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Multi-Objective Optimization for Synthesis Heat Exchanger Network Using TOPSIS Method

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Abstract

The effective utilization and conservation of energy are crucial challenges in industrial process systems. The chemical engineering industry is actively researching the integration of processes via heat exchanger networks synthesis. The strategy presented in this work utilizes recent advancements in pinch technology to investigate the impact of minimum approach temperature variation on energy and capital costs. The multi-objective problem considered in this approach involves minimizing utilities of heating and cooling, minimizing the area of heat exchanger, minimizing irreversibility, and maximizing effectiveness. The technique of order preferences by similarity to an ideal solution (TOPSIS) is applied to determine the optimal heat exchanger network based on the compromise solution concept, which is achieved by selecting the network having the closest Euclidean distance to the perfect solution. The practicality of this methodology is validated by resolving two distinct cases, the first case involve ten streams, the second industrial case is a separating crude oil into its primary constituents namely naphtha, kerosene, diesel and residue which demonstrate that this technique can provide more practical solutions compared to prior literature. Additionally, the study reveals that the novel approach can identify other multi criteria decision making problems with a discrete number of alternatives, criteria and are more cost-effective networks than those produced by alternative techniques.

Keywords: *Multi-attribute decision making; TOPSIS; Exergy; Pinch analysis; Multi objective optimization; Optimal design.*

1. Introduction

Process optimization requires the integration of networks that exchange heat, which is a vital component of the process. There are various techniques available for the synthesis and improvement of HENs, which can be categorized as four primary categories: thermodynamic methods and pinch technology [1-2], mathematical programming methods [3], deterministic methods [4] and stochastic methods [5].

Pinch analysis is a form of thermodynamic approach that was initially developed to establish design objectives in advance [1], while these methods offer a flexibility and provide a comprehensive overview to the designer, they do not consider the complex interplay between heat exchange area, energy consumption, and cost. In contrast, pinch technology comprises two main stages for process analysis, with one stage setting the energy targets for the process, and the other stage establishing design patterns to achieve those targets [6].

Moreover, utilizing these techniques to design the network involves a considerable manual development, which can be an extremely tedious process, particularly for large-scale industrial problems [7]. There are several methods available that address the optimization problem concurrently [8-9] optimization models solved in a series, are the most commonly used sequential method, where the models employ utility cost [10], the simultaneous methods find the best HEN without decomposition of the problem [11].

Traditional simultaneous synthesis method usually involves solving mixed integer nonlinear programming (MINLP) problem, as well as structure models relying on stage-wise superstructure [12] and might be able to develop HENs that are more effective than sequential models. However, the complication of these models can lead to their size becoming unmanageable. Broadly speaking, optimization algorithms ca n be categorized into two groups: a) Deterministic algorithms which adhere to a strict process and produce consistent results in terms of both the design variables and objective function values, such as outer approximation [4], branch and bound can establish the optimum solution in a finite amount of time [13] However, when it comes to solving partial problems of a large scale, they are not very efficient. b) The stochastic algorithms rely on hand, also lean from swam intelligence techniques [14-15] or randomness techniques [16-17] in contrast to deterministic approaches.

This paper presents a novel approach for multiobjective functions, such as minimum utilities of heating/cooling, minimum area of heat exchanger, minimum irreversibility, and maximum effectiveness then select the best network by using TOPSIS method. Two cases are examined and solved to demonstrate the application of this approach.

2. Methodology

The study of optimum heat exchanger network was conducted using multi-criteria decision technique (TOPSIS) to address conflicting objectives such as heating and cooling requirements, irreversibilities, area, thermal effectiveness and total cost.

