SIMULATION OF SARIR CRUDE OIL REFINERY USING ASPEN HYSYS

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الملخص

في الوقت الحاضر، يعد تقطير النفط الخام عملية أساسية في جميع المصافي تقريباً. تقطير الخام هو عملية فصل الهيدروكربونات في النفط الخام بناءً على درجة غليانها. تجزئة النفط الخام هي عملية معقدة للغاية، هذا التعقيد ناجماً عن عدد كبير من العناصر كأدوات النزع الجانبي والضخ حولها مما يجعل من مهمة تقييم مصافي النفط مهمة صعبة. في هذه الدراسة أستخدم برنامج محاكاة العمليات Aspen Hysys (الإصدار 11) في حالة تشغيل مستقرة لمحاكاة مصفاة نفط موجودة في حقل السرير لإعادة تقييمها. تتم معالجة خام نفط السرير- المستخدم في هذه الدراسة- في مصفاة السرير التي تبلغ طاقتها القصوى 10,000 برميل في اليوم. خام نفط السرير هو خام شمعي ذو كثافة قياسية متوسطة تبلغ حوالي 36.5 API. ينتج النفط الخام الذي يتم تكريره في المصفاة: النافثا الخفيفة والنافثا الثقيلة والكيروسين والديزل والبقايا. تهدف هذه الدراسة إلى محاكاة الوحدات الحالية لعملية التكرير واقتراح إضافة وحدة قبل عمود التقطير الجوي تسمى "برج الوميض المسبق""Pre flash column". تضمنت الدراسة التنبؤ بكل من درجات الحرارة والضغط خلال وحدة التقطير الجوي . تم إستخلاص معلومات مفصلة لتوزيع درجات حرارة المنتجات بواسطة منحنيات ASTM-D86 لكل من المنتجات التالية: النافثا الخفيفه، النافثا الثقيلة، الكيروسين، الديزل، والبقايا. تم مقارنة منحنيات ASTM D86 المحاكاة مع البيانات المختبرية لكل منتج باستثناء البقايا التي لم تكن منحنياتها متوفرة. أظهرت نتائج المحاكاة توافقًا جيداً مع منحنيات المختبر ل ASTM-D86 لجميع المنتجات باستثناء النافثا الخفيفه، والتي أظهرت فرقًا ملحوظاً. تمت مقارنة نتائج محاكاة معدلات الإنتاج مع بيانات المصفاة الفعلية التي أظهرت نتائج معدل تدفق الكيروسين والديزل والبقايا اختلافات ملحوظة مقارنة ببيانات معمل التكرير. في نفس الوقت، أظهر محاكاة معدل التدفق الكلي للنافثا أدنى مستوى اختلاف مقارنة ببيانات مصنع التكرير بنسبة خطأ بلغت حوالي 0.3٪. كما اظهر برج الوميض المسبق المقترح تحسناً في استهلاك الطاقة للفرن وبرج التقطير الجوي.

ABSTRACT

Nowadays, distillation of crude oil is an essential process in almost all refineries. Crude distillation is the process of separating the hydrocarbons in crude oil based on their boiling point. The crude oil fractioning is a very intensive complex process. Such complexity was due to a large number of products, side stripper, and pump around which makes the task of evaluating oil refinery tedious. In this study, a process simulation Aspen HYSYS (Version 11) is used at steady state operation to simulate an existing oil refinery in Sarir field for re-evaluation. Sarir crude oil, used in this study, is processed in the Sarir refinery, which has a maximum capacity of 10,000 barrels per day. Sarir Crude oil is waxy Crude which has a medium gravity of about 36.5 API°. The Crude processed on the refinery produces Light Naphtha (LN), heavy Naphtha (HN), Kerosene, Diesel, and Residual (RES.). This study aims to simulate existing units of the refinery process and proposes adding a unit before atmospheric distillation column (ADU) called “Pre-flash column". The study involved the prediction of both temperature and pressure profiles through the atmospheric distillation unit (ADU). Detailed information was found for the temperature distribution of product cuts by ASTM-D86 curves for each product: Light

Naphtha, Heavy Naphtha, Kerosene, Diesel, and Residual. Simulated ASTM D86 curves were compared with laboratory data for each product except residual whose curves were not available. The simulation results showed a good agreement with laboratory ASTM-D86 curves for all products except Light Naphtha, which revealed a noticeable difference. Simulation results of production rates were compared with the actual refinery data. The results of the flow rate of Kerosene, Diesel and Residual showed noticeable differences from refinery plant data. At the same time, a simulated Total Naphtha flow rate showed the lowest difference compared with the refinery plant data with a percentage error of about 0.3%. The Proposed pre-flash column showed an improvement in the furnace and the ADU energy consumption.

KEYWORDS***:*** Sarir Crude Oil; Atmospheric Distillation Unit (ADU); Pre-flash Column.

