Thermal Transport to a Reactor Wall with a Time-Varying Ash Layer

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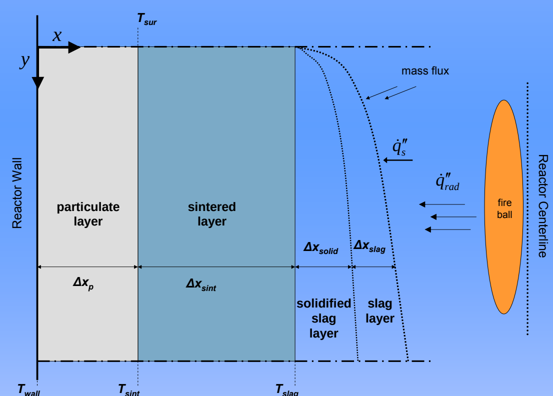
Background

In coal-fired and other low rank fuel boilers inorganic constituents in the fuel are the principle factor determining the boiler size, gas to steam heat transfer characteristics, and boiler side surface corrosion rates. Ash deposits form on boiler tubes and walls and result in reduced heat transfer and increased corrosion. Additionally, ash deposit morphology will change with temperature, which in turn is dependent upon deposit thickness. Modeling ash deposition rate, deposit thickness, and net heat transfer is essential to improving boiler reliability, flexibility (types of coal or fuel burned), and ultimately efficiency.

Objectives

- Characterize the transient and steady state thermal transport through a solid / slagging ash deposit
- Model the morphology, heat flux, surface temperature, and thickness of a temporally varying ash layer

Ash Deposit Model



Ash Deposit Thermal Transport Analysis

for the i^{th} layer at position y

- mass balance

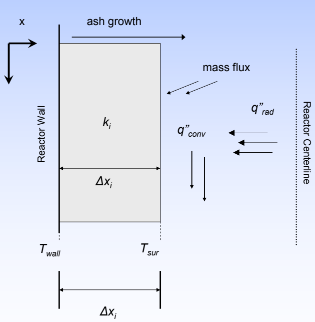
$$\Delta x_i(y) = \frac{\dot m'' G(\Delta t)}{\rho_a}$$

- wall-normal heat flux

$$\dot q''_x(y) = \frac{1}{R_{tot}(y)}(T_w - T_{sur}) = \sum_i \frac{k_i}{\Delta x_i(y)}\Delta T$$

- T_{sur} initially guessed
- FLUENT determines $\dot q''_x(y)$
- T_{sur} computed again and compared

$$\dot q''_{sur} = \dot q''_{conv} + \dot q''_{rad} = \dot q''_x(y)$$



- iteration with FLUENT to convergence of q'' and T_{sur}
- time is incremented and the process is repeated

Steady State Mass Transport Analysis

- y-component of Navier-Stokes Equations (μ evaluated at an average slag temperature)

$$\frac{\partial}{\partial x}\left(\mu \frac{\partial u}{\partial x}\right) = -\rho_{sl} g$$

- integrate twice to obtain slag velocity

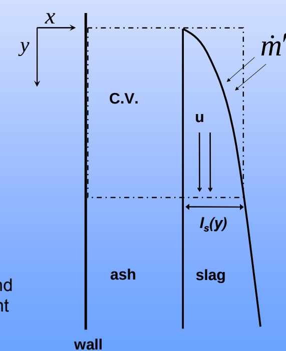
$$u = \frac{\rho_{sl} g}{\mu}\left(-\frac{1}{2}x^2 + x l_s(y)\right)$$

- total mass flow of the slag equals the deposition rate

$$\int_0^{l_s(y)} \rho_{sl} u \, dx = \dot m'' y$$

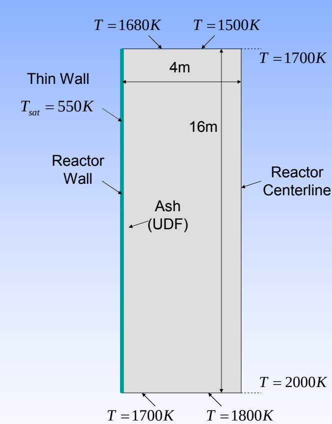
- substituting the velocity distribution and integrating yields the height-dependant slag thickness

$$l_s(y) = \left(\frac{3\mu \dot m'' y}{(\rho_{sl})^2 g}\right)^{1/3}$$



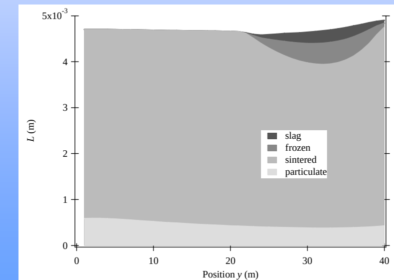
Model Scenario

A User Defined Function (UDF) was written to model the growth of and thermal transport through an ash deposit. The model is coupled thermally with FLUENT through wall surface temperature and heat flux. A scenario, representing the high heat flux of a dominantly radiative section of an industrial coal-fired boiler, was examined.

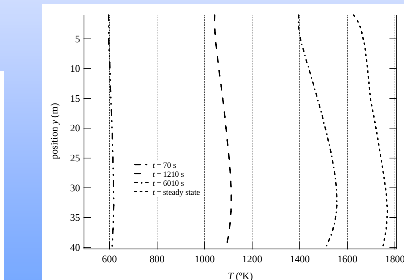


Results

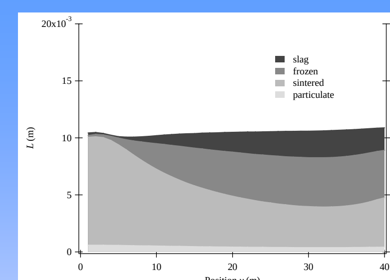
Spatial and temporal data obtained for
- deposit thicknesses
- deposit surface temperature
- net heat flux through the deposit



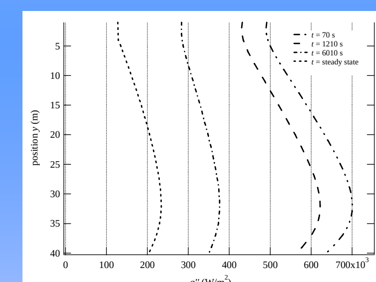
Deposit layers and thicknesses at t = 140 min. vs. vertical wall position



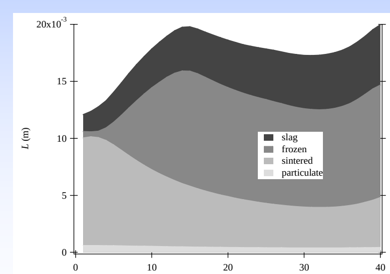
Ash surface temperature profiles at t = 1.0 min, 20 min, 100 min, and at steady state



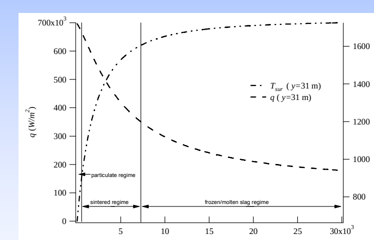
Deposit layers and thicknesses at t = 318 min. vs. vertical position



Wall heat flux profiles at t = 1.0 min, 20 min, 100 min, and at steady state



Deposit layers and thicknesses at steady state conditions (10 hrs) vs. vertical position



Heat flux (left axis) and ash surface temperature (right axis) as a function of time, at position y = 31m.