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Analysis of the Process Parameter in Fluid Catalytic Cracking Unit for a Refining and Petrochemical Company in Nigeria

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Abstract

The aim of this study is to generate operational data that can be used to improve the production capacity in the Fluid Catalytic Cracking Unit (FCCU) in a Refinery and Petrochemical Company. This will aid in tackling the daunting challenge of unavailability of operational data that can be used to better understand and improve production capacity and ensure maximizing catalyst utilization. In addition, it addresses the challenges of analysis and control of the FCCU process due to its very complicated and little-known hydrodynamics, complex kinetics of both reactions of cracking and coke burning, strong interaction between the reactor and regenerator, and numerous operating constraints. Aspen HYSYS version 8.0 was used in modeling the cracking process using parameters extracted from the operating manual of the FCCU in the refinery. The operational data was used to compare the simulated effect of stepwise input in feed and reactor plenum temperatures as well as stepwise increase in reactor length on yield, catalyst-to-oil-ratio and catalyst regeneration. An optimum flow in naphtha was obtained by the interaction of the inlet crude flow rate, riser height, and temperature this optimum was supported by the study of the interaction of these parameters when, catalyst to oil ratio was set as the dependent parameter. The inferences drawn from the results are that the reactor plenum temperature of 560˚C and a riser length of 27 m are recommended for optimum performance that ensures lasting effect of an efficient catalyst activity.

Keywords

FCCU, Catalyst, Coke, Simulation, Reactor, Regenerator

1. Introduction

This Refining petroleum is a complex process that generates a diverse slate of fuel and chemical products, ranging from heating oil to gasoline [1]. The process involves cracking, separating, treating, restructuring and blending hydrocarbon molecules to generate petroleum products. A refinery is a chemical plant containing various units that carries out variety of operations involved in processing crude oil. The primary aim is to process the undesirable components of raw crude oil and upgrade them into more valuable products. Gasoline, jet fuel and diesel are among the most valuable products. Originally, thermal operations were used to crack heavy oil, but the discovery of catalyst that gives a higher yield of gasoline with a higher octane number quickly brought about the use of catalytic cracking units. Today, the most commonly used catalytic cracking unit is the Fluid Catalytic Cracker (FCC) [2]. The procedure consists of a catalyst section in which the catalyst can be manipulated [3] and a fractionating section that operate together as an integrated processing unit. Another aspect of research that uses similar procedure is still in current study for example the work of [4] have adopted the catalytic unit in kinetic studies. Also the unit is so efficient that they process biofuels too [5]. The catalyst section contains the reactor and regenerator, which, with the standpipe and riser, are said to be the catalyst circulation unit. The primary aim of the fluid catalytic cracking unit is to crack low-valued heavy gas oils into a lighter more valuable hydrocarbon using a moving bed catalytic converter. Fresh feed gas oil preheated in the heater is injected into the riser reactor through the inlet zone, leading to high turbulence and concentration gradients which partly crack the high molecular weight feed into low molecular weight products. The required heat for this endothermic cracking reaction is provided by hot catalyst. During this reaction, there is deposition of coke (carbon) on the catalyst (Zeolite) which reduces the catalyst activity [6]. The separation of the entrained catalyst from the product gas takes place in the cyclones at the top of the reactor (so as to minimize secondary reactions) and returned to the stripping section of the reactor where steam is injected to strip off the entrained hydrocarbons from the catalyst [7]. The fundamental purposes of the catalyst include selectivity of the reactions, transport of necessary heat to the cracking reactions, and absorption of the coke produced during conversion. This is removed from the catalyst via regeneration; a process of combustion, caused by introducing air into suitable equipment and under suitable conditions [8]. The catalyst is repeatedly circulated in the reactor as connected to the regeneration. In the regenerator controlling the temperature of the regenerator is necessary [9].

The temperature of the regenerator needs to be kept under control in order to prevent undue combustion in the regenerator [10]. Given that the FCC units should be controlled and these controls are intricate and difficult to understand, a new control system based on variable modeling was created not subject to conventional control methods [11]. For the optimization of refining operations, the use of catalyst which causes gas phases to be at equilibrium with the circulating catalyst in FCC are essential [12] [13].

Going by the after-burn of CO to form CO_2 in the diluted phase, which are either continuous or stage wise, post-combustion is linked to the localization of extremely high temperatures in the freeboard. When entrained catalysts enter this zone due to extensive exposure to elevated heating or overheating, they either become incandescent and damages or lose activity due to adverse changes in their pores and bulk density [14]; this is observed in all regenerator mode (whether the mode burns fully or partially). Cyclones, plenums, and overhead flue gas exit ducts are all affected by post-combustion, which is mostly detrimental to the freeboard. The dense bed, however, is somewhat stable since the heat of combustion is released by regeneration. This is as a result of the high catalyst storage and holdup, which absorb the heat of combustion released as they are regenerated, also the dense bed is unsusceptible to post-combustion, which affects plenums, cyclones and flue gas up in exit ducts [15]. As a result, extremely high heat in the dense bed are evenly distributed and ducked. Post-combustion effect makes auto-monitoring and control to be impractical because it necessitates sporadic operator involvement. Additionally, the process must be done to run the bed at forced reduced heating, which has a negative impact on the throughput of the equipment carrying the catalyst (this can cut the catalyst circulate rate by almost 10%) and the overall profitability [16].

Most FCC regenerators has operations of some post-combustion, but when the temperature rises above the threshold set by the metallurgical contents fixed for the material, post-combustion ultimately controls the structural integrity of these components. As a result, one of the crucial variables for determining the efficiency of coke combustion and a major performance determinant of regenerators is the degree of post-combustion.

