

Heat Exchanger Network Retrofit for Energy Savings in a Catalytic Reforming Naphtha Unit at Zawia Oil Refinery Using Pinch Technology

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ABSTRACT

Energy conservation in oil refineries is essential for reducing operational costs and minimizing environmental emissions. One effective approach is optimizing the Heat Exchanger Network (HEN) design. In this research, pinch technology was applied to optimize the preheat exchanger network of the catalytic reforming unit at the Zawia Oil Refining Plant. The optimized configuration simplified the network to one heater and three coolers, significantly reducing the need for external utilities. The analysis was performed using HINT software. Results showed that the optimal minimum temperature difference (ΔT_{min}) is 25°C, while the pinch point was identified at 212.5°C. The minimum heat required from hot utilities was 4450.09 kW, and 3932.73 kW needed to be removed by cold utilities. The annual operating cost for hot and cold utilities was estimated at \$573,329.7, while the annual capital cost was \$100,108.7, resulting in a total annual cost of \$673,438.4. Although these values do not represent the total plant energy savings, they highlight the strong potential of pinch analysis to improve thermal efficiency, reduce energy waste, and support sustainable operations in energy-intensive industries.

Keywords: Heat Integration, Catalytic Reforming, Pinch Technology, Oil Refinery, Energy Savings.

تحسين شبكة المبادلات الحرارية لتوفير الطاقة في وحدة الإصلاح التحفيزي للنفثا في مصفاة الزاوية للنفط باستخدام تقنية Pinch

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ملخص البحث

يُعد ترشيد استهلاك الطاقة في مصافي النفط ضروريًا لتقليل التكاليف التشغيلية والانبعاثات البيئية. ومن بين أهم التقنيات المستخدمة لتحقيق ذلك تحسين تصميم شبكة المبادلات الحرارية (HEN). في هذه الدراسة، تم تطبيق تقنية الـ Pinch لتحسين شبكة التسخين المسبق في وحدة الإصلاح الحفزي بمصفاة الزاوية، حيث أدى التصميم المحسن إلى تبسيط الشبكة لتشمل سخانًا واحدًا وثلاثة مبردات مع تحسن واضح في الكفاءة الحرارية. أُجري التحليل باستخدام برنامج HINT، حيث تبين أن القيمة المثلى لفرق درجة الحرارة الدنيا (ΔT_{min}) تبلغ 25°C، بينما تم تحديد نقطة الـ Pinch عند 212.5°C والحد الأدنى للتدفق الحراري المطلوب من وحدات التسخين بلغ 4450.09 كيلواط، في حين يجب إزالة 3932.73 كيلواط بواسطة وحدات التبريد. قُدرت تكلفة التشغيل السنوية للوحدات بحوالي 573,329.7 دولار، بينما بلغت تكلفة رأس المال السنوية 100,108.7 دولار، ليصل إجمالي التكلفة السنوية إلى 673,438.4 دولار. وتوضح النتائج فعالية تحليل الـ Pinch في تحسين الكفاءة وتقليل الفاقد في الصناعات عالية الاستهلاك للطاقة.

الكلمات الدالة: التكامل الحراري، الإصلاح التحفيزي، مصافي النفط، توفير الطاقة.

1. INTRODUCTION

The oil and gas industry remains a cornerstone of the global economy, with petroleum refineries serving as the backbone for producing high-quality fuels and essential petrochemical feed stocks. Among various refinery operations, the catalytic reforming unit holds particular significance, as it not only enhances fuel quality by increasing octane numbers but also produces valuable aromatics. However, this unit is highly energy-intensive, consuming substantial thermal energy and thus representing a primary target for efficiency optimization. In an era characterized by volatile energy prices and stringent environmental regulations, improving energy efficiency in such units has become both an economic necessity and an environmental responsibility.

In order to reduce energy consumption and operating costs, pinch analysis has become a reliable technique for developing and retrofitting heat exchanger networks (HENs) over the past few decades [1,2].