INTRODUCTION

In this study, the Libyan Oil Refinery in Sarir field has been simulated. The study focuses on the topic unit atmospheric distillation column. This Oil Refinery has a maximum capacity rate of 10,000 barrels per day. The refinery was founded in 1984 and became operational in 1987. It has operated by Arabian Gulf Oil Company (AGOCO), a subsidiary of National Oil Corporation (NOC). The crude oil used in this refinery comes from the Sarir field. Sarir Crude oil is paraffinic crude has a medium gravity of about 36.5 API° with pour point (+21℃) [1,2] (see Table 1). The Crude is processed in the refinery to produce Light Naphtha (LN), Heavy Naphtha (HN), Kerosene, Diesel, and Residual (RES.) (See Figure 1).

This study aims to simulate the refinery using process simulation Aspen HYSYS (Version 11). Oil Manager option in HYSYS was used to characterize Sarir crude oil using crude assay as required input in the simulation then compared the results with experimental crude assay. Furthermore, refinery process units were simulated to evaluate product specification and operating conditions. The modelled Crude Oil was processed in three parts: preheat train, atmospheric distillation unit (ADU), and dependanizer unit (DPU). A pre-flash column was proposed through a case study.

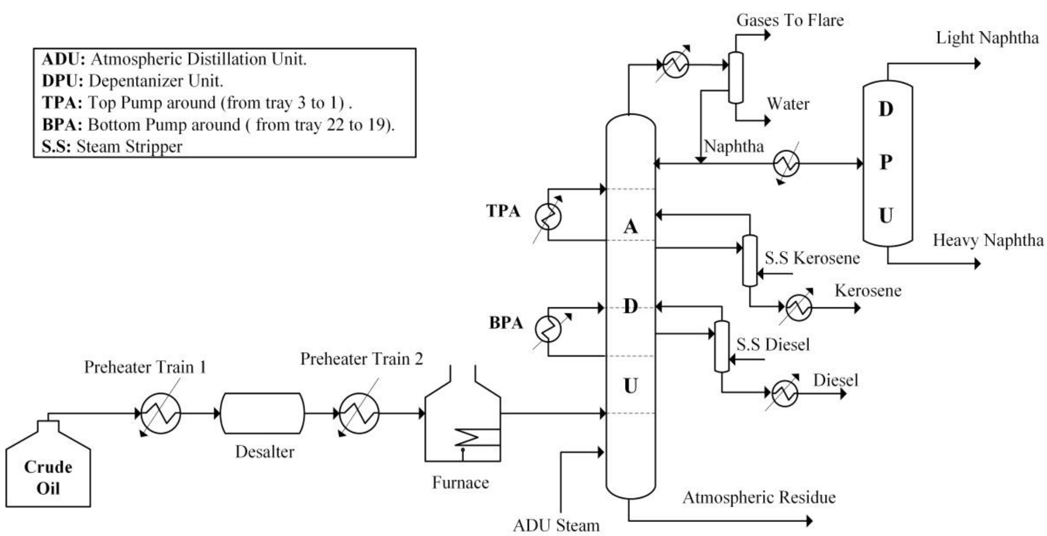

Figure 1: Process Flow Diagram of Sarir Crude Oil Refinery.

PROPERTIES OF SARIR CRUDE OIL

Sarir crude is classified as paraffinic crude oil, having a gravity of 36.5API° and a total sulphur content of 0.12 wt.%. The Crude is paraffinic in nature in the middle and upper part of its boiling range. Sarir crude has a high pour point of (+21℃) and a kinematic viscosity of 10.63cSt at 37.7℃ [1,2].

Table 1: Properties of Sarir Crude Oil

Property	Value	Ref.
Density @ 15°C g/ml	0.8415	1
API gravity @60°F	36.5	1
Sulfur Content, wt.%	0.120	1
Asphaltenes Content, wt.%	0.20	1
Mercaptan Sulphur ppm wt.	8	2
Water and Sediment Content, vol.%	0.05	3
Cloud point °C	48.7 - 49.6	3
Pour point °C (°F)	+21(+70)	1-2
Viscosity @100°F cSt	10.63	1
Avg. Molecular Weight Mw	244.7	3

METHODOLOGY

Process simulation software, Aspen HYSYS (Version 11), is used to model and simulate the refinery process. The Aspen HYSYS option Oil Manager is used to define crude oil, which is described by the TBP distillation curve taken from crude oil assay reported by Libyan Petroleum Institute (LPI) [1,4]. HYSYS contains several components in its data bank. The components are well defined with their thermodynamic and physical properties, temperature-dependent properties such as enthalpy and critical properties. Other unknown components of the Crude are determined from the crude characterization in HYSYS. The property package in HYSYS includes the equation of states (EOSs), activity models, Chao Seadre models, and vapor pressure models. One of the property packages in EOS is Peng-Robinson. It is chosen as it is properly suited crude oil analysis. The Peng-Robinson method utilizes EOS in its enthalpy calculations. Crude oil is a mixture of many identified chemical components and pseudo-components whose chemical identity might be difficult and sometimes impractical to determine. Hence, there is a need for the characterizations of the Crude. The Crude was characterized using an experimental assay that includes the bulk crude properties, ASTM distillation, API gravity, and TBP distillation (see appendix). The result of the characterization is detailed chemical compositions of the identified components and the pseudo-components. The complete and definitive analysis of crude oil is called crude assay [4,5].