Evidently, less than 50% of this heat is produced by the heterogeneous burning of CO in the dense bed, compared to the majority homogenous uncontrolled oxidation of CO in the dilute phase. Due to the different heat of production and temperatures caused by this, homogenous-full CO combustion [17] [18], which cannot be controlled, produces the best regenerator temperature.

Inadequate burning kinetics, uneven distribution of used catalyst and air in the bed, and ineffective mixing of the catalyst-feed gas are three broad categories that can be used to classify the many causes of post-combustion in FCC regeneration systems. A circuitous catalyst flow from the stripper in the reactor section may also start the post-combustion in the regenerator [19]. The possible remedies require that the system of fluidized catalytic cracking be taken as a continuous circulating catalyst system. The use of CO combustion promoters, modifying the operation parameters, and improving the mechanical designs are the most recent centrally effective techniques to operate FCCU optimally. In this work therefore the operational parameter are modified, analyzed and parameter are obtain for the process temperature and riser length to cater for the former challenges itemized which are common to the FCCU in KRPC. The essence to determine the extent of cooling required for the incoming regenerated catalyst.

Aspen HYSYS is a combination of tools that are used for estimating the physical properties and liquid-vapour phase equilibrium of various inbuilt components. The liquid vapour phase is studied via equation of state [20]. These components are the catalyst and feedstock that are used within the plant, within the reaction and separation sections. The program is such that it converge both energy and material balances and has standard unit operations typical of any FCC plant. The software updates the calculations as the user enters information and does it as fast as it can. The successful completion of an operation is seen by the changes in colour on screen [21].

This research work included simulating the FCCU of KRPC for the ultimate purpose of maximizing catalyst usage while increasing present yield of gasoline in Nigerian refineries through better understanding of the effect of stepwise input in feed and reactor plenum temperatures as well as stepwise increase in reactor length for maximum gasoline yield, catalyst to oil ratio during catalyst regeneration.

2. Methodology

2.1. Data Extraction

First, Operating data were collected from the piping and instrumentation diagram of FCCU of Kaduna Refinery and Petrochemical Company (KRPC). The process flow diagram indicating the feed to the unit and the fractions of fuel used to extract all the temperature, pressure of air flow and feed flow into the riser through the regenerator were taken. The product from the fractionator was recorded. These data were used to carry out the process simulation of the FCCU of the refineries [22] [23] [24] [25]. The feed compositions from the operating record were used to characterize the oil simultaneously; the stream temperatures, pressures and mass flow rates were adopted to carry out the process simulation using Aspen HYSYS version 8.0.

2.2. Process Description and Data Extraction

The heavy gas oils, light vacuum gas oil and heavy vacuum gas oil were fed as streams to FCC unit. The feed were introduced into the unit via a surge drum D01 then it was charged by feed pump P01through a series of heat exchangers E01, E02 and E03 where it was sequentially pre-heated before being sent to the main Heater H-01 (referred to as fresh feed furnace) to further raise the feed temperature to the required temperature of 320˚C. The product of Heater H-01 was passed to the Reactor R01 (referred to as converter) for conversion into light products. The process that takes place in the reactor involves the oil feed being atomized into a stream of very hot regenerated catalyst at the bottom of a vertical "riser" reactor R01. The charge was combined with a recycle stream within the riser, vaporized, and raised to reactor temperature (520˚C - 560˚C by the hot catalyst. As the mixture travels up the riser, the charge is cracked at 10 - 30 psi, the mixture of catalyst and now-vaporized oil shoots to the top of the riser (disengager) where catalyst and hydrocarbon reaction products are separated by inertial means. This is followed by passage of the vapour product through a cyclone separator to remove virtually all entrained catalyst powder.

Spent catalyst then flows to the regenerator, where the coke is burnt off using hot air supplied by an air blower and uniformly distributed at the bottom of the regenerator by an air grid. The upward velocity of the air tends to lift the catalyst particles, so that the bed of catalyst behaves as a fluid. Flue gases from the regenerator were sent to the CO boiler via a slight valve and an orifice chamber. Reaction product vapour from the overhead of the disengager was processed at low pressure in the Main Fractionating Column C01 where decanted oil and light cycle oil streams are separated stripped in side strippers and partly recycled as pump around back to the column C01 via heat exchange in feed preheaters E01 and E02 and partly sent to tank. The bottom slurry is partly recycled via heat exchange in E03 back to the column C01 and partly sent to tank. The overhead vapour is further condensed to liquid in the Air Cooler A01 (referred to as overhead condenser) before being separated in high pressure Separator D02 to produce gasoline and off gas.

2.3. Parametric Studies

The modeling of the Fluid Catalytic Cracking Unit was completed and the parametric study was then carried out on the Reactor (R-01) by selection of dependent and independent process variables. A boundary was set for the dependent variables and step sizes were specified before the run button was clicked. The generated results were plotted as graphs in the software plot mode. Extensive procedure is in [7] and [26] [27] [28] [29] [30].

3. Results

The modeled FCC unit in the simulation environment of Aspen HYSYS version 8.0 software is as shown in **Figure 1**.

The effects of step input in Feed and Reactor-Plenum Temperatures and step increase in riser length on yield are shown on **Figures 2-7**. Increase in reactor was found to cause proportionate increase in Fuel Gas yield and the inversely (decreased) in the yield of Light Cycle Oil (LCO), an interception of the two was observed at riser length of 26.2 m as shown on **Figure 2**. Thus a step increase of 0.5 m in reactor length brought about an increase of 0.25 wt% in the yield of Fuel Gas and reduction of 0.15 wt% in LCO yield.

An increase in reactor feed temperature was found to bring a reduction in both yields of Naphtha and Coke, a step increase of 10˚C brought a decrease of 1 wt% and 0.17 wt% in respective yields of Naphtha and Coke as shown in **Figure 3**.

