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CFD deposition modeling of fly ash particles on biomass fired boilers

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Objetives

Detecting and preventing ash deposits in boilers is critical for improving their availability in terms of working hours and for avoiding outages and related costs. To accomplish this goal, a useful, accurate and reliable computational tool for predicting and preventing fouling problems in boilers that fire troublesome biofuels is presented. Our model uses inertial particle deposition in a fully developed turbulent boundary layer using the Lagrangian stochastic particle tracking method of quadrant analysis. The model considers the condensation of alkali salt vapours as well as the impact mechanism of coarse sticking particles in fluegas. A reference viscosity based on kinetic energy is used in order to settle proper sticky limits. Finally, the deposition modelling result is compared to deposit probe measurements in existing boilers.

Mechanical tracking model

The aim of this work is to develop a practical engineering tool to predict fouling problems and avoid them from the initial stages of the boiler design. Fly Ash Particles (FAPs) deposition modelling follows a stochastic model of coherent structures [1]. This model is known and referred as the quadrant model (Figure 1). It has a high accuracy respect to other conventional near-wall particle tracking models mainly for particles relaxation time below τ_p^+=10.

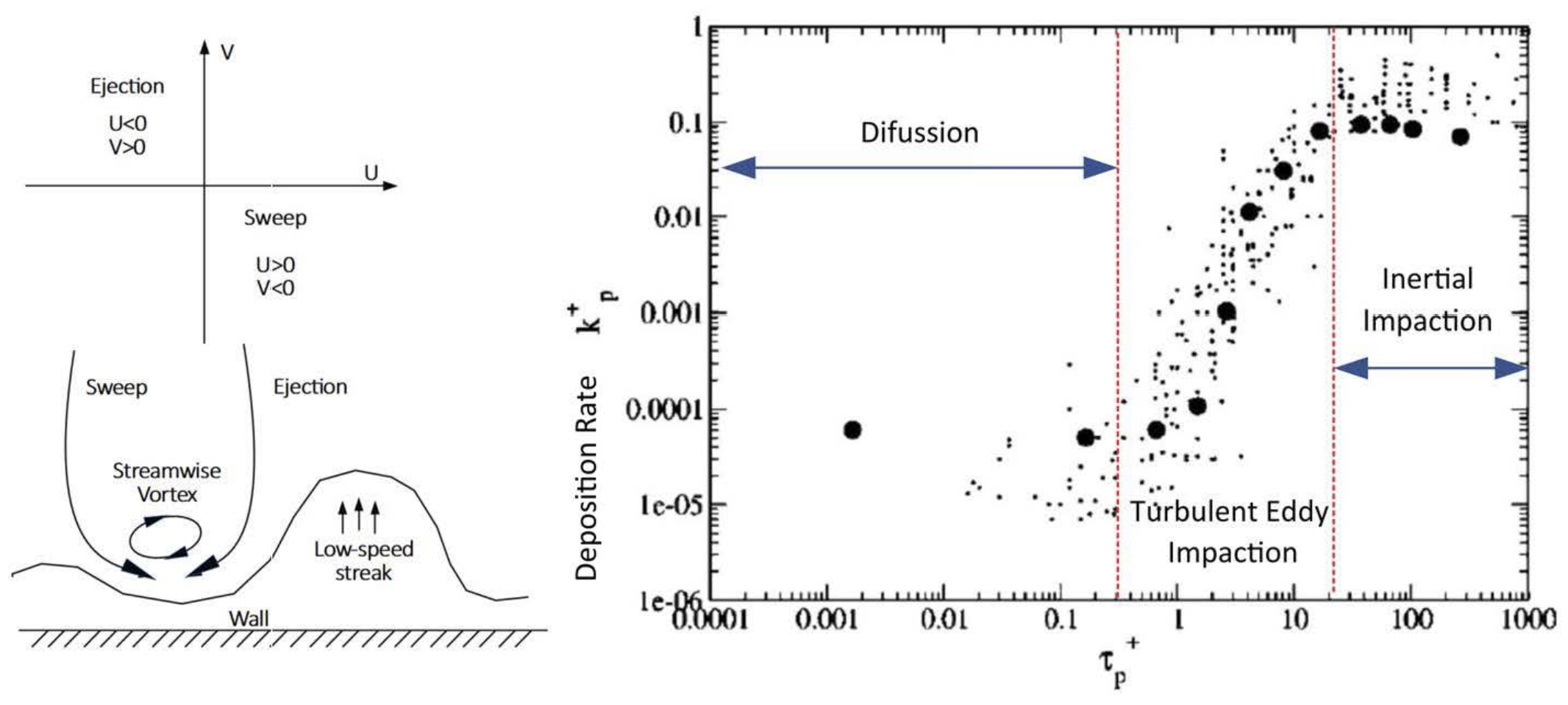


Figure 1: Left: Near-wall coherent structures. Sweeps and ejections. Quadrant analysis [1]. Right: Fitting of quadrant analysis (black dots) over experimental Papavergos cloud.[2]

Quadrant analysis includes diffussion and turbulent eddy-impaction regime (Figure 1). FAPs tracking and deposition modelling have been studied from a general point of view considering inertial impaction, diffusion and turbulent eddy impaction. Even more, the model includes also rebounds of FAPs on surfaces, depending on impact angle and surface roughness.

