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RESEARCH ARTICLE OPEN ACCESS

Comparative Study of the FCCU Regenerator Using Aspen Hysys

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ABSTRACT
A study of the Fluid catalytic cracking Unit, with more emphasis on the regenerator is presented. Predictive simulation results for the regenaration temperature, quantity of coke burnt and flue gas composition at different operating conditions are also presented using Hyspen Hysys. The predicted results are compared with plant data and a very good agreement is obtained. Simulation results indicated that the variation of inlet air flowrate have a significant influence on the performance of the regenerator and so the simulation results using the Aspen Hysys can be used to predict the FCCU parameters even if experimental data are not available.

***Keywords**: FCCU Regenerator, Aspen Hysys, coke combustion, catalyst, Simulation.*

I. INTRODUCTION

The Fluid catalytic cracking unit (FCCU) (fig.1) converts heavy petroleum fractions using catalyst into more usable products such as gasoline, middle distillate and light olefins. Fluid catalytic cracking (FCC) process provides 35 to 45 percent of blending stocks in the Port Harcourt refinery of gasoline pool. A detailed study of the FCCU is presented elsewhere [10]; [17]; [18]. The regenerator contains a fluidized bed catalyst (Zeolite). To maintain the activity of the catalyst it is necessary to burn off deposited carbon on the catalyst. This was done once the regenerator and the active catalyst is further feed back to the reactor. The cracking reaction is endothermic so that energy required for the process comes from the regenerator where catalyst is burned off in the presence of air which is an exothermic reaction. A controlled amount of air is supplied to the fluidized bed and the coke is burnt off the catalyst, although complete combustion is not achieved, the heat released from this reaction heats the catalyst, which in turn provides the necessary energy for cracking process in the reactor riser. Flue gas exits the regenerator through a series of internal cyclone located at the top of the system [15]. Regenerated catalyst passes from the regenerator back into the reactor. Internal cyclones are widely used in regenerator to remove catalyst particles from the flare gas stream and return these particles to the fluidized bed. Since their development in the late 1800s cyclones have become the most common mechanical separation device used in the industry [12], [6]; [6]; [8]; [9]; [13], [14]. The FCC process employs a catalyst in the form of very fine particles (size of the catalyst is about 75 micrometer), which behave as fluid when aerated with vapor so here the catalyst acts as an agent for the mass transfer operation and heat transfer operation. Catalyst moves from the regenerator to the reactor and vice versa as fresh catalyst provide heat to the reactor. Usually two types of FCC units are used in industrial scale which are side by side type and ortho-flow or stacked type reactor. In side by side which will be used in this project for simulation purposes, reactor and regenerator is separated vessel placed side by side. In the case of stacked type, reactor and regenerator are mounted together. In order to study the complex mechanisms, reactions and process flows in the regenerator, numerical methods are employed. Some engineering softwares contain these numerical methods. Some researchers have used different softwares to simulate part of the unit [5]; [17]; [18]. In this work, the Aspen Hysys is used to study the FCC regenerator so as to predict the Optimum operating conditions of the regenerator and compare the predicted results with plant data.