2.1. Annual total cost

2.1.1. Operating cost

$$Op.C = C_{HU}Q_{HU} + C_{CU}Q_{CU} \quad ; \tag{1}$$

2.1.2. Capital cost

$$Capt.Cost = A_0 + A_1(area)^{A_2} \tag{2}$$

which includes positive real values A_0, A_1, and A_2, the area is determined by equation (3) and (4).

$$Area = \frac{Q}{(U)(LMTD)} \tag{3}$$

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{ln(\frac{\Delta T_1}{\Delta T_2})} \tag{4}$$

However, the term in the denominator of equation (4) can lead to mathematical difficulties when $\Delta T_1 = \Delta T_2$, so an approximation known as Chen's approximation is commonly used.

$$LMTD = \left[\Delta T_1 * \Delta T_2 * \left(\frac{\Delta T_1 - \Delta T_2}{2}\right)\right]^{0.33} \tag{5}$$

Or using the Paterson (1984) approach,

$$LMTD = \frac{2}{3}(\Delta T_1 * \Delta T_2)^{\frac{1}{2}} + \frac{1}{3}\left(\frac{\Delta T_1 - \Delta T_2}{2}\right) \tag{6}$$

Then, TAC is given by equation (7)

$$TAC = Op.Cost + Capt.Cost \tag{7}$$

2.2. Thermal effectiveness analysis

$$\varepsilon = \frac{Q}{Qmax} \tag{8}$$

$$Q = Cp_H(T_{H,in} - T_{H,out)} = Cp_C(T_{C,in} - T_{C,out}) \tag{9}$$

$$Q_{max} = \min(Cp_H, Cp_C)(T_{H,in} - T_{C,in}) \tag{10}$$

Equation (8) provides a thermodynamic definition of ε. In heat exchangers operating under normal conditions.

$$Q_{max} = (Cp_{min})(\Delta T_{max}) \tag{11}$$

The definition of thermal effectiveness can be rewritten as follows

$$\varepsilon = \frac{C_H(T_{H,in} - T_{H,Out})}{C_{min}(T_{H,in} - T_{C,in})} = \frac{C_C(T_{C,Out} - T_{C,in})}{C_{min}(T_{H,in} - T_{C,in})} \tag{12}$$

2.3. Exergy analysis

The term "exergy" refers to the amount of energy which can be retrieved from a thermodynamic system. Exergy analysis is a valuable tool for analyzing such systems, as it allows for the measurement of the thermodynamic irreversibility associated with a given process.

$$Irr. = \Delta Ex_{Hot} - \Delta Ex_{Cold} \tag{13}$$

$$\Delta Ex_{Hot} = Q_H\left(1 - \frac{T_O}{T_{AMH}}\right) \tag{14}$$

$$\Delta Ex_{Cold} = Q_C\left(1 - \frac{T_O}{T_{AMC}}\right) \tag{15}$$

where, T_o is ambient temperature and equal 290 K.

2.4. Multiple attribute decision making

The process of decision-making involves selecting the best alternative between several reasonable alternatives. When (MCDM) problems, firstly is recognize and understand the nature of the problem. Secondly, involves collecting relevant data that accurately reflects the decision-makers' preferences, establishing a set of possible alternatives, and evaluating them to ensure that the desired outcome is achieved. Once this is done, an appropriate method is chosen to evaluate and rank the alternatives to identify the best one. MCDM problems can be denoted in a matrix [18]

$$D = \begin{array}{c} \\ G_1 \\ G_2 \\ \vdots \\ \\ G_m \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & .. & .. & C_n \end{array} \\ \begin{bmatrix} Y_{11} & Y_{12} & .. & .. & Y_{1n} \\ Y_{21} & Y_{22} & .. & .. & Y_{2n} \\ .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. \\ Y_{m1} & Y_{m2} & .. & .. & Y_{mm} \end{bmatrix} \end{array} \tag{16}$$

where G_i, $(i = 1,2, \dots \dots, m)$ are alternative C_j, $(j = 1,2 \dots \dots, n)$ are criteria, for a clear view of this method.

TOPSIS method consists of a series of sequential steps that are presented next.

