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Simulation and Energy Saving Optimization in Naphtha Splitter

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Abstract

The simulation and optimization of the naphtha splitter in the Basra Crude Oil Refinery by Aspen HYSYS are studied. The simulation results of the naphtha splitter column were attained and compared with the practical refinery data, such as flow rates, pressures, and temperatures. Sensitivity analyses are used to examine the effect of the process operating conditions on the flow rates of light naphtha (LN) and heavy naphtha (HN) as well as heat duties of reboiler and condenser. The results showed that is possible to decrease the duties of the reboiler and condenser by 37% and 43%, respectively when the reflux rate is reduced to 6334 Kg/h. The LN flow rate is increased not that much when the top pressure is reduced from 6 to 5.9 bar. The optimum operating conditions determined by the simulation reduced the energy consumed in heat transfer equipment.

Disciplinary: Chemical, Petrochemical, Petroleum Engineering.

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1 Introduction

The most concern for researchers in the field of oil and gas is the process of distillation and the most significant concentrating in kinds of literature is on enhancing the recovery of energy in both multi-component and binary units (Osuolale, 2014; and Al-Mutairi, 2014)

The processes of chemical, biological, and physical can be simulated in engineering software to predict, improve, optimize, and analyze the effect of operating conditions in such processes (Robertson, 2011). According to analysis, the software helps to improve the performance of any process and obtain the optimum operation conditions and optimizer is a tool of the chief quantitative in the making of decisions for the industrial processes (Osuolale, 2016). Li (2012) reported that an optimization tool reduces the cost of the process such as crude oil distillation by decreasing the consumption of energy by about 35% in a recent study (Li, 2012). Wang et al. (2016) presented simulation and optimization investigated using two different feeds in the crude distillation (Wang, 2016). Khalaf, (2018) simulated the performance of crude oil distillation located in the Basra Refinery and compared the obtained results with practical results which gives a good match between the practical and simulated results. In the same issue, the unit of atmospheric distillation is also simulated using Aspen HYSYS (Osuolale, 2017). Ali Jalali et al. optimized the energy of unit of naphtha treating in the company of petrochemical using Aspen HYSYS (Jalali, 2018). Many studies simulated the process of distillation using dynamic and steady modes in the Aspen software to show the behavior of the time of real environment (Yadav, 2020; Bao, 2002; Abdulwahab, 2012; Taqvi, 2016; Luyben, 2015).

This work is simulated and optimized in the naphtha splitter in the Basra Crude Oil Refinery, Iraq by Aspen HYSYS software. Both reboiler and condenser consume energy. The main objective of such a study is to alter the operating conditions to save energy in the naphtha splitter.

2 Methodology

2.1 Naphtha Properties

The whole naphtha has a specific gravity (15.6°C) of 0.7151, API at 15.6°C is 66.3, sulfur content 0.049 w%, and RVP at 37.8°C 6.8. For any crude oil analysis, a curve of True Boiling Point TBP is a plot of the boiling point of the mixture as a function of volume fraction or cumulative weight distilled. Table 1 includes the TBP assay of the whole naphtha used in this study and the light end composition (Aspen Tech, 2014).

Table 1: Basra whole naphtha assay data (Basra Crude Oil Refinery)

TBP Distillation		Light End Hydrocarbons	
Volume %	TBP (°C)	CO	Wt. %
05%	64	i-butane	0,113
10%	75	n-butane	0.996
30%	102	i-pentane	12.745
50%	116	n-pentane	18.3
70%	132	cyclopentane	0,013
90%	156	hexane	25.096
95%	164	heavy naphtha	42.729

2.2 Description of Naphtha Splitter Unit

The naphtha splitter distillation tower is designed to operate at top stage pressure of about 6 bar as shown in Figure 1. There will be 20 conventional valve single pass stages in the upper section and 22 two-pass valve stages in the lower section. The naphtha splitter distillation tower is reboiled by a fired reboiler heater with forced circulation by the pump. The overhead vapors are condensed in an air-cooled condenser at 105 °C. The external reflux flow is controlled by a cascade control loop with top stage temperature, as showed in Figure 2. Overhead LN feeds to the LN stabilizer tower while bottom-HN is fed to the hydrogenation reactor (Basra Crude Oil Refinery).

