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EFFECTS OF OPERATING PARAMETERS - FLOWRATE AND TEMPERATURE ON PRODUCTS OF CRUDE DISTILLATION UNIT

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Abstract: The aim of this study is to determine the effect of flow rate and temperature of the feed (crude oil) on the products of the crude distillation unit (CDU). Crude oil ASSAY, operating conditions of the various units involved, and other essential data were collected from Kaduna Refining and Petrochemical Company (KRPC) and entered into the simulation software (ASPEN HYSYS V8.8) to generate the Crude Distillation Unit (CDU) model. This unit models a crude oil processing facility consisting of a pre-fractionation train used to heat the crude liquids, and an atmospheric crude column to fractionate the crude into its straight run products. The feedstock to the crude system is the ESCRAVOS LIGHT Nigerian crude oil. The higher the feed flow rate, the higher the products feed flow rates. The simulation converged and the results was studied. The crude column used is a refluxed absorber, equipped with three pump arounds and three side stripper operations. Three temperatures; 370^{o}C, 380^{o}C, 390^{o}C and three flowrates; 393 m3/hr, 500 m^3/hr, 700 m^3/hr were varied. KRPC operates at 370^{o}C and 393 m^3/hr. After the simulation, there was no convergence at 370-C/393 m^3/hr, 3+C/ 500 m^3/hr. At 380^{o}C and 700 m^3/hr, Atmospheric Residue had the highest flowrate of 378.48 m^3/hr followed by Diesel and Naphtha with 128.88 m^3/hr and 104. 30 m^3/hr respectively. Kerosene had 64.10 m^3/hr while (AGO) had the lowest flowrate of 30.69 m^3/hr. 29 stages was needed for the column convergence and the feed entered at the 28th stage.
Keywords: ASPEN HYSYS v8.8, CDU, simulation, operating parameters.

1. INTRODUCTION

Distillation is one of the most common separation processes employed in separating a liquid mixture of different components based on their relative volatilities or differences in their boiling points (Anderson, 1998). The deterioration of the petroleum industry has become a major challenge in Nigeria. A good step towards tackling this issue is simulation studies of the process. Simulation has become an important tool in the performance of major chemical processes. Modeling and simulation are important in engineering because description of system behavior by experimentation might not be feasible due to inaccessible inputs and outputs, very high experimentation cost, experimental behavior might be obscured by disturbances and/or time constants of the system may not be compatible with human dimensions. Modeling also enables the manufacturers to understand the process behavior and to determine the optimum operating conditions of the process for high output at low cost (Shankar *et al.*, 2015). Steady state simulation softwares such as PRO II, SPEEDUP, SimuSolv, ASPEN Plus are some of the widely used applications in the chemical and hydrocarbon industries (Himmeblau, 2001). The case study for this research is the Kaduna Refining and Petrochemical Company (KRPC), which was initially designed to process 100,000 Barrels per Stream Day (BPSD). The Crude Distillation Unit –I was originally designed to process 50,000 BPSD or 331 m3/hr of Nigerian Crude. The capacity was

expanded to 60,000 BPSD (398 m3/hr) in 1986. It processes Escravos light crude oil and Ughelli Quality Control Centre (UQCC) crude oil. (Jibril *et al*, 2012). In this research, only the Escravos light crude was considered. Crude Distillation Unit is a basic distillation process for crude oil. It takes advantage of one of the physical characteristics of each hydrocarbon, its boiling point. The study explained development of crude column model starting from crude oil characterization then followed by the steady state modelling. Atmospheric Crude Columns are one of the most important pieces of equipment in the petroleum refining industry (Liebmann and Dhole, 1995). The process in the units involves passing the crude oil through preheat trains of exchangers, a desalter (to remove salt and metals that could cause corrosive damage or catalyst deactivation in downstream units) and a preflash drum prior to the main distillation. The liquids are then heated to 380^{o}C in the furnace and sent to the Atmospheric Distillation Unit (ADC). Most distillation systems were designed on the basis that they operate at almost constant pressures. The Atmospheric Unit distills the crude oil into various cuts like naphtha, kerosene, light diesel, heavy diesel, and Atmospheric Gas Oil (Chiyoda, 1980). The crude column is a refluxed absorber, equipped with three pump-around and three side stripper operations (Chiyoda, 1980). A flow sheet model developed as a collection of Sub-flow sheets are connected through streams. Within each Sub-flow sheets are a collection of unit operations and streams that are appropriate to be solved together (Box, 1965). The rapid growth in demand and usage of crude oil and its products in industries such as pharmaceuticals, petrochemicals, etc. has caused a limited supply in the global market. Steady state modelling of a crude distillation unit is necessary to study and obtain a high efficiency refining process which can increase the yield of the petroleum product. The research aimed at studying the effect of flowrate and temperature on the products of crude distillation unit (CDU), and it was achieved by developing a steady state model of a CDU and comparing the results with past researches. To achieve these objectives, the scopes were: to develop model based on the overall material balance equation, component balance equation, liquid and vapor summation equation amongst others. The crude oil has a standard liquid density of 849.51 kg/m3, signifying it is a light crude.

