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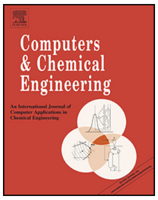

Modelling and simulation of an industrial riser in fluid catalytic cracking process

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ABSTRACT

Fluid Catalytic Cracking (FCC) unit is an important unit of modern refineries and any improvement in the unit's operations and design to increase yield and meet the ever increasing demand for fuel brings about the overall profitability of the FCC. In this work, simulation of an FCC riser of varied diameter was carried out to improve the unit's operations and design, and the results are compared with risers of different diameters. The riser with varied diameter produces 53.4 wt%, a 3.18% increased yield of gasoline at low catalyst to oil (C/O) ratio of 1.27 compared to 51.7 wt% from a 1 m diameter riser. At increased C/O ratio, more gases and coke are produced in the varied diameter riser. Larger diameter demands more catalyst but yields more gases. Process variables can be directly correlated with yield of gasoline, which can aid process design.

1. Introduction

The FCC unit is the workhorse of modern refineries (Bollas et al., 2007), which converts gas oil into lighter hydrocarbons used as valuable transportation fuels such as gasoline and diesel. A typical barrel of crude produces approximately 20% straight run gasoline. However, demand is nearly 50% per barrel and hence there is the need for an efficient process to increase the gasoline production. In the FCC unit, gasoline is produced in the riser and therefore it must be given considerable attention for improvement in gasoline yields.

To meet the demand for gasoline, many researchers have considered the simulation of the riser as a major strategy to improve the yield of gasoline. To do this, some important success factors like the riser design and operations must be improved. Two important factors to consider in trying to achieve optimum yield of gasoline in the riser, is to have uniform catalyst density and very effective hydrodynamics. In situations where the catalyst activity is excellent but the yield poor, the cause would be attributed primarily to the riser hydrodynamics (Kalota and Rahmim, 2003), which is a function of riser design. Therefore, riser diameter is an important factor to consider because of its effect on the riser hydrodynamics.

Although a lot of work has been carried out on the modelling of the riser, it is done by considering the riser to be of a uniform cross section (Fernandes et al., 2007; Duduku et al., 2007; Gupta and Subba Rao, 2003; Elshishini and Elnashaie, 1990). For some, the riser comprises of a number of equal sized compartments (or volume elements) of circular cross section, but not varied diameters (Gupta et al., 2007), and for others it comprises of a cylindrical vertical vessel where cracking of gas oil is carried out using a catalyst in a vaporised upward fashion (Han and Chung, 2001a). Even when a comprehensive three-dimensional (3-D) heterogeneous riser model was applied to simulate the turbulent gas–solid flow and reaction in a polydisperse FCC riser, the entire zones of the riser were considered as a uniform cross sectional tubes (Li et al., 2013).

The riser unit has many sections; feed preheater, the vaporization section and the riser, which are sometimes modelled differently. Although an attempt to simulate the riser unit with varied diameter (between 1 m at the bottom to 1.4 m at the top) was made (Novia et al., 2007), only a quarter of the riser was considered because they modelled the riser unit in two sections; the vaporization section (found to have no chemical reactions) as 1 m diameter and the riser section as 1.4 m, a uniform cross section. They also included the vaporization section in the riser unit model. In some cases, the model of the vaporization section was included in the riser unit simulation but the length of the riser (uniform cross section) considered did not include the vaporization section (Han and Chung, 2001a,b). It is also clear that the vaporization section of the riser unit has unique hydrodynamics and can be treated differently, because it takes about 3% of the riser residence time (Ali