ADU PRODUCT SPECIFICATION

Product quality specification is a measure of the yield of ADU products. Product quality can be specified in terms of product boiling ranges (T95 %), the boiling temperature when 95 % of the material has vaporized using a standard test, such as ASTM D86 [5]. Table (2) shows the product specification of the Sarir oil refinery reported by Libyan Petroleum Institute (LPI) [1].

Table 2: ADU Product Specifications

Products	Specifications (°C)
Light Naphtha	ASTM D86 95% = 90
Heavy Naphtha	ASTM D86 95% = 160
Kerosene	ASTM D86 95% = 221
Diesel	ASTM D86 95% = 327
RES	ASTM D86 95% = < 550+

SIMULATION RESULTS

This section presents the summary results calculated by Aspen HYSYS simulation (Version 11). All the presented data and findings will be mentioned and discussed further in the following sections.

Refinery Process Simulation

The crude oil is heated by preheat trains with some of the hot cuts from the atmospheric distillation unit (ADU). The oil then is pumped to desalter at pressure 863 kPa and temperature at 150°C, with a flow rate of 55683 kg/h (10,000 BPD) and water is added with a flow rate 3306 kg/h (5% of Oil flow rate) mixed with the Crude to desalt the inorganic salts, such as sodium chloride. The crude oil is then routed to a furnace (main heating process), where it is heated to a temperature of about 350°C at this temperature, the crude oil is a two-phase mixture of liquid and vapour. The Crude oil at a rate of 54420 kg/h is fed to the ADU (34 valve trays) at a pressure about 233 kPa, sent to the bottom of ADU at the thirty first tray (flash zone). The ADU serves to distil the crude oil into several cuts. These cuts include Naphtha, Kerosene, Diesel and Atmospheric Residue. Then, the side product Naphtha is heated to a temperature about 186 °C and fed to a depentanizer column (15 valve trays) at eighth tray with a flow rate of 8706 kg/h and pressure of 1825 kpa, to split Naphtha into Light and Heavy. Figure 2 shows the complete steady state model for the refinery process units. All operation conditions flow rates, temperatures and pressure have been taken from the AGOCO operations department & T.A.D [6].

Simulation of ADU

The main column ADU in Sarir Refinery consists of 34 valve trays with a partial condenser, two pumps around top and bottom for Naphtha and Diesel respectively and two side steam strippers for Kerosene and Diesel, see Figure (3). The streams inlet and outlet of the ADU are shown in Table (3) and pump around specifications are shown in Table (4).