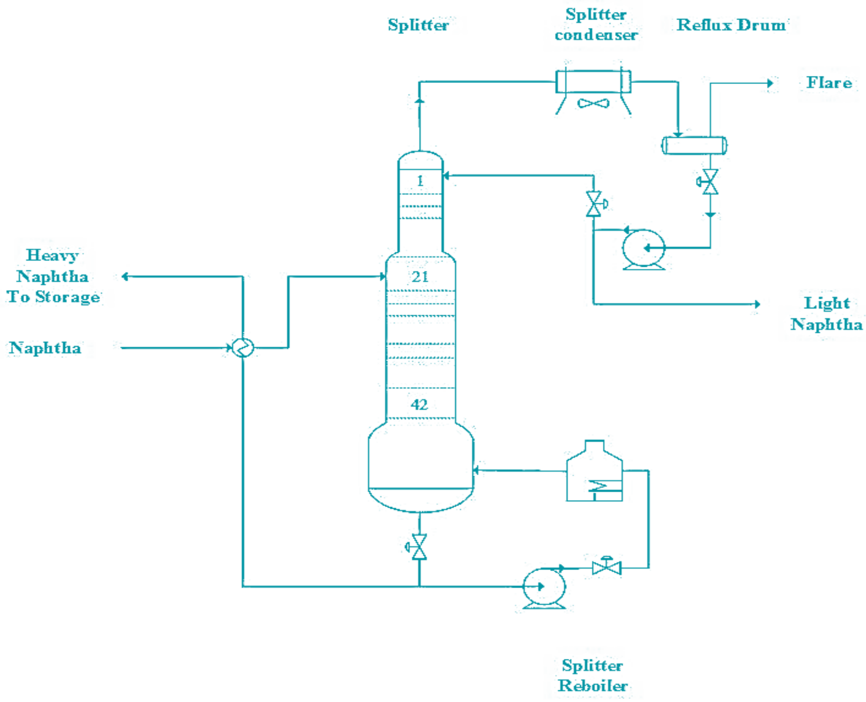

Figure 1: Naphtha splitter distillation unit.

2.3 Sensitivity Analysis

There are currying out of Sensitivity analysis by optimization tool in HYSYS software: the first step to specify the optimum variables then to find the effect of all variables that depends on the unit by one of optimization technique.

2.4 Optimization Simulation

HYSYS software package used to calculate thermodynamic properties and physical properties then is simulate the process. In the second step, the variables most influencing the design limits are set for each variable to be an input to the optimization stage. After analyzing the results obtained by the optimization techniques of selecting the most robustness model and testing with practical results that give the least deviation. The objective function selected for the reboiler heat duty (Q_R),

$$Q_R = Q_C + H_{LN} \times LN + H_{HN} \times HN - F \times H_F \quad (1).$$

By sensitivity analysis, there are four independent variables to simulate the splitter distillation unit. To speed up the improvement process, the number of iteration loops can be reduced to find the best solution by reducing the design variables to only two variables: temperatures of the top and bottom tower. Also, the Mass Flowrate of HN is constrained by,

$$3100 \le HN \le 3200 \quad (2).$$

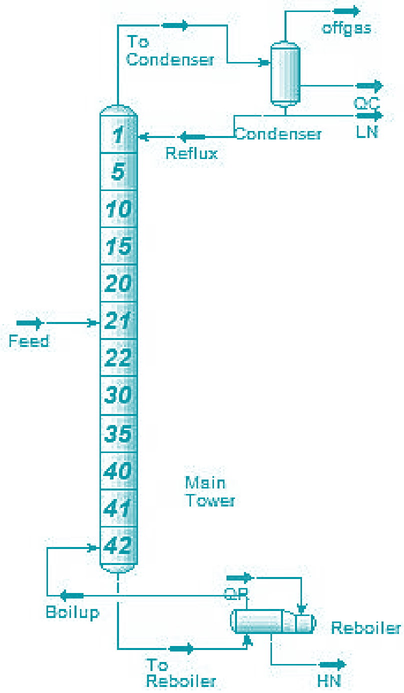

Figure 2: Naphtha splitter flow diagram simulated in Aspen HYSYS

3 Result and Discussion

To check whether Aspen HYSYS process modeling software for the present situation works accurately or not, the product yields obtained from both the program and the real refinery are compared to one another. It was observed that the product yields in both simulated and practical results are quite close to one another for the whole naphtha having the same properties. This comparison indicated that in the present research the HYSYS software can be reliable and safely used to simulate the process by hand (KAMIŞLI, 2019).