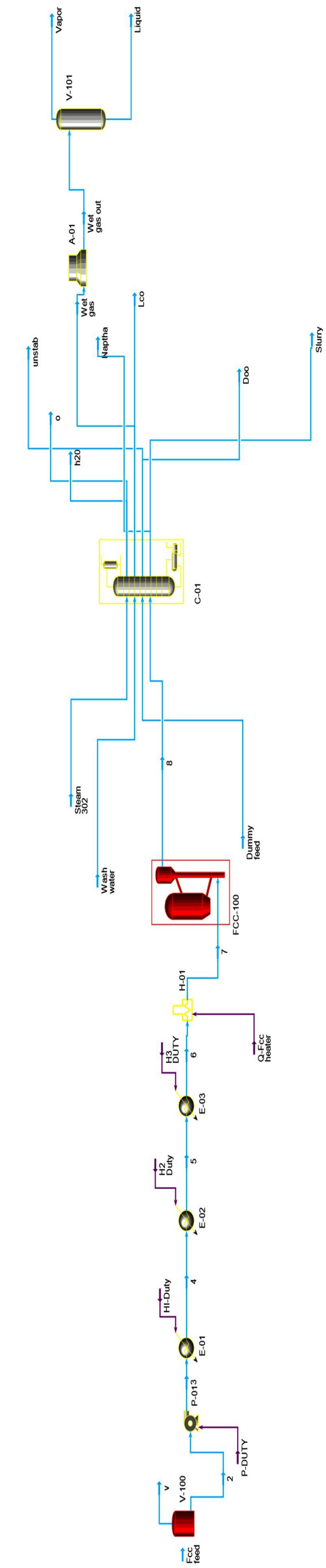

Figure 1. Modeled FCC unit.

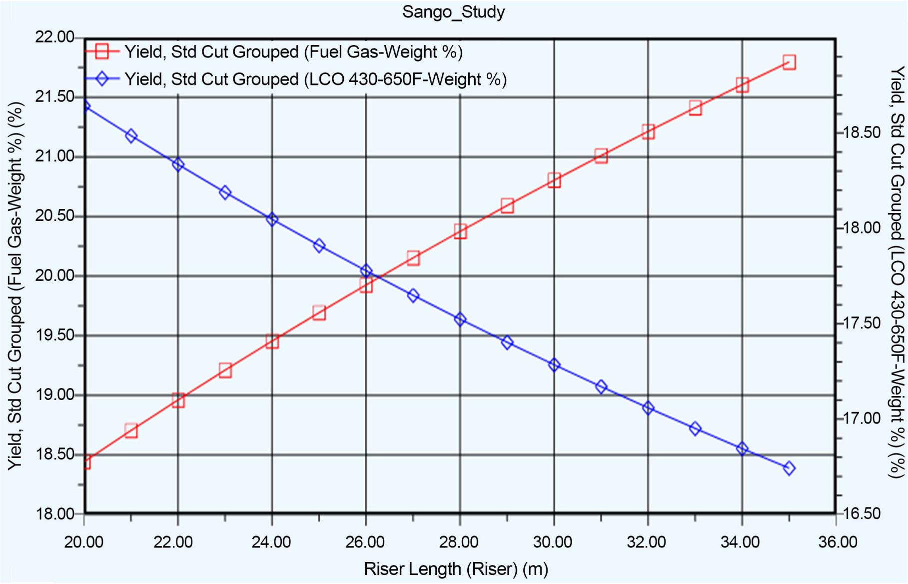

Figure 2. Plot of riser length against fuel gas and LCO yields.

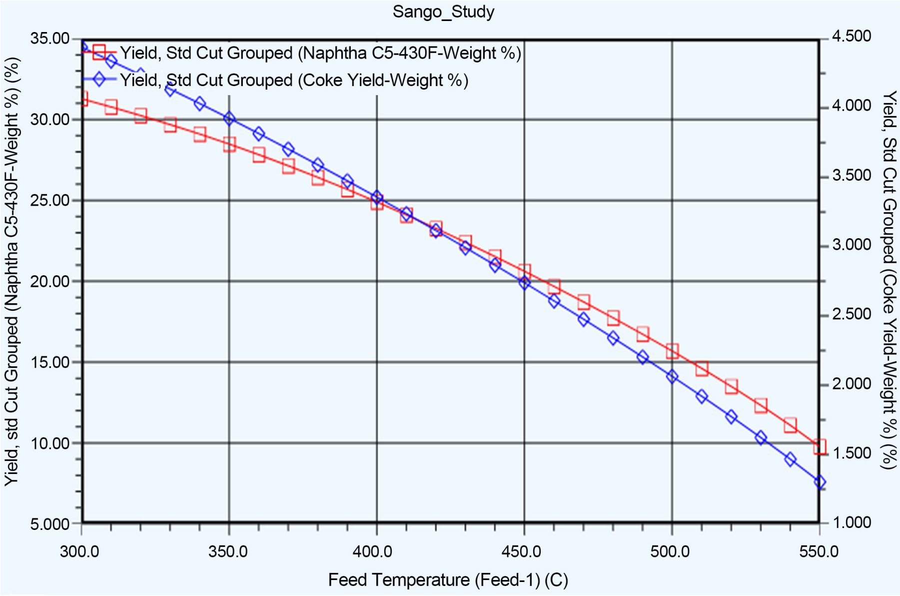

Figure 3. Effect of feed temperature on naphtha and coke yield.

An increase in Reactor Plenum Temperature was found to cause an increase in conversion, the increment caused by step input in temperature was more pronounced between temperatures of 520˚C to 560˚C as shown in Figure 4.

