

Journal of Chemical Engineering and Material Science

Volume 6 Number 1 April 2015

ISSN 2141-6605



*Academic
Journals*

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ARTICLE

Research Article

Effects of mass transfer resistance and coking on yield during fluid catalytic cracking of heavy hydrocarbon fractions **1**

Olanrewaju Omotola F., Okonkwo Paul C. and Aderemi Benjamin O.

Full Length Research Paper

Effects of mass transfer resistance and coking on yield during fluid catalytic cracking of heavy hydrocarbon fractions

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Received 23 September, 2014; Accepted 10 April, 2015

A transient model for an industrial fluid catalytic cracking (FCC) riser is here presented. The FCC riser models of previous researchers were mostly based on the assumption of negligible mass transfer resistance. This assumption reduced the accuracy of the models. In this work, the effects of mass transfer resistance and coking on the yield of FCC reactions were modeled and simulated. A five-lump reaction scheme was used to model the cracking reactions. Catalyst deactivation was modeled based on the exponential decay function. The mass transfer coefficient and the catalyst effectiveness factor were estimated from empirical correlations obtained from literature. The model parameters that were used in this investigation were sourced from the field as well as from literature. The reaction model was solved using COMSOL Multiphysics 4.0. The major difficulty encountered in this investigation was the unavailability of experimental data from which the mass transfer resistance, catalyst effectiveness factor, kinetic constants of the cracking reactions and effective diffusivities of species could be determined. This challenge was overcome by using empirical correlations from literature to estimate the terms. Model data which could not be obtained from the plant were sourced from literature and duly referenced. The proposed model vividly showed that mass transfer resistance significantly affects FCC reactions. Previous models over-predicted the residence time of the riser while under-predicting the over-cracking point of gasoline (the key product). A residence time of 2s and a gasoline yield of 45% were predicted by this model.

Key words: Fluid catalytic cracking (FCC), Transient model, mass transfer resistance, catalyst deactivation, Riser models.

INTRODUCTION

Fluid catalytic cracking (FCC) is one of the most profitable processes in oil refineries. It is the major producer of gasoline in refineries and as such it is sometimes referred to as the heart of the refinery. FCC converts vacuum gas oils and heavy feed stocks from other refinery operations into high octane gasoline, light

fuel oils and gases (Bessiris and Harismiadis, 2007).

FCC unit comprises mainly of the riser, the regenerator and the main fractionators. The reactor section of FCC units has been an active area of research in industry and academia alike, (Weekman and Nace, 1970; Corella and Frances, 1991; Martin et al., 1992; Ali and

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Rohanni, 1997; Den Hollander et al., 2003; Praveen and Shishir, 2009; Heydari et al., 2010; Alsabei, 2011). The authors often neglected one or more crucial aspects of the process and as such the accuracy of their models was reduced. For example, in the three-lump model of Weekman and Nace (1970), coke was not factored in by the authors. Hence, their model could not predict the coking of FCC catalyst. In the models of Corella and Frances (1991), Martin et al. (1992), Ali and Rohanni (1997), Den Hollander et al. (2003), Praveen and Shishir (2009), Heydari et al. (2010) and Alsabei (2011), mass transfer resistance was not considered. The negligence of mass transfer resistance led to the over-prediction of the riser residence time and the under-prediction of gasoline over-cracking point in the model of Den Hollander et al. (2003). These inadequacies can have adverse effects on reactor design and operation. Other authors have used higher number of lumps in their models, Gupta et al. (2007) and Gao et al. (1999) used 3-D models having 50 and 13 lumps, respectively. Lopes et al. (2012), on the other hand, used a 3-D, 4-lump reaction scheme to investigate the effects of various exit configurations of the riser on the hydrodynamics of the reactor as well as the yield of gasoline. They found that the T-shape exit configuration enhanced the yield of gasoline owing to enhanced solid (catalyst) reflux. However, models that have such large number of lumps are unwieldy and they have high costs of computation.

In the present work, a five-lump reaction scheme was employed and the effect of mass transfer resistance on FCC reactions was given its due consideration. A transient mathematical model was developed for the reaction scheme and the model was solved in COMSOL Multiphysics software environment. Experimental data were not available for the evaluation of mass transfer coefficients, kinetic constants and particle effectiveness factor. Kinetic constant values obtained from literature were used in this study due to unavailability of experimental data. Empirical correlations were used to evaluate the mass transfer resistance and particle effectiveness.