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Nomenclature

A	Surface area, m^2
A_{ptc}	Effective interface heat transfer area per unit volume, m^2/m^3
C	Mole concentration, kg mole/m^3
C_{pg}	Gas heat capacity, kJ/kg K
C_{ps}	Solid heat capacity, kJ/kg K
D	Diameter, m
d_c	Catalyst average diameter, m
E	Activation energy, kJ/kg mole
F	Mass flow rate, kg/s
H	Specific enthalpy, kJ/kg
ΔH	Heat of reaction kJ/kg
h	Enthalpy of reaction kJ/kg
h_p	Interface heat transfer coefficient between the catalyst and gas phases
h_T	Interface heat transfer coefficient, kJ/m^2 s K
k_{i0}	Frequency factor in the Arrhenius expression, 1/s
K_i	Rate coefficient of the four-lump cracking reaction, 1/s
K_g	Thermal conductivity of hydrocarbons
L	Length, m
M_w	Molecular weight
P	Pressure, kPa
Q_{react}	Rate of heat generation or heat removal by reaction, kJ/s
R	Ideal gas constant, 8.3143 kPa m^3/-kg mole K or kJ/kg mole K
RAN	Aromatics-to-naphthenes ratio in liquid feedstock
S_c	Average sphericity of catalyst particles
S_g	Total mass interchange rate between the emulsion and bubble phases, 1/s
T	Temperature, K
u	Superficial velocity, m/s
V	Volume, m^3
y	Weight fraction
Zg	Gas compressibility factor

Greek

Ω	Cross-sectional area
ρ	Density, kg/m^3
ϕ	Catalyst deactivation function
ε	Voidage
α	Catalyst deactivation coefficient

Subcript

cc	Coke on catalyst
ck	Coke
g	Acceleration m/s^2
gl	Gasoline
go	Gas oil
gs	Gases
MABP	Molal average boiling temperature, K
MeABP	Mean average boiling temperature, K
pc	Pseudo-critical
pr	Pseudo-reduced
Rs	Riser

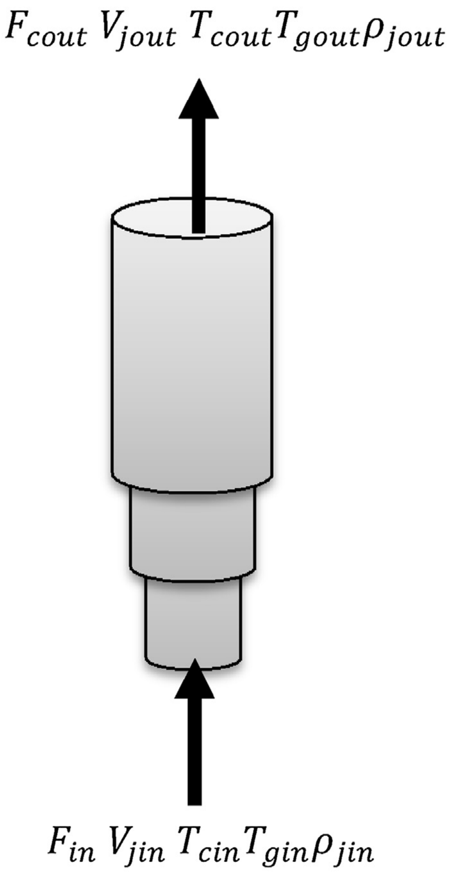

Fig. 1. The Riser.

and Rohani, 1997). For this reason, the riser has been modelled differently from the vaporization section with the assumption that the gas oil vaporizes instantaneously (Ahari et al., 2008; Al-Sabawi et al., 2006; Araujo-Monroy and López-Isunza, 2006). Therefore, modelling the riser unit by having different diameters for the vaporization and riser sections, is different from modelling the system where the diameter of the riser is varied. This is what this work sets to achieve; to model the riser section as a varied diameter with three different cross sections.

The riser unit of the FCC unit of Kaduna Refinery and Petrochemicals Company (KRPC) in Nigeria is a vertical cylinder but with varied diameters. This design is such that the reaction proceeds as the catalyst and vapour mixture flows up through the riser. The lower part of the riser is sized to provide sufficient pick up velocity and as cracking proceeds, the riser diameter is increased to handle the increasing volume and provide the desired reaction time. The mixture then flows through the remainder of the vertical riser.

This work modelled the riser according to geometric differences of the riser and validated against industrial data. gPROMS software is used for the simulation with C/O ratio, catalyst temperature and gas phase temperature are used as manipulating variables. The various effects of the riser geometry on the conversion of gas oil and yield of gasoline were determined.

2. Process modelling

This section presents the description of the riser and its model assumptions, the model equations, degree of freedom analysis, the parameters used and method of solution of the model.

2.1. The riser

The riser has always been modelled as a single vertical tube or cylinder but risers can have varied diameters. The riser unit of the FCC unit of KRPC is a type with varied diameters as shown in Fig. 1.

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