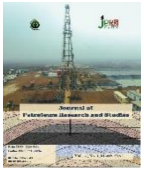
Journal of Petroleum Research and Studies

journal homepage: https://jprs.gov.iq/index.php/jprs/

Print ISSN 2220-5381, Online ISSN 2710-1096



Enhancing Distillation Efficiency at Petroleum Refinery Through Hydraulic Performance Analysis of Atmospheric Distillation Tower

Ahmed Qasim[1*], Muhanad Mohan[1], Nazar Qasim[2]

[1]Midland Refineries Company, Ministry of Oil, Iraq.

[2]Oil Products Distribution Company, Ministry of Oil, Kirkuk, Iraq.

[*]Corresponding Author E-mail: darkknight199090@gmail.com

Article Info

Received 15/12/2024
Revised 19/01/2025
Accepted 22/01/2025
Published 19/03/2026

DOI: http://doi.org/10.52716/jprs.v16i1.1057

Abstract

Efficient operation of petroleum refineries is crucial for optimizing energy production and economic viability. This study innovatively applies aspen HYSYS Version.14 to conduct a comprehensive hydraulic performance analysis of atmospheric distillation tower trays at Refinery. By integrating real plant operational data, the research addresses pivotal inefficiencies in the distillation process, particularly focusing on mechanical challenges such as tray weeping and flooding. The simulation efforts validate the model against empirical data, showcasing high correlation coefficients for key petroleum fractions, with values exceeding 0.93 for light naphtha, heavy naphtha, and gasoil, and slightly lower at 0.86 for kerosene. The findings highlight specific hydraulic deficiencies in the lower trays of the stripping section and propose precise improvements in tray design and alignment. Implementation of these recommendations is projected to substantially enhance separation efficiency, reduce maintenance frequency, and decrease operational disruptions. This paper contributes a novel, validated methodology for employing simulation tools in troubleshooting and optimizing refinery operations, offering a significant advancement in applying simulation technology to improve the petroleum industry's sustainability and reliability. The actionable insights derived from this study, demonstrated through the enhanced correlation coefficients, have the potential to revolutionize refinery practices by providing a robust basis for future enhancements.

Keywords: Crude distillation, Refinery, Simulation, Trays, Weeping.

تعزيز كفاءة التقطير لمصفاة النفط من خلال تحليل الأداء الهيدروليكي لبرج التقطير الجوي

الخلاصة

تعد الكفاءة التشغيلية لمصافي النفط أمرًا بالغ الأهمية من أجل تحسين إنتاج الطاقة والجدوى الاقتصادية. يطبق هذا البحث بشكل مبتكراستخدام برنامج aspen HYSYS الإصدار الرابع عشر لإجراء تحليل شامل للأداء الهيدروليكي لصواني برج التقطير الجوي لمصفاة النفط. من خلال دمج بيانات التشغيل الفعلية للمصنع، يعالج البحث الكفاءات غير الفعّالة في عملية التقطير، مع التركيز بشكل خاص على التحديات الميكانيكية مثل التسرب والفيضانات في الصواني. تساهم جهود المحاكاة في التحقق من صحة النموذج من خلال مقارنة

البيانات التجريبية، مما يظهر ارتباطًا عاليًا للمعاملات بين مكونات النفط الرئيسية، حيث تتجاوز القيم 0.93 للنافثا الخفيفة، والنافثا الثقيلة، وزيت الغاز، بينما تنخفض قليلاً إلى 0.86 للكيروسين. تبرز النتائج العجز الهيدروليكي المحدد في الصواني السفلية في قسم الاسترجاع، وتقدم اقتراحات لتحسينات دقيقة في تصميم الصواني ومحاذاتها. من المتوقع أن تؤدي تطبيق هذه التوصيات إلى تحسين كبير في كفاءة الفصل، وتقليل تكرار الصيانة، والحد من اضطرابات العمليات. يساهم هذا البحث بمنهجية مبتكرة وموثوقة لاستخدام أدوات المحاكاة في تحديد المشكلات وتحسين عمليات المصافي، مما يشكل تقدمًا كبيرًا في تطبيق تقنيات المحاكاة لتحسين استدامة وموثوقية صناعة النفط. إن الأفكار القابلة للتنفيذ المستخلصة من هذه الدراسة، التي تم إظهارها من خلال الارتباطات المعززة، تتمتع بإمكانية تحويل ممارسات المصافي عبر توفير أساس قوي للتحسينات المستقبلية.

1. Introduction

The refinery process uses crude oil as fuel source to produce a wide range of petroleum-based products [1]. The crude oil distillation unit (CDU), also known as the atmospheric distillation column, is an essential part of nearly every refinery [2]. The crude oil refining process begins, separating the crude oil into its various components according to their boiling points [3]. Petroleum refinery, established in 2008, has an atmospheric distillation unit with a production capacity of 10,000 barrels per day. The refinery's atmospheric distillation unit produces various crude oil derivatives, including off gases, light naphtha (L.N), heavy naphtha (H.N), kerosene, gasoil, and reduced crude residue (R.C.R), with volumetric proportions: off gases at 1%, light naphtha and heavy naphtha at 17%, kerosene at 8%, gasoil at 13%, and reduced crude residue at 62%. The presence of trays in the atmospheric distillation tower enhances the effectiveness of separating crude oil derivatives by improving the interaction between liquid and vapor, hence increasing the yield of petroleum products [4]. The trays allow for temperature control within the tower, ensuring optimal conditions for distillation. Various issues can arise with the trays that significantly impact separation efficiency and overall production of petroleum derivatives. These issues include tray corrosion, fouling, flooding, weeping, and damage [5]. There are different types of trays used in distillation columns, including bubble cap trays, sieve trays, and valve trays. Each type has its own advantages and applications [6]. Petroleum refinery's atmospheric distillation column consists of 29 valve trays, which combine features of both bubble cap and sieve trays. Valve trays provide adjustable vapor flow and reduce the risk of weeping and flooding, making them versatile for a wide range of operating conditions. Petroleum refinery evaluates the atmospheric distillation tower trays by placing sensors along the tower to monitor temperature and pressure, conducting visual inspections for wear, corrosion, and fouling, conducting mechanical integrity testing to ensure structural soundness, and using flow meters to measure liquid and vapor distribution across the trays. This data aids in assessing the trays' efficiency in maintaining the required conditions for optimal separation. Now, the advantage of using process simulation is its ability to predict potential issues and identify areas for improvement in a cost-effective and time-efficient manner [7]. By using aspen HYSYS to simulate the performance of atmospheric distillation tower trays, engineers can find out how things like the design of the tray, the material used to make it, and the operating conditions affect how well it separates things and how well the column works overall [8]. This allows engineers to troubleshoot potential problems, such as flooding, weeping, and fouling, without the need for expensive and time-consuming pilot plant testing or plant shutdowns. Using aspen HYSYS V.8, a study [9] found optimal operating conditions for an atmospheric distillation column at Al-Dura refinery, capable of processing various blends of heavier, moderate, and lighter crude oils. The simulation closely matched industrial plant results and effectively predicted conditions for distilling a light-heavy crude oil blend at different mixing ratios. A study [10] explored the feasibility of using aspen HYSYS for simulating a crude distillation tower in Basra refinery under steady state operations. The comparison between the simulation and actual plant data showed that the mass flow rates of kerosene, LGO, off gas, and HGO matched perfectly with those of the real tower conditions. However, the flow rates for naphtha, residual, and wastewater varied slightly, with an error difference ranging from 6% to 11% between the simulated and actual plant results. Research [11] focused on the optimization of Iraqi oil blending by analyzing the physical and chemical properties of three types of Iraqi crude oils. Each oil underwent a specific petroleum assay to measure boiling temperatures, density, viscosity, and sulfur content of fractions derived from air distillation. The study utilized aspen HYSYS to calculate the necessary blending ratios to enhance or produce a distillation product, potentially increasing the final product's market value.