Step 1:

The most common normalization method is;

1- for max, we have

$$p_{ij} = \frac{Y_{ij} - min(Y_{ij})}{max\,(Y_{ij}) - min(Y_{ij})} \quad ,(i \in m \quad , \; j \in n) \tag{17}$$

2- for min, we have

$$p_{ij} = \frac{max(Y_{ij}) - Y_{ij}}{\max\,(Y_{ij}) - \min(Y_{ij})} \quad , \; (i \in m \quad , \; j \in n) \tag{18}$$

As a consequence, a normalized decision matrix *M* representing the relative performance of the alternatives is obtained as

$$M = \begin{bmatrix} p_{11} & p_{12} & .. & .. & p_{1n} \\ p_{21} & p_{22} & .. & .. & p_{2n} \\ .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. \\ p_{m1} & p_{m2} & .. & .. & p_{mn} \end{bmatrix} \tag{19}$$

Step 2:

The standard deviation method calculates the objectives weights by:

$W_i = \frac{\sigma_i}{\sum_k^m \sigma_k}$ (20); where,

$\sigma_i = \sqrt{\frac{\sum_{i=1}^m (Y_i - Y^{\sim})^2}{n-1}}$ (21); and,

$Y^{\sim}$ = mean variable

$$Y^{\sim} = \sum_{i=1}^m Y_i / n \tag{22}$$

Step 3:

A set of weights *(w₁, w₂...............wₙ)* and $\sum_i^n w_i = 1$, where $w_i > 0$, *(i = 1, 2, …, n)* is given to the corresponding criterion Y_i, where *(i = 1,2,…, n)*.

The matrix $V = w_i p_{ij}$ is calculated by multiplying the elements at each column of the matrix M by their associated weights w_i, *(i = 1,…, n)*.

$$V = \begin{bmatrix} w_1p_{11} & w_2p_{12} & .. & .. & w_np_{1n} \\ w_1p_{21} & w_2p_{22} & .. & .. & w_np_{2n} \\ .... & .... & .. & .. & .... \\ .... & .... & .. & .. & .... \\ w_1p_{m1} & w_2p_{m2} & .. & .. & w_np_{mn} \end{bmatrix} \quad (23)$$

Step 4:

Calculate the separation measures (β_i^+ *and* β_i^-) between alternatives using the distance Minkowski Lp Metric as follow:

$$\beta_i^+ = \sqrt{\sum_{j=1}^{m}(V_{ij} - V_j^+)}^2, \ (i = 1, \dots \dots \dots, n) \quad (24)$$

$$\beta_i^- = \sqrt{\sum_{j=1}^{m}(V_{ij} - V_j^-)}^2, \ (i = 1, \dots \dots \dots, n) \quad (25)$$

Step 5:

In terms of performance evaluation of alternatives, the higher value, the better performance. Optimum alternative is selected according to the greater relative closeness.

$$F_i = \frac{\beta_i^-}{\beta_i^- + \beta_i^+}, \text{ where } 0 \le F_i \le 1 \quad (26)$$

3. Case studies

3.1. Case 1

This case studied firstly by using pinch method [19], it involves ten streams. A combination between pinch method and genetic algorithm [14], differential evolution method [15]. Table 1 displays the specifications for both the plant data and streams. Table 2 display multi-objective function including minimum utilities of heating and cooling, minimum area of heat exchanger, minimum irreversibility and maximum effectiveness are calculated for ΔT_{min} variation. By using TOPSIS method which presented previously, the standard deviation (σ_i) and the objective weight (w_i) are calculated using equation (21 & 22) as shown in Table 2. Table 3 display the normalized decision matrix for different ΔTmin by using equation (18 &19) and the weighted normalized decision matrix.

Table 1. Data Specifications and cost for Case 1.

Streams	T^S (°C)	T^t (°C)	MC_p (kW/°C)
H1	85.0	45.0	156.30
H2	120.0	40.0	50.00
H3	125	35.0	23.90
H4	56.0	46.0	1250.0
H5	90.0	86.0	1500
H6	225	75.0	50.00
C1	40.0	55.0	466.7
C2	55.0	65.0	600.0
C3	65.0	165.0	180.0
C4	10.0	170.0	81.30
Hot Utility	200.0	198.0	-
Cold Utility	15.0	25.0	-
Cost for Case 1			
Utility cost data	Hot utility cost = 100 ($. $kW^{-1}.Yr^{-1}$)		
	Cold utility cost = 15 (. $kW^{-1}.Yr^{-1}$)		
Capital cost data	Installed unit cost = (60 x Area)($)		
	U = 0.025 ($kW.m^{-2}.°C^{-1}$)		
	Annualization factor = 0.1627		

Table 2. Analysis function of HEN at different ΔT_{min}, standard deviation (σ_i) and objective weight (w_i) results for Case 1.

