Deposition prediction in a pilot scale pulverized fuel-fired combustor

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Cranfield University

www.cranfield.ac.uk

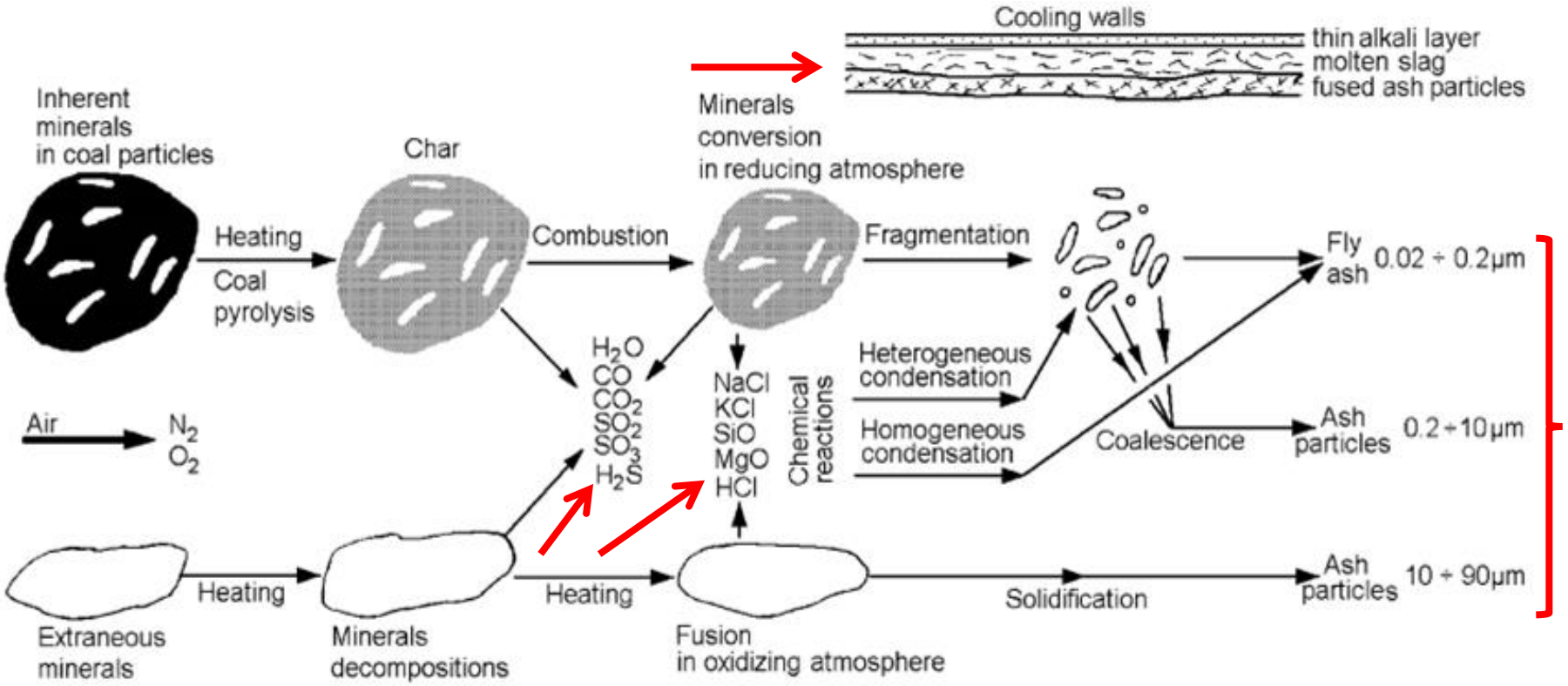
Where is Cranfield University?

Presentation Outline

- Background
- Methodology
  - Experiments
  - Modelling
- Results and Discussions
  - Deposit characterization
  - Model prediction
- Conclusions

Slag on superheaters tubes (www.boilers.guide)

Background



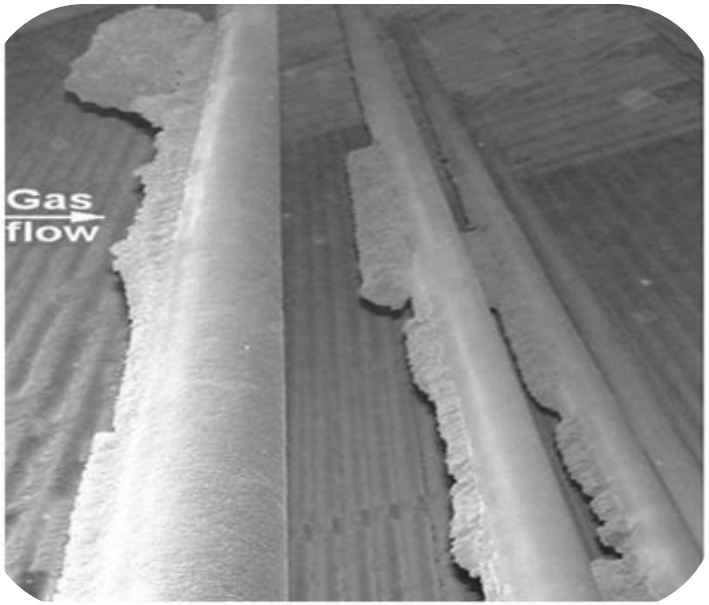
Mineral matter transformation mechanism (Tomeczek and Palugniok, 2002)

Background

Consequences (Rushdi et al., 2005a; Wacławiak and Kalisz, 2012)

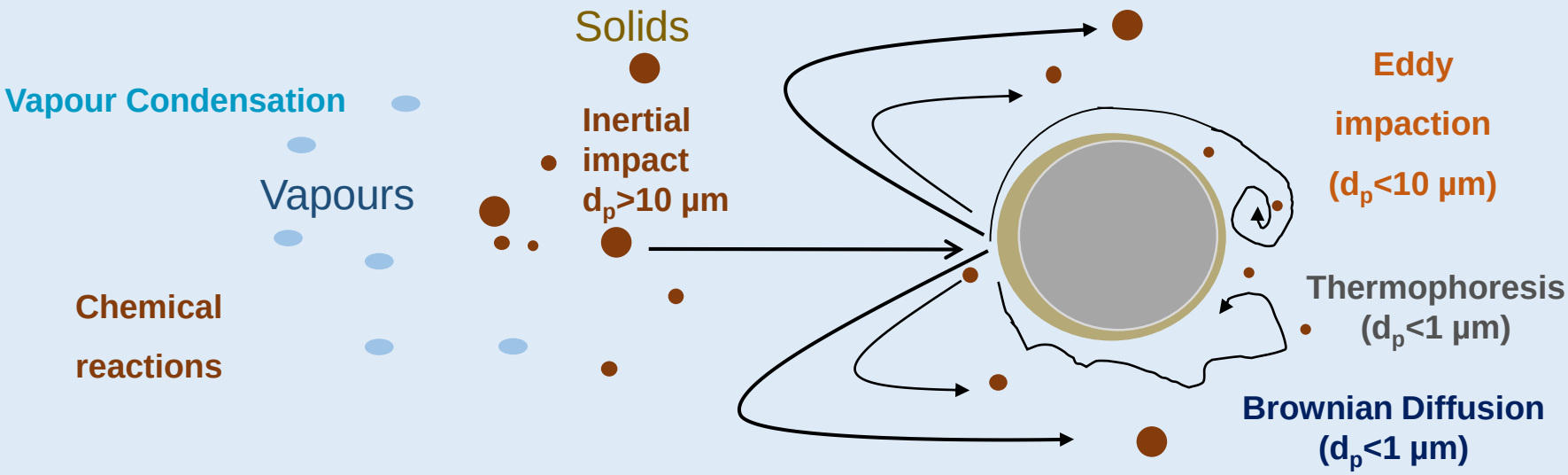
- Insulation of heating surfaces and deterioration of boiler thermal efficiency.
- Corrosion of tubes leading to outages.
- High maintenance costs.

