GTT User Meeting 2016, June 29th to July 1st

CFD Modelling of Power Station Boilers for the VerSi Project

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Background

- RECOM Services offers 3D-Combustion Modelling
  as a tool for the assessment of technical risks involved with:
  - Fuel Changes (Coal, Oil, Gas, Secondary Fuels)
  - Operational Changes (Air Distribution, Coal Bias, Particle Fineness)
  - Design Changes in Combustion Equipment (Low-NOx Burners, Overfire Air)

  for the Power and Process Industry

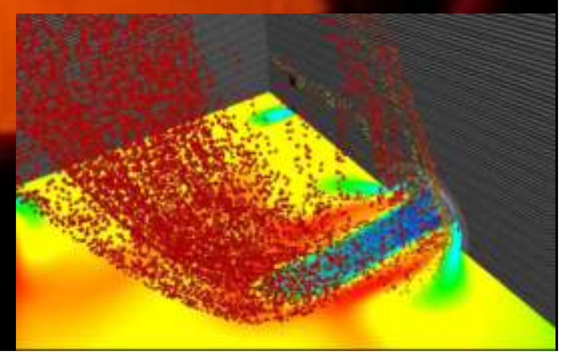
- RECOM Services is a Spin-Off from Stuttgart University (founded in 1999)

- RECOM Services uses an in-house developed CFD Code RECOM-AIOLOS, that is based on the AIOLOS code originally developed at Stuttgart University.

- RECOM-AIOLOS is a preconfigured CFD Software for the description of combustion processes in industrial-scale firing systems.

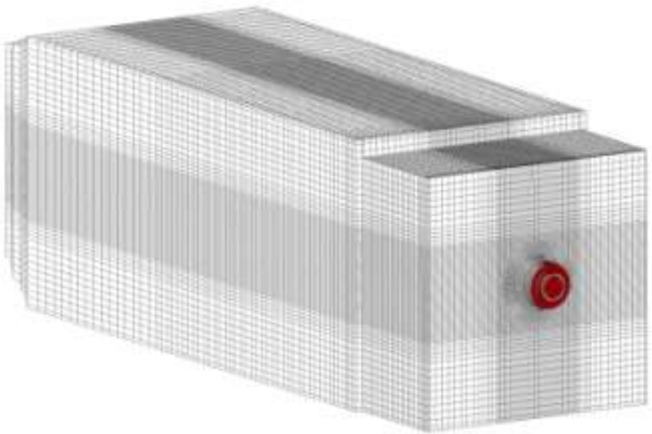
3D-CFD Simulation Software RECOM-AIOLOS

- **RECOM-AIOLOS contains a tailored model setup for the description of:**
  - **Fluid Flow and Turbulence**
  - **Multi-Phase continuum mechanics: solid fuels (e.g. biomass, coal), liquid fuels (e.g. oil), gaseous fuels (e.g. natural gas, syngas, etc.)**
  - **Combustion chemistry and pollutant formation (species transport, reaction kinetics, etc.) for solid, liquid and gaseous fuels.**
  - **Heat transfer (radiation and convection)**
  - **Deposit formation (slagging and fouling)**



CFD Model Development@

Single Burner Test Facilities



Tasks:

Calibration of Model Parameters for the Physical/Chemical Models

Verification of correct implementation

Analysis of the impact of spatial resolution

Assessment of predictive capabilities @

Full Scale Boiler

Assess Model Reliability for a wide variety of firing systems

No changes in Model Parameters

Only geometry, operational and fuel parameters are subject to change

Required spatial resolution identified in small scale testing has to be maintained also in the burner nearfield of the large scale model

RECOM Combustion Modelling Expertise and Validation Base

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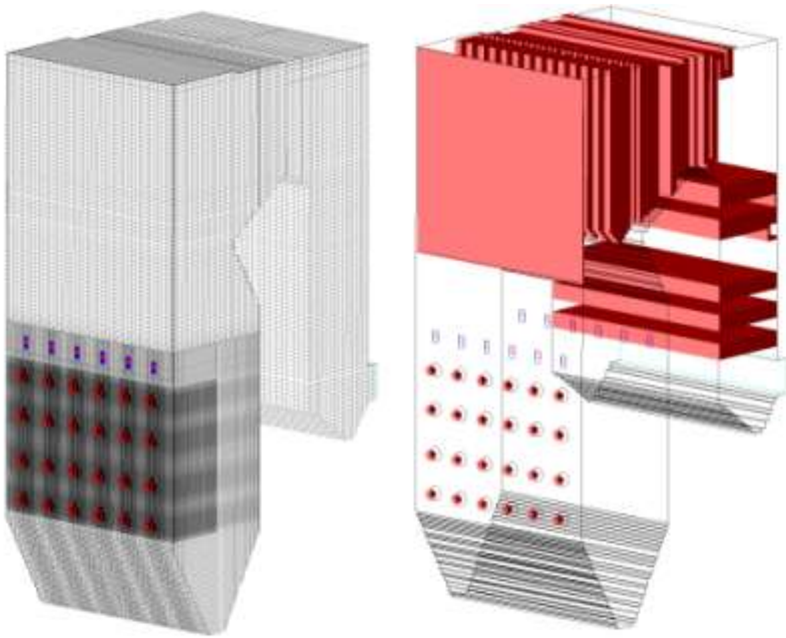
REACTION & COMBUSTION MODELLING

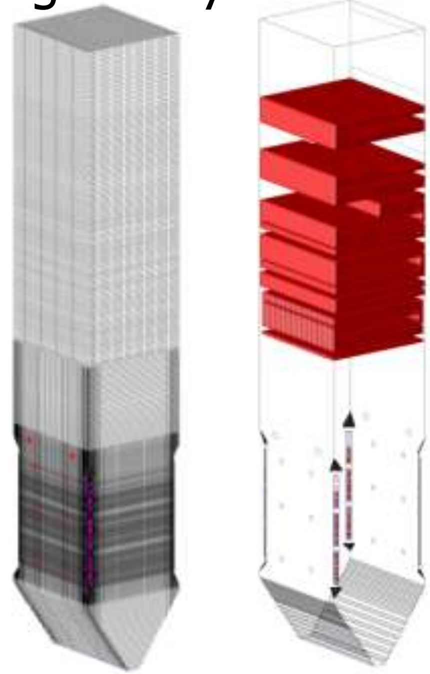
- In the past years RECOM has performed around 100 baseline simulations with comparison between field measurements and model predictions, and simulated more than 1000 boiler variations