MATERIALS AND METHODS

The following materials were used for this investigation:

1. Software: COMSOL Multiphysics 4.0
2. Computer:
Processor type: Pentium (R) Dual-core CPU, 2.20GHz, 2.20GHz
Model: Compaq Presario CQ61 notebook PC
RAM: 3.00GB

The following assumptions were made to develop and solve the model in this study:

1. Significant mass transfer resistance was anticipated based on the micro-porous nature of the commonly employed catalysts in the process (Missen et al., 1999).
2. The catalyst and gas are at thermal equilibrium (Ahari et al., 2008).

3. Hydrocarbon feed comes into contact with the hot catalyst coming from the regenerator and instantly vaporizes (Gupta, 2006).
4. There is no heat loss from the riser and the temperature of the reaction mixture (hydrocarbon vapors and catalyst) falls only because of the endothermicity of the cracking reactions (Gupta, 2006).

Modeling FCC reactions using the five-lump model

In the five-lump model given in Figure 1, the eight reactions of the model were taken to follow first order kinetics as follows:

$$\tau_j = \frac{c_i}{\left(\frac{1}{k_g} + \left(\frac{1}{\eta k_j}\right)\right)} \quad j = 1, \dots, 8 \quad (1)$$

$$\eta = \frac{3}{\varphi} \left(\frac{1}{\tanh \varphi} - \frac{1}{\varphi} \right) \quad (2)$$

$$\varphi = R \left(\frac{k_j}{D_e} \right)^{\frac{1}{2}} \quad (3)$$

c_i = species concentration (weight fraction), k_g = mass transfer coefficient of reactant in m/s, η = particle effectiveness factor, k_j = reaction rate constant in s^{-1} , φ = Thiele modulus and D_e = effective diffusivity in m^2/s . Equation 1 is the model rate equation which incorporates mass transfer resistance terms, k_g and η . Equation 1 reverts to the classical first order rate equation when $\frac{1}{k_g} = 0$, $\eta = 1$. (Previous researchers that neglected mass transfer resistance used the classical first order rate equation: $r_j = k_j c_i$).

The particle effectiveness factor, η expressed by Equation 2 is the ratio of the reaction rate when there is diffusion resistance to the rate when there is no diffusion resistance. It is a direct measure of the extent to which diffusion resistance reduces the rate of chemical reactions in solid catalysis and it is a function of Thiele modulus. Thiele modulus, φ is the ratio of intrinsic reaction rate to diffusion rate. Equation 3 provides a yardstick for determining the rate-determining step in solid catalysis; the rate-determining step can be the reaction or the diffusion stage. Equation 3 holds for spherical particles only, a correction factor is required for other shapes.

The basic parameters that had to be determined in Equations 1 to 3 were D_e and k_g . D_e was estimated from empirical correlations obtained from literature (Missen et al., 1999) while k_g was estimated from Sherwood number for gases (Geankoplis, 2011).

The modeling was carried out in two stages in COMSOL Multiphysics. For each stage, the model was solved for both non-coking and coking conditions. Plug-flow reactor was assumed at a temperature of 791K. Resistance to mass transfer was neglected in the first stage whereas in the second stage, it was taken into consideration. For the case of negligible mass transfer resistance, $\frac{1}{k_g} = 0$, $\eta = 1$ were used in Equation 1.

The mass balance for the reactions in Figure 1 was given by Equation 4.

