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Editorial

We start this pioneering work, which do not seek perfection as much as aiming to provide a scientific window that opens a wide area for all the distinctive pens, both in the University of Sabratha or in other universities and research centers. This emerging scientific journal seeks to be a strong link to publish and disseminate the contributions of researchers and specialists in the fields of applied science from the results of their scientific research, to find their way to every interested reader, to share ideas, and to refine the hidden scientific talent, which is rich in educational institutions. No wonder that science is found only to be disseminated, to be heard, to be understood clearly in every time and place, and to extend the benefits of its applications to all, which is the main role of the University and its scholars and specialists. In this regard, the idea of issuing this scientific journal was the publication of the results of scientific research in the fields of applied science from medicine, engineering and basic sciences, and to be another building block of Sabratha University, which is distinguished among its peers from the old universities.

As the first issue of this journal, which is marked by the Journal of Applied Science, the editorial board considered it to be distinguished in content, format, text and appearance, in a manner worthy of all the level of its distinguished authors and readers.

In conclusion, we would like to thank all those who contributed to bring out this effort to the public. Those who lit a candle in the way of science which is paved by humans since the dawn of creation with their ambitions, sacrifices and struggle in order to reach the truth transmitted by God in the universe. Hence, no other means for the humankind to reach any goals except through research, inquiry, reasoning and comparison.

Editorial Committee

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- Keywords, max. 5 words.
- Introduction.
- Methodology.
- Results and Discussion.
- Conclusion.
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- Medical Science & Technology.
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Editorial Committee

CONTENTS

SIMPLIFIED SUPERSTRUCTURE APPROACH FOR DESIGNING HEAT EXCHANGER NETWORK IN HEATING SYSTEMS OF DISTILLATION CRUDE OIL UNIT: ZAWIYA REFINERY PLANT CASE STUDY

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Abstract

This study presents an analysis of the heat exchanger network design for the crude oil refinery's distillation unit at the Zawia plant. Optimization software was utilized to determine an optimal minimum temperature difference (ΔT_{min}) of approximately 20°C. The HINT software also calculated the minimum hot utility (Qh_{min} = 23,457.156 kW) and cold utility (Qc_{min} = 10,882.814 kW) requirements for the fractional distillation unit. The analysis indicated that a total of 29 shells are necessary based on the thermal requirements of the hot streams. A systematic superstructure approach was employed to segment the composite curves into eight distinct intervals. A graphical technique provided a theoretical minimum that effectively informed the design optimization process. Additionally, grid diagram simulations were conducted to refine the configuration by incorporating practical constraints. To enhance the efficiency of the superstructure, the integration of single-shell and multi-shell heat exchangers is proposed, resulting in a reduction of total units to 18. This study underscores the efficacy of the proposed methodology as a robust tool for achieving optimal heat integration solutions, thereby maximizing energy savings and minimizing costs in refinery operations.

Keywords: Heat exchanger network; Distillation crude oil unit; Zawiya Refinery Plant; Number of shells; Energy saving.

Introduction

Heat exchanger networks (HENs) are essential components in industries such as petroleum refining and chemical plants. They optimize energy efficiency, minimize operational costs, and facilitate heat transfer between process streams (El-Halwagi, M., 2006). In the context of crude oil distillation units, heat exchanger networks play a crucial role in optimizing energy efficiency by transferring heat between different streams, thereby reducing energy consumption and operational costs (Al-Mutairi, E., 2010). When designing a heat exchanger network, one of the key objectives is to find the minimum number of shells required, as this affects the capital cost and overall efficiency of the system. The goal is to achieve a heat exchanger network that minimizes the number of shells and units while meeting the heat transfer requirements at the lowest total cost (Azzawiya Oil Refining Company; Goswami, D. Y., and Kreith, F., 2016; El-Halwagi, M. M., 2006; Linnhoff, B., et al., 1978; Linnhoff, B., et al., 1980; Gadalla, M., 2015).

Furthermore, the minimum number of units can be predicted independently of the specific stream matches, whereas the number of shells required in the network is contingent upon the configuration of the stream matches. The number of shells depends on factors such as temperature differences and the placement of the exchangers (Trivedi, K., et al., 1987). Therefore, accurately determining the optimal number of shells is crucial for achieving cost-effective and efficient heat exchanger networks in industrial applications.

In the field of heat exchanger network synthesis, various methods are available for designing efficient and cost-effective networks. This study primarily focuses on two prominent methods: the pinch method and the superstructure method. Both methods aim to minimize the total cost of the heat exchanger network but have distinct advantages. The selection of the appropriate method depends on project-specific factors, including process complexity, available resources, and design objectives.

The superstructure method has been proposed as an approach to address the heat exchanger network synthesis (HENS) problem. One such method, introduced by Yee et al. in 1990, involves generating a superstructure by fixing the number of stages based on the maximum number of hot or cold streams. The streams are split and matched within each stage, resulting in the formation of heat exchangers. Various modifications and extensions have been proposed, such as using genetic algorithms to minimize the total annual cost or considering multipass heat exchangers within the network structure. Huang, B., et al. (2012) improved the mathematical model by incorporating heat exchanger efficiency and variations in heat transfer coefficients. While superstructure methods offer flexibility in network configuration, they may overestimate the number of heat exchangers and prioritize network structure over detailed heat exchanger design (Lotfi, F., et al., 2010; Toffolo, A., 2009; Asma A., et al., 2022; Ponce-Ortega, J., et al., 2008).

To address the issue of overestimating units during heat exchanger network design, Yee and Grossmann discovered that a cost-optimal design is typically uncomplicated and does not necessitate a large number of heat exchangers (Yee, T., et al., 1990). Consequently, each stream within the system is not required to exchange heat with multiple other streams. This finding has been corroborated by numerous case studies, further emphasizing the significance of simplicity in optimal designs. To attain their objective, the researchers simplified the superstructure method, which encompasses all conceivable configurations and connections of process units in a system. Their investigation focused on a specific scenario involving sets of hot and cold streams. Within this simplified superstructure, the researchers constrained the structure to a pairwise matching approach. This implies that each stream is engaged in only one process-process match within each stage or subsystem. The aim was to exclude stream splitting and sequential matches, as these would complicate the design and potentially escalate costs.

