Fuel 206 (2017) 657–674

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Optimal design and operation of an industrial fluidized catalytic cracking reactor

Aysar T. Jarullah [a], Noor A. Awad [a], Iqbal M. Mujtaba [b,*]

[a] Chemical Engineering Department, College of Engineering, Tikrit University, Iraq
[b] Chemical Engineering Division, School of Engineering, University of Bradford, Bradford BD7 1DP, UK

HIGHLIGHTS

- Fluid catalytic cracking (FCC) is an important process in petroleum refining.
- FCC process model is developed and validated against experimental data.
- Maximum conversion of VGO to lighter products in Industrial FCC process considered.
- Cost of the process is minimized while octane number is maximised.

ARTICLE INFO

Article history:
Received 10 March 2017
Received in revised form 23 May 2017
Accepted 25 May 2017

Keywords:
Fluidized catalytic cracking
Modelling
Optimisation
Vacuum gas oil

ABSTRACT

Fluidized catalytic cracking (FCC) is regarded one of the most significant operations in the oil refining industries to convert feedstock (mainly vacuum gasoil) to valuable products (namely gasoline and diesel). The behavior of the fluidized catalytic cracking process is playing a main part on the overall benefits of refinery units and improving in process or control of fluidized catalytic cracking plants will result in exciting benefits economically. According to these highlights, this study is aimed to develop a new mathematical model for the FCC process taking into account the complex hydrodynamics of the reactor regenerator system with a new six lumps kinetic model for the riser. The mathematical model, simulation and optimization have done utilizing vacuum gas oil (VGO) as a feedstock and zeolite as a catalyst under the following operating conditions: temperature (733 K, 783 K, and 813 K), weight hourly space velocity (5, 20 and 30 h^{-1}) and catalyst to oil ratio (4, 7 and 10). The best kinetic parameters of the relevant reactions are estimated using the optimization technique based on the experimental results taken from literature. The effect of operating condition (mainly, reaction temp (T), catalyst to oil ratio (CTO) and weight hourly space velocity (WHSV) on the product composition has also been discussed. The optimal kinetic parameters obtained from the pilot plant scale have been employed to develop an industrial FCC process, where optimal operating condition based on maximum conversion of VGO with minimum cost in addition to maximizing the octane number of gasoline (GLN), have been studied. Minimum coke content deposition the catalyst within the regenerator is also investigated here. New results (the highest conversion and octane number, and the lowest coke content) have obtained in comparison with those reported in the literature.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Cracking is the process where the large undesirable compounds break down into smaller compounds and extra beneficial molecules. Such process is conducted without catalyst at high reaction temperature (T) and pressure (P), or with the catalyst at low or moderate T and P. Based on the market request, oil industries have used the FCC processes for the purpose of increasing the valuable products (mainly car fuels) and decreasing the heavy oil fractions obtained by oil distillation. The riser reactors of the fluidized catalytic cracking process have designed based on acidic catalyst, where heavy cuts (namely reduced crude residue and vacuum gas oil (VGO)) are decomposed into more valuable products at a specified process conditions. Also, the quality of the products in the reactors depends on the operating conditions and such products can be improved via changing the process conditions

* Corresponding author.
E-mail addresses: A.T.Jarullah@tu.edu.iq (A.T. Jarullah), I.M.Mujtaba@bradford.ac.uk (I.M. Mujtaba).

http://dx.doi.org/10.1016/j.fuel.2017.05.092
0016-2361/© 2017 Elsevier Ltd. All rights reserved.