$$\frac{dF_i}{dV} = \sum_j v_{ij} r_j = r_i \quad (4)$$

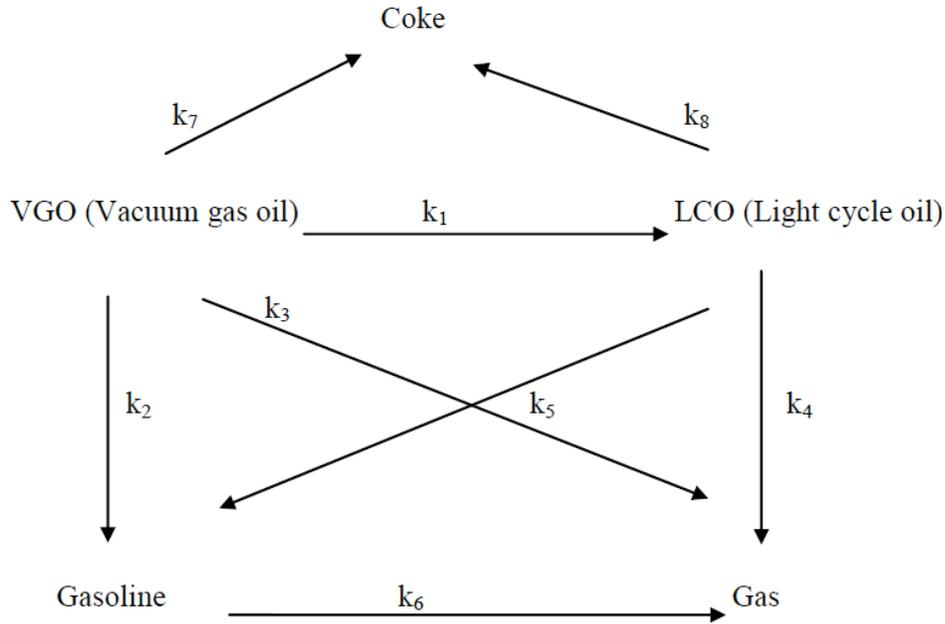


Figure 1. Five-lump model (Den Hollander et al., 2003).

Where F_i is the species mass flow rate, V is the reactor volume, v_{ij} is the stoichiometric coefficient and r_i the net rate of production of species i .

The species concentration gradient as a function of residence time (t) was derived from Equation 4 and expressed as in Equation 5.

$$\frac{dF_i}{dV} = \frac{d(vc_i)}{dV} = \frac{dc_i}{dt} = r_i \quad (5)$$

In Equation 5, v is volumetric flow rate in m^3/s .

The lumped species mass balances for the model without coking were given by Equations 6 to 9.

$$\frac{dc_{vgo}}{dt} = -r_1 - r_2 - r_3 \quad (6)$$

$$\frac{dc_{lco}}{dt} = r_1 - r_4 - r_5 \quad (7)$$

$$\frac{dc_{gasoline}}{dt} = r_2 + r_5 - r_6 \quad (8)$$

$$\frac{dc_{gas}}{dt} = r_3 + r_4 + r_6 \quad (9)$$

When coking reactions are considered, the overall activity of the model is dominated by two different time scales. This is because coke formation takes place on the millisecond scale while the formation of the other products occurs in seconds. This challenge was overcome in COMSOL Multiphysics by using two different activity functions, a and b for the non-coking and the coking reactions, respectively (Den Hollander et al., 2003). A coke concentration-based decay model, 'a' given by Equation 10 was

used for the non-coking reactions. The function, b on the other hand was based on catalyst time-on-stream (Equation 11).

$$a = \exp(-k_d c_{coke}) \quad (10)$$

$$b = \exp(-\alpha' t) \quad (11)$$

$$k_d = 8.2, \alpha' = 10s^{-1} \quad (\text{Den Hollander et al., 2003}).$$

In the second stage of the work, mass transfer resistance and coking were taken into consideration. The rate expressions were given by Equations 12 and 13 for the non-coking reactions and the coke-generating reactions, respectively.

$$r_j = \frac{ac_i}{\left(\frac{1}{k_g} + \left(\frac{1}{\eta k_j}\right)\right)} \quad j = 1, \dots, 6 \quad (12)$$

$$r_j = \frac{bc_i}{\left(\frac{1}{k_g} + \left(\frac{1}{\eta k_j}\right)\right)} \quad j = 7, 8 \quad (13)$$

The reactor lumped species balances for the second stage of the work were given by Equations 14 to 18.

$$\frac{dc_{vgo}}{dt} = -r_1 - r_2 - r_3 - r_7 \quad (14)$$

$$\frac{dc_{lco}}{dt} = r_1 - r_4 - r_5 - r_8 \quad (15)$$

$$\frac{dc_{gasoline}}{dt} = r_2 + r_5 - r_6 \quad (16)$$

Table 1. Kinetic constants for five-lump model (Den Hollander et al., 2003).

Reaction number	k (s ⁻¹)
1	1.90
2	7.50
3	1.50
4	0.00
5	1.00
6	0.30
7	0.21
8	0.50

Table 2. Model parameters (Source: KRPC Plant data).