Distillation columns are critical in the chemical and petrochemical industries for separating mixtures into their individual components based on vapor-liquid equilibrium principles [12]. Each tray in a distillation column operates at its respective bubble and dew points, forming an equilibrium system essential for effective separation. Generally, three main sections divide the column: rectification, stripping, and feed or flash zone [13]. Figure (1) shows main sections of the atmospheric distillation column [14].

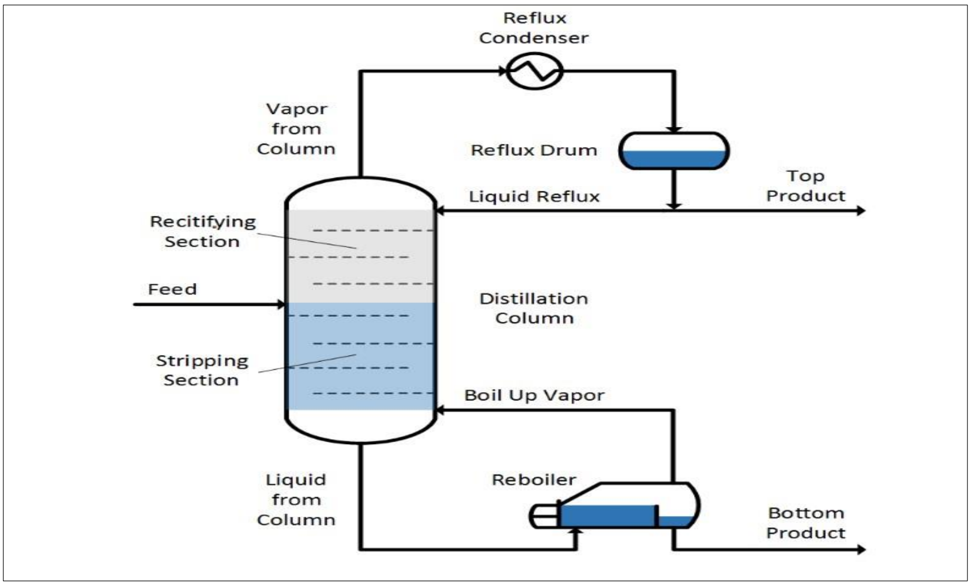


Fig. (1): Main sections of distillation column

In the rectification section, rising vapor interacts with down flowing liquid to remove less volatile components from the vapor. Conversely, the stripping section involves the rising vapor removing more volatile components from the down flowing liquid. The feed section, situated between these two sections, introduces the mixture into the column [15]. Trays within the distillation column enhance mass transfer by providing a structured environment for phase contact [16]. These trays, equipped with openings to facilitate interaction, are evenly distributed inside the cylindrical column casing. Each tray typically includes down comers that allow liquid to flow from one tray to the next via gravity. While one-pass trays are common, two-, three-, and four-pass trays can also be used to reduce liquid flow paths [17]. Liquid flows from the tray above into the down comer, across the tray below, and over a weir into another down comer. The weir controls the liquid level on each tray, ensuring consistent phase contact in the active area where vapor from the tray below interacts with the liquid [18]. A proper down comer design is critical to preventing froth and ensuring smooth liquid flow. Tray spacing is optimized based on economic trade-offs between column height and diameter [19]. Figure (2) shows main parts of tray [20].

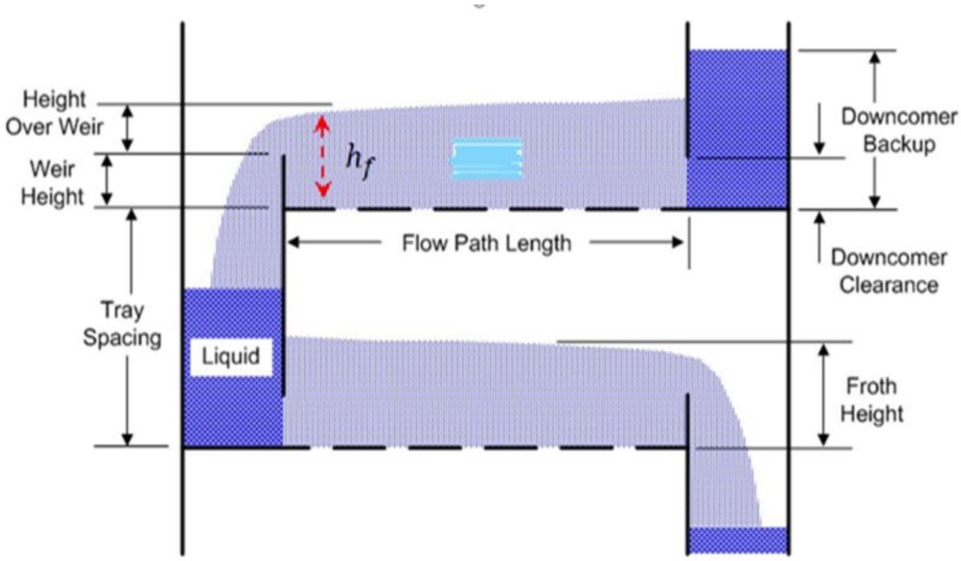


Fig. (2): Parts of tray

The vapor and liquid flow rates govern the operational efficiency and safety of a distillation column as shown in Figure (3) [21]. Deviations from optimal flow rates can lead to various hydraulic issues that hinder mass and thermal transfer, thereby affecting the column's overall performance such as: Flooding occurs when liquid accumulates excessively on a tray, indicating the column's maximum capacity. Either jet flooding or downcomer flooding can cause this sudden pressure drop [22]. Weeping happens when vapor rates are too low to support the liquid on the tray, allowing the liquid to seep through the perforations. This reduces the column's efficiency as the desired vapor-liquid equilibrium cannot be maintained [23]. Entrainment involves the excessive velocity of vapor, which carries liquid droplets from one tray to the above tray. This phenomenon not only reduces tray efficiency by mixing lower-volatility liquid with higher-volatility liquid but also contaminates high-purity distillate with nonvolatile components [24]. Dumping is a condition where liquid bypasses the normal flow path on the tray and falls directly into the down comer without adequate contact with the vapor phase. This can occur due to improper tray design, excessive liquid flow rates, or significant vapor flow maldistribution. Dumping significantly reduces mass transfer efficiency, which can lead to poor separation performance in the column [25].

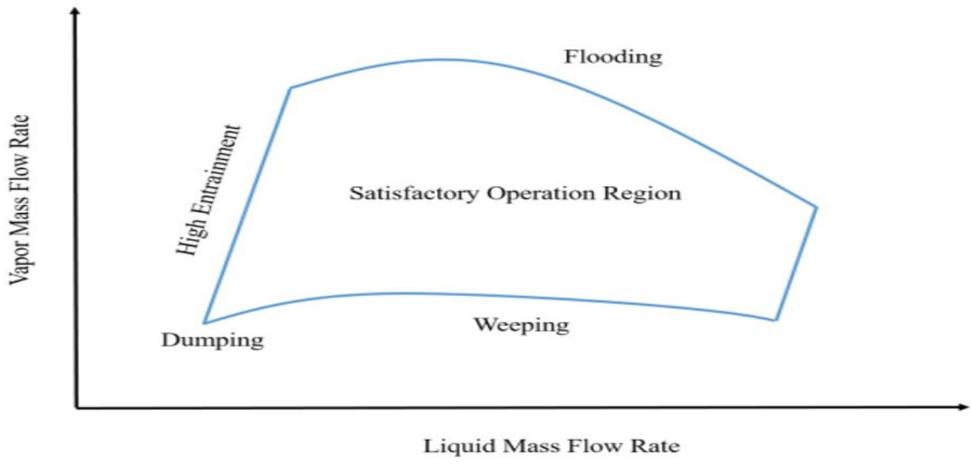


Fig. (3): Operation limits of tray

A thorough understanding and management of these hydraulic issues are essential for maintaining the effectiveness and reliability of distillation columns. Advanced monitoring and control systems are often employed to detect and mitigate such issues, ensuring consistent and efficient column operation [26]. The objective of this study is to assess the performance of the atmospheric distillation tower trays at petroleum refinery through the use of aspen HYSYS V.14. This assessment involves simulating the steady-state operation process and comparing the simulation results to actual plant data to evaluate the accuracy and efficiency of the distillation system.