3.1 Simulation of Naphtha Splitter Distillation Tower

The naphtha splitter distillation tower was simulated by Aspen HYSYS. The column consists of 42 stages with a partial condenser and one furnace. The heated whole naphtha is sent into stage number 21.

The profile of temperature across the naphtha splitter is presented in Figure 3 representing the model of steady-state of the unit of crude oil distillation which is useful to identify the points of steady-state of temperatures' stage and the composition of products. The profile of temperature displays how alteration of the temperature in the column. In the first stage, the temperature is roughly 116 °C due to the introduction of reflux to the column. The increase of temperatures continues as the stages come down until the stage of feed where a feed enters at 129°C which is a high temperature. The temperature dramatically increases in the place closing to the reboiler due to the heat duty of the re-boiler where the needing of high temperature to evaporate all the components existing in the reboiler.

Figure 4 demonstrates the simulation of the rates of mass flow for phases of liquid and vapor inside the column. As introducing the feed in the phase of liquid, a mass flow of liquid on stage 21 is increased. However, the flow rate is decreased because of the high temperature at which controls the columns' bottom. The flow of vapor seems to be fixed in the column, excluding stages 21 and 1, this might occur because the temperature of reflux is low and can condensate several heavy components in the phase of vapor. In stage 21, while the temperature of feed is extremely high and evaporates several heavy components and trace amounts of light gases in the phase of liquid. For stages that locate upper the stage 21, the vapor gradually increases because of the more volatile components being presented in the feed together with the vapor's amount resulting in the evaporating liquid coming down to the reboiler.

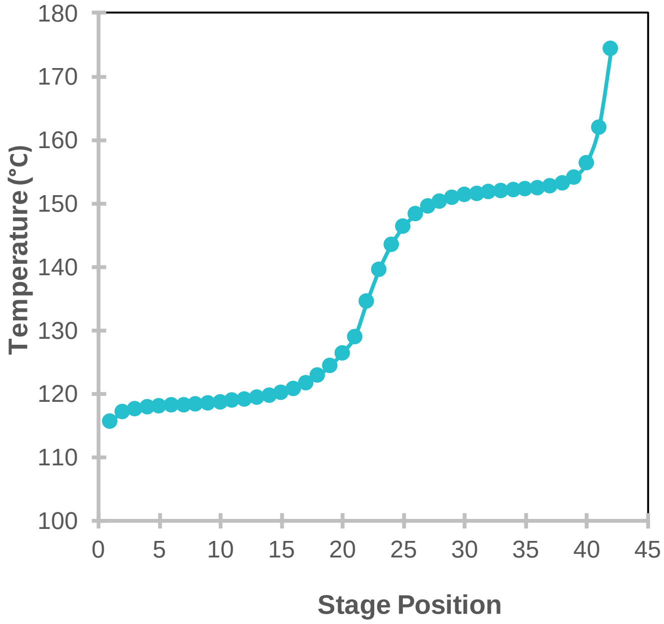

Figure 3: Temperature profile of naphtha splitter.

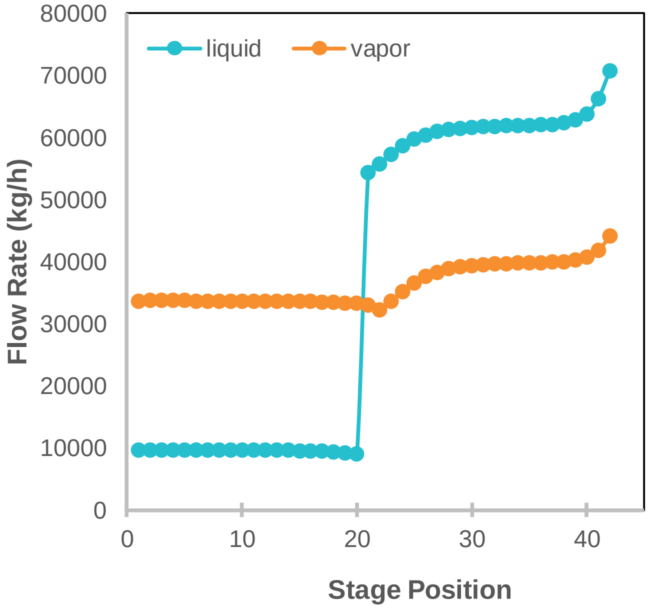

Figure 4: The rates of mass flow for phases of liquid and vapor profile inside the column.