S/N	Parameter	Value
1	Reactor inlet temperature, T ₀ (K)	791
2	Gas superficial velocity, U (m/s)	18
3	Feed flow rate, F _f (kg/s)	35.5
4	Riser diameter, D _R (m)	1.146
5	Riser height, H (m)	25
6	Gas average density ρ _g (kg/m ³)	0.92
7	Riser pressure, P (atm)	2.94

$$\frac{dc_{gas}}{dt} = r_3 + r_4 + r_6 \quad (17)$$

$$\frac{dc_{coke}}{dt} = r_7 + r_8 \quad (18)$$

Simulation Setup

The following steps were taken to solve the model equations in COMSOL Multiphysics 4.0.

1. COMSOL Multiphysics was launched.
2. The preferences were set by selecting Reaction Engineering application mode (time-dependent study type).
3. Reaction engineering was selected in the model tree and the reaction temperature (791K) was entered.
4. In the Reaction Tab (in the model tree), six reactions were added (the non-coking reactions with rate constants k₁ to k₆ as depicted in Figure 1).
5. Each of the reactions was selected and the actual irreversible reaction was entered in the Setting's page. The corresponding forward rate constants for the reactions were also entered.
6. The global parameters to be used in Equations 10 and 11 (α' and k_d) were entered.
7. The global expressions (Equations 10 and 11) were then entered.
8. The reaction rate expression for each of the reactions was multiplied by α.
9. The Species tab was expanded and each species' molecular

weights and initial concentrations were entered in the Settings page (species concentrations were expressed in weight fraction).

10. The time step and the duration of the simulation were specified on the Study Settings page. Time steps of 0.001 s (initial), 0.1 s (maximum) and a simulation time of 5 s were used for this work.

11. The sequence was generated from the study and the results were computed from the sequence so generated (the number of time steps used was 50 while the maximum number of iterations was 10,000). This completed the modeling of the non-coking reactions.

The steps highlighted above were taken to model the effect of mass transfer resistance on FCC reactions independent of coking.

To model the FCC reactions with coking taken into consideration:

1. Two more reactions were added in the model tree.
2. The two reactions that led to coke via k₇ and k₈ (Figure 1) were entered in the Settings page.
3. The rates of the non-coking reactions were multiplied by the concentration-dependent deactivation expression, (Equation 10) while the rates of the coking reactions were multiplied by the time-dependent expression (Equation 11).
4. Finally, the sequence was regenerated from the study and the solution was computed again to model the effects of mass transfer resistance and coking on FCC reactions.

Model data

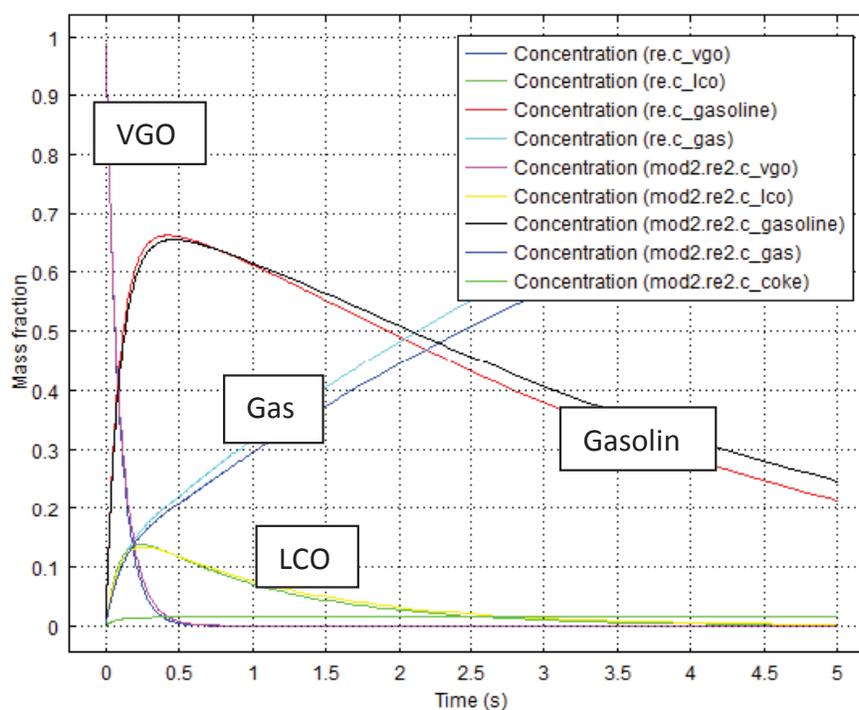
The model data were given in Tables 1 and 2. The properties of the feed stock (VGO) and catalyst were given in Tables 3 and 4, respectively.

