



University of Sistan  
and Baluchestan

# Chemical Process Design

Available online at <http://cpd.usb.ac.ir/>



## Heat Integration of Isomerization Unit Using Loop Breaking

Maryam Hosseini<sup>1</sup>, Zahra Ghazizahedi<sup>2</sup>, Majid Hayati-Ashtiani<sup>3</sup>✉ 

<sup>1</sup> Department of Chemical Engineering, Faculty of Engineering, University of Kashan, Iran. E-mail: [aym.hosseini@gmail.com](mailto:aym.hosseini@gmail.com)

<sup>2</sup> Department of Chemical Engineering, Faculty of Engineering, University of Kashan, Iran. E-mail: [z.ghzahedi@gmail.com](mailto:z.ghzahedi@gmail.com)

<sup>3</sup> Corresponding Author, Department of Chemical Engineering, Faculty of Engineering, University of Kashan, Iran.  
E-mail: [hayati@kashanu.ac.ir](mailto:hayati@kashanu.ac.ir)

### ARTICLE INFO

#### Article type:

Research Article

#### Article history:

Received: 2025-02-16

Received in revised form: 2025-05-21

Accepted: 2025-05-22

Available online: 2025-05-22

**Keywords:** Energy-saving; Gasoline production; Heat exchanger network; Heat Integration; Loop breaking

### ABSTRACT

A significant portion of operating costs in process industries is spent on energy consumption; therefore, exploring heat integration methods is essential to reduce production costs without compromising product quality or performance. In this study, process data from an isomerization unit was used to simulate the process in Aspen HYSYS (V9), and the heat integration analysis was conducted using Aspen Energy Analyser (V9). Initially, heat exchanger data was entered into the software, and the resulting heat exchanger network (HEN) was examined. To optimize energy consumption, the pinch analysis technique—specifically the loop breaking method—was applied to eliminate redundant heat loops. As a result, the number of heat exchangers was reduced from 28 to 25. This modification led to a reduction in capital cost from  $\$2.196 \times 10^7$  to  $\$2.113 \times 10^7$  and in annual cost indicator from  $\$2.394 \times 10^7/\text{yr}$  to  $\$2.373 \times 10^7/\text{yr}$ . Therefore, capital and annual costs decreased by 3.77 and 0.87%, respectively. These savings are attributed to the removal of unnecessary heat exchangers, which lowered both the heat duty and the surface area required. Furthermore, the applied modifications led to a noticeable improvement in energy efficiency through better heat recovery within the system. The novelty of this research lies in the integrated use of pinch analysis and loop breaking for optimizing the HEN of a real isomerization unit—an approach rarely addressed in previous industrial studies. This method provides a practical and cost-effective model for sustainable design in process industries.

**Cite this article:** Hosseini, M., Ghazizahedi, Z., Hayati-Ashtiani, M., (2025), Comprehensive Heat Integration of Isomerization Unit Using Loop Breaking, *Chemical Process Design*, 4(2), 1-11. <http://doi.org/10.22111/cpd.2025.51163.1049>



© The Author(s).

DOI: <http://doi.org/10.22111/cpd.2025.51163.1049>

Publisher: University of Sistan and Baluchestan.

### 1. Introduction

The process of light naphtha isomerization is one of the most widely-used catalytic processes in producing high-octane gasoline thereby contributing to the reduction of environmental damage [1]. Isomerization involves converting

normal paraffins into branched isomers that possess different chemical and physical properties, despite having the same molecular formula [2]. The recent investigations in the field of energy-saving clearly show the significant role of reforming processes. Various refineries use different isomerization methods to produce isomerates, all of which are energy-consuming [3]. Therefore, retrofitting the isomerization processes to decrease energy consumption is both important and quite necessary.

A "heat loop" refers to a circuit through the Heat Exchanger Network (HEN) that starts at one exchanger in the network and ends in the same exchanger. In energy-intensive processes, identifying and eliminating such loops becomes essential, as it can significantly minimize the total annual cost by redefining heat transfer paths. A path is a circuit through the network that starts at a heater and ends at a cooler, or vice versa. The minimum values of energy loads are achieved by breaking the loop using the heat paths [4]. The new heat exchanger network is created by removing some heat exchangers to break the loops to decrease the number of the loops and the removal of the extra heat exchangers causes energy relaxation and breaks the loops. Pinch technology is an appropriate energy-integration method that helps eliminate the loops and minimize the amounts of heat loads and the amounts of hot and cold utility and heat exchangers [5-7].

Recently, scientists have increasingly focused on retrofitting of the various processes by eliminating the loops in some Minimum Energy Requirement or Maximum Energy Recovery (MER) designs. Li et al. have adequately investigated the preheating of crude oil to save 2579 \$/yr by loop breaking through Pinch Analysis (PA). They decreased cross pinch heat transfer caused by 7 heat exchangers [8]. Elias et al. optimized a Bio methanol production process, resulting in a 4.72% energy saving and 148,956 kW energy generation [5]. In another study, a 20% reduction in carbon emission intensity was achieved in a palm oil refining process through carbon emission pinch analysis [9]. Loop breaking also led to cost reductions in three separate units, with annual cost decreases of approximately 2.17%, 10.64%, and 3.68%, respectively [7]. Gabr (2018) showed in Grass-root HEN designs for a case study using Pinch Analysis (PA) that the energy might be saved up to 65% compared with the base case using the loop breaking methodology. He suggested four Grass Root designs after combining the above and below designs using Pinch Design Method (PDM) [10]. Manizadeh et al. (2018) suggested a retrofit design of the HEN for a naphtha unit by eliminating the heat exchanger, which had the lowest surface area, resulting in a 5.1% reduction in energy consumption [6]. Through HEN design and loop breaking, Anastasovski identified two loops in a HEN design and introduced two heat paths between the utility heaters and coolers, achieving a reduction of 12 kW in hot and cold utility loads [11]. Furthermore, recent studies have introduced innovative methods to enhance pinch-based retrofitting. One study applied a combined Pinch Analysis and Thot–Tcold diagram to optimize energy use in a residue hydrogenation process, resulting in 202.71 GJ/h of energy recovery and approximately \$2.76 million in annual savings [12]. Another research advanced the traditional Spaghetti structure into an Enhanced Spaghetti Pinch Analysis (ESPA), which improved cost prediction accuracy and reduced cost target deviations to within  $\pm 5\%$  [13].