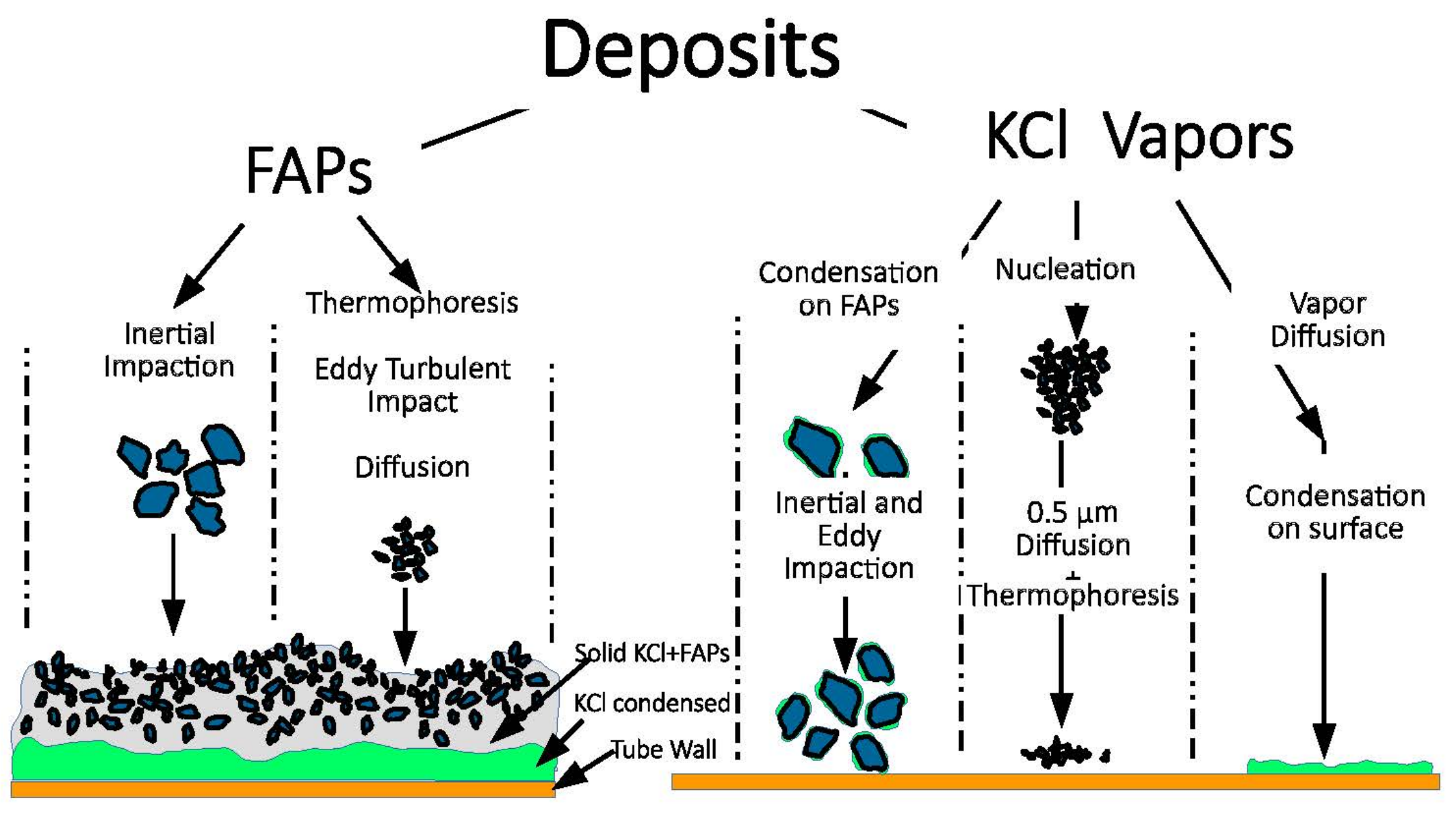


Figure 2: How the deposition model works. Involved mechanisms.[3]

Deposition Mechanisms

FAPs deposition on boiler surfaces must consider, in addition to the former factors, the sticking propensity of FAPs in order to predict which portion of the colliding particles will remain on thesurface tube as deposited (η_{stick}).

Condensation of salts are related to the salt vapour concentration and temperatures of fluegas and tubes surfaces. The most important deposition mechanism on convective surfaces is inertial impaction, counting around 95 % to 98 % of the total deposited mass. The next one, composed of thermopheresis, diffusion and eddy deposition is much lower, around 1 % sticking probability to 5 %. The contribution of condensed vapours is very low in terms of mass ($< 1\%$ in many cases). But condensed vapours, mainly KCl, have an important role in deposition progress. Vapours built up the first layers of condensed glue on tube surfaces. Nucleation of aerosol forms small particles which deposit on the first layers. Under certain FAP temperature, vapour also condenses on FAPs surface, creating a stickier coating.