Table 3. Properties of VGO.

S/N	Property	Value
1	Molecular weight (kg/kgmol)	333 (Ahari et al., 2008)
2	Specific heat capacity (kJ/kgK)	2.67 (liquid), 3.30 (gas) (Ahari et al., 2008)
3	Specific gravity	0.9 (Gupta, 2006)
4	Sulphur (wt%)	1.15 (Gupta, 2006)
5	Nitrogen (wt%)	1.035 (Gupta, 2006)
6	Conardson carbon (wt%)	0.2 (Gupta, 2006)
7	Viscosity (N.s/m ²)	1.4e-5 (Ahari et al., 2008)
8	Enthalpy of vaporization (J/kg)	190 (Ahari et al., 2008)
9	Vaporization temperature (K)	698 (Ahari et al., 2008)

Table 4. Properties of FCC Catalyst.

S/N	Property	Value
1	Specific heat capacity (kJ/kgK)	1.09e3 (Ahari et al., 2008)
2	Density (kg/m ³)	1250 (KRPC)
5	Pore diameter, (m)	2.00e-9 (KRPC)
4	Particle diameter, (m)	60e-6 (KRPC)
5	Particle tortuosity	7 (Missen et al., 1999)

**Figure 2.** FCC species concentration profiles (mass transfer resistance neglected).

RESULTS AND DISCUSSION

The results obtained at the end of the investigation were

presented as plots of species concentration against time as shown in Figures 2, 3 and 4. Figure 2 is similar to the result obtained by Den Hollander et al. (2003) in which

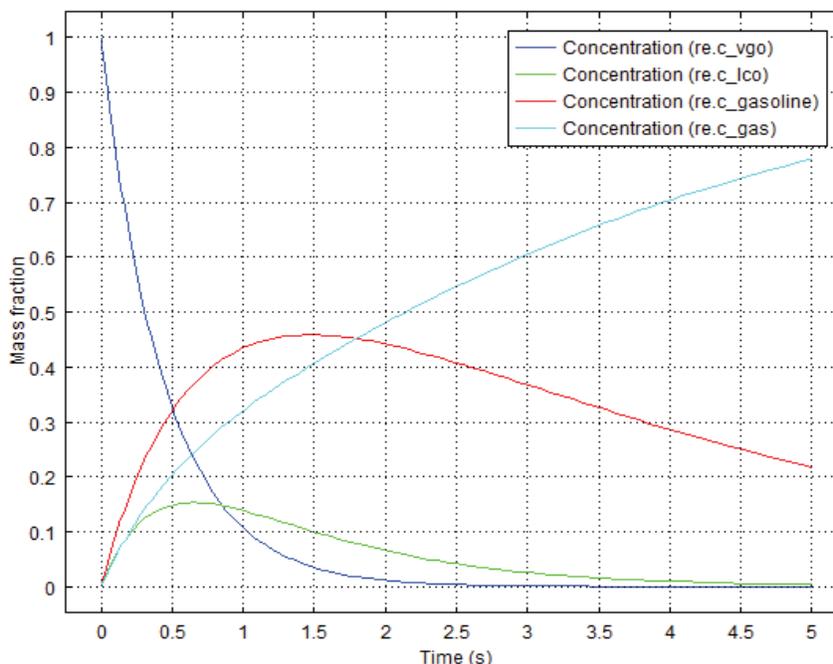


Figure 3. Effect of mass transfer resistance on FCC reactions (coking neglected).

