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Developing a Modeling-Based Approach to Design a Riser Reactor in the Fluid Catalytic Cracking (FCC) Process

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1. ABSTRACT

The fluid catalytic cracking (FCC) process is a cost-effective and reliable route to convert heavy oil fractions into valuable and light products. The riser reactors are commonly commercialized to perform this process. In this study, using a novel modeling-based approach, the design of the FCC riser reactor system is presented based on the gas oil feed with 24.1 kg s^{-1} mass flow rate. Subsequently, the performance of the designed reactor is examined under various operating conditions. For this purpose, an algorithm is proposed as the design procedure. Initially, the numerical model of the riser reactor is developed and then validated using experimental data including product distribution and outlet temperature. The presented numerical model matches the experimental data of an industrial unit with an average error of 7.52%. Based on the proposed design, the gas oil conversion is 94.32% and the mass fractions of products including diesel, gasoline, LPG, dry gas, and coke are 21.66%, 49.82%, 12.55%, 4.35%, and 5.94%, respectively. The process controllability to operating conditions is also determined based on the sensitivity analysis so that the catalyst-to-oil ratio (COR), feed flow rate, feed temperature, and catalyst temperature can be adjusted to achieve a desirable product distribution.

Keywords: FCC Process, Fluidized Bed, Riser Reactor, Lumped Model, Modeling and Simulation.

2. INTRODUCTION

The fluid catalytic cracking (FCC) process is one of the most significant refinery units, which converts gas oil feed into valuable and lighter products including diesel, gasoline, LPG, and dry gas [1]. The evolution of FCC units is important due to their significance in the global refinery economy. Kinetic studies can assist in facilitating the comprehension of the catalytic cracking process, enhancing the catalyst performance, and designing the reactive fluidized beds [2–4]. Lumped kinetic models of the FCC process are well-developed. However, these model's applications in the design development of the riser reactors and the sensitivity analysis of the operating conditions with the aim of design optimization have received less attention. As a result, this approach is followed in the present study.

3. MATERIALS AND METHODS

In this study, a 6-lumped kinetic model is considered to simulate the system's behavior. This model, which was first presented by Du et al. [5], has been utilized in various kinetic studies of the FCC process. The model's components can be classified into six categories: (1) Gas oil (2) Diesel (3) Gasoline (4) LPG (5) Dry gas and (6) Coke. A wide variety of

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parameters influences the FCC process riser reactor's performance, thus an algorithm is required to achieve the desired system design. Fig. 1 illustrates the proposed riser reactor design flowchart.

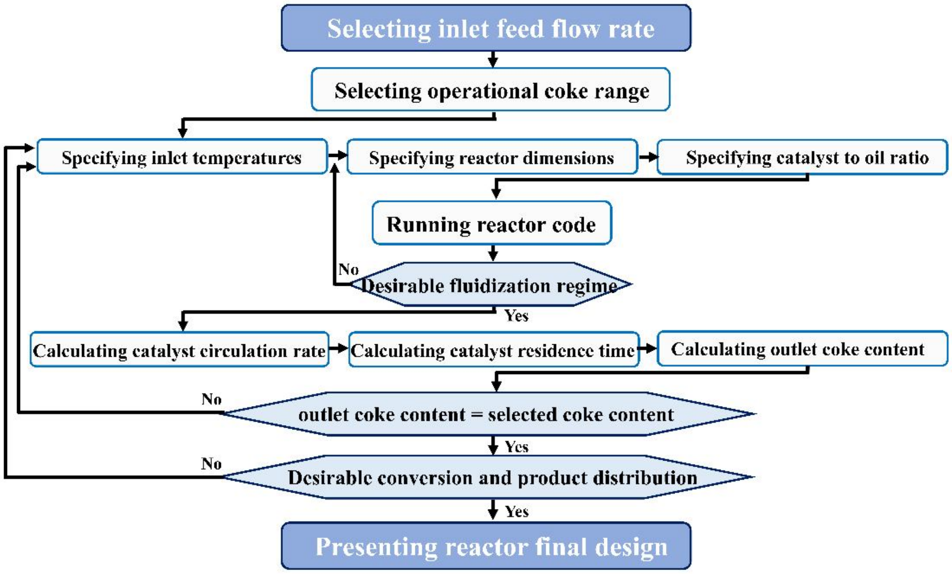

Figure 1. Design procedure of the riser reactor system

4. RESULTS AND DISCUSSION

The available experimental data [4] are compared with the obtained simulation results to validate the numerical model. As can be seen in Table 1, the simulation results agree well with the experimental data.

Table 1. Comparison of the simulated results with the experimental data obtained from the industrial FCC plant

	Parameters							
	Gas oil (wt.%)	Diesel (wt.%)	Gasoline (wt.%)	LPG (wt.%)	Dry gas (wt.%)	Coke (wt.%)	Gas temperature (K)	Catalyst temperature (K)
Simulation	5.29	21.05	46.37	15.00	4.41	7.88	732.96	732.96
Industrial plant [4]	4.78	18.57	47.31	15.18	4.83	8.91	773.20	773.20
Error (%)	10.67	13.35	1.99	1.19	8.70	11.56	5.20	5.20

The design flowchart in Fig. 1 is utilized to achieve the FCC riser reactor's design parameters. In this design, the gas oil conversion is 94.32% and the mass fractions of diesel, gasoline, LPG, dry gas, and coke in the products are 21.66%, 49.82%, 12.55%, 4.35%, and 5.94%, respectively. The parameters of the performed design are presented in Table 2.

