Studying the combustion of biomass particles using a Lagrangian Method

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Overview

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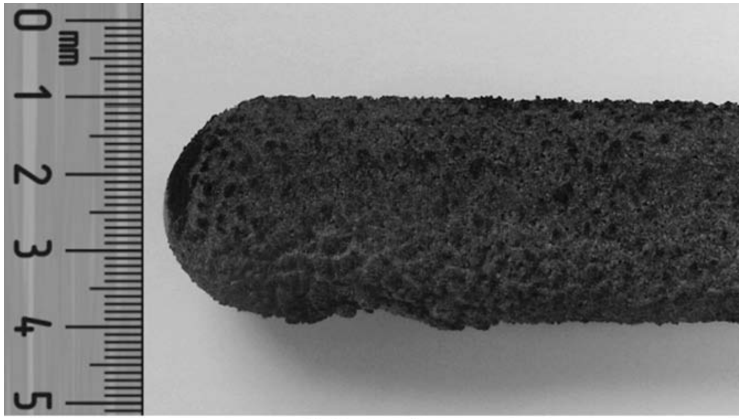
Co-combustion

- Combustion of two different fuels in the same combustion system (e.g. coal (~90% wt) and biomass (~10% wt)).

  ⇨ **Reduction of CO_2 emissions**

- **Negative aspects:**
  - High slagging and fouling tendency
  - High carbon content in fly and bottom ash

  ⇨ **CFD modelling of co-combustion in order to optimize the combustion process**



(a) Neat coal.


(b) Coal+15% biomass.

Modeling approaches

Eulerian modeling of pulverized coal combustion

- Particles are assumed to be sufficiently small to adapt instantly to the local conditions of the carrier field.

⇨ Transport equations are written for the gas/particle mixture assuming a negligible slip-velocity between the gas phase and the fuel particles

Lagrangian modeling of biomass combustion – a post-processing approach

- Due to the increased inertial forces biomass particles do **NOT** instantly adapt to the local conditions of the carrier field

⇨ Lagrangian modeling of the particle movement.

- Mass fractions of biomass are assumed to be small

⇨ Post-processing approach

Langrangian modeling of biomass combustion

- **Particle motion**

a) Momentum equation for dense particles

$$\frac{d\vec{u}_p}{dt} = \frac{\vec{u}_s - \vec{u}_p}{\tau_p} + \vec{g} \text{ where } \tau_p = \frac{\rho_p}{\rho_f} \frac{4d_p}{3C_d|\vec{u}_s - \vec{u}_p|}$$

b) Closure is obtained through the use of a stochastic term

$$d\vec{u}_s = -\frac{1}{\rho_f}\vec{\nabla}\langle P\rangle dt - \frac{\vec{u}_s - \langle\vec{u}_f\rangle}{T_L^*}dt + \sqrt{C_0\varepsilon}\, d\vec{W}$$

where $d\vec{W}$ is an increment of the Wiener process and $T_L^* = \frac{T_L}{1 + \beta\frac{|\vec{u}_s - \vec{u}_p|}{\sqrt{\frac{2}{3}k}}}$

- **Physicochemical phenomena**

a) Particle drying – pressure equilibrium assumption

- Mass transfer $\dot{m}_{vap} = 2\pi r_p \frac{\lambda}{c_p} Sh \ln\left(\frac{1 - c_{vap}^{\infty}}{1 - c_{vap}^{sat}}\right)$ where $c_{vap}^{sat} = f(T_p)$
- Heat transfer $\phi_{evap} = L_v^0\, \dot{m}_{vap}$