A rise in the slope of LCO yield up to 35.9 wt% was observed at Reactor Plenum temperatures below 520˚C before a steep fall to 18.5 wt% at 580˚C. A gradual increase in yield of Fuel gas from 1 wt% to 3.8 wt% between temperatures of 500˚C to 560˚C, the slope however increased drastically onwards to a yield of 22.5 wt% at reactor plenum temperature of 600˚C as shown in Figure 5. This temperature is due to the high regeneration temperature circulated into the plenum and must be forced to the metallurgical value for the process material.

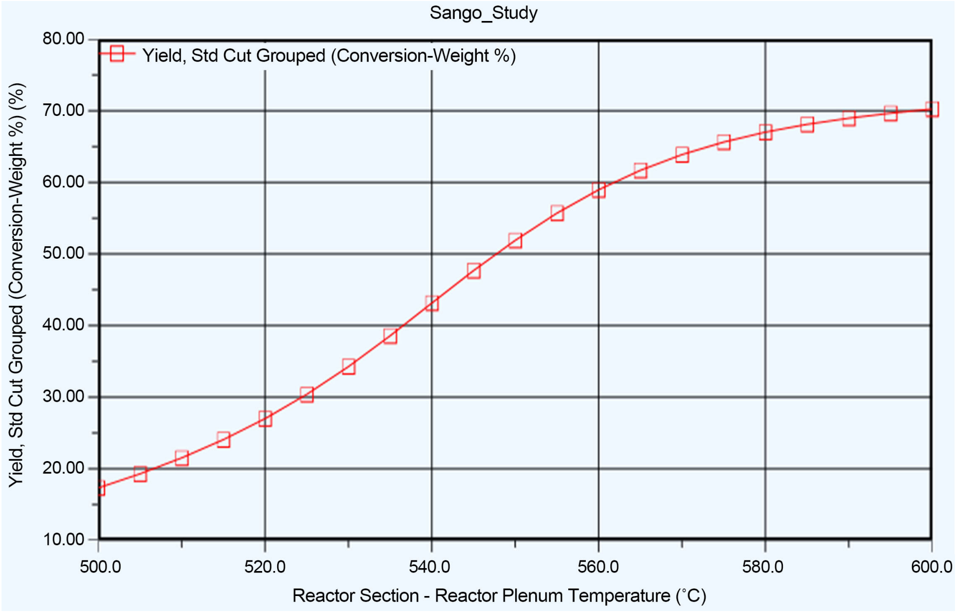

Figure 4. Effect of reactor plenum temperature on conversion.

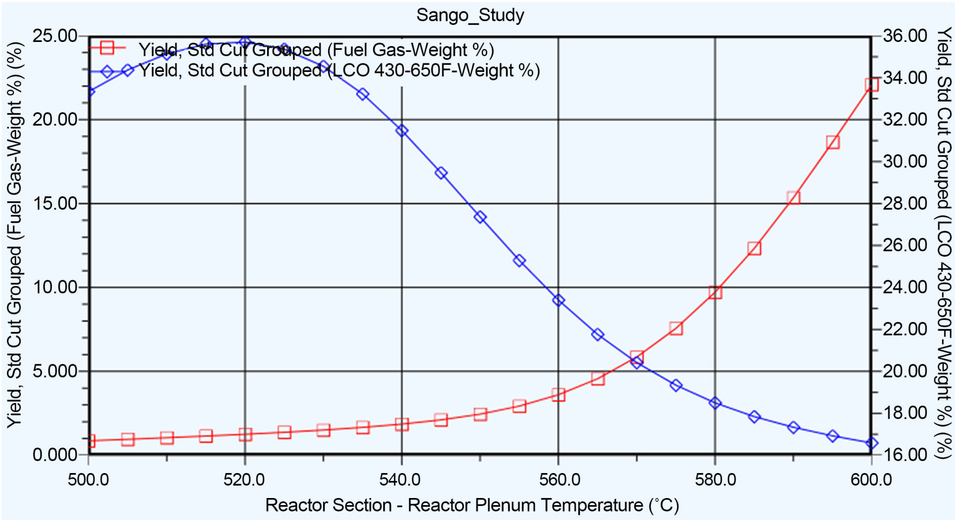

Figure 5. Effect of reactor plenum temperature on fuel gas and LCO yield.

An increase in reactor temperature gave rise to increase in Naphtha yield which was at a peak value of 37.5 wt% at reactor plenum temperature of 560˚C was observed before a steep and steady fall to 4 wt% at temperature of 600˚C. A rising slope showing an increase in Coke yield with each step input of about 10˚C increase in reactor plenum temperature giving rise to an increment of about 2 wt% was observed. Both slopes are shown in **Figure 6**.

An increase in riser length brought about stepwise increase and decrease in Kinetic Coke and Catalyst/Oil Ratio with each increment of 1 m in riser length giving rise to an increase of about 0.1 wt% in kinetic coke yield, and a decrease of about 0.01 ratio of catalyst to oil as shown in **Figure 7**.

An increase in reactor plenum temperature gave rise to a steady reduction in

Coke deposits on spent catalyst and coke remains on the regenerated catalyst as shown in **Figure 8**. These reductions in coke deposits on spent catalyst makes regeneration more efficient while and the reduction in coke remains will aid effective utilization of catalyst as it enhances activity of regenerated catalyst thus increasing life span of the catalyst and maximizing productivity.

An increase in reactor plenum temperature from 500˚C to 570˚C was found to steadily reduce the required heat of combustion by the regenerated coke from 3.967e+004 KJ/kg to 3.930e+004 KJ/kg and remained so till a steady rise in the slope was observed from plenum temperature of 570˚C to 600˚C. Temperature increase from 500˚C to 535˚C had no effect on catalyst stripper coke but temperature increase beyond this point caused a steady rise in the slope indicating an increase from 0.1 wt% at 540˚C to 3.3 wt% at plenum temperature of 600˚C as shown in **Figure 9**.

