULING
START
SETTINGS

Salts Deposition Risk – Straw Co-firing



- Different coal ashes qualities studied (AL1, SA1, CO1)
  - High ash, low alkali content, AL1
  - Intermediate ash coal, SA1
  - Low ash, high alkali CO1
- Alkali metals interactions with Silicates/Clays considered
- Buffering effect of AL1 Coal – reduces alkali available for condensation -> captured by Si/Al ash particles
- Up to 30th% no chlorides in deposits

Conclusions

- Co-firing with biomass may have a positive or negative impact on the ash deposition (non-additive behaviour).
- The quality of coal fired has a crucial role in reducing ash deposition when co-firing with high alkali salts biomass
- Interactions between biomass and coal inorganics may influence the viscosity of the silica-based ash particles leading to the increase in slagging risk
- The developed predictive tool is most useful for comparing the relative slagging/fouling performance of coals/biomass blends.
- Future work will focus on gathering deposition data to validate and improve simulations.

Thank you for your Attention!

Reference List:

[1] Plaza P. et al., Use of a predictive model for the impact of co-firing coal/biomass blends on slagging and fouling propensity, Energy & Fuels, 23, 3437 – 3445, 2009

[2] Plaza P. et. al., Zone modeling approach for the assessment of the effects of biomass co-firing on pf boiler performance, Paper to be presented and published on the 37th Clearwater Clean Coal Conference, 3-7June, Florida

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