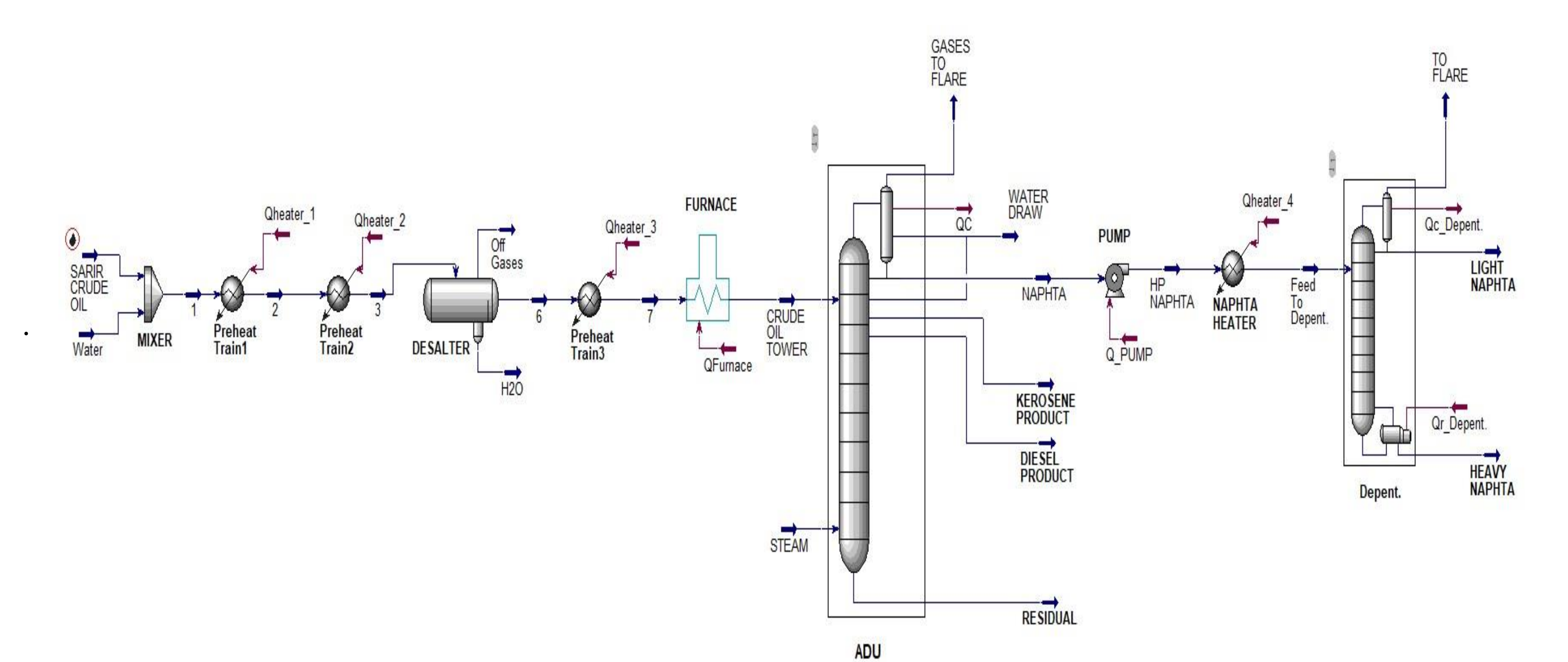

Figure 2: The Complete Steady State Model of the Sarir Oil Refinery

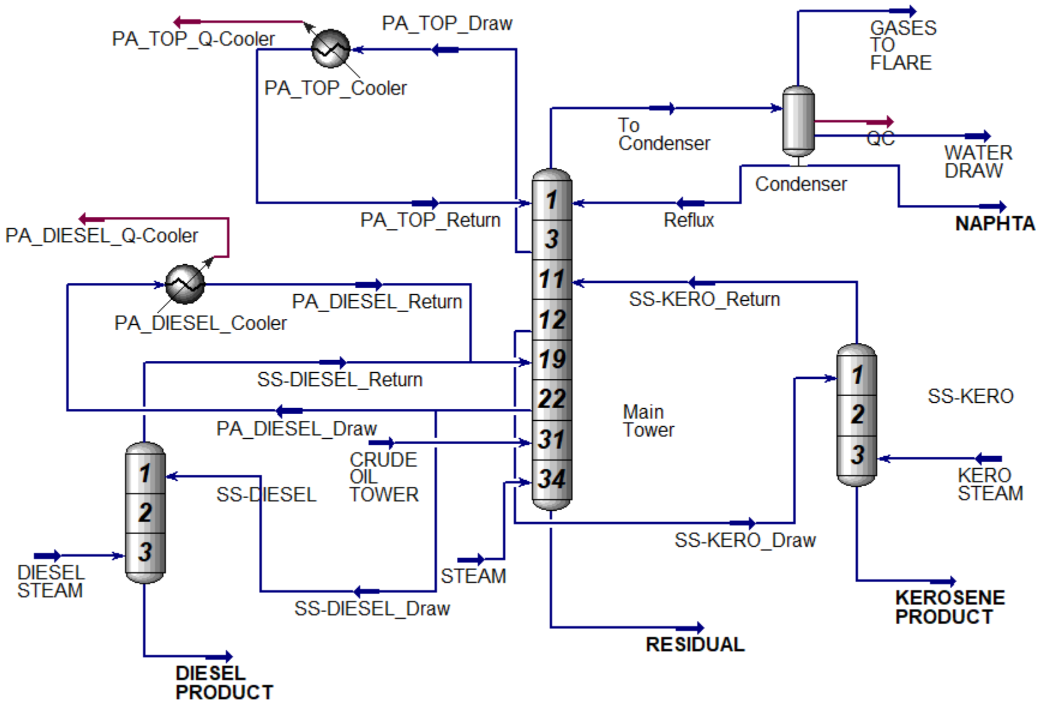

Figure 3: The Simulation of Atmospheric Distillation Unit (ADU).

Table 3: Inlet and Outlet Streams of ADU

Stream Name	Temperature °C	Pressure kPa	Mass flow kg /h
Crude oil tower	350	233	54420
Steam	150	476	340.2
Kerosene steam	150	476	68.04
Diesel steam	150	476	226.8
Gas To Flare	49	140	6.985E-6
Naphtha	49	140	8706
Kerosene product	126.3	210	952.2
Diesel product	214.8	219.1	17709.24
Residual	341.9	230	26937.99
Water draw	49	140	745.5

Table 4: Pump around Specifications

Pump around	Draw Tray	Return Tray	Flow Rate (kg/h)	Draw Temperature (°C)	Return Temperature (°C)
Top pump around (TPA)	3	1	29777.64	143.9	80.99
Bottom pump around (BPA)	22	19	60423.66	232.4	173.99

Temperature Profile

The temperature profile across the ADU is shown in Figure (4), which represents the steady-state model of the crude distillation unit, which will be helpful to know the steady-state points of tray temperatures and product composition [9].

Loading Profile

Figure (5) shows the simulated loading profiles of net liquid and net vapor flow rates in the atmospheric unit. The vapor inside the tower comes from both steam and hydrocarbons vapor. Water enters the system from desalter carryover, soluble water from the feed, atmospheric tower stripping steam, and side-stripper steam. There was an increase in liquid mass flow rate between stages 1 to 3 and stages 19 to 22 because of the top and bottom pump around external flow (Naphtha and Diesel pump around). The vapor phase flow rate for all products is approaching zero at the bottom of ADU, indicating that they are entirely in the liquid phase (atmospheric residue).