    - The RECOM boiler model data base contains more than 100 boiler models

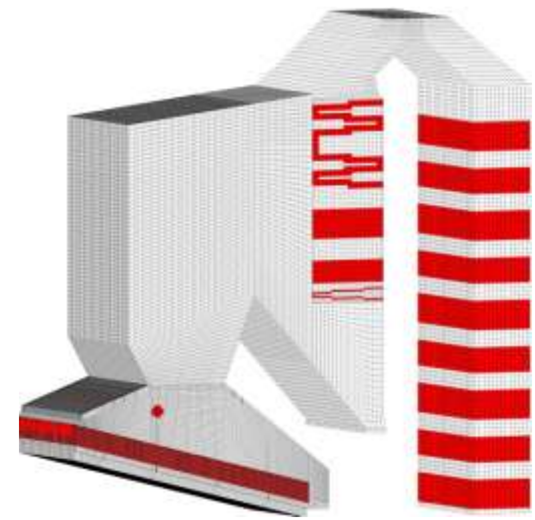
Wall-Fired Units



Tangentially Fired Units

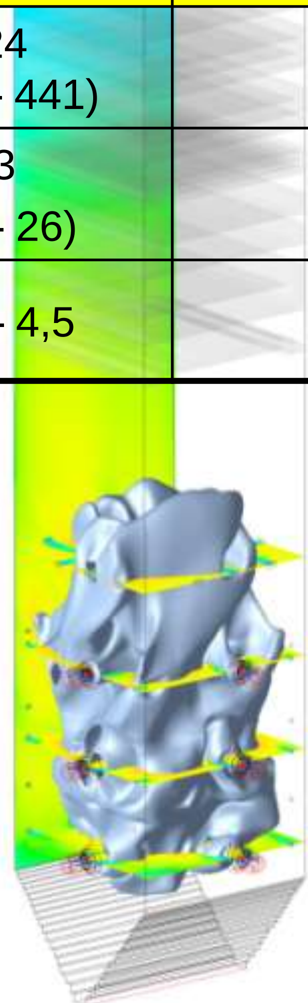


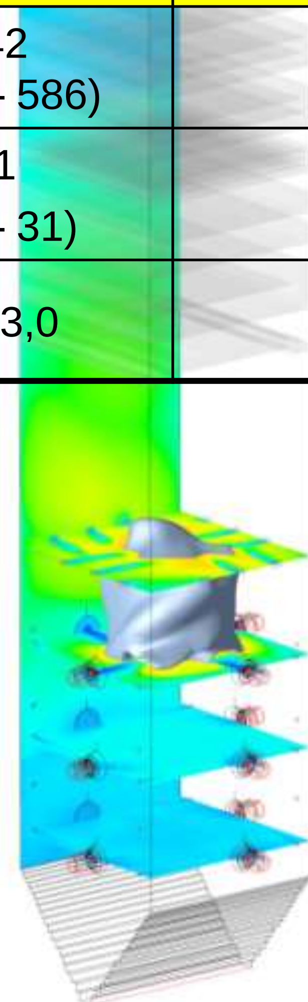
Stokers



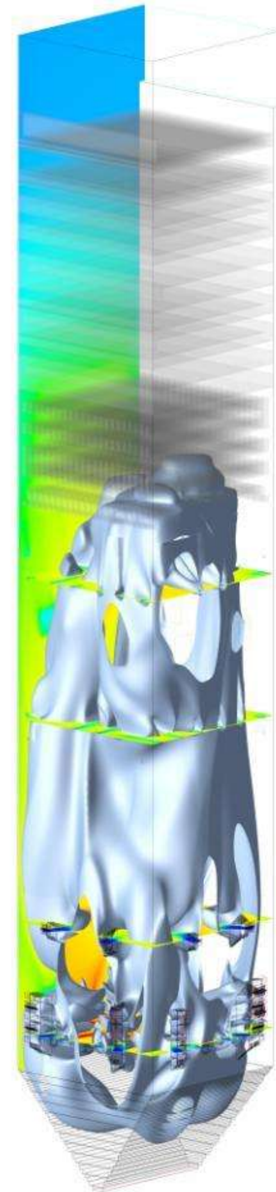
Reliable prediction of exit values for a bituminous coal boiler (staged)

	100% Load		28% Load	
	Measured	Simulation	Measured	Simulation
NOx [mg/Nm³@6%O2]	424 (411 – 441)	431	542 (508 – 586)	598
CO [mg/Nm³@6%O2]	23 (20 – 26)	20	31 (30 – 31)	26
Carbon in Fly Ash [wt.-%]	4,0 – 4,5	4,5	2,0-3,0	2,1





	Measured	Simulation	Measured	Simulation
Thermal Load raw / pre-dried lignite [%]	**100/0**		**79/21**	
NOx [mg/Nm³,6% O2]	**ø 166 (155 – 179)**	**169**	**ø 187 (138– 210)**	**188**
CO [mg/Nm³,6% O2]	**ø 5 (1 –10)**	**8**	**ø 4 (1 – 10)**	**8**



Customer base comprises original equipment manufacturers as well as companies of the power and process industry

