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Steady State Simulation of Basrah Crude Oil Refinery Distillation Unit using ASPEN HYSYS

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Abstract

This work describes the steady state simulation of the current performance of the crude oil distillation column at Basrah refinery, Iraq. Steady state simulation results were obtained by ASPEN HYSYS V9 simulation software and compared with the real plant operation conditions, such as temperatures, flowrate of refinery products (total naphtha, kerosene, light gas oil, and heavy gas oil). Also plant experimental ASTM D86 curves of different products were compared to those obtained by simulations. Finally, the temperature and flowrates profiles along the distillation column were obtained. The result shows that the simulated total naphtha mass flow rate (80600 kg/hr) was higher than plant value (73960 kg/hr) flowrate, while simulated residue mass flow rate (203900kg/hr) and waste water mass flow rate (6497 kg/hr) have the lowest mass flowrates than plant data (230200kg/hr,6910kg\hr) respectively. Also the simulated temperatures of product stream for, kerosene, LGO, HGO products (200.3 oC,261.5 oC, and 295 oC) shows good agreement with the plant data (191 oC ,260, oC and 301 oC) respectively, the maximum difference between the plant and simulation results were around 9 oC.

Introduction:
The crude oil distillation unit (CDU) is one of the important units in almost any refinery. It receives crude oil after heating it in a furnace that is easy to separate its components for different boiling points. It is also known as an atmospheric distillation column as it operates at atmospheric pressure. It is the first major unit in refineries for crude oil processing, the central, and the most important unit of all crude oil refineries. Because distillation is the first step in the processing of crude oil, CDUs are key process plants in petroleum refinery because they produce intermediate streams that are used in the subsequent units [1].

crude oil, which is a mixture of many types of hydrocarbons, is boiled and condensed to separate the crude oil into various components such as naphtha, kerosene, diesel and gas oil, based on the boiling points of the respective components. Crude oil is a complex mixture of hundreds of hydrocarbon compounds, liquid or gas. The proportions of these components vary according to the oil field properties. The oil components of light gases such as methane and ethane vary from high molecular weights to hydrocarbons, which is the remaining solid components of crude oil distillation unit. In addition, it may contain minerals or compounds of sulfur and nitrogen as well as water [2,3].

Crude oil distillation simulation and models have become an important tool for obtaining a broader understanding of the distribution of products ratios and specifications, as well as in the startup operation of the units or their shutdown procedure. These models enable exhalant development of a realistic model with high safety and performance. In order to obtain a high precision simulation model, many data must be provided on the specifications of crude oil such as pressure, temperature and flow rates for all internal and external streams until the steady state design is obtained with a high degree of accuracy and stability [4].

Due to the large interaction between the heat and mass transfer processes in the distillation of crude oil as well as changes in the thermodynamic properties of liquid and gas streams which depends on the pressure and temperature, it is a great challenge when calculating the composition and flowrates for products from the unit using simple models or using a personal computer [5].Currently, simulation is one of the most powerful and time-consuming tool, which can be used for various purposes such as design, performance development, control and predictability of system behavior when there is a change in any of the operating conditions. this task can be done easily, instead of attempting to understand the plant or unit behavior by performing many experiments [6].

Aspen Hysys software has a large database that includes various types of equation of state of gas and liquids over wide range of pressure and temperature, making it more accurate in design processes and more flexible in most operating conditions. These specifications and features make the results more realistic and compatible with the real performance of the of separation units. The program includes a huge amount of experimental information for pure components, solutions and mixtures in the form of tables or equations [7].

In order to conduct the simulation, the operational conditions of the distillation tower, as well as the specifications of the crude oil mixture, should be determined and its components should be classified according to a specific range of boiling points [8]. Simulation can be used in a wide range of purposes including:

- Defining the performance and design of existing systems and identifying potential operational problems in the future.
- Improve product specifications and study the efficiency of the system to reduce the cost of heat loads and increase profitability.
- Study how the effect of adding any new accessory equipment on the performance and operation of the system.

Simulation has provided a new way to model crude oil distillation towers by mixing different types of oil, avoiding the tendency to focus on the solution without the use of repeated attempts multiple and boring until a stable solution reached with high accuracy [9]. Pan, et al. [10] have presented a new criterion for crude oil modeling, they have used a new mixed integer non-linear programming (MINLP) for crude oil properties firstly, and then proposed some design rules collected from experience to linearize bilinear terms and prefix some binary variables in the MINLP model. Robertson, Palazoglu [11] suggested a multi-level simulation approach for the crude oil loading/unloading scheduling problem. They have used the nonlinear simulation model for the process units to find optimized refining costs and output blends.

Crude Distillation Unit:

Figure 1 shows a typical diagram of the crude distillation unit, CDU. Crude oil is heated using another streams within the unit. During heating, it is pumped and desalted. The main heating process is done in a furnace, the unit itself comprises an atmospheric distillation tower and three side strippers. the CDU serves to distil the crude oil into several cuts. These cuts include Naphtha, Kerosene, Light Gas Oil, Heavy Gas Oil diesel and Atmospheric Residue [12]. As these streams and the atmospheric tower pump-around are cooled, they provide external heating for the crude. Furthermore, there is reflux drum and recycle stream which consists of an overhead gas producing off-gas and Naphtha, suitable for the catalytic reforming unit.

