Simulation of Kaduna Refining and Petrochemical Company (KRPC) Crude Distillation Unit (CDU I) Using Hysys

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ABSTRACT

Optimization of Crude Distillation Unit of Kaduna Refinery and Petrochemical Company was carried out using Hysys Process Simulator. After the simulation, Atmospheric Residue has the highest volumetric flowrates of 313.7m^3/hr while AGO has the lowest with 10.90m^3/hr. Naphtha, Kerosene and Diesel has volumetric flowrates of 129.8 m^3/hr, 42.14 m^3/hr and 164.5 m^3/hr respectively. 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. Preheat crude (from a preheat train) is fed to the pre-flash drum, where vapors are separated from the crude liquids. The liquids are then heated to 350 ^{o}F in the crude furnace. The pre-flash vapors bypass the furnace and are recombined, using a mixer, with the hot crude stream. The combined stream is then fed to the atmospheric crude column for separation. The crude column is a refluxed absorber, equipped with three pump around and three side stripper operations.

Key words: Simulation, KRPC, Crude Distillation Unit, Hysys

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INTRODUCTION

The Kaduna Refinery and Petrochemical Company (KRPC) were commissioned in 1980, with an initial capacity of 100,000 Barrels per Stream Day (BPSD). It has a Fuel Plant Crude Distillation Unit I (CDU I) and a Lube Plant Crude Distillation Unit II (CDU II). The Fuel Plant was designed to process 50,000 Barrels Per Stream Day (BPSD) but was later upgraded to 60,000 Barrels Per Stream Day (BPSD).It processes Escravos light crude oil and Ughelli Quality Control Centre (UQCC) crude oil while the Lube Plant has capacity to process 50,000 Barrels Per Stream Day (BPSD) of imported Paraffin rich crude oil for the manufacture of lubricating oils. The crude oils available in Nigeria cannot produce the whole range of fractions for the production of lubricating oils, hence Nigerian National Petroleum Corporation (NNPC) imports from Venezuela, Kuwait or Saudi Arabia.

Crude distillation units (CDU) of Kaduna Refinery and Petrochemical Company (KRPC) are the most strategic units for the processing of the crude oil. The process in the units involves passing the crude oil through preheat trains of exchangers prior to the main distillation or fractionation and the products are also cooled before sending to storage units. Atmospheric Crude Columns are one of the most important pieces of equipment in the petroleum refining industry [1]. Typically located after the Desalter and the Crude Furnace, the Atmospheric Tower serves to distil the crude oil into several different cuts. These include naphtha, kerosene, light diesel, heavy diesel and Atmospheric Gas Oil (AGO) [2].
The recipes developed in the laboratory are implemented conservatively in production, and the operator uses heuristics gained from experience to adjust the process periodically, which might lead to slight improvements from batch to batch [3]. In the past, the stumbling blocks for the use of computer simulation in industrial practice have been:

- *Reliable Modeling Tools*
- *Reliable Measurements*

Nevertheless, there is a clear indication that recent advances in both computer simulation software and sensor technology are helping remove the two handicaps mentioned above and, thus, are opening up new avenues to reliable process optimization. Software tools such as Hysys, SimuSolv, SPEEDUP, ASPEN Plus, or gPROMS [4], have helped to reduce the time and effort necessary to obtain reliable models.
The Crude Distillation Unit of the Kaduna Refinery and Petrochemical Company is 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. Preheated crude (from a preheat train) is fed to the pre-flash drum, where vapours are separated from the crude liquids. The liquids are then heated to 650°F in the crude furnace [5]. The pre-flash vapours bypass the furnace and are re-combined, using a mixer, with the hot crude stream. The combined stream is then fed to the atmospheric crude column for separation. The crude column is a refluxed absorber, equipped with three pump-around and three side stripper operations [2].
The main column consists of 29 trays plus a partial condenser. The tower feed enters on stage 28, while superheated steam is fed to the bottom stage. In addition, the trim duty is represented by an energy stream feeding onto stage 28. The Naphtha product, as well as the water stream Waste water, is produced from the three-phase condenser. Crude atmospheric Residue is yielded from the bottom of the tower. Each of the three-stage side strippers yields a straight run product [6]. Kerosene is produced from the reboiled Kerosene side stripper, while Diesel and AGO (Atmospheric Gas Oil) are produced from the steam-stripped Diesel and AGO side strippers, respectively [2].