On the other hand, Trivedi, K., et al. (1987) proposed a technique that involves dividing the balanced composite curves, including the utilities, into sections. This approach forms the basis for simplifying the estimation of temperature intervals in the superstructure while avoiding any temperature cross within the heat exchangers. By breaking down the superstructure into manageable sections, the design process is streamlined. It guarantees the preservation of composite-stream enthalpy balances and facilitates the efficient placement of exchanger matches, ultimately minimizing the number of required shells. Euler's theorem is utilized to determine the optimal configuration for each section, thus optimizing the design of the overall superstructure (El-Halwagi, M., 2011). In this paper, a combination of the simplified approaches of the superstructure method is demonstrated by its application to a crude oil distillation unit at the Zawiya refining plant.

The Azzawiya Oil Refinery in Zawiya, Libya, owned by the National Oil Corporation, plays a significant role in crude oil refining, blending and filling mineral oils, and asphalt production (Azzawiya Oil Refining Company, 2024). Crude oil distillation units within the refinery are crucial for separating crude oil into various fractions, such as gasoline, diesel fuel, jet fuel, and heating oil, through a distillation process. The associated heat exchanger network in the distillation unit requires adjustments to accommodate changing operating conditions and product specifications. While previous research has focused on optimizing crude oil distillation systems, there is a research gap concerning the application of multipass heat exchangers in this specific unit, which could potentially enhance energy efficiency and operational effectiveness (Lotfi, F., et al., 2010; Toffolo, A., 2009; Asma A., et al., 2022; Ponce-Ortega, J., et al., 2008).

This research aims to address this gap by designing a heat exchanger network for the crude oil distillation unit in the Azzawiya refinery using integrated composite curves and simplified superstructure techniques. The sub-objectives of this study include targeting the minimum number of shells for the heat exchanger network using analytical methods, applying pinch analysis to optimize heat recovery and integration, and designing the heat exchanger network to meet process requirements and specified targets. The ultimate goal is to achieve a heat exchanger network that minimizes the number of shells required while maintaining optimal heat transfer efficiency and minimizing capital costs. By achieving these objectives, it is expected that product revenue will increase, energy consumption will decrease, and overall efficiency of the crude oil distillation process in the Azzawiya refinery will be enhanced.

Methodology

1 Data Collection and Extraction

The necessary data for the study of the thermal heat exchanger network was collected from the crude oil distillation unit at Al-Zawiya Oil Refining Company (Azzawiya Oil Refining Company, 2024). The analysis procedure for studying crude distillation processes can be summarized as follows:

1.1 Identification of Streams

In the first step, the streams were identified. Hot streams are those that require cooling or are available to be cooled, while cold streams require heating. Utility streams are used to heat or cool process streams when direct heat exchange is not practical or economical, employing various hot utilities (e.g., steam, hot water) and cold utilities (e.g., cooling water, refrigerant).

1.2 Extraction of Thermal Data

Next, the thermal data was extracted for each identified hot and cold process stream. This included the supply temperature (Ts, the initial temperature of the stream), the target temperature (Tt, the desired temperature), and the heat capacity flow rate (CP, the product of the mass flow rate and specific heat capacity). This data was tabulated in Table (1).

Table 1: Thermal Stream Data for Zawiya Crude Oil Distillation Unit.

Stream type	Stream number	Ts (°C)	Tt (°C)	$CP(KW/^{\circ}C)$	$\Delta H(KW)$
$Residue\backslash hot$	$H-1$	319	80	68.711	16421.929
$HGO\backslash hot$	$H-2$	298	47	27.347	6864.097
$BPA\backslash hot$	$H-3$	261	192	95.13	6563.97
$LGO\backslash hot$	$H-4$	231	47	34.421	6333.464
$Kerosene\backslash hot$	$H-5$	173	34	41.29	5739.31
$TPA\backslash hot$	$H-6$	126	53	229.595	16760.435
$Crude1\backslash cold$	$C-1$	20	116	201.126	-19308.09
$Crude2\backslash cold$	$C-2$	116	332	238.563	-51529.60
$Water\backslash cold$	$C-3$	80	99	22.097	-419.843

Table (1) as stated above presents the thermal stream data specifically related to the crude oil distillation unit. Upon examining the Table, it can be observed that the crude oil distillation unit consists of a total of nine streams, comprising six hot streams and three cold streams. Each stream is accompanied by essential parameters such as source and target temperatures, enthalpy, and heat capacity flow rate.

1.3 Using HINT Software

To address the complex design challenges associated with the heat exchanger network in a crude distillation unit, the HINT software was employed. Composite curves used for shell targeting were obtained from HINT, enabling a detailed analysis of heat transfer requirements. To utilize HINT, users begin by accessing the streams section, selecting the "add" option, and entering the necessary stream data. In this project, emphasis was placed on linear types characterized by a constant heat capacity (Cp), which simplified the analysis and calculations within the software. Additionally, the design of the primary heat exchanger network was conducted using HINT, ensuring an efficient and effective approach to the overall design process.

1.4 Determining the Optimum ΔT_{min}

The optimum ΔT_{min} (minimum temperature difference) was determined. The design of heat transfer equipment must adhere to the second law of thermodynamics, which requires maintaining a minimum temperature difference between the hot and cold streams to enable feasible heat transfer. To establish a starting point, the widely accepted range of 20°C to 40°C for ΔT_{min} (Kemp, I. C., 2007) was considered. Based on this range, an initial value of 20°C was selected as the starting ΔT_{min}. To identify the actual optimal ΔT_{min} for our crude oil distillation unit, the HINT software was used. This software is specifically designed to optimize process parameters of heat exchanger networks.

The software's capabilities include analyzing cost targets and ΔT_{min} values to identify the configuration that minimizes the total annual cost.

2 Shell Targeting

Shell targeting involves constructing a graphical representation of all the streams contributing to the network using composite curves at a minimum temperature difference.