2. Materials and Methods

2.1. Materials

The crude oil used at petroleum refinery as detailed in Tables (1) and (2) is sourced from petroleum fields.

Table (1): Specifications of crude oil

Property	API (-)	Density (kg/m^3)	Bs &W (V%)	Salt content (ppm)	Sulfur content (ppm)	Viscosity (cSt)
Value	29.8	876	0.15	159	30000	12.7

Table (2): Distillation of crude oil

Volume %	2	3.5	5	7.5	10	13	15	18	20	25	30	35	40	45	50
Temperature(°C)	40	52	62	77	95	112	128	143	159	189	218	249	279	310	342

2.2. Methods

10,000 barrels of crude oil per day (66 m^3/hr) is drawn from storage tanks using a feed pump. The first preheat train of the heat exchangers network (HEN) raises the temperature from 25°C to 150°C, and the second train uses a furnace to raise the temperature from 150°C to 300°C. The outlet from the furnace is going to ADC (Atmospheric distillation column). ADC is equipped with 29 trays and feed enters flash zone between 3 and 4 trays with temperature and pressure 300°C, 1.5 bar-g respectively. The CDU aims to refine the crude oil to many fractions. These cuts include Naphtha, Kerosene, Gasoil and Reduced crude residue. The L.N is extracted from the top column, condensed, and then transferred to the reflux drum. From there, the off gas is burned off. In the reflux drum, L.N is returned to the top of the column for further processing, while a portion of it is directed towards the product. H.N I and H.N II have been withdrawn from the 24th and 22nd trays, respectively. Kerosene is withdrawn from tray no. 15 and flows to the stripper column. Gasoil is withdrawn from tray no. 9 and flows to the stripper column then cooled. After Gasoil is cooled, it is pumped around to tray 8 and part of it sent to product. The pump around specifications are provided in Table (3) and Table (4) provides the specifications for the side strippers.

Table (3): properties of Pump around Gasoil

Position between the trays.	Volume Flowrate. (m^3/hr)	Return temp. °C
8 and 9	3	60

Table (4): Steam mass flow rates and product flow rates for strippers

Strippers	Steam mass Flowrate (kg/hr)	Product, (m^3/hr)
Kerosene	75	6
Gasoil	125	9

The residual components in the atmosphere are removed in the lower part of the distillation column. The lowermost steam enters tray 1 with a flow rate of 300kg/hr at a temperature of 220˚C and a gauge pressure of 5 bar. The pressure at the top of the ADC is 0.75 bar-g, while the pressure at the bottom stage is 1.2 bar-g. Figure (4) shows the crude distillation unit of the refinery, consists of 29 stages, a partial condenser, two side strippers, and one pump around.

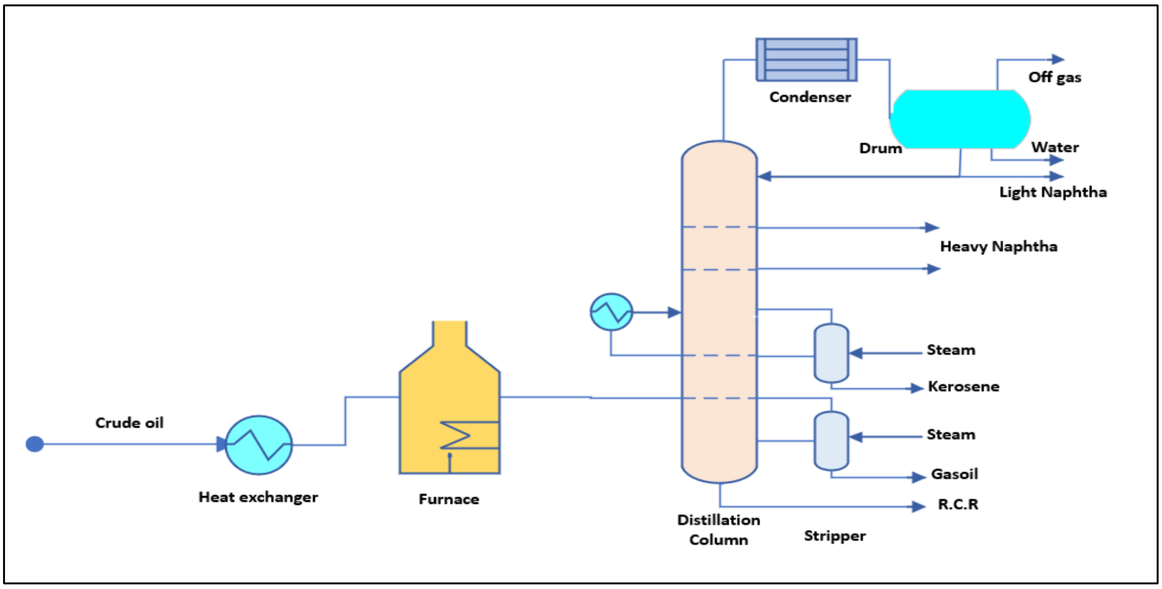


Fig. (4): Typical Crude Distillation Unit and Associated Unit Operations

Through the partial condenser, 8 m^3/hr of Light Naphtha and 0.4 m^3/hr of water stream are generated. 1 m^3/hr is also the off-gas production rate from the partial condenser. The liquid naphtha and gas mixture that exits the overhead condenser at around 60 ˚C can be used as fuel for the furnace or transferred to the flare. From the bottom of the tower, 42 m^3/hr of crude atmospheric residue is produced. The bottom plate of each side stripper produces a straight run output. Using steam to strip the kerosene side stripper allows for a 6 m^3/hr output, while steam stripping the gasoil side stripper yields 9 m^3/hr of gasoil.

Aspen HYSYS V.14 was utilized for process simulation due to its robust capabilities in modeling and optimizing refinery processes. This software is widely recognized in the industry for its accuracy and reliability in simulating complex distillation units [27]. The decision to use aspen HYSYS was influenced by its ability to provide precise control over process parameters and its extensive database, which includes the properties of various hydrocarbons and their behavior under different conditions [28]. The aspen HYSYS environment develops a steady-state model for the atmospheric distillation column of the refinery, which we use for simulation. For the thermodynamic behavior of streams, the Peng-Robinson property package is chosen. Selecting the right fluid package in aspen HYSYS is critical for precisely modeling the system's thermodynamics and equilibrium. The fluid package, or thermodynamic model, is used to calculate properties including phase behavior, heat capacity, enthalpy, and vapor-liquid equilibrium [29]. After the feed, product, and other streams have been defined, the simulation can start by defining the design variables. All product streams' flowrates in the simulation are fixed, including L.N., H.N., kerosene, gasoil, off gas, and residue. Figure (5) shows an ADU that separates the crude into its straight run products after heating the liquids in a pre-fractionation train. Figure (6) shows the flow diagram of the simulated refinery process and the data input stages for the simulation block.