CLYDE BERGEMANN
GDF SUEZ – BY PEOPLE FOR PEOPLE
LABORELEC
RWE
essent

Budenheim
VATTENFALL
MVV Energie
EnBW

PCK
ThyssenKrupp
EDF
e·on
Eskom

BILFINGER
steag
DSC
TARONG ENERGY
BWE – BURMEISTER & WAIN ENERGY A/S

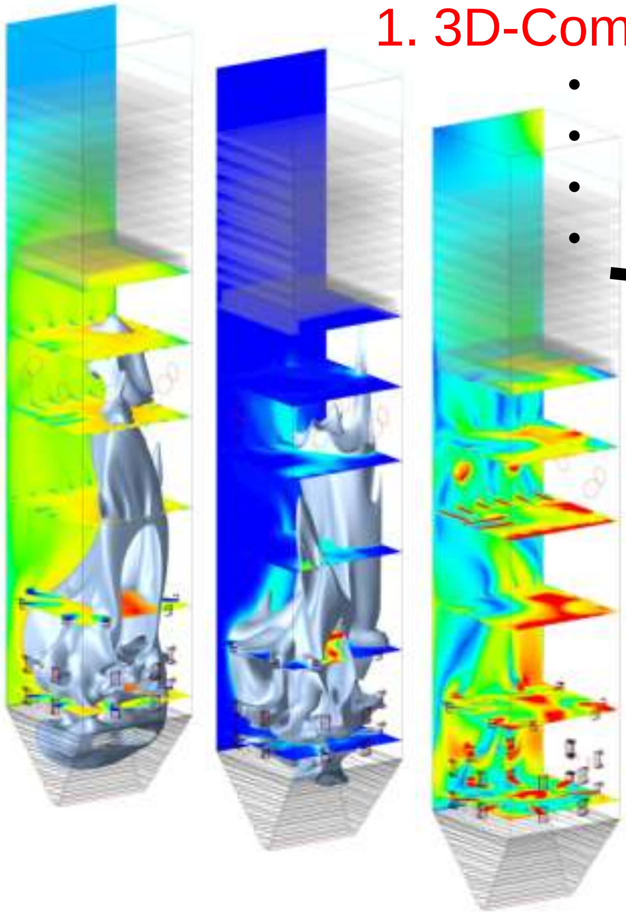
POWER SYSTEMS
ALSTOM
steinmüller engineering
SIEMENS
Balcke-Dürr

MITSUBISHI HITACHI POWER SYSTEMS EUROPE

Slagging phenomena threatens availability and efficiency of power plants

Deposition Modelling is an important part of many computer-aided optimization projects

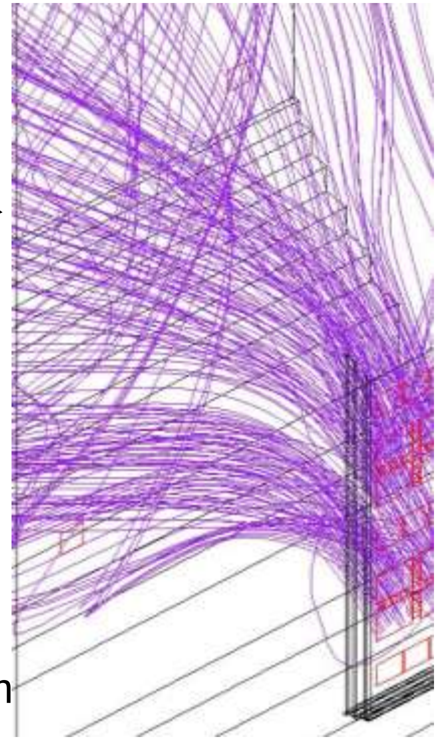
Current Approach for Deposition Modeling at RECOM



1. 3D-Combustion Simulation

- Temperature distribution
- Species Concentrations
- Flow Field
- …..

2. Deposition Simulation



- Computation of the deposit formation by Post-Processing
- Results of the 3D-Combustion Simulation are used as input for the Deposition Simulation
- Particle tracking determines the particle trajectorys for ca. 1 mio. particles using the input data from the combustion simulation
- Particle properties (e.g. mass, diameter, temperature, etc.) change during the particle flight as a consequence of the particle burnout

Sticking criteria judged based on ash melting temperature

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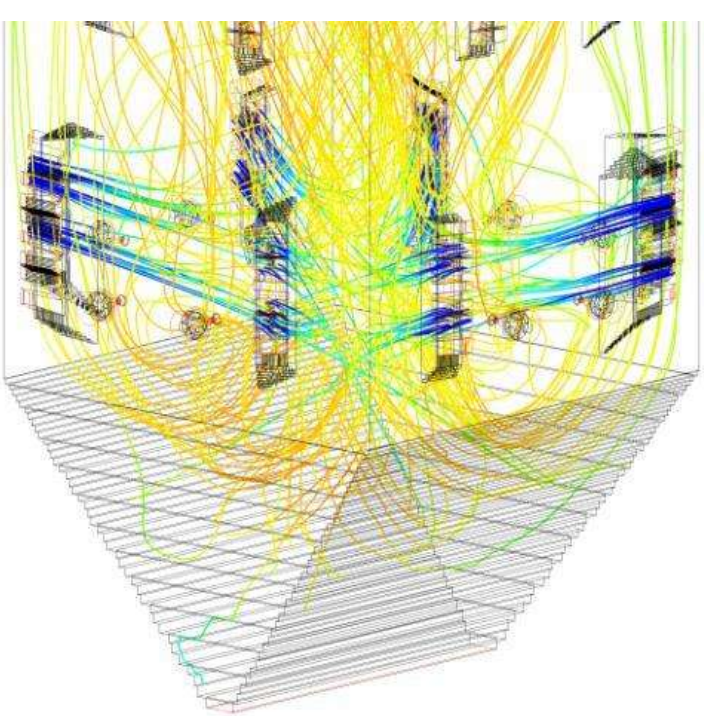
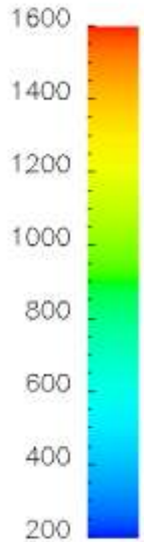
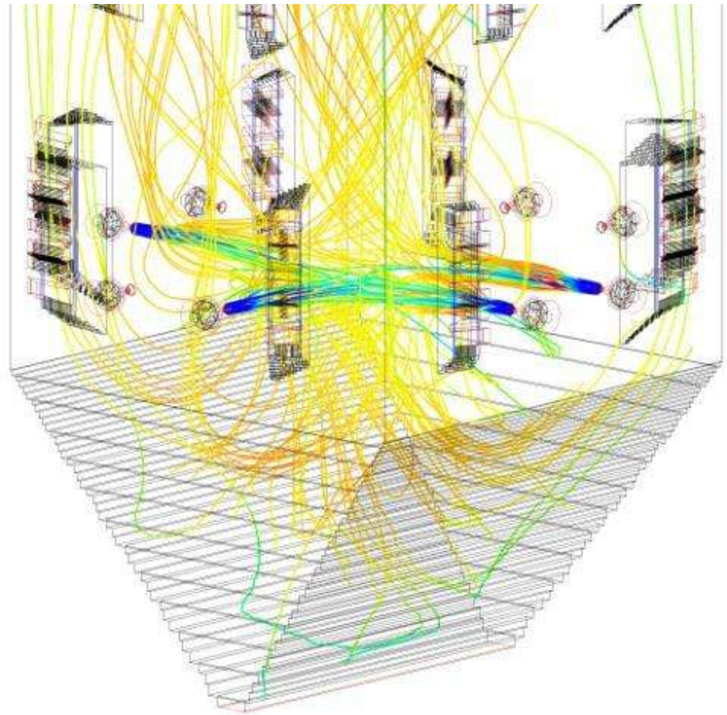
Main burner