Figure 2 shows the crude distillation unit in Basrah refinery which consists from 46 stages with a partial condenser, three side strippers and two pump rounds. The heated crude oil is sent to in the tray 41. Crude oil at a rate of 411860 kg/hr is fed to tower at a temperature at 356˚C and a pressure of 3.5 bar. The bottom steam entering at tray 46 is which exchanging heat twice by absorbing heat from the liquid stream flowing down the trays and then exchanging heat with the upward flowing vapors entered at a rate 4000kg/hr at 340˚C and 3.2 bar. The pressure at top of the CDU is 1.2 bar and bottom stage pressure of 1.8 bar. The external reflux from the condenser is normally no flowrate for Basra crude oil column, while the internal reflux has been ensured by two pump rounds. The specification of pump around are given in table 1.

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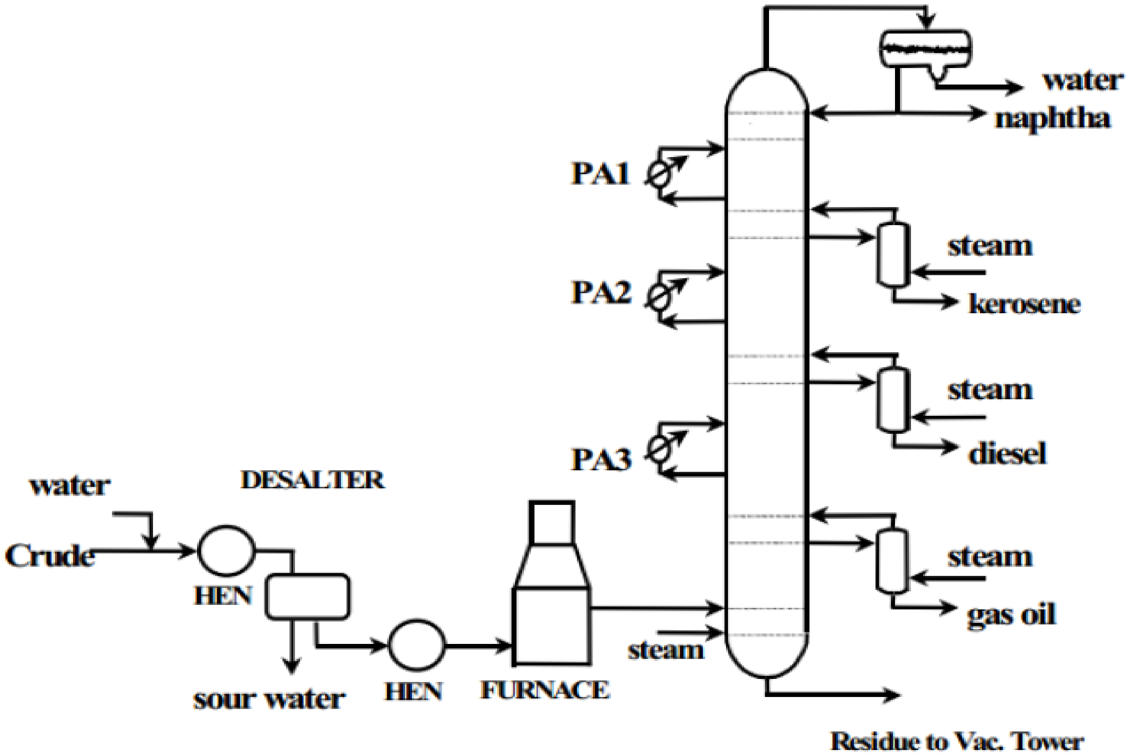

Figure 1: Typical Crude Distillation Unit and Associated Unit Operations.

