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The Optimum Value of Minimum Temparature Gap in The Energy Targeting of Distillation Columns Sequence by Thermal Pinch Analysis

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ABSTRACT

The purpose of this research is to investigate the essential parameter in energy integration of distillation columns sequence via Thermal Pinch Analysis, which is the minimum temperature difference, ΔT_{min}. The distillation process of five alkane components has been selected as a case study for this research. From there, the shortcut simulations of all possible sequences have been simulated by using a process simulation software. Then, the energy consumption will be ranked accordingly whereby the lowest will be further simulated via a rigorous simulation before the application of the Thermal Pinch Analysis with a range of $\Delta Tmin$ from 5 to 40 °C. Next, the energy requirement before and after the Thermal Pinch Analysis has been compared to determine the energy saving and to generate the economic analysis. According to the parametric analysis result, the optimum ΔT_{min} is in between the range of 20 to 25°C and the best sequence is Sequence 3 (direct-direct-indirect) which recorded 7.72% of total energy saving, USD 1274.45 MM per year of cost utility and USD 1.91 MM of capital expenditure. This can be termed as a conclusive remark to state the importance of ΔT_{min} role in balancing the energy saving of the process with the costs incurred for the process.

Keywords: dist. columns sequence, heat integration, thermal pinch analysis, min. temp. difference

1. INTRODUCTION

The distillation column is a common unit operation in the chemical and petrochemical industries. It is preferred over other unit operations due to its ability to separate the chemical components in an enormous volume without reducing the quality of the products. Despite that, this process requires a high energy consumption [1]. Therefore, there will always an opportunity to enhance energy efficiency in the process in a way to solve the above-mentioned issue.

One of the most beneficial and method to reduce the energy consumption in distillation columns sequence is the energy integration via energy targeting namely thermal pinch analysis. This method has pioneered by Hohmann [2] and later on by Linnhoff and Flower [3] mainly on the energy targeting and the synthesis of heat exchanger network. Since then, many researches have been performed to investigate the feasibility of such method for the distillation columns sequence.

In a recent development, the research on energy targeting which specifically for distillation column has also being addressed in a form of optimization problem [4] whereby it may result-in more accurate solution but tend to be complicated due to the rigorous usage of computation and programming. Meanwhile, a simpler graphical method has also been proposed which still related to energy targeting in a distillation column. For instance, a recent study from Shahruddin et al. that successfully recorded energy saving in alkanes mixture case study [5], alcohol mixture case study [6] and aromatic mixture case study [7]. This can be a profound evidence to state that the thermal pinch analysis can be employed to save energy within the distillation columns sequence without any integration from background or other processes. Nevertheless, those publications were only focusing on the thermal pinch analysis with a fixed value of minimum temperature difference, ΔT_{min}. Furthermore, the feasibility in terms of economic has never been mentioned in those papers as well.

According to Bakar et. al [8], the value of ΔT_{min} has been the deciding factor in balancing the operating and capital cost for the heat exchanger network. The higher value of ΔT_{min} will result in less area for heat exchanging process thus reduce the capital cost. However, the operating cost will increase due to lesser energy saving recorded in that particular situation. The effect would be vice-versa for lower value of ΔT_{min}. On the other hand, the research has mentioned that this finding was mainly for general heat exchanger network. Therefore, it is an intention of this research to investigate the extent of ΔT_{min} impact towards the feasibility of the process and economic in a distillation column sequence, specifically. This paper will also continue to reaffirm the findings by the work of Shahruddin et al. on the significant of thermal pinch analysis in energy saving of distillation columns sequence, this time with the involvement of the ΔT_{min} as a subject matter.

A method that consist of 4 stages framework will be used in this research including the shortcut simulations, rigorous simulations, thermal pinch analysis via problem table algorithm, heat exchanger network design and the economic analysis. From there, the effect of ΔT_{min} will be addressed and can also be seen in a form of parametric study for the optimum value throughout the range of ΔT_{min}.

2. METHODOLOGY

2.1 Research Framework

In this research, the simulation is done by referring to the flow chart of the research that is shown in Fig 1.