14,0 %



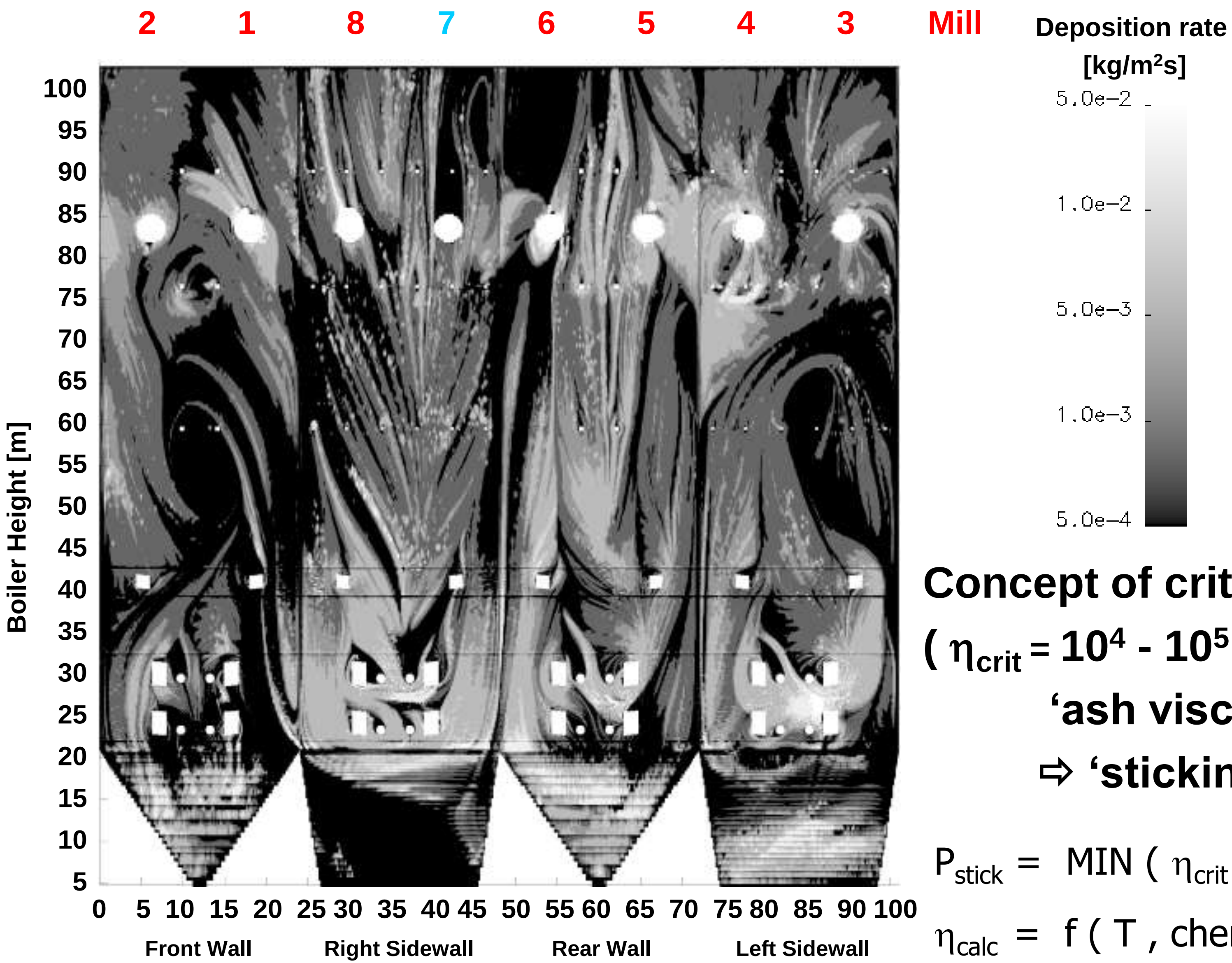
TBK burner



29,6%

The portion of ash, that hits the walls above the ash melting point of ca. 1050 °C, is significantly higher for the TBK-burners compared to the main burners.

Ash deposition rates on the furnace walls derived from viscosity



Concept of critical viscosity

($\eta_{crit} = 10^4 - 10^5$ Pa·s)