Langrangian modeling of biomass combustion

b) Devolatilisation – Kobayashi model

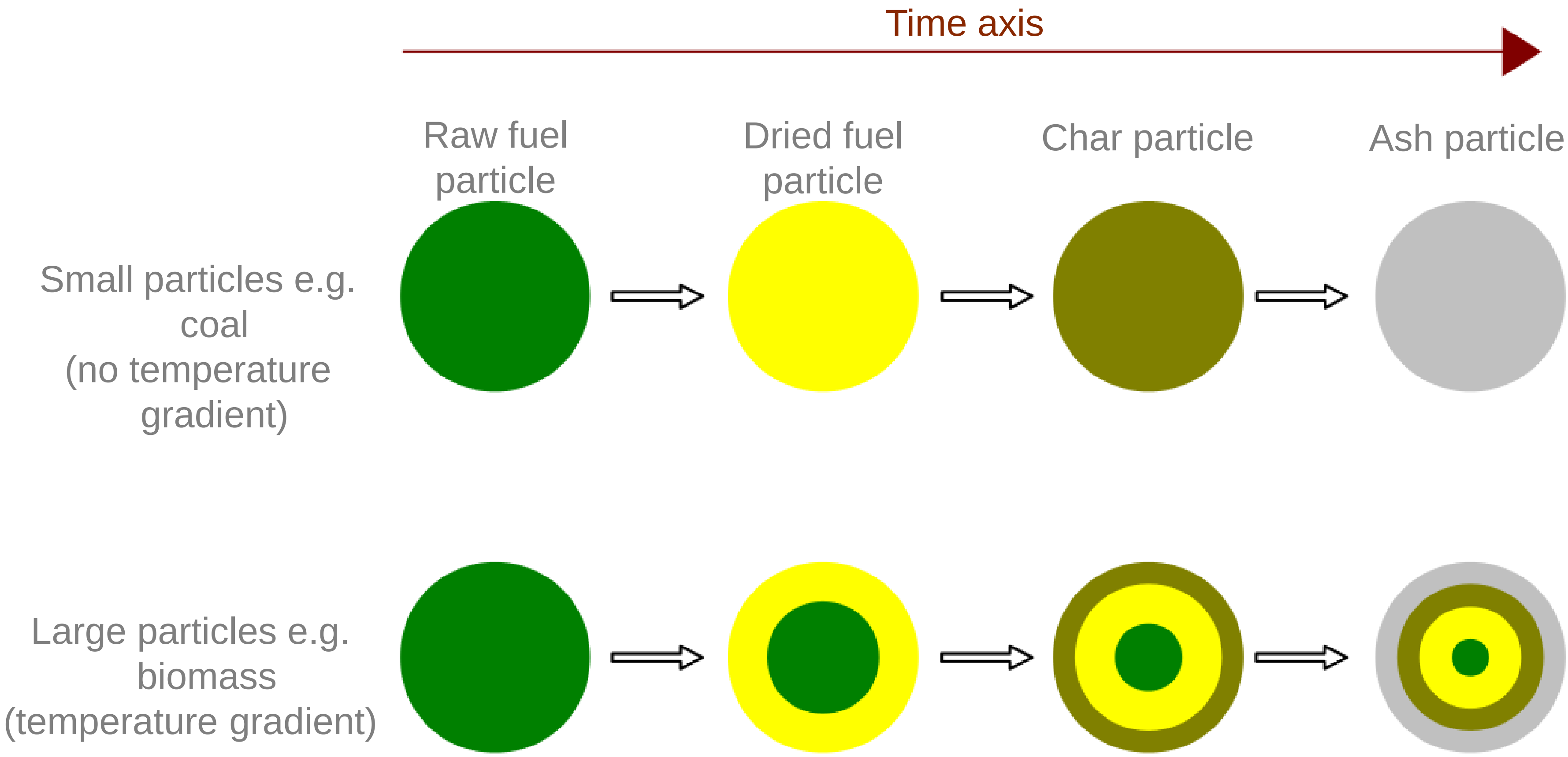
- Kinetic is given by two competitive reactions
- Mass transfer $\frac{dm_{ch}}{dt} = -(k_1 + k_2)\, m_{ch}$ where $k_{1,2} = f(T_p)$
- Heat release of the slightly endothermic reactions is neglected