3.2 Sensitivity Analysis

3.2.1 Influence of Increasing Top Tower Temperature

Increasing the top temperature of the distillation tower, HN goes towards the top stages, which increases the production of LN. The data about increasing the top temperature of the distillation tower were obtained in terms of mass flow rates of LN, mass flow rates of HN, reboiler duty (QR), and condenser duty (QC). The results are illustrated in Figures 5 and 6, the LN flow rate increases as the upper temperature increases since the HN becomes a part of the LN; therefore, the LN yield increases. The heat duty for the condenser and reboiler are shown in Figure 6. The energy consumption and rejection for the reboiler and condenser, respectively are decreased with increasing temperature in a top tower because the temperature profile is increased; therefore, the energy demand to reach the bottom column temperature decreased (KAMIŞLI, 2019).

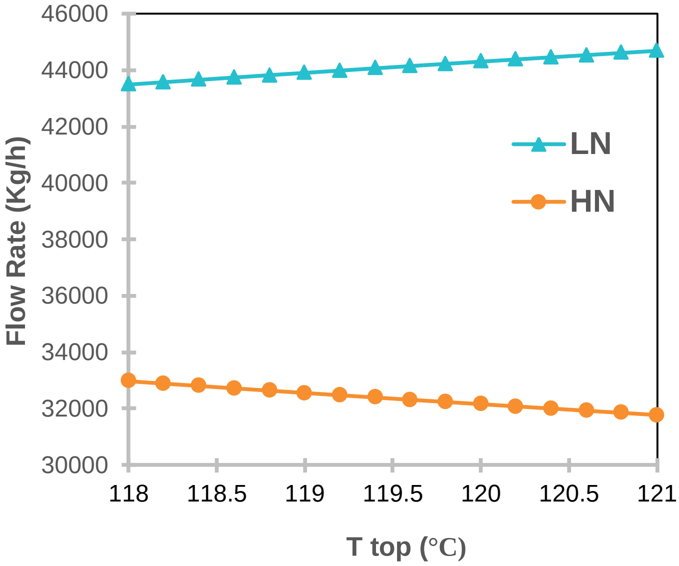

Figure 5: The effect of increasing top tower temperature on the HN and LN flow rates

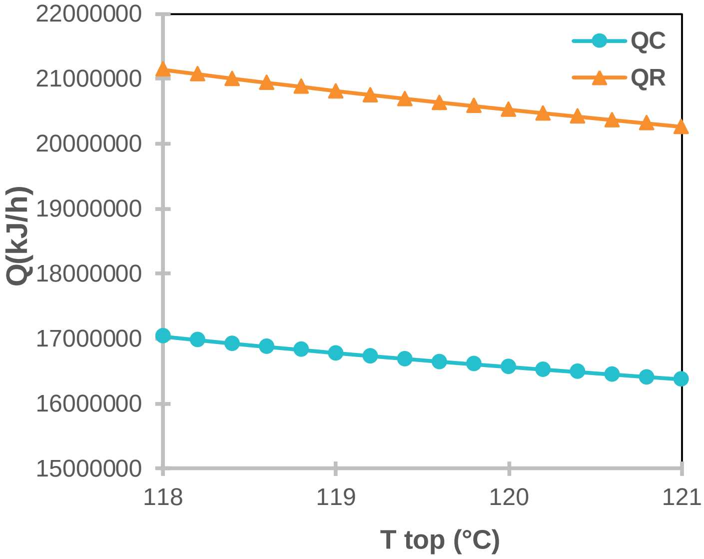

Figure 6: The effect of increasing top tower temperature on the reboiler and condenser duties

3.2.2 Influence of Increasing Bottom Tower Temperature

The increasing bottom temperature is studied and showed in Figures 7 and 8. The LN flow rate increases as the bottom tower temperature are increased. The increased bottom tower temperature causes high boiling point components that go up in the distillation tower to affect the quality of the products, while the flow rate of HN is reduced. This condition generates a higher yield for LN with higher specific gravity and a higher boiling point. The reboiler duty increases with an increase in the temperature in the bottom while condenser duty decreases as shown in Figure 8.