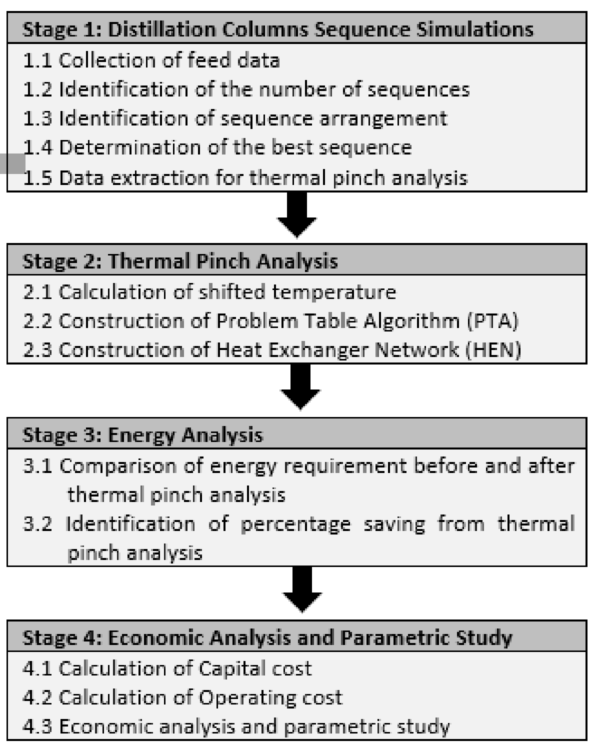


Fig 1 Research Framework

The case study that will be used in this research is a distillation process of 5-component alkane mixture. The feed data can be found in Table 1. The simulation is done by using 1.2 reflux ratio and assuming 98% to 99% purity of all components.

Table 1. Feed condition of the selected case study [9]

Input Data		Value
Feed compositions	n-pentane (A)	0.35
	n-hexane (B)	0.10
	n-heptane (C)	0.10
	n-octane (D)	0.40
	n-decane (E)	0.05
Feed flowrate (kmole/h)		100
Pressure (bar)		2
Temperature(°C)		25

2.2 Stage 1: Distillation Columns Sequence Simulations

At this stage, the simulation process is started with the shortcut simulation to determine the energy consumption for all the possible sequences and the best sequences of the distillation column have been simulated using rigorous simulation of Aspen HYSYS V10. Several parameters from the shortcut simulation such as actual number of trays, number of feed stage, flowrate of distillate and external reflux ratio were required to further carried out the rigorous simulation

Prior to that, the number of sequences can be determined by the following formula, whereby N is the number of sequences and P is the number of products.

$$N = \frac{[2(P-1)]!}{P!(P-1)!} \quad (1)$$

2.3 Stage 2: Thermal Pinch Analysis

By using the information extracted from rigorous simulations (target/supply temperature and total loads) thermal pinch analysis is carried out by constructing PTA. From there the minimum energy requirement will be obtained and compared with the energy before pinch analysis. The value of ΔT_{min} used in this study is from 5 °C to 40°C. Lastly, the HEN will be designed to satisfy the energy requirement from the pinch analysis application.

2.4 Stage 3: Energy Analysis

The value of energy consumption before and after Pinch Analysis have been compared and percentages of saving will be recorded.

2.5 Stage 4: Economic Analysis and Parametric Study

The utilities used and its price is listed in Table 2 and the formula to calculate capital and operating costs are shown in equations below.

Table 2. Price of material and utilities used [10]

Utility	Cost (USD M)
Refrigerant 1(per GJ)	7.89
HP steam (per GJ)	9.88

Capital Cost (Stainless steel) = 30,800 + $1644A^{0.81}$ (2)

Operating Cost = Operating hour x Energy Load (Hot/Cold) x Cost of utility (Hot/Cold) (3)

A in Equation 2 is the area of heat exchanger. The operating condition can be assumed as 24 hours per day and 330 days per year.

Lastly, parametric study aims to proportionate the capital and operating costs in order to obtain the optimum value of ΔT_{min} for the process. It can be done by converting those values in a form of fraction and will be plotted against ΔT_{min}.

