SIMULATION OF A FLUID CATALYTIC CRACKING REGENERATION UNIT

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ABSTRACT

There is an ever increasing demand for high quality yields and products from chemical processes. Chemical processes are very complex to undusted design and operate. In the petroleum refinery systems, the regenerators of the fluid catalytic cracking unit play key roles. The reactor-regenerator system is the main facility. The activation of the spent catalyst takes place in the regenerator. A model of the regenerator that adepts two phase theory of the regeneration of the spent catalyst has been presented using Aspen Hysys version 8.4. The model is based on its temperature, and pressure conditions and flow rate of the air. The profiles of the quality of the burnt coke, air flow rate, flue gas compositions are presented. These parasites were compared with practical data from a Nigerian refinery.

Keywords: *FCC regenerator, Hysys, modeling, optimum conditions.*

INTRODUCTION

In fluid catalytic cracking units, the cracking reactor produces light gas oil, fuel gas and coke. The coke is deposited on the surface of the catalyst. The coke deposition reduces the available area of the reactants and catalyst. The catalyst is deactivated. The catalyst is sent to the regenerator where its activity is restored. Air is injected into the regenerator and forms a non-homogeneous fluidised bed with the catalyst. The coke on the surface of the catalyst is burnt off in the bed. The burning of the coke provides the regeneration of the catalyst, restoring the catalyst activity and also increases the temperature of the catalyst which provides energy to the cracking process when it returns to the riser. Several authors have conducted studies on the modeling and simulation of the regeneration process. False-saravalou and vasalos (1991) presented a dynamic model of the bed with a rigorous hydrodynamics description. They described the devise bed as two phases, bubbling and emulsion. They modeled the dilute bed above the dense phase as one dimensioned flow reactor. Guigon and Large (1994) applied two phase model to a regenerator. Marcel et al (1996) explored the influence of the air jet at the feed gril. Ali et al (1997) assumed that the carbon monoxide combustion taking place in the bubble phase was negligible compared with carbon monoxide reaction of coke combustion occur in the emulsion of regenerator. Dagede and Pyate (2013) presented predictive models for the process parameters during the regeneration of the spent catalyst in an industrial fluid catalytic cracking unit. They decided the dense region of the regenerator into a bubble phase and an emulsion phase. The bubble phase was modeled as a plug flow reactor (PFR) and the emulsion phase as a continuously stirred tank reactor (CSTR). They provided profiles for the temperature of the regenerator, quantity of coke burnt and flue gas composition. They reported that there was good agreement of the model prediction and practical data. The study is aimed at the simulation of a regenerator of an FCC Unit using Aspen Hysys version 8.4.

Simulation Procedures

The simulation was performed using Hysys version 8.4. The steady state simulation of the full fluid catalytic cracking unit was carried out and convergence achieved. The regenerator unit was then selected for running rigorous simulation. The components were selected and the selection of the thermodynamic model, the types of reactions were stipulated and operating units were chosen and the setting up of the input conditions. The input conditions included the flow rate, temperature, pressure and catalyst blend information. Peng Robinson model was used to predict the activity coefficients of the components in the liquid and vapour phases. The reaction sets were created from the kinetics of the main reactions: the combustion of coke to form carbon dioxide, carbon monoxide and the conversion of the carbon monoxide to carbon dioxide.

$$C + 0_2 \rightarrow C0_2 + Heat \quad (1)$$

$$C + ½\, 0_2 \rightarrow C0 + Heat \quad (2)$$

$$2C0 + 0_2 \rightarrow 2C0_2 + Heat \quad (3)$$

The irreversible coke combustion reactions were assured to occur in the emulsion phase of the dense region of the regenerator. Coke is a mixture of different components like carbon, hydrogen and nitrogen but it is considered to be mainly carbon in the regenerator (Rao et al 2004). The carbon monoxide combustion taking place in the bubble phase is assumed to be negligible in compassion with carbon monoxide combustion in the emulsion phase. The rate expression for the combustion gases in the emulsion phases were adopted from literature. The kinetic parameters of coke burning reactions for zeolite catalyst were applied to simulate the industrial Fluid catalytic cracking regenerator. The Kinetic parameters for the coke burning reactions for zeolite catalysts were applied to simulate the regenerator and are given in Table 1