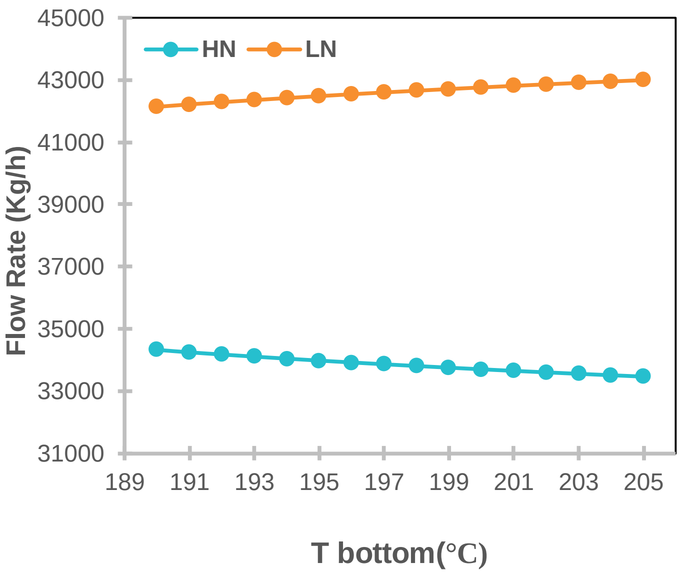

Figure 7: The effect of increasing bottom tower temperature on the HN and LN flow rate

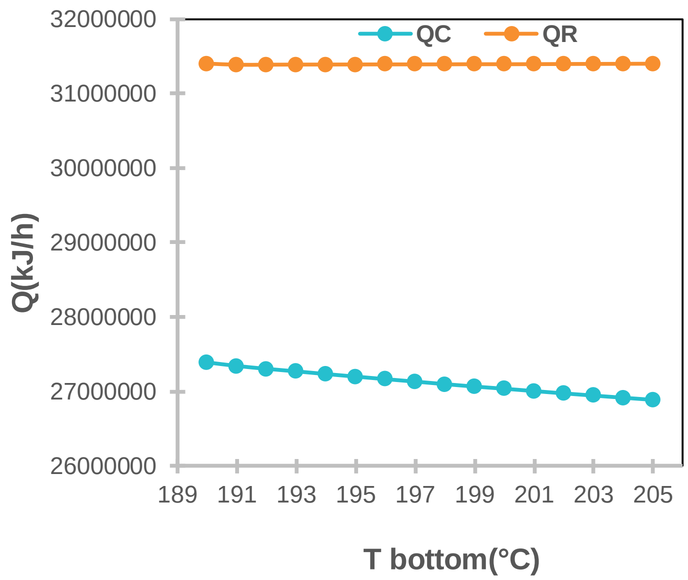

Figure 8: The effect of increasing bottom tower temperature on the reboiler and condenser duties

3.2.3 Influence of Increasing Naphtha Feed Temperature

As shown in Figures 9 and 10, increasing the temperature of the crude oil feed to the distillation tower increases the rate of process separation of the product and decreases the time of the process, but increasing the pressure of the tower. This causes high boiling points for components and; thus, the heavier products that go up in the distillation tower affect the quality of the products. The increase in the temperature of feed increases the flashing of high molecular weight compounds to the top of the column; therefore, the LN's flow rate increases while the HN’s flow rate decreases. This situation leads to an increase in temperatures inside the column, at the same time decreases heat consumption and rejection in reboiler and condenser, respectively as shown in Figure 11(KAMIŞLI, 2019).

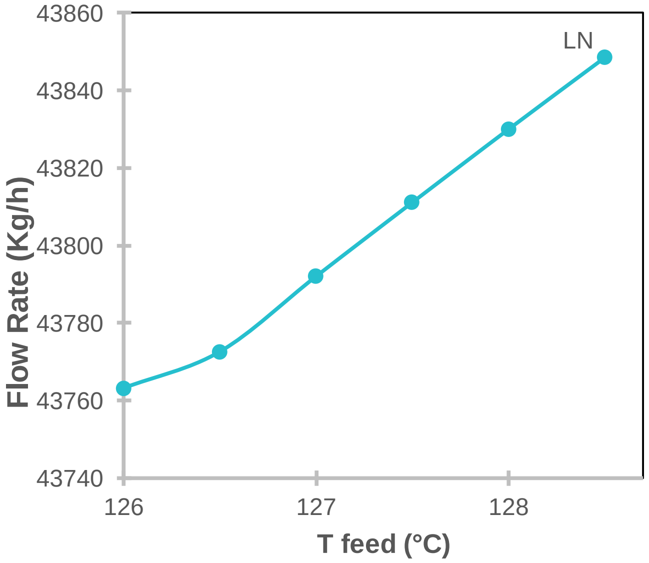

Figure 9: The effect of increasing feed temperature on the LN flow rate.