case, mass transfer resistance was not considered. In Figure 2, when resistance to mass transfer was neglected, the predicted feed stock (VGO) conversion time was 0.5 s; the predicted gasoline over-cracking point was 0.5 s while the predicted maximum theoretical yield of gasoline was 65%. Figure 3 shows the effect of mass transfer resistance on FCC reactions when coking was not considered (by neglecting reactions 7 and 8 in Figure 1). When mass transfer resistance was taken into account in isolation, a forward shift was observed in the profiles (Figure 3). When resistance to mass transfer was considered, the predicted conversion time of VGO was 2.3 s, the predicted gasoline over-cracking point was 1.5 s and the predicted maximum theoretical yield of gasoline was 46%. The result in Figure 3 shows that mass transfer resistance significantly reduces the rate of FCC reactions thereby increasing the reaction time '(the reactions do not occur as instantaneously as predicted by Den Hollander et al. (2003))'. Figure 4, on the other hand depicts the combined effects of mass transfer resistance and coking of the catalyst on FCC reactions. The result depicted in Figure 4 predicts a feed stock conversion time of 2.3 s, gasoline over-cracking point of 1.7 s and a gasoline peak yield of 45%. The predictions of the FCC model here proposed are obviously closer to plant data than those of the models that neglected mass transfer resistance.

In Figure 4, it can be seen that coking of FCC catalyst further reduces the rate of the reactions. Coking also reduces the yield of products in FCC. As a result of coking of the catalyst, the VGO profile shifts from the blue curve position to the purple position whereas for the

products (gasoline and gas), the profiles move below the curves for no-coking condition. By implication, coking of FCC catalysts increases the feed stock conversion time while reducing the yield of products due to the decline in catalyst activity. It can be observed in Figure 4 that the yields of gasoline and gas when there is coking of the catalyst as well as the yield of gasoline for no-coking condition are coincident at time, $t = 2$ s (which time corresponds to the reactor's exit). The physical significance of the point of coincidence of the curves is that it defines the optimum residence time for risers provided that gasoline is the desired product. This explains why risers are designed to have a residence time of 2 s. The catalyst activity decline as predicted by the model is 0.88 (Figure 5). The results obtained in this investigation are specifically for VGO feed. However, the model can be modified to suit other feed stocks and reaction conditions. The model results were compared with literature prediction and plant data as shown in Table 5.

Conclusions

In this transient study of fluid catalytic cracking (FCC) reactions, mass transfer resistance was incorporated in the first order model rate equation. Other terms that featured in the model rate equation due to the incorporation of mass transfer resistance were effective diffusivity, particle effectiveness factor and Thiele modulus. The results obtained in this work vividly showed

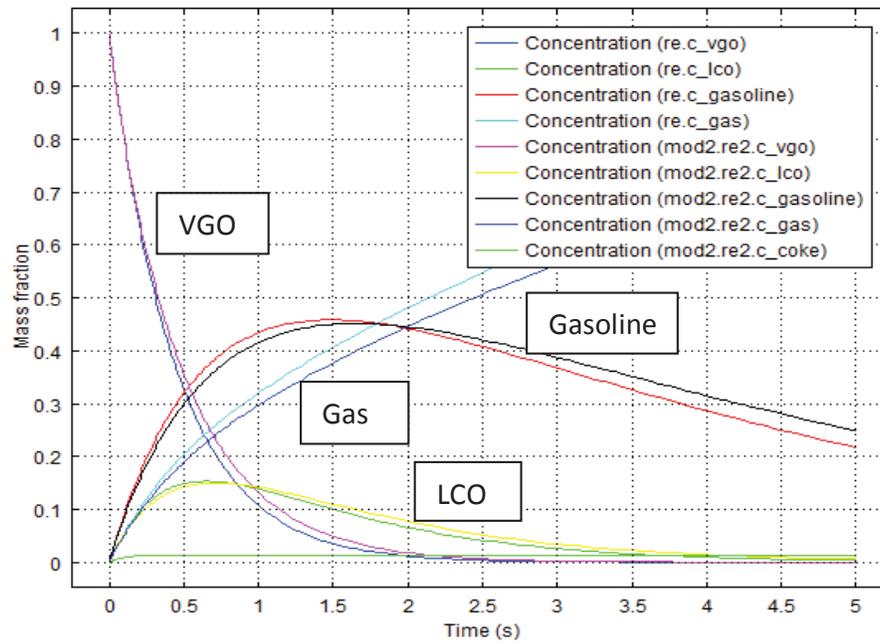


Figure 4. Effects of mass transfer resistance and coking on FCC reactions.