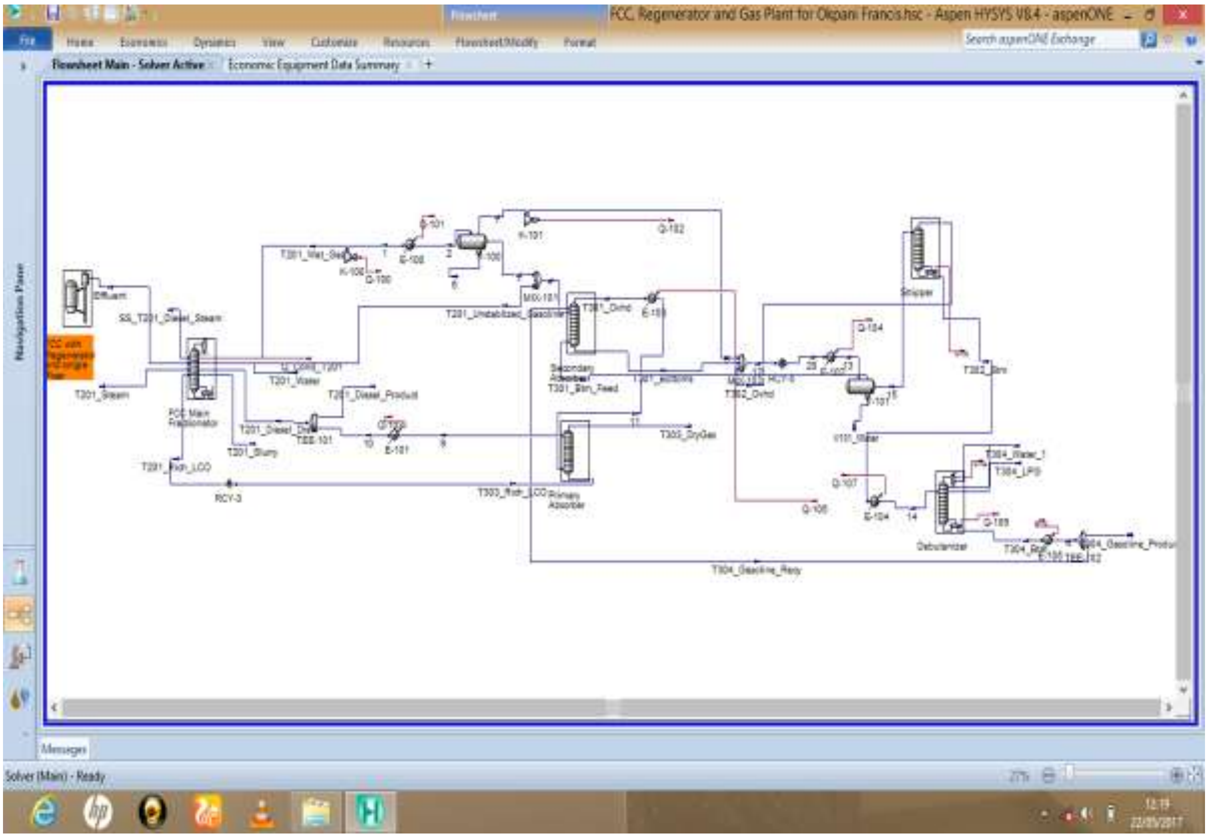
Table 1: Kinetic Parameters for Coke Burning

Reaction	Pre-exponential Constant	Activation Energy(kj/kmol)
Coke burning, K_C	$1.4 \times 10^8 m^3 kmol^{-1} s^{-1}$	224.99
CO catalytic combustion, K_{CO}	$247.75 (m^3)^{1.5} kmol/s^{-1} kg^{-1}$	70.74

The air distributor, spent catalysts and cydrone recycle pipes in the emulsion phase were assumed to produce enough turbulence that justified the phase to be modeled as CSTR. The reaction sets were coupled with the thermodynamic model. The model required inputs into the regenerator were the rate of circulation of the catalyst, air inlet temperature, pressure, dense bed temperature, and coke on spent catalyst and the coke on regenerated catalyst. The regenerator temperature was varied to examine the effects on the catalyst regeneration, composition of flue gases, per flow rate and riser outlet temperatures.

RESULTS AND DISCUSSION

Figure 1 shows the Converged Model of FCC regenerator and the gas separation section of the unit.



The regenerator conditions at the steady state are given in Table 2

Table 2: Regenerator parameters on steady state conditions

Catalyst Circulation Rate (tonnes/hr)	2103
Air inlet Temperature (°C)	378
Pressure (kpa)	300
Dense Bed Temp (°C)	745.5
Coke on spent catalyst (%)	0.81
Coke on Regenerated catalyst (%)	0.01

In the simulation, the inlet spent catalyst and air flow rates were considered constant and the regenerated catalyst flow rate taken as equal to the inlet flow rate. The gas flow rate control the pressure within the regenerator.

The results of the sensitivity analysis regarding the air flow rates and the coke fraction in the catalyst are shown in Table 3.