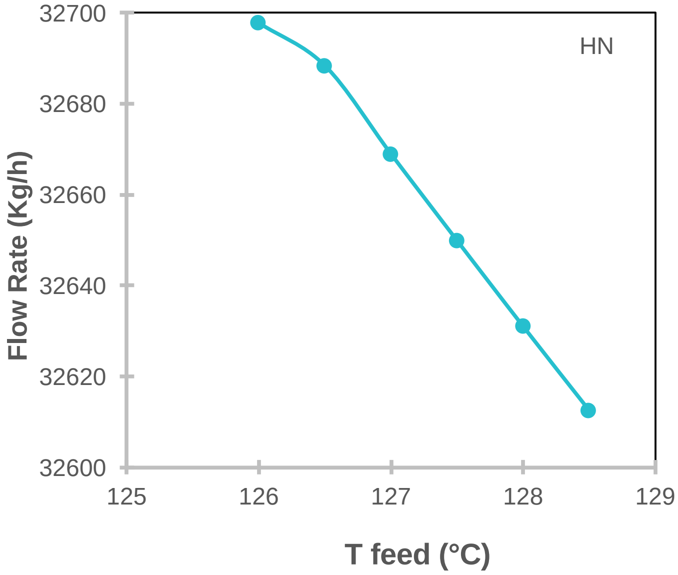

Figure 10: The effect of increasing bottom tower temperature on the HN flow rate.

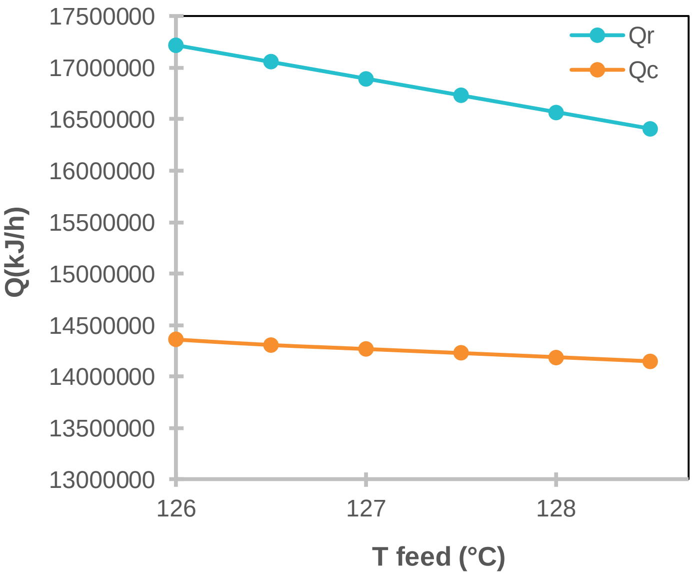

Figure 11: The effect of increasing feed temperature on the reboiler and condenser duties

3.2.4 Influence of Increasing Reflux Rate

The flow rate of reflux can be used to adjust the temperature profile. The increased flow rate of reflux decreases temperatures along the column and the rising vapor condensates in a large amount before reaching the top of the column. The increased reflux rate increases HN and decreases LN as shown in Figure 12. In Figure 13, the energy duty of the condenser and reboiler is analyzed. As it can be seen, more reflex rate requires more consumption of energy, where at a higher rate of reflux, the greater duty of reboiler and condenser is needed (Abolpour, 2013).

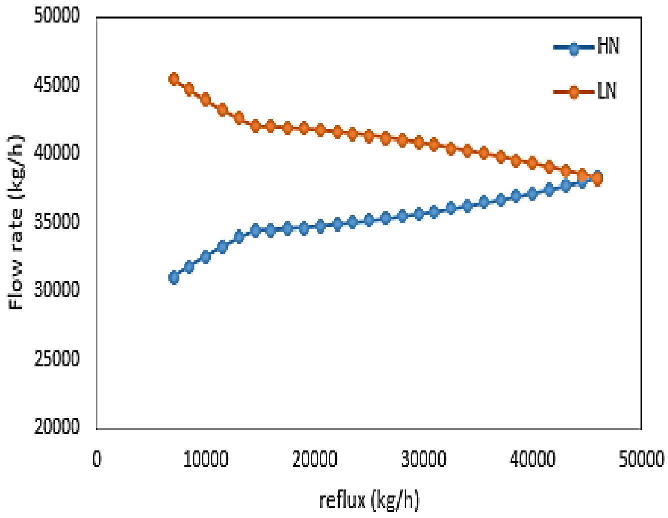

Figure 12: The effect of increasing reflux rate on the HN and LN flow rate.

