2D Axisymmetric Temperature Profile Modeling of a Delayed Coking Drum During Pre-Run Warm Up

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Introduction: Delayed Coking is a "bottom of barrel" refining process. A typical feed to this unit is heavy petroleum residue. Before processing the residue, nitrogen is fed to the coke drums, as a way to check restrictions in the flow lines among other safety and process reasons. Nitrogen is also circulated during pre-heating of the unit at the run furnace outlet temperature. A 2D axisymmetric stationary model of the coke drum (Figure 1) was created in order to simulate this pre-run condition with nitrogen gas, as an attempt to calibrate the model before simulating with an oil residue. The single-phase laminar flow and the heat transfer in fluids modules were used simultaneously.

Figure 1. Pilot Unit from the University of Tulsa Delayed coking project, showing the coke drum and the furnace.

Computational Methods: The 2D axisymmetric model is a time independent study. The coke drum was represented by a 1.5" x 76" rectangle, with inlet flow through its bottom. The laminar flow module was set to run N_2, at 2 ft³/h and the pressure across the coke drum was set to be 15 psig. For the heat transfer in fluids module, the temperature values set for the boundary and initial conditions were obtained by averaging the experimental data recorded from the equally spaced internal thermocouples throughout the coke drum length.

The boundary condition at z=0 was set to be 900.0°F, while at z=76 in, 797.2°F. A convective heat flux boundary condition was set at the wall, with the heat transfer coefficient of 44.78 W/m²*K. This was calculated using the constant wall heat flux for Laminar Newtonian flow of 4.364 and the thermal conductivity of stainless steel 316 at 900°F obtained from material properties built-in the software. For the external temperature, a linear fit of the experimental data was used.

The equations used for the simulation were the ones built in the software, which were the conservation of mass (Equation 1), conservation of momentum (Equation 2) and conservation of energy (Equation 3).

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0 \qquad (Equation\ 1)$$

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u} \cdot \nabla)\mathbf{u} = \nabla \cdot [-\mathrm{p}\mathbf{I} + \tau] + \boldsymbol{F} \qquad (Equation\ 2)$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + (u \cdot \nabla)T\right) = -(\nabla \cdot \boldsymbol{q}) + \tau : \frac{1}{2}(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T) - \frac{T}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P \left(\frac{\partial p}{\partial t} + (\boldsymbol{u} \cdot \nabla)p\right) + \boldsymbol{Q} \qquad (Equation\ 3)$$

Results: The results obtained for the fluid flow shows a laminar flow, with Re = 0.09 and maximum velocity of 76.2 ft/h, leaving the system. This shows the characteristic of creeping flow, because of the very low flow rate of 2 ft³/h. This result is carried over to the temperature profile (Figure 2), which varies only in the z direction, having an instantaneous heat transfer, due to the vanishingly viscous forces of the system (very low Reynolds number). Moreover, the temperature values calculated by the model are very close to the ones obtained experimentally (Figure 3).

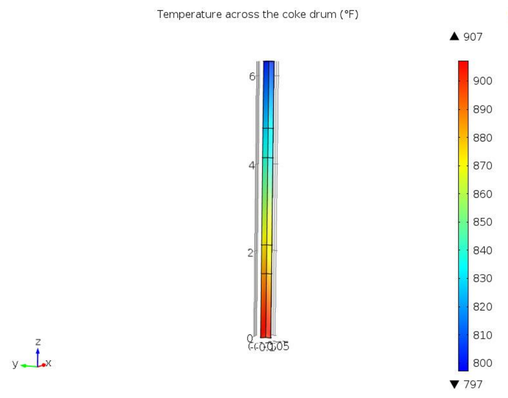

Figure 2. Temperature profile across the coke drum for the pre-run warm up with N_2.

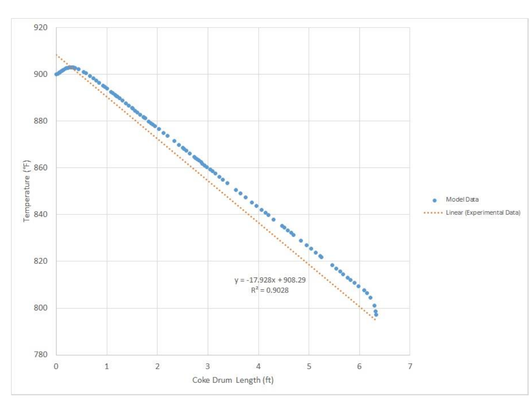

Figure 3. Comparison between experimental temperatures (orange) and model temperatures (blue).

Conclusions: The model achieved its objective, giving a fairly close representation of the temperature values and the flow profile observed experimentally during the pre-run warm up. For the future work, the model will be tested with petroleum oil residue to observe the same parameters studied in this case, and then it will be improved by adding reaction kinetics.

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