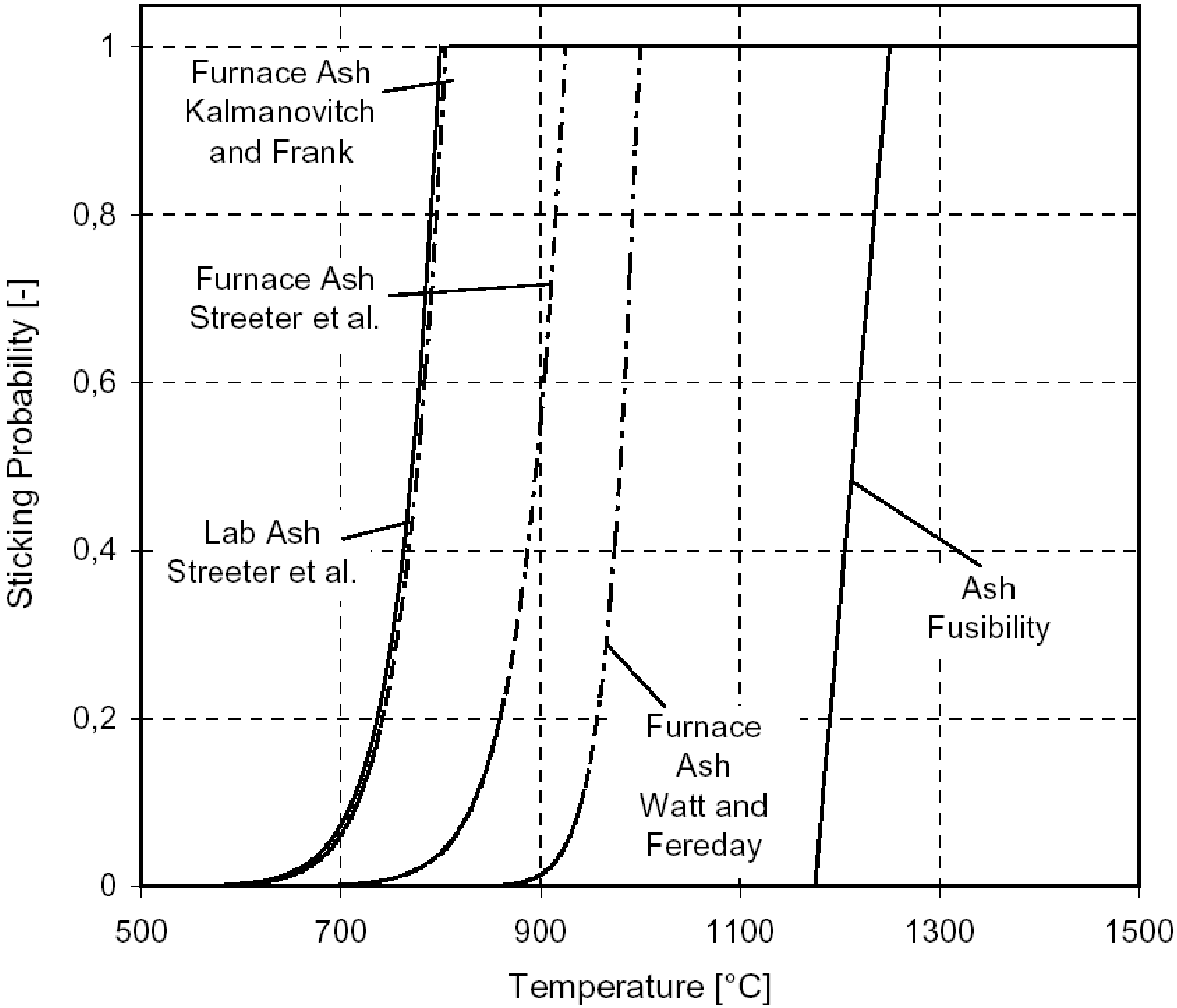
'ash viscosity' (η_{calc})

⇨ 'sticking probability' (P_{stick})

$$P_{stick} = \text{MIN} (\eta_{crit} / \eta_{calc} \; , \; 1)$$

$$\eta_{calc} = f (T \text{, chemical composition of ash})$$

Viscosity Models Applied to Bulk Ash Composition



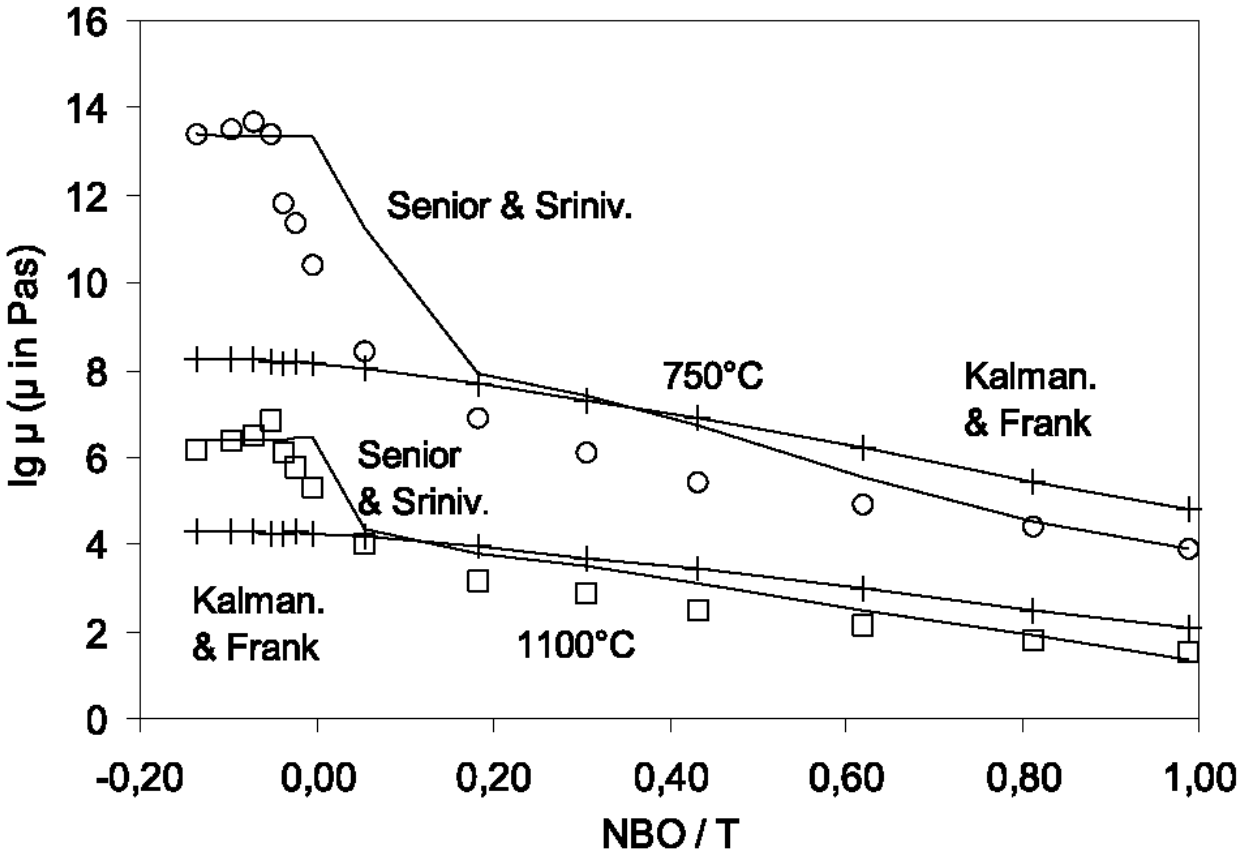
Oxide [%-wt]	Lab Ash	Furnace Ash
SiO_2	25.4	61.19
Al_2O_3	14.6	7.96
Fe_2O_3	0.3	3.87
CaO	26.9	20.58
MgO	3.08	1.65
Na_2O	0.11	0.23
K_2O	0.17	0.4
TiO_2	1.49	0.92
SO_3	26.0	2.42