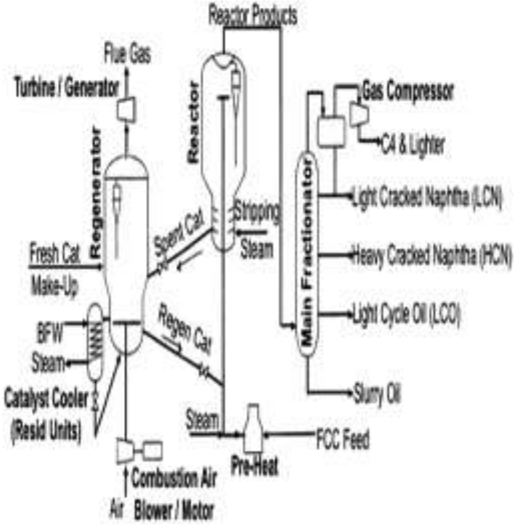

Figure 1: FCC Unit Process Flow Diagram

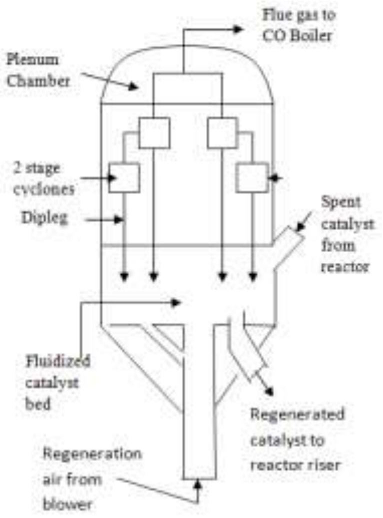

Figure 2: Schematic of FCCU Regenerator

II. METHODOLOGY

2.1 THE REGENERATOR

Fig.2 shows a schematic diagram of the FCCU Regenerator. The Port Harcourt refinery company (PHRC) utilizes a series of 12 internal cyclones, arranged in six group of two in the regenerator.

2.2 THE FCCU REGENERATION EQUATIONS

Coke combustions reactions are found in the regenerator [1]. Thus during catalyst regeneration in FCC unit, coke is burnt to produce carbon monoxide and carbon dioxide [11]; [2]. Also, the homogeneous CO combustion reaction taking place in bubble-phase is assumed to be negligible compared with the catalytic CO combustion in the emissions-phase [1]; [7].Hence, the following irreversible coke combustion reactions occurs in the emulsion phase of a regenerator [16]. The three combustion reactions that exist in the emulsion-phase of the regenerator during combustion are:

- $C + {}^{1}/_{2}\, O_2 \rightarrow CO$
- $CO + {}^{1}/_{2}\, O_2 \rightarrow CO_2$
- $C + O_2 \rightarrow CO_2$

2.3 MATERIALS AND PROCESS SIMULATION

Aspen Hysys version 8.0 was used. Operating plant conditions of fluid catalytic cracking unit regenerator of the Port Harcourt refinery company (PHRC) were collected from PHRC AREA III and are also used in this study. In this study, the simulation of FCC unit regenerator was developed in the simulation environment of HYSYS 8.0 software Figure 2. Detail work is shown elsewhere [3]; [4].

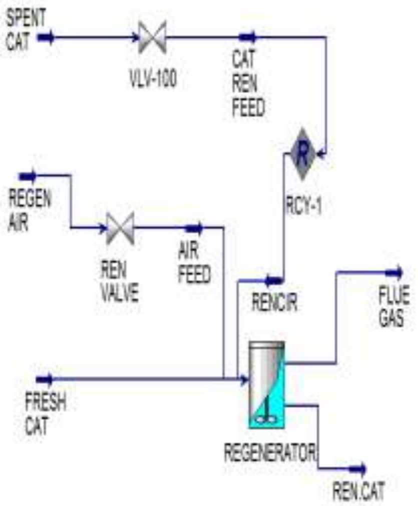

Figure 3: Model and simulated diagram of FCC Unit Regenerator.

To present the fluid catalytic cracking regenerator in Aspen Hysys, the following steps were carried out using the aspen Hysys simulation software. The first step is mainly defining chemical components. In the Simulation Basic Manager, a fluid package was selected along with the combustion reaction set containing the three combustion reactions (RXN-1, RXN-2 and RXN-3). In the process Peng-Robinson was selected as fluid packages as it was able to handle the hypothetical components (pseudo-components). Data on carbon (coke), CO, CO_2, sulphur, nitrogen, oxygen and hydrogen are available in the Hysys component library. The Y-zeolite (Magnesiev-138) was cloned using the hypo-manager component with the data in table 1.

Table 1: Catalyst properties.

S/No	Catalyst properties	Value and Units
i.	Particle size distribution	$75 \times 10^{-6}\mu m$
ii.	Bulk density	$(0.8 \text{ to } 1.0)\ {}^{g}/_{cm^3}$
iii.	Molecular weight	$162.04\ {}^{g}/_{cm^3}$
iv.	Surface area	$200 - 300\ {}^{m^2}/_{g}$
v.	Melting point	870^0C

The selected combustion reaction set was modeled in the regenerator with carbon and oxygen as the base components and in order to allow Aspen Hysys calculate the overall mass balance, Heat transfer of the combustion and regenerator. The data in table 2 were used in the reaction kinetics during simulation:

Table 2: Kinetics Parameter for Coke burning

Reaction	**Pre-experimental constants**	**Activation**
Coke Combustion	$1.4 \times 10^8 m^3 kmol^{-}$	$224.9\ {}^{kg}/_{mol}$
CO catalytic combustion	$247.75 m^{3(1.5)}K$	$70.74\ {}^{kg}/_{mol}$

The Arrhenius equation ($(K = A^* Exp^{(-E/_{RT})*} T^{*b}$) was used, where b = 0 was assumed and the orders of the reactions were assumed to be first order. T is the reaction temperature (200-300)^{0}C and R as the ideal gas constant. The parameters in table 2 remain valid for the calculation and estimation of the reaction rate constant K_o and K_{co} used in the simulation of coke combustion reaction in the regenerator using Aspen Hysys.