Analysis function of HEN at different ΔT_{min} for Case 1					
ΔT_{min}	Hot Utility	Cold Utility	Area	Irreversibility	Thermal effectiveness
10	15400	9794.0	122635.0	1880.41	8.12
12.5	16770	11164	88711.98	1757.58	7.85
15	18140	12534	72979.69	1867.56	7.05
17.5	19033	13428	55513.00	1929.75	6.41
20	19609	14003	55070.70	1959.01	5.43
22.5	20184	14579	51906.13	2219.09	4.19
25	20760	15154	47936.29	2127.25	4.12
Standard deviation (σ_i) and objective weight (w_i) results					
Standard deviation (σ_i)	0.014798	0.021203	0.054568	0.011576	0.037959
Objective weight (w_i)	0.105620	0.151336	0.389483	0.082626	0.270935

Table 3. The normalized and weighted normalized decision matrix of HEN at different ΔT_{min} for Case 1.

The normalized decision matrix of HEN at different ΔT_{min} for Case 1					
ΔT_{min}	Hot Utility	Cold Utility	Area	Irreversibility	Thermal effectiveness
10	1.000000	1.00000	0.000000	0.733852	1.0000
12.5	0.744393	0.744393	0.454131	1.000000	0.9325
15	0.488787	0.488787	0.664741	0.761695	0.7325
17.5	0.32212	0.32212	0.898569	0.626941	0.5727
20	0.214747	0.214747	0.904491	0.563541	0.3278
22.5	0.107373	0.107373	0.946855	0.000000	0.01802
25	0.000000	0.000000	1.000000	0.198998	0.00000
The weighted normalized decision matrix of HEN for Case 1					
ΔT_{min}	Hot Utility	Cold Utility	Area	Irreversibility	Thermal effectiveness
10	0.105620	0.151336	0.000000	0.060635	0.270935
12.5	0.078623	0.112653	0.176876	0.082626	0.252647
15	0.051626	0.073971	0.258905	0.062935	0.198459
17.5	0.034022	0.048748	0.349977	0.051801	0.155175
20	0.022682	0.032499	0.352283	0.046564	0.088818
22.5	0.011341	0.016249	0.368784	0.000000	0.004884
25	0.000000	0.000000	0.389483	0.016443	0.000000

Table 4. The relative closeness results for Case 1.

ΔT_{min}	β_i^+	β_i^-	$F_i = \beta_i^- / (\beta_i^- + \beta_i^+)$
10	0.390102947	0.333377717	0.460796996
12.5	0.218532279	0.347684285	0.614048241
15	0.177794699	0.344184714	0.659383694
17.5	0.177656034	0.390871695	0.687515622
20	0.238436678	0.368416859	0.607093535
22.5	0.324308349	0.369347886	0.532465315
25	0.334431324	0.389829544	0.538244659

In the next step, calculate the separation measures ($\boldsymbol{\beta_i^+}$ ***and*** $\boldsymbol{\beta_i^-}$) between alternatives by using equation (27 & 28) and calculate (F_i) for various ΔT_{min}. Results are shown in Table 4. The optimum solution equal to (0.68751) which correspond to ΔT_{min}= 17.5 °C. Fig. 1. represent the grid diagram for the final solution at the optimum minimum approach temperature. Comparison between different solutions is shown in Table 5. The network cost is ($/Yr 2,886,300) with minimum approach temperature 10 [19], ($/Yr 2,830,340) [14], ($/Yr 2,850,154) by employing the differential evolution method [15] and ($/Yr 2,646,631) by using TOPSIS method.

Table 5. Results obtained by different methods for Case 1.