Viscosity Model used by RECOM

- Combination of Kalmanowitch and Frank (1988) and Senior & Srinivasachar (1995):
- Parameter introduced by Senior & Srinivasachar :

$$\frac{NBO}{T} = \frac{CaO + MgO + FeO + Na_2O + K_2O - Al_2O_3 - Fe_2O_3}{(SiO_2 + TiO_2)/2 + Al_2O_3 + Fe_2O_3}$$

Non-bridging Oxygens / Tetrahedral Oxygens



Model Validity according to authors:

Silicates with

35-99% SiO_2

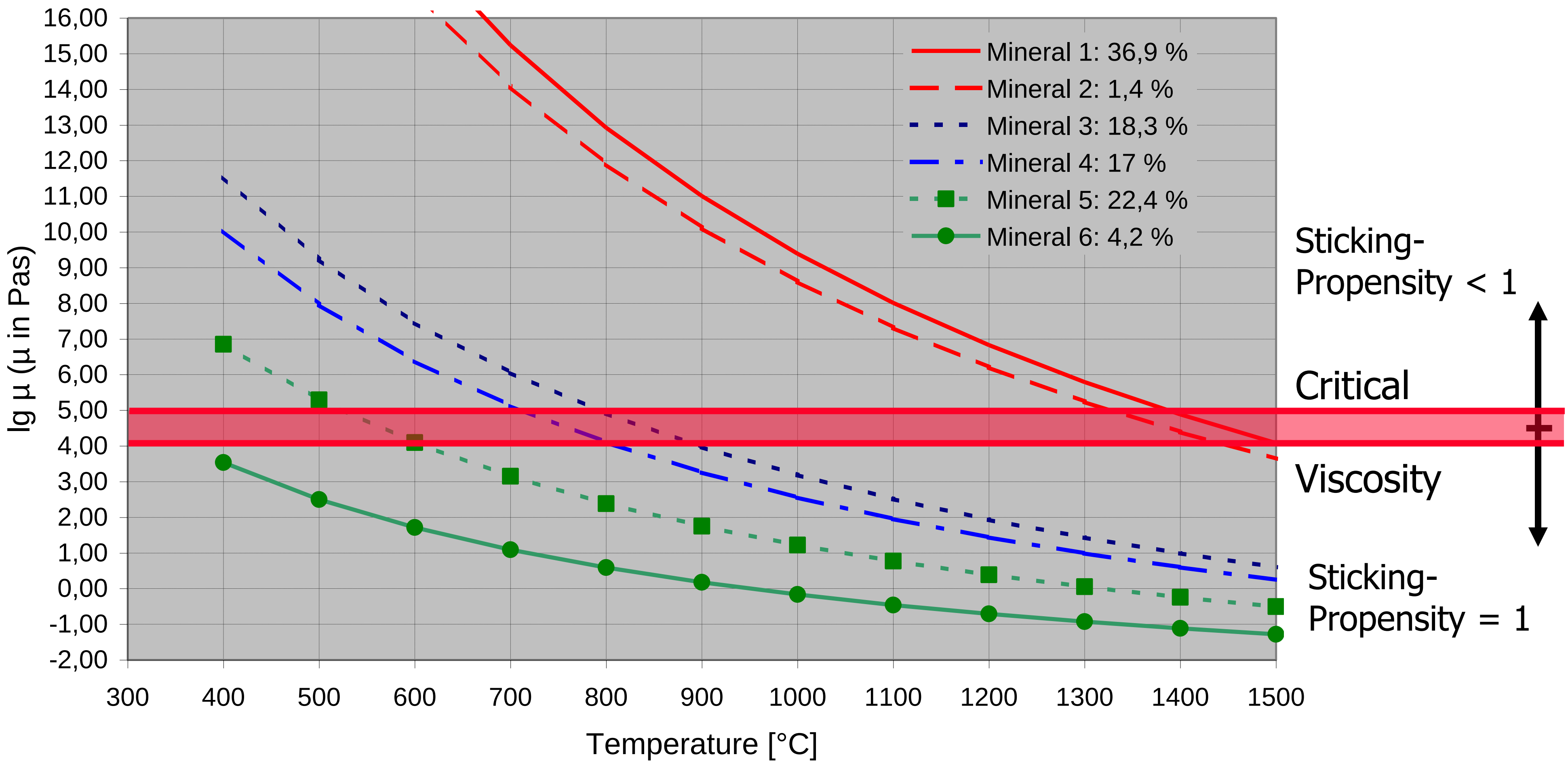
and

Al_2O_3; Fe_2O_3; TiO_2; K_2O; Na_2O; CaO; MgO; FeO; SO_3

