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ENHANCED DIESEL PRODUCTION VIA MODELLING AND SIMULATION OF CRUDE DISTILLATION UNIT II OF KADUNA REFINING AND PETROCHEMICAL COMPANY

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ABSTRACT

Human activities in the world has increased due to the growing population of people and commercial activities which results in the demand growth for diesel heavy trucks in the delivery of goods. This study was carried out to investigate suitable operating conditions that would yield higher diesel production and minimum residue using the crude distillation unit II of Kaduna Refining and Petrochemical Company (KRPC) as a case study. The virtual representation of the process was modelled successfully using design procedures and operational data of crude distillation unit of KRPC while the Aspen Hysys 2006 process simulator was used to simulate the unit using Venezuelan crude oil as the feedstock. A rigorous analysis was made on operating conditions such as the temperature and diesel steam mass rate that led to the optimization of the unit based on some key parameters. After successfully simulating the crude distillation unit of KRPC, the optimum feed temperature was found to be 290 °C and the diesel obtained was 94360.34 kg/hr as compared to 313.2 °C and 80678.10 kg/hr normally obtained at the KRPC. This showed about 13.2 % increase in diesel yield.

Keywords: Aspen Hysys, CDU, Optimization.

INTRODUCTION

Since 1998, diesel demand in the World market has increased by approximately 40% (EIA, 2019; Gollarkota et al., 2018), and is expected to continue increasing as distillate margins outperform gasoline in the long term. In addition, the heavy use of transportation trucks and diesel generators necessitates refiners to evaluate their processing options towards enhanced diesel production. Primary processing of oil gives fraction such as gas, gasoline, kerosene, gas oil, atmospheric residue, light gas oil (LGO), heavy gas oil (HGO) and heavy residue (Stojic et al., 2004). The quantity of each fraction is specified by the composition of crude oil. The main parts of this process are the pre-flash, atmospheric, and vacuum distillation units. Due to the complex nature of the refining operation, petroleum refining planning activities demand accuracy in the modelling of petroleum refinery processes since the results from planning models should be realizable in the refinery operation (Kumar et al., 2001). However, accuracy of products yield and quality prediction in petroleum refinery planning models is a difficult task because of the extremely complex economics of petroleum refinery and inherent nonlinearity of refinery process (Bhowmik et al., 2009). Crude distillation is one of the most important process units in any refinery. It is comprised of side strippers, pump-arounds and a large number of equilibrium stages. The CDU fractionates crude oil into different products such as light ends naphta, kerosene, diesel and atmospheric residue. Some of these products can be sent to the blending system directly (depending on its quality and the finished products specification) or can be processed in refinery downstream units to convert them into more saleable products (Liebmann, 1995). Petroleum refineries are trying to process different variety crude oil from different sources in order to drastically reduce separation costs. This modification is explained by the availability of uncertain crude quality in the market at a given moment and the change in quality of crude from traditional sources. This is one of the reasons to retrofit oil refineries, to increase CDU flexibility to crude quality (Wang et al., 2016). Therefore, several steps are needed to build a correct simulation model. These steps include a good knowledge of the chemical components and their respective compositions, a correct thermodynamic model, definition of the process scheme with all the unit operations and operating conditions (Himmelblau, 2001). A well-tuned model can be used to optimize the operating variables. After the simulations, the results can then be tested in real conditions to test the model validity. These type of models are applicable in checking the validity of certain revamp options, which can alternatively be checked by detailed engineering companies or process licensors (Himmelbau and Thomas, 2005). Without the help of this type of process simulator, optimization can only be achieved by manipulating the operating parameters using trial and error during the plant operation. This could result in huge risks, losses in production and/or product quality. Therefore, there is a need to come up with a model of CDU II of the KRPC that would give the best processing option for a higher diesel production so as to complement the global demand and gain more profit. This paper is aimed at modelling the CDU II of the KRPC using design and operational data obtained from KRPC, and subsequently simulating the results towards enhanced diesel production using Aspen Hysys simulator.

MATERIALS AND METHODS

Process Simulation Procedure

Aspen Hysys process simulator was used for simulation of the Crude Distillation Unit II (CDU I). Peng Robinson model was selected as the thermodynamic model because it is the most suitable model for refining operations. The CDU II was simulated based on 52 trays. The following steps were adopted as follows:

1. Data Collection: Operating Data, Design data and Piping and Instrumentation Diagram of Crude Distillation Unit (CDU) of Kaduna Refinery and Petrochemical Company (KRPC) were obtained from KRPC.
2. Constructing a Crude Distillation Column Model in a Process Simulator: Building the crude distillation column and the side operating equipment of crude distillation column model of KRPC in Hysys using the data collected in 1 above.
3. Computer Simulation: Computer simulation of the model was carried out using Hysys.