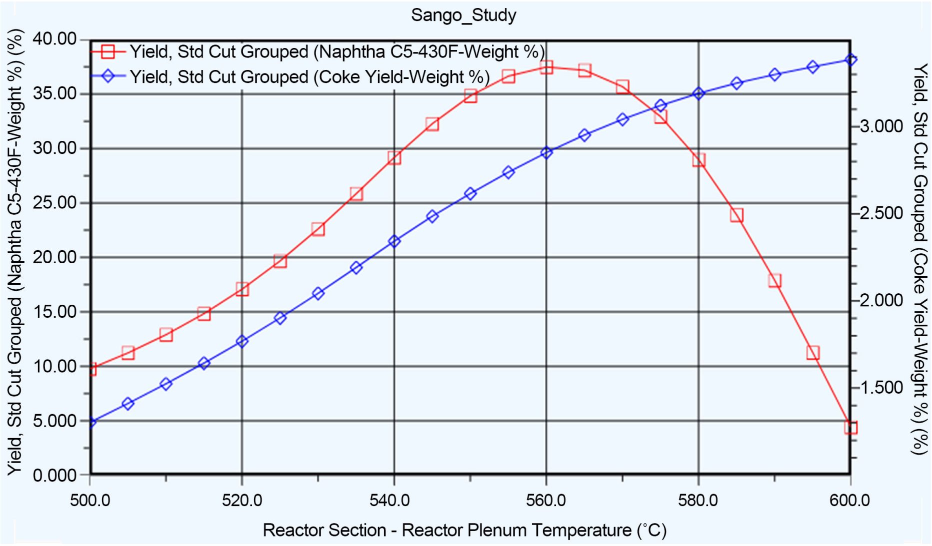

Figure 6. Effect of reactor plenum temperature on naphtha and coke yield.

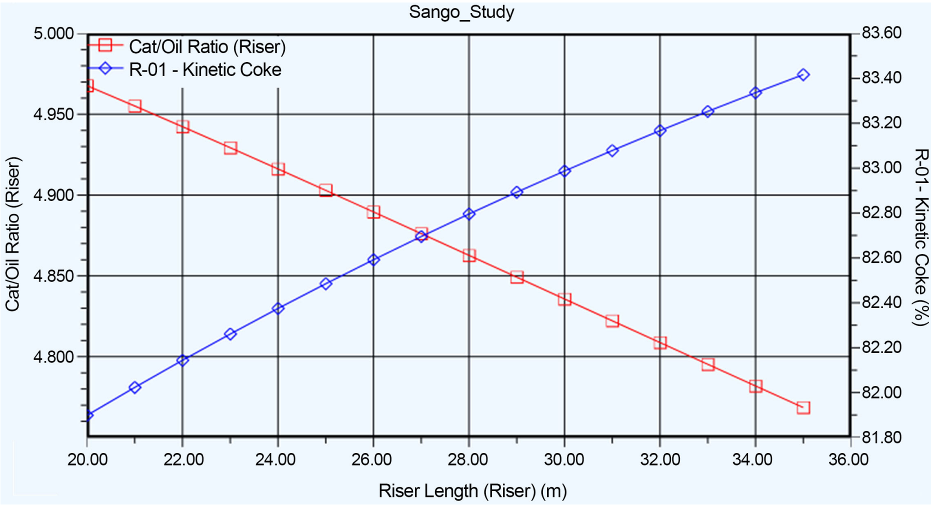

Figure 7. Plot of riser length against Cat/Oil ratio and kinetic coke.

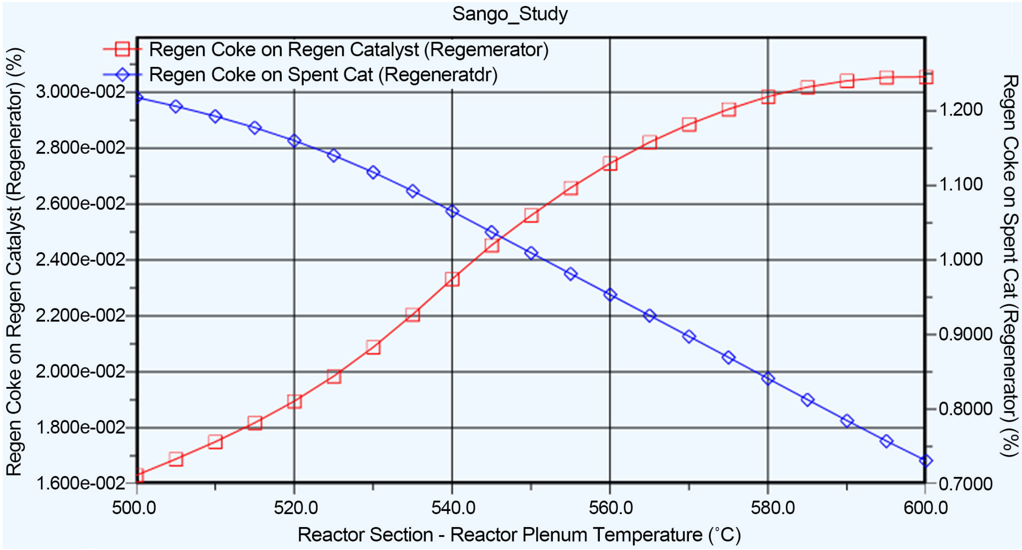

Figure 8. Effect of reactor plenum temperature on coke on regenerated and spent catalyst.