2. MATERIALS AND METHOD

2.1 Procedure

1. Collection of Data: Design data, Operating Data and Piping and Instrumentation Diagram of Crude Distillation Unit (CDU) of Kaduna Refinery and Petrochemical Company (KRPC) were collected 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 constructed in 2 was carried out using Hysys.

2.2 Crude Oil Characterization

The crude oil used was first characterized by the HYSYS v8.8 software, beginning with analysis of the True Boiling Point (TBP) data for the given crude oil as described by Kumar *et al*. (2013). Assay properties comprising refinery related properties such as cloud point, octane numbers, flash point, freeze point, Sulphur content, Paraffins, Olefins, Naphthenes and Aromatics (PONA) distribution, Gas Chromatography (GC) data etc. The light ends data input is shown in Table 1. The TBP distillation data for the crude oil used (Escravos Light Nigerian crude) is shown in Table 2. Figure 1 shows the product cut distribution for the crude.

TABLE 1: Light ends input data.

Light ends	Liquid Volume (%)
Methane	0.000
Ethane	0.137
Propane	0.220
i-butane	0.143
n-butane	0.433
i-pentane	0.434
n-pentane	0.647

TABLE 2: TBP distillation data (Liq Vol %)

Assay (%)	Temperature [°C]
0	-79.103
5	71.134
10	98.671
30	200.218
50	282.824
70	376.954
90	535.153
95	602.553
98	890.941

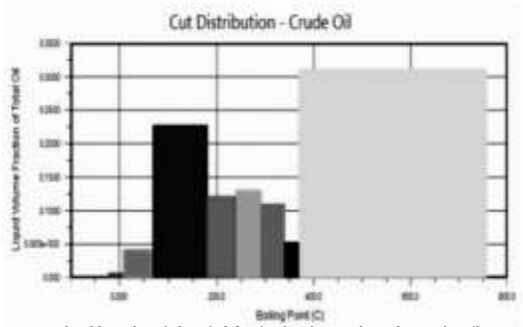

Figure 1: Product Cut Distribution for Crude Assay

After adding the pure components (methane, ethane, propane, n-butane, i-butane, n-pentane, i-pentane and water), the thermodynamic property package was added for the Vapor-Liquid Equilibrium (VLE) calculations and the TBP curve was generated.

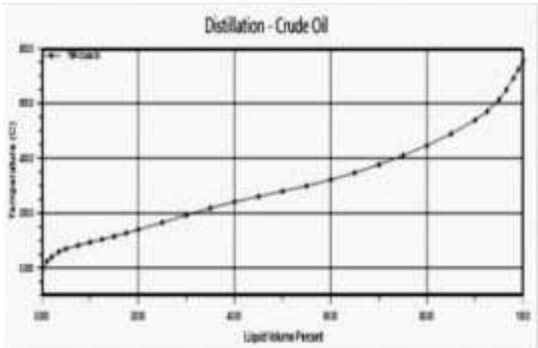

Figure 2: Escravos Light TBP curve

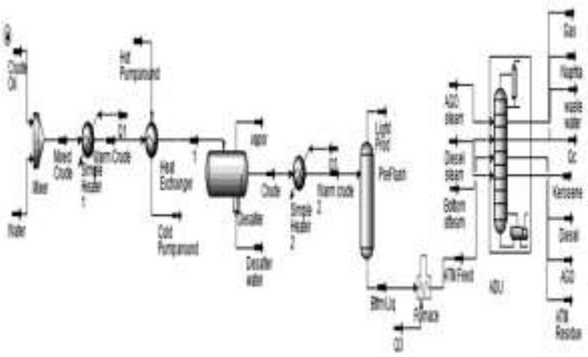

Figure 3: Steady State model for crude distillation unit

2.3 Steady State Model Development

The steady state model provides the complete material and energy balance across the flow scheme. Properties and compositions of all products and intermittent streams can also be derived using the model. After the essential data has been filled in the basis environment, the flow scheme was developed in the simulation environment as shown in Figure 3. The steady state model converged to an optimum solution (380^{o}C and 700 m3/hr).

3. RESULTS AND DISCUSSION

Table 4: Naphtha Product stream properties

Properties	Base case
Vapour / Phase Fraction	0.0000
Temperature [C]	33.10
Pressure [kPa]	140.0
Molar Flow [kgmole/h]	643.6
Mass Flow [kg/h]	7.423 e+004
Std Ideal Liq Vol Flow [m3/h]	104.3
Molar Enthalpy [kJ/kgmole]	-2.532e+005
Molar Entropy [kJ/kgmole-C]	214.4
Heat Flow [kJ/h]	-1.630e+008