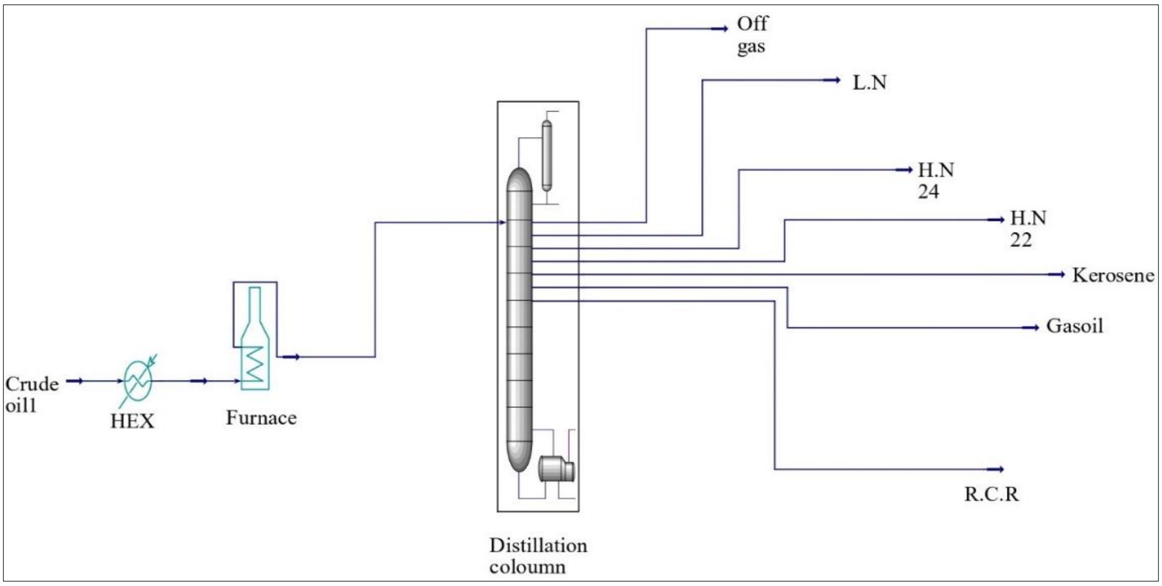


Fig. (5): Simulation of preheat trains and CDU

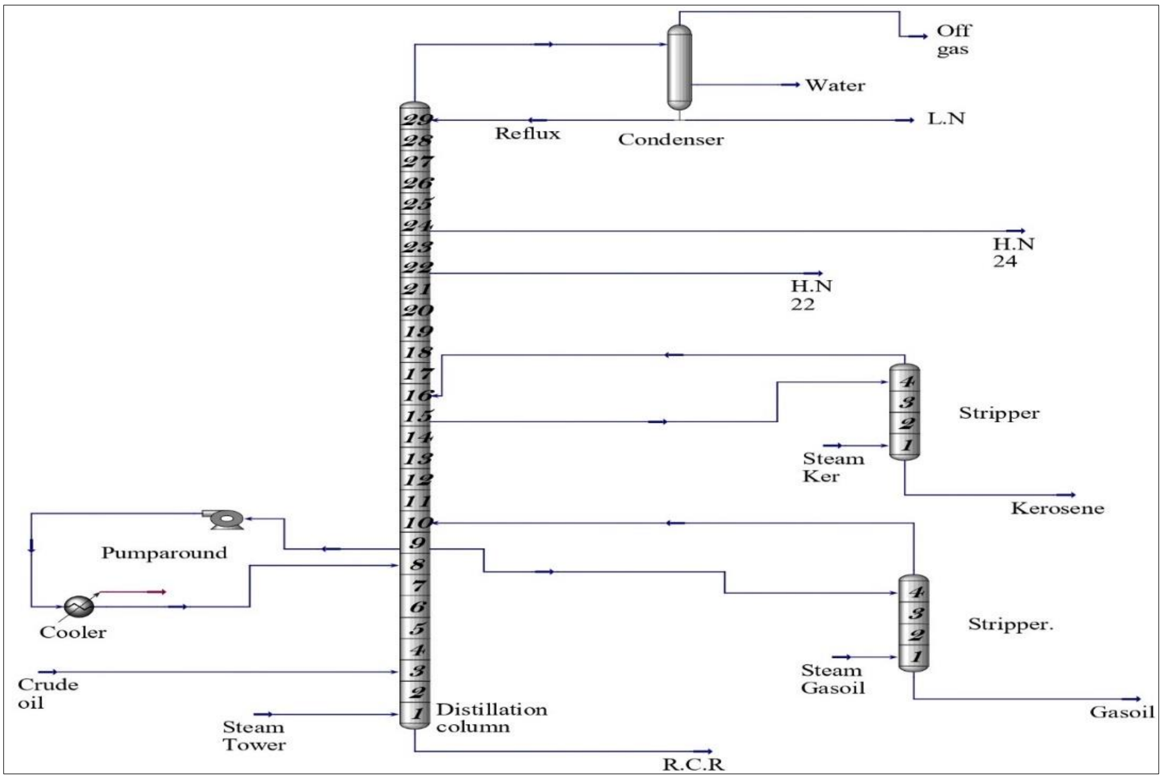


Fig. (6): Distillation column sub flow sheet in aspen HYSYS

The ASTM D86 distillation method for products was employed to validate the simulation results due to its standardization and widespread acceptance in the industry for determining the boiling range characteristics of petroleum products. This method provides a clear and consistent basis for comparing the simulated results with actual laboratory data, ensuring the reliability and accuracy of the findings [30]. The alignment of simulation results with laboratory ASTM D86 distillation curves was crucial for validating the model's accuracy. This validation step ensures that the model making the findings robust and applicable to real-world scenarios [31]. After model validation, the column hydraulic tool in aspen HYSYS was used to model the column internals. With the aid of hydraulic plots, the operating conditions of each tray were determined to identify hydraulic issues and observe how they affect other process variables. Distillation column consists of 29 valve trays (Ballast-V1). There are two main tray diameters (1.52 m, 2.13 m), resulting in varying numbers of holes per tray. One-pass trays in the column, tray spacing, weir, and down comer configurations were simulated appropriately as specified in the column data sheet. Figure (7) shows hydraulic plot of distillation column in aspen HYSYS.

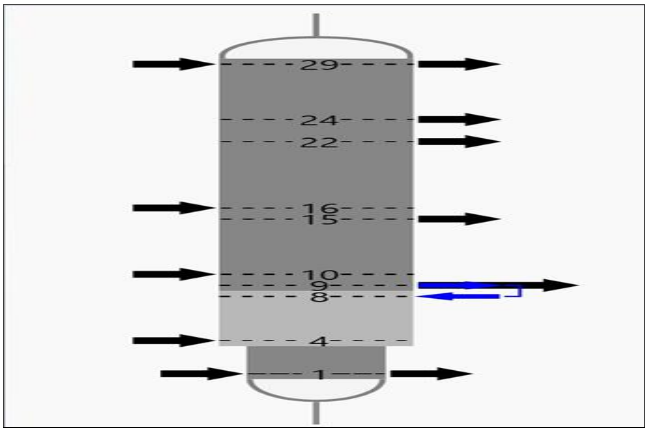


Fig. (7): Hydraulics plots of ADU

3. Results and Discussion

3.1. Comparison between simulation and actual results for distillation products

Figures (8) to (11) illustrate the comparison between the simulation results obtained using aspen HYSYS and the actual plant data for several distillation products, including L.N., H.N., kerosene and gasoil, as per ASTM D86 distillation curve standards.