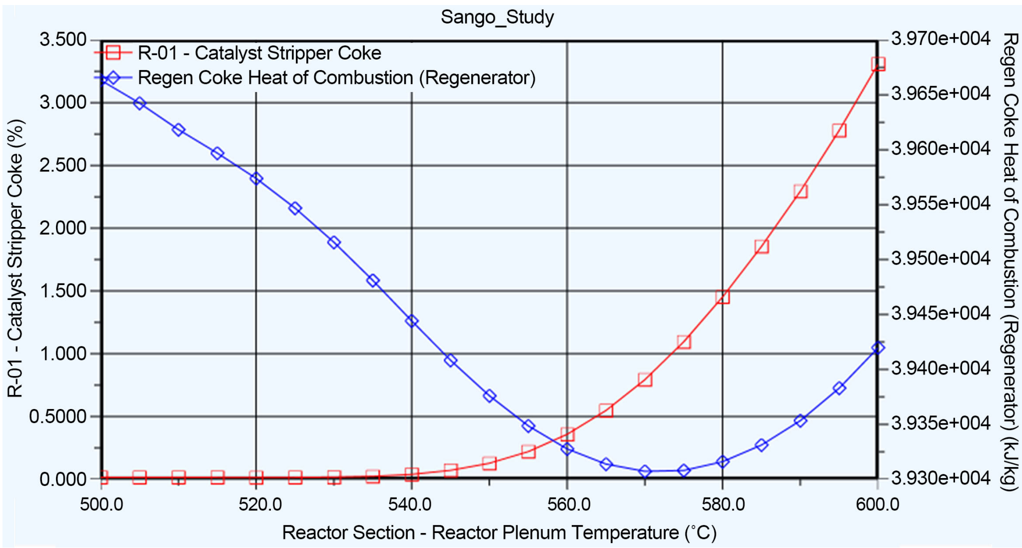

Figure 9. Effect of reactor plenum temperature on cat stripper and heat of combustion coke.

An increase in reactor plenum temperature from 500˚C to 600˚C caused a steady increase in the regenerated catalyst circulation rate from 1.5e+005 Kg/hr to 8.5e+005 Kg/hr with an increment of 10˚C in temperature causing. Similarly the increase in plenum temperature from 500˚C to 560˚C caused steady increase in the Air Mass Flow into the regenerator, the rate of increase with step input in temperature however reduced at temperatures above 560˚C as shown on **Figure 10**.

Increase in reactor plenum temperature had influence on Non-stripper Coke Hydrogen and caused an increase of 0.2 wt% in Stripper Coke Hydrogen between reactor plenum temperatures of 500˚C to 560˚C, while a more rapid increase of 2 wt% was observed between plenum temperatures of 560˚C to 595˚C as shown in **Figure 11**.

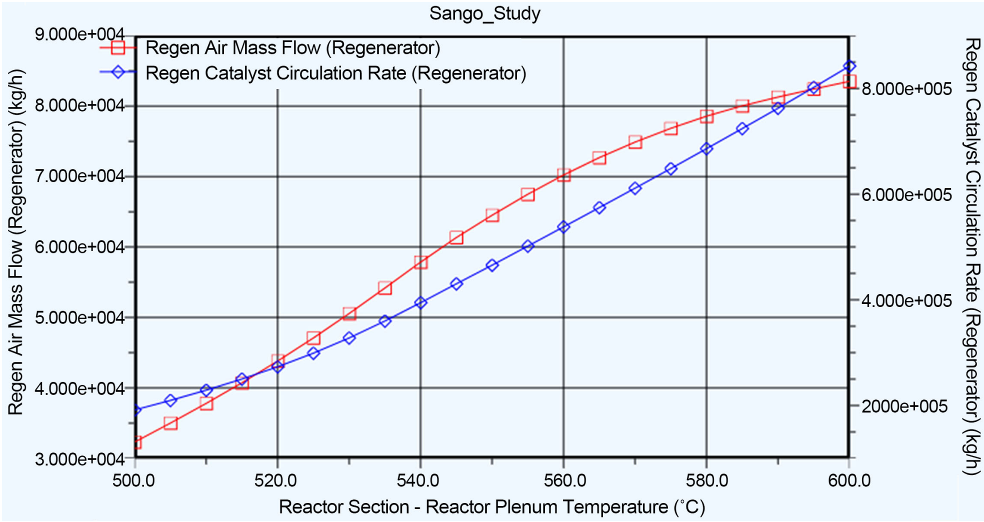

Figure 10. Reactor plenum temperature against regen air mass flow and cat circulation rate.

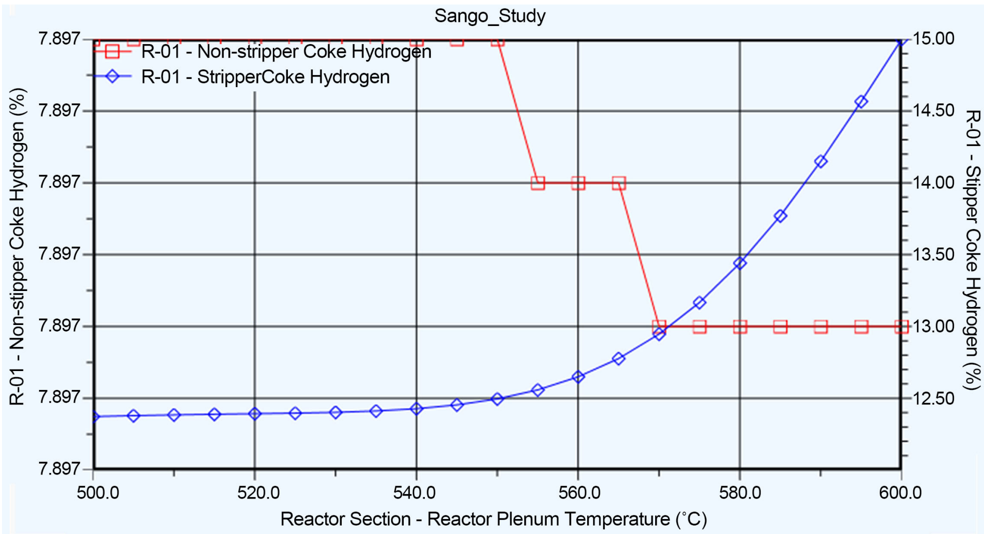

Figure 11. Effect of reactor plenum temperature on stripper and non-stripper coke hydrogen.