In order to go to the process flow diagram (PFD) of the fluid catalytic cracking unit regenerator screen, the option "Enter Simulation Environment" was clicked. An object "Palatte" appeared at right hand side of the screen displaying various operations, streams and units.

Then materials stream (blue) was clicked to create material stream for Regenerator Air Feed, spent catalyst feed, and fresh catalyst feed imputing various compositions and conditions (temperature, flow rate and pressure) for each of the stream that was created.

The palatte was clicked and the regenerator was selected (CSTR). The dimension of the regenerator modelled was set up using the data in table 3.

Table 3: Dimension of Some component of FCC Unit [10]

Equipment	Height	Dimension
Regenerator	35.45	9.8m

The Regenerator Air Feed was fed into the regenerator at approximate flow rate of 135 KN m^3/hr, temperature 180^{0}C and pressure 2.5 Kg/cm^2. The fresh catalyst was fed into the regenerator at approximate flow rate 480.49 Kg/s, temperature 700^{0}C and pressure 0.700Kg/cm^2, and lastly the spent catalyst was fed into the regenerator at 500^{0}C temperature, flow rate 480.49 Kg/s and pressure 0.500 Kg/cm^2.

The main processing unit includes the valves and the regenerator (CSTR). After the input information, operating unit of the regenerator were setup, the process steady-state simulation was executed by Aspen Hysys mass and energy balances of the regenerator unit.

2.4 EMULSION PHASE SIMULATION

This phase is considered as a continuous stirred tank reactor (CSTR), composed of solids (catalyst and coke), air (O_2, N_2) and gases formed in the combustion (CO, CO_2, H_2O).

2.5 REFINERY OPERATING CONDITION AND PARAMETERS OF (PHRC)

The conditions stated in the tables 4 and 5 are the operating conditions obtained from the New Port Harcourt Refining Company (NPHRC) [10].

Table 4: Spent Catalyst Stream Feed Stock Composition

Components	**Mass fraction (wt%)**
Coke	0.05
Hydrogen	0.05
Sulphur	0
Magnesiev-138 (Y-zeolite)	0.860.9
CO	0
Nitrogen	0.02

Table 5: PHRC operating condition

Stream	**Temp-erature**	**Pressure**	**Flow rate**
Spent catalyst	500° C	0.500kg/cm^2	480.49kg/s
Fresh catalyst	700° C	0.700 kg/cm^2	480.49kg/s
Flue Gas	713° C	0.160 kg/cm^2	
Air	180° C	2.5 kg/cm^2	135KNm^3/hr

III. RESULTS AND DISCUSSION

3.1 SIMULATION RESULTS

The simulation results for steady state are presented in Table 6. It shows the FCCU regenerator at various temperatures and flow rates and the corresponding simulation prediction results of CO_2, CO and Coke using the Aspen Hysis. In the simulations, the inlet spent catalyst and air flow rates are considered constant and the regenerated catalyst flow rate is made equal to the inlet fresh catalyst flow rate. The gas flow rate controls the pressure within the regenerator and it depends on the difference of pressure through the valve. A sensibility analysis regarding the inlet air flow rate and the coke fraction in the spent catalyst was conducted. These variables were chosen because of their direct influence on the rates of reactions.

