MODELLING AND SIMULATION OF INDUSTRIAL FLUID CATALYTIC CRACKING UNIT USING DIFFERENT KINETICS OF HEAVY OIL CONVERSION

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN CHEMICAL ENGINEERING IN THE DEPARTMENT OF CHEMICAL ENGINEERING, COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA, OGUN STATE, NIGERIA

OCTOBER, 2022

ACCEPTANCE

This is to attest that this thesis is accepted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy in Chemical Engineering in the Department of Chemical Engineering, College of Engineering, Covenant University, Ota, Nigeria

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DECLARATION

I, **ABATAN, OLUBUNMI GRACE (CUPG100343)** declare that this research was carried out by me under the supervision of Prof. Olaosebikan A. Olafadehan of the Department of Chemical Engineering, University of Lagos, Akoka, Nigeria and Prof. Vincent E. Efeovbokhan of the Department of Chemical Engineering, College of Engineering, Covenant University, Ota, Nigeria. I attest that the thesis has not been presented either wholly or partially for the award of any degree elsewhere. All sources of data and scholarly information used in this thesis are duly acknowledged.

ABATAN, OLUBUNMI GRACE

Signature and Date

CERTIFICATION

We certify that this thesis titled **"MODELLING AND SIMULATION OF INDUSTRIAL FLUID CATALYTIC CRACKING UNIT USING DIFFERENT KINETICS OF HEAVY OIL CONVERSION"** is an original research work carried out by **ABATAN, OLUBUNMI GRACE (CUPG100343)** in the Department of Chemical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria under the supervision of Prof. Olaosebikan A. Olafadehan and Prof. Vincent E. Efeovbokhan. This work has been examined and found to be acceptable as part of the requirements for the award of Doctor of Philosophy (Ph.D) degree in Chemical Engineering.

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(External Examiner) **Signature and Date**

Prof. Akan B. Willams
(Dean, School of Postgraduate Studies) **Signature and Date**

DEDICATION

This work is dedicated to the Almighty God, the Alpha and Omega who knows everything and makes every crooked path straightened.

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ABSTRACT

There is a constant increase in the demand for petroleum products including gasoline due to the increasing population and advances in technology. The Fluid Catalytic Cracking Unit (FCCU) has played a major role in gasoline production, which has made it an important area of research. This study presents the simulation of FCCU using a modified five-lump kinetic model for the description of the catalytic cracking of heavy oil (HO) into light cycle oil (LCO), gasoline (GA), light gas (LG) and coke (CK) using Kaduna Refining and Petrochemical Company's (KRPC) FCCU as a case study. The cracking of HO in the riser-reactor was simulated as instantaneous vapourisation with a quasi-steady-state dynamic. The heat transfer resistance considered negligible in past works, was accounted for based on the temperature difference between the catalyst and gas. The mass transfer resistance was taken into cognisance in the continuity equation of the riser-reactor. A thorough description of the hydrodynamic model, momentum and energy balances, was presented with the former comprising the hydrostatic head of the catalyst, the solid acceleration, solid and gas frictions in the riser reactor, as against the general norm in the literature. The resulting stiff ODEs were solved numerically using the MATLAB-R2019a bulti-in routine, ode23tb, to determine salient process variables investigated. Sensitivity analyses were carried out to determine optimal conditions considering the change in catalyst-to-oil ratio (COR) and catalyst temperature (T_{cat}) using MINITAB-2017. The separator and regenerator were modelled inclusive of the dense and dilute beds of the regenerator. KRPC data was used to validate the simulated results, which gave the yields as HO-17.85%, LCO-14.95%, GA-50%, LG-16.73% and CK-5.13%, with %error of $< \pm 3$ for HO, LCO, GA, and CK, while it gave 6.43% for LG. The best-optimised condition was given at COR=3.35 and T_{cat} =900K. At this condition, the yield of GA, the premium product, was 56.78%. Catalyst deactivation from this study was not by coking activity alone but also due to adsorption characteristics of asphaltenes, resins, aromatics, and basic nitrogen. Catalyst activity is indirectly proportional to coke deposited. The separator model shows that energy was not lost as the outlet temperature of 786.85K was similar to the inlet temperature. The mass flow rate of CO and CO_2 at the entry point was zero but exited the dense bed after the combustion of coke to CO and CO_2 at 0.0345 kg/s and 0.165863 kg/s respectively. CO was further reduced in the dilute bed to 0.0344891 kg/s, and CO_2 increased to 0.1658642 kg/s. The temperature obtained from the simulation of the dilute bed is 926K which agrees well with the industrial data of 924K, %error being 0.002. This model can be adopted in improving the yield of gasoline and used for higher lumps if needed. It is suggested that the height of the reactor could be reduced to 12.75 m as more than 86% of cracked products would have been obtained to reduce both capital and operational costs. The results obtained from the regenerator dense bed confirms efficiency of combustion in the reactor.

Keywords: FCCU riser reactor, Separator, Catalytic Cracking, Five-lumps Kinetics, Sensitivity, Modelling.