c) Char combustion - $C + \frac{1}{2}O_2 \rightarrow CO$

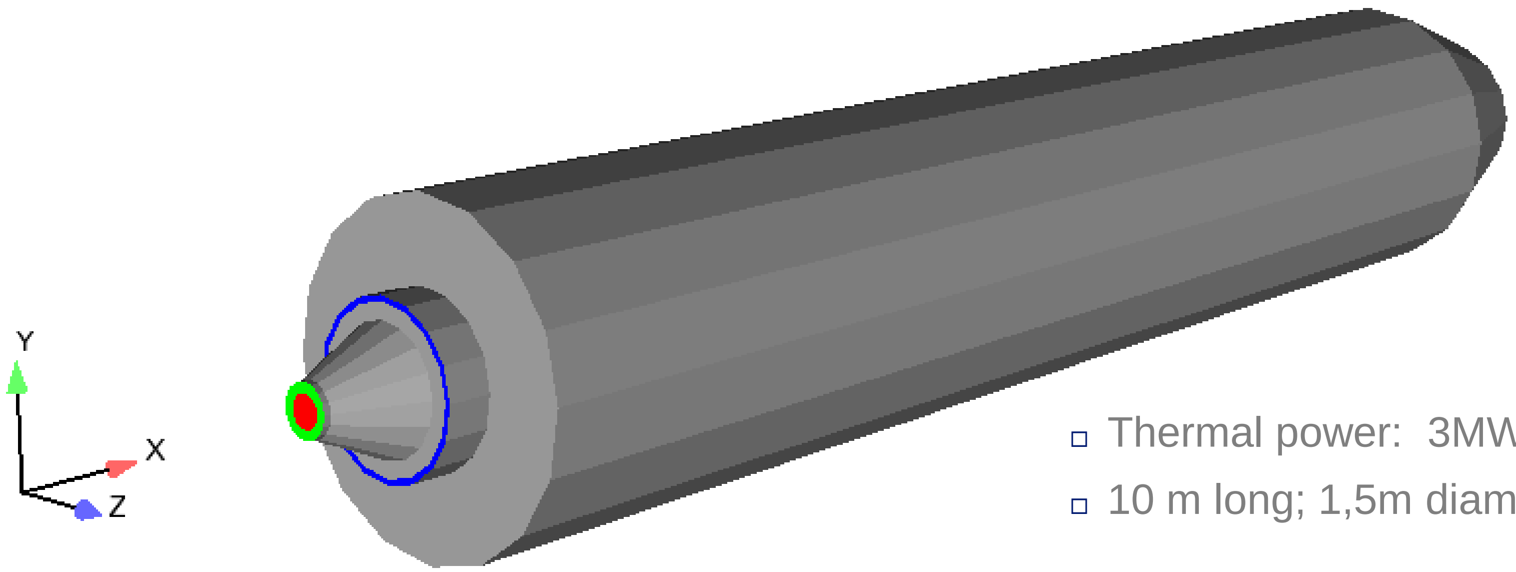
- Mass transfer $\frac{dm_{ck}}{dt} = -\; S_e\; P_{O_2}^{\infty} K_{\mathrm{glob}}$ where $K_{glob} = f(T_p)$
- Heat release $\Delta_r h_{comb} = \Delta_f h_{CO}(T_p) - \left(\Delta_f h_{ck}(T_p) + \frac{1}{2}\Delta_f h_{O_2}(T_f)\right)$

! All physicochemical phenomena depend on the particle temperature !

Impact of the particle temperature profile



Combustion System



- Thermal power: 3MWth
- 10 m long; 1,5m diameter

Inlet	Mass flow rate Air (kg/s)	Mass flow rate Coal (kg/s)
Primary air (**red**)	0,19	0,125
Secondary **swirled** air (**green**)	0,64	-
Tertiary air (**blue**)	0,58	-

Results: Flow field characteristics

- **Simulated velocity field of the gas phase obtained using an Eulerian approach.**

Three distinct recirculation zones can be observed

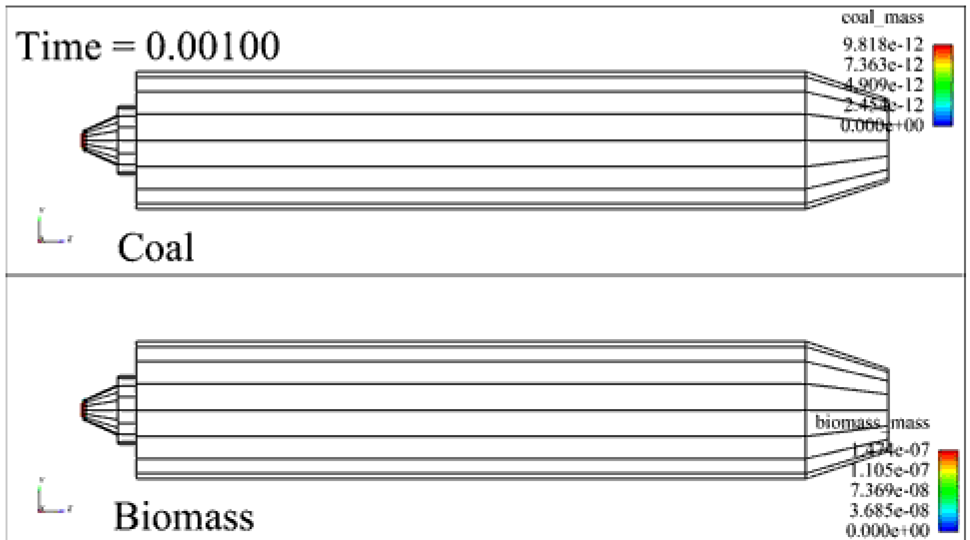
Results: Coal particle movement

- **Simulated particle motion of coal particles (25µm) using a Lagrangian approach.**

! Coal particles are sufficiently small to adapt instantly to local flow field changes !