This research aims to investigate and implement systematic approaches developed to integrate the process to satisfy the heating, cooling, and costs of a light naphtha isomerization process. Initially, the base-case was analyzed to determine energy targets, specially the heating and cooling utilities during heat transfer between the hot and cold streams at the pinch point. Subsequently, the heat exchanger network (HEN) was retrofitted using the loop breaking method—a technique within pinch analysis that allows heat transfer across the pinch point to eliminate unnecessary heat loops. A review of the existing literature revealed that the application of loop breaking in isomerization processes

for energy savings has been rarely explored. Addressing this gap, the present research evaluates the simultaneous effects of HEN retrofit on capital, operational, and total annual costs in a comprehensive manner. Simultaneous effects of retrofitting isomerization process on operating, Capital, and Total Annual costs were studied from scratch and, finally yet importantly, this study is only a starting point promising some further studies in this field. This work serves as a preliminary step toward more advanced studies in sustainable process design and energy integration in industrial units.

## 2. Concepts and methodology

### 2.1. Process description

The feed to the isomerization unit consists of light naphtha direct streams, which are rich in normal pentanes and normal hexanes [1]. The isomerization process converts normal hydrocarbons to branched isomers that have the same molecular formula but different structural formulas. These isomers increase the octane number [14].

To separate the isopentane and improve the octane number, the feed is transferred to the deisopentanizer column. The product from the bottom of the column is then sent to the dryer to prevent moisture contamination, as the isomerization unit catalyst is sensitive to moisture [13]. Then, it enters the reactor, where isomerization and hydrogenation reactions of benzene take place. The reactor effluent stream is directed to the stabilizer to separate hydrochloric acid and light gases [14-15]. Then a low-stabilized product is sent to the deisohexanizer, where the octane number of gasoline is further increased. In this tower, the straight-chain hydrocarbons are recycled back to the reactor as a recycle stream [3, 14]. Fig. 1 shows the pictorial description of the process.

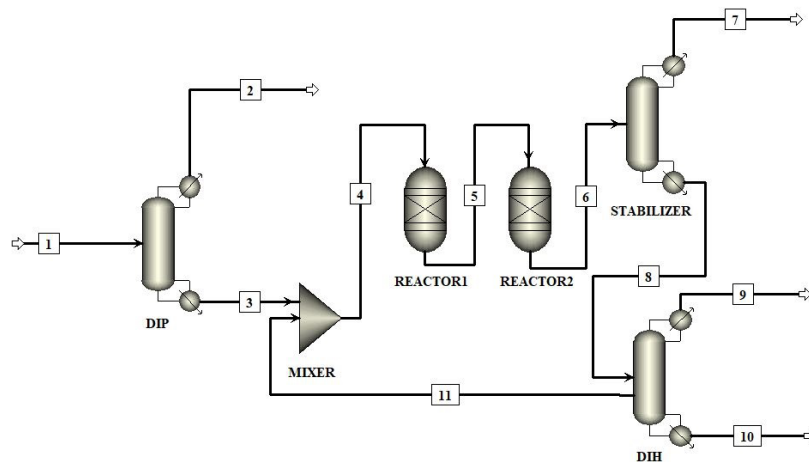


Fig. 1. A pictorial description of the process

### 2.2. Pinch technology

Pinch technology, like the thermal coupling method [16], is recognized as a method for heat integration is a tool for energy calculations and energy targeting to optimize energy consumption. Composite Curves (CC) play an important role in the direct design of a Heat Exchanger Network (HEN), and the Grand Composite Curve (GCC) is essential in process integration [10]. In the composite curves, the overlapping region between the two composite curves of cold and hot streams indicates the maximum heat recovery that can be achieved in the process [17-18].

### 2.3. Loops and loops breaking

A loop is a closed path that begins at a heat exchanger and, passes through the streamlines, and ends at the same heat exchanger. Once a HEN that meets the the Minimum Energy Requirement (MER) targets is designed, the next step is typically to reduce the heat exchangers number to the minimum. The first task to be worked out in the breaking loop is the minimum number of the exchanger ( $U_{\min}$ ) in the network, which is calculated by Eq. (1) [18]:

$$U_{\min} = N_{\text{stream}} + N_{\text{Util}} - 1 \quad (1)$$

Where  $U_{\min}$  is the minimum number of exchangers,  $N_{\text{stream}}$  is the streams number and  $N_{\text{Util}}$  is the number of utilities used in the design. The loops number in the network is determined by Eq. (2):

$$\text{The number of loops} = U_{\text{HEX}} - U_{\min} \quad (2)$$

Where  $U_{\text{HEX}}$  is the number of exchangers in the design [7, 10, 20]. Therefore, a Heat Exchanger Network involves  $U_{\text{HEX}}$  units ( $U_{\text{HEX}} > U_{\min}$ ) has  $(U_{\text{HEX}} - U_{\min})$  independent “heat loops”. Generally, heat flows across the pinch and the number of heat exchangers is decreased when heat loops are “broken”, but the loads of utility are increased.

The loop breaking occurs when an exchanger is removed from the loop, and its heat duty is transferred to the other heat exchanger of the broken loop [8]. After removing the exchanger, the network should be checked for  $\Delta T_{\min}$  violation, and in case of the existing  $\Delta T_{\min}$  violation, this problem should be solved by correcting the heat duty of the exchanger through the heat path. After breaking the loop, the number of heat exchangers decreases but the amounts of hot and cold utility will be increased [6]. A small schematic diagram illustrating a loop-breaking scenario is shown in Fig. 2.