Method	Pinch technique [19]	Pinch+Genetic algorithm [14]	Differential evolution method [15]	Decision making (TOPSIS) (this work)
ΔT_{min}	10	24	19.46	17.5
Hot utility	15,400	20,529	20,745	19,033
Cold utility	9,796	14,925	15,141	13,428
Total area	-	56,006	56,085	55,513
Energy cost ($/Yr)	1,686,940	2,276,787	2,301,641	2,104,713
Capital cost ($/Yr)	1,199,360	553,553	548,513	541,918
TAC ($/Yr)	2,886,300	2,830,340	2,850,154	2,646,631

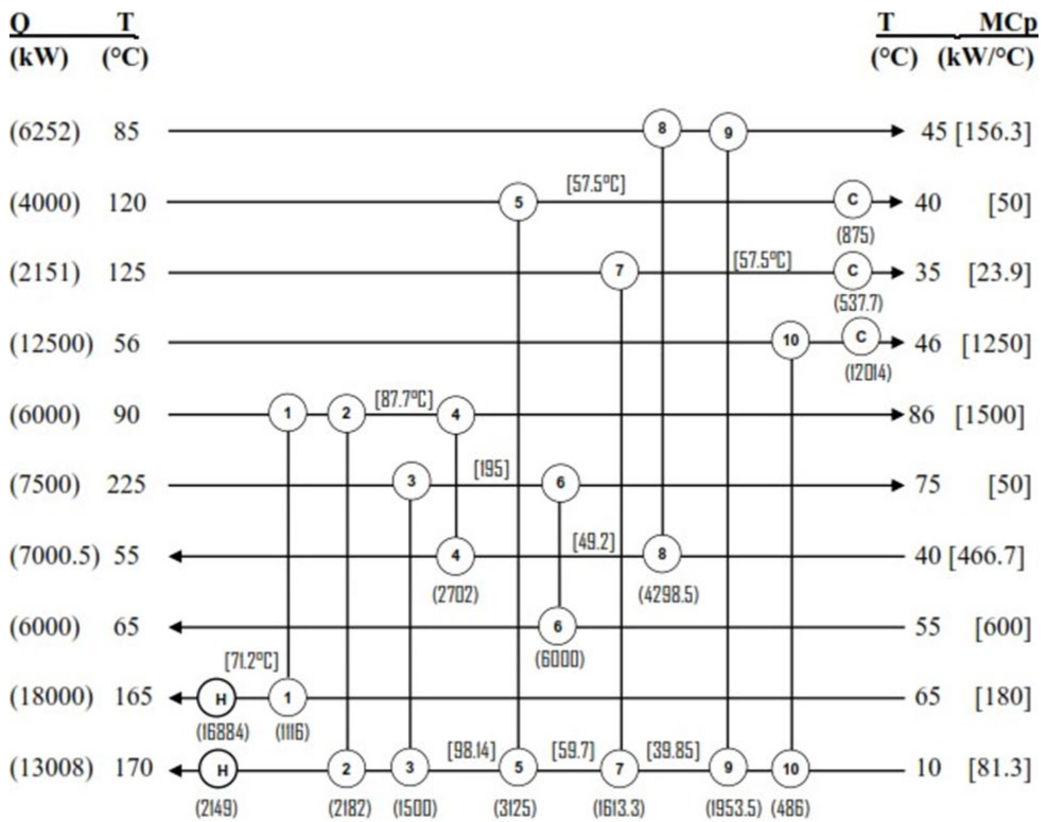

Fig. 1. Final solution at ΔT_{min}=17.5°C

3.2. Case 2

The process described in this instance has been extensively documented in various published works [20]; This process involves separating crude oil into its primary constituents, namely naphtha, kerosene, diesel, and residue, which is a crucial aspect of oil refining. The process includes eight streams. Detailed information of plant data and specifications for all streams is available in Table 6. Multi-objective function including minimum utilities of heating and cooling, minimum area of heat exchanger, minimum irreversibility and maximum effectiveness are calculated for different values of ΔT_{min} and are shown in Table 7. By using TOPSIS method which presented previously, the standard deviation (σi) and the objective weight (w_i) are calculated by using equation (21 &22) as presented in Table 7.

