CPFD Simulation of Combustion Process and Investigation of Associated Heat Transfer and Hydrodynamics in Fluidized Bed

E.A Alshaafi, A. Prakash, C. Zhang
a Department of Chemical and Biochemical Engineering, Western University, London, ON
b Mechanical and Materials Engineering Department, Western University, London, ON

Background:
- Gas-solid fluidized bed reactor offers several advantages, including high heat and mass transfer rates, and good mixing of solids, making them attractive for several industrial processes.
- The most important application of the FB reactor is fluid catalytic cracking (FCC). FCC unit is to convert high-boiling petroleum fractions called gas oil to high-value fuels (gasoline, jet fuel, and diesel).
- There are over 400 FCC/RFCC units operating worldwide with a total processing capacity of over 20 million barrels per day and generate approximately 40% of the world’s gasoline.
- High heat transfer efficiency and good equipment reliability are two main concerns for industrial operators. To achieve the two objectives, a deep understanding of the relationship between hydrodynamic phenomenon and heat transfer properties is needed.
- Most previous literature reported using dimensionless number Nusselt number as a function of Prandtl number and Reynolds number to heat-transfer coefficients predictions in fluidized bed. Few studies were on surface hydrodynamics, which is directly related to the heat transfer mechanism.

Objectives:
- Investigate heat transfer and mixing processes for better overall thermal management.
- The coke combustion process will be simulated with the help of CFPO software accounting for kinetics, mass transfer, and mixing effects.
- Heat transfer process in a fluidized bed will be simulated and validated by experimental measurements.
- Particle mixing behavior will be analyzed with appropriate experimental measurement.
- To evaluate design alternatives to improve the operation of a FCC regenerator.
- To develop CFPO simulations to better understand the behavior of an industrial FCC regenerator.

Research Methodology (Experimental vs Numerical):
- Measurements have been carried out in a Plexiglas column of inner diameter 0.25 m and height of 2 m. The bed consisted of 150 μm sand particles of static bed height 0.45 m. The gas velocity was varied from 0.1 to 0.4 m/s.
- Radial and axial variations in heat transfer coefficients captured by fast response probe (0.02s).
- Numerical model successfully predicted the heat transfer coefficients and effect of bed hydrodynamics.

Motivation:
About 90% of 400 FCC/RFCC units are operating in the partial combustion mode. Thermal management of these processes is always challenging and becomes even more challenging with variations in feedstock compositions affecting the reaction environment. A good understanding of the hydrodynamics, mixing, and heat transfer process is required for better management and control. The exothermic coke combustion process requires careful control and thermal management of the unit to avoid temperature surges in the bed and minimize alkilnaphthenes in the freeboard region due to incomplete combustion in the bed. Carbon monoxide produced due to incomplete combustion can continue to react in the freeboard region of the regenerator and resulting in high temperature, which impacts the regenerator internals and affects the catalyst activity.

Results:
- Minimum fluidization velocity
- Effect of superficial gas velocity
- Axial variations of heat transfer coefficient (distributor and bulk regions)

Conclusions:
- The heat transfer in the distributor regime is lower than in the bulk regime, where large bubbles wake region is well developed.
- Heat transfer in the center region is higher than near the wall due to more frequent packet renewal on the tube surface at the bed’s center.
- The time series data obtained from simulations compare well with the heat transfer process captured with a fast response probe.
- Coke combustion was successfully simulated using the kinetic model, and the results were well-matched with industrial data.

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