The first step is estimating the number of shells required by the cold process streams and cold utility streams. Starting from the target temperature of a cold stream, draw a horizontal line until it intersects the hot composite curve. From that point, drop a vertical line to the cold composite curve. This section represents a single exchanger shell where the cold stream gets heated without a temperature cross. This process ensures that the cold stream will have at least one match with a hot stream and a log mean temperature correction factor (FtF_tFt) of at least 0.8. Repeat the procedure until a vertical line intercepts the cold composite curve at or below the starting temperature of that particular stream. The number of horizontal lines represents the number of shells required by the cold stream to reach its target temperature. Repeat the procedure for all cold streams, including cold utility streams. The sum of the number of shells for all cold streams gives the total number of shells required by the cold streams.

The second step is estimating the number of shells required by the hot process streams and hot utility streams. Starting from the initial temperature of a hot stream, drop a vertical line on the balanced composite curve until it intercepts the cold composite curve. From that point, construct horizontal and vertical lines until a horizontal line intercepts the hot composite curve at or below the hot stream's target temperature. The number of horizontal lines represents the number of shells required by the hot stream for heat exchange in the network. Repeat the procedure for all hot streams, including hot utility streams. The sum of the number of shells required by the hot streams gives the total number of shells required by the hot streams.

The final step is determining that the minimum number of shells required in the network is the larger of the total number of shells required by the hot streams or the cold streams (Goswami, D., et al., 2016).

3 Integrated Methodology for Superstructure HEN Design

The integrated methodology for heat exchanger network (HEN) design begins with visualizing process streams and identifying potential heat exchange ranges. This is achieved by creating balanced composite curves. Initially, a temperature-enthalpy (T-H) diagram is generated to visualize both hot and cold streams. Individual heat transfer curves for each stream are plotted on this diagram. The data from these curves is then integrated to create one composite curve for cold streams and one for hot streams. Both curves are overlaid to identify potential process-to-process heat exchange opportunities.

Next, the pinch point is determined. This involves combining the normalized heat transfer curves and adjusting the composite curves to achieve a common minimum approach temperature (ΔT_{min}), which is crucial for efficient heat transfer. The balanced composite curves and utility requirements are then divided into sections using the superstructure approach. Each section represents a sub-network where exchangers have a single shell, allowing for easier management of heat transfer.

3.1 Stream Matching Criteria

Stream matching is executed within each section, ensuring that enthalpy balances are maintained. The implementation of specific algorithms within the HINT software aids in this process, facilitating the identification of optimal matches based on temperature and heat load criteria. For example, streams are paired according to their thermal characteristics, prioritizing those with the highest heat loads to maximize efficiency.

3.2 Splitting Composite Curves

The logic behind splitting the composite curves lies in the need to optimize heat recovery while minimizing the number of units required. Each interval represents a unique heat exchange scenario, allowing for detailed analysis and design adjustments.

3.3 Sub-Network Design

Finally, a sub-network is designed for each section, determining the minimum number of units needed using Euler's theorem. The overall superstructure design is then optimized to minimize energy consumption, maximize heat recovery, and meet process requirements, focusing on achieving the minimum number of units, each with a known number of shells.

4 Design of a primarily heat exchanger network

The design process begins by identifying non-balanced enthalpy intervals where either hot or cold utility demands exist. The design can commence from any of these independent temperature intervals. Basic rules of pinch technology must be adhered to, ensuring no temperature crossing occurs and that the ΔT_{min} constraint is satisfied.

4.1 Stream Pairing

Heat loads of stream fragments are compared, and streams with identical heat load values are paired, starting with those exhibiting the highest heat loads. For pairing with a single heat exchanger, the criteria of no temperature crossing and adherence to the ΔT_{min} constraint are straightforward. For a second heat exchanger, the feasibility of a serial connection must be assessed by checking specific criteria for the placement of heat exchangers.

4.2 Temperature Constraints

When designing the network from right to left, the new supply temperature for the cold stream's residue must be lower than or equal to the target temperature of the hot stream minus ΔT_{min}. Conversely, when designing from left to right, the new supply temperature for the hot stream's residue must be higher than or equal to the target temperature of the cold stream plus ΔT_{min}. If two residuals need to be paired, their temperatures must satisfy the new supply temperature requirements for both streams (Goswami D., et al. 2016).

5 Simplification of the heat exchanger network

The initial step is to primary design the heat exchanger network according to the Pinch technology rules, both above and below the Pinch point. This may identify any loops in the designed network, which can then be addressed by creating a new heat exchanger with the sum of the heat loads of the heat exchangers in that loop. The heat exchanger network is then redrawn, incorporating the new heat exchangers while ensuring the basic principles of Pinch technology are satisfied.

Next, the designed network in previous step is examined for any other loops and paths, such loops are between heat exchangers, and the paths are connecting the heater and the cooler. The rule for loops is applied to the network, creating a new HEN design. This network is then analyzed for opportunities to reduce the cold and hot utility, such as the path between the cooler and the heater going through another heat exchanger. The final solution is implemented, ensuring that it does not violate the minimum approach temperature (ΔT_{min}) and temperature crossing constraints.

Results and Discussion

1 Optimum Minimum Temperature Differences Value (ΔT_{min})

The design of an energy-efficient heat exchange network involves finding a balance between equipment costs and operating costs. This trade-off is crucial in achieving the best possible design. To aid in this process, the HINT software was employed. By systematically varying the ΔT_{min} values and evaluating the corresponding total annual costs, the relationship between them was obtained. The HINT software, resulted in the creation of Figure (1).