Temperature of the Process

By raising the internal temperature of the reactor at a constant circulation rate, increasing conversion and coke yield is anticipated to enhance stripper performance since the hydrogen content of the coke will drop. As a result, this modification will reduce the amount of light hydrocarbon products that the used catalyst burns in the diluted phase. The temperature of the catalyst bed in the regenerator will also rise with increased coke production. According to the refiner goals (better conversion, diesel or gasoline optimization, octane number and improving the yield of propylene/isobutylene) and equipment constraints, the FCC reaction temperature is typically optimized (potentiality limit of wet gas compressor, considerable yield in dry gas over gas consumption of refinery fuel, coke combustion, physical plant design and metallurgy design temperature of reactors). Due to goals set for the refining, the ROT (Riser Outlet Temperature) moved to 540˚C before TAR so as to optimize yield of gasoline and retard gas yield.

The diluted and gas phases temperatures of post-combustion are reduced to about 30˚C when processing with a +3˚C higher ROT, according to the evaluation of the findings obtained under various operating parameter. Maximizing the surplus oxygen in the flue gas to ensure complete coke combustion. The primary FCCU restriction that impacts the oxygen availability required for coke burning is the extent of the air blower (**Figure 1**). If such a condition exists, raising the flow rate of feedstock above the capacity of the air blower may cause some of the coke to partially burn into CO, which will increase post-combustion. In order to have enough oxygen during FCCU operation, the air flow rate was managed and adjusted at the FCCU feed flow rate. The effect of pressure was discussed in the research reported by [29] [30].

For the highest capacity of the air blower, high post-combustion up to 113˚C was observed, and an excess of O_2 in the flue gas was maintained between 2.3 and 3.4 vol.% (1 - 365 days). The after-burning at 40˚C was reduced by the decrease in air flow rate (360 - 560 days). The oxygen breakthrough on one side of the dense bed and the reaction in the diluted phase with the CO escaping from another area of the reactor were the results that were seen, and these results were explained by air transmitting and emerging as the air flow rate increases. As a result, lesser afterburning is attained at lower values of flue gas excess oxygen between 1 and 2 vol.% (360 to 470 days), rather than at higher values above 3 as the vol.% of O_2.

4. Conclusion

The Fluid Catalytic Cracking process that takes place in the FCC Unit plant of the refinery was modeled and simulated using Aspen HYSYS version 8.0. A reactor plenum temperature of 560˚C and a riser length of 27 m are recommended for optimum performance and ensure efficient catalyst activity and durability. When the FCCU is operated under afterburning conditions, regenerator temperatures can rise above those specified by metallurgical design, which can cause the cyclones and plenum chamber to malfunction mechanically. By raising riser height (+3%), catalyst stripping steam (+0.5 t/h), ROT (+4˚C), and e-cat activity (+4 wt%), afterburning was reduced by 30˚C (38% reduction). Due to uneven distribution, additional process variables like, slurry recycling, and extra oxygen have little impact on afterburning. The riser height and adjusted plenum temperature affected the regenerator because it ensures that the cyclones release the catalyst in order to reduce afterburning. The afterburning was reduced by 64˚C, or 86%, using this modification. As a result, the regenerator temperatures dropped to about 700˚C, which was below the internal design temperature of 799˚C.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Rader, M.L. (1996) Worldwide Refining, Oil & Gas Journal. Tony, Baker Petrolite, Houston, 52-62.

[2] Wilczura-Wachnic, H. (1973) Catalytic Cracking of Hydrocarbons. Chemical Technology Division, Faculty of Chemistry, University of Warsaw, Warsaw, 7-9.

[3] Martínez, V. and Shadman, F. (2020) Improving the Performance of Fixed-Bed Catalytic Reactors by Innovative Catalyst Distribution. *Journal of Applied Mathematics and Physics*, **8**, 672-683. https://doi.org/10.4236/jamp.2020.84052

[4] Hadi, G. and Hadi, A. (2022) Kinetic Study of Methanol Dehydration to Dimethyl Ether in Catalytic Packed Bed Reactor over Resin. *Journal of Materials Science and Chemical Engineering*, **10**, 45-58. https://doi.org/10.4236/msce.2022.106005

[5] Olugbenga, A.G., Olujinmi, J.O., Yahya, M.D. and Garba, M.U. (2018) Simulation and Unit Cost of Using Fluid Catalytic Cracking of Soyabeans Oil for the Production of Bio-Gasoline. *Covenant Journal of Entrepreneurship*, **2**, 27-33. https://journals.covenantuniversity.edu.ng/index.php/cjoe/article/view/1170

[6] Ramasubramanian, S. (2001) Optimization of a Model IV Fluidized Catalytic Cracking Unit.

[7] Raji, O.Y., El-Nafaty, U.A. and Jibril, M. (2012) Effect of Operational Variables on Riser Reactor of FCCU Using Hysys. *A Proceeding of International Journal of Computer Application*, **3**, 1-8.

[8] Ibsen, K. (2006) Equipment Design and Cost Estimation for Small Modular Biomass Systems, Synthesis Gas Clean Up, and Oxygen Separation Equipment. NREL Technical Monitor, San Francisco, 1-12.