Fouling in heat exchangers (http://scopewe.com)

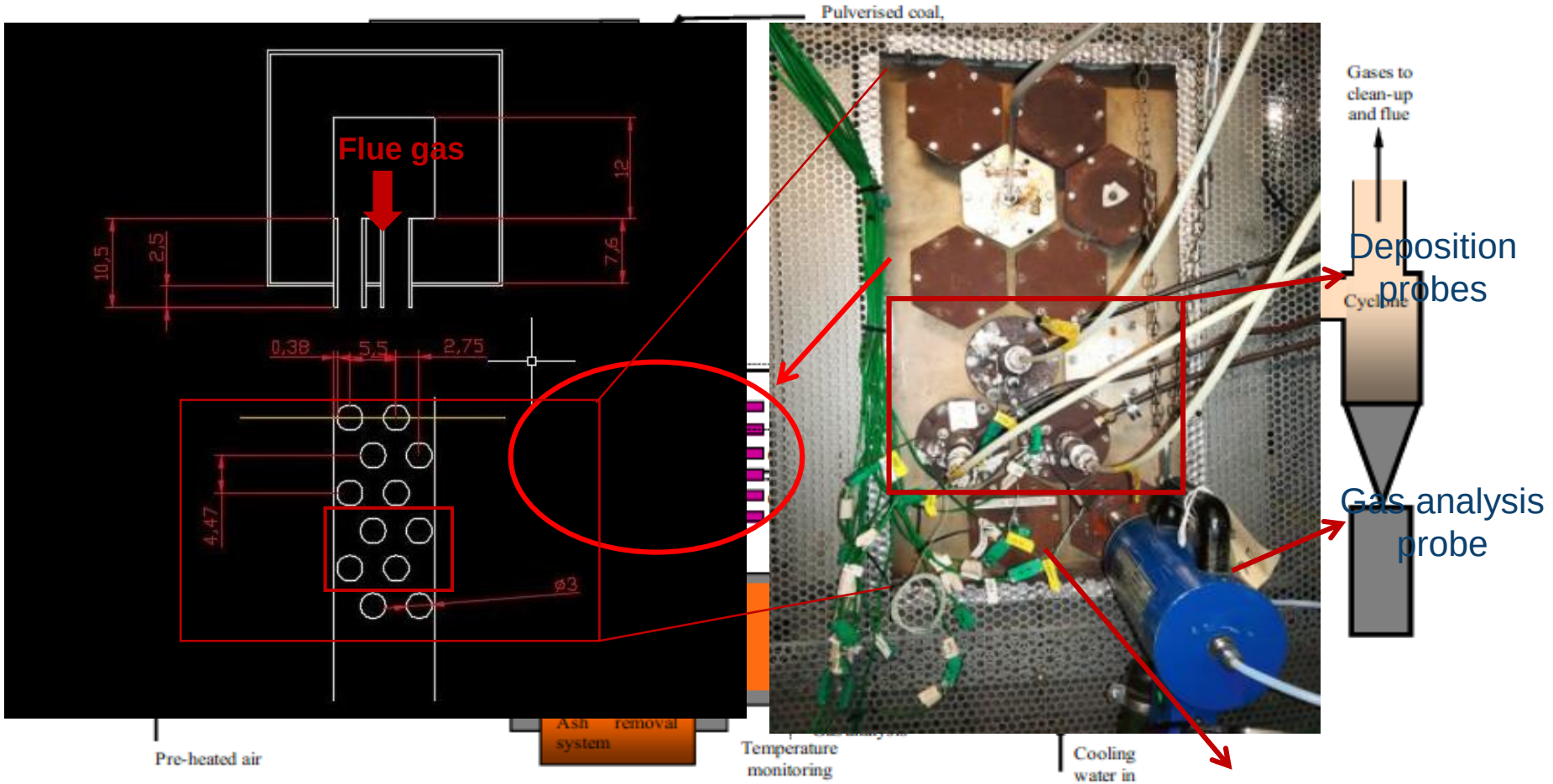


Deposit on real superheater tubes (Tomeczek and Palugniok, 2004)

Background
Deposition Mechanisms



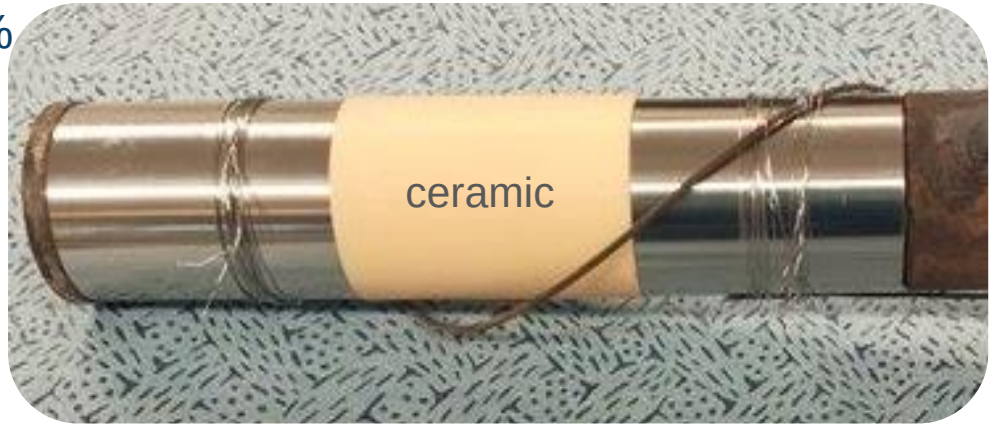
Methodology
Experiments



Combustion rig at Cranfield

Methodology
Experiments

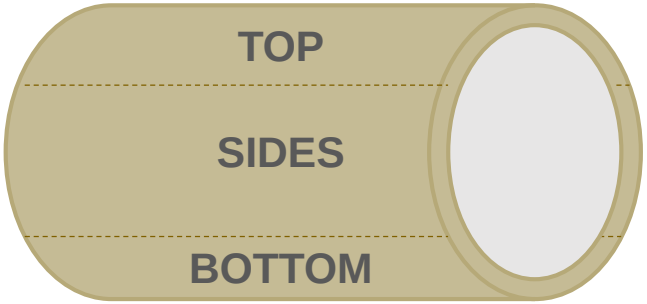
- Fuel: Daw Mill-Miscanthus 12 wt. %
- Probe configuration:



