EFFECT OF PULSATING FLOW IN FCC RISER

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Abstract

Gas-solid flow in fluid catalytic cracking (FCC) riser exhibits heterogeneous "core-annulus" radial profile of solids holdup, which causes poor mixing and also reduces overall performance. To overcome this shortcoming, pulsating (regular variations) gas flow can be useful in riser. In this study, impact of pulsating gas flow on gas-solid hydrodynamics and performance of FCC riser is investigated by using computational fluid dynamic (CFD) approach. Simulations of gas-solid cold-flow and reactive flow in FCC riser are performed without and with pulsating gas flow of various amplitudes and frequencies. Predictions from pulsating gas flow show improved homogeneity in radial profiles of phase holdup, concentrations and temperature.

Keywords

Riser, fluid catalytic cracking, CFD, Pulsating flow

Introduction

In a fluid catalytic cracking (FCC), a riser is a long vertical pipe where catalyst is fluidized by gas flowing at high velocity. Mixing between gas and solids governs conversion and yield. Several previous studies on riser hydrodynamics have shown an existence of 'core-annulus' flow pattern, which is characterized by higher solids volume fraction (10-30% depending on solid loading) near wall and a dilute flow at center. Due to the core-annulus flow pattern, significant amount of catalyst near wall and gas at center remain non-participating in reactions, and result in a narrow reaction zone with presence of both gas and catalyst. Thus, enhanced mixing is desired for higher performance of FCC riser.

In dense fluidized beds, pulsating fluidization, where gas velocity fluctuates with time in regular patterns, has resulted in improved gas-solid mixing. Devahastin and Mujumdar (2001) have found that pulsating spouted bed shows superior mixing behavior at certain low frequency of pulses. Wang and Rhodes (2005) have found that both sinusoidal and square pulsations improve quality of fluidization over a wide range of pulsation amplitudes and frequencies. Hamed Bizhaem and Tabrizi (2013) have shown that pulsating airflow enhances mixing of fine cohesive particles in poly-dispersed fluidized bed.

In this study, the effect of pulsating flow on hydrodynamics and performance of FCC riser is investigated by performing 2D CFD simulations of gas-solid flow in risers with two different flow conditions, namely cold-flow (FCC catalyst-air, H = 14 m, D_t = 0.2 m, G_s = 489 kg/m^{2}s, U_g = 5.2 m/s; Knowlton et al., 1995) and reactive flow (FCC catalyst-VGO vapor and steam, H = 30 m, D_t = 1 m, G_s = 470 kg/m^{2}s, Catalyst to oil = 5.10, Steam = 5% in feed, feed inlet temp = 652 k; Derouin et al., 1997). The CFD model of this study is based on Eulerian-Eulerian gas-solid flow model, where interphase drag is modelled by using the energy minimization multi-scale (EMMS) model and reaction kinetics is modelled by using the 4-lump cracking kinetic model (Lee et al. 1989).

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The model is initially validated and then used to simulate different cases without and with pulsating flow of different amplitudes and frequencies.

Results and discussion

In this work, the effect of pulsating flow on radial and axial profiles of holdup, temperature and concentration, and time series of catalyst accumulation and mass flow rates are analyzed for gas-solid cold-flow and reactive flow in FCC riser. Table-1 lists only representative cases, for which the effect of pulsating flow only on radial profiles is discussed in this abstract.

*Table-1. Simulated cases (*pulsating flow cases)*

		Gas velocity	Pulse frequency
Reactive-flow	Case-1	9.39 m/s	
	Case-2*	4.69-14.08 m/s	2 Hz
	Case-3*	2.34-16.43 m/s	2 Hz

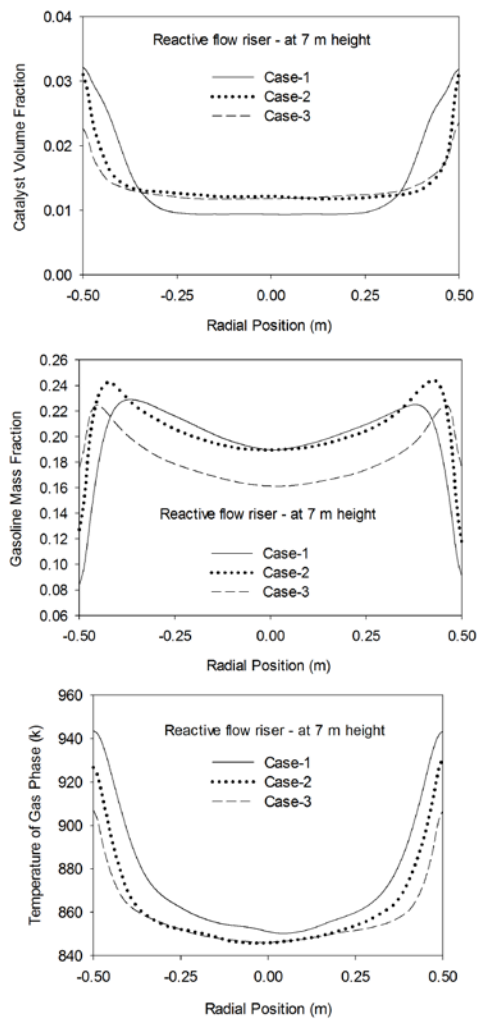

Figure 1. Radial profiles (a) catalyst volume fraction, (b) gasoline fraction mass fraction and (c) temperature

Fig-1(a) shows predicted radial profiles of catalyst volume fraction. Higher volume fraction at wall and lower values at center, consistent with the core-annulus structure, can be seen. However for the pulsating flow cases, values near wall are lower and at center are higher than those for without pulsating flow case. Furthermore, the effect of pulsating flow is even higher for high amplitude pulses (case-3). Fig-1(b) shows radial profile of gasoline mass fraction. Gasoline mass fractions are higher at some distance away from both wall and center of riser. This is because reactions take place where catalyst and VGO contact or at boundaries of core and annular regions. In Fig-1(b), the values near walls increase with increase in amplitude of pulses. Furthermore, difference between values at wall and center of riser decrease with increase in amplitude of pulses. This also suggests that the reaction zone expanded towards the walls. However, gasoline mass fraction is significantly lower in the core region for case-3 than those in cases-1 and 2. This is attributed to lower VGO concentration in the core region (not shown here). Fig-1(c) shows radial profiles of temperature. According to core-annular profile, higher values near wall can be attributed to higher temperature and concentration of catalyst. For cases-2 and 3, temperature values at both wall and center decreases. This can be attributed to higher heat transfer between the two phases and higher reaction rates in pulsating flow resulting in higher endothermic heat of reactions.

The use of pulsating gas flow gives less dense annular region with it being more penetrated by reactant. As a result, participation of annular region in reactions increases by using pulsating flow. This results in lower difference between values at wall and center, suggesting reduced heterogeneity in radial profiles. Currently, simulation work is in progress to investigate the effect of pulsating flow in three-phase flow with droplet vaporization in FCC riser.

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