METHODOLOGY

Simulation within HYSYS is based on a simultaneous modular approach. A flow sheet model is developed as a collection of Sub-flow sheets (SFS or the modular blocks) are connected through streams. Within each Sub-flow sheets are a collection of unit operations and streams that are appropriate to be solved together [7]. During the course of the simulation run, each Sub-flow sheet is solved using one of the standard HYSYS solvers (sequential quadratic programming optimizer) [8]. When the model is being posed to the simulator, each product stream from one Sub-flow sheet that serves as a feed stream to the main Sub-flow sheet is

"torn" (i.e. creation of a collection of connection equations which the simulator solves as part of its calculations)
Recycle locations in the flow sheet were defined at the transition across a Sub-flow sheet boundary. This additional transfer basis allows the flow sheet to be initialized correctly, and then have the recycle replaced by connection equations when the model is posed to the simulator. Within each of the Sub-flow sheets are a number of decision variables, true process constraints and objective function variables. These were individually selected, configured and are automatically associated with the corresponding block when the problem is posed to the optimizer.
Upon configuration of the flow sheet, Derivative Utilities were attached to the various Sub-flow sheet operations. These utilities allow the tearing of the appropriate streams to be invoked, and the various simulation objects (decision variables, constraints, objective function variables) collected into lists which are then provided to the simulator. When the simulator is invoked, it accesses these lists from each of the utilities to construct its solution matrix. During the course of its solution, the simulator configures the necessary information from each of the objects to determine aspects such as step size, derivative evaluations etc.
The derivatives that the simulator then sees from any block are of the entire constraints vector with respect to each individual variable within the block. If the block contains variables which are part of the objective function, the gradient is also determined for each of the variables. During the simulation, values were returned to the flow sheet through the utilities to be evaluated by the models, with the calculated results (tear equation residuals, process constraint values, objective function, etc.) returned to the simulator. The interaction between the simulator and the flow sheet continues until the defined solution criteria were met [9].

- *Simulation Variable*. Decision variables for the simulator that must be specified (blue) variables.
- *Constraints*. True process constraints, bounded variables that are initiated by the user. These must be calculated (black) variables.
- *Objective Function Variables*. A variable that is part of the overall objective function. Each variable has its own defining equation, the results of which are combined into a single flow sheet objective function. These must be calculated (black) variables.

Process Simulation 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.

Results and discussion

Table 1: Naphtha Product Stream Properties for the simulation

Properties	Base Case
Vapour/Phase Fraction	0.0000
Temperature: (^oC)	53.13
Pressure: (kPa)	140.0
Molar Flow (kgmole/h)	1039
Mass Flow (kg/h)	9.488e+004
Std Ideal Liq Vol. Flow (m^3/h)	129.8
Molar Enthalpy (kJ/kgmole)	-2.014e+005
Mass Enthalpy (kJ/kg)	-2205
Molar Entropy (kJ/kgmole-^oC)	50.38
Mass Entropy (kJ/kg-^oC)	0.5516

Table 2: Kerosene Product Stream Properties for the simulation

Properties	Base Case
Vapour/Phase Fraction	0.0000
Temperature: (^oC)	220.5
Pressure: (kPa)	208.6
Molar Flow (kgmole/h)	240.9
Mass Flow (kg/h)	3.493e+004
Std Ideal Liq Vol Flow (m^3/h)	42.14
Molar Enthalpy (kJ/kgmole)	-2.534e+005
Mass Enthalpy (kJ/kg)	-1748
Molar Entropy (kJ/kgmole-^oC)	210.4
Mass Entropy (kJ/kg-^oC)	1.451

Table 3: Diesel Product Stream Properties for the simulation

Properties	Base Case
Vapour/Phase Fraction	0.0000
Temperature: (^oC)	245.6
Pressure: (kPa)	217.1
Molar Flow (kgmole/h)	689.5
Mass Flow (kg/h)	1.436e+005
Std Ideal Liq Vol Flow (m^3/h)	164.5
Molar Enthalpy (kJ/kgmole)	-3.500e+005
Mass Enthalpy (kJ/kg)	-1681
Molar Entropy (kJ/kgmole-^oC)	416.4
Mass Entropy (kJ/kg-^oC)	2.000

Table 4: Atmospheric Gas Oil (AGO) Product Stream Properties for the simulation

Properties	Base Case
Vapour/Phase Fraction	0.0000
Temperature: (°C)	279.2
Pressure: (kPa)	222.5
Molar Flow (kgmole/h)	32.72
Mass Flow (kg/h)	1.000e+004
Std Ideal Liq Vol Flow (m^3/h)	10.90
Molar Enthalpy (kJ/kgmole)	-4.849e+005
Mass Enthalpy (kJ/kg)	-1586
Molar Entropy (kJ/kgmole-°C)	756.7
Mass Entropy (kJ/kg-°C)	2.475

Table 5: Atmospheric Residue Stream Properties for the simulation

Properties	Base Case
Vapour/Phase Fraction	0.0000
Temperature: (°C)	344.8
Pressure: (kPa)	230.0
Molar Flow (kgmole/h)	716.8
Mass Flow (kg/h)	3.028e+005
Std Ideal Liq Vol Flow (m^3/h)	313.7
Molar Enthalpy (kJ/kgmole)	-5.883e+005
Mass Enthalpy (kJ/kg)	-1393
Molar Entropy (kJ/kgmole-°C)	1303
Mass Entropy (kJ/kg-°C)	3.085