Table 3: Variations of Quantity of Coke burnt and Regenerator-temperature with Inlet-air Temperature

Air Blower Temp (°C)	Regenerator Temp (°C)	Coke on Spent Catalyst %	Coke on Regenerated Catalyst %	Catalyst Flow Before Reg [tonnes/hr]	Catalyst Flow rate After Reg [tonnes/hr]
200	745.5	0.77	0.05	2088	2103
250	752.1	0.77	0.04	2019	2033
400	772.8	0.78	0.03	1831	1845
600	802.3	0.81	0.02	1615	1627

The variables were chosen because of their direct influence on reaction rates (Dagde and Puyate 2013).

The variation of air flow rate was conducted to observe its influence on the combustion (partial or total) in the regenerator.

Figure 2 shows the variation of the composition of the flue gases on the air flow rates.

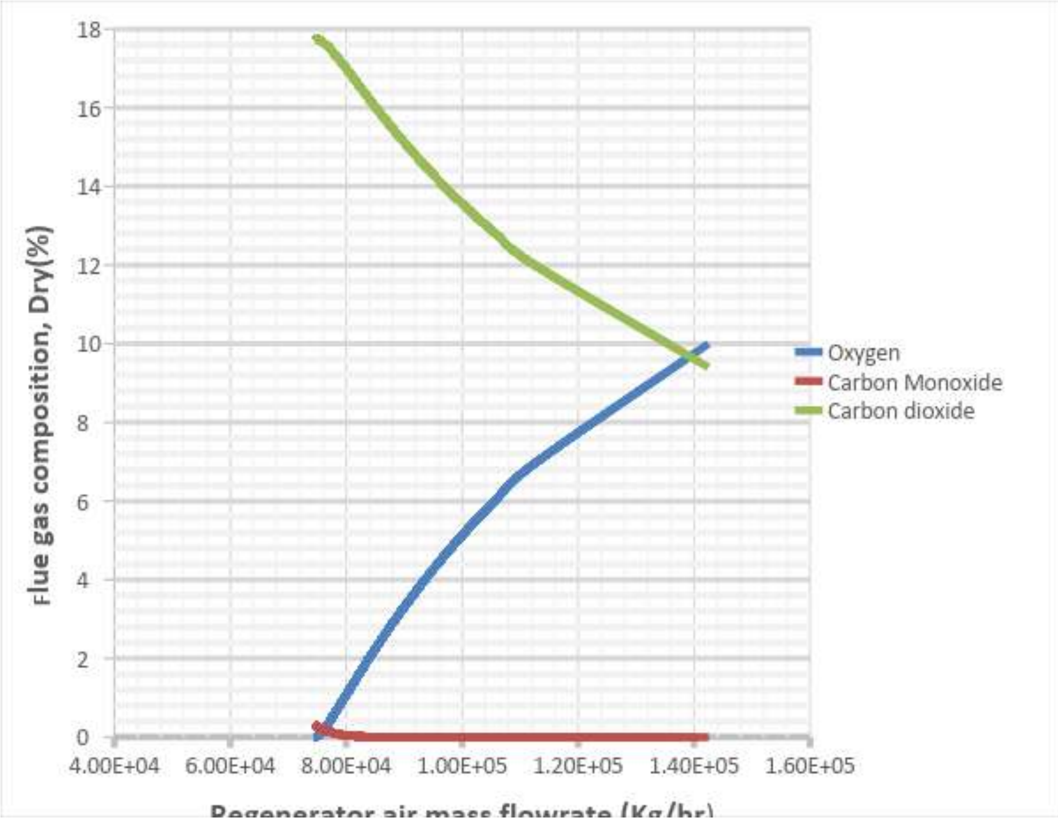


Figure 2: Variation of Flue Gases Composition with Air Flow Rates

The figure shows that air flow rate has influence on the combustion process. At a regenerator air flow of 7.5E+04 kg/hr the Concentration of carbon monoxide fall to a very small value that can be considered zero. On the other hand, the carbon dioxide concentration increases with the air flow rate but the oxygen concentration decreases. These occurrences indicate complete combustion process in which there is no carbon monoxide in the exiting flue gases and the oxygen is being used up with the formation of predominately carbon dioxide.

Figure 3 shows the sensitivity of coke on the spent catalyst with the temperature at the riser outlet temperature. There is a decrease in the quantity of coke on the spent catalyst with increase in temperature at the outlet of the riser.