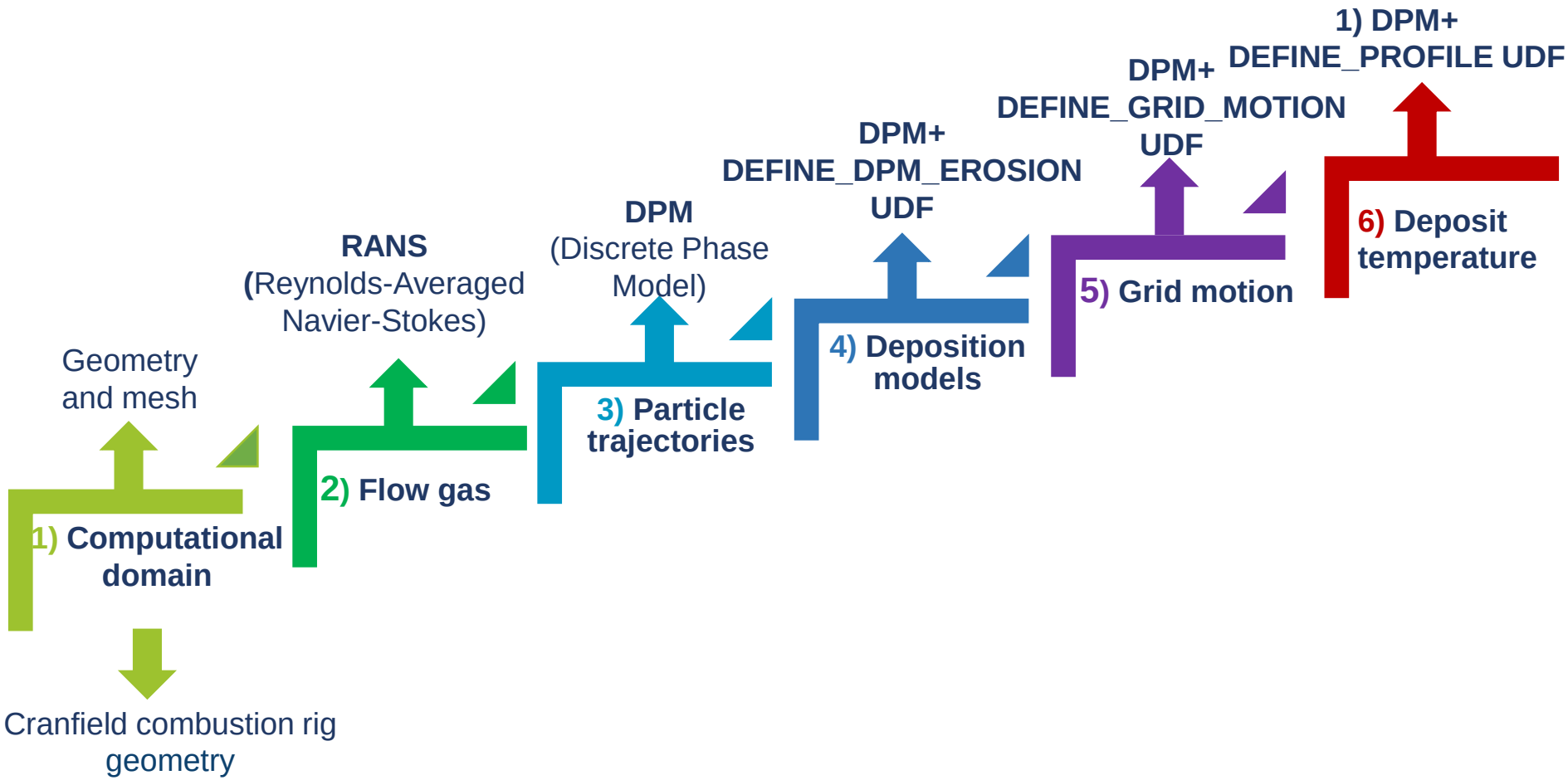
T_{PROBE} = 773 K

Methodology
Experiments

- Ash collection
- Deposition flux [mg/(cm^2 hr)]
- Ash analysis – Scanning electron microscope
- Ash particle size distribution - Laser diffraction



Methodology
CFD Modelling



UDF (User Defined Function)