Characterization of Crude Feed

The petroleum characterization in Aspen Hysys accepts different types of information about the oil. There are three steps involved in characterizing any oil in HYSYS: Characterize the assay, generate hypo-components and install the oil in the flow sheet.

Characterization of the Petroleum Crude Assay

The assay contains all of the petroleum laboratory data, boiling point curves, light ends, property curves and bulk properties as shown in Table 1. Assay data was used to generate internal True Boiling Point (TBP), molecular weight, density and viscosity curves (referred to as working curves). The TBP assay fraction was obtained from KRPC as presented in Table 2.

Table 1: Input Assay Properties

Option	Selection
Bulk properties	Used
Assay data type	TBP
Light ends	Input composition
TBP Distillation conditions	Atmospheric

Table 2: TBP Assay Fraction

Assay Percent	Temperature (°C)
0.00	-12
4.00	32
9.00	74
14.00	116
20.00	154
30.00	224
40.00	273
50.00	327
60.00	393
70.00	450
76.00	490
80.00	516

As the assay was calculated, the working curves were generated, regressed and extrapolated from the assay input. From the user-supplied data, HYSYS generated curves for NBP, molecular weight, mass density and viscosity. The working curves were subsequently used in determining the properties of the hypo-components generated in the blend step. Components such as pre-fractionation train, pre-flash separator, crude furnace, mixer and side stripper columns were installed into the object palette.

A summary of the crude feed input specification is shown in Table 3.

Table 3: Crude Feed Input Specification

Stream Name	Venezuelan Feed
Temperature (°C)	254
Pressure (kPa)	116.5
Std Ideal Liq Vol Flow (m^3/hr)	662.4
Molar Flow (kgmole/hr)	2816
Molar Enthalpy (kJ/kgmole)	-3.291×10^5
Heat Flow (kJ/hr)	-9.627×10^8
Fluid Package	Peng-Robinson

The parameters for the equipment sizing of the CDU II as shown in Table 4 were run in the HYSYS package which generated a total of 52 trays equivalent to that in KRPC.

Table 4: Equipment Sizing of the CDU

Section diameter (m)	3.754
Max Flooding (%)	87.58
X-Sectional area (m^2)	24.82
Section height (m)	33.08
Section delta p (kPa)	23.93
Number of flow paths	3.15
Flow length (mm)	1586.87
Flow width (mm)	4852.93
Max DC Back up (%)	50.55
Max Weir load (m^3/h.m)	48.25
Max Dp/Tray (kPa)	1.28
Tray spacing (mm)	640.08
Total weir length (mm)	13685.50
Weir height (mm)	53.34
Active area (m^2)	22.00
DC Clearance (mm)	40.00
DC Area (m^2)	1.41
Side weir length (m)	2.73

RESULTS AND DISCUSSION

Mass and Energy Balance

A summary of material balance across the distillation column is presented in Table 5 based on input data. The result obtained shows that feed rate to the column is 574642.68 kg/hr, while the products recovered from the column was found to be 574642.68 kg/hr. This suggests that a balanced material distribution was achieved across the column. In addition, diesel production shows a significant output production of 94332.9 kg/hr which accounts for about 16.4% of output production. Similarly, Table 6 shows the energy balance across the distillation column. Both feed and product streams were found to have a balanced energy distribution with -823470884 kj/hr. The occurrence of negative energy balance implies that more energy was given out than taken during the distillation process (Hill et al., 2013)

Table 5: Mass Balance across CDU II

Streams	Input (kg/hr)	Output (kg/hr)
Buttom steam	3401.98	0
Hot crude	569506.71	0
Diesel steam	600	0
AGO Steam	1134	0
Residue	0	275834.88
Napthta	0	100080.94
Off gas	0	0.0242
Waste H_20	0	4867.08
Kerosene	0	70139.52
Diesel	0	94332.92
AGO	0	29387.31
Total	574642.68	574642.68

Table 6: Energy Balance across CDU II

Energy Stream	Input (kJ/hr)	Output (kJ/hr)
Buttom steam	-44544429.78	0
Hot crude	-847263297.90	0
Trim duty	83235485.32	0
Kero SS_Energy	7912131.65	0
Diesel Steam	-7893034.99	0
AGO Steam	-14917738.26	0
Residue	0	-411678582.90
Cond duty	0	71582212.71

Naphtha	0	-208127840.30
Off gas	0	-80.09
Waste H2O	0	-75818194.11
Kerosene	0	-121718839.10
Diesel	0	-163256141.00
AGO	0	-46334827.80
PA_1_Q	0	58028085.38
PA_2_Q	0	36926963.43
PA_3_Q	0	36926963.43
Total Energy	-823470884	-823470884