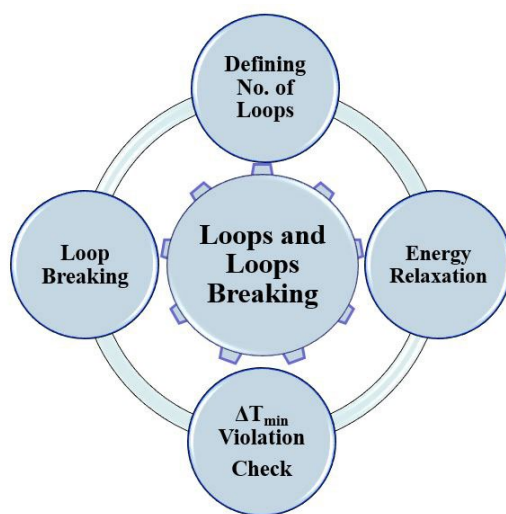


Fig. 2. Schematic diagram of loop-breaking

### 3. Results and discussion

#### 3.1. Base-case analysis

The heat exchangers network of the studied unit, designed using Aspen Energy Analyzer V9, is shown in Fig. 3. Aspen Energy Analyzer is a software for energy management that enables the optimum design of a HEN for minimizing process energy consumption. The use of this software for development of heat integration projects not only significantly reduces capital and operating costs but also minimizes the energy requirements of the HEN, allowing the user to identify the best design solutions. In Fig. 3, cold streams are represented in blue and hot streams are shown in red. This unit includes 13 process hot streams and 9 process cold streams. Additionally, the network includes 6 shell and tube heat exchangers, 8 heaters, and 14 coolers, with one of the existing heaters being an electrical heater.

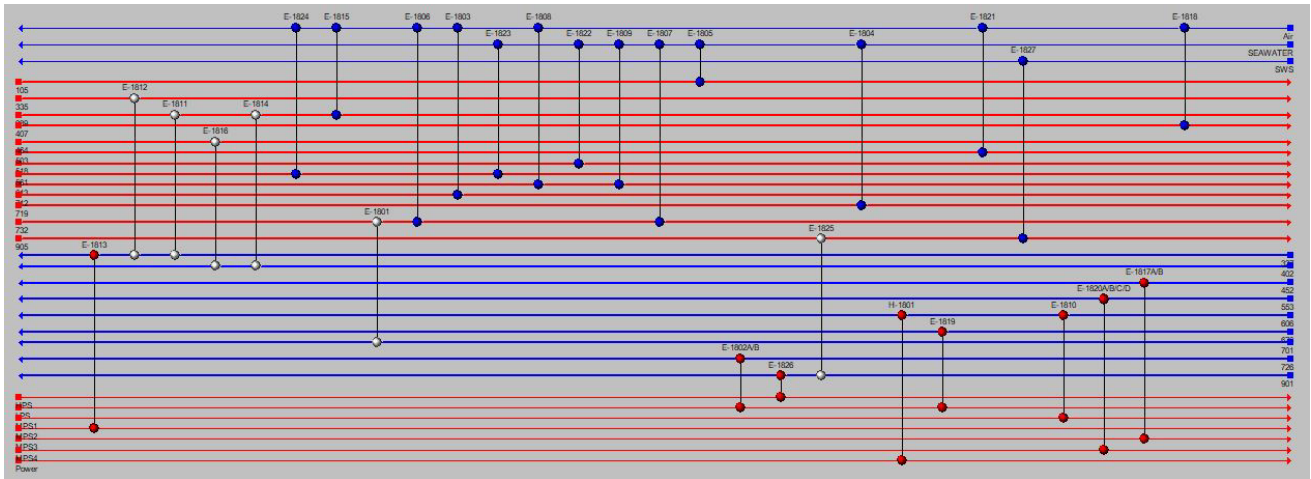


Fig. 3. HEN of the base-case

In this unit, there are seven types of hot utility and three types of cold utility. Hot utilities include LPS, MPS1, MPS2, MPS3, MPS4, HPS steam, and power, where MPS steam is present in four different temperatures and names in the network. Cold utilities include air, seawater, and water service (supplemental) water system (SWS). The outlet and inlet temperatures and also the duty of each exchanger are shown in Table 1. The data collected for this research has collected from the Process Flow Diagram (PFD) of the studied isomerization unit. The period during SOR (Start of Run) to EOR (End of Run) is called cycle length. It is assumed that this study is based on SOR conditions. The lowest temperature at which plant is commissioned to yield desired product quality is called SOR. The next assumption is that the simulation is based on steady-state condition.

Table 1. Data extraction

Heat Exchanger	Type	Cold Stream	Cold in	Cold Out	Hot Stream	Hot in	Hot Out
E-1804	Cooler	SWS	20.0	20.7	719	56.0	40.0
H-1801	Heater	606	146.0	316.0	Power	326.0	226.0
E-1824	Cooler	Air	30.0	30.0	561	130.0	60.0
E-1807	Cooler	SWS	21.2	26.6	732	60.0	40.0
E-1815	Cooler	Air	29.4	30.0	339	99.0	53.0
E-1805	Cooler	SWS	20.7	21.2	105	79.0	40.0
E-1801	Process to Process	701	40.0	83.1	732	102.0	72.0
E-1803	Cooler	Air	28.0	29.4	712	64.0	56.0
E-1813	Heater	327	130.5	146.0	MPS2	215.0	211.0
E-1819	Heater	676	48.0	49.0	LPS	141.1	141.0
E-1821	Cooler	Air	25.3	27.8	503	75.0	58.0
E-1827	Cooler	SWS	30.0	40.0	905	59.7	40.0
E-1810	Heater	606	40.0	146.0	MPS1	191.0	173.0
H-1812	Process to Process	327	80.8	130.5	335	186.0	138.0
E-1814	Process to Process	402	53.0	82.0	339	115.8	99.0
E-1806	Cooler	Air	29.4	29.4	732	72.0	60.0
E-1802A/B	Heater	726	99.0	101.0	LPS	147.0	141.1
E-1820A/B/C/D	Heater	553	130.0	132.0	MPS4	188.0	168.0
E-1822	Cooler	SWS	27.3	29.6	518	58.0	40.0
E-1826	Heater	901	186.0	210.0	HPS	253.0	252.0
E-1817A/B	Heater	452	175.0	177.0	MPS3	204.0	195.0
E-1809	Cooler	SWS	26.6	27.3	613	60.0	40.0
E-1811	Process To Process	327	49.0	80.8	339	147.0	115.8
E-1823	Cooler	SWS	29.6	30.0	561	60.0	40.0
E-1825	Process To Process	901	32.0	186.0	905	213.0	59.7
E-1816	Process To Process	402	82.0	134.0	464	175.0	127.7
E-1818	Cooler	Air	25.0	25.3	407	92.0	53.0
E-1808	Cooler	Air	27.8	28.0	613	304.0	60.0