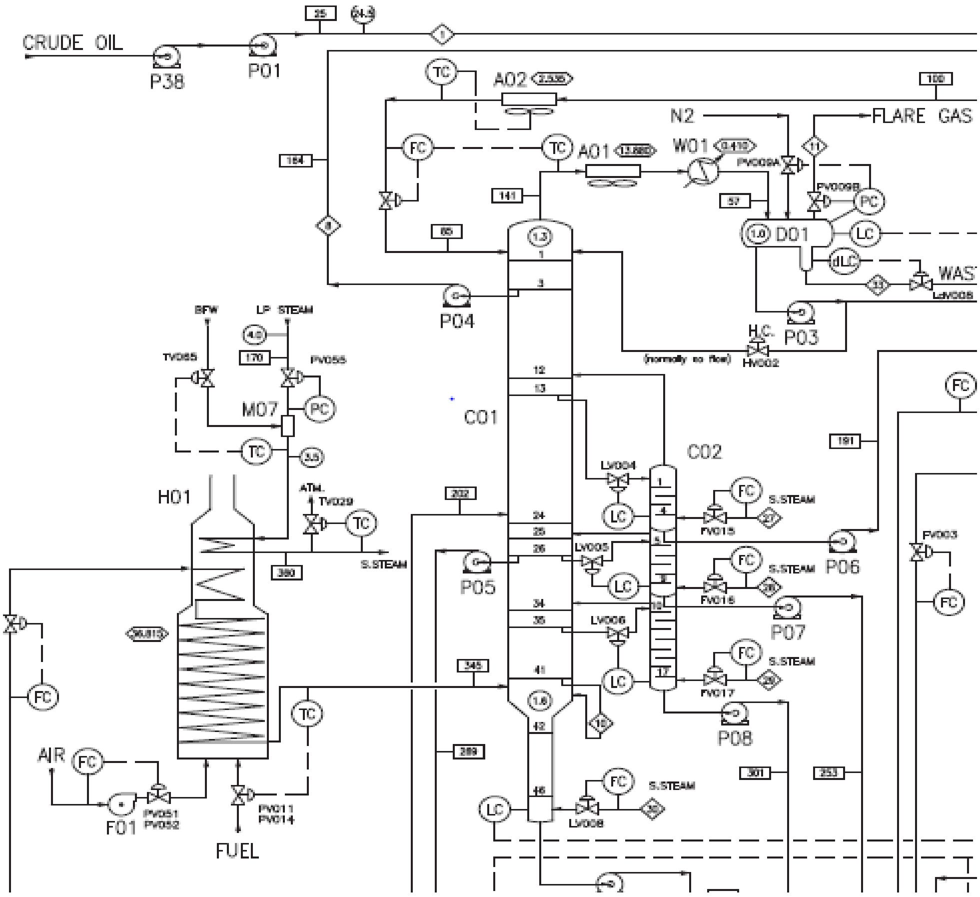

Figure 2: Crude distillation unit in Basrah refinery.

Table 1: Pump around Specifications.

Pump around	Location between trays	Flow rate(kg/hr)	Return temperature(^{o}C)
PA1	1and3	287520	85
PA2	24and26	300000	207

The total Naphtha product with a rate of 73960 kg/hr, as well as the water stream (Waste water) at a rate of 6910 kg/hr is produced from the partial condenser. Also the off gas is produced from the partial condenser at a rate of 90 kg/hr. The outlet of the overhead condenser at about 41 ^{o}C contain the existed of liquid naphtha and mixture of gas which will transfer to total naphtha line for further process. Crude atmospheric Residue is yielded from the bottom of the tower at a rate of 230200 kg/hr. Each of the three-stage side strippers yields a straight run product from the bottom plate of each stripper. Kerosene is produced from the steam stripped Kerosene side stripper at a rate of 35300 kg/hr, while LGO (Light Gas Oil) and HGO (Heavy Gas Oil) are produced from the steam-stripped LGO and HGO side strippers, at flowrates of 58400 and 13600 kg /hr respectively. The specification of the side strippers is given table 2.

Table 2: Side Strippers Specifications.

Stripper	No. of Trays	Steam Flowrate(kg/hr)	Product Flowrate(kg/hr)	Product Temperature (^{o}C)
Kerosene Stripper	4	500	35300	191
LGO Stripper	6	900	58400	260
HGO Stripper	7	1200	13600	301

Input Data and Oil Characterization:

In any simulation case, all feeds flowrates into the distillation column must be known and pre-defined before the simulation process should be carried out and sufficient information for the chemical, physical, and thermal properties of the pure components and mixtures should be available and specified first [13,14]. Because crude oil is usually made up of a large number of unknown hydrocarbons compounds and chemicals for which there is insufficient information, crude oil is often defined based on the boiling point of the hypothetical components that fall within a specified temperature range and for a certain period of time.

In this research, the true temperature curve (TBP) for crude oil was adopted, on the basis of which the heavy and light components of the refined oil were defined and analyzed. Table 3 shows the input of TBP and the light end hydrocarbon, and other properties into ASPEN Plus for basrah crude oil.

The TBP curve is one of the most significant characteristic features of the feedstock which decides the amounts of various products compositions available from the crude as well as the properties of these products. The accuracy and success of simulation depends mainly on the accuracy of the TBP curve used [15].

Table 3: Basrah Crude oil assay data [16].

TBP Distillation		Light End Hydrocarbons	
Temperature(ºC)	Volume %	Component	Weight%
50	3.7	C_2	0.01
60	4.0	C_3	0.28
70	5.7	i-C_4	0.18
80	6.5	n-C_4	0.91
100	9.3	i-C_5	0.73
120	11.5	n-C_5	1.25
150	17.0	Properties	
180	22.23	API Gravity at 15.6 ºC : 33.8	
200	33.86	Specific Gravity :0.856	
250	42.34	Sulphur content :2.1wt%	
300	50.58	Kinematic Viscosity (cSt)	
350	58.15	at 20 ºC	9.67
400	71.77	at 37.5 ºC	6.14

The design equations of the distillation tower are included during the ASPEN Plus software and are solved simultaneously with each other during simulation calculations. In the case of stability, the equilibrium equations of material and energy and change of momentum are the basic equations in simulation calculations. Generally, the composition of crude oil and products streams will be in term of hypothetical components of complex mixture of hydrocarbons with a range of boiling points.

Simulation of Refinery Process flow diagram:

Figure 3 shows the flow diagram of the simulated refinery process in ASPEN Plus V9. The diagram consists of a simple heat exchanger system consisting of a heat exchanger, two small heaters, and a pre-flash separator. The feed stream then enters the distillation tower. Crude oil is heated in a furnace before entering the tower where crude oil is fed at a rate of 411860 kg / h to pre-flash tower at 175 ° C and 3.5bar pressure. The pre-flash tower separates the raw oil into and liquids and vapors as