Results: Comparison coal/biomass

- **Simulated particle motion of coal (25µm) and biomass (800µm) particles using a Lagrangian approach.**

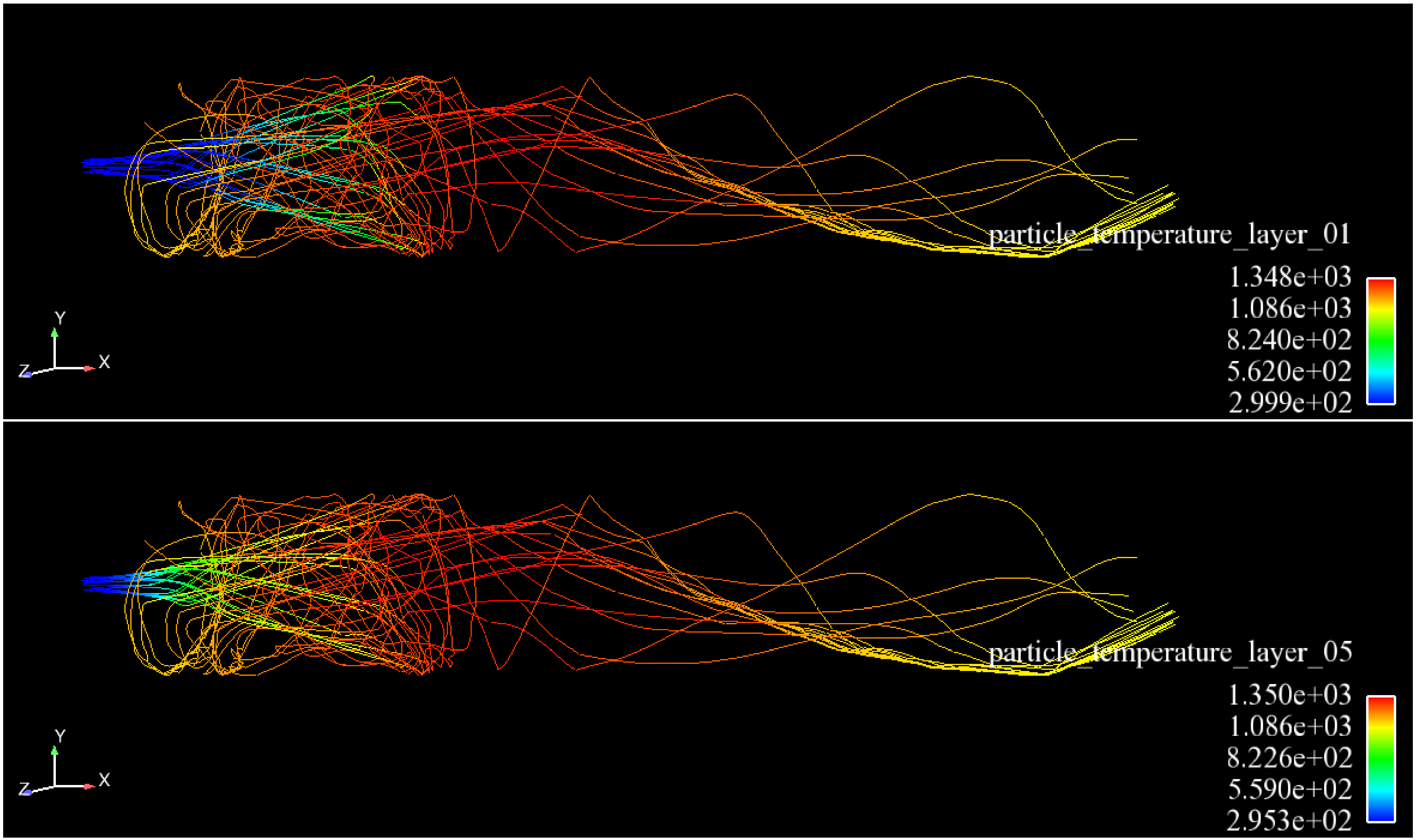


! Biomass particles do **NOT** instantly adapt to local flow field changes !