[9] Gómez-Velásquez, N., López-Montoya, T., Bustamante-Chaverra, C.A. and Nieto-Londoño, C. (2021) Parametric Study of Particles Homogenization in Cold-Flow Riser Reactors. *International Journal of Thermofluids*, **9**, Article ID: 100058. https://doi.org/10.1016/j.ijft.2020.100058

[10] Lopez-Isunza, F. (1992) Dynamic Modelling of an Industrial Fluid Catalytic Cracking Unit. *Computers & Chemical Engineering*, **16**, S139-S148. https://doi.org/10.1016/S0098-1354(09)80016-1

[11] Rajeev, N., Prasad, R.K. and Ragula, U.R. (2015) Process Simulation and Modeling of Fluidized Catalytic Cracker Performance in Crude Refinery. *Petroleum Science and Technology*, **33**, 110-117. https://doi.org/10.1080/10916466.2014.953684

[12] Fals, J., Garcia, J. R., Falco, M. and Sedran, U. (2020) Performance of Equilibrium FCC Catalysts in the Conversion of the SARA Fractions in VGO. *Energy & Fuels*, **34**, 16512-16521. https://doi.org/10.1021/acs.energyfuels.0c02804

[13] Heydari, M., AleEbrahim, H. and Dabir, B. (2010) Study of Seven-Lump Kinetic Model in the Fluid Catalytic Cracking Unit. *The American Journal of Applied Sciences*, **7**, 71-76. https://doi.org/10.3844/ajassp.2010.71.76

[14] Kassel, L.S. (1948) Prevention of Afterburning in Fluidized Catalytic Cracking Processes. U.S. Patent 2,436,927A.

[15] Oloruntoba, A., Zhang, Y. and Hsu, C.S. (2022) State-of-the-Art Review of Fluid Catalytic Cracking (FCC) Catalyst Regeneration Intensification Technologies. *Ener-*

gies, **15**, 2061. https://doi.org/10.3390/en15062061

[16] Blaser, P., Pendergrass, J., Gabites, J. and Brooke, A. (2018) Viva Energy's Geelong Refinery Reduces FCCU Turnaround Risk. *Hydrocarbon Processing*, 1-6. https://www.hydrocarbonprocessing.com/magazine/2018/september-2018/special-focus-refining-technology/viva-energy-s-geelong-refinery-reduces-fccu-turnaround-risk

[17] Arbel, A., Huang, Z., Rinard, I.H., Shinnar, R. and Sapre, A.V. (1995) Dynamic and Control of Fluidized Catalytic Crackers. 1. Modeling of the Current Generation of FCC's. *Industrial & Engineering Chemistry Research*, **34**, 1228-1243. https://doi.org/10.1021/ie00043a027

[18] Wu, D., Schmidt, M., Huang, X. and Verplaetsen, F. (2017) Self-Ignition and Smoldering Characteristics of Coal Dust Accumulations in O_2/N_2 and O_2/CO_2 Atmospheres. *Proceedings of the Combustion Institute*, **36**, 3195-3202. https://doi.org/10.1016/j.proci.2016.08.024

[19] Oloruntoba, A., Zhang, Y. and Xiao, H. (2022) Study on Effect of Gas Distributor in Fluidized Bed Reactors by Hydrodynamics-Reaction-Coupled Simulations. *Chemical Engineering Research and Design*, **177**, 431-447. https://doi.org/10.1016/j.cherd.2021.10.031

[20] Olugbenga, A.G., Al-Mhanna, N.M., Yahya, M.D., Afolabi, E.A. and Ola, M.K. (2021) Validation of the Molar Flow Rates of Oil and Gas in Three-Phase Separators Using Aspen Hysys. *Processes*, **9**, 327. https://www.mdpi.com/2227-9717/9/2/327 https://doi.org/10.3390/pr9020327

[21] Vogt, E.T. and Weckhuysen, B.M. (2015) Fluid Catalytic Cracking: Recent Developments on the Grand Old Lady of Zeolite Catalysis. *Chemical Society Reviews*, **44**, 7342-7370. https://doi.org/10.1039/C5CS00376H

[22] Aspen Technology Inc. (2011) Aspen HYSYS® Dynamics V7.3. https://www.aspentech.com

[23] Idris, M.N., Mahmud, T. and Gibbs, B. (2007) Hydrodynamics Design of a Robust Fluid Catalytic Cracking (FCC) Riser Reactor Model. *Petroleum Training Journal*, **4**.

[24] Ikeda, S. and Ino, T. (1999) Down-Flow FCC Pilot Plant for Light Olefin Production. In: *Proceeding of the Symposium on Advances in Fluid Catalytic Cracking*, American Chemical Society, New Orleans, 22-26.

[25] Kaduna Refinning and Petrochemical Company (1980) Handbook for Process Operations. Chioda Chemical Engineering Company, Yokohoma.

[26] Zhang, Y., Li, Z., Wang, Z. and Jin, Q. (2021) Optimization Study on Increasing Yield and Capacity of Fluid Catalytic Cracking (FCC) Units. *Processes*, **9**, 1497. https://doi.org/10.3390/pr9091497

[27] Reza, S. (2000) FCC Handbook, Design, Operation and Trouble Shooting of FCC facilities. 2nd Edition, Gulf Professional Publishers, Houston, 1-39, 40, 45, 52.

[28] Tungler, A. (2012) Catalytic Technologies of the Oil Industry. HAS CER.

[29] Becerril, E.L., Yescas, R.M. and Sotelo, D.S. (2004) Effect of Modeling Pressure Gradient in the Simulation of Industrial FCC Risers. *Chemical Engineering Journal*, **100**, 181-186. https://doi.org/10.1016/j.cej.2004.03.001

[30] Philip, K., Niccum, M. and Chris, R. (2002) Handbook of Petroleum Refining Process. McGraw-Hill, New York, 3.0-3.33.