Table 5: Kerosene Product stream properties

Properties	Base case
Vapour / Phase Fraction	0.000
Temperature [C]	270.4
Pressure [kPa]	208.6
Molar Flow [kgmole/h]	250.9
Mass Flow [kg/h]	5.002e+004
Std Ideal Liq Vol Flow [m3/h]	64.10
Molar Enthalpy [kJ/kgmole]	-3.044e+005
Molar Entropy [kJ/kgmole-C]	700
Heat Flow [kJ/h]	-7.637e+007

Table 6: Diesel product stream properties

Properties	Base case
Vapour / Phase Fraction	0.0000
Temperature [C]	282.8
Pressure [kPa]	217.1
Molar Flow [kgmole/h]	387.6
Mass Flow [kg/h]	1.051e+005
Std Ideal Liq Vol Flow [m3/h]	128.9
Molar Enthalpy [kJ/kgmole]	-4.038e+005
Molar Entropy [kJ/kgmole-C]	1003
Heat Flow [kJ/h]	-1.565e+008

Table 7. Atmospheric Gas Oil (AGO) Product Stream Properties

Properties	Base case
Vapour / Phase Fraction	0.0000
Temperature [C]	317.7
Pressure [kPa]	222.5
Molar Flow [kgmole/h]	71.2
Mass Flow [kg/h]	2.608e+004
Std Ideal Liq Vol Flow [m3/h]	30.69
Molar Enthalpy [kJ/kgmole]	-5.052e+005
Molar Entropy [kJ/kgmole-C]	1449
Heat Flow [kJ/h]	-3.599e+007

Table 8: Atmospheric Residue Stream Properties

Properties	Base case
Vapour / Phase Fraction	0.0009
Temperature [C]	371.5
Pressure [kPa]	230.0
Molar Flow [kgmole/h]	633.9
Mass Flow [kg/h]	3.447e+005
Std Ideal Liq Vol Flow [m3/h]	378.5
Molar Enthalpy [kJ/kgmole]	-6.602e+005
Molar Entropy [kJ/kgmole-C]	2373
Heat Flow [kJ/h]	-4.185e+008

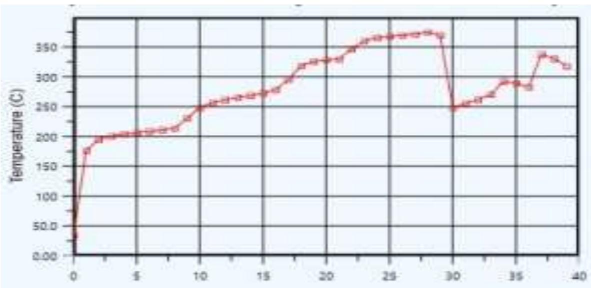

Figure 4: Temperature against stage position at 380oC and 700 m^3hr.

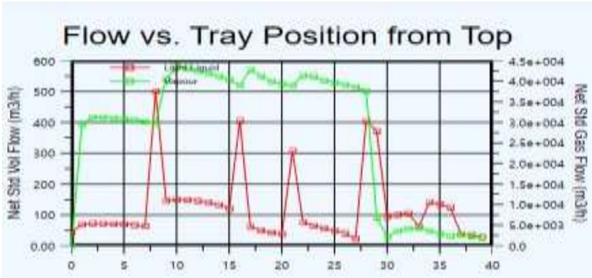

Figure 5: Graph of pressure against stage position

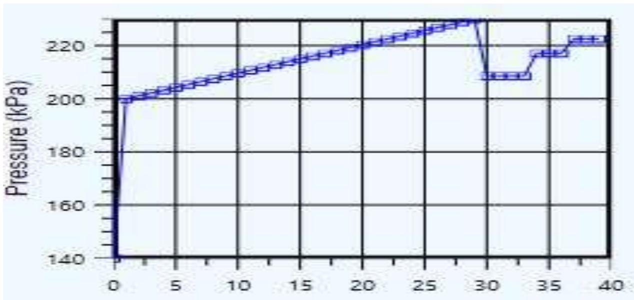

Figure 6: flow vs tray position

The simulated volumetric flow rates with their corresponding temperatures for Naphtha product, kerosene product, diesel product, AGO product and ATM residue product were 104.3 m^3/hr and 33.10°C, 64.10 m^3/hr and 270.40°C, 128.9 m^3/hr and 282.80°C, 30.69 m^3/hr and 317.70°C, and 378.5 m^3/hr and 371.50°C as shown in Tables 3 through 8 respectively. The Vapor Phase fraction for all products is zero indicating that they are completely in the liquid phase.

CONCLUSION

Within the limit of simulation error from the Aspen Hysys v8.8, it was determined that 29 stage columns were needed to achieve a production capacity of 700 m^3/hr (106,600 BPSD) coming as feed at a pressure of 325.0 kPa and temperature of 380°C. A light crude, such as Escravos Light, will produce a high quantity of light products such as gasoline and naphtha, while a heavier crude will produce a higher quantity of heavier products such as kerosene, diesel, and fuel oil. This showed that the Column needed to be optimized in order to convert more of the atmospheric residue into other premium products like diesel, kerosene and naphtha.

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