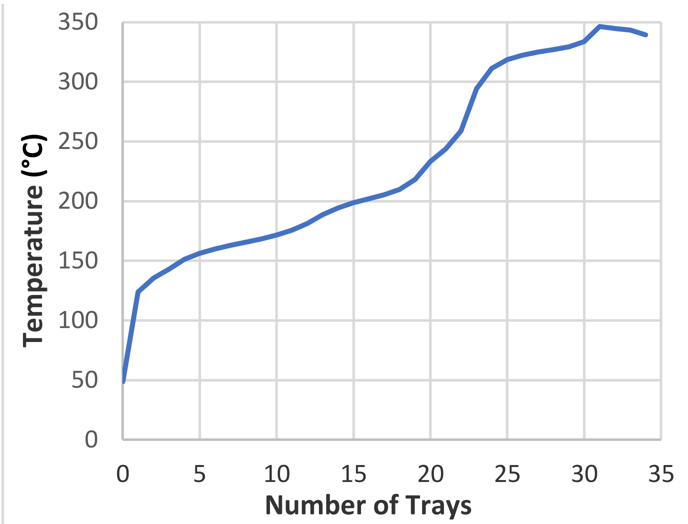

Figure 4: Temperature Profile Through the ADU.

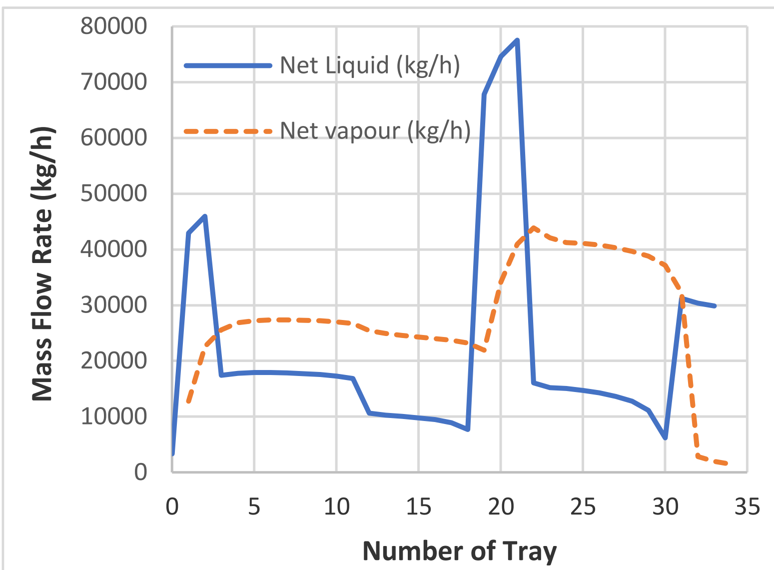

Figure 5: Loading Profiles Through the ADU.

Simulation of Refinery Products

The final product qualities are evaluated in simulation through the ASTM D86 distillation curves for light Naphtha, Heavy Naphtha, Kerosene, Diesel, and residual. The most critical points of these curves, which define the separation between products, are the 95% ASTM D86. These correspond to temperatures where 95% of the products vaporized under the specific conditions of the quantification method; the quality of the product can be regarded as satisfaction guaranteed [5,8] (see Table 5). Figures (6 – 9) show the lab and simulated ASTM D86 curves for light Naphtha, Heavy Naphtha, Kerosene, and Diesel, respectively. Figure (10) shows only the simulated ASTM D86 curve of residual as the lab data were not available to compare with. The simulation results of products show a good agreement with laboratory ASTM-D86 curves. However, some minor differences between lab and simulated ASTM-D86 curves for light Naphtha were revealed. This slight difference in light Naphtha might be arisen due to the absence of light hydrocarbon, which was auto calculated in the simulation itself. Also, the simulation results of production rates were compared with the actual refinery data (see Table 6). The simulated Total Naphtha flow rate showed the lowest difference compared with the refinery plant data with a percentage error of about 0.3%.

Table 5: Comparison between Laboratory and Simulated ASTM D86 Temperatures for Refinery Products.

Product	Lab Result (°C)		Simulation Result (°C)	
Volume %	5%	95%	5%	95%
Light Naphtha	42	90	-9	97
Heavy Naphtha	96	160	83	153
Kerosene	185	221	159	214
Diesel	262	346	235	339
Residual	346	< 550+	329	738