$\Delta T_{\min}$  plays a decisive role in designing of the HEN. The optimum  $\Delta T_{\min}$  was at  $10^{\circ}\text{C}$  calculated by Aspen Energy Analyzer considering the minimum Total Cost (Table 2). The Total Cost of the unit at  $\Delta T_{\min} = 10^{\circ}\text{C}$  is  $2.394 \times 10^{+7}$  \$/yr, which represents the lowest calculated Total Cost. The Total Cost at  $\Delta T_{\min} = 10^{\circ}\text{C}$  is 2% more than that of reported for  $\Delta T_{\min} = 5^{\circ}\text{C}$ . This difference is due to the displacement of the pinch point and changes in the number of hot and cold streams on both sides of the pinch point. The Capital Cost Index and Operating Cost Index of the unit at  $\Delta T_{\min} = 10^{\circ}\text{C}$  are  $\$ 3.529 \times 10^{+7}$  and  $1.425 \times 10^{+7}$  US \$/yr, respectively. Fig. 4 shows the effect of different  $\Delta T_{\min}$  value on the Capital and Operating costs of the heat exchanger network.

Fig. 4 shows the optimization of  $\Delta T_{\min}$  on the overall costs of the heat exchanger network. Results shows that the best minimum temperature difference that gives the lowest total cost for this unit is  $10^{\circ}\text{C}$ . At this temperature, the amount of hot and cold side service ( $Q_{H\min}$  and  $Q_{C\min}$ ) consumed is 81.01 MW and 30.95 MW, respectively.

Fig. 5 shows that the hot utility ( $Q_H$ ) and cold utility ( $Q_C$ ) requirements are 96.35 MW and 121.9 MW, respectively. The heat imbalance between the cold and hot streams of the process results in the need for external utilities, as the internally generated heat is not fully recovered. In some parts of Fig. 5 where the vertical distance between the hot and cold stream is small, the energy recovery is high and the energy loss is low. Conversely, in the other parts where the vertical distance between hot and cold composite curves is high, the energy loss is high and the energy recovery is low. Composite curves indicate one main process pinch and three utility pinches, and since the optimum  $\Delta T_{\min}$  is  $10^{\circ}\text{C}$ , the temperatures of the hot and cold process pinch are  $92$  and  $82^{\circ}\text{C}$ , respectively. The hot pinch temperature is  $92^{\circ}\text{C}$  and the  $\Delta T_{\min}$  is  $10^{\circ}\text{C}$ , therefore, the cold pinch temperature is  $82^{\circ}\text{C}$ .

**Table 2.** Optimization of  $\Delta T_{\min}$  versus total cost.

DTmin (°C)	Heating (MW)	Cooling (MW)	Area 1-1 (m <sup>2</sup> )	Area 1-2 (m <sup>2</sup> )	Units	Shells	Cap. Cost Index (\$)	Op. Cost Index (\$)	Total Cost Index (\$)
2.0	77.46	91.75	1.9558e+0	2.0935e+0	39	166	4.162e+007	8.076e+006	1.906e+007
2.9	77.85	92.14	1.7552e+0	1.8217e+0	38	144	3.629e+007	8.136e+006	1.771e+007
3	77.88	92.17	1.7181e+0	1.8132e+0	37	139	3.598e+007	8.141e+006	1.764e+007
3.9	78.24	92.53	1.6409e+0	1.7147e+0	46	134	3.432e+007	8.244e+006	1.730e+007
4.0	78.30	92.59	1.6304e+0	1.7018e+0	46	130	3.396e+007	8.262e+006	1.723e+007
4.8	78.64	92.92	1.5792e+0	1.6411e+0	46	121	3.244e+007	8.363e+006	1.693e+007
5.0	78.72	93.01	1.5674e+0	1.6276e+0	46	122	3.232e+007	8.390e+006	1.692e+007
5.3	78.83	93.12	1.5539e+0	1.6122e+0	56	130	3.255e+007	8.416e+006	1.701e+007
5.7	79.03	93.31	1.5313e+0	1.5867e+0	56	126	3.190e+007	8.458e+006	1.688e+007
6.0	79.14	93.43	1.5189e+0	1.5728e+0	56	120	3.149e+007	8.483e+006	1.680e+007
6.6	79.42	93.70	1.4929e+0	1.5440e+0	56	119	3.097e+007	8.542e+006	1.672e+007
7.0	79.57	93.85	1.4804e+0	1.5302e+0	56	113	3.051e+007	8.573e+006	1.663e+007
7.1	79.61	93.90	1.4764e+0	1.5259e+0	56	116	3.058e+007	8.584e+006	1.666e+007
7.6	79.81	94.10	1.4613e+0	1.5094e+0	56	109	2.998e+007	8.626e+006	1.654e+007
8.0	79.99	94.27	1.4488e+0	1.4957e+0	56	107	2.961e+007	8.664e+006	1.648e+007
8.5	80.25	94.53	1.4328e+0	1.4768e+0	58	109	2.942e+007	8.714e+006	1.648e+007
9.0	80.48	94.77	1.4194e+0	1.4595e+0	58	105	2.898e+007	8.760e+006	1.641e+007
9.0	80.50	94.78	1.4187e+0	1.4585e+0	58	109	2.916e+007	8.763e+006	1.646e+007
9.9	80.96	95.25	1.3958e+0	1.4289e+0	58	105	2.857e+007	8.853e+006	1.639e+007
10.0	81.01	95.30	1.3932e+0	1.4259e+0	47	95	2.789e+007	8.867e+006	1.623e+007
10.8	81.44	95.72	...	...	...	...	...	...	...
11.0	81.52	95.81	...	...	...	...	...	...	...
12.0	82.03	96.32	...	...	...	...	...	...	...
18.0	85.11	99.40	...	...	...	...	...	...	...
27.0	89.72	104.0	...	...	...	...	...	...	...
42.0	97.14	111.4	...	...	...	...	...	...	...
66.0	105.8	120.1	...	...	...	...	...	...	...
106.0	121.9	136.2	...	...	...	...	...	...	...
169.0	135.9	150.1	...	...	...	...	...	...	...
272.0	137.6	151.8	...	...	...	...	...	...	...