This method, which was first presented by Linnhoff et al. (1979), determines the minimal heating and cooling needs by locating the "pinch point," a crucial temperature barrier that divides areas that need external heating from those that need external cooling [3].

The efficiency of pinch analysis in lowering energy consumption in petrochemical and refinery operations has been shown in numerous research. For example, by adding more heat exchangers, Babaqi et al. (2020) used pinch analysis with particle swarm optimization to lower utility demand by 16.20 percent [4].

In a similar vein, Jiang et al. (2022) refined the process model to achieve several objectives, including high-octane gasoline and aromatics output [5].

Several industrial case studies were compiled in a thorough study by Khan and Lee (2023), who noted that 8–20% energy reductions are typical [6]. Even though pinch analysis has been widely used, it is still rarely used in catalytic reforming units, especially in North Africa.

The possibility of energy integration in these units has not received much attention in research, which leaves a large number of optimization options untapped. Ballut (1989) conducted preliminary research on an existing catalytic reforming unit at Zawia Refinery to assess energy utilisation efficiency and identify areas for improvement [7]. Additionally, research by Muhammad (2013) and Khasheh (2015) showed that using pinch analysis in catalytic reforming units resulted in notable energy reductions [8, 9].

The benefits of this strategy are still being demonstrated by more recent research. According to Silva et al. (2022), capital cost reductions could be achieved by retrofitting HENs in petrochemical processes using pinch-based techniques [10].

In a similar vein, refinery HEN optimization by Maruyama et al. (2021) revealed energy savings of more than 10% [11].

The use of pinch analysis in a variety of refinery units, such as hydrocracking and fluid catalytic cracking, is further illustrated by the work of Al-Musawi and Al-Shehri (2020), Ahmed and Al-Shehri (2019), and Bandar et al. (2021), [Auta et. al. \(2012\)](#) [12, 13, 14,15].

Building on this framework, the current study analyses the heat exchanger network of the catalytic reforming unit at the Zawia Oil Refinery using Aspen Pinch software.

Finding the ideal ΔT min, locating the pinch point, figuring out the minimal heating and cooling requirements, evaluating

the effectiveness of the current HEN, suggesting changes to fix mismatched stream pairings, and estimating the related capital and utility costs are the goals. It is anticipated that the results will promote the larger shift toward more sustainable and energy-efficient refining techniques by producing both financial savings and environmental advantages.

2. MATERIALS AND METHODS

2.1. Study Approach

Actual operational data obtained from Zawia Oil Refinery's catalytic naphtha reforming unit were used in this study Figure1. The simulation for the heat integration study was conducted using Hint software.

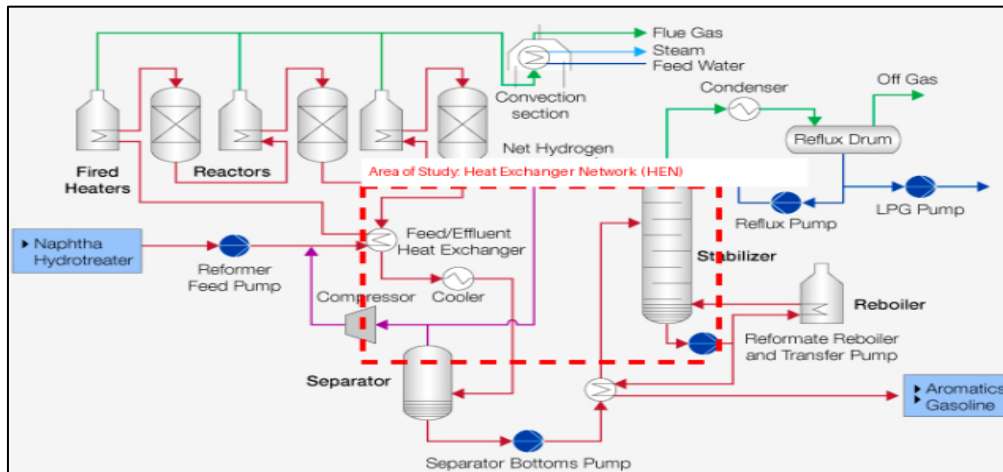


Fig 1. Process flow of the catalytic reforming unit highlighting the HEN area.