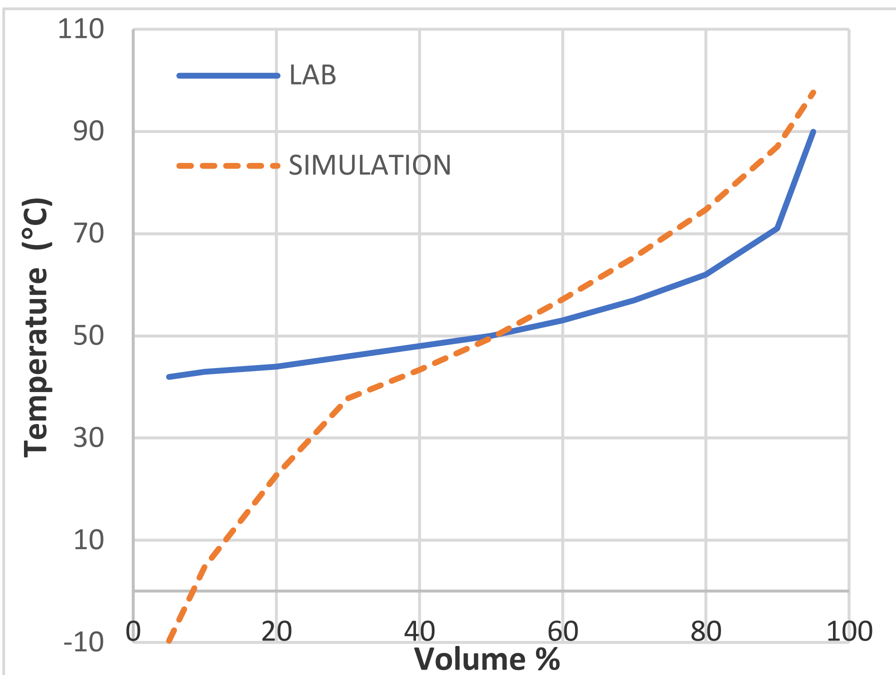

Figure 6: Laboratory and Simulated ASTM D86 Curves of Light Naphtha.

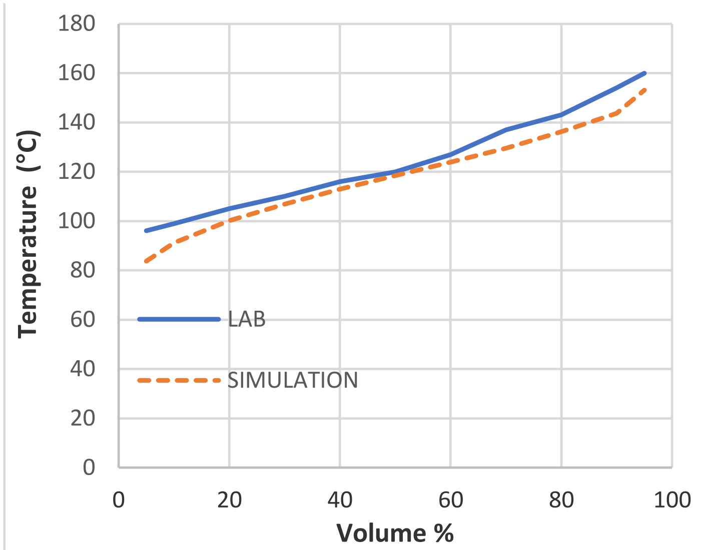

Figure 7: Laboratory and Simulated ASTM D86 Curves of Heavy Naphtha.

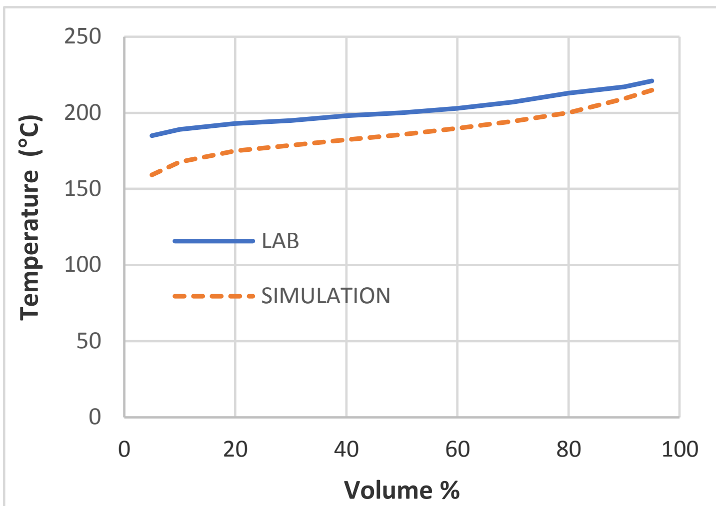

Figure 8: Laboratory and Simulated ASTM D86 Curves of Kerosene.

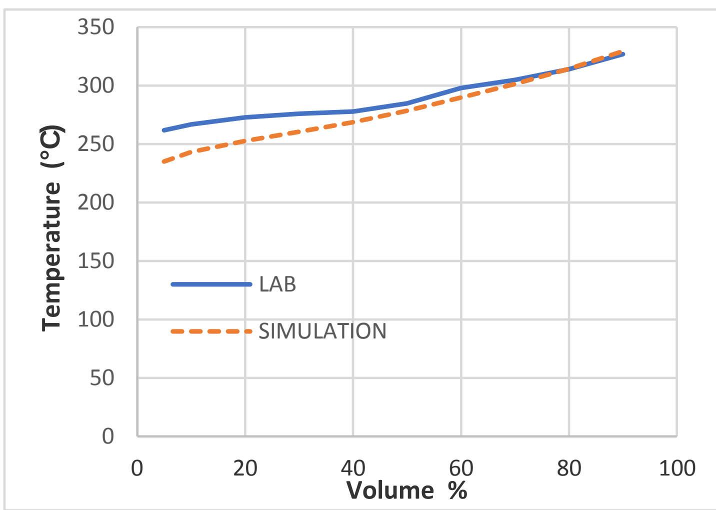

Figure 9: Laboratory and Simulated ASTM D86 Curves of Diesel.