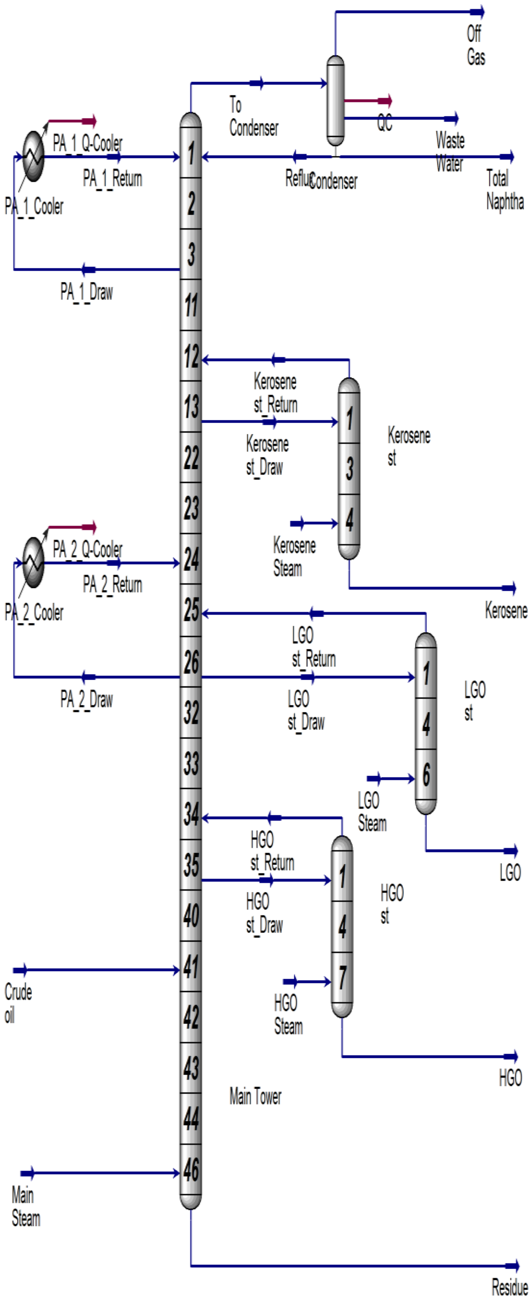

Figure 3: Refinery process flow diagram simulated in Aspen Hysys.

feeding from the bottom [17]. The super-heated steam inters the lower part of the column at 3.5 bar and 356 ° C. The simulation was carried out in steady state form. The simulation was beginning with defining the crude oil feed where defining the component, assay data for crude oils, blending the crude oils to produce the crude feed, generate the pseudo-components for the blend and defined the Assay Data Analysis. After the blending crude and its fractions steps, the simulation was proceeds to add an atmospheric crude distillation unit in the simulation flow-sheet.

The first step for an accurate simulation is correct choice of the thermodynamic method that will be used in the calculations of the state variables and the physical properties, like calculate enthalpy, entropy, K-values, density, transport properties. The exact and appropriate selection of the thermodynamic model makes the results of the simulation calculations more realistic and the incorrect selection makes the results unstable during the calculations and takes too much time and gives incorrect results [18]. The Peng-Robinson equation of state is normally accepted for the compounds in the crude distillation unit process stream. The equation is applicable to all calculation of all fluid properties in natural gas processes.

When the information for the feed stream, product stream and other stream had been specified, the simulation will begin by specifying the design variables. In simulation the flowrates of all products streams (Kerosene, Naphtha, LGO, HGO, and Residue) fixed, while the temperatures of products will have calculated as a result from simulation run. There is no reflux stream in Basrah refinery so in simulation its value kept zero.

Results and Discussion:

The final products qualities are evaluated in simulation through the ASTM D86 distillation curves for naphtha, kerosene, LGO, and HGO. The most important points of these curves, which define the separation between products, are the 95% ASTM D86. These correspond to temperatures where 95% of the products are vaporized under the specific conditions of quantification method**.** the quality of the product can be regarded as satisfaction guaranteed. Figures 4-6 shows the simulated ASTM D86 curves for kerosene, LGO, and HGO respectively.

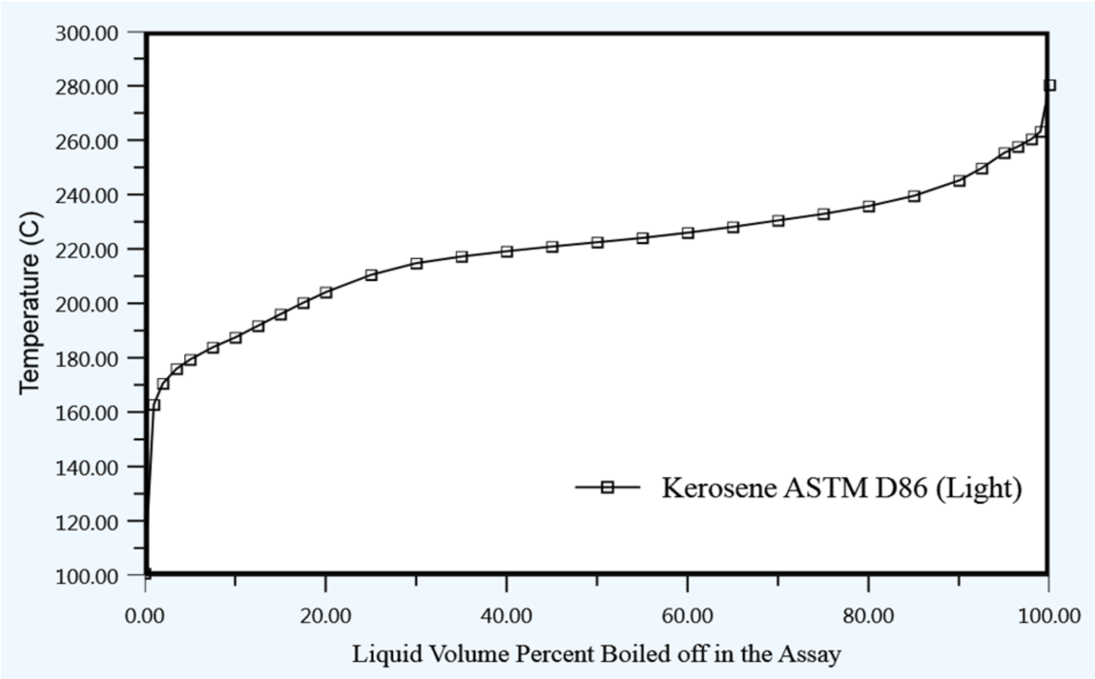

Figure 4: Simulated ASTM D86 curves of Kerosene.