In pinch analysis, whether it is for a new project or a retrofit situation, a well-defined stepwise procedure should be followed Figure2. Iteration between some steps may be necessary before proceeding, and re-simulation or data modification can be useful in many situations. The following are the key steps:

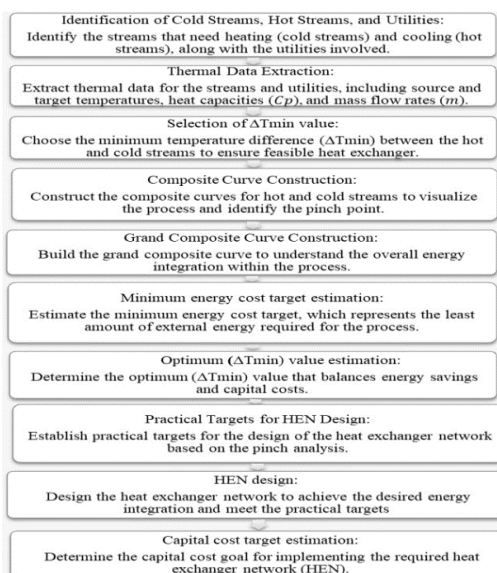


Fig 2. Overview of the step-by-step methodology used in pinch analysis for HEN design.

Data collection, target appraisal, and HEN design were the three primary stages of the study's methodical and structured approach. To guarantee precise and trustworthy results, the analytical method was by its very nature iterative, requiring constant simulation and data correction.

2.2 Data Collection

During the data collection phase, the hot, cold, and utility streams were identified from the process flow diagrams (PFDs) obtained from Zawia refinery. Essential thermal data for these streams were then extracted from both the PFDs and plant operational records. An initial ΔT_{min} was selected at 10 °C based on standard engineering practices and published literature [15]. Subsequent iterative analyses were conducted to determine the optimal ΔT_{min} value. Finally, the composite curves and grand composite curve were generated to evaluate the potential for energy recovery.

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2.3 Target Evaluation and Heat Exchanger Network Design

In the target evaluation and design phase, the theoretical minimum energy requirements for heating and cooling were assessed, and the optimal capital cost for the heat exchanger

network was estimated. The ideal ΔT_{\min} that balances utility costs and capital expenditure was identified, and practical targets for HEN design were established. The HINT software was then used to perform a comprehensive pinch analysis of the unit. The thermal data collected were input into the software to generate composite curves and the grid diagram at various ΔT_{\min} values, allowing the

identification of the optimal value. The results were cross-verified using the Problem Table Algorithm to ensure the accuracy of the software outputs. The heat exchanger network was subsequently designed based on the grid diagram, strictly adhering to pinch principles, which include no heat transfer across the pinch, no external cooling above the pinch, and no external heating below the pinch, thus ensuring that the minimum energy targets were achieved [2].

3. RESULTS AND DISCUSSION

Pinch analysis of the catalytic reforming unit at Zawia Oil Refinery was performed using Aspen Pinch software and validated by manual calculations. The unit comprises three hot streams and four cold streams, as listed in Table 1. In pinch analysis, a hot stream requires cooling (temperature decreases from source to target), while a cold stream requires heating (temperature increases from source to target). This classification is consistent with thermodynamic principles and is applied in Table 1. Stream data were obtained from the original process calculations and verified against the grid diagrams and composite curves. The minimum approach temperature (ΔT_{\min}) was selected as 25 °C, in line with refinery practice.