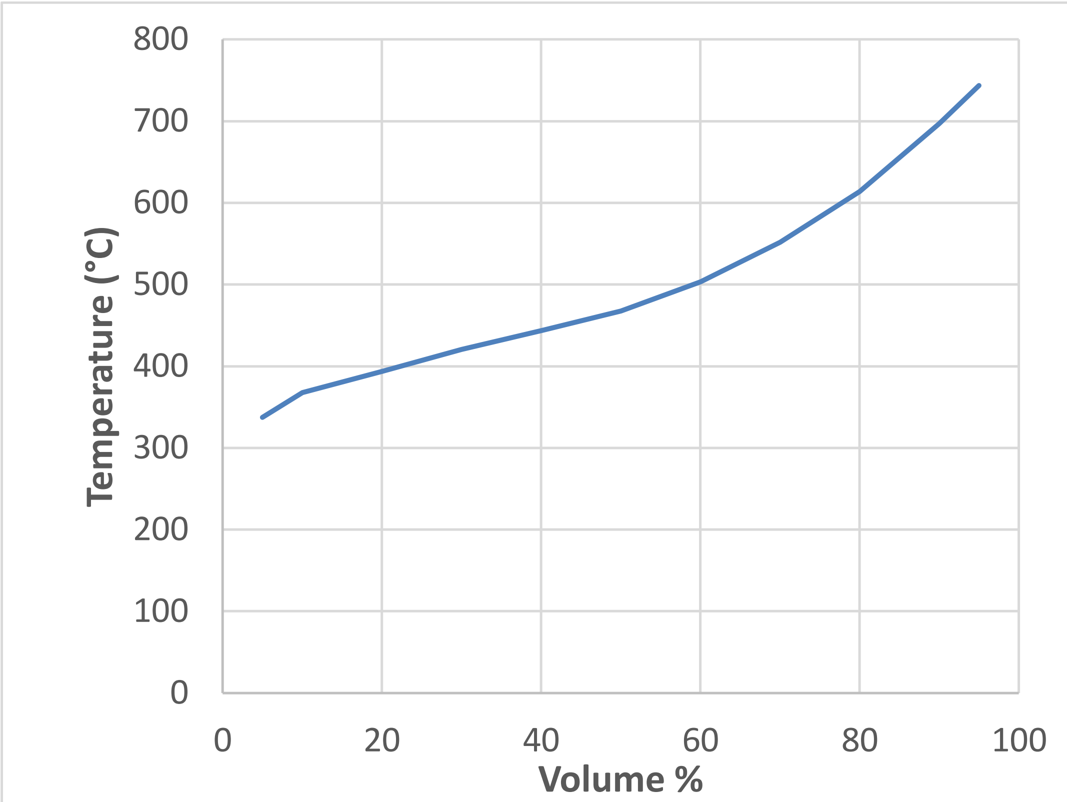

Figure 10: Simulated ASTM D86 Curve of Residual.

Table 6: Comparison of Products Flow Rates between Actual Refinery Data and Simulation Results.

Product	**Product in the Refinery (Metric Tons/day)**	**Product in the Simulation (Metric Tons/day))**	**Error %**
Total Naphtha	208.2	208.95	0.360
Kerosene	20	22.85	12.5
Diesel	393	425.018	7.53
Residual	706.1	646.5	9.22

CASE STUDY

Here in the case study, a pre-flash column was proposed to be added before the furnace (see Figure 11). This approach allows the vapor leaving the flash unit to be fed to a suitable location to the main column (according to the temperature of the tray). On one hand, the simulation results for adding the pre-flash column showed no significant effect on the product quality. On the other hand, energy consumption in the furnace and ADU was decreased (see Table 7 and 8). Similar results were found in the study of Martínez et al. (2017) [7].