Nomenclature

A_i	Rate coefficient, (–)
A_r	Archimedes number, (–)
A	Riser, Regenerator cross section area, (m^2)
API	Density parameter, (–)
a_{ij}	Pre-exponential factor, (cm^3 gm s^{-1})
b_{ij}	Cracking kinetic parameter of the reaction lump i → j, (–)
c_i	Cracking kinetic parameter for the formation of $lump_i$, (–)
C_{rge}	Weight fraction of coke on regenerated catalyst, kg of coke/kg of cat
C_{sc}	Weight fraction of coke on spent catalyst, kg of coke/kg of cat
C_H	Weight fraction of hydrogen in coke, kg of H_2/kg of coke
cp_g	Specific heat capacity of vacuum gas oil, j/g.k
cp_c	Specific heat capacity of catalyst, j/g.k
cp_{air}	Specific heat capacity of air, k j/kg.k
cp_{co}	Specific heat capacity of carbon monoxide, k j/kg.k
cp_{co_2}	Specific heat capacity of carbon dioxide, k j/kg.k
cp_{o_2}	Specific heat capacity of oxygen, k j/kg.k
cp_{N_2}	Specific heat capacity of Nitrogen, k j/kg.k
$D_{e,vgo}$	Effective diffusivity of vacuum gas oil, cm^2/s
$D_{m,vgo}$	Molecular diffusivity of gas oil in liquid phase, cm^2/s
$D_{k,vgo}$	Knudsen diffusivity of vacuum gas oil, cm^2/s
d_p	Diameter of catalyst particle, cm
d_{pe}	Equivalent particle diameter, cm
d_t	Tube diameter, cm
D	Riser, Regenerator diameter, cm
E_i	Activation energy, k j/kmol
F_g	Vacuum gas oil mass flow rate, kg/s
F_{cat}	Catalyst mass flow rate, kg/s
F_r	Frond number, (–)
F_{rt}	Terminal Frond number, (–)
f_i	Molar flow rate of i gas in regenerator, k mol/s
f_{TOt}	Total gas flow rate at any location in the regenerator, k mol/s
F_{sc}	Mass flow rate of spent catalyst, kg/s
F_{sc}	Mass flow rate of regenerated catalyst, kg/s
H_{co}	Heat of formation of carbon monoxide, k j/k mol
H_{co_2}	Heat of formation of carbon dioxide, k j/k mol
H_{H2O}	Heat of formation of water, k j/k mol
K_{ij}	Cracking kinetic constant of the reaction in riser lump i → j, cm^3/gm.s
$k_1, k_2, k_3 k_{3c}, k_{3h}$	Reaction rate constant for composition reaction in regenerator, (–)
k_c	Overall rate combustion of coke, (–)
k_{co}	Frequency factor for ith reaction, (–)
m_w	Mass flow rate of cooling water, gm/s
M_{MI}	Mobil metal index, ppm
MW_g	Molecular weight of vacuum gas oil, gm/g mol
MW_{LCO}	Molecular weight of light cycle oil, gm/g mol
MW_{GLN}	Molecular weight of gasoline, gm/g mol
MW_{LPG}	Molecular weight of liquefied petroleum gases, gm/g mol
MW_L	Molecular weight of liquid phase, gm/g mol
MW_{DG}	Molecular weight of dry gas, gm/g mol
MW_T	Average vapor phase Molecular weight, gm/g mol
MW_{CK}	Molecular weight of coke, gm/g m
n_1	Order of vacuum gas oil concentration, (–)
n_2	Order of light cycle oil concentration, (–)
n_3	Order of gasoline concentration, (–)
n_4	Order of concentration of liquefied petroleum gases, (–)
N_i	Nickel content in the equilibrium catalyst, ppm
p_{o_2}	Partial pressure of oxygen, atm
p	Riser, regenerator pressure, atm
Re_t	Reynolds number, (–)
R_j	rate formation, gm/cm^3.s
R	Gas constant, j/mol.k
r_{ij}	Rate of reaction lump i → j, gm/cm^3.sec
r_P	Radius of catalyst particle, cm
r_g	Mean pore radius, cm
S_P	Total geometric surface area of catalyst, cm^2
S_g	Specific surface area of particle, cm^2/gm
S	Sulfur content in feed stock, wt%
T_{meABP}	Mean average boiling point, K
T_R	Riser temperature, K
T_{dil}	Temperature of dilute phase at any location, K
T_{rge}	Regenerator temperature, K
T	Temperature of reaction, K
T_{VABP}	Volume average boiling temperature, K
T_{sc}	Temperature of spent catalyst, K
$T_{10}, T_{30} T_{50}, T_{70}, T_{90}$	ASTM D86 distillation temperature at distilled vol% equal to 10, 30, 50, 70, 90, respectively., K
T_{base}	Base temperature for heat balance calculation, K
u_g	Velocity of gas, m/s
u_t	The partial terminal velocity, m/s
u_p	Velocity of solid particle, m/s
u_o	Superficial gas velocity, m/s
V_P	Total geometric volume of catalyst particle, cm^3
V_g	Total pore volume, cm^3/gm
V_{cat}	Volume of catalyst, cm^3
V	Vanadium content in equilibrium catalyst, ppm
x_{pt}	Relative (catalytic) co combustion rate, (–)
z	Height of riser, regenerator, m

Greek symbols

β_c	CO/CO_2 ratio at catalyst surface in regenerator, (–)
β_i	Frequency factor, (–)
ε	Void fraction in regenerator at any location, (–)
ε_g	Void fraction of gas phase in riser, (–)
$\in_B$	Porosity, (–)
$\in_s$	Catalyst particle porosity, (–)
ΔH_{crk}	Heat of cracking per unit mass of gas oil converted, j/kg
ΔT_{sc}	Stripper temperature drop, °C
η_o	Effectiveness factor, (–)
μ_l	Liquid viscosity, Pa.s
μ_g	Gas viscosity, Pa.s
ρ_p	Particle density, gm/cm^3
ρ_c	Catalyst density, gm/cm^3
ρ_g	Gas density, gm/cm^3
φ	Catalyst activity factor, (–)
Φ	Thiele modulus, (–)
Sph	Sphericity, (–)
Ω_{RS}	Cross section area of riser, m^2
$\mho$	Tortuosity factor, (–)
v_{cg}	Critical volume of vacuum gas oil, cm^3/g mol
v_g	Molar volume of liquid, cm^3/g mol
v_l	Molar volume of liquid, cm^3/g mol

[62,32]. Recently, the worldwide is producing approximate 45% of the car fuel (gasoline) via fluidized catalytic cracking plants (directly) in addition to other supplementary process (indirectly) such as alkylation process [6]. During 2006, fluidized catalytic cracking process have reported at 400 oil industries and about 1/3 of those petroleum refining companies were operated in the

Download English Version:

https://daneshyari.com/en/article/4768608

Download Persian Version:

https://daneshyari.com/article/4768608

Daneshyari.com