Table 6: Simulation results

Air flow rate(Kg mole/hr)	**Regen Temp (°C)**	CO_2 **(Mol.%)**	**CO (Mol.%)**	**Coke. (Wt%)**
6023	627.7	0.0371	0.0236	0.4061
8523	639.7	0.0511	0.0169	0.3162
12023	656.3	0.0634	0.0115	0.2328
15023	670.3	0.0703	0.0088	0.1838
17523	681.8	0.0746	0.0072	0.1526
20023	693.1	0.0780	0.0059	0.1275
22523	704.3	0.0808	0.0049	0.1069
26523	722.0	0.0843	0.0037	0.0806
29523	735.1	0.0864	0.0030	0.0648
32023	745.9	0.0879	0.0025	0.05335
36523	765.0	0.0901	0.0018	0.0367
40023	779.6	0.0915	0.0013	0.0258
44523	798.0	0.0931	0.0007	0.0142
48023	812.0	0.0941	0.0003	0.0064
49023	816.1	0.0944	0.0002	0.0044

The graphical representation of the effect of temperature on CO_2, CO and Coke is shown in figure 4 and 5 while that of Air flow rate to CO_2, CO and Coke are shown in figure 6 and 7.

Once the catalyst is free of coke in the beginning of the simulation, there is a lack of energy generation and the temperature of the regenerator reduces (Fig.4 and 5). In this initial period, the amount of coke within the regenerator increases (Fig.5) and reaches its maximum value 0.4061% at a temperature of 627.7°C. It then reduces to 0.0064% at a temperature of 812.0°C. Coke is maximum at the point the concentration of CO is maximum (Figure 4 and 5).

In the steady state, the temperature is higher at 816.1°C and the CO mole fraction falls to a very small value that can be considered zero (Fig.4). On the other hand, the CO_2level increases with the temperature and its molar fraction stabilizes at 0.0944% (Fig.5).This happens because the constant consumption of oxygen and the temperature elevation that increases the speed of the reaction and favours the complete combustion. The variation of air flow rate was carried out to observe its influence on the combustion condition (partial or total) of the regenerator and the step change of coke fraction to verify the dependence of the regenerator transient behaviour on the step change. Some simulations were carried out with different air flow rates (Fig 6 and 7). In order to evaluate the influence of the inlet air flow on the performance of the regenerator, the simulation was carried out using different air flow rate in a steady state. The results indicate the inlet air flow rate has a direct influence on the combustion, affecting the temperature, species concentration and coke amount. Fig.6 shows the different steady state for distinct values of inlet air flow rates. As seen in Fig 7, the temperature increases to a maximum value and the CO concentration reduces to zero as the air flow rate increases. At the maximum temperature, the regenerator operation has reached its total combustion regime. Analysing the composition of the gases, one can see from partial to total combustion takes place above an air flow rate of 48023kgmole/hr.

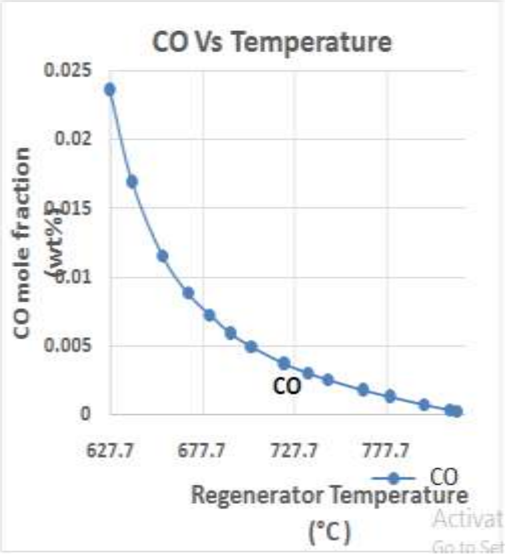

Figure 4: Effect of Temperature and CO mole fraction.

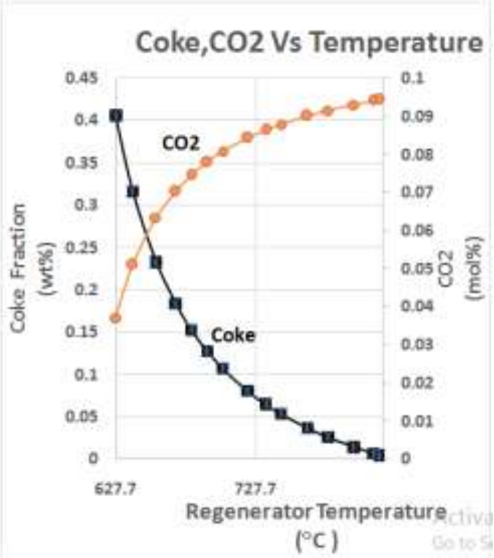

Figure 5: Effect of Temperature and CO_2 mole fraction on Coke.