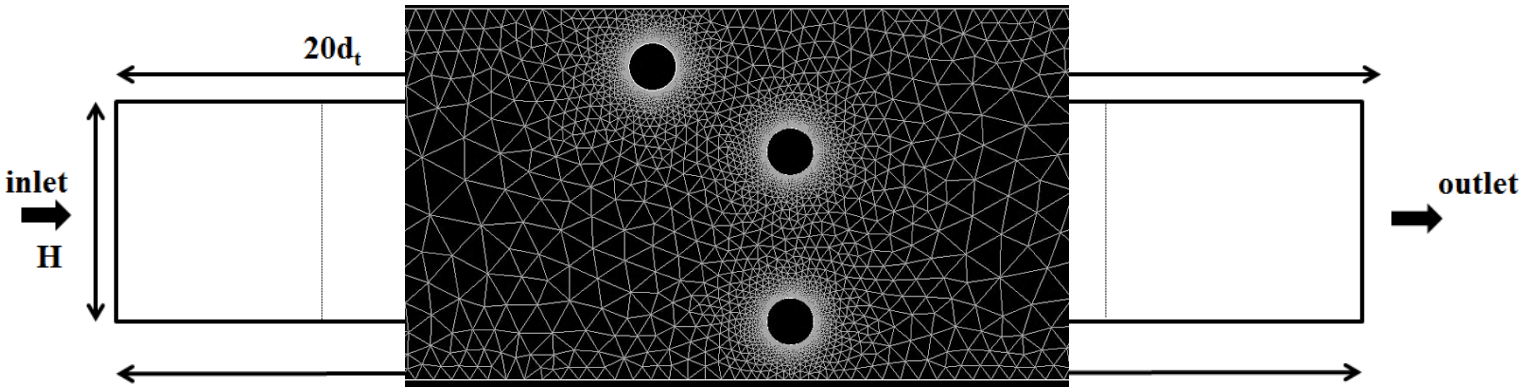
Methodology
CFD Modelling

$U_0 = 2$ m/s

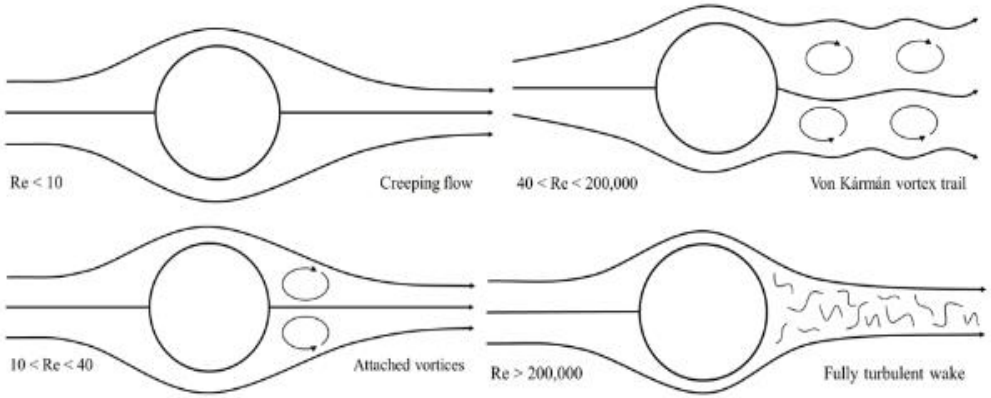
$T_{in} = 1273$ K

$T_{wall} = 773$ K

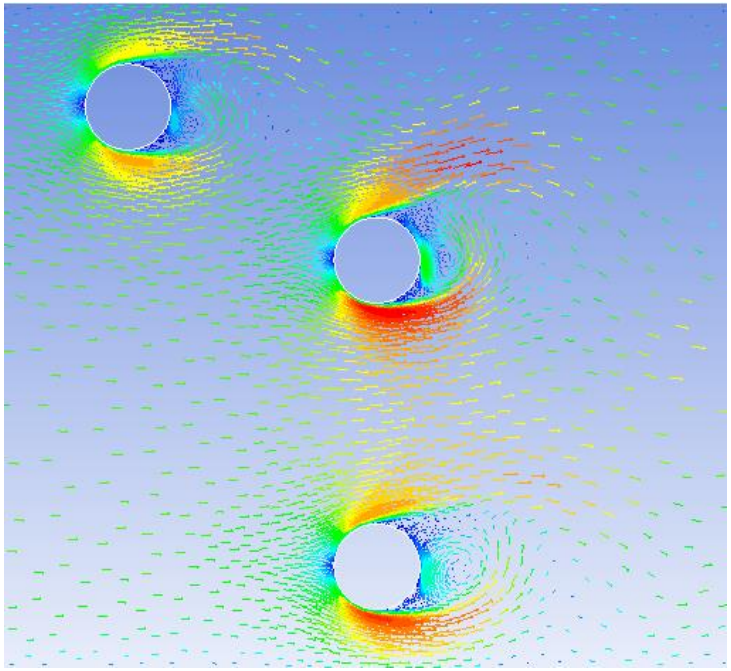
$d_t = 0.039$ m



$$Re = \frac{\rho_g u_g d_t}{\mu_g} \approx 610$$

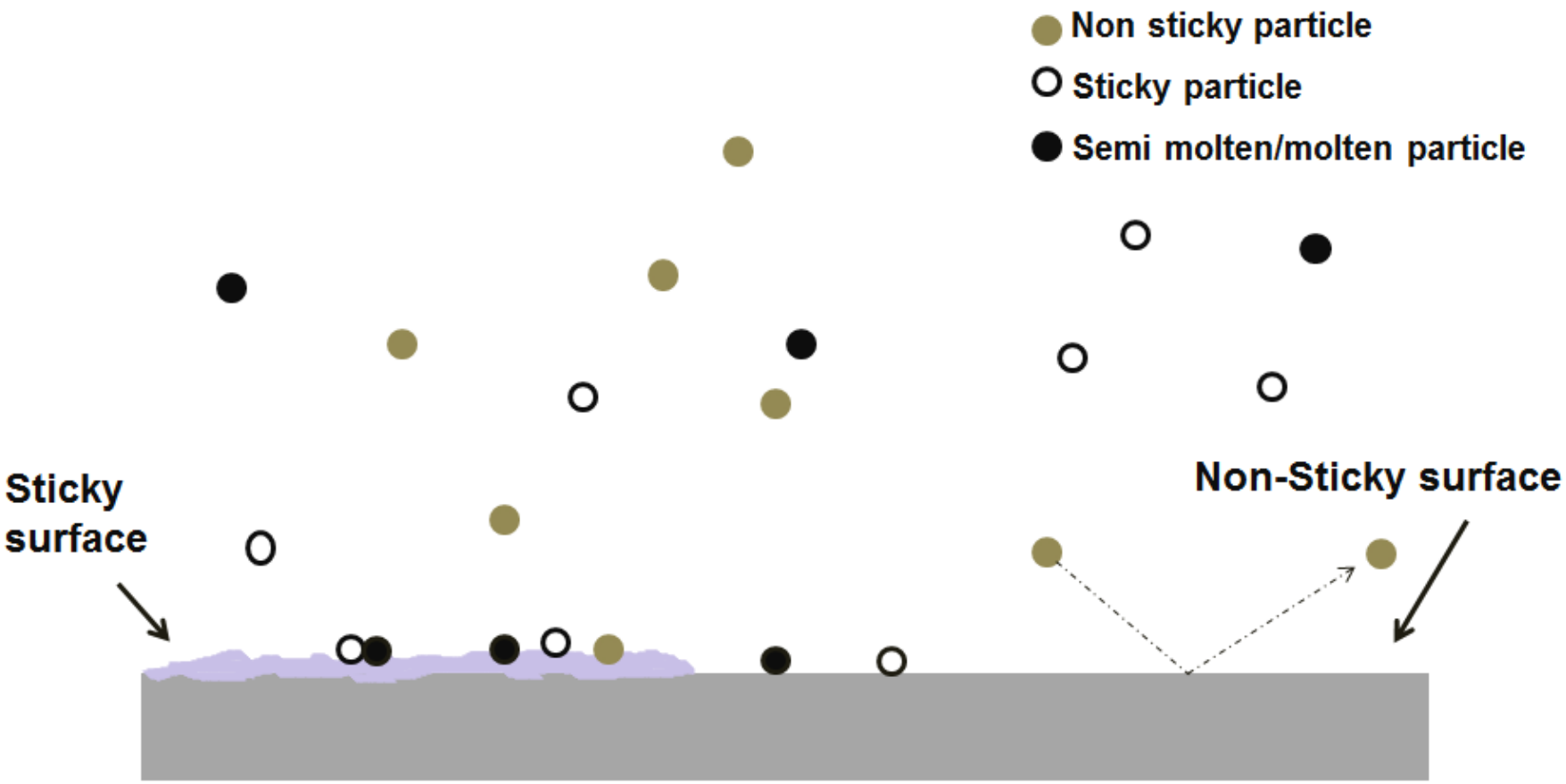


Flow around a cylinder

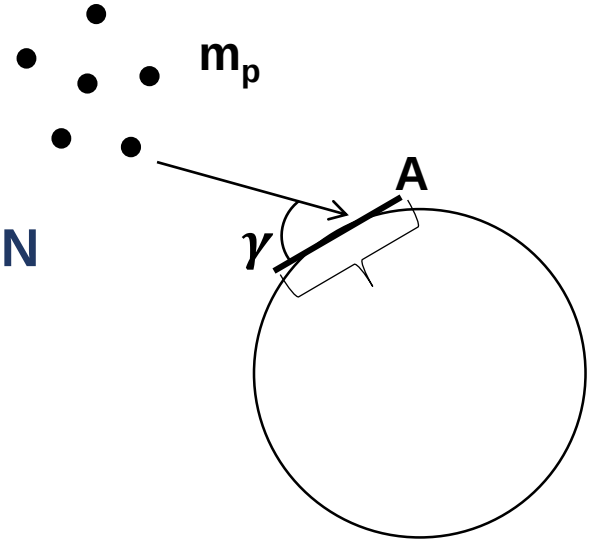


Velocity vectors

Methodology
Modelling



Methodology
Modelling



MODIFIED FLUENT UDF: DEFINE_DPM_EROSION

Deposition flux:

$$m_{TOT,A} = P_{TOT} \frac{dm_p}{dA} sin(\gamma) + m_{c,A} \text{ [kg/(m}^2 \text{ s)]}$$

$$P_{TOT} = P_S + P_P - P_S P_P$$

P_S= surface stickiness probability= f(vapour condensation)