For each function we calculate the normalized and weighted normalized decision matrix for different ΔT_{min} by using equation (18 &19). The results are shown in Table 8.

Table 6. Data Specifications and cost for Case 2.

Streams	T^s (°C)	T^t (°C)	MC_p (kW/°C)	Stream
Cold	43	356	231.6	Crude
Hot	337	80	74.1	Residue
Hot	276	234	243.4	BPA
Hot	270	60	62.7	Diesel
Hot	239	40	42.1	Kerosene
Hot	209	135	119.4	KPA
Hot	140	97	316.6	TPA
Hot	131	60	249.4	Naphtha
Cost for Case 2				
Utility cost data	Hot utility cost = 55 ($. kW^{-1}.Yr^{-1})			
	Cold utility cost = 9.3 ($. kW^{-1}.Yr^{-1})			
Plant Data	U = 0.5 ($kW.m^{-2}°C^{-1}$)			
Capital cost data	Installed unit cost = 700 $(A)^{0.83}$ ($)			
	Annualization factor = 0.2638			

Table 7. Analysis function of HEN at different ΔT_{min}, Standard deviation (σ_i) and objective weight (w_i) results for Example 2

Analysis function of HEN at different ΔT_{min} for Case 2					
ΔT_{min}	Hot Utility	Cold Utility	Area	Irreversibility	Thermal effectiveness
8	15861	34338	12613.41	2490.78	8.72
10	16324	34801	10957.48	2602.56	8.29
12	16787	35264	8824.523	2710.36	7.91
14	17250	35728	8760.864	2817.05	7.58
16	17714	36191	7981.202	2921.26	7.27
18	18177	36654	7334.103	3021.29	7.00
20	18640	37117	6786.196	3120.45	6.74
Standard deviation (σ_i) and objective weight (w_i) results					
Standard deviation, (σ_i)	0.008287	0.004001	0.032705	0.011516	0.013271
Objective weight, (w_i)	0.118753	0.057337	0.46869	0.16503	0.19019

Table 8. The normalized and weighted normalized decision matrix of HEN at different for Example 2

The normalized decision matrix of HEN at different ΔT_{min} for Case 2					
ΔT_{min}	Hot Utility	Cold Utility	Area	Irreversibility	Thermal effectiveness
8	1.00000	1.00000	0.000000	1.00000	1.00000
10	0.833333	0.833333	0.284171	0.82247	0.781332
12	0.666667	0.666667	0.650205	0.651273	0.590875
14	0.500000	0.500000	0.66113	0.481848	0.421483
16	0.333333	0.333333	0.794927	0.316348	0.268449
18	0.166667	0.166667	0.905974	0.157483	0.128706
20	0.000000	0.000000	1.00000	0.000000	0.000000
The weighted normalized decision matrix of HEN for Case 2					
ΔT_{min}	Hot Utility	Cold Utility	Area	Irreversibility	Thermal effectiveness
8	0.118753	0.057337	0.000000	0.16503	0.19019
10	0.098961	0.047781	0.133188	0.135732	0.148602
12	0.079169	0.038225	0.304744	0.107479	0.112378
14	0.059377	0.028669	0.309865	0.079519	0.080162
16	0.039584	0.019112	0.372574	0.052207	0.051056
18	0.019792	0.009556	0.424621	0.025989	0.024479
20	0.000000	0.000000	0.46869	0.000000	0.000000

In the next step, calculate the separation measures ($\boldsymbol{\beta_i^+}$ ***and*** $\boldsymbol{\beta_i^-}$) between alternatives by using equation (27 &28) and calculate (F_i) for various ΔT_{min}. Results are shown in Table 9. The optimum solution equal to (0.64385), with minimum cost ($/ Yr 1,854,205) which correspond to ΔT_{min}=12°C as shown in Table 9. Fig. 2 represent the grid diagram for the final solution at the optimum minimum approach temperature.

Table 9. The relative closeness results for Case 2.