3. RESULTS

The possible sequences were undergone the shortcut simulations and it can be found in Fig 2. The total loads from condenser and reboiler of each column is total-up and compare for all 14 sequences. Table 3 shows the total energy consumption for all sequences. Seq. 1 which is direct sequence give the highest amount of energy consumption with 2.60 GJ/h. In general, all other sequences recorded lower energy consumption but the best energy saving sequence is Seq. 3 which is direct-direct-indirect sequence which consumes 2.293 GJ/h amount of energy. From there, it can be confirmed that the sequence arrangement played an important role in reducing energy consumption and the optimum sequence in that term should be established prior to further energy saving by thermal pinch analysis.

Based on the lowest value, Seq. 3 has been selected to undergo rigorous simulation together with the conventional sequence which is direct sequence (Seq. 1). Then, the data from rigorous simulations has been extracted and Problem Table Algorithm (PTA) were develop for both sequences with the range of ΔT_{min} from 5 °C to 40°C with 5 °C interval to determine the point of pinch for every value of ΔT_{min}. The energy analysis for both sequences have been summarized in Table 4.

Table 3. Energy consumption for all sequences

Sequence	Name of Sequence	Total Loads (GJ/h)
1	Direct (D)	2.600
2	Indirect (I)	2.297
3	DDI	2.293
4	IID	2.296
5	DID	2.299
6	DII	2.298
7	IDD	2.299
8	IDI	2.299
9	D-Split	2.298
10	I-Split	2.299
11	Top Split-D	2.299
12	Bot Split-D	2.299
13	Top Split-I	2.298
14	Bot Split-I	2.299

Table 4. Energy consumption for all sequences

Sequence 1			
ΔT_{min}	MER	Total Energy Saving	Percentage of Saving
°C	GJ/h		%
5-25	1.813	3.626	19.579
30	0.552	1.104	5.611
35-40	0.002	0.004	0.022
Sequence 3			
ΔT_{min}	MER	Total Energy Saving	Percentage of Saving
°C	GJ/h		%
5-20	2.252	4.504	25.074
25	0.652	1.304	7.719
30-40	0.003	0.006	0.024

From Table 4, the thermal pinch analysis successfully enhance energy saving in both sequences. Based the lesser energy consumption, Sequence 3 recorded better Maximum energy recovery (MER) which also will reflect to both total energy saving and percentage of energy saving as well.

This result is also aligning with the theory of changes in ΔT_{min} values [8]. Further increment in ΔT_{min} will increase the energy consumption thus will contribute to higher operating cost. This may have resulted from the larger gap between hot-cold composite streams thus will lead to less amount of exchangeable heat within the process [5]. Therefore, the energy saving will be lesser for the higher value of ΔT_{min}.

If the consideration for the optimum value of ΔT_{min} would be solely based on the MER or total energy saving, the lowest value would be favorable to suit the situation. However, it will come with the additional cost to cater for the area of heat exchange. Therefore, it is crucial to assess the extent of ΔT_{min} towards the economic aspect