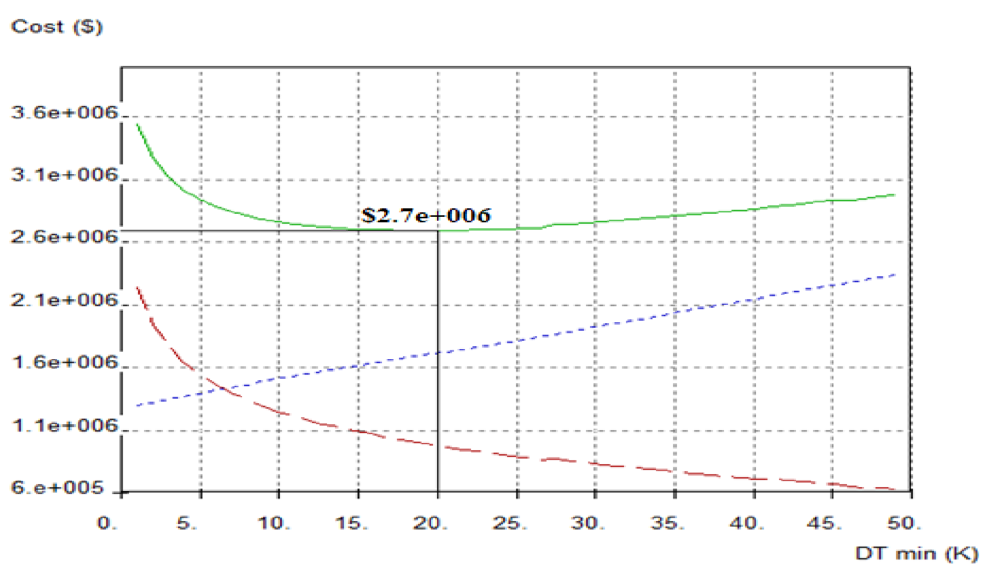

Figure (1): Cost Target Versus ΔT_{min} Graphs, Generated from HINT Software.

The figure provides valuable insights into the optimization of the heat exchange network's total annual cost with respect to ΔT_{min}. By analyzing this graph, one can observe that the selection of a lower ΔT_{min} leads to reduced energy costs but increased capital costs for heat exchangers. This is because lower temperature differences in the network necessitate larger heat exchange surfaces. Conversely, choosing a larger ΔT_{min} leads to higher energy costs due to reduced overall heat recovery.

Additionally, the required capital costs for heat exchangers are lower in this scenario. Therefore, there exists a trade-off between capital costs and operating (energy) costs when determining the optimal ΔT_{min}. By considering such trade-off one can select a ΔT_{min} value that optimizes the total annual cost for the specific requirements of the Crude Distillation Unit in the Zawia Oil Refinery.

The HINT software efficiently identified the optimal ΔT_{min} value that minimized the overall cost. This is in fact done in very short period of time, which save us a great time. Thus, by employing the HINT software and considering the cost target versus ΔT_{min} diagram, the initial assumed ΔT_{min} value were conformed and refine to be approximately 20°C. The obtained value from the HINT was in the recommended range for ΔT_{min} in petroleum industry falls between 20 and 40 C Kemp, I. C. (2007), and This agreement in the results illustrates the accuracy of the HINT software, which is available free of charge.

2 Energy Target:

The results shown in Figure (2) were obtained by utilizing the HINT software. The figure illustrates the changes in the values of $Q_{C_{min}}$ and $Q_{H_{min}}$ as a consequence of altering the value of ΔT_{min} , which represents the minimum temperature difference, ranging from 5 to 50 degrees Celsius. By considering the optimal temperature difference of 20 degrees Celsius, it was determined that the required values of $Q_{H_{min}}$ and $Q_{C_{min}}$ n in the fractional distillation unit for crude oil are equal to 23457.156 and 10882.814 kilo wat, respectively. These values are crucial for determining the minimum heat duty required for effective distillation.

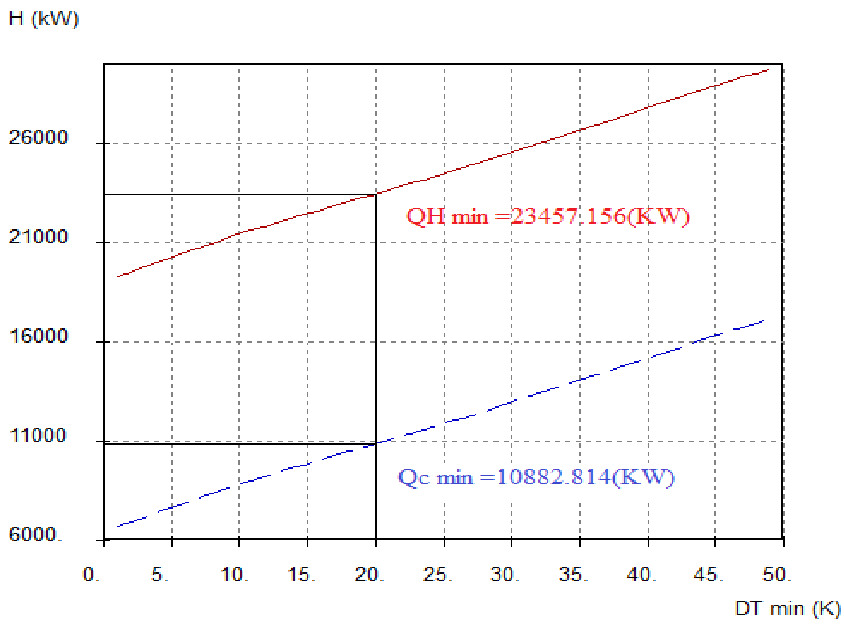

Figure (2): Energy Target Against ΔT_{min} for HEN of Crude Oil Distillation Unit.

3 Minimum Number of Shells Target

Estimation of the required number of shells in the heat exchanger network was performed using the graphical method, as outlined in the methodology section. This approach involves constructing the composite curves of the streams at a minimum temperature difference (ΔT_{min}) of 20°C. The number of shells needed for the heat exchanger network was then determined by staging the hot streams, starting from the hottest stream and progressively adding shells until the entire hot stream network was accounted for.

3.1 The Hot Streams

The results of graphical analysis are presented in Figure (3). The figure shows the staging of the individual hot streams and the number of shells required for each stream. For hot stream 1, the analysis in Figure (3-a) indicates that 6 shells are required to cool the stream temperature from 319°C down to 80°C. This result reflects the significant temperature difference that needs to be accommodated and the corresponding need for a staged heat transfer process to maintain an appropriate minimum temperature difference (ΔT_{min}) between the hot and cold streams. Similarly, Figure (3-b) shows that 7 shells are required for hot stream 2 to cool the temperature from 298°C down to 47°C. The higher number of shells compared to hot stream 1 is due to the larger temperature difference that needs to be addressed, as the stream is cooled from a higher initial temperature to a lower final temperature.