Sticking propensity

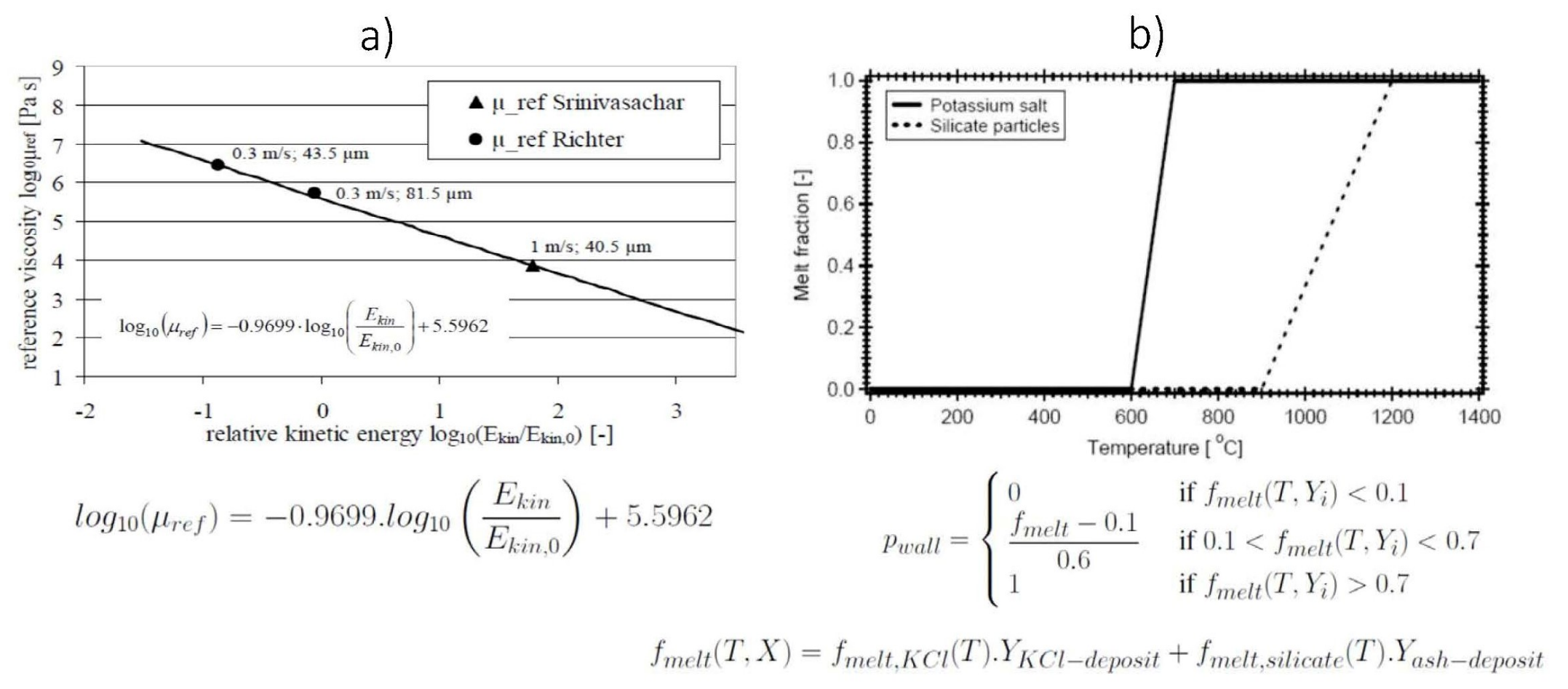
Once the FAP reaches the boundary layer, it is not necessarily fully deposited. This will depend on its sticking propensity (or probability) η_{stick} and the concentration factor of FAPs into the total stream of gas. η_{stick} shall be a function of particle deposition probability (p_{part}) and wall deposition probability (p_{wall}), $\eta_{stick} = p_{part} + (1 - p_{part}).p_{wall}$. Calculation of η_{stick} can be seen in Figure 3. Sticking propensity has two main terms. The first term is the sticking probability of the particle. The second term considers the portion of FAPs not directly deposited and calculatse the probability to deposit due to surface conditions, this is, the sticking probability of the wall. The probability of the particle is $p_{part} = \frac{\mu_{ref}}{\mu_{part}}$ for $\mu_{partr} > \mu_{ref}$ and $p_{part} = 1$ for $\mu_{partr} <= \mu_{ref}$.