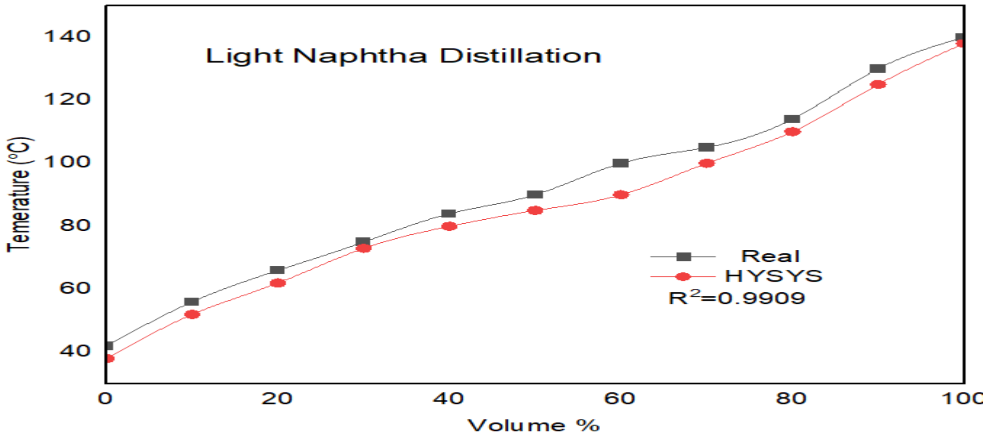


Fig. (8): Simulated and plant data ASTM D86 curves of L.N

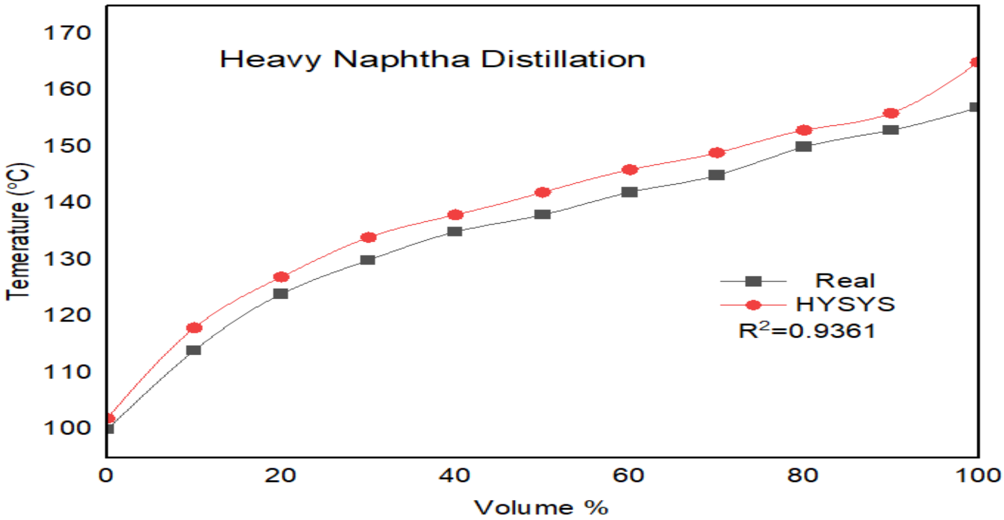


Fig. (9): Simulated and plant data ASTM D86 curves of H.N

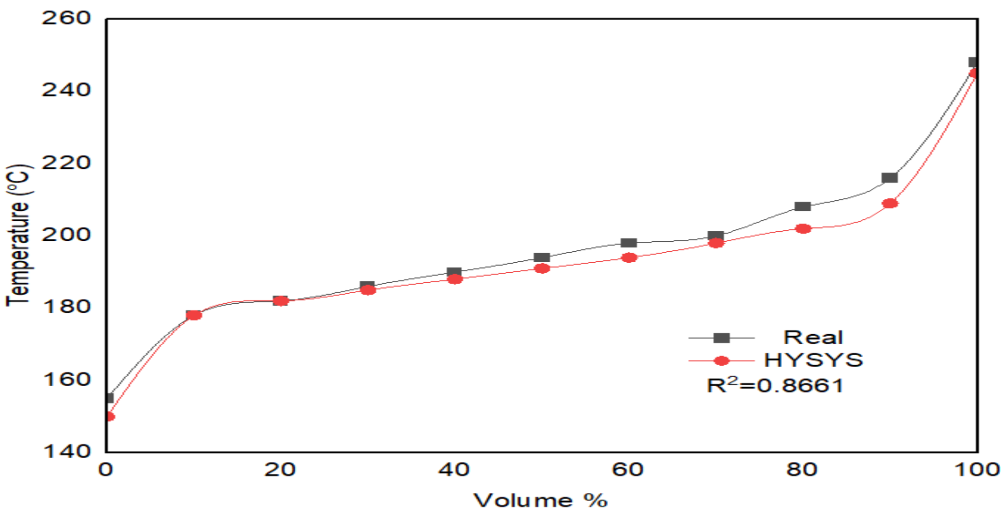


Fig. (10): Simulated and plant data ASTM D86 curves of Kerosene

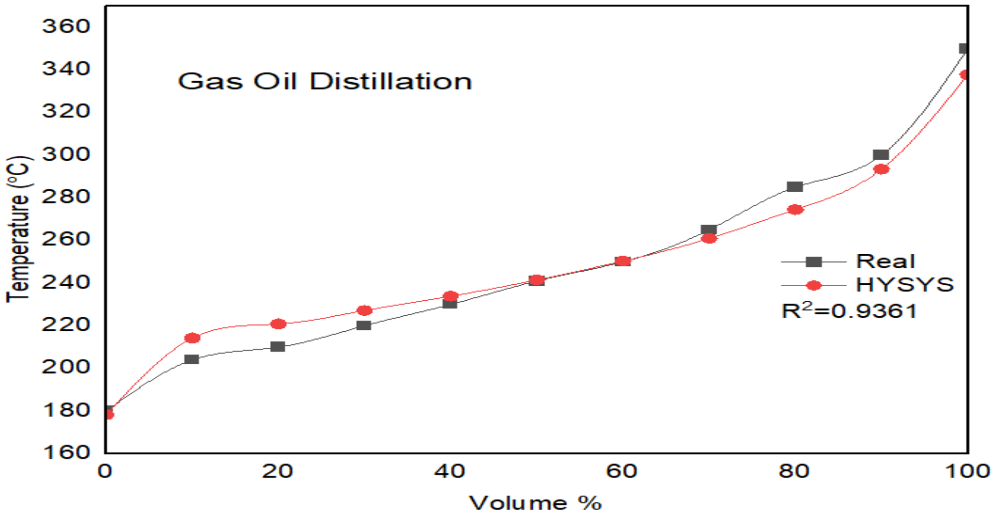


Fig. (11): Simulated and plant data ASTM D86 curves of Gasoil

3.2. Results for Model Validation

For validation purposes, the coefficient of determination (R^2) is a crucial statistical metric that quantifies how well the regression predictions align with the actual data points [32]. An R^2 value of 1 signifies a perfect fit between the regression predictions and the observed data [33]. In this study, the R^2 values for light naphtha (L.N), heavy naphtha (H.N), and gasoil exceeded 0.93, demonstrating a strong correlation between the simulation outcomes and the experimental data. However, the R^2 value for kerosene was 0.86, which, while still indicative of a reasonable fit, suggests the need to consider the limitations and uncertainties inherent in experimental measurements. Factors such as measurement accuracy, instrumentation precision, and process variability may have contributed to the observed discrepancies [34].

3.3. Analysis of Hydraulic Performance

Model validation suggests that the simulation model accurately predicts the behavior of the distillation columns and provides reliable results for the study. Once the process model was complete, the column hydraulic tool in aspen HYSYS was used to model the column internals. The operating conditions of each tray were determined using hydraulic plots to identify hydraulic issues and observe their impact on other process variables. Changes in the tray hydraulic condition were monitored via color changes in the hydraulic plot diagram in aspen HYSYS. A blue color means that the tray includes the region of satisfactory operation. A yellow color signifies that the tray closes to the limit of operability, while a red color signifies that the tray has exceeded the limit of operation. Figure (12) shows hydraulic plot in aspen HYSYS for atmospheric distillation column.