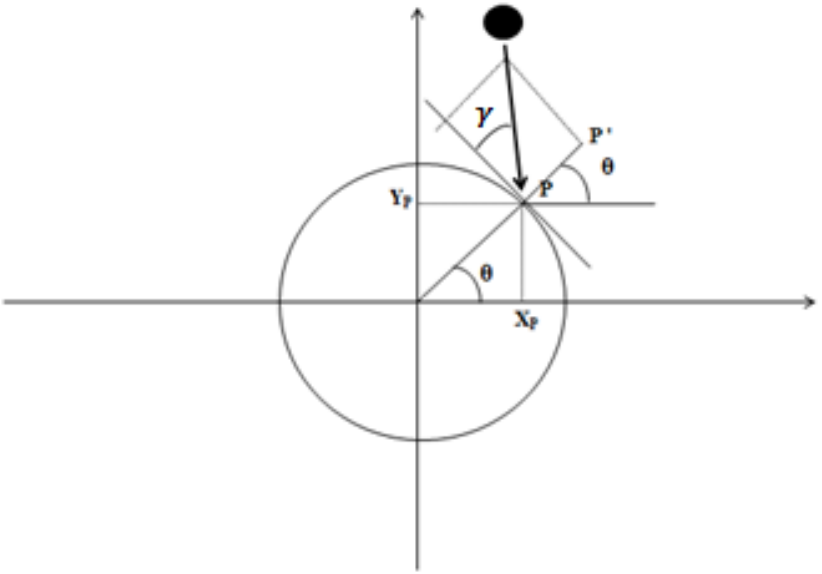
P_P= particle stickiness probability = f(ash composition, ash T) → critical viscosity model

m_c= condensation flux

Methodology
Modelling

MODIFIED FLUENT UDF: DEFINE_GRID_MOTION

$$\delta_i = \frac{(m_{f,A})_i}{\rho_{dep}} * t$$



δ_i= deposition thickness at node *i* [m];

ρ_{dep} = deposit density [kg/m^3];

t = time [s].

$$\begin{cases} x'_p = x_p + \delta_i \cos\theta \\ y'_p = y_p + \delta_i \sin\theta \end{cases}$$

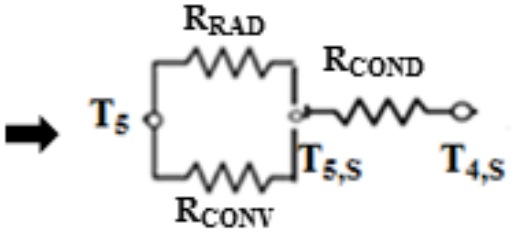
- Deposit shape
- Deposit temperature

Methodology
Modelling

MODIFIED FLUENT UDF: DEFINE_PROFILE

NO DEPOSIT

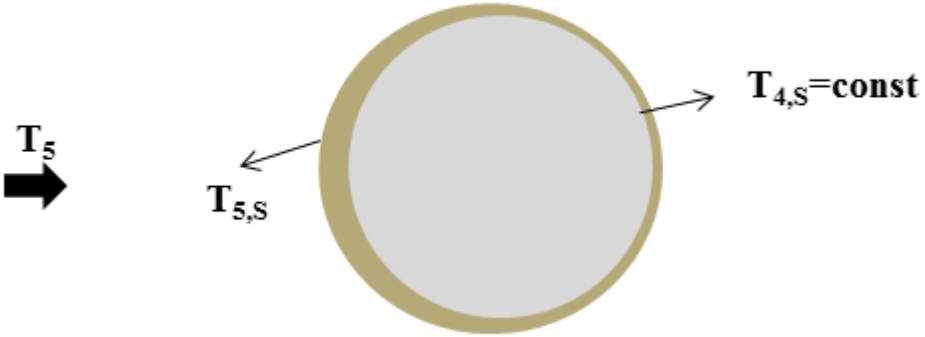
$$\dot{q}_{tot} = h_{conv}\,(T_5 - T_{4,S}) + h_{rad}\,(T_5 - T_{4,S})$$