Effect of Process Conditions

The temperature profile across the column stages of the CDU II was represented as shown Figure 1. It was observed that temperature increases from 86.13 °C to 305.4 °C down the column from the condenser to the reboiler. On the other hand, the pressure profile across the column increases from 135.8 kPa to 225.5 kPa from the condenser to the reboiler as shown in Figure 2. This is in conformity with literature which suggests that temperature profile across the stages down the column increases with temperature (Chiyoda, 1980). In addition, fluids closer to the reboiler are expected to be hotter resulting in formation of vapour phase products which travel upwards towards the condenser. This corresponds to the net vapour volume which increased from 400 m^3/hr to 1450 m^3/hr as shown in Figure 2. It can also be observed that at stage 49 of the column, temperature peaked at 371 °C which corresponds to the reboiler temperature. The profiles observed clearly shows an increasing pattern with column stages.

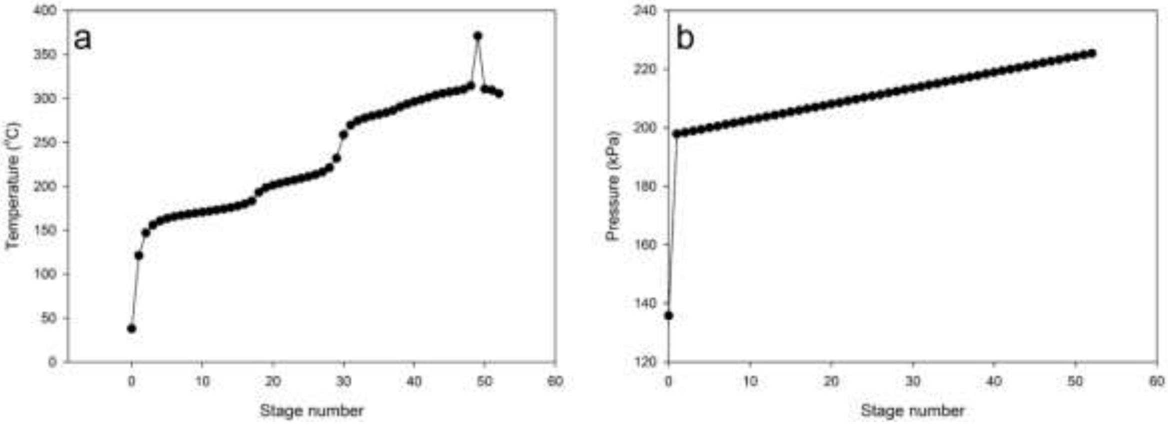

Fig. 1: Profile across CDU Column Stages for a) Temperature and b) Pressure

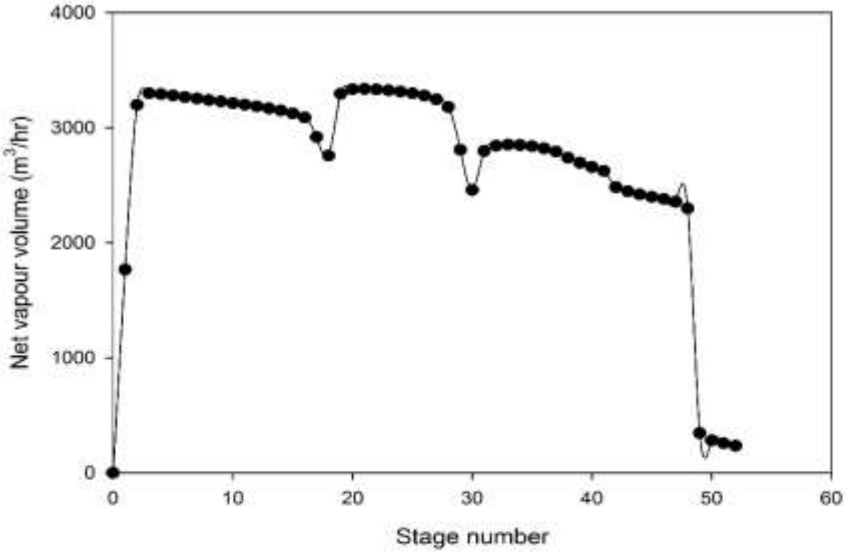

Fig. 2: Net Vapour Volume across the CDU column stages

Figure 3 shows the influence of temperature between 250 and 320 °C towards higher diesel production. A slight increase in diesel production was observed when temperature was increased from 250 to 290 °C before subsequent drop was observed. At 290 °C, the highest amount of diesel obtained was 94360.342 kg/hr which corresponds to stage 49 of the CDU column at diesel cut point of 340.2 °C (Figure 1). Subsequently, the amount of diesel obtained from simulation result shows an improved 13.2 % yield when compared to 80678.1 kg/hr of diesel normally produced at KRPC. This improvement suggests that the production of diesel from CDU II in KRPC is below optimal output.