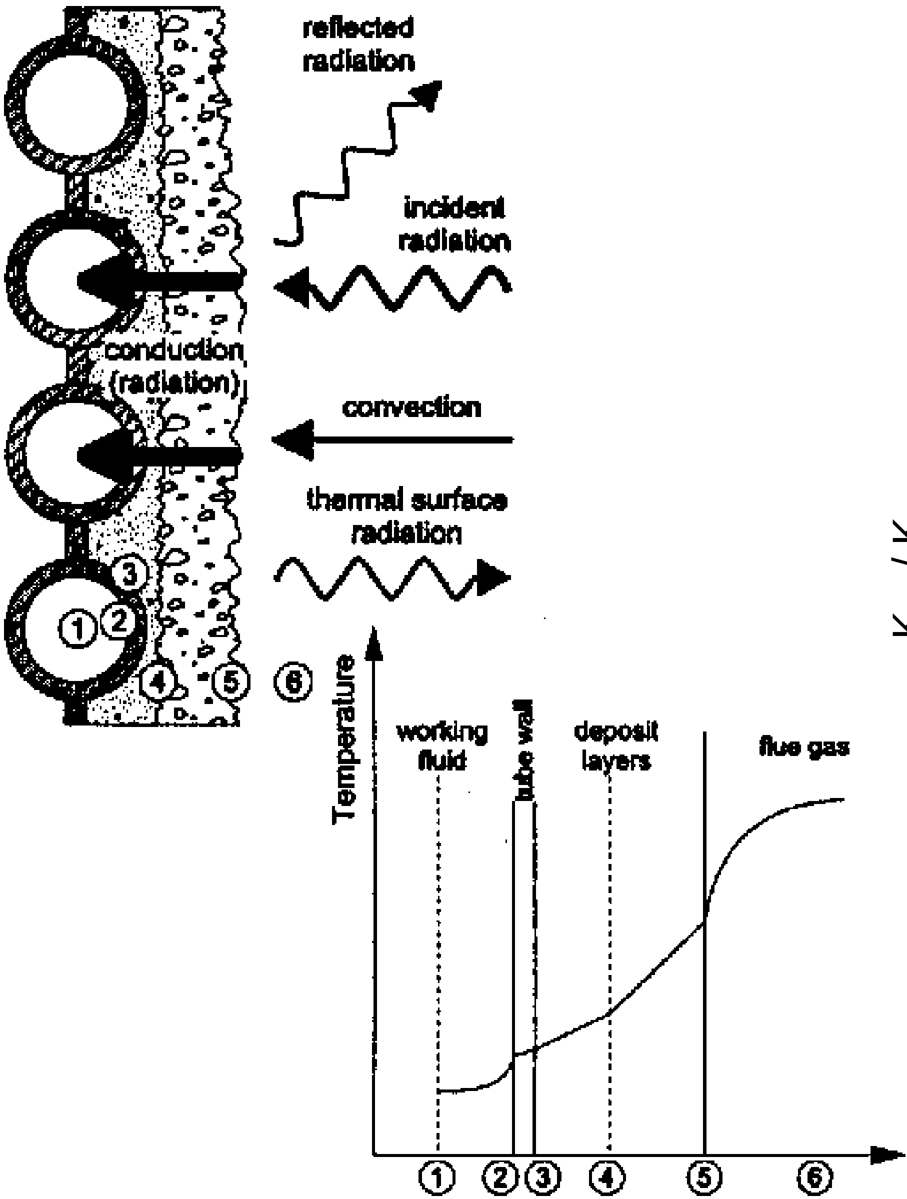
CCSEM-EDX Analysis of Mineral Matter in the Ash

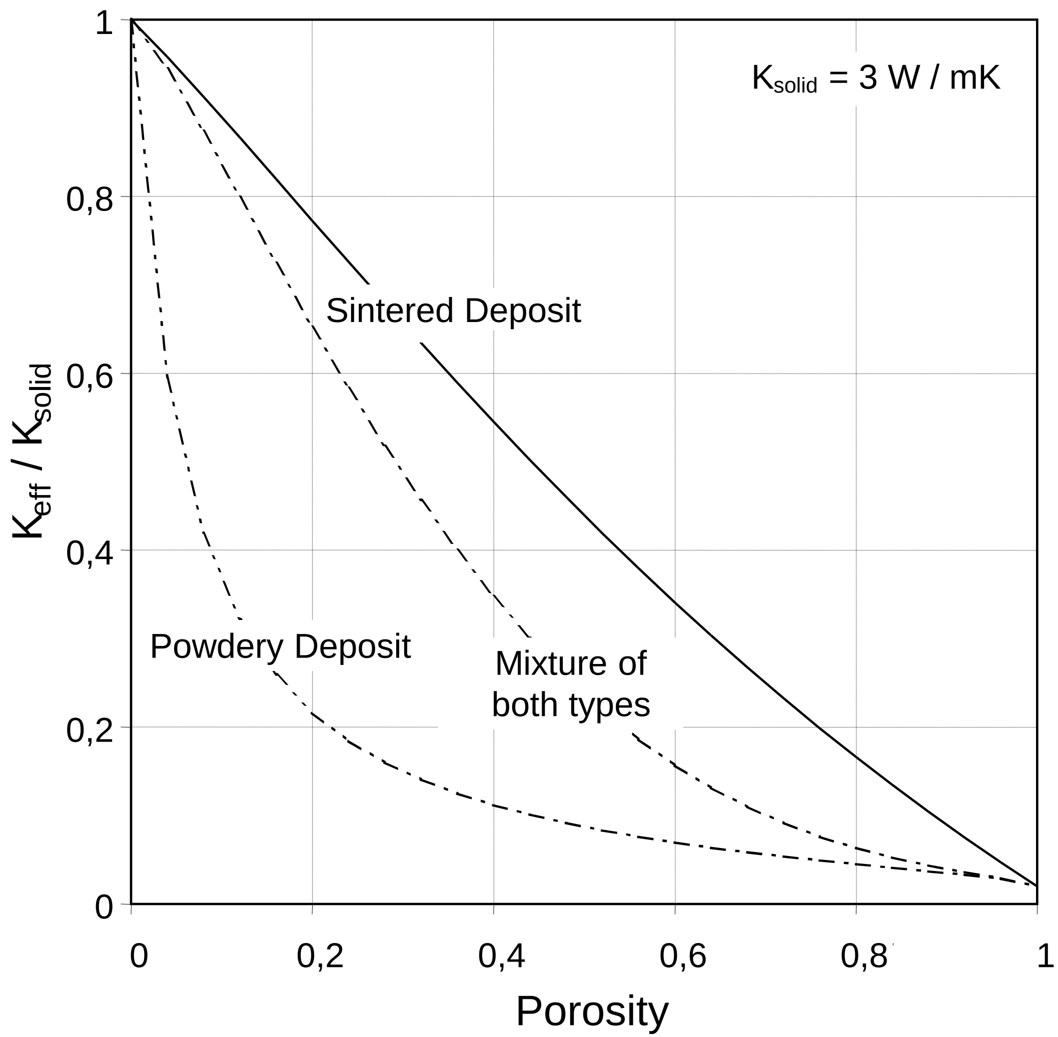
	Element Composition [wt.-%]									[wt.-%]
Mineral Category	Si	Al	Fe	Ca	Mg	Na	K	Ti	S	Share of Total Ash
1	93.9	1.73	0.03	4.22	0.0	0.0	0.0	0.01	0.08	36.93
2	83.9	13.7	0.0	2.21	0.0	0.0	0.0	0.15	0.0	1.38
3	47.4	25.2	0.09	24.8	1.89	0.0	0.05	0.17	0.4	18.25
4	54.5	10.2	0.62	32.3	1.85	0.0	0.0	0.02	0.61	16.96
5	22.8	13.6	0.41	43.7	5.36	0.0	0.0	0.07	14.1	22.37
6	1.56	5.97	0.10	48.1	5.28	0.0	0.0	0.0	39.0	4.12