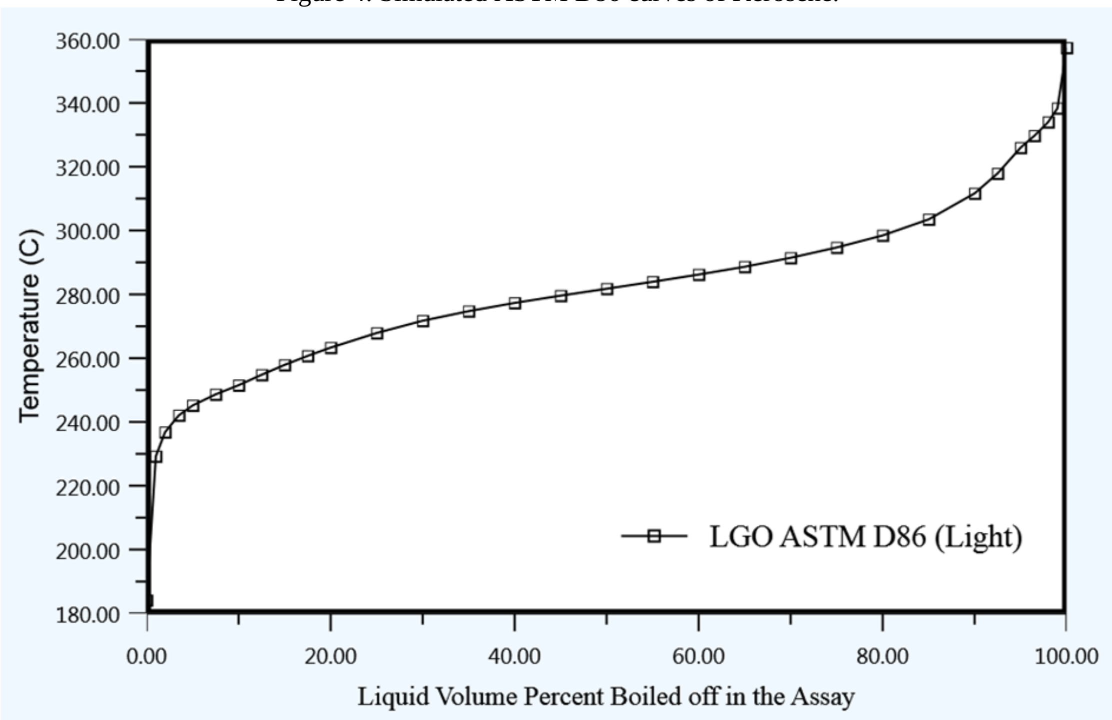

Figure 5: Simulated ASTM D86 curves of LGO.

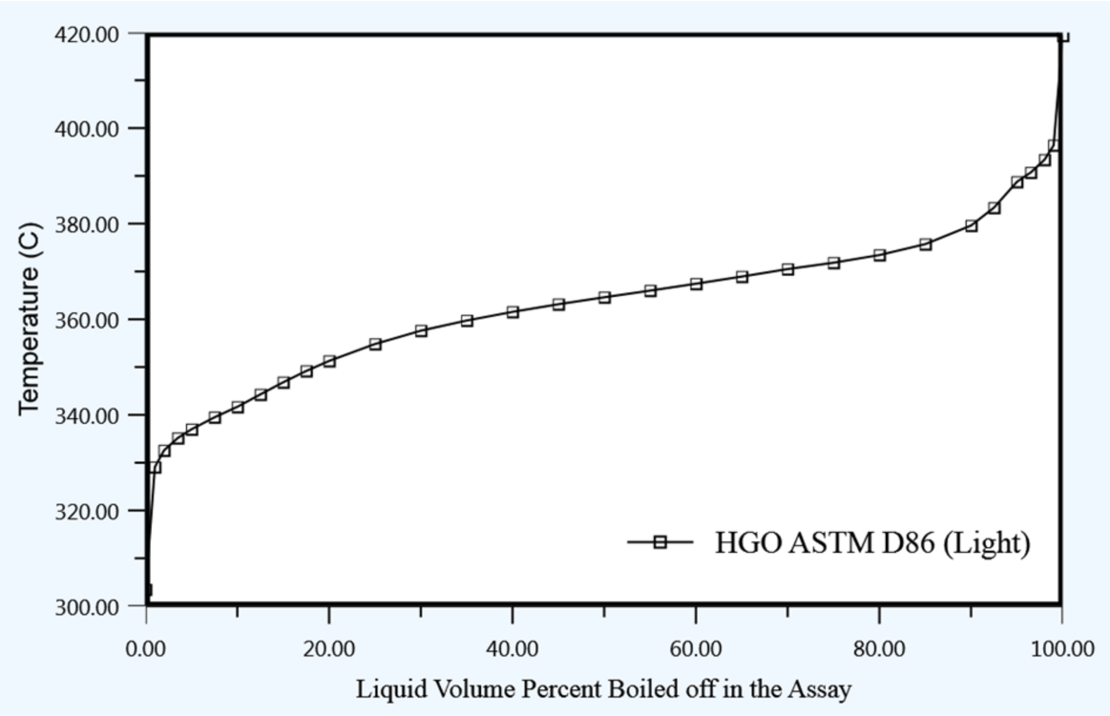

Figure 6: Simulated ASTM D86 curves of HGO.