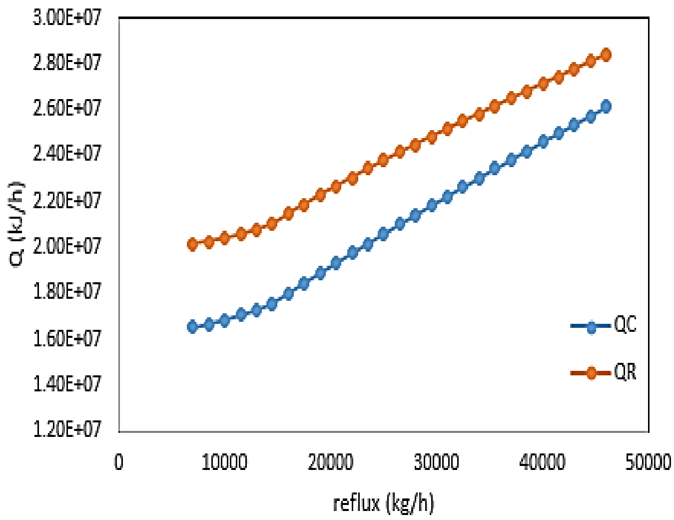

Figure 13: The effect of increasing reflux rate on the reboiler and condenser duties.

3.3 Optimum Operation Conditions

The summary of the optimum operation conditions for this simulation is specified by HYSYS in Table 2.

Table 2. Optimized cases and base cases summary

Parameter	Units	Base Case	Optimized Case
Whole Naphtha Flow rate	Kg/h	76464	76464
Column top temperature	°C	117	122
Column top pressure	bar	6	5.9
Column bottom temperature	°C	197	195
Whole Naphtha temperature	°C	128	130.2
Reflux rate	Kg/h	45529	6334
Reboiler duty	Mj/h	31399	19812
Condenser duty	Mj/h	28040	16109
LN Flow rate	Kg/h	44371	44888
HN Flow rate	Kg/h	32095	31575

The effect of increasing top temperature, decreasing top pressure, decreasing the reflux rate, and increasing feed temperature lead to saving energy splitter and a few increases in the LN. Then, the HN feeds to the naphtha hydrogenated treatment reactor downstream. The HN operation flow rate must be in range (31000-32000) Kg/h, therefore the optimum HN flow rate (31575 Kg/h) in the specified range.

The LN is changed in a little amount from real value because the top pressure is reduced from 6 bar to 5.9 bar. The LN product is sold and not enter any treatment process. The operating reflux rate reduced to 6334 Kg/h and led to a decrease in the duty of the reboiler to 37% as compared to the operation value. Also, the condenser duty ere decreased to 43% as compared to the operation value. Therefore, this is a good saving of energy leading to reduce the consumption of the fuel gas in the reboiler and this reflected on saving money.

4 Conclusion

Simulation and optimization of naphtha splitter in Basra Crude Oil Refinery are done by HYSYS using the Peng-Robinson package. The simulation results were compared with the real refinery results. It is found a variation in some variables between simulated and practical results. The results show that the mass flow rates of LN and HN were found to be identical with those for the practical unit conditions. The feed of top and bottom temperatures exhibited a slightly different, the error difference found for the bottom temperature is 2 °C. This difference may be attributed to the fact that the refinery uses the feed compositions different from the feed compositions in the datasheet. This causes great differences in the true temperature curve for crude oil distillation according to the boiling points.

A case study by HYSYS was utilized to estimate the influence of parameters on the production of LN and HN and energy consumption. The optimum results indicated a decrease in reboiler and condenser duties. Also, it is noted a slight increase in the LN flow rate and a slight decrease in the HN flow rate. Both simulation and optimization were tested for different operating conditions and it was observed that software achieved a rapid convergence of the used models. Future work will be using the dynamic mode for the naphtha splitter. It is suggested to use different feed compositions.

5 Availability of Data And Material

Data can be made available by contacting the corresponding author.

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