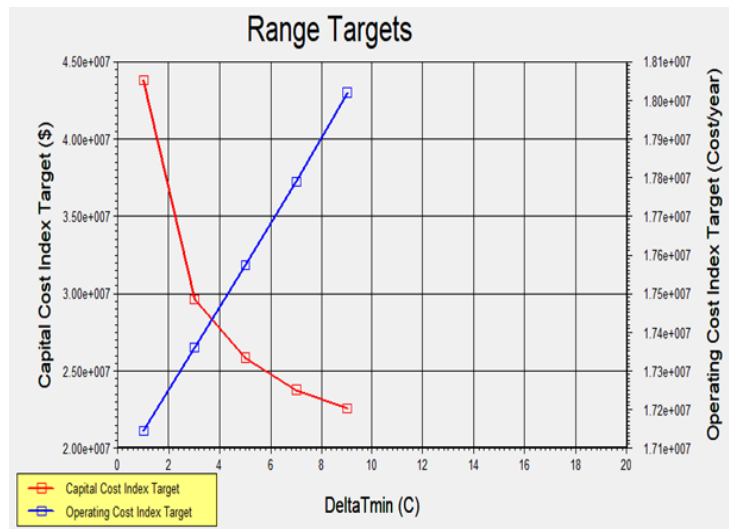


Fig. 4. Effect of  $\Delta T_{\min}$  on capital and operating costs of the Heat Exchanger Network

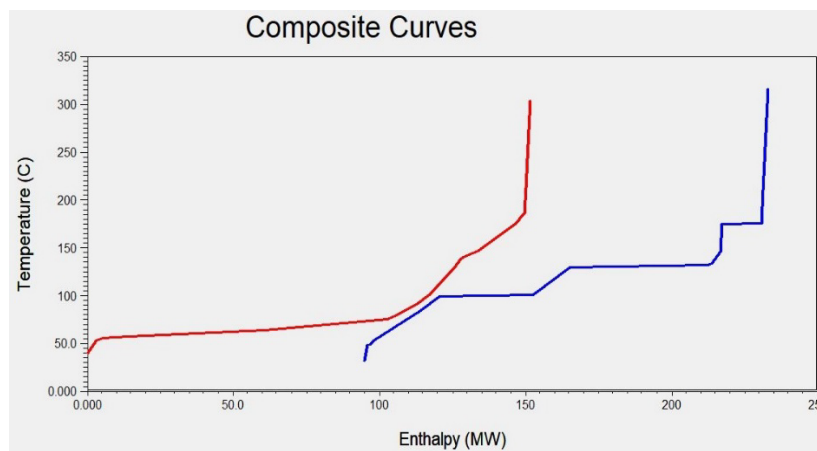


Fig. 5. Hot and cold composite curves of HEN at  $\Delta T_{\min} = 10^{\circ}\text{C}$

The cross-pinch heat transfer of understudy unit is 20.99 MW. The heat exchangers contributing to cross-pinch heat transfer include E-1811, E-1814, E-1808, E-1815, E-1801, E-1819, E-1810, E-1824, E-1812, E-1825 and E-1816. Among these, E-1811 exhibits the highest and E-1816 the lowest cross-pinch heat transfer. Cross-pinch transfer moves the unit away from minimum utility consumption. Improper design of the exchanger network and improper exchanger matches leads to significant heat flow across the pinch point and resulting in uneconomical configurations. Fig. 6 presents the Grand Composite Curve (GCC), in which the temperature of the pinch is  $82^{\circ}\text{C}$ . In this diagram, the values of hot and cold utility targets are 95.30 MW and 81.01 MW, respectively. A thermal pocket exists in the  $135\text{--}180^{\circ}\text{C}$  temperature range of the GCC, containing 15 MW of surplus energy. This excess energy could potentially be recovered in a different retrofit scenario, which is beyond the scope of the current study.

Based on the HEN shown in Fig. 3, the unit includes a total of 28 heat exchangers: 6 process-to-process heat exchangers, 8 heaters, and 14 coolers. Also, the software has calculated the minimum unit heat exchanger to be 25. Therefore, according to Eq. (2), there are three loops. The loop in the HEN increases the cost and number of unit exchangers. Therefore, breaking the loops in the network is one way to reduce the unit cost. Now, the loops are identified and removed to design the minimum unit heat exchangers ( $U_{\min}$ ).