Table 2. Design parameters of the riser reactor system

	Parameter	Unit	Symbol	Value
Input	Gas oil mass flowrate	kg s^{-1}	F_{go}	24.1
	Catalyst coke range	%	W_C	0.1-0.9
Results	Diameter	m	D	0.82
	Height	m	H	31
	Inlet gas oil temperature	K	$T_{in, go}$	488
	Inlet catalyst temperature	K	$T_{in, cat}$	972
	Outlet temperature	K	T_{out}	772.62
	Catalyst to oil ratio	-	COR	5.9
	Catalyst circulation rate	kg s^{-1}	G_{cat}	142.19
	Operational bed voidage	%	ε	94.59
	Gas velocity	m s^{-1}	U_{gas}	10.01
	Catalyst velocity	m s^{-1}	U_{cat}	3.83
	Gas residence time	s	Tr_{gas}	3.10
	Catalyst residence time	s	Tr_{cat}	8.10
	Gas oil conversion	%	X_{go}	94.32
	Diesel mass fraction	%	X_{diesel}	21.66
	Gasoline mass fraction	%	$X_{gasoline}$	49.82
	LPG mass fraction	%	X_{LPG}	12.55
	Dry gas mass fraction	%	X_{DG}	4.35
	Coke mass fraction	%	X_{coke}	5.94

The variations of feed and product mass fractions with the reactor height are illustrated in Fig. 2a. It can be observed that the variations gradient of gas oil mass fraction near the reactor inlet is significantly higher than the reactor outlet. So, it can be concluded that most of the cracking reactions occur near the bottom of the riser reactor. The variation of temperature with the reactor height is also shown in Fig. 2b. It is evident that the temperature decreases more quickly in the first 5 m of the reactor. Since the cracking reactions are endothermic, the temperature and catalyst activity decrease with increasing reactor height.

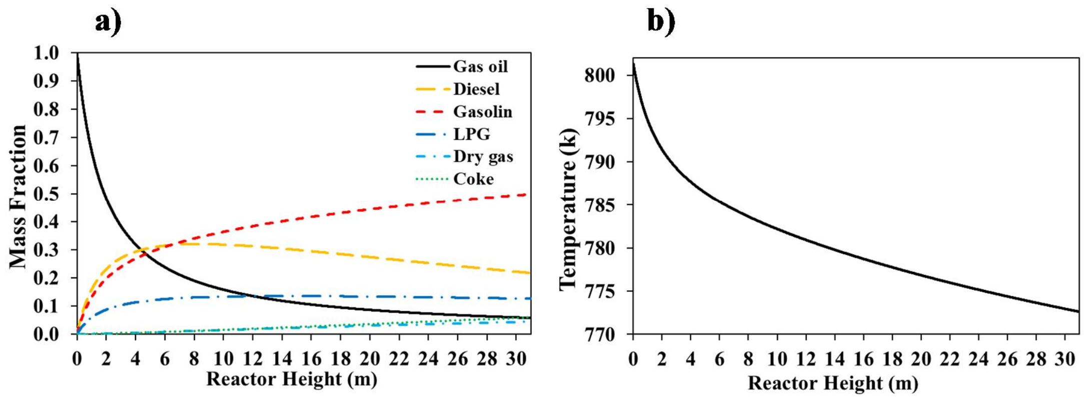

Figure 2. Performance of the riser reactor system. a) reactor gases mass fraction. b) reactor temperature. Operating conditions are based on Table 2

Finally, it should be mentioned that the process controllability with respect to the operating conditions is determined based on the sensitivity analysis so that the catalyst-to-oil ratio (COR), feed flow rate, feed temperature, and catalyst temperature can be tuned to achieve a suitable product distribution.

5. CONCLUSION

In this study, a modeling-based approach was introduced and implemented to design and investigate the performance of the FCC riser reactor. The deviation of simulation results and experimental data for gas oil mass fraction, diesel mass fraction, gasoline mass fraction, LPG mass fraction, dry gas mass fraction, coke mass fraction, and reactor outlet temperature were 10.67%, 13.35%, 1.99%, 1.19%, 8.70%, 11.56%, and 5.20%, respectively. Using the proposed design algorithm, the final reactor design was presented based on the gas oil feed with 24.1 kg s^{-1} mass flow rate. Following the repetitive loops, the respective reactor diameter, rector height, and catalyst circulation rate were obtained 82 cm, 31 m, and 142.19 kg s^{-1}. Performing the sensitivity analysis on the operating conditions, the process controllability was demonstrated and the desirable parameter values were determined to achieve the appropriate product distribution.

6. REFERENCES

[1] Sadeghbeigi, R., Fluid catalytic cracking handbook: An expert guide to the practical operation, design, and optimization of FCC units, Butterworth-Heinemann, 2020.

[2] Afshar Ebrahimi, A., Mousavi, H., Bayesteh, H.,Towfighi, J., Nine-lumped kinetic model for VGO catalytic cracking; using catalyst deactivation, Fuel. Vol. 231, pp. 118–125. 2018.

[3] Sani, A.G., Ebrahim, H.A., Azarhoosh, M.J., 8-Lump kinetic model for fluid catalytic cracking with olefin detailed distribution study, Fuel. Vol. 225, pp. 322–335, 2018.

[4] John, Y.M., Mustafa, M.A., Patel, R., Mujtaba, I.M., Parameter estimation of a six-lump kinetic model of an industrial fluid catalytic cracking unit, Fuel. Vol. 235, pp. 1436–1454, 2019.

[5] Du, Y.P., Yang, Q., Zhao, H., Yang, C.H., An integrated methodology for the modeling of Fluid Catalytic Cracking (FCC) riser reactor, Appl. Petrochemical Res. 4, pp. 423–433, 2014.