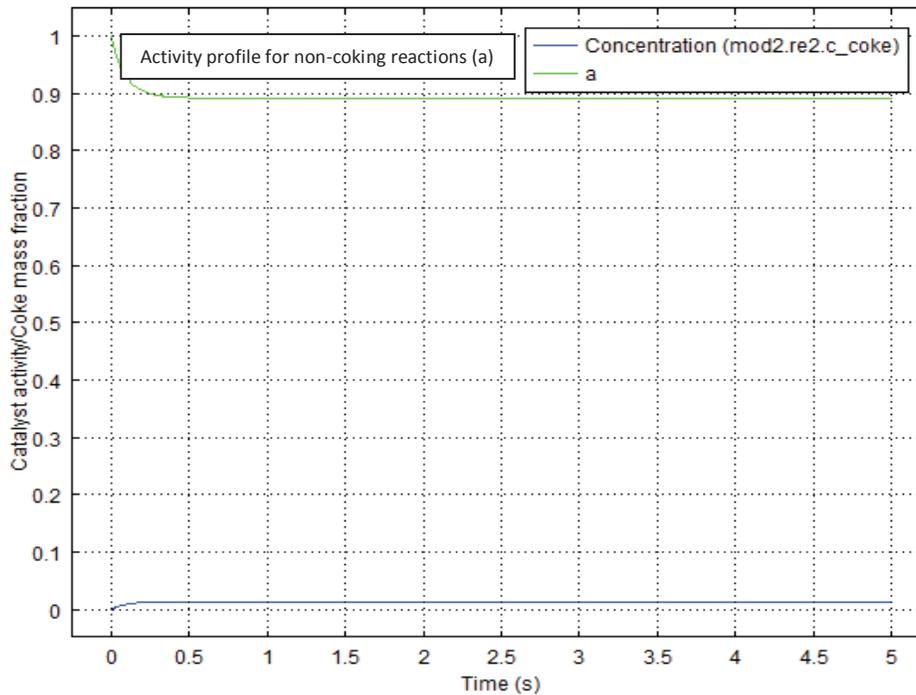


Figure 5. Catalyst activity decline profile.

that mass transfer resistance plays a significant role in FCC reactions and hence, it should not be neglected by researchers in the development of riser models. The model here presented predicts a reactor residence time

of 2 s and a gasoline yield of 45%.

Verification of the results with plant data showed that the incorporation of mass transfer resistance in the riser model enhanced the accuracy of the model predictions. It

Table 5. Comparison of model result with literature prediction and plant data.

S/N	Item	Den Hollander et al. (2003)	Model prediction	KRPC plant data	% Deviation from plant
1	Conversion time	0.50 s	2.00 s	2.00 s	0.00
2	Gasoline over-cracking point	0.50 s	1.50 s	-	-
3	Gasoline peak yield	60.00%	45.00%	43.94%	2.41
4	Catalyst final activity	0.85	0.88	-	-
5	Coke yield	2.00%	2.00%	-	-

can be inferred from the results of this investigation that risers should be designed to operate at a short residence time of 2 s to ensure maximum yield of gasoline (the key product). Short residence time operation will also reduce the duration of coke deposition on the catalyst. Less quantity of coke on FCC catalyst will reduce the cost of regeneration of the catalyst thereby increasing the profitability of the plant. The major challenges encountered in this study were the unavailability of experimental equipment and experimental data for the complex reactions that occur in FCC. As such, empirical equations obtained from literature were used to estimate the mass transfer resistance and the associated terms mentioned above. Model constants which could not be obtained from the plant were also sourced from literature as cited in the work. This work can be improved in the future by using experimental data in lieu of empirically evaluated data to solve the model.

Conflict of Interest

The authors have not declared any conflict of interest.

Nomenclature: **a**, Catalyst activity for non-coking reactions; **b**, catalyst activity function for coking reactions; c_i , species concentration (weight fraction); D_e , effective diffusivity (m^2/s); D_p , particle diameter (m); D_R , riser diameter (m); F_f , feed flow rate (kg/s); F_i , flow rate of species i (kg/s); **H**, reactor height (m); k_d , deactivation constant; k_g , mass transfer coefficient (m/s); k_j , reaction rate constant (s^{-1}); **P**, pressure (Pa); P_d , pore diameter; **R**, particle radius (m); r_j , species reaction rate (kg species (kg catalyst) $^{-1}s^{-1}$); **t**, time (s); **T**₀, reactor inlet temperature (K); **U**, gas superficial velocity (m/s); **V**, Reactor volume (m^3); ν_{ij} , stoichiometric coefficient;

Greek letters: α' , Decay constant; η , particle effectiveness factor; μ_g , gas average viscosity ($Pa \cdot s$); ϕ , Thiele modulus; ρ_g , gas average density (kg/m^3); τ_p , particle tortuosity

Subscripts: i , Species number; j , Reaction number.