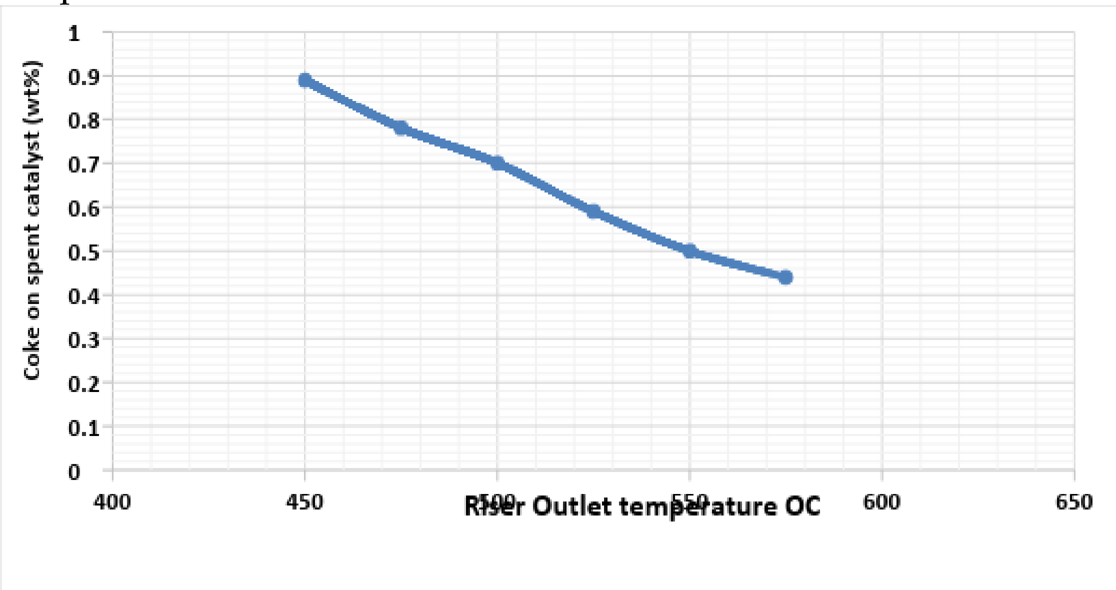


Figure 3: Variation of Quantity of Coke on Spent Catalyst with Riser Outlet Temperature

Figure 4 shows the effect of the regenerator temperature on the quantity of coke on the regenerated catalyst. It indicates that at about 750 °C, the coke has been completely burnt off A temperature beyond this value may result in the excessive heating of the catalyst particles. Hence care should be taken to ensure that the temperature in the regenerator is not above this value.

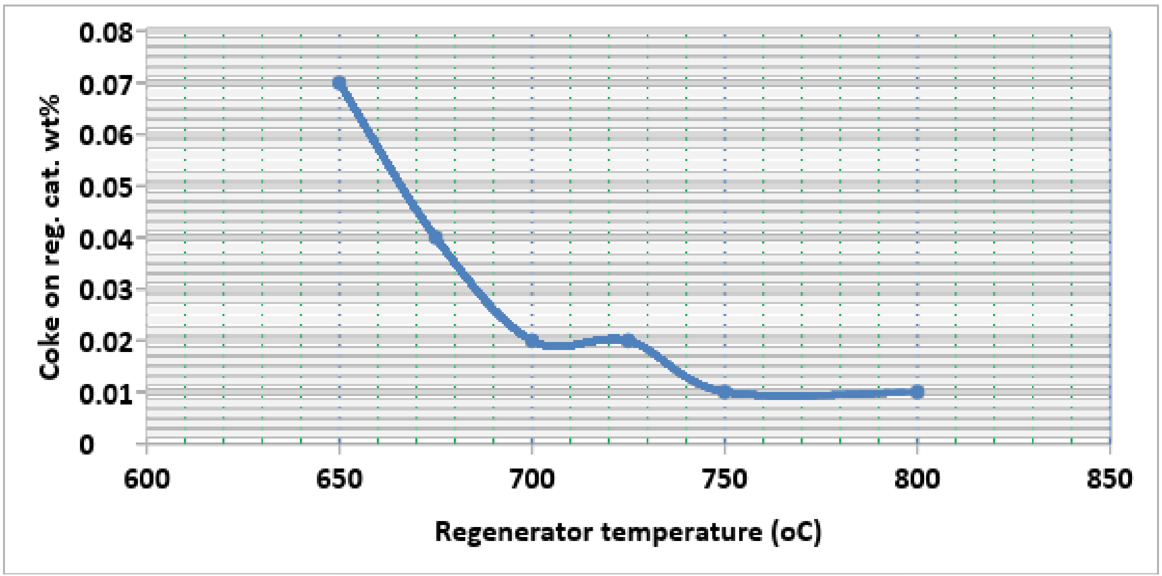


Figure 4: Variation of Quantity of Coke on Regenerated Catalyst with Regenerator temperature.

CONCLUSION

A catalytic regenerator in a Nigerian refinery has been simulated using Aspen Hysys version 8.4. The results show that the air inlet temperature and flow rate , and the temperature of the spent catalyst influenced the performance of the regenerator. The operating conditions were found to be environmentally friendly as the level of concentration of carbon monoxide was very low. The converged model was able to satisfactorily reproduce the performance of the regenerator data. These simulated data provide important tool for the operation and modification of operation and control of the regenerator.

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