⇨ Impact on the physicochemical phenomena

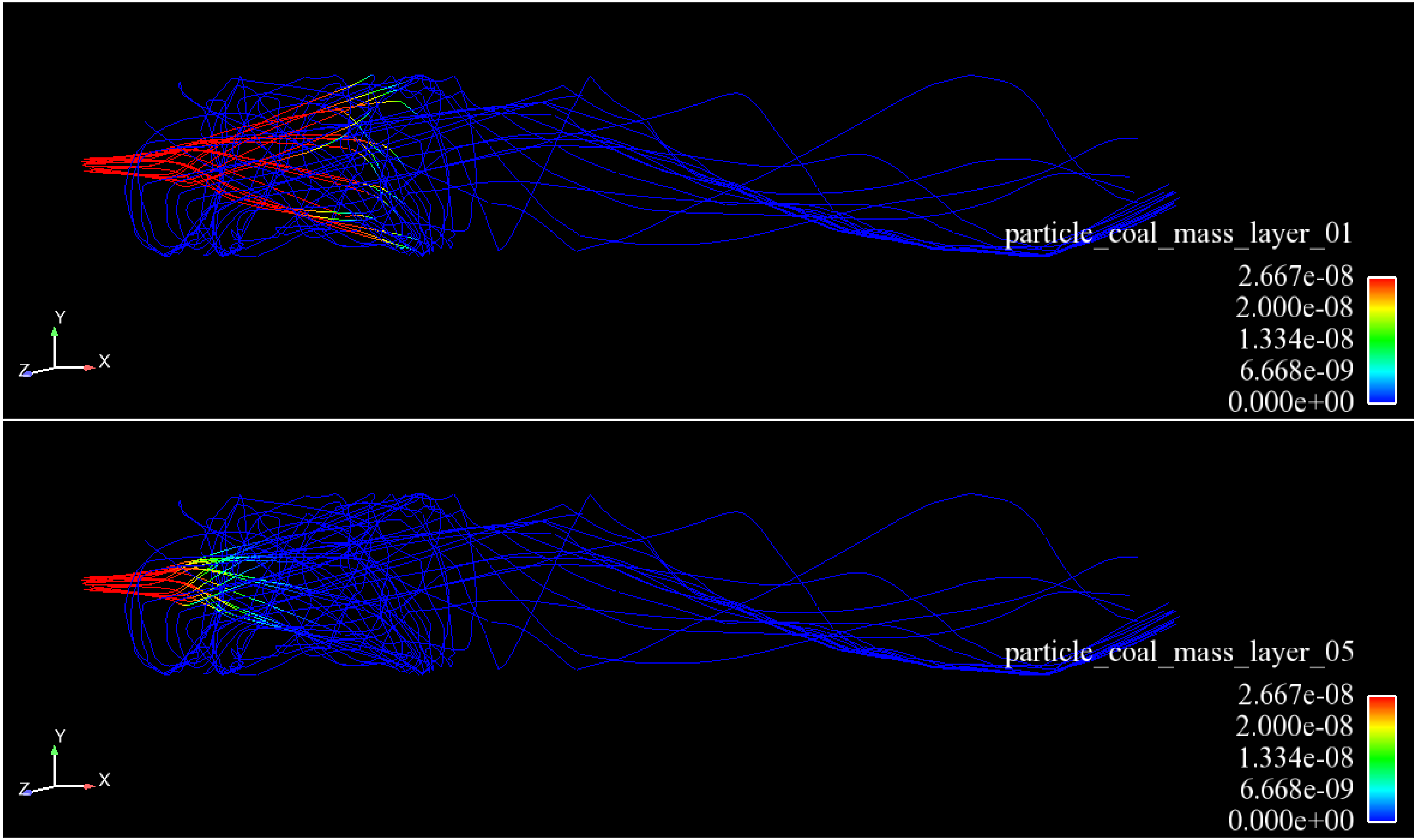
Results: Biomass particle temperature

- **Temperatures in the particle core (layer1) and the most outer layer (layer5); Biomass particles 800µm.**