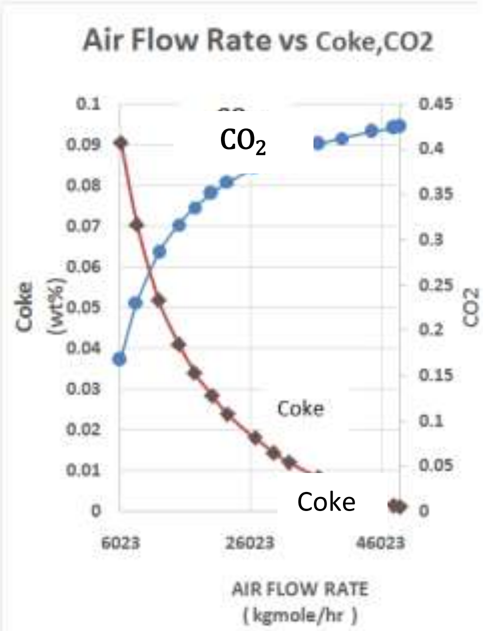

Figure 6: Effect of the air flow rate on the Coke burnt and CO_2 mole fraction.

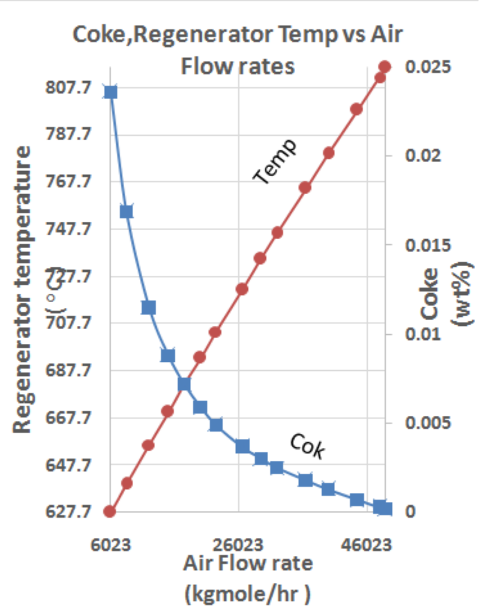

Figure 7: Effect of the air flow rate on Coke burnt and Temperature.

3.2. COMPARING PREDICTED RESULTS WITH AVAILABLE PLANT DATA

At the time of this study, there was no information about predicted results with other softwares in the open literatures and so the predicted results using the Aspen Hysys were compared with plant data. Table 7 shows the compared parameters. The predicted simulation results are obtained from table 6 while the plant data are obtained from PHRC.

The deviation of the predicted results from the plant data as shown in table 7 is very small: 68.54 ^{o}C for regeneration temperature; -0.0006 wt% for Coke; -0.0656 wt% for CO_2; 0.03214 mol.% for O_2 and 0.0003 mol.% for CO. This implies that simulation results using the Aspen Hysys can be used to predict regeneration parameters if experimental data is not available.

Table 7: Comparison between plant data of PHRC and Predicted simulation results

Parameter	**Plant data (P)**	**Simulation prediction (S)**	**Deviation (P-S)**
Regenerator temperature (°C)	743.46	812.0°C	68.54
Coke (wt%)	0.007	0.0064	-0.0006
CO_2 (mol.%)	0.16	0.0941	-0.0656
O_2(mol.%)	0.003	0.03514	0.03214
CO (mol.%)	0	0.0003	0.0003

IV. CONCLUSION

The FCCU regenerator was studied using the Aspen hysys. The simulation results for various parameters profiles were obtained. The predicted results from the Aspen Hysis were compared with data from PHRC and there was a very good agreement which is an indication that the Aspen Hysys can be used to predict the regenerator parameters even when there are no experimental results.

V. NOMENCLATURE

Regen	Regeneration
Temp	Temperature
PHRC	Port Harcourt Refining Company
CAT	Catalyst
E-cat	Equilibrium Catalyst
REN.CAT	Regenerated Catalyst
SPENT CAT	Spent Catalyst
REGEN AIR	Regenerator Air
VLV	Valve
CAT	Catalyst
RCY	Recycler
RENCIR	Recycled Spent Catalyst
CO_2	Carbon (iv) Oxide
CO	Carbon (ii) Oxide
FCCU	Fluid Catalytic Cracking Unit
NPHRC	New Port Harcourt Refining Company

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