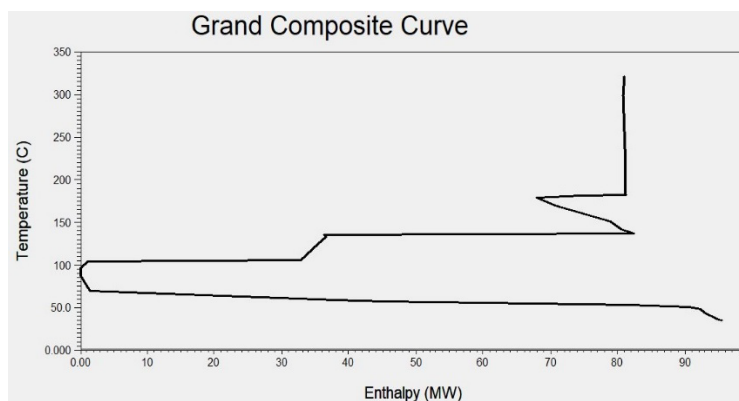


Fig. 6. GCC at  $\Delta T_{\min} = 10^{\circ}\text{C}$

### 3.2. Identification and elimination of 1<sup>st</sup> loop

Fig. 7 shows the three loops with paths labeled ABCD, A'B'C'D', and A''B''C''D'', which are part of the HEN. The 1<sup>st</sup> loop ABCD consists of four exchangers, namely, E-1807, E-1806, E-1823, and E-1824. Fig. 7 highlights the portion of the HEN where the loop exists. The streams flowing from left to right are hot streams and the streams flowing from right to left are cold streams. Fig. 7 shows that the 1<sup>st</sup> loop is not simple and consists of four exchangers: E-1807/ E-1806/ E-1823/ E-1824. A simple loop, by contrast, consists of four exchangers arranged in a rectangular configuration and is easier to identify.

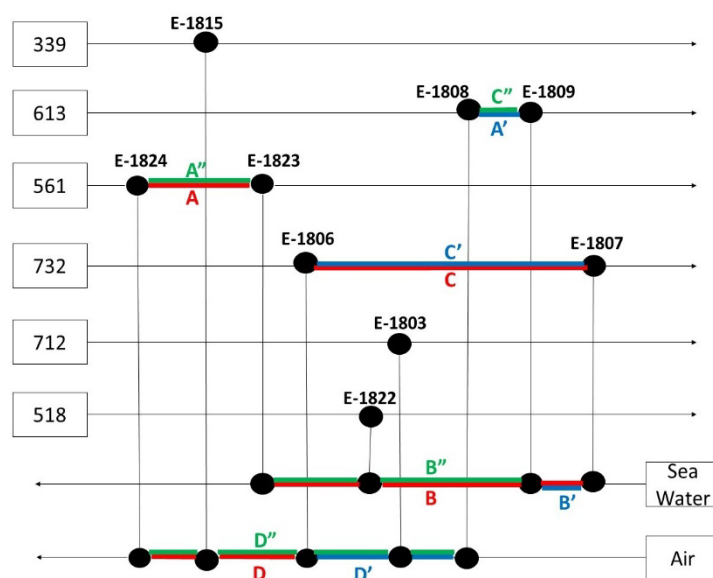


Fig. 7. The 1<sup>st</sup> loop (ABCD), 2<sup>nd</sup> Loop (A'B'C'D') and 3<sup>rd</sup> Loop (A''B''C''D'')

The simplest modification for breaking the loop ABCD is to remove heat exchanger E-1823, transferring its heat duty to heat exchangers E-1824 and E-1807. This action reduces the heat duty of the cooler on stream 561 by the corresponding amount, and increases the heat duty of the coolers on stream 561 and 732 by the same amount. This process is commonly referred to as loop breaking. Typically, the heat exchanger with smallest heat duty in the heat loop is removed, since the area cost saved with omitting a small heat exchanger is often greater than the cost incurred by increasing the area of a larger one. Exchanger E-1823 is a cooler, which reduces the temperature of stream 561 using seawater and has a duty of 0.1933 MW. Its elimination causes heat to flow across the pinch. The pinch heat-cross is such that the amount of E-1823 duty is shared with the two exchangers E-1824 and E-1807 and the duty of E-1807 is correspondingly reduced from E-1806.

If a  $\Delta T_{\min}$  violation occurs, then energy relaxation will be required and there will be changes in the utility targets. E-1824 located on stream 561 increases the temperature of stream 561 from 130 to 60°C before loop breaking. The temperature of stream 561 changed from 130 to 40°C and no  $\Delta T_{\min}$  violation was observed after loop breaking. The values of hot and cold utility targets following the 1<sup>st</sup> loop breaking are 81.01 MW and 95.29 MW, respectively. The Capital Cost Index and Operating Cost Index respectively showed reduction of 3.77% and 0.87% compared to the base-case values and the new values are  $\$2.113 \times 10^{+7}$  and  $2.373 \times 10^{+7}$  US \$/yr. This cost reduction is attributed to the removal of one exchanger, and in terms of the Capital Cost Index, a larger heat exchanger is less expensive than several separate heat exchangers. The Total Cost reduction is because of the cost of depreciation, repair, and maintenance and design and installation of an exchanger with a larger area are less than a few exchangers in smaller sizes. In addition, in this way, lower annualized costs may be achieved when the fuel cost is low compared to the purchase cost of exchangers. The duty changes of the heat exchangers after the 1<sup>st</sup> loop breaking are presented in Table 3.

**Table 3.** The duty of heat exchangers in base-case and after breaking the 1<sup>st</sup> loop

Heat exchangers	Base case (MW)	First loop break (MW)
E-1806	1.574	1.38
E-1807	2.623	2.816
E-1808	4.187	4.187
E-1809	0.3432	0.3432
E-1823	0.1933	-
E-1824	0.6767	0.87
Total	9.5972	9.5962

### 3.3. Identification and elimination of 2<sup>nd</sup> loop

The 2<sup>nd</sup> loop, identified by the path A'B'C'D', consists of four exchangers, namely, E-1809, E-1808, E-1807, and E-1806. Within this loop, the E-1809 heat exchanger with duty 0.3432 MW is the loop smallest exchanger and is therefore eliminated. As a result of eliminating E-1809, its heat duty is redistributed to exchangers E-1808 and E-1807, while an equivalent amount of heat duty is subtracted from E-1806.