Some authors relate μ_{ref} only to a fixed value below which particle sticks on the surface. We can find in literature this fixed value of μ_{ref} from 8 Pa·s [4] to 10^6 Pa·s, resulting in a high variation in the mass deposited.

In the present work, μ_{ref} will be a function of the kinetic energy [5] depending on the velocity and mass of FAP,

$$log_{10}(\mu_{ref}) = -0.9699.log_{10}\left(\frac{E_{kin}}{E_{kin,0}}\right) + 5.5962$$

and the viscosity corresponding to the softening temperature [6]. This will be a new incorporation to former deposition models. Relationship between kinetic energy (E_{kin}) and reference viscosity (μ_{ref}) is shown in Figure 3.



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$$p_{wall} = \begin{cases} 0 & \text{if } f_{melt}(T, Y_i) < 0.1 \\ \frac{f_{melt} - 0.1}{0.6} & \text{if } 0.1 < f_{melt}(T, Y_i) < 0.7 \\ 1 & \text{if } f_{melt}(T, Y_i) > 0.7 \end{cases}$$

$$f_{melt}(T, X) = f_{melt,KCl}(T).Y_{KCl-deposit} + f_{melt,silicate}(T).Y_{ash-deposit}$$

Figure 3: Calculation of sticking propensity η_{stick}. a) μ_{ref} fuction of kinetic energy,[5] b) Sticking probability of particle and wall [3] .

Particle classes

Two main classes of particles are considered: one coarse-size distributed in a bimodal distribution of 0.2 μm and 15 μm of mean diameter and same chemical composition, determined by analysis; and other composed of 100% KCl vapor particles of 0.5 μm constant diameter.

Metering at site

Since this work is aimed to be a practical tool, metering is done on real existing biomass plants. For that purpose, a probe (Figure 4) is inserted into the boiler fluegas path. Concentrical tubes with air and cool water streams allow to maintain the desired wall temperature. Material deposited on the probe is weighted. Sample of FAPs on windward and leeward areas are analysed with SEM/EDS to calculate the sizes and chemical composition of the FAPs, Figure 5.