Figures 7 and 8 show a comparison of the simulated ASTM D86 curve with the plant data for products from CDU. ASTM D86 curves of showed a noticeable difference between the simulation and experimental plant data. Generally, simulation results are in quite good agreement with the plant data. However, the first part of the curve, corresponding to light components, shows better conformity between the simulation and plant data. In comparing ASTM D86 data for the plant and the simulation it is helpful to look at several plant measurements to see the fluctuations that are occurring in the plant products. There are two sources of fluctuation in the plant measurements: small changes in the plant operation and differences in the laboratory measurements. It must be remembered that the sampling techniques can cause some differences in the lab measurements as well as the repeatability of the ASTM D86 measurements. The ASTM D86 procedure is designed for repeatability of temperature measurements within plus or minus 6 degrees F (3.3 degrees C) [19].

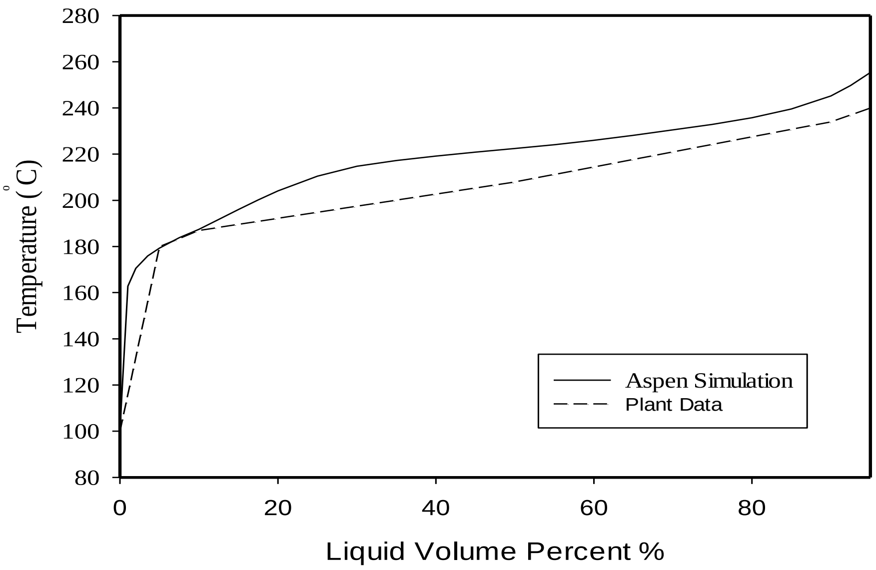

Figure 7: Simulated and plant data ASTM D86 curves of Kerosene.

The temperature profile across the CDU is shown in Figure 9 which represent the steady state model of crude distillation unit which will be helpful to know steady state points of tray temperatures and product composition.

Figure 10 shows the simulated mass flow rates for vapor and liquid phases within the column. There was an increase in liquid mass flow rated between stages 1 to 3 and between stages 24 to 26 because of the pump around external flow. The vapor phase flow rate for all products is approach zero at the bottom of CDU indicating that they are completely in the liquid phase (atmospheric residue).

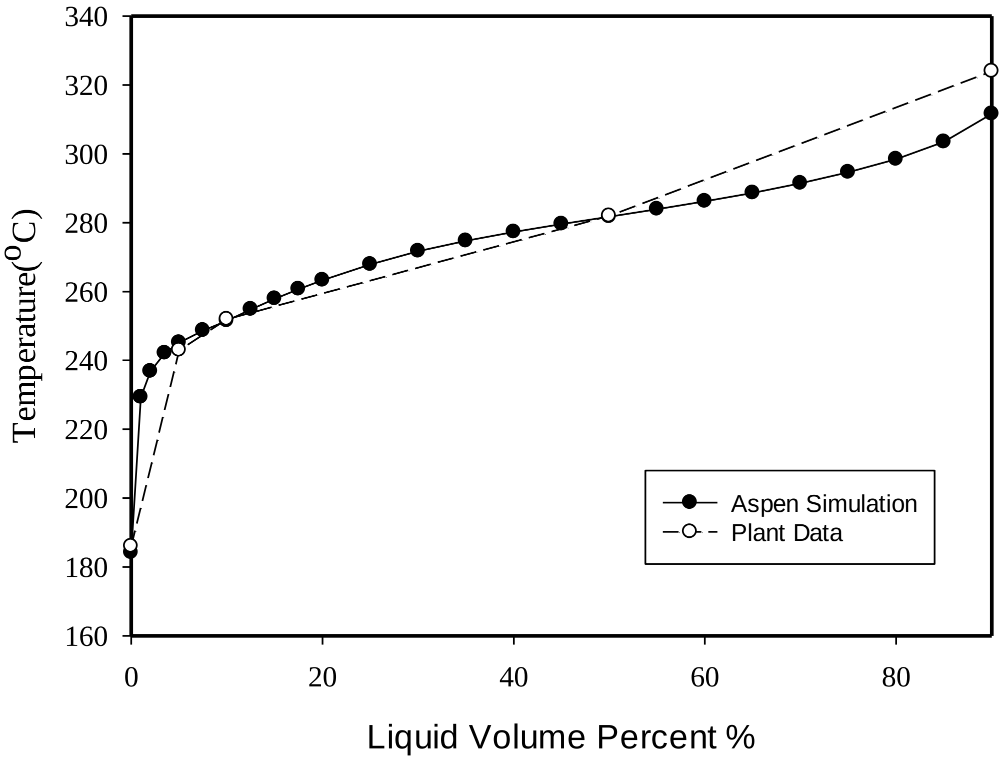

Figure 8: Simulated and plant data ASTM D86 curves of LGO.