Table 1. Process stream data for the catalytic reforming unit.

Stream No	Stream name	Type	T_{source} (°C)	T_{target} (°C)	CP (kW/°C)	H load (kW)
H1	V-12 OVHD	Hot	136	55	7.9636	-645.003
H2	Stap to storage	Hot	200	60	19.9592	-2794.29
H3	Feed to v-9	Hot	300	60	19.4621	-4670.9
C1	Feed to compressor	Cold	34	58	10.6211	254.906
C2	Feed to V-12	Cold	34	180	5.518	805.628
C3	Feed to reboiler	Cold	200	345	40.7565	5909.68
C4	Water	Cold	20	95	22.097	1657.28

3.1 Energy Targets and Pinch Point

The composite curves shown in Figure 2 identify a pinch point at 212.5 °C. At this condition, the minimum hot utility requirement is 4450.09 kW, while the minimum cold utility requirement is 3932.73 kW. The grand composite curve Figure 3 illustrates that external heating and cooling are only required outside the pinch region, confirming adherence to pinch design principles.

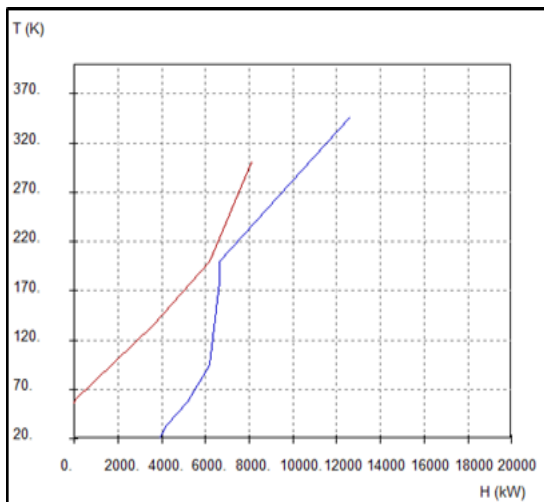


Fig 2. Composite curves for hot and cold streams at $\Delta T_{\min} = 25$ °C.

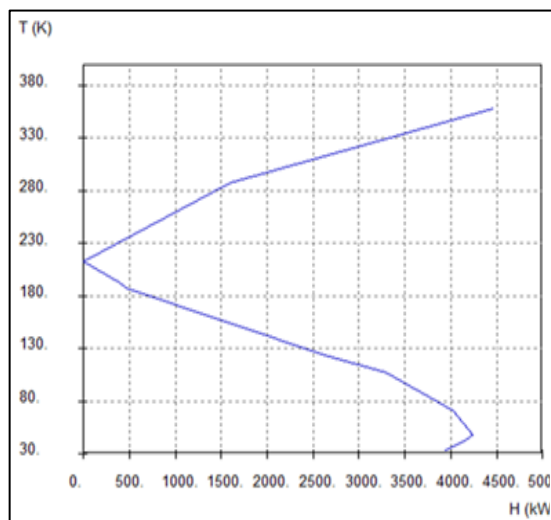


Fig 3. Grand composite curve showing the pinch point (212.5 °C) and minimum utility targets.

3.2. Heat-Exchange Area Target

The exchanger area requirement was estimated by dividing the balanced composite curves into enthalpy intervals. Using the log-mean temperature difference (ΔT_{LM}) approach, the manually calculated total area was 1738.04 m², while HINT software predicted 1623.59 m², with a margin of error of 7.04%. This strong agreement validates model reliability.

The area target curve Figure 4 shows the trade-off between ΔT_{\min} and exchanger area: a smaller ΔT_{\min} increases heat recovery but requires a larger area, whereas a higher ΔT_{\min} reduces area but increases utility consumption. The chosen value of 25 °C lies in the optimal “flat region,” balancing energy savings with capital cost.