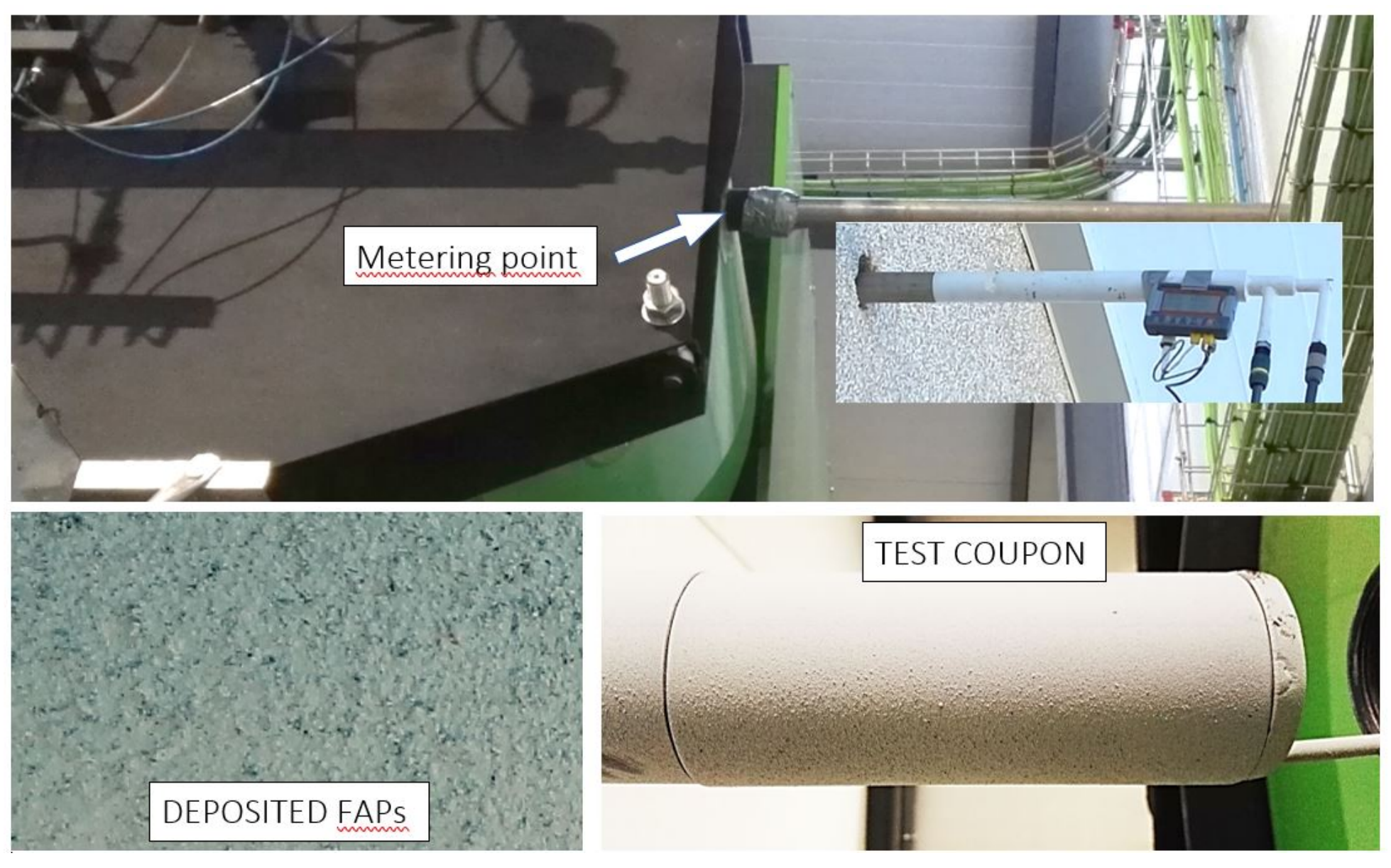

Figure 4: Insertion of the probe in a mixed watertube-firetube grate biomass boiler. Fuel almond shells. In this case, probe had to cross side wall of the boiler house.