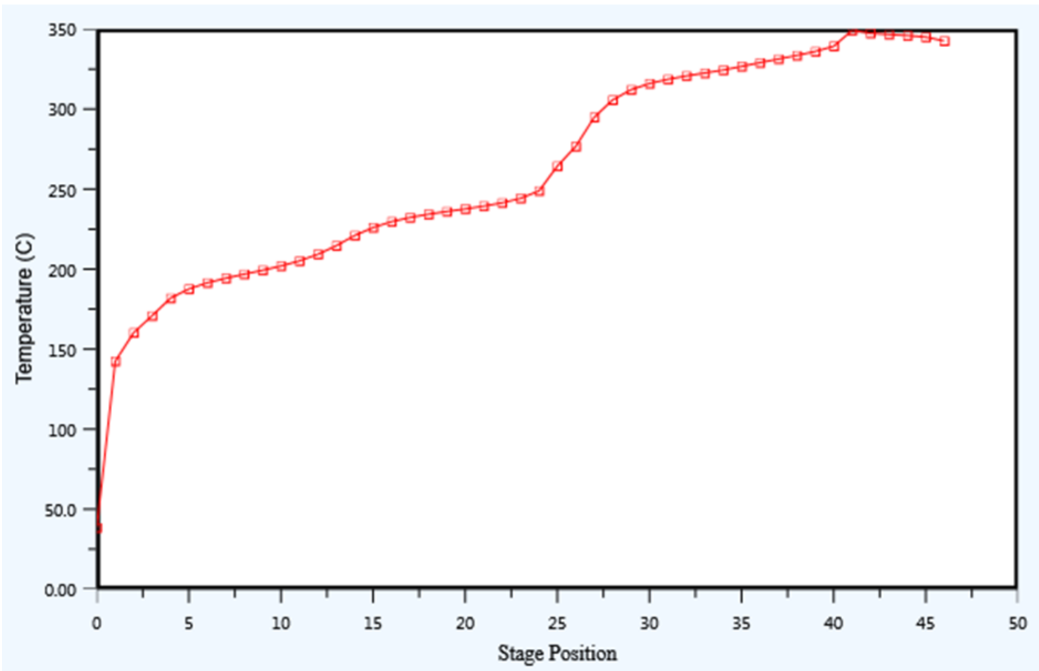

Figure 9: Temperature profile of crude distillation column.

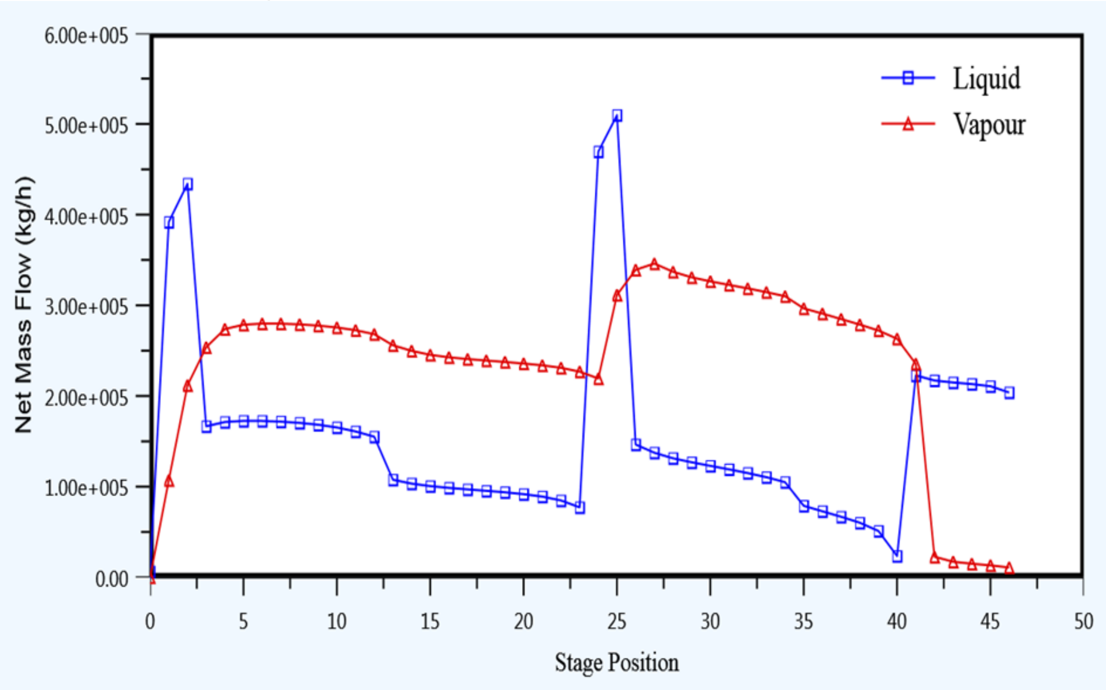

Figure 10: simulated mass flow rates for vapor and liquid phases within the column.