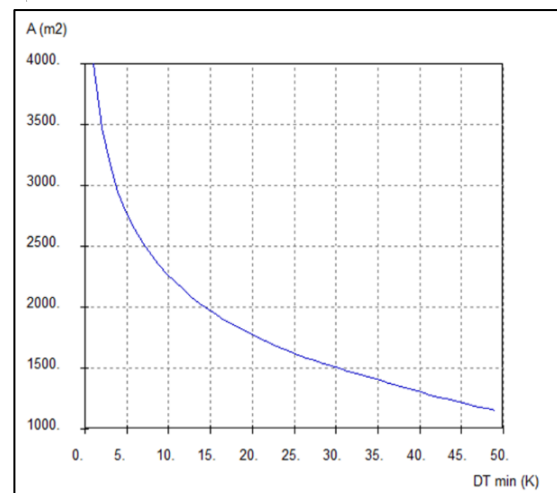


Fig 4. Variation of heat-exchanger area with ΔT_{\min} , showing optimum at 25 °C.

3.3. Heat Exchanger Network Design

The grid diagrams presented in Figures 5 and 6 illustrate the systematic matching of hot and cold streams above and below the pinch point. The same stream identification used in Table 1 is consistently applied in both figures. Partial temperature ranges appearing in the grid diagrams represent stream segments generated during network synthesis and do not correspond to additional process streams.

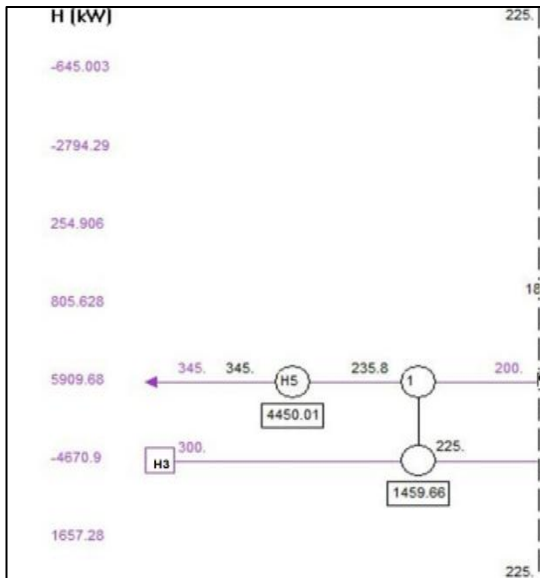


Fig 5. Grid diagram for HEN design above the pinch.

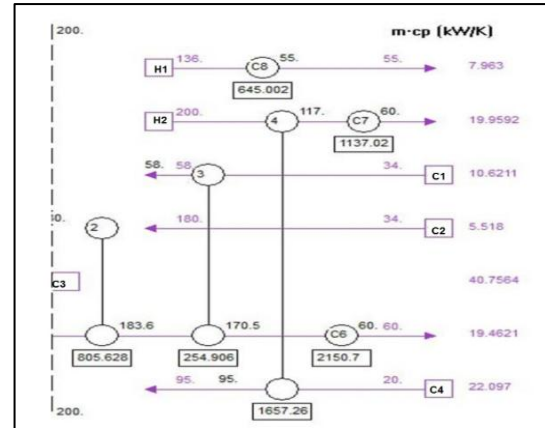


Fig 6. Grid diagram for HEN design below the pinch.

The final heat exchanger network, shown in Figure 7, integrates both regions and consists of eight heat exchangers, including one heater and three coolers. The design satisfies all process heating and cooling requirements while strictly following pinch rules, namely no heat transfer across the pinch, no external heating below the pinch, and no external cooling above the pinch.