E-1809 is a cooler that reduces the temperature of stream 613 from 60 to 40°C using seawater. After loop breaking, the the outlet temperature of E-1808 is 40°C and there is no  $\Delta T_{\min}$  violation after the 2<sup>nd</sup> loop breaking. There are not any changes in the utilities value since there is no  $\Delta T_{\min}$  violation is observed, as well as the 1<sup>st</sup> loop breaking. Therefore, the hot and cold utility targets are 81.01 MW and 95.29 MW, respectively. The Capital Cost Index and Operating Cost Index also remain unchanged at  $\$2.113 \times 10^{+7}$  and  $2.373 \times 10^{+7}$  US \$/yr, respectively. The 1<sup>st</sup> and 2<sup>nd</sup> loops that do not change the unit costs after breaking are called closed loops. The changes in heat exchanger duties after the second loop breaking are provided in Table 4.

**Table 4.** The duty of heat exchangers in base-case and after breaking the 1<sup>st</sup> and 2<sup>nd</sup> loops

Heat exchangers	Base case (MW)	Breaking first loop (MW)	Breaking second loop (MW)
E-1806	1.574	1.38	1.037
E-1807	2.623	2.816	3.159
E-1808	4.187	4.187	4.529
E-1809	0.3432	0.3432	-
E-1823	0.1933	-	-
E-1824	0.6767	0.87	0.87
Total	9.5972	9.5962	9.595

### 3.4. Identification and elimination of 3<sup>rd</sup> loop

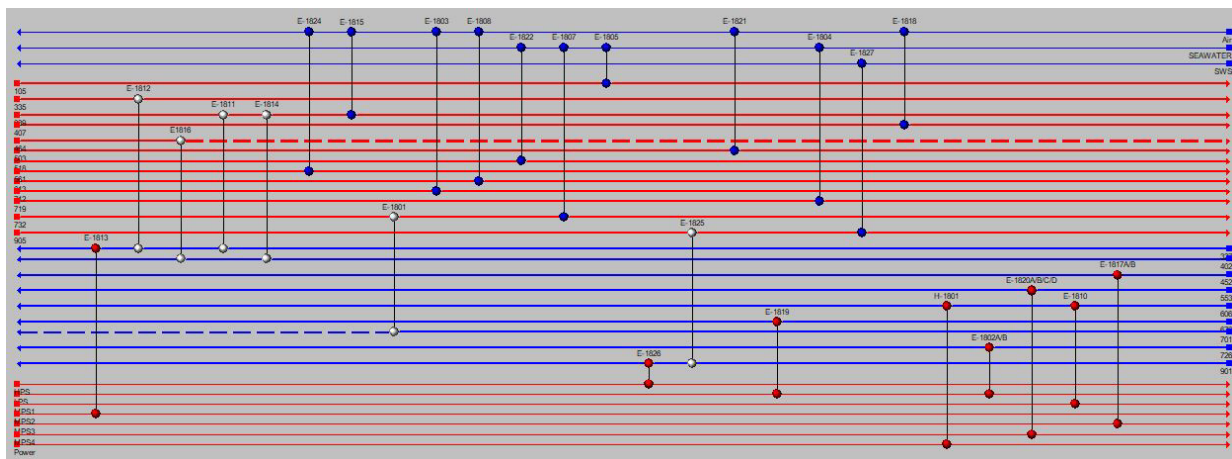
Fig. 7 shows the 3<sup>rd</sup> loop, with the path A"B"C"D", which is not a simple loop. It consists of four exchangers: E-1808, E-1809, E-1823, and E-1824. These exchangers are shared with the other two loops: E-1823 and E-1824 are common to both the first and third loops, while E-1808 and E-1809 are shared with the second and third loops.

Among the remaining two exchangers, the E-1806 exchanger, which is an air cooler with 1.037 MW duty, has smaller duty than that of the E-1807 exchanger. To reduce the number of units, the 1.037 MW exchanger is merged with the 2.623 MW exchanger. This breaks the heat loop and there is no  $\Delta T_{\min}$  violation in the heat exchangers network after breaking the 3<sup>rd</sup> loop.

The amounts of hot and cold utility are 81.01 MW and 95.29 MW, respectively. Also, the Capital Cost Index and Operating Cost Index are  $\$2.113 \times 10^{+7}$  and  $2.373 \times 10^{+7}$  US \$/yr, respectively. The results obtained from breaking the 3<sup>rd</sup> loop show that the 3<sup>rd</sup> loop has no changes in unit costs similar to the 1<sup>st</sup> and 2<sup>nd</sup> loops. The duties of heat exchangers in the three cases are summarized in Table 5 and the final HEN is shown in Fig. 8.

**Table 5.** The duties in base-case and after breaking the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> loops

Heat exchangers	Base case (MW)	Breaking first loop (MW)	Breaking second loop (MW)	Breaking third loop (MW)
E-1806	1.574	1.38	1.037	-
E-1807	2.623	2.816	3.159	4.196
E-1808	4.187	4.187	4.529	4.53
E-1809	0.3432	0.3432	-	-
E-1823	0.1933	-	-	-
E-1824	0.6767	0.87	0.87	0.87
Total	9.5972	9.5962	9.595	9.596



**Fig. 8.** HEN after final loop breaking

The 2<sup>nd</sup> and 3<sup>rd</sup> loops did not change the unit costs after breaking, as they share mutual heat exchangers with other loops. Such loops are referred to as dependent loops. In the network, breaking independent loops cause changes in the unit; consequently, only the independent loops are broken in the heat exchangers network. While the presence of loops enhances energy recovery and provides greater flexibility in heat duty distribution (utilities), it also increases the overall unit cost. Thus, it is recommended not to eliminate a loop if its removal does not lead to a reduction in costs.

Although no direct experimental validation was conducted through additional simulations or pilot studies, the output temperatures obtained after implementing modifications—such as loop breaking and adjusting  $\Delta T_{\min}$ —showed strong agreement with the real operational temperatures of the unit. This close match between simulated and actual temperature profiles provides reasonable confidence in the reliability of the Aspen model used in this study.