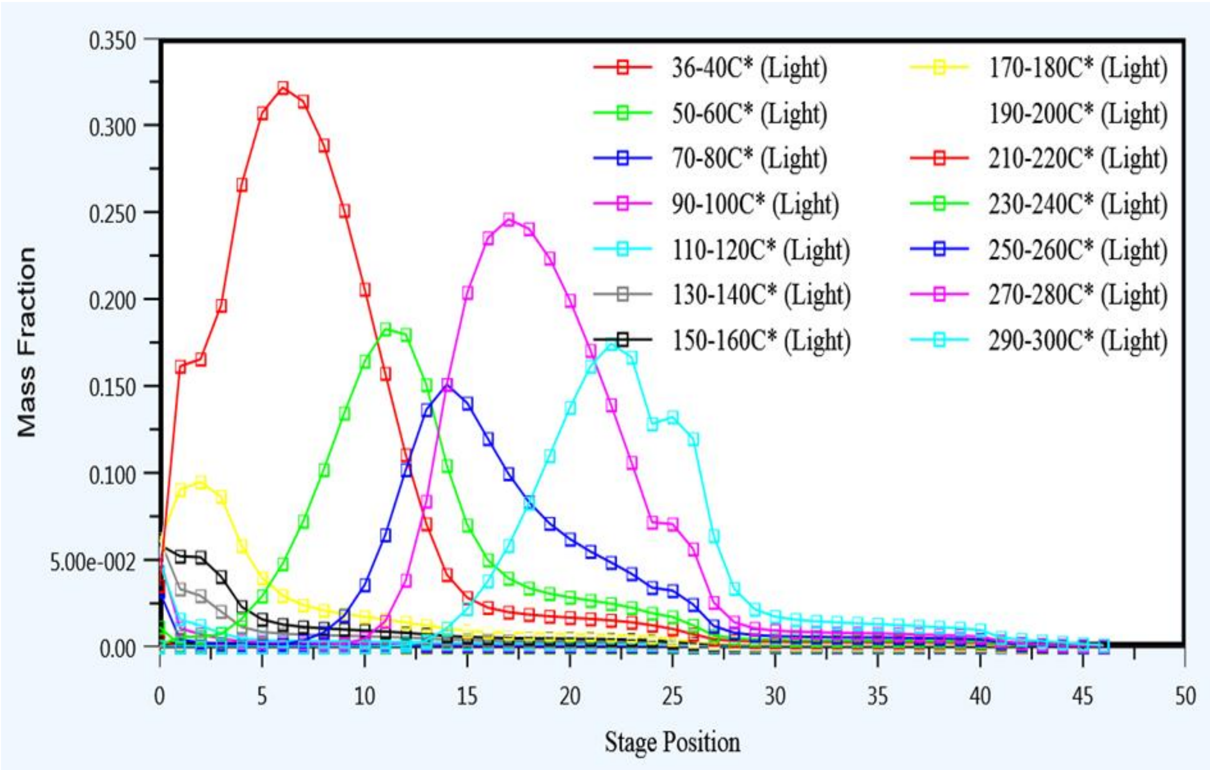

Figure 11: simulated mass fractions for light liquid phase within the column according to boiling points range.

Tables 4 show a comparison of the simulated mass flow rates and temperatures with plant products data. The simulated mass flow rates for, kerosene product, LGO, HGO product and atmospheric residue shows good agreement with the plant data. However, the flowrates for Naphtha and residue shows a noticeable difference from plant data. The maximum difference between the plant and simulation results were around 9 ºC.

The distribution of products mass fraction behavior according to their boiling points range through the column is given in figure 11. The lighter fraction, Naphtha (TBP - 110°C) have higher mass fraction at the upper trays and recovered in the column as the overhead product. The removal of the lighter fraction decreases after tray 30 and only the heaviest components remains as atmospheric residue.

Tables 4 Comparison between mass flow rates and temperatures for Aspen simulation and plant data.

Product	Mass Flow Rate(kg/hr)			Temperature (C)		
	Plant Data	ASPEN Simulation	Error%	Plant Data	ASPEN Simulation	Error%
Kerosene	35300	35300	0	191	200.3	-4.8
LGO	58400	58400	0	260	261.5	-0.57
HGO	13600	13600	0	301	295	2.0
Naphtha	73960	80600	-8.9	41	38.46	6.2
Off Gas	90	90	0	41	38.46	6.2
Residue	230200	203900	11.4	351	346	1.1
Waste Water	6910	6497	5.9	41	38.46	6.2

The simulated results revealed that total naphtha had the highest mass flowrate, while residue and waste water have the lowest value of mass 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. The optimum operational conditions for the atmospheric tower, calculating products yields and their properties, temperatures and duties of exchangers responsible for crude pre-heating.

CONCLUSIONS:

This study aims to show the possibility of using Aspen Plus software for simulation of the crude distillation tower in Basra refinery at steady state the operation. Detailed information was found for the temperature distribution of product cuts on each plate as well as the composition and structure of the resulting final products such as kerosene, light naphtha and light and heavy gas oil.

When comparing simulation results with the true plant data, the results shows that the mass flow rates of kerosene, LGO, off Gas, and HGO were found to be identical with those for the real tower condition. While the flow rates for naphtha, residual, and waste water were slightly different, the error difference between the plant and simulated results ranged from (6 - 11) %. This difference probably due to the fact that the refinery not only uses light crude oil but also mixes light crude with other heavy oil from other oilfields. This causes great differences in true temperature curve for crude oil distillation according to the boiling points.

The study also showed a significant difference in temperature of products from the tower and the difference between the temperature of the simulation and the temperature of the real product around (6-9) ^{o}C.

The simulation process was very useful tool in understanding the composition of the products in each plate of the tower and the concentrations of light and heavy components according to their actual boiling points.

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