ΔT_{min}	β_i^+	β_i^-	$F_i = \beta_i^- / (\beta_i^- + \beta_i^+)$
8	0.468689539	0.284248102	0.377518783
10	0.34004752	0.265181021	0.438150225
12	0.195389059	0.353240398	0.643859701
14	0.22133931	0.336322442	0.603093974
16	0.221482035	0.38219854	0.633113861
18	0.246598582	0.426685437	0.633737657
20	0.284248102	0.468689539	0.622481217

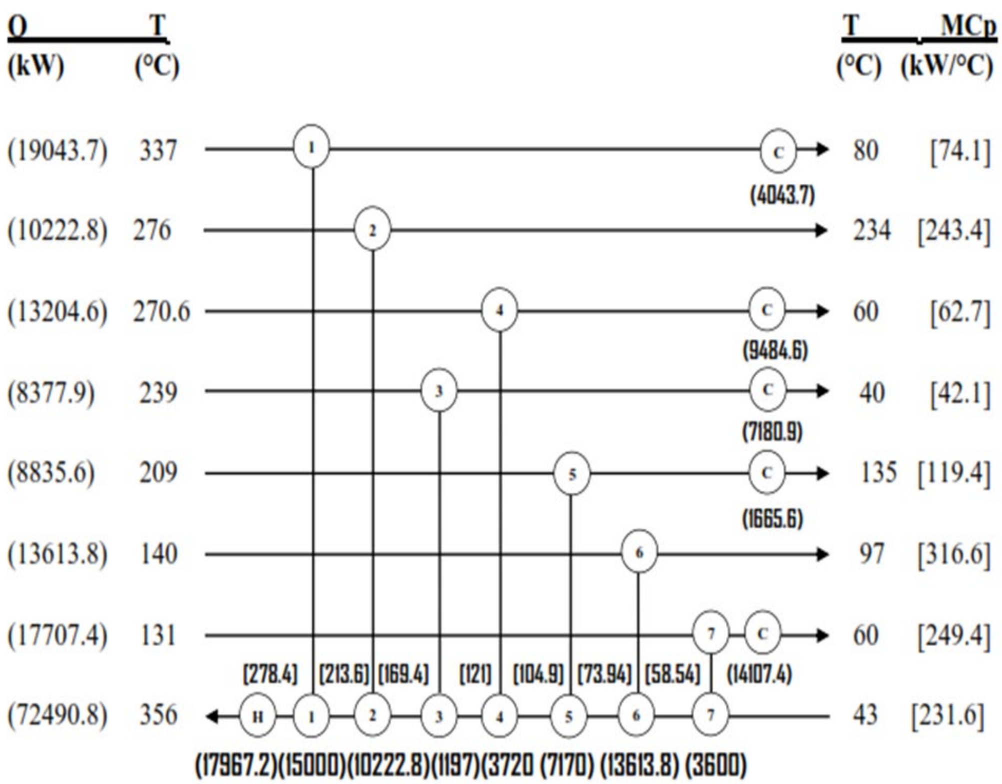

Fig. 2. Final solution at ΔT_{min} =12°C

4. Results and discussions

The results of this study demonstrate the effectiveness of the proposed multi-objective optimization model in identifying the optimal configuration for heat exchanger networks. In each of the two cases tested, the optimal outcome was identified using the TOPSIS method, confirming the model's ability to address conflicting objectives

Building upon prior research in related areas, this study introduces an innovative multi-objective optimization model that addresses conflicting objectives through a multi-criteria decision-making process. While earlier studies focused on singular objectives such as hot and cold utilities or exergy or controllability, this research simultaneously considers multiple objectives, presenting a comprehensive approach to optimizing heat exchanger networks. The TOPSIS technique offers distinct advantages over the VIKOR method, providing a different approach to managing diverse criteria and conflicting goals. This study introduces a novel perspective on heat exchanger networks optimization, yielding insightful implications and potential advantages for the broader gas industry and beyond.

The research findings demonstrate strong evidence of the proposed model's scalability and effectiveness in handling larger and intricate heat exchanger networks. The TOPSIS technique effectively identifies optimal outcomes across a diverse range of input parameters, showcasing its applicability. By incorporating multiple objectives and reconciling conflicting priorities, the multi-objective optimization model provides valuable insights into resource allocation and cost-effective operation. However, it is crucial to acknowledge that the TOPSIS technique, like any analytical approach, has its limitations and potential drawbacks.