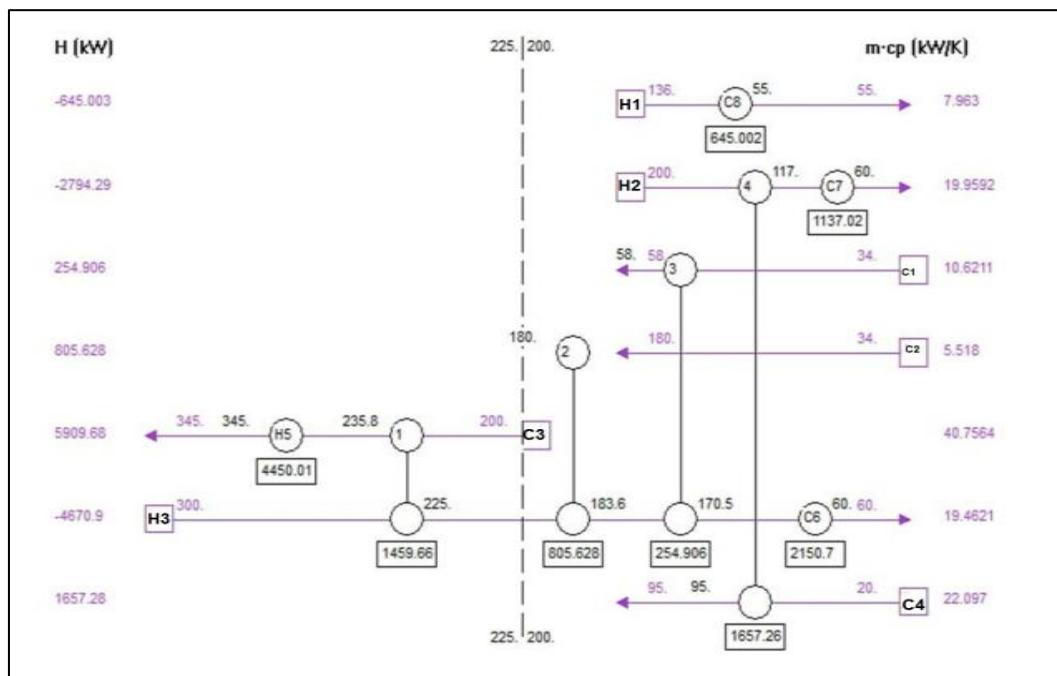


Fig 7. Final HEN design integrating above and below pinch regions.

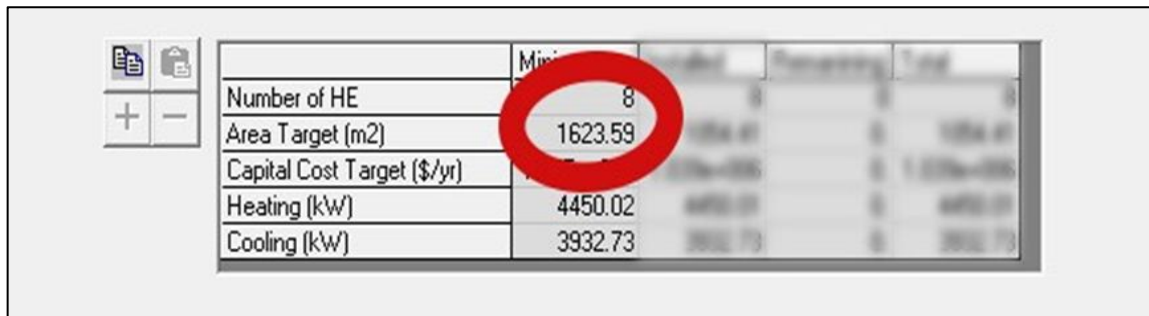
3.4 Validation and Economic Evaluation

To validate the Aspen Pinch results, manual calculations were performed using the Problem

Table Algorithm and the logarithmic mean temperature difference (LMTD) method. The total heat exchanger area calculated manually was 1738.04 m², while the software predicted an

area of 1623.59 m², resulting in a deviation of less than 7%. This close agreement confirms

the reliability and consistency of the obtained results as shown in Figure 8.