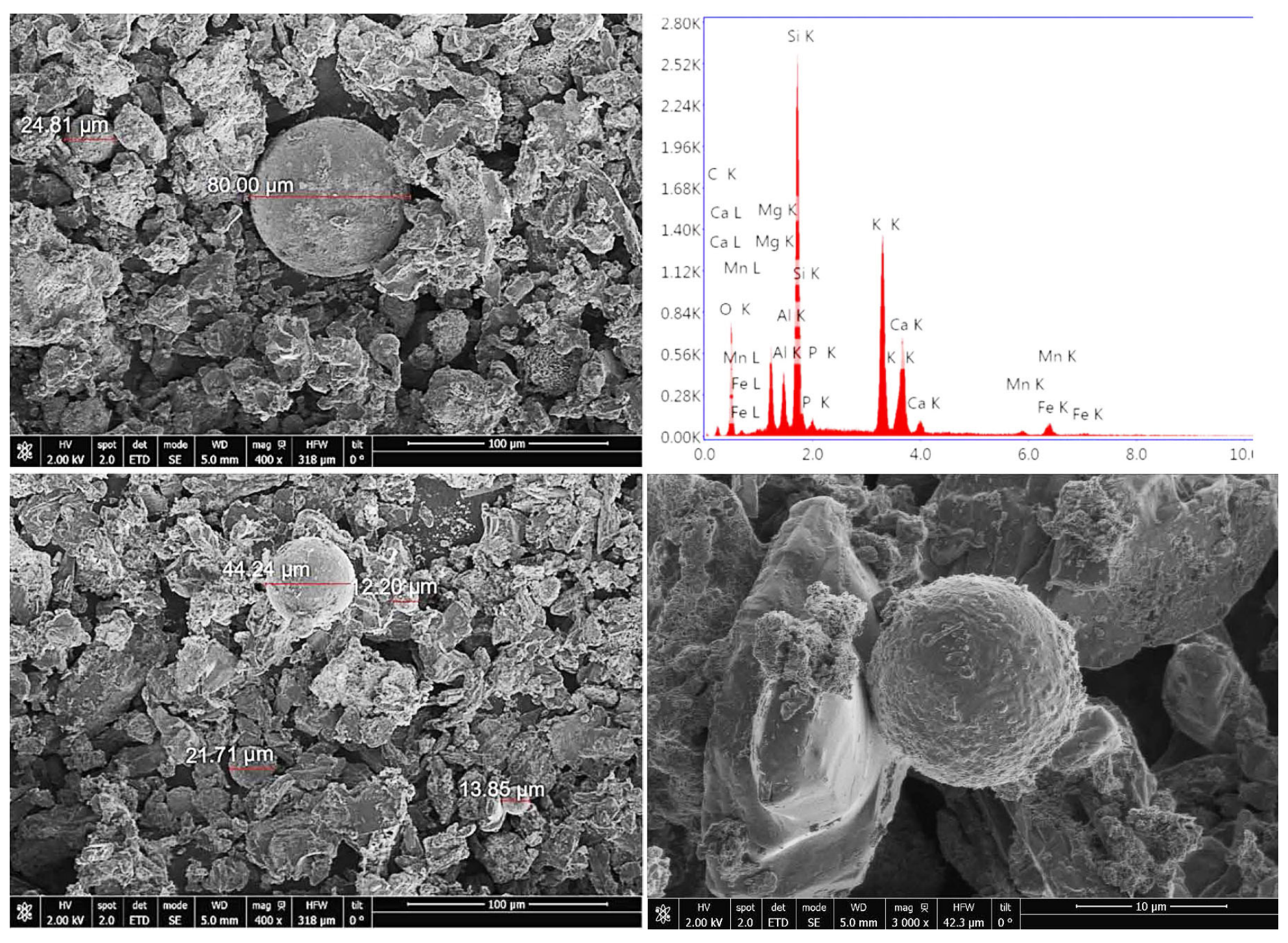

Figure 5: Size of FAPs and main components (SEM/EDS analysis)

Simulation

Once we have got the boiler information: geometry, combustion data, fuel composition, excess air, recirculation ratio, etc., and deposited FAPs composition, we can run the simulation model adapted to these particular data and geometry of the selected boiler. We can see in Figure 6 the geometry of boiler. First results of deposited FAPs in mg are also shown.