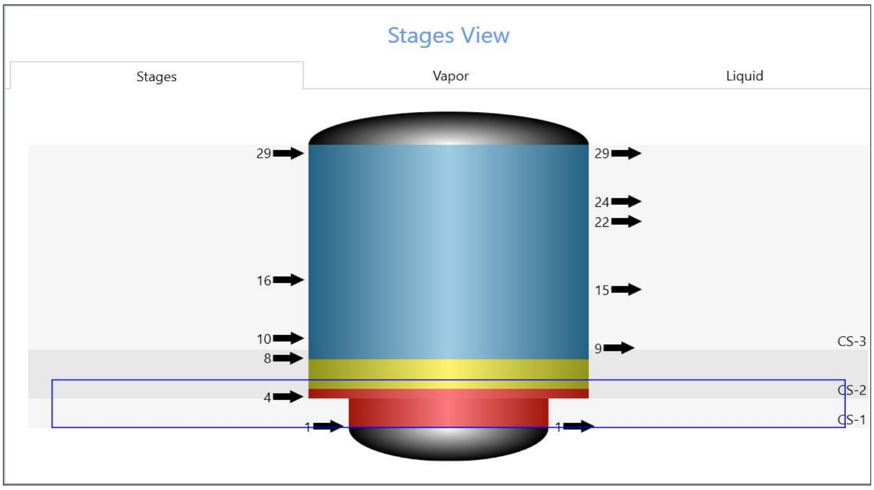


Fig. (12): Hydraulic plot of trays

As depicted in Figure (12), the rectifying section of the column, spanning trays 5 to 29, currently exhibits no hydraulic issues. Nevertheless, there are early indications of potential future complications, particularly observed in trays 5, 6, and 7. In contrast, the stripping section, from trays 1 to 4, encounters a weeping phenomenon. This issue is attributed to the deviation of both the vapor and liquid mass flow operating points from the acceptable operational region, thereby falling outside the safe operational envelope. Figures 13-16 shows weeping phenomenon for trays in stripping section.