DEPOSIT

$$T_{5,S} = \dot{q}_{tot}\,\mathrm{R} + T_{4,S}$$

$$\mathrm{R} = \frac{\delta_i}{k_{dep}}$$

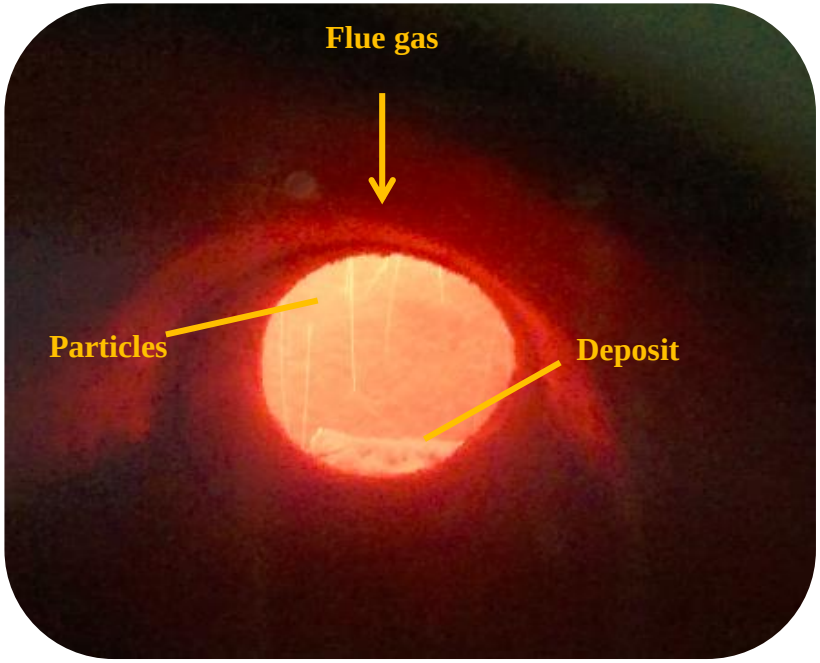


Results and Discussion
Deposition Flux

Deposit after 2.5 hours

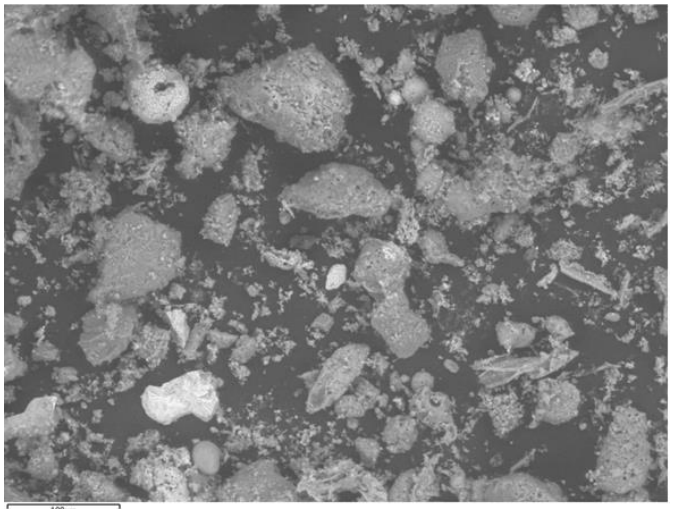
Deposit after 5 hours

video-1519143187.mp4



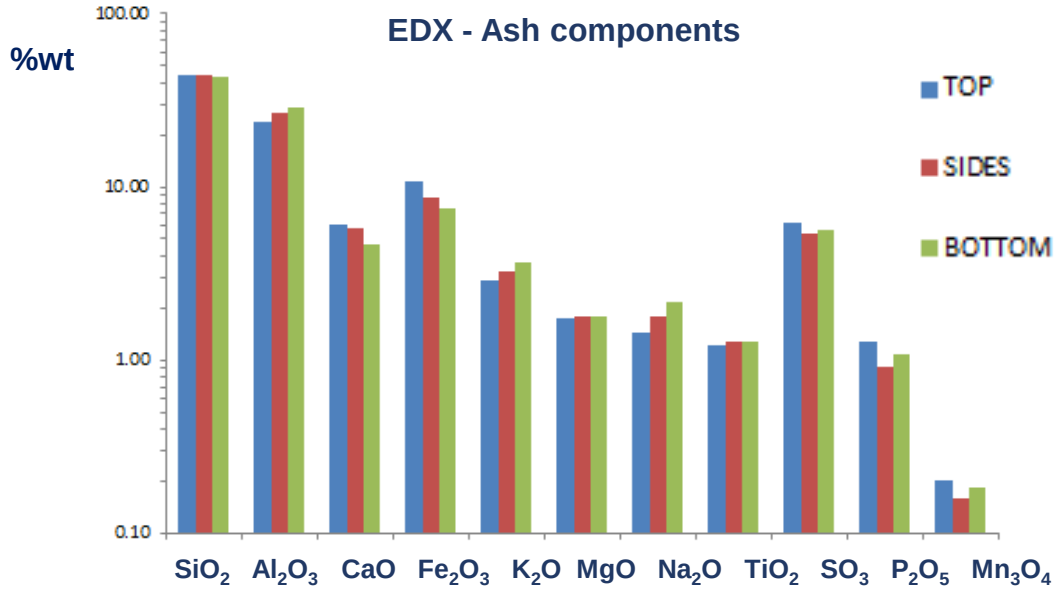
Deposition probe during test