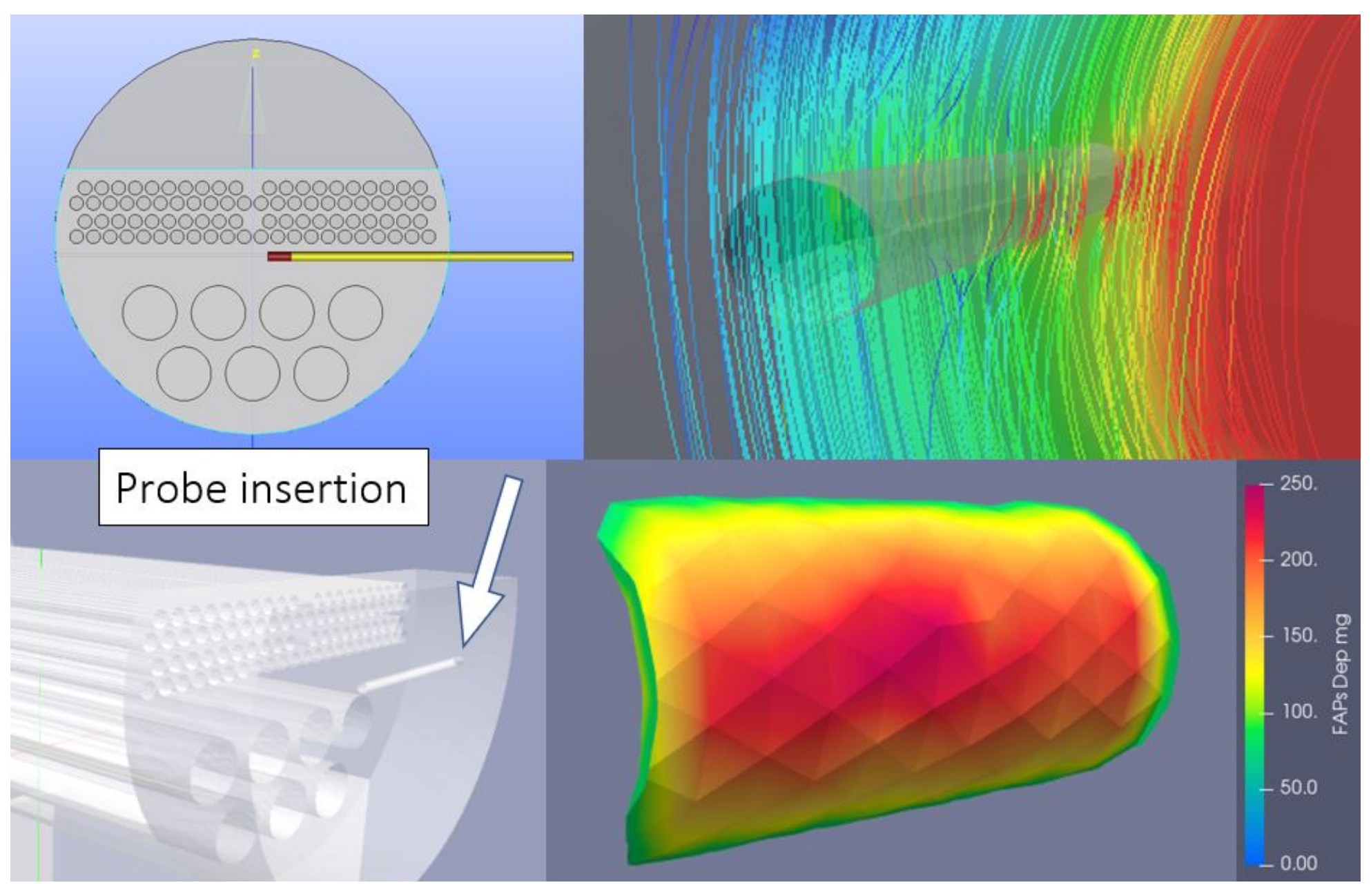

Figure 6: Insertion point of the FAPs probe (left). Stream lines crossing probe profile (right up). Isovolume (100-250 mg) of FAPs deposited mass on probe (right down).

Conclusions

Currently, the tool is prepared just for modelling of the deposition area. Monitorization of at least 8-10 sample is required to adjust the proper μ_{ref} ,depending on chemical composition and kinetic energy of FAP. So far, regions of depositions are correctly located.

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