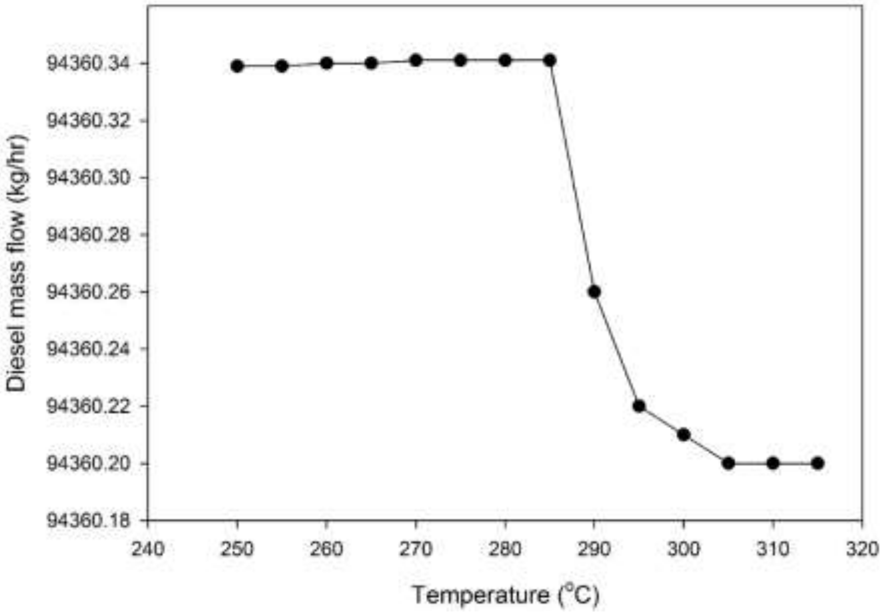

Fig. 3: Effect of Increasing Feed Temperature on Diesel Mass Flow

The sensitivity of diesel steam rate on the production of diesel is shown in Figure 4. As diesel steam rate was increased from 650 to 750 kg/hr, diesel production rate increased from 94342.48 to 94355.99 kg/hr which shows an insignificant increase of less than 1 %. This suggests that increasing the rate of diesel steam during the CDU process does not contribute much on the overall diesel production.

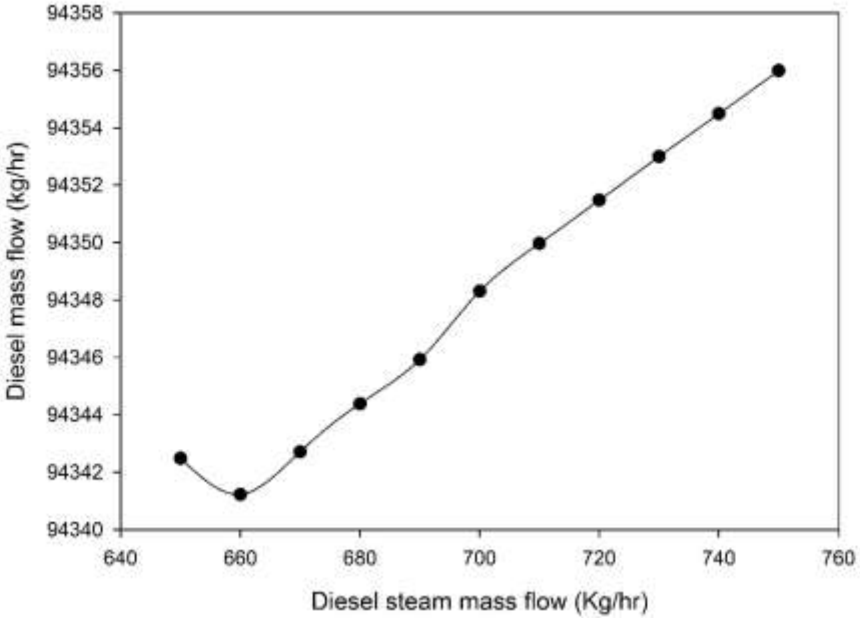

Fig. 4: Effect of Diesel Steam Flow on Diesel Mass Flow

CONCLUSION

Crude distillation Unit (CDU II) of Kaduna Refining and Petrochemical Company was successfully modelled and simulated based on its design and operational data using Venezuelan crude and Aspen Hysys simulator. The work optimized operating conditions of the unit was based on the increase in production rate of diesel. The optimized results obtained showed that a feed temperature of 290°C, diesel cut oint of 340.2 °C and a feed tray position of 32, the diesel obtained was 94360.3 kg/hr as compared to 8068.1 kg/hr normally obtained at KRPC, which shows an improved diesel yield of 13.2%.

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