Mineral Matter Data in the Viscosity Model

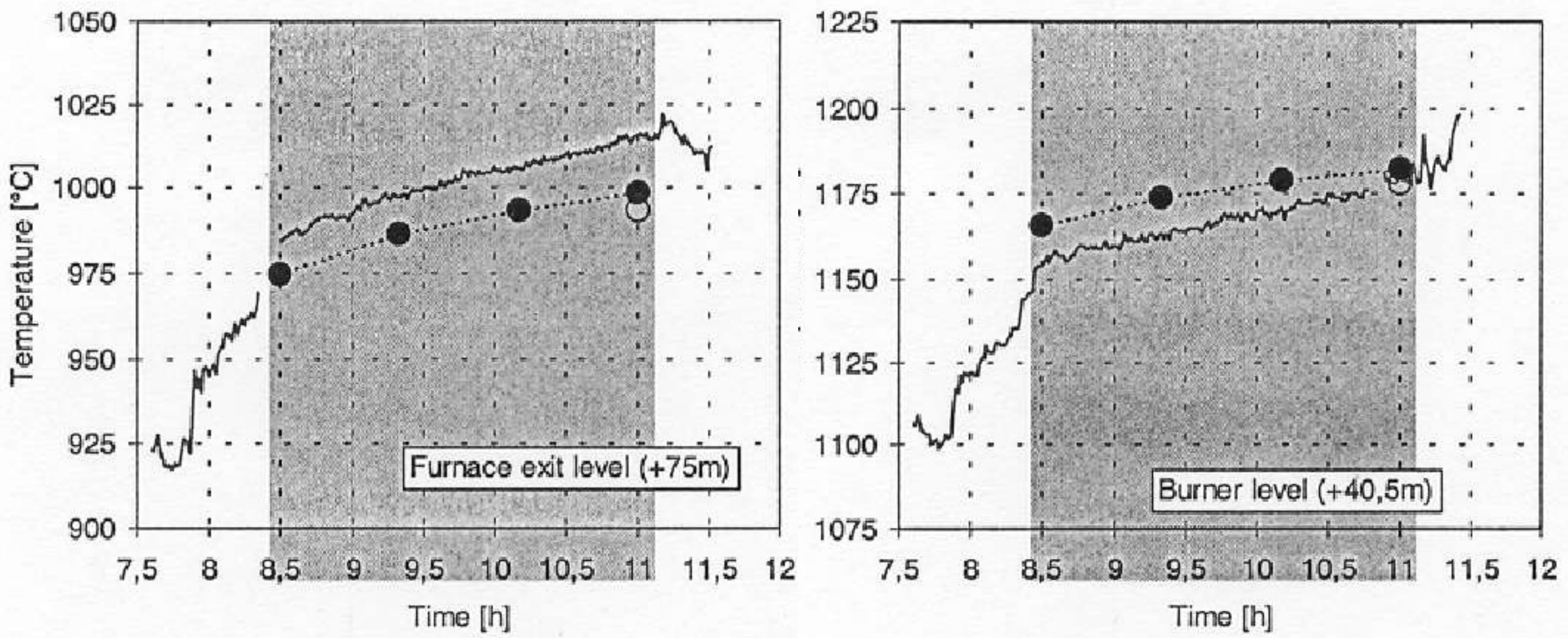


Degradation of Heat Transfer





Comparison of measured versus predicted temperature increase between a soot blowing cycle of 2,5 h for furnace exit (left) and burner level (right).



Measurement Technique: Acoustic Pyrometry

Limitations of the current approach

- The deposit prediction scheme needs a representative analysis of furnace ash, so it is not predictive regarding changes in ash composition.

  Possible remedies:

  Generate representative ash analysis in pilot scale combustion chambers. Viability of this approach has to be demonstrated by comparing pilot scale and full scale ash for a number of firing systems and fuels.

  Generate representative ash analysis by chemical fractionation and additional thermo-chemical equilibrium calculation (Methodology developed and applied at Abo Akademi in Finland)

- Viscosity approach only valid for Si-dominated ashes (> 35 Wt.-%). Other complex mechanisms in ash chemistry need to be added that are dominated by e.g. Sodium-Potassium-Chlorine, etc.

→ **RECOM work programme in the VerSi project**

On-Going Research Project – VerSi

- Project started in August 2015

- Basic Research Target of RECOM:
  Combining Thermochemical Equilibrium Calculations with detailed reacting CFD models to extend the applicability of the deposit prediction scheme

- Development Work in the Project:
  - Integrating Thermo-chemical Equilibrium Calculations during Particle Tracking in the model to derive the amount of molten phase in the particle when hitting the walls
  - Implementation of a model that describes vaporization and condensation of sodium and potassium
  - Validation of Model Extensions at pilot scale test facilities and full scale boilers (two dedicated measurement campaigns at full scale units are performed during the project)
  - Introducing Virtual Reality (VR) Techniques to fully exploit the comprehensive information delivered by the CFD model.

Cray XC40 at the High Performance Computing Center (HLRS) in Stuttgart

7712 Dual-Socket 12C Intel Haswell nodes (~ 185.000 cores)
Intel Xeon CPU E5-2680 v3 @ 2.5 GHz
Peak Performance of 7.42 Petaflops

No. 8 of the TOP500 list in Nov. 2015