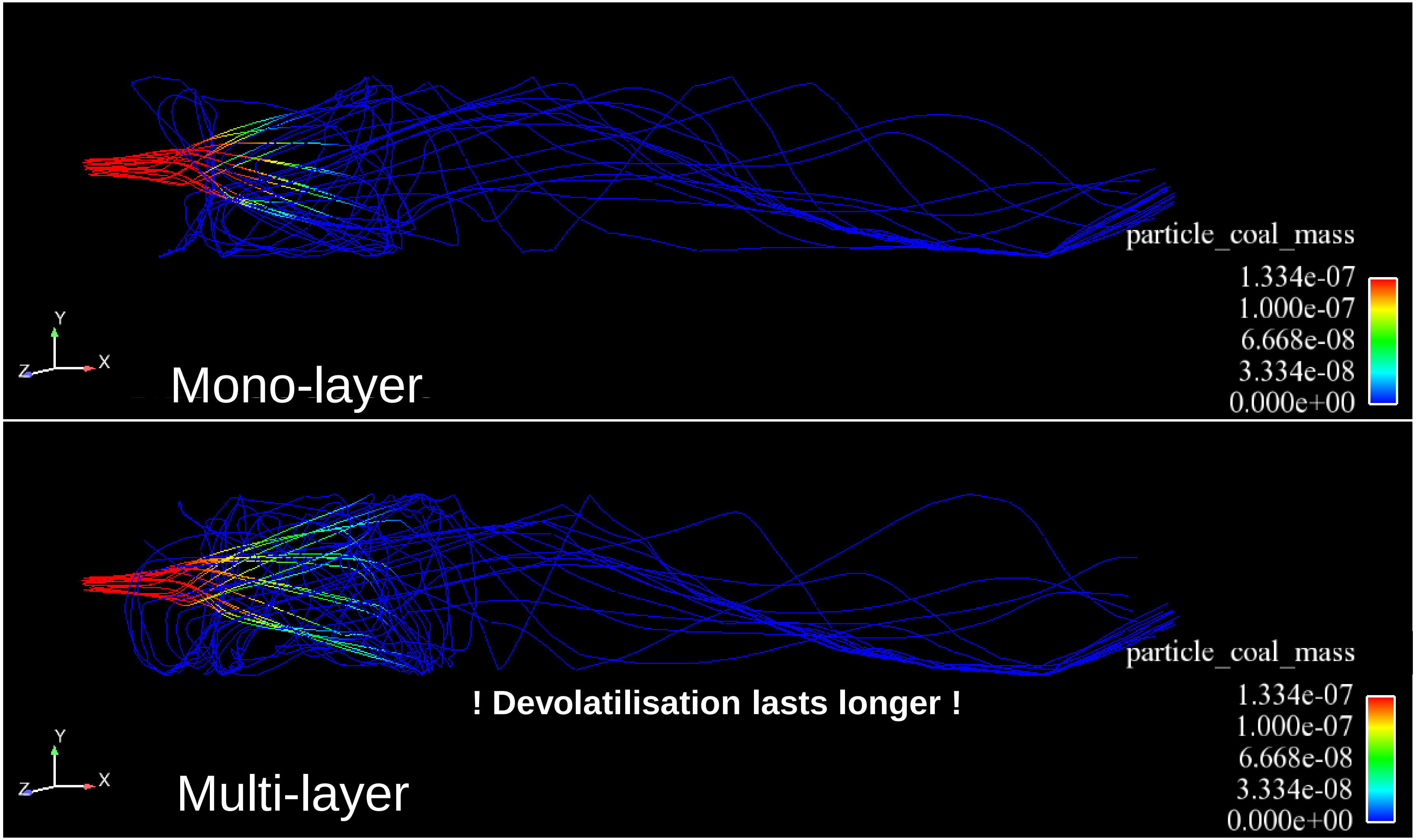
Results: Impact on devolatilisation

- **Coal mass fraction in the particle core (layer1) and the most outer layer (layer5); Biomass particles 800µm.**



Results: Comparison of mono-/multilayer

- **Coal mass fractions obtained considering (multi-layer) and neglecting (mono-layer) temperature gradients inside the particles; Biomass particles 800µm.**