	Min	Max	Target	Value
Number of HE	8			8
Area Target (m2)	1623.59			1623.59
Capital Cost Target (\$/yr)				1,000,000
Heating (kW)	4450.02			4450.02
Cooling (kW)	3932.73			3932.73

Fig 8. Validation of exchanger area: manual calculation (1738.04 m²) vs. HINT software (1623.59 m²).

As shown in Figure 9 and Figure 10, the heat exchanger network after heat integration is presented. The comparison with the existing network demonstrates a significant reduction in utility consumption and total heat exchanger area following integration. The before-and-after comparison (Table 2) highlights the benefits of integration. The total utility demand decreased by 49.9%, with hot and cold utilities reduced by

48.4% and 51.5%, respectively. Moreover, the total heat exchanger area decreased from 2730 m² in the base case to 1738 m² after optimization. Economic analysis indicated a capital cost of \$379,490, with an annualized cost of \$100,109/yr. The utility operating cost was \$573,330/yr, yielding a total annual cost of \$673,438/yr.

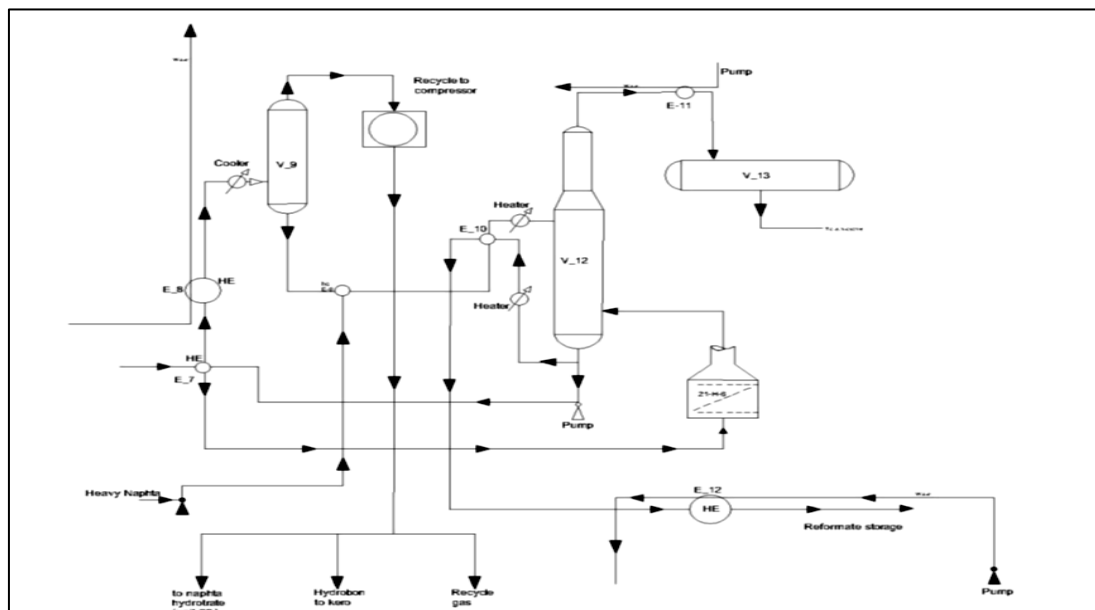


Fig 9. Zawia refinery catalytic reforming of naphtha process flow before Heat integration.