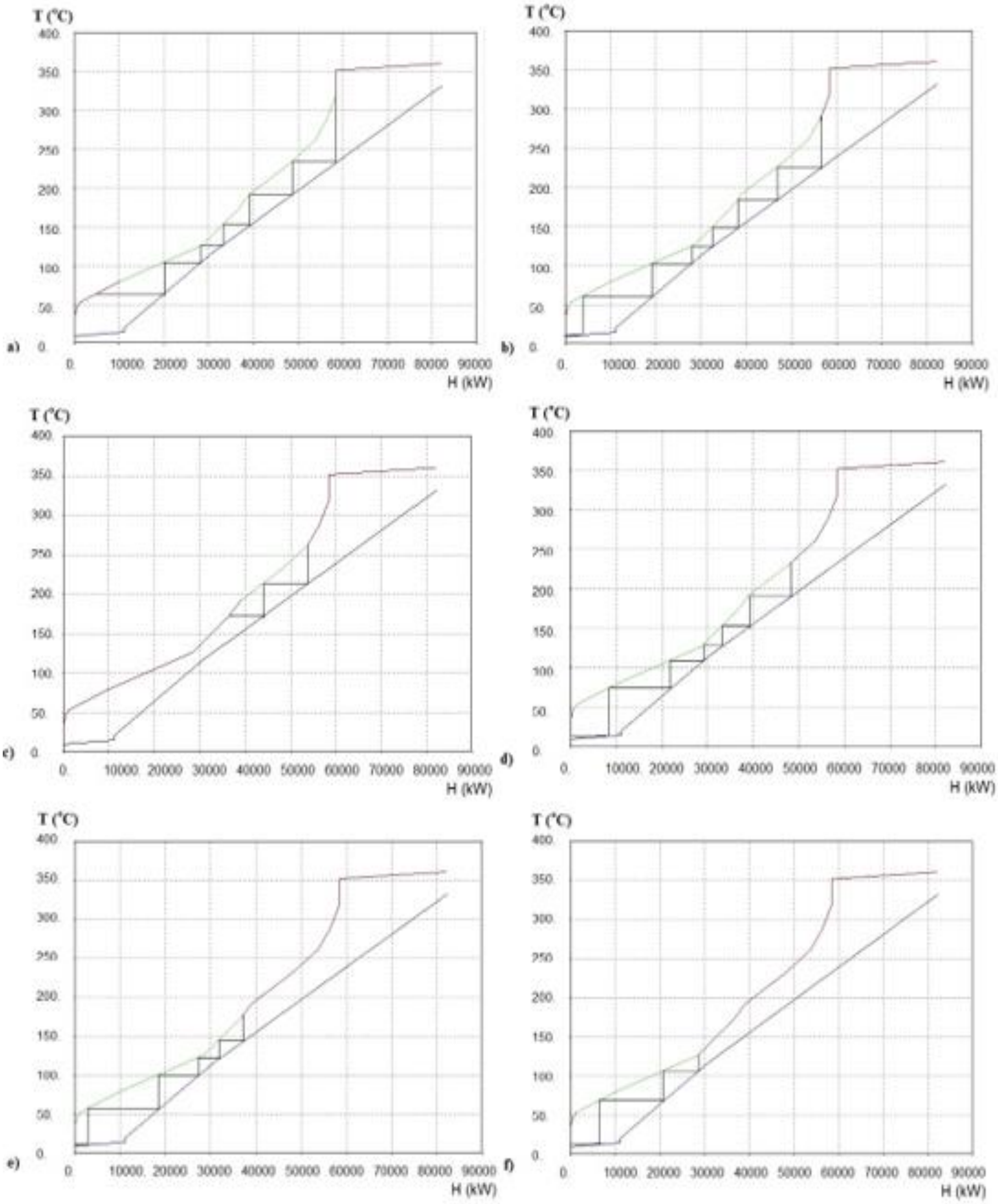

Figure (3): Minimum Number of Shells for a) Hot Streams Number 1 (H-1), b) Hot Streams Number 2 (H-2), c) Hot Streams Number 3 (H-3), d) Hot Streams Number 4 (H-4), e) Hot Streams Number 5 (H-5), and f) Hot Streams Number 6 (H-6).

Continuation of 3.1 The Hot Streams

The analysis continues with hot stream 3 Figure (3-c), which requires two shells to bring the temperature down from 261°C to 192°C, and hot stream 4 Figure (3-d), which requires seven shells to cool the temperature from 231°C to 47°C. The differences in the number of shells can be attributed to the varying temperature differences and the need to maintain the ΔT_{min} throughout the heat exchanger network.

Furthermore, the analysis for hot stream 5 Figure (3-e) indicates that five shells are required to cool the temperature from 173°C to 34°C, while for hot stream 6 Figure (3-f), three shells are needed to reduce the temperature from 126°C to 53°C.

Summing up the total number of shells required for all the hot streams, the analysis shows that the overall heat exchanger network requires 30 shells to effectively cool the hot streams and achieve the desired temperature targets. This comprehensive information provides valuable insights into the design and optimization of the heat exchanger network, ensuring efficient heat recovery and process integration.

3.2 The Cold Streams

Figure (4-a) reveals that for cold stream 1, 3 shells are required to raise the temperature from 20°C to 116°C. This staged heating process allows for the gradual increase in temperature while maintaining the necessary minimum temperature difference (ΔT_{min}) between the hot and cold streams.