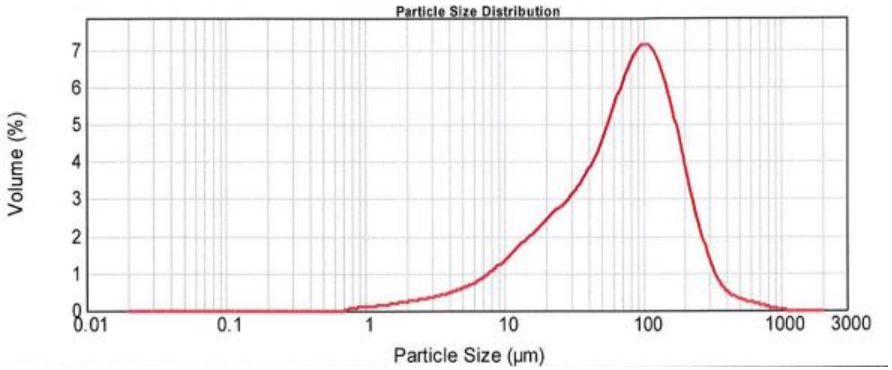
Results and Discussion
Ash Analysis

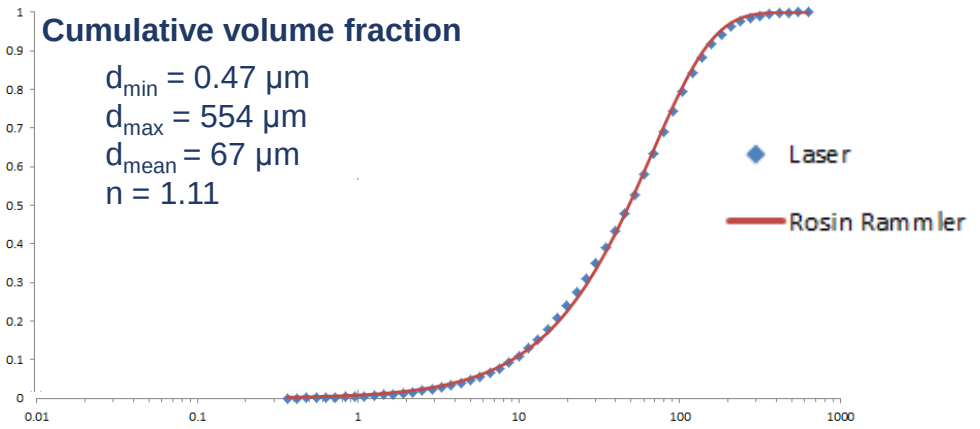


100 µm

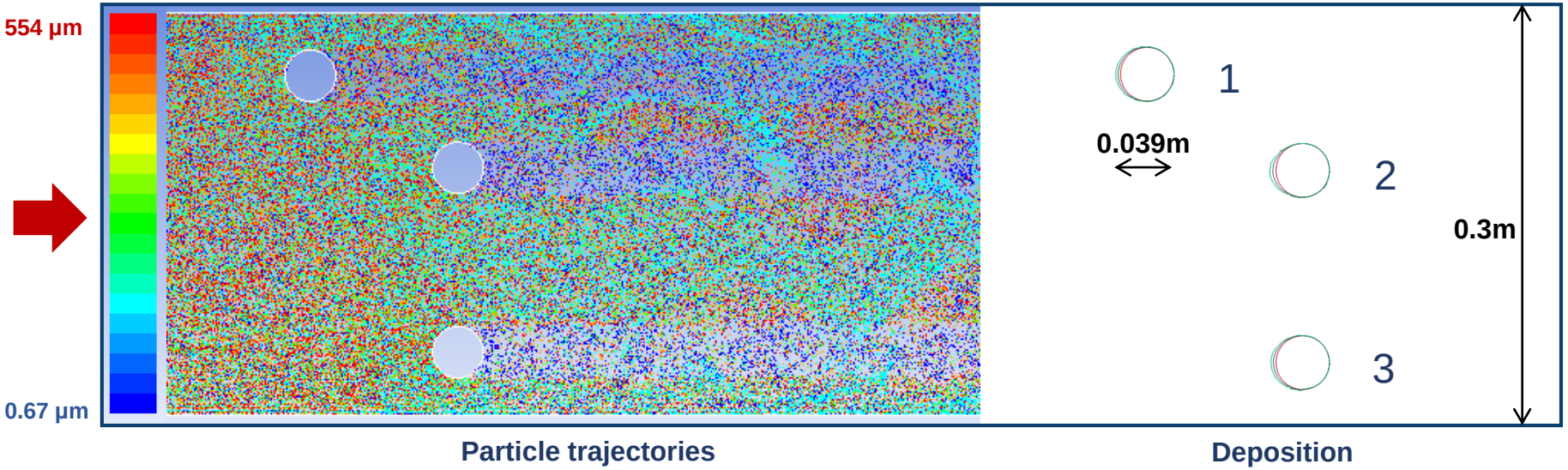
SEM analysis



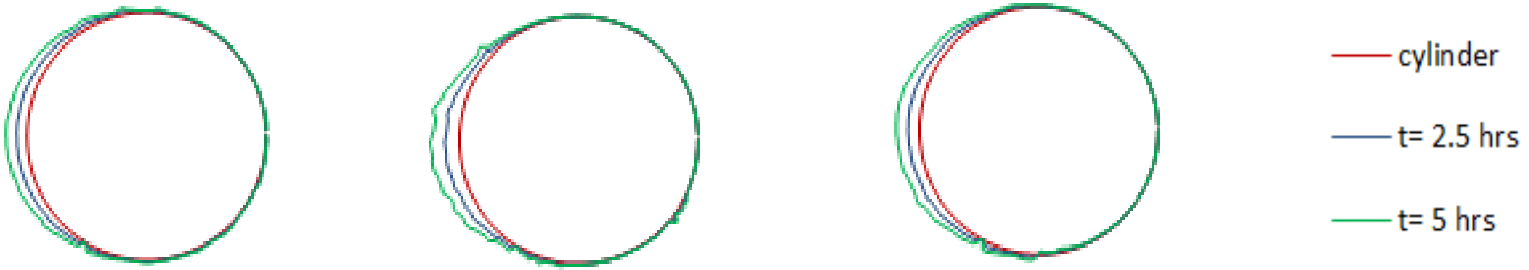




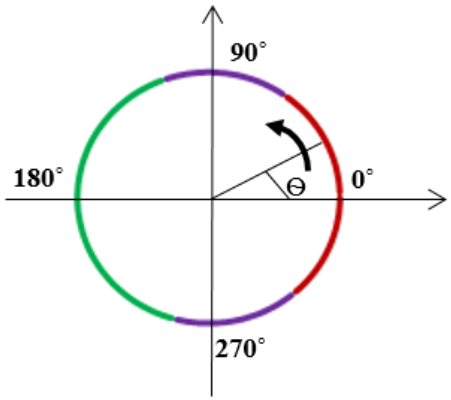
Results and Discussion
Modelling – Particle trajectories and deposit shape