Specifically, the TOPSIS technique may be sensitive to the normalization procedure and assumes equal importance for all criteria, which could affect its practical applicability. Additionally, it lacks consideration for uncertainty and risk, necessitating the adoption of strategic measures to address these limitations. Conducting sensitivity analysis, incorporating weighting factors that reflect stakeholder preferences, and utilizing probabilistic methods such as Monte Carlo simulation or fuzzy logic can help mitigate these challenges. Validating the results of the TOPSIS technique using real-world data and comparing them with alternative optimization approaches will further ensure its robustness.

In conclusion, although the TOPSIS technique represents a valuable tool for heat exchanger network optimization, implementing strategic measures to address its limitations will enhance its reliability and practical effectiveness in real-world applications.

5. Conclusion

This study describes an approach for optimizing the synthesis of HENs, which involves four key functions. These functions aim to minimize heating and cooling utilities, area of heat exchanger, irreversibility, and maximize thermal effectiveness. The ΔT_{min} has a significant impact on the hot, cold stream matches and limits the consumption of hot/cold utility, which affects the network configurations, obtained using recent technological advancements. A TOPSIS method was used to select the best network relied on established criteria that represent different effects. The proposed method was tested on well-known case studies of HENs, and it yielded high-quality solutions that were more cost-effective than previously optimal results obtained in the literature. Furthermore, the method is user-friendly and does not require any specialized mathematical or computational skills.

Nomenclature

HENs	*Heat Exchanger Networks*
MCDM	*Multi-criteria Decision Making*
MINLP	*Mixed-Integer Nonlinear Programming*
TOPSIS	*Technique for Order Performance by Similarity to Ideal Solution*
C_h	*Thermal capacity ratio of hot stream*
C_c	*Thermal capacity ratio of cold stream*
Irr.	*Irreversibility*
Q	*The amount of actually heat transferred*
C_{HU}	*Cost of hot utility in $.kw-1.year-1,*
C_{CU}	*Cost of cold utility in $.kw-1.year-1,*
Q_{HU}	*Hot utility demand in kW,*
Q_{CU}	*Cold utility demand in kW.*
Q_{max}	*The maximum amount of theoretically transferable heat.*
Q_i	*Heat duty of stream i*
T_0	*Ambient Temperature*
T_{AM}	*Logarithmic mean temperature difference*
ΔT_{LMK}	*Log mean temperature difference for interval K*
T_{AMH}	*Logarithmic mean temperature difference for hot streams*
T_{AMC}	*Logarithmic mean temperature difference for cold streams*
ΔT_{max}	*Fluid inlet temperature difference*
Cp	*Heat capacity flow rate of the streams*
Cp_H	*Heat capacity flow rate of hot streams*
Cp_c	*Heat capacity flow rate of cold streams*
Cp_{min}	*Smaller Cp in Cp_H and Cp_c*

T	*Temperature of streams*
q_i	*Stream duty on hot stream (i) in enthalpy interval K*
q_j	*Stream duty on cold stream (j) in enthalpy interval K*
A	*Heat exchanger area for vertical heat transfer required by interval*
h_i and h_j	*Film transfer coefficients for hot and cold stream including wall and fouling resistances*
Y_{ij}	*Performance (or rating) of alternative A_i with respect to attribute C_j*
σ_i	*Standard deviation of performance rating factor$(P_{1j}, P_{2j}, \dots\dots\dots P_{mj})$in M matrix.*
W_i	*Objective weight*
ΔEx	*Specific exergy*
$\Delta Ex]_{Hot}$	*Exergy Supplied by Hot Stream*
$\Delta Ex]_{Cold}$	*Exergy Received by cold Stream*

Superscripts

S	*Source*
t	*Target*

Subscripts

i	*Stream i*
j	*Stream j*
H	*refers to hot streams*
C	*refer to cold streams*

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