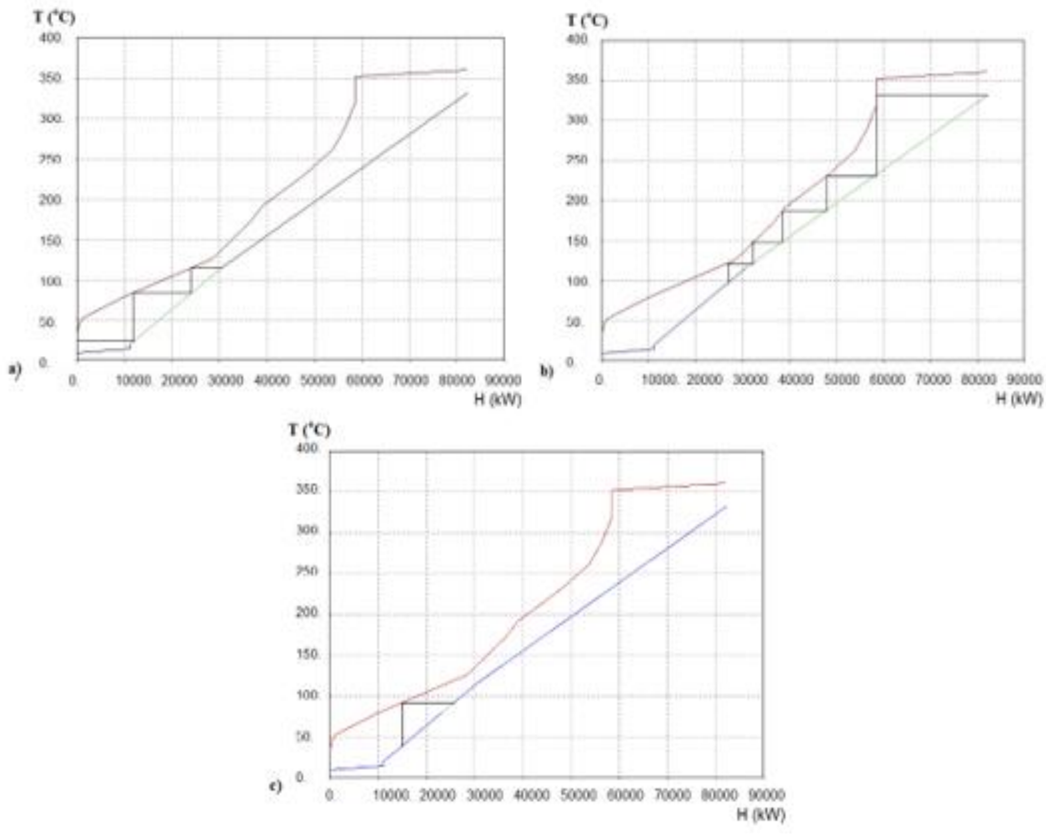

Figure (4): Minimum Number of Shells for a) Cold Streams Number 1 (C-1), b) Cold Streams Number 2 (C-2), and c) Cold Streams Number 3 (C-3).

Examining Figure (4-b), the analysis indicates that 5 shells are needed for cold stream 2 to further increase the temperature from 116°C to 332°C. The higher number of shells compared to cold stream 1 is a result of the larger temperature difference that needs to be accommodated, as the stream is heated from a lower initial temperature to a higher final temperature. Finally, Figure (4-c) shows that for cold stream 3, only 1 shell is required to raise the temperature from 80°C to 99°C. This relatively small temperature increase can be achieved with a single shell, demonstrating the flexibility of the graphical approach in identifying the appropriate number of heat exchanger shells for each individual stream.

The analysis of the results for the cold streams reveals that a total of 9 shells are required to meet the temperature targets for the three cold streams. Therefore, the required number of shells was determined based on the hot streams, as this approach yielded the largest number of shells needed, which is 30. This ensures that the overall heat exchanger network is designed to accommodate the most demanding temperature requirements, guaranteeing the efficient and effective cooling and heating of all the process streams.

4 Superstructure Method Results

The simplified superstructure approach involves dividing the balanced composite curves, which include the utilities, into sections. After careful analysis, it was determined that our plant necessitates a total of eight intervals to effectively address its requirements, which illustrates in Figure (5). These intervals will be individually designed, with each one potentially encompassing utilities and/or heat exchangers within its sub-network.

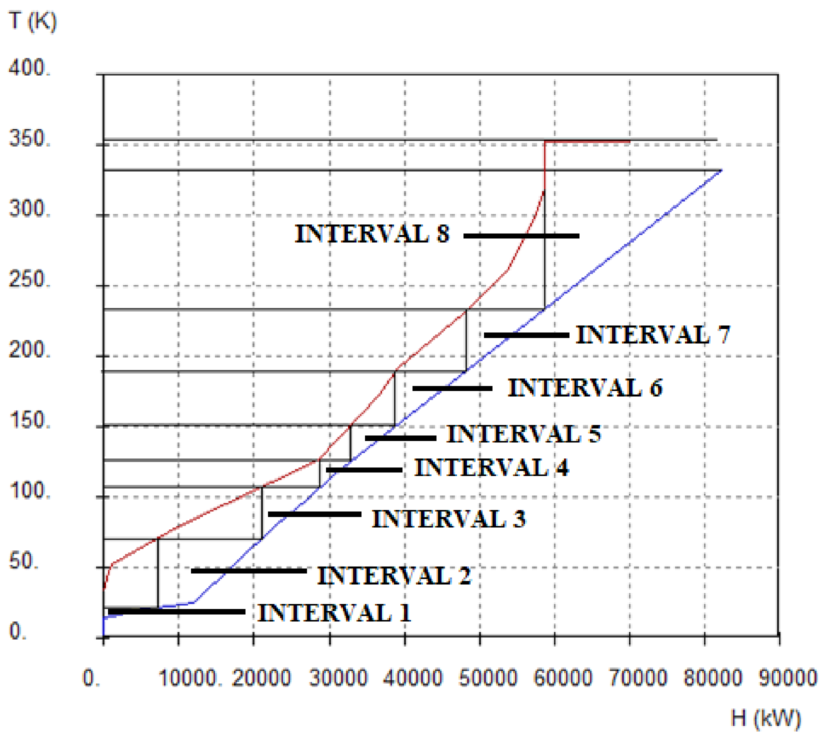

Figure (5): Composite Curve with Utility, Divided to Eight Intervals.