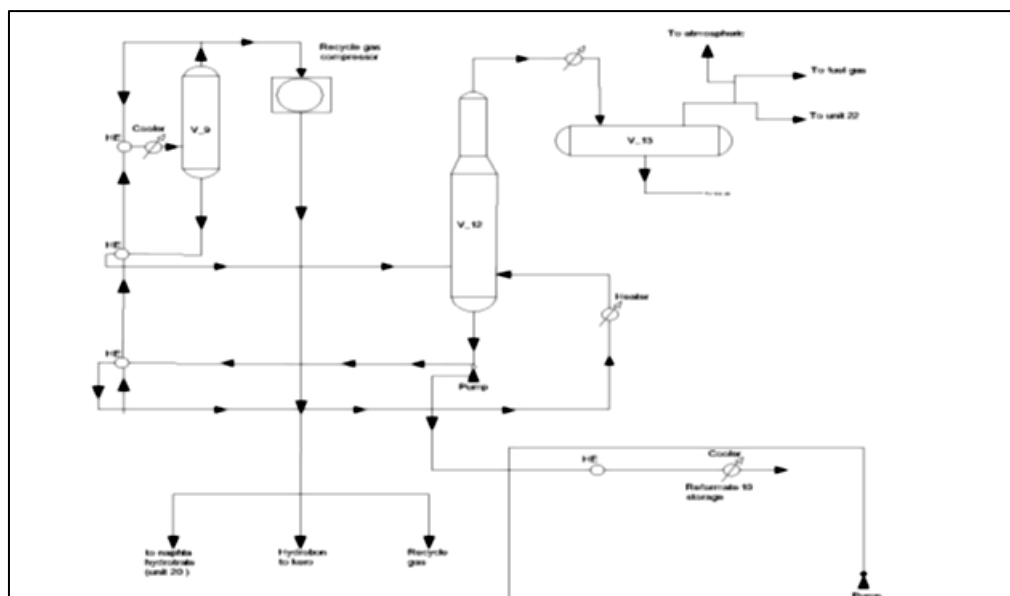


Fig 10. Zawia refinery catalytic reforming of naphtha process flow after heat integration.

Furthermore, the heat integration strategy was meticulously designed to ensure that the proposed Heat Exchanger Network (HEN) retrofit maintains the critical operating conditions of the catalytic reforming unit. The primary objective of the unit producing high-octane naphtha (reformate) that meets standard market specifications is not compromised by the energy optimization. The design strictly adheres to the required inlet and outlet temperatures of

the process streams, particularly the feed to the reboiler (Stream C3) and the feed to the reactor section, ensuring that the necessary reaction kinetics and product quality are preserved. The energy savings achieved are solely a result of maximizing process-to-process heat recovery, thereby reducing the reliance on external utilities without altering the core chemical process parameters essential for high-quality naphtha production.

Table 2. Comparison of utility requirements and heat exchanger area before and after heat integration.

//	Before heat integration	After heat integration
Number of heat exchanger	6	4
Number of heaters	2	1
Number of coolers	1	3
Hot utility, KW	8627.494	4450.09
Cold utility, KW	8109.383	3932.73
Total utility, KW	16736.877	8382.82
Area, m ²	2730	1738.036
Exchanger cost (C.C), \$	613557.306	379490.789
Operating cost, \$	1116393.11	573329.7
Annual capital cost (A.C.C), \$	161854.871	100108.714
Total annual cost, \$	1278247.981	673438.414

The comparison presented in Table 2 clearly demonstrates the effectiveness of the retrofit strategy. Total utility demand decreased by 49.9%, with hot and cold utilities reduced by 48.4% and 51.5%, respectively. In addition, the total heat exchanger area decreased from 2730 m² in the base case to 1738 m² after optimization. The retrofit also led to a reduction in the number of heat exchangers from six to four, while the number of coolers increased from one to three. This configuration results from maximizing heat recovery above the pinch point, thereby prioritizing the preheating of cold streams using available process heat and reducing the duty of the main

fired heater. As a result, the number of process-to-process heat exchangers is optimized, and additional coolers are required to remove the remaining heat from hot streams after the maximum recoverable energy has been transferred. The energy savings achieved (~50%) surpass many previously reported values. The higher savings here indicate that catalytic reforming units, being highly energy-intensive, are excellent candidates for pinch-based optimization.

4. Conclusion

This study demonstrated the successful application of pinch technology to the catalytic

6. References

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