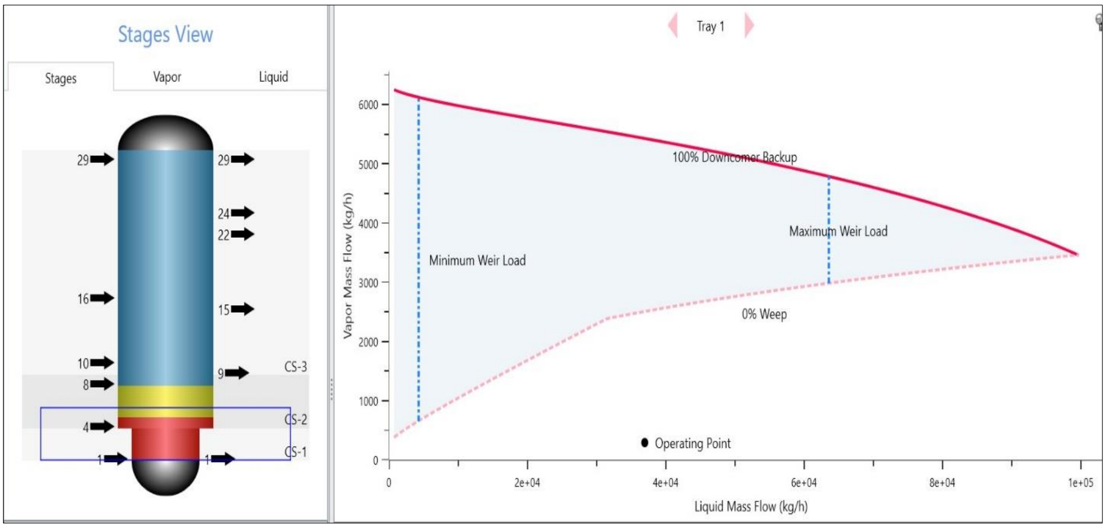


Fig. (13): Hydraulic issue of tray 1

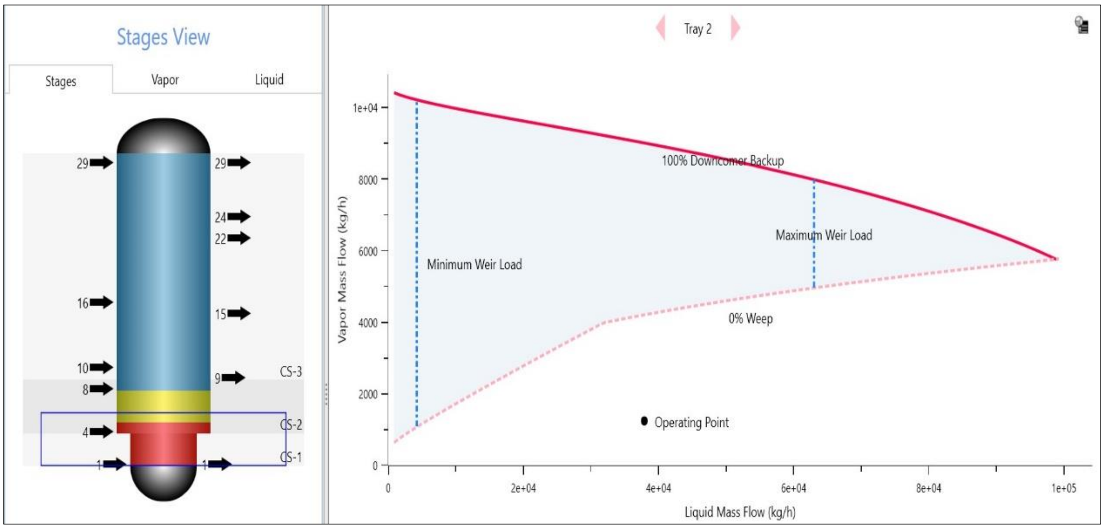


Fig. (14): Hydraulic issue of tray 2

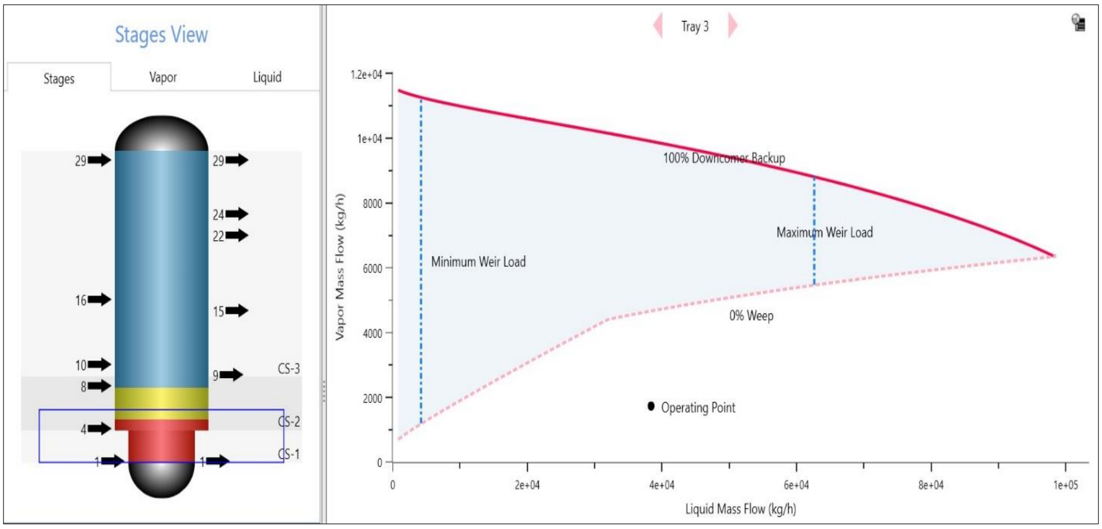


Fig. (15): Hydraulic issue of tray 3

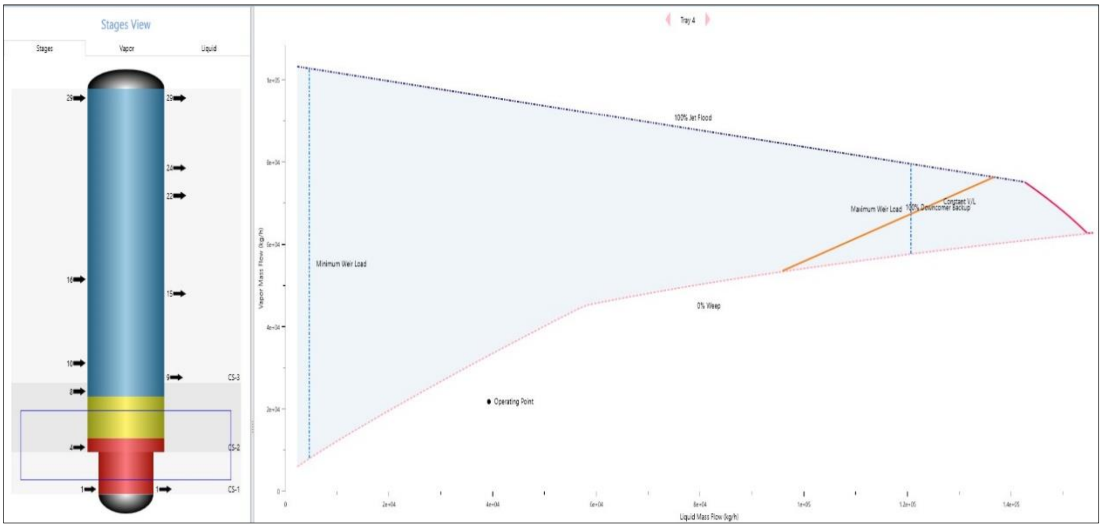


Fig. (16): Hydraulic issue of tray 4

Due to the weeping phenomenon in the stripping section of the column, the volume flow rate of R.C.R distilled by 62% of the crude oil feed, amounting to 42 cubic meters per hour. This increase occurred because the vapor rates were too low to adequately support the R.C.R on the valve trays, allowing it to seep through the perforations. Consequently, this rise in R.C.R represents a loss in terms of the heavy-to-light product ratio, as the insufficient separation of light fractions within the R.C.R could not be achieved. Under similar operating conditions to those in the second atmospheric distillation unit at refinery, the atmospheric residue for medium crude oil (API 29.8) at a furnace temperature of 300°C is expected to be approximately 55-60% by volume. Any deviation from this expected range may indicate performance issues, which could be attributed to mechanical problems such as inadequate tray design, misalignment, or damage to the tray components. These issues can lead to insufficient liquid distribution and flow malfunctions, thereby affecting the efficiency of the distillation process [35]. Consequently, in our proposed study, the occurrence of the weeping phenomenon is attributed to mechanical causes. This necessitates prompt maintenance to address and repair the affected trays, ensuring the continued efficiency and reliability of the distillation process.

4. Conclusions:

This study employed advanced simulation techniques using aspen HYSYS V.14 to rigorously assess the hydraulic performance of atmospheric distillation tower trays at petroleum Refinery. Our findings elucidate several key aspects of tray efficiency, highlighting the crucial role of tray design and alignment in mitigating common operational issues such as weeping and flooding. Notably, the simulation results demonstrated a significant correlation with actual plant performance data, validating the predictive accuracy of our model. The theoretical contributions of this research lie in its detailed analysis of tray mechanics and the subsequent identification of specific hydraulic deficiencies within the lower trays of the stripping section. By addressing these deficiencies through targeted design improvements, this study offers a novel approach to enhancing distillation efficiency a critical factor in reducing operational disruptions and maintenance requirements in petroleum refineries. However, this study is not without its limitations. The scope of simulation was constrained by the initial configurations of the tray designs and operational settings provided by the refinery, which may not encompass all potential variables affecting tray performance. Future research should therefore expand on the variety of tray configurations and operational parameters to explore their effects on distillation efficiency more comprehensively. This research contributes significantly to the field by providing a validated framework for using simulation tools in the optimization of refinery operations. It paves the way for more informed and strategic enhancements in refinery tray design, encouraging the academic and industrial communities to adopt similar methodologies in their practices.

Author Contributions Statement: Ahmed Qasim contributed to the Conception; Methodology; Data Curation and Analysis. Muhanad Mohan contributed to the Data Analysis; Writing – Review & Editing. Nazar Qasim contributed to the Data Interpretation; Writing Original Draft. All authors have read and approved the final version of the manuscript.

References

[1] A. Qasim and H. H. Alwan, "Enhancement of light Naphtha quality using calcite adsorbent from eggshells by adsorptive desulfurization", *South African Journal of Chemical Engineering*, vol. 46, pp. 196–204, 2023. https://doi.org/10.1016/j.sajce.2023.08.007.

[2] A. Khalili-Garakani, N. Kasiri, and J. Ivakpour, "Feasibility study on replacement of atmospheric distillation column with new sequences in a natural gas condensate refinery", *Computers & Chemical Engineering*, vol. 135, p. 106745, 2020. https://doi.org/10.1016/j.compchemeng.2020.106745.

[3] A. F. Nader, R. J. Muhammad, W. M. Saleh, M. S. Abdullah, and A. Q. Atwan, "Evaluation of main pay-Zubair Formation after operations re-injection of produced water directly in Rumaila Oil Field norths under matrix condition", *Journal of Petroleum Research and Studies*, vol. 12, no. 2, pp. 13–36, 2022. https://doi.org/10.52716/jprs.v12i2.655.

[4] G. J. Matrood, A. M. Al-Gaban, and H. M. Yousif, "Optimizing Study of Some Factors That Influence the Performance of Valve Trays in Crude Oil Distillation Towers", in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, p. 012043, 2020. http://dx.doi.org/10.1088/1757-899X/978/1/012043.

[5] N. P. Patil and V. S. Patil, "Operational and economic assessment of distillation column from the performance of tray", *Int. J. Engg. Trends Technol*, vol. 4, pp. 500–505, 2016.

[6] M. J. Hossain, H. M. Salman, S. I. Ahmed, M. U. Monir, K. Techato, S. Chowdhury, M. A. Habib, and K. Phoungthong, "Separation and purification apparatus safety: separators, trays, towers, etc.," in *Crises in Oil, Gas and Petrochemical Industries*, Elsevier, pp. 177–209, 2023. https://doi.org/10.1016/B978-0-323-95163-0.00014-1.

[7] E. Tekin and I. Sabuncuoglu, "Simulation optimization: A comprehensive review on theory and applications", *IIE transactions*, vol. 36, no. 11, pp. 1067–1081, 2004. https://doi.org/10.1080/07408170490500654.

[8] P. U. Ndunagu, E. E. Alaike, O. F. Joel, A. Oji, and T. Megueptchie, "Crude Fractionating Column Hydraulic Study with Feedstock Variation using Column Analysis Tool", in *SPE Nigeria Annual International Conference and Exhibition*, SPE, p. D013S018R003, 2020. https://doi.org/10.2118/203622-MS.

[9] S. M. Ali, H. S. Moshref, H. A. Mohammed, Z. M. Shakor, and S. Mohmud, "Studies and Modeling for Upgrading Units for Heavy Oil Refineries", *Journal of Petroleum Research and Studies*, vol. 8, no. 2, pp. 240–255, 2018. https://doi.org/10.52716/jprs.v8i2.247.