By breaking down the composite curves, one can identify specific intervals where the heat transfer and utility requirements which involves considering various factors such as temperature ranges, heat transfer rates, and utility demands. By designing the intervals separately, the equipment and configurations are used to effectively meet the specific needs of each segment. This level of granularity also facilitates the identification of more opportunities for integration within each interval.

4.1 The Complete Superstructure HEN Results

The complete superstructure heat exchanger network design is shown in Figure (6). The network analysis revealed the presence of eight intervals within the composite curve. These intervals represent distinct segments of the optimization process, each characterized by a specific arrangement of heat exchangers, coolers, and heaters. Notably, the intervals can be categorized into two groups based on their positions relative to the pinch point. The first three intervals are situated below the pinch, similar to the region below the pinch in the pinch method. In these intervals, heat exchange occurs without the involvement of heaters. Instead, the focus is on utilizing four coolers to effectively lower the temperature of the process streams. This arrangement facilitates efficient energy conservation and heat transfer in the system.

The five intervals above the pinch involve a combination of heat exchangers and heaters designed to meet specific temperature profiles and optimize heat transfer efficiency. Each interval features a distinct arrangement of heat exchangers, reflecting the varying heat exchange requirements throughout the optimization process.

In detail, the first interval contains no heat exchangers or heaters, only four coolers, resembling the region below the pinch. The second interval includes five heat exchangers and one cooler. In the third interval, the number of heat exchangers increases to six. The fourth interval again has five heat exchangers, while the fifth and sixth intervals each contain four. The seventh interval features three heat exchangers alongside one heater, and the eighth interval has a single heater, consistent with the area above the pinch. The total number of shells required for the entire network is 34, encompassing those associated with each heat exchanger, cooler, and heater.

The graphical technique used to estimate the number of shells provides a theoretical minimum, guiding the design and optimization of the heat exchanger network to achieve target performance. However, when the actual network is designed and simulated using grid diagrams, the required number of shells may exceed this theoretical minimum. This is due to practical considerations, equipment constraints, and potential heat transfer limitations, which may necessitate additional shells to ensure the feasibility and reliability of the final design.

Combining the graphical technique with grid diagram simulations yields a comprehensive approach to heat exchanger network design. This integrated methodology ensures that the final design is optimized, efficient, and practical for implementation in real-world processes.

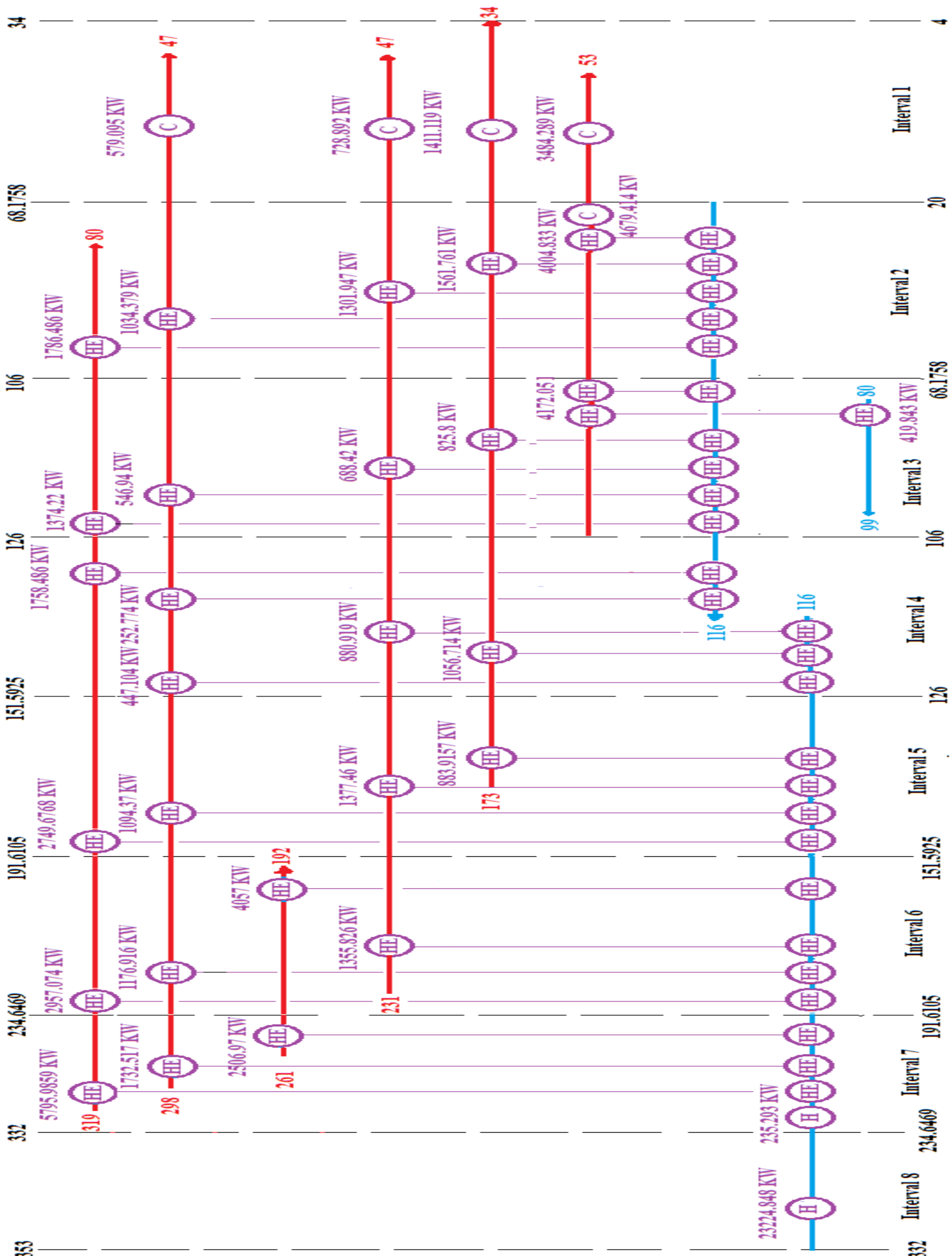

Figure (6): Complete Superstructure Network Design.