Abbreviation: **KRPC**, Kaduna Refinery and Petrochemicals Company Ltd.

REFERENCES

- Ahari JS, Farshi A, Forsat K (2008). A mathematical modeling of the riser reactor in industrial FCC unit. *Pet. Coal* 50(2):15-24.
- Ali H, Rohanni S (1997). Dynamic modeling and simulation of a riser-type fluid catalytic cracking unit. *Chem. Eng. J. Technol.* 20:118-130. <http://dx.doi.org/10.1002/ceat.270200209>
- Alsabei RM (2011). Model based approach for the plant-wide economic control of fluid catalytic cracking unit. P. 12.
- Bessiris Y, Harismiadis V (2007). Dynamic simulation of a fluid catalytic cracking unit. *Topical A: 10th Topical Conference on Refinery Processing-TA007 Advances in FCC*. P. 1.
- Corella J, Frances E (1991). Analysis of the riser reactor of a fluid catalytic cracking unit. *ACS Symposium series*, 452:165-182. Washington American Chemical Society.
- Den Hollander MA, Wissink M, Makkee M, Moulijn JA (2003). Fluid catalytic cracking. *J. Appl. Catal. A*. 223:103. [http://dx.doi.org/10.1016/S0926-860X\(01\)00746-3](http://dx.doi.org/10.1016/S0926-860X(01)00746-3)
- Gao J, Xu C, Lin S, Yang G, Guo Y (1999). Advanced model for turbulent gas-solid flow and reaction in FCC riser reactor. *AIChE J.* 45: 1095-1113. <http://dx.doi.org/10.1002/aic.690450517>
- Geankoplis CJ (2011). *Transport processes and separation process principles* (4th ed.). New Jersey, U.S.A. Pearson Education Inc. 2011 pp. 425, 482.
- Gupta R, Vineet K, Srivastava VK (2007). Modeling of non-isothermal fluid catalytic cracking riser reactor. *WCECS* pp. 2-3.
- Gupta RS (2006). Modeling and simulation of fluid catalytic cracking unit. Retrieved June 12, 2012 from <http://www.dspace.thara.edu:8080/dspace/bitstream/123456789/56/3/T56.pdf>.
- Heydari M, Ebrahim HA, Dabir B (2010). Modeling of an industrial riser in the fluid catalytic cracking unit. Retrieved November 7, 2013 from www.core.kmi.open.ac.uk/downloadpdf/5575427; <http://dx.doi.org/10.3844/ajassp.2010.221.226>
- Lopes GC, Rosa LM, Mori M, Nunhez JR, Martignoni WP (2012). CFD study of industrial FCC risers: the effect of outlet configurations on hydrodynamics and reactions. Retrieved November 7, 2013 from <http://www.hindawi.com/journals/ijce/2012/193639/>; <http://dx.doi.org/10.1155/2012/193639>
- Martin MP, Derouin PT, Forriessier M, Wild G, Bernard JR (1992). Catalytic cracking in riser reactors. core-annulus and elbow effects. *J. Chem. Eng. Sci.* 47:2319-2324. [http://dx.doi.org/10.1016/0009-2509\(92\)87054-T](http://dx.doi.org/10.1016/0009-2509(92)87054-T)
- Missen RW, Mims CA, Saville BA (1999). *Introduction to chemical reaction engineering and kinetics*. New York. John Wiley & Sons Inc. pp. 198-214.
- Praveen CH, Shishir S (2009). Effect of pressure on height of regenerator dense bed in an FCCU. *J. Pet. Coal* 51(2):124-135.
- Weekman VW, Jr, Nace DM (1970). Kinetics of catalytic cracking selectivity in fixed, moving, and fluid-bed reactors. *AIChE J.* 16:397-405. <http://dx.doi.org/10.1002/aic.690160316>

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