Results: Comparison of mono-/multilayer

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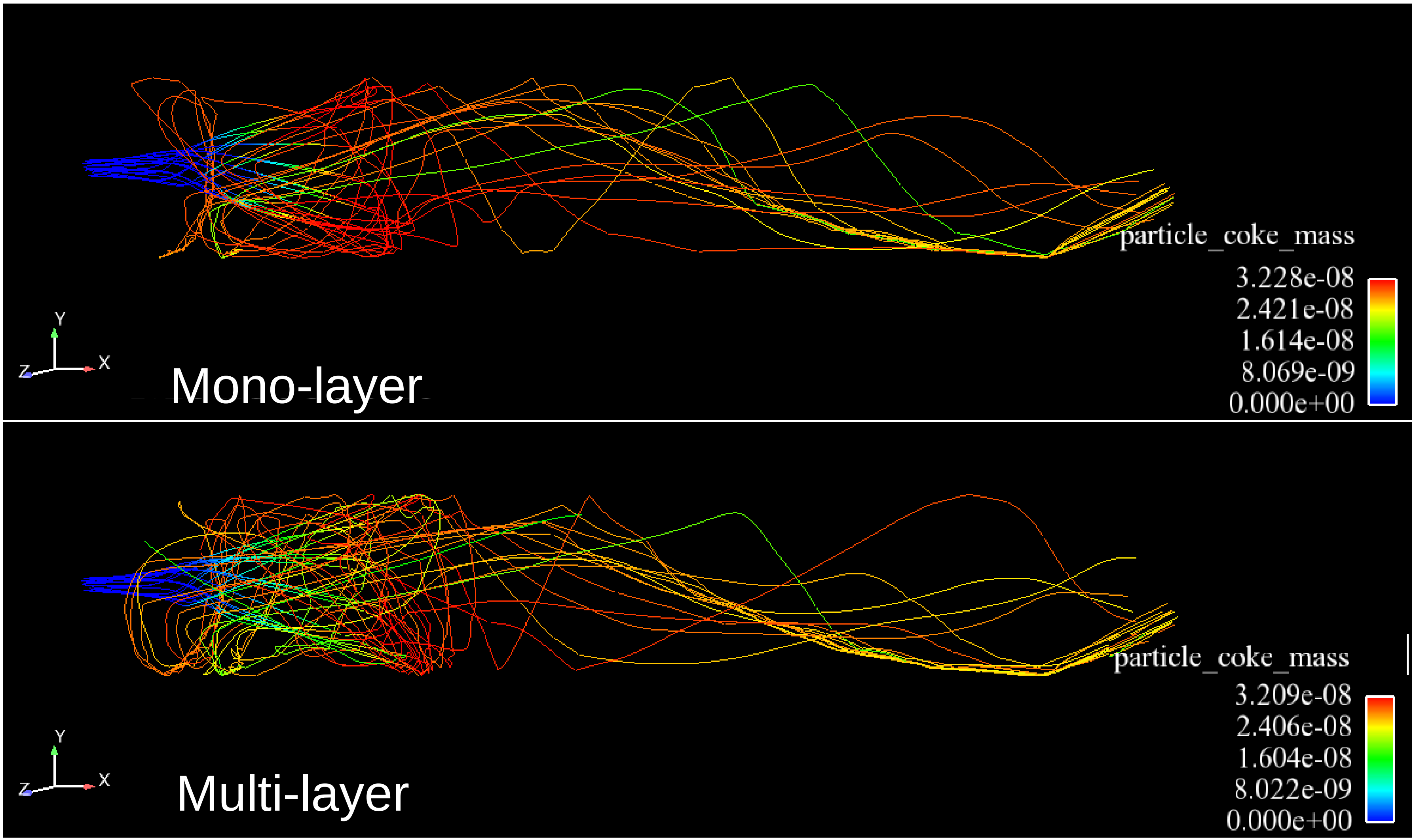


Slagging models

Coal particles

- The slagging probability is given by: $\kappa = \begin{cases} \frac{\mu_c}{\mu_p} & \text{si } \mu_p > \mu_c \\ 1 & \text{si } \mu_p \leq \mu_c \end{cases}$

- Additionally, a critical temperature condition is considered. If the particle temperature is lower than the critical temperature T_c it will not stick to the wall.

Biomass particles **! Not available yet !**

- The slagging probability is a fu[illegible] melted ash mass fraction

$$\kappa = Y_{f,\text{sel}}(T_p)\frac{m_{\text{sel}}}{m_{\text{sel}} + m_{\text{silice}}} + Y_{f,\text{silice}}(T_p)\frac{m_{\text{silice}}}{m_{\text{sel}} + m_{\text{silice}}}$$

- Additionally, a critical temperature condition is considered. If the particle temperature is lower than the critical temperature it will not stick to the wall

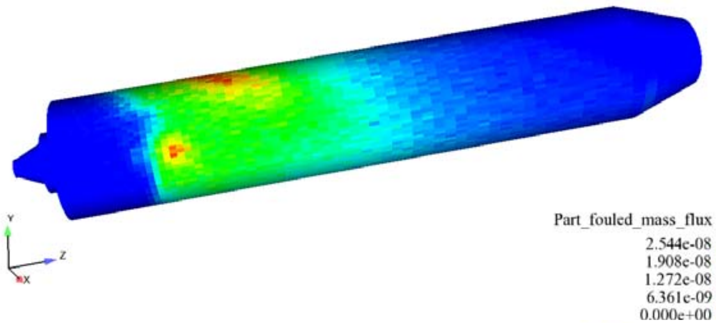
Results: Slagging of coal particles

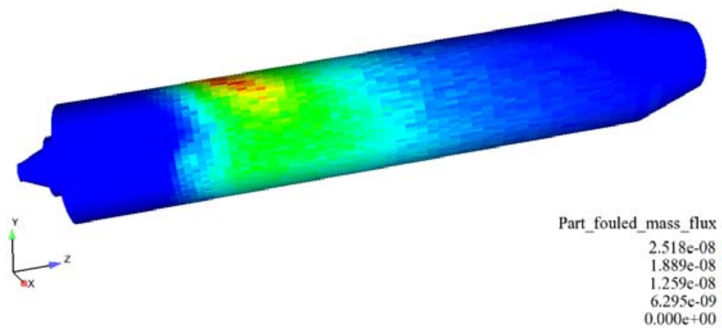
- **Mass flux of deposited particles for several critical temperatures T_c and viscosities μ_c**