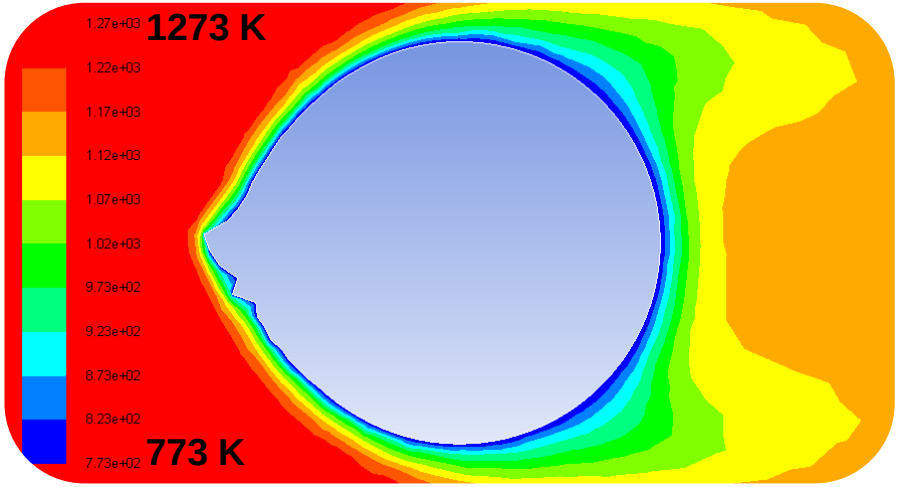


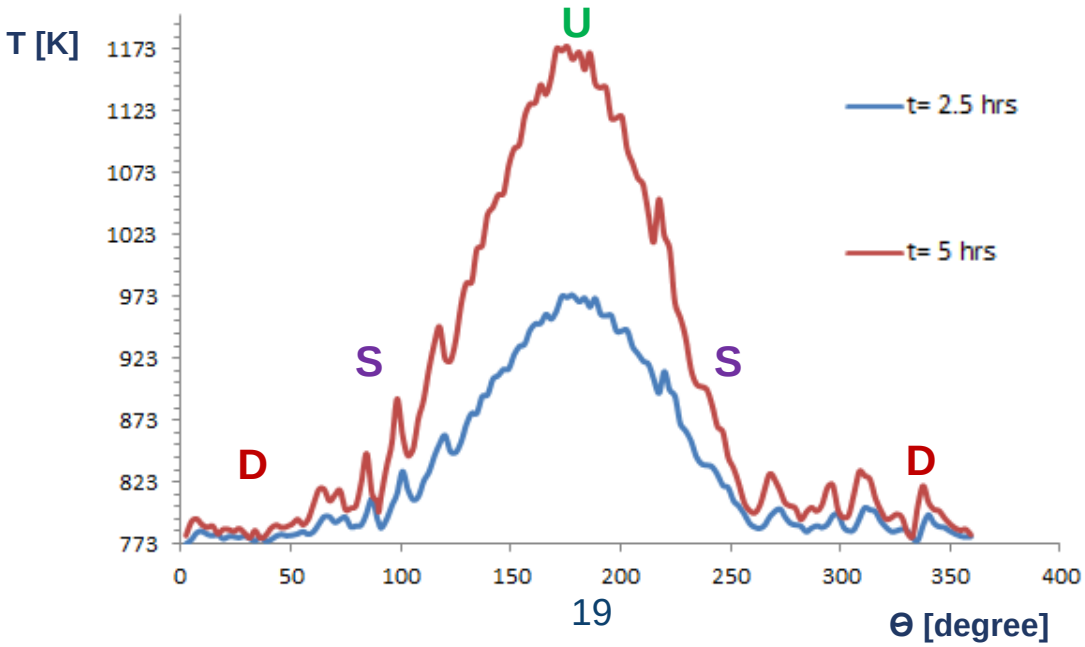
Probe 1 **Probe 2** **Probe 3**



Results and Discussion
Modelling – Deposit temperature

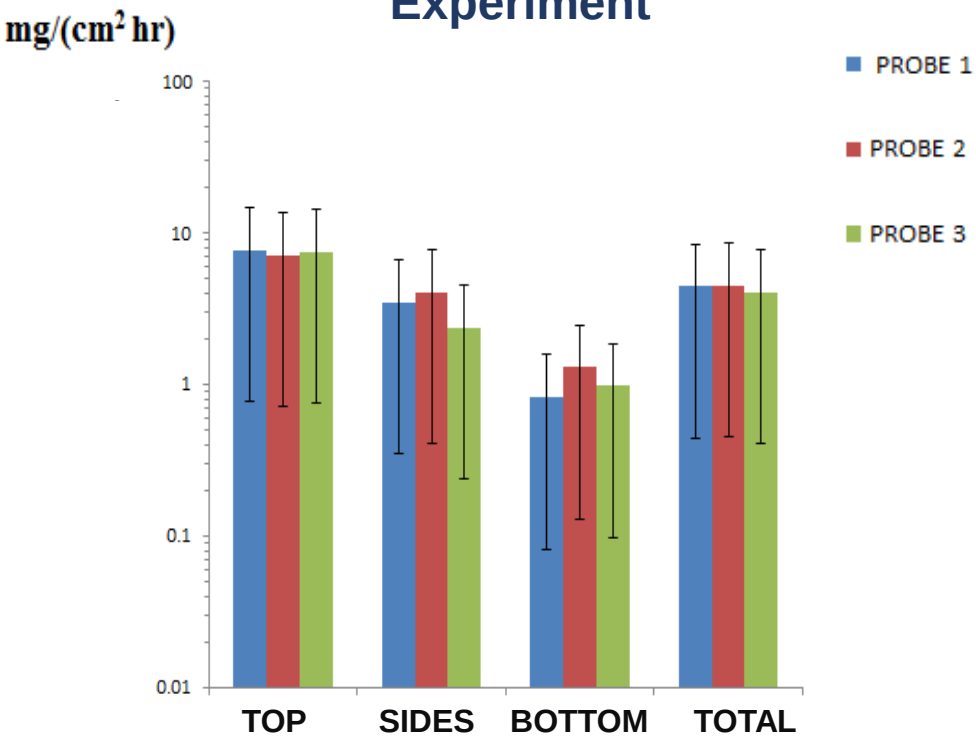




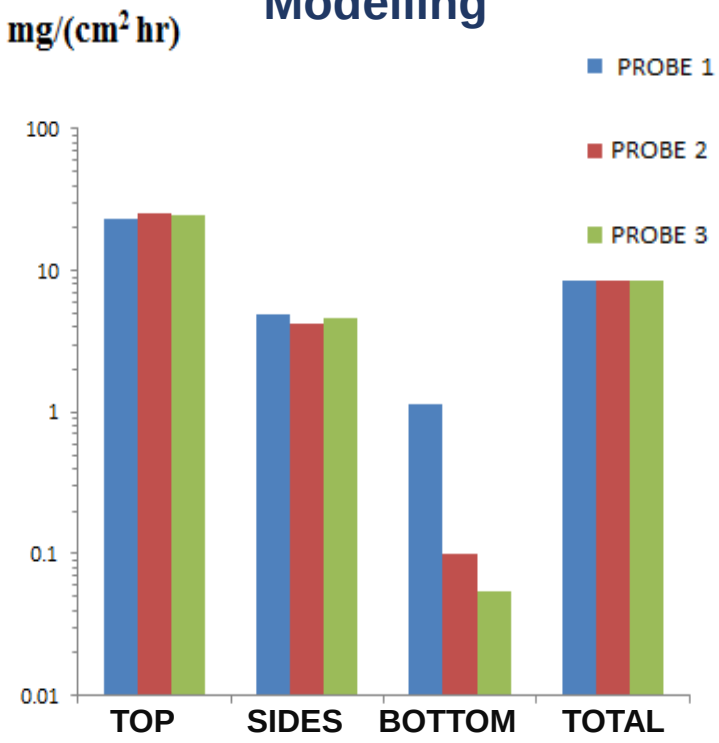


Results and Discussion
Model Validation

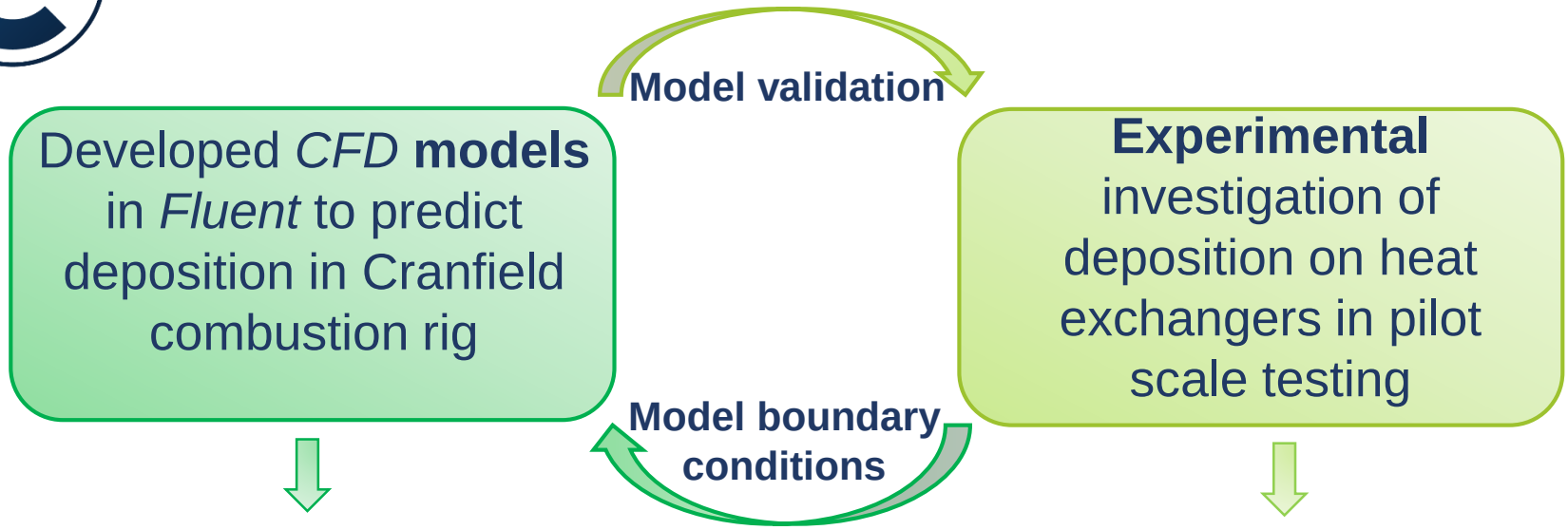
Experiment



Modelling



Conclusions



- Ash particle trajectories (DPM)

Modified UDFs:

- Deposition flux (DEFINE_DPM_EROSION)
- Deposit shape (DEFINE_GRID_MOTION)
- Deposit temperature (DEFINE_PROFILE)

Predictions:

Deposition fluxes, deposit shapes…

- Daw Mill and Miscanthus 12 wt.%
- Ash composition and fly ash particle size distribution analyses
- Deposition flux measurements
- Deposit shapes

Acknowledgment

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- Sponsor: Doosan Babcock
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  Prof. John Oakey

Thank you for your attention!!!

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