#### 4. Conclusion

Using the breaking loop technique, additional exchangers in the HEN can be identified and removed to minimize the number of heat exchangers. In this research, after drawing the HEN and examining its structure, three loops were identified within the network. Then three exchangers, namely, E-1806, E-1809, and E-1823 were removed through the application of the loop-breaking method. After breaking the loop, the number of loops in the network was minimized. Moreover, the Capital Cost Index was reduced from  $2.196 \times 10^{+7}$  to  $\$ 2.113 \times 10^{+7}$  and the Operating Cost Index from  $2.394 \times 10^{+7}$  to  $2.373 \times 10^{+7}$  \$/yr. In this retrofit strategy, utility consumption remained unchanged, as there was no requirement for additional energy relaxation within the system. Following the loop removal, no further adjustment of heat exchanger duties was necessary, since no violations were observed. Ultimately, the number of exchangers was reduced by three without incurring any energy penalty.

#### References

- [1] Naqvi, S.R., Bibi, A., Naqvi, M., Noor, T., Nizami, A.S., Rehan, M., Ayoub, M., 2018. New trends in improving gasoline quality and octane through naphtha isomerization: a short review. *Applied Petrochemical Research*, 8, 131–139. <https://doi.org/10.1007/s13203-018-0204-y>
- [2] Valavarasu, G., Sairam, B., 2013. Light Naphtha Isomerization Process: A Review. *Petroleum Science and Technology*, 31, 580-95. <https://doi.org/10.1080/10916466.2010.504931>
- [3] Jarullah, A.T., Abed F.M., Ahmed A.M., Mujtaba, L.M., 2019. Optimisation of Several Industrial and Recently Developed AJAM Naphtha Isomerization Processes Using Model Based Techniques. *Computers & Chemical Engineering*, 126, 403-20. <https://doi.org/10.1016/j.compchemeng.2019.04.018>
- [4] Smith, R., 2016. *Chemical process: design and integration*, second ed., John Wiley & Sons.
- [5] Elias, A.M., Giordano R.C., Secchi, A.R., Furlan, F.F., 2019. Integrating pinch analysis and process simulation within equation-oriented simulators. *Computers & Chemical Engineering*, 130, 106555. <https://doi.org/10.1016/j.compchemeng.2019.106555>
- [6] Manizadeh, A., Entezari, A., Ahmadi, R., 2018. The energy and economic target optimization of a naphtha production unit by implementing energy pinch technology. *Case Studies in Thermal Engineering*, 12, 396-404. <https://doi.org/10.1016/j.csite.2018.06.001>
- [7] Rezaei, E., Shafiei, S., 2008. An NLP approach for evolution of heat exchanger networks designed by pinch technology. *Iran. Chemical Engineering Journal*, 5, 13-21. <https://doi.org/20.1001.1.17355397.2008.5.1.2.9>
- [8] Li, B.H., Castillo, Y.E.C., Chang, C.T., 2019. An improved design method for retrofitting industrial heat exchanger networks based on Pinch Analysis. *Chemical Engineering Research and Design*, 148, 260-270. <https://doi.org/10.1016/j.cherd.2019.06.008>
- [9] Ramanath, T., Foo, D.C.Y., Tan, R.R., Tan, J., 2023. Integrated Enterprise Input-Output and Carbon Emission Pinch Analysis for Carbon Intensity Reduction in Edible Oil Refinery. *Chemical Engineering Research and Design*, 193, 826-842. <https://doi.org/10.1016/j.cherd.2023.03.045>
- [10] Gabr, E.M., 2018. Step by step for designing an optimum heat exchanger network. *International Journal of Scientific & Engineering Research*, 9, 827-845.
- [11] Anastasovski, A., 2014. Enthalpy Table Algorithm for design of Heat Exchanger Network as optimal solution in Pinch technology. *Applied Thermal Engineering*, 73, 1113-1128. <https://doi.org/10.1016/j.applthermaleng.2014.08.069>
- [12] Zhi, K., Wang, B., Guo, L., Chen, Y., Li, W., Ocloń, P., Wang, J., Chen, Y., Tao, H., Li, H., Varbanov, P.S., 2024. Graphical pinch analysis-based method for heat exchanger networks retrofit of a residuum hydrogenation process. *Energy*, 299, 131538. <https://doi.org/10.1016/j.energy.2024.131538>
- [13] Fu, D., Nguyen, T., Lai, Y., Lin, L., Dong, Z., Lyu, M., 2022. Improved pinch-based method to calculate the capital cost target of heat exchanger network via evolving the spaghetti structure towards low-cost matching. *Journal of Cleaner Production*, 343, 131022. <https://doi.org/10.1016/j.jclepro.2022.131022>
- [14] Jones, D.S.J., Pujadó, P.P., 2006. *Handbook of petroleum processing*, Springer, New York.
- [15] Meyers, R.A., 2016. *Handbook of petroleum refining processes*, fourth ed., McGraw-Hill, New York.
- [16] Mostofian, T., Noori Keshkar, M., Ebrahimi, Sh., 2023. Exergy Analysis and Heat Integration of Distillation Columns using Thermal Coupling Method for Separation of Ternary Mixture. *Chemical Process Design*, 2(1), 71-80. <https://doi.org/10.22111/cpd.2023.45993.1024>
- [17] Ghazizahedi, Z., Hayati-Ashtiani, M., 2020. Retrofitting isomerization process to increase gasoline quality and decrease CO<sub>2</sub> emission along with energy analysis using Pinch Technology. *Energy Sources Part A: Recovery, Utilization, and Environmental Effects*, <https://doi.org/10.1080/15567036.2020.1859008>
- [18] Linnhoff, B., Townsend, D.W., Boland D., Hewitt, G.F., Thomas, B.E.A., Guy, A. R., Marshland, R.H., 1982. *A user guide on process integration for the efficient use of energy*, Houston, Texas.
- [19] Seider, W.D., Seader, J.D., Lewin, D.R., Vidalgo, S., 2016. *Product and Process Design Principles: Synthesis, Analysis and Evaluation*, fourth ed. John Wiley & Sons.
- [20] Hohmann Jr, E.C., 1971. *Optimum networks for heat exchange*, Ph.D. thesis, University of Southern California, California.