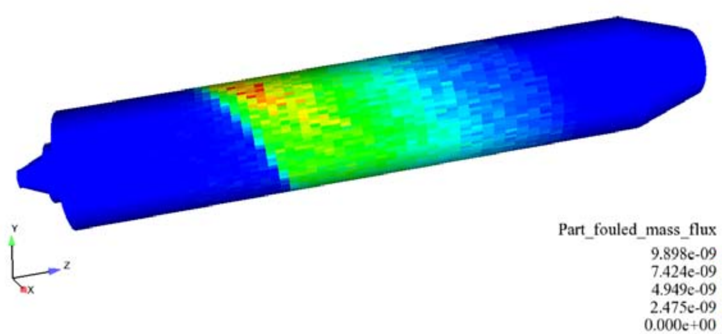
	μ_c (Pa s)	T_c (K)
Case 1	10^6	1 173
Case 2	10^4	1 273
Case 3	768	1 400

High deposition rate

Low deposition rate







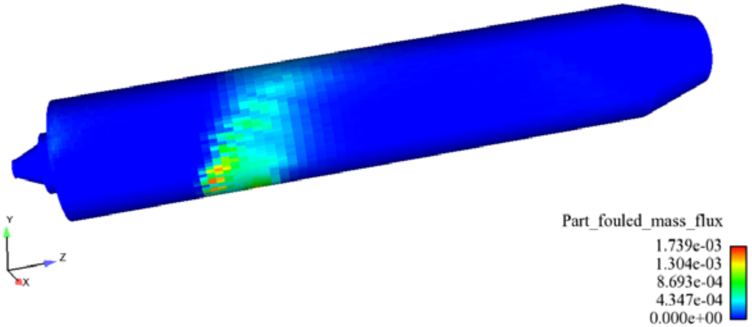
Results: Slagging of biomass particles

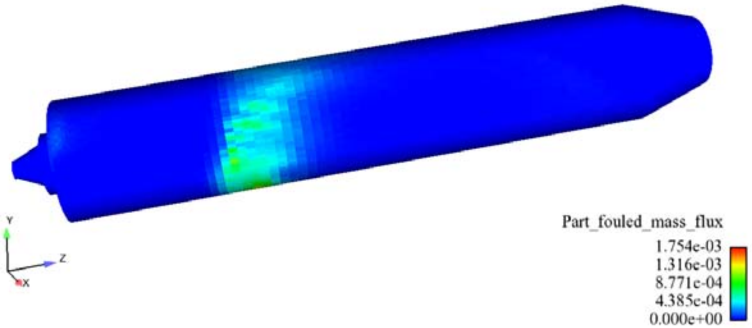
- **Mass flux of deposited particles for several critical temperatures T_c**

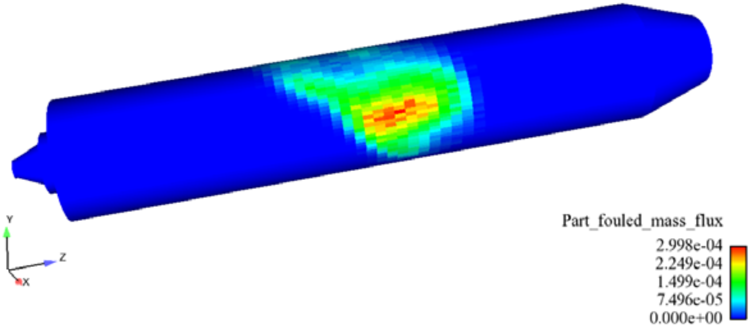
	T_c
Case 1	900
Case 2	1 000
Case 3	1 402

High deposition rate

Low deposition rate







Conclusion

- **Slipping velocities between the gas phase and the fuel particles are considered applying the Lagrangian approach**
  - Coal particles adapt instantly to local flow field changes.
  - Biomass particles **don't** adapt instantly to local flow field changes.

- **Determination of particle temperature profiles by means of a multilayer model**
  - The temperature profile has a significant impact on the devolatilisation process.
  - Better prediction of the particle composition (coal, char, ash and moisture content) at the outlet.
  - Differences concerning unburned carbon can be neglected.

- **Implementation of a slagging model which allows to predict the areas where slagging is more likely to occur**

Thank you for your attention