[10] A. N. Khalaf, "Steady state simulation of Basrah crude oil refinery distillation unit using aspen hysys", *University of Thi-Qar Journal for Engineering Sciences*, vol. 9, no. 2, pp. 29–39, 2018. http://dx.doi.org/10.31663/tqujes.9.2.312(2018).
[11] F. A. Naji, A. A. Ateeq, and M. A. Al-Mayyah, "Optimization of blending operation for the Iraqi oils", in *Journal of Physics: Conference Series*, IOP Publishing, p. 012037, 2021. http://dx.doi.org/10.1088/1742-6596/1773/1/012037.
[12] S. Fraser, "Distillation in refining", *Distillation*, pp. 155–190, 2014. https://doi.org/10.1016/B978-0-12-386876-3.00004-1.
[13] A. A. Kiss, "Distillation technology–still young and full of breakthrough opportunities", *Journal of Chemical Technology & Biotechnology*, vol. 89, no. 4, pp. 479–498, 2014. https://doi.org/10.1002/jctb.4262.
[14] E. Magaril and R. Magaril, "Effect of pressure on the rectification sharpness in rectifying sections of tray distillation columns in oil and gas refining", *Separation and Purification Technology*, vol. 223, pp. 49–54, 2019. https://doi.org/10.1016/j.seppur.2019.04.058.
[15] G. E. Cortes Garcia, J. van der Schaaf, and A. A. Kiss, "A review on process intensification in HiGee distillation", *Journal of Chemical Technology & Biotechnology*, vol. 92, no. 6, pp. 1136–1156, 2017. https://doi.org/10.1002/jctb.5206.
[16] V. Vishwakarma, M. Schubert, and U. Hampel, "Assessment of separation efficiency modeling and visualization approaches pertaining to flow and mixing patterns on distillation trays", *Chemical Engineering Science*, vol. 185, pp. 182–208, 2018. https://doi.org/10.1016/j.ces.2018.03.052.
[17] N. V. D. Long and M. Lee, "Advances in distillation retrofit", 2017.
[18] A. Hug, P. W. Faessler, K. Kolmetz, W. K. Ng, and K. Watari, "Fractionation technology for the petroleum refining industry", *Asia-Pacific Journal of Chemical Engineering*, vol. 2, no. 4, pp. 245–256, 2007. https://doi.org/10.1002/apj.16.
[19] F. J. Zuiderweg, "Sieve trays: a view on the state of the art", *Chemical Engineering Science*, vol. 37, no. 10, pp. 1441–1464, 1982. https://doi.org/10.1016/0009-2509(82)80001-8.
[20] S. Herbert and N. Sandford, "Consider Moving to Fixed Valves", *Chem. Eng. Prog. (CEP)*, pp. 34–41, 2016.
[21] N. M. A. Al-Lagtah, S. Al-Habsi, and S. A. Onaizi, "Optimization and performance improvement of Lekhwair natural gas sweetening plant using Aspen HYSYS", *Journal of Natural Gas Science and Engineering*, vol. 26, pp. 367–381, 2015. https://doi.org/10.1016/j.jngse.2015.06.030.
[22] M. M. Donahue, B. J. Roach, J. J. Downs, T. Blevins, M. Baldea, and R. B. Eldridge, "Dividing wall column control: Common practices and key findings", *Chemical Engineering and Processing-Process Intensification*, vol. 107, pp. 106–115, 2016. https://doi.org/10.1016/j.cep.2016.05.013.
[23] J. Riese and M. Grünewald, "Challenges and opportunities to enhance flexibility in design and operation of chemical processes", *Chemie Ingenieur Technik*, vol. 92, no. 12, pp. 1887–1897, 2020. https://doi.org/10.1002/cite.202000057.
[24] V. Vishwakarma, M. Schubert, and U. Hampel, "Assessment of separation efficiency modeling and visualization approaches pertaining to flow and mixing patterns on distillation trays", *Chemical Engineering Science*, vol. 185, pp. 182–208, 2018. https://doi.org/10.1016/j.ces.2018.03.052.
[25] W. L. Luyben, "Effect of feed composition on the selection of control structures for high-purity binary distillation", *Industrial & engineering chemistry research*, vol. 44, no. 20, pp. 7800–7813, 2005. https://doi.org/10.1021/ie0580147.
[26] M. Gadalla, L. Jiménez, Z. Olujic, and P. J. Jansens, "A thermo-hydraulic approach to conceptual design of an internally heat-integrated distillation column (i-HIDiC)", *Computers & chemical*

engineering, vol. 31, no. 10, pp. 1346–1354, 2007. https://doi.org/10.1016/j.compchemeng.2006.11.006.

[27] A. G. Abo-mousa, D. A. Kamel, H. A. Elazab, M. A. Gadalla, and M. K. Fouad, "Graphical analysis and revamping of crude distillation units under variable operational scenarios", *Case Studies in Chemical and Environmental Engineering*, vol. 8, p. 100490, 2023. https://doi.org/10.1016/j.cscee.2023.100490.

[28] J. de Tommaso, F. Rossi, N. Moradi, C. Pirola, G. S. Patience, and F. Galli, "Experimental methods in chemical engineering: Process simulation", *The Canadian Journal of Chemical Engineering*, vol. 98, no. 11, pp. 2301–2320, 2020. https://doi.org/10.1002/cjce.23857.

[29] V. Villazón-León, A. Bonilla-Petriciolet, J. C. Tapia-Picazo, J. G. Segovia-Hernández, and M. L. Corazza, "A review of group contribution models to calculate thermodynamic properties of ionic liquids for process systems engineering", *Chemical Engineering Research and Design*, vol. 185, pp. 458–480, 2022. https://doi.org/10.1016/j.cherd.2022.07.033

[30] R. Rannaveski, M. Listak, and V. Oja, "ASTM D86 Distillation in The Context of Average Boiling Points as Thermodynamic Property of Narrow Boiling Range Oil Fractions", *Oil Shale*, vol. 35, no. 3, pp. pp. 254–264, 2018. https://doi.org/10.3176/oil.2018.3.05.

[31] R. N. G. Santos, E. R. A. Lima, and M. L. L. Paredes, "ASTM D86 distillation curve: Experimental analysis and premises for literature modeling", *Fuel*, vol. 284, p. 118958, 2021. https://doi.org/10.1016/j.fuel.2020.118958.

[32] Y. Sun, S. Lei, Y. Zhao, C. Wei, X. Yang, X. Han, Y. Li, J. Xia, and Z. Cai, "Spatial distribution prediction of soil heavy metals based on sparse sampling and multi-source environmental data", *Journal of Hazardous Materials*, vol. 465, p. 133114, 2024. https://doi.org/10.1016/j.jhazmat.2023.133114.

[33] D. Chicco, M. J. Warrens, and G. Jurman, "The coefficient of determination R-squared is more informative than SMAPE, MAE, MAPE, MSE and RMSE in regression analysis evaluation", *Peerj computer science*, vol. 7, p. e623, 2021. https://doi.org/10.7717/peerj-cs.623.

[34] F. Raposo, "Evaluation of analytical calibration based on least-squares linear regression for instrumental techniques: A tutorial review", *TrAC Trends in Analytical Chemistry*, vol. 77, pp. 167–185, 2016. https://doi.org/10.1016/j.trac.2015.12.006.

[35] Ž. Olujić, M. Jödecke, A. Shilkin, G. Schuch, and B. Kaibel, "Equipment improvement trends in distillation", *Chemical Engineering and Processing: Process Intensification*, vol. 48, no. 6, pp. 1089–1104, 2009. https://doi.org/10.1016/j.cep.2009.03.004.