4.2 Results of the Simplification of the Superstructure HEN

To reduce the number of units in the network, some single-shell heat exchangers were combined into multi-shell units. Specifically, there are 2 single-shell exchangers above the pinch and 4 below, while 3 two-shell exchangers are above and 6 below the pinch. Additionally, one exchanger above the pinch has three shells, and another has four.

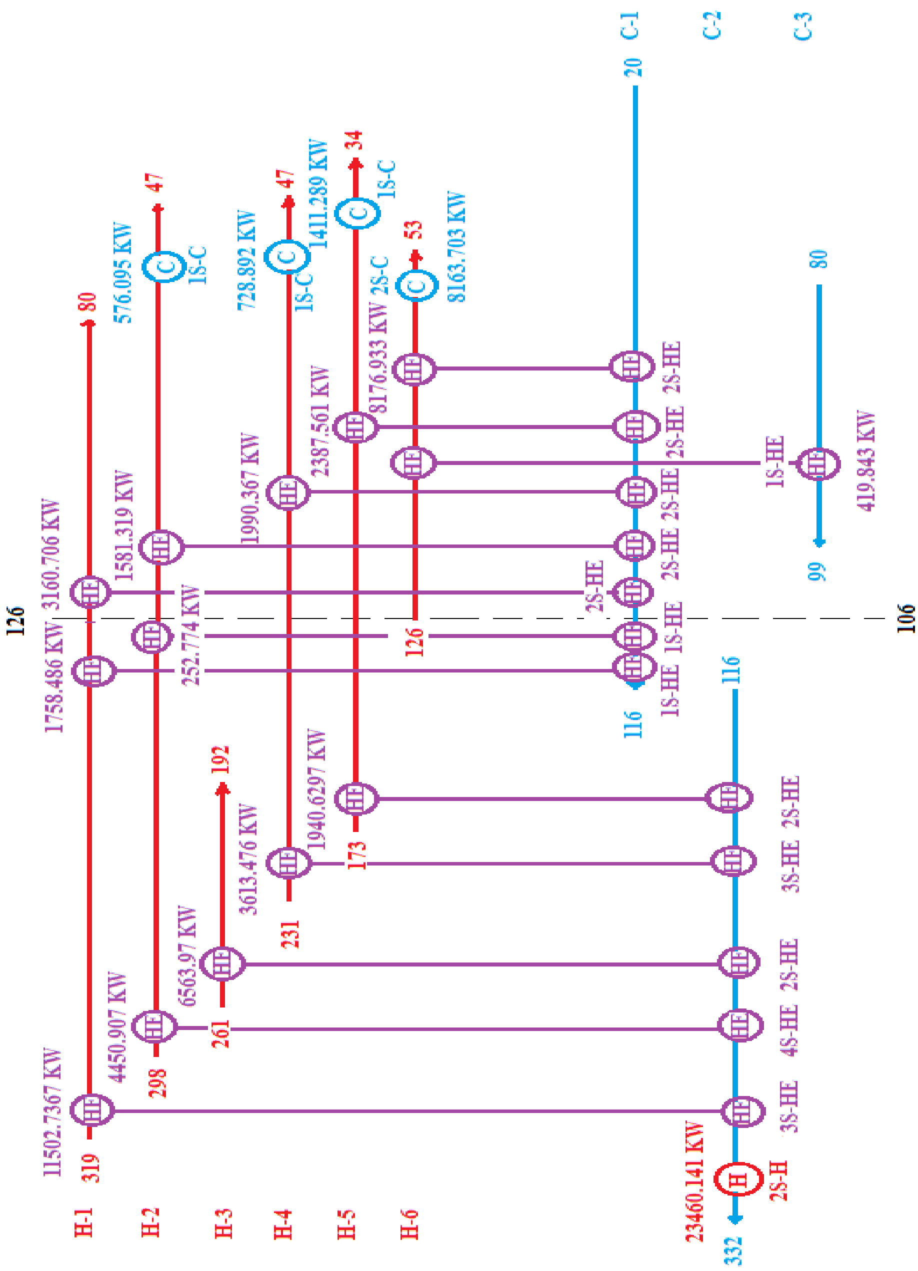

Figure (7): Heat Exchanger Network with the Minimum Number of Units, Considering a Specified Number of Shells.

All coolers are designed with a single shell, whereas heaters utilize two shells. This results in a total of 18 units in the network. To enhance the efficiency of the superstructure and further reduce the number of units, exchange integration is recommended. This process involves applying loop breaking rules to combine exchanges. However, it is important to note that this approach may diverge from the main focus of the study.

Conclusions

In conclusion, the key highlights from the analysis of the heat exchanger network design for crude distillation unit are:

1- The HINT software was used to optimize the total annual cost of the heat exchange network by identifying an optimal minimum temperature difference ΔT_{min} of around 20°C. This balanced the trade-off between capital and operating costs.
2- The HINT software also determined the required values of hot utility (Qh = 23457.156 kW) and cold utility (Qc = 10882.814 kW) for the fractional distillation unit of the crude oil refinery, representing the minimum heat duty needed for effective distillation.
3- The analysis determined that the minimum number of shells required for the heat exchanger network is 30, based on the more stringent requirements of the hot streams, which needed between 2 to 7 shells to accommodate the varying temperature differences and maintain the minimum temperature difference (ΔT_{min}) of 20°C.
4- The systematic superstructure approach divided the composite curves into 8 distinct intervals, with the first 3 intervals below the pinch point focused on coolers, and the remaining 5 intervals above the pinch point involving a combination of heat exchangers and heaters.
5- The graphical technique provided a theoretical minimum number of shells, which informed the design optimization, and the subsequent grid diagram simulation accounted for practical considerations to refine the final network configuration.
6- To further simplify the superstructure, a combination of single-shell and multi-shell heat exchangers was proposed, reducing the total number of units to 18, with the suggestion to utilize exchange integration for improved efficiency.

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