Graphical Result

The graphical results obtained from the simulation is shown

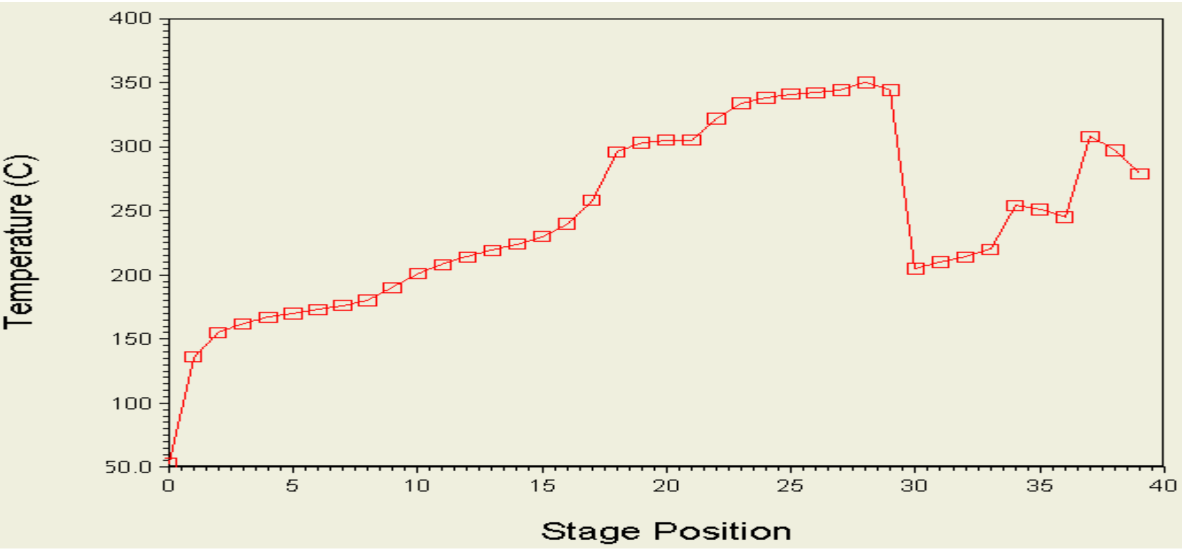

Fig. 1 Graph of Temperature against Stage Position for the Simulation

Discussion

Tables 1 through 5 are the process simulation results. The simulated volumetric flow rates with their corresponding temperatures for Naphtha product , kerosene product, diesel product, AGO product and ATM residue product were 129.8m^3/hr and 53.13^{O}C , 42.14m3/hr and 220.5^{O}C, 164.5m3/hr and 245.6^{O}C, 10.90m3/hr and 279.3^{O}C, and 313.7m3/hr and 344.8^{O}C as shown in Tables 1 through 5 respectively. The Vapour Phase fraction for all products is zero indicating that they are completely in the liquid phase.

Nonetheless, Figure 1 showed that the base case condenser temperature was 50^{O}C which later increased to 170^{O}C that is from condenser stage to tray 5.

There was an increase in temperature for kerosene side stripper (tray 30 to 32) from 210^{O}C to 260^{O}C for the base case, a decrease in temperature for diesel side stripper (tray 33 to 35) from 260^{O}C to 240^{O}C for the base case.Finally a decrease in temperature for the AGO side stripper (tray 36 to 38) from 310^{O}C to 275^{O}C for the base case was observed.

CONCLUSION

The simulated results revealed that atmospheric residue had the highest volumetric flowrate, while diesel had the lowest value of volumetric flowrate. 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.

REFERENCES

1. K. Liebmann, V. R. Dhole. Integrated Crude Distillation Design.European Symposium on Computer aided Process Engineering. Vol. 5, pp. 119-124, New Jersey, 1995.
2. Chiyoda. “Process and Operating Manual for Crude Distillation Unit” Chiyoda Chemical Engineering, pp. 84-125. Tokyo, 1980.
3. www.aspentech.com.paper
4. D.M. Himmeblau. “Basic Principles and Calculation in Chemical Engineering, Prentice Hall, pp. 76-82, New Jersey, 2001.
5. S.M. Brown. The drive for Refining Energy Efficiency, Global Technology Forum. The European Refining Technology Conference, pp. 14-30, Berlin, 1998.
6. C.D. Holland. “Multicomponent Distillation” Prentice Hall Englewood Cliff, pp. 60-89, New Jersey, 1963.
7. M.J. Box. “A New Method of Constrained Optimization and a Comparison with other Methods,” Computer J., Vol. 8, pp. 42-4, Ontario, 1965.
8. J.L. Kuesterand, J.H. Mize. “Optimization Techniques with FORTRAN,” McGraw-Hill Book Co., pp. 35-108, New York, 1973.
9. D.M. Himmeblau, E. Thomas. “Process Optimization and Simulation, Prentice Hall, pp. 45-90, New Jersey, 2005.