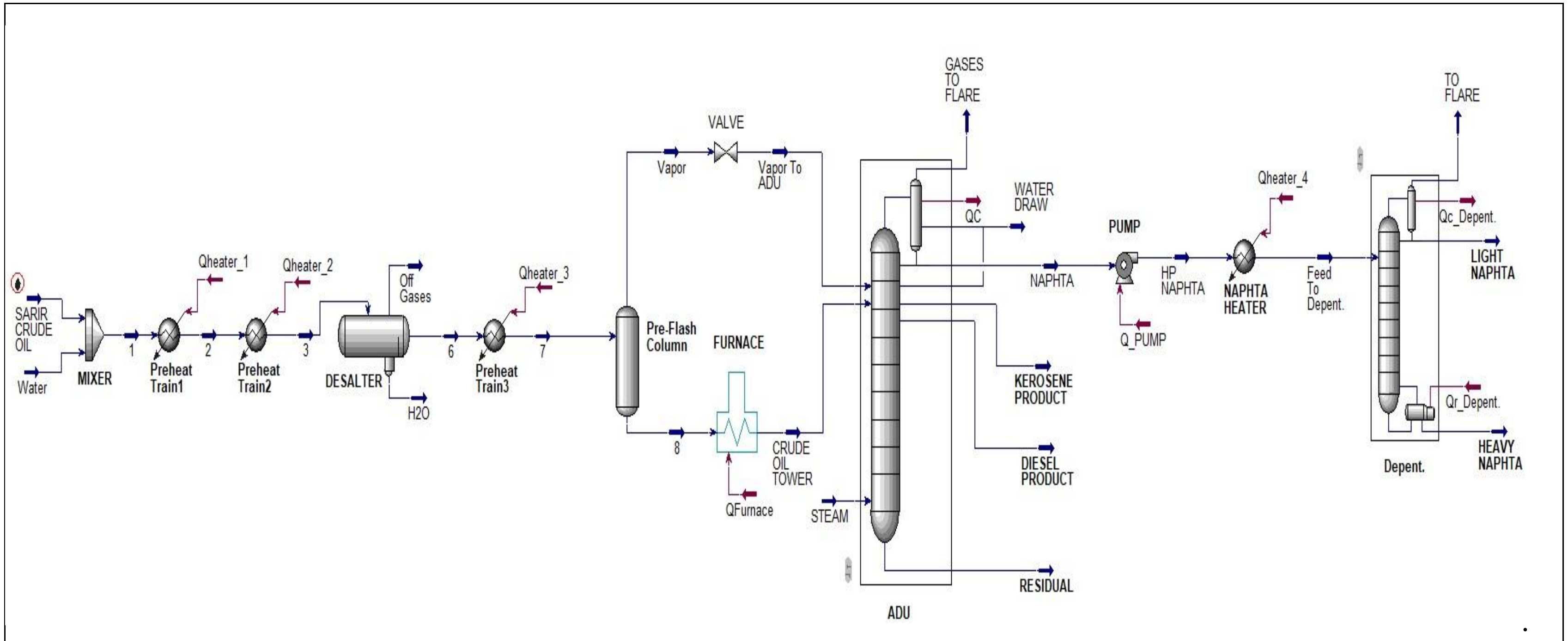

Figure 11: The Complete Steady State Model of the Sarir Oil Refinery with a Pre-Flash Unit.

Table 7: Comparison between Base Case and Study Case by ASTM D86 Temperatures.

Product	Study Case (With Pre-Flash) ASTM D86 (°C)		Base Case (Without Pre-Flash) ASTM D86 (°C)	
Volume %	5%	95%	5%	95%
Light Naphtha	-9.695	97.68	-9.697	97.53
Heavy Naphtha	83.71	153.1	83.75	153.6
Kerosene	159.2	214.7	157.9	233.5
Diesel	235.2	339.7	226.2	347.1
Residual	329.4	738.8	321.6	738.8

Table 8: Shows the Main Features between the Base Case and Study Case.

Variable	Units	Base Case (No flash)	Study Case (With flash)
Mainstream flow rate	kg h^{-1}	54420	49230
TPA duty	kW	1255.46	1216.32
BPA duty	kW	2637.99	2513.47
TPA ΔT	°C	-62.86	-61.02
BPA ΔT	°C	-58.43	-55.75
Flash Temperature	°C	-	254.9
Vapor feed (section No.)		-	22
Furnace duty	kW	5294.5	4776
Condenser duty	kW	2587	2279

CONCLUSION

The commercial software Aspen HYSYS is used to simulate Sarir crude oil Refinery at steady-state operation.

The study involved predicting both temperature and loading profiles across the atmospheric distillation unit (ADU).

Detailed information was found for the temperature distribution of product cuts by ASTM-D86 curves for each product Light Naphtha, Heavy Naphtha, Kerosene, Diesel, and residual.

Simulated ASTM D86 curves were compared with laboratory data for light Naphtha, Heavy Naphtha, Kerosene, Diesel, and residual. The simulation results show a good agreement with laboratory ASTM-D86 curves for all products except Light Naphtha, where a noticeable difference was revealed.

Simulation results of production rates were compared with the actual refinery data. The results of the flow rate of Kerosene, Diesel and Residual showed noticeable differences from refinery plant data. At the same time, a simulated Total Naphtha flow rate showed the lowest difference compared with the refinery plant data with a percentage error of about 0.3%.

The Proposed pre-flash column showed an improvement in the furnace and ADU energy consumption.

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APPENDIX

The following table shows the evaluation of Sarir crude oil, prepared by the Libyan Petroleum Institute [1]. This crude assay was used as input parameters required in HYSYS simulation. The Oil Characterization option in Aspen HYSYS is used to model a crude oil.

Sarir Crude Oil Assay

TBP Distillation		**Light End Hydrocarbons**	
Temp. (°C)	**Vol. %**	N. D	
70	7.44	**Properties**	
90	10.47	Density @ 15°C g/ml	0.8415
110	13.83	API gravity @60°F	36.5
150	21.16	Sulphur Content, wt.%	0.120
195	28.52	Viscosity @100°F cSt	10.63
215	31.54	Avg. Molecular Weight	244.7
255	38.03		
275	41.76		
295	44.68		
335	51.97		
370	59.19		
400	63.50		
460	72.52		
480	75.61		
500	78.66		
520	81.05		
550	83.70		
550+	100		