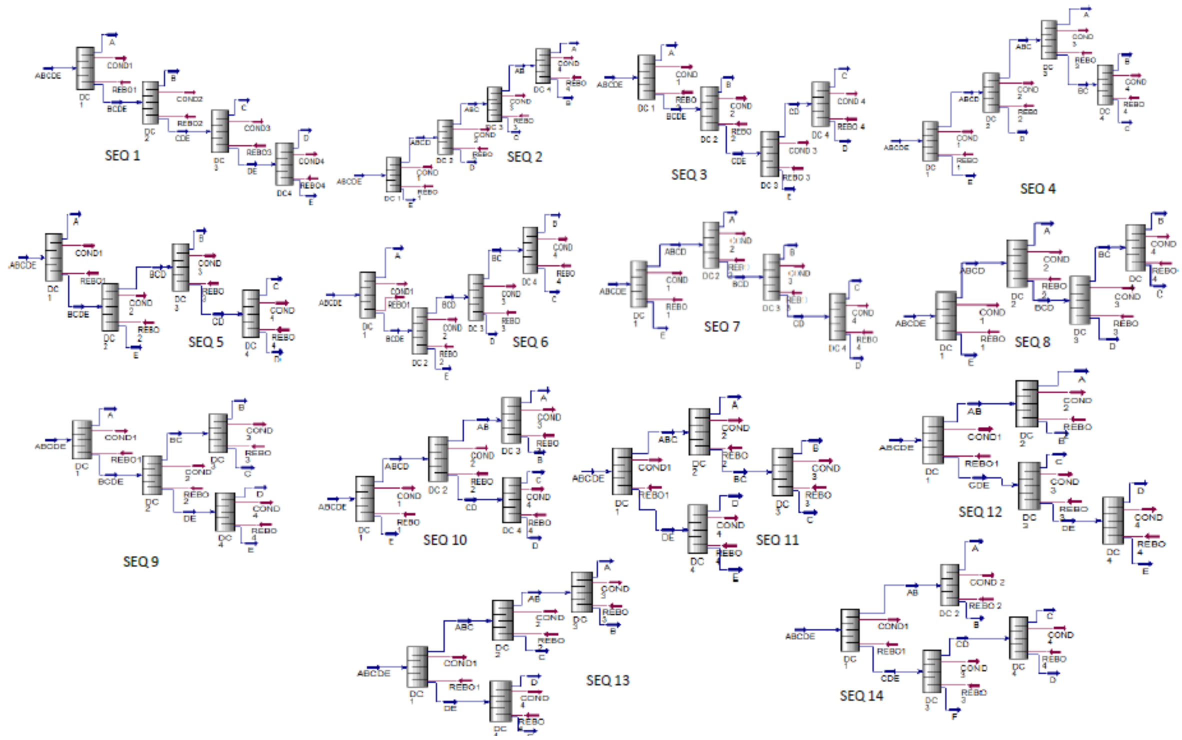


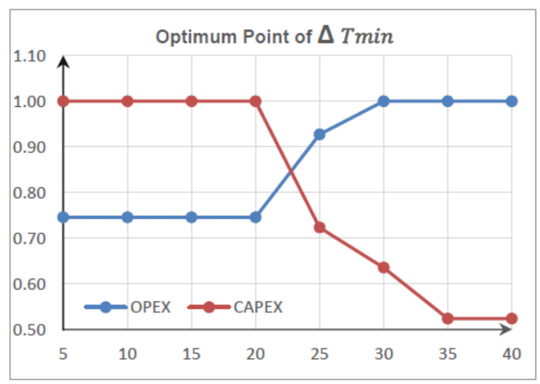
Fig 2 All possible sequences from the shortcut simulations

of the process. Based on the HEN, the resulting capital cost and operating have been calculated and been summarized in Table 5.

Table 5. Economic analysis for Sequence 1 and 3

Sequence 1		
ΔT_{min}	Capital Cost	Operating Cost
°C	USD MM	USD MM/yr
5-25	1.99	1136.21
30	1.84	1337.70
35-40	1.49	1417.81
Sequence 3		
ΔT_{min}	Capital Cost	Operating Cost
°C	USD MM	USD MM/yr
5-20	2.34	1024.80
25	1.91	1274.45
30-40	1.52	1374.59

According to the table, it can clearly be seen that the operating cost follows the trend of the energy consumption in Table 4 whereby the operating will be higher with the increase of ΔT_{min}. Therefore, with the lower value of operating cost, Sequence 3 produced better results compared to Sequence 1. However, there are the other way around for capital cost. Since more area needed for heat exchanger, the cost will be slightly on higher side for Sequence 3. This is again in-line with the trend from the literature [8]. That is why, the parametric study is needed to determine the optimum value of ΔT_{min}. It is shown in the Fig 3.



ΔT_{min}	5	10	15	20	25	30	35	40
OPEX	0.75	0.75	0.75	0.75	0.93	1.00	1.00	1.00
CAPEX	1.00	1.00	1.00	1.00	0.72	0.64	0.52	0.52

Fig 3 Parametric Analysis for Sequence 3

From Fig 3, it can clearly be seen that, the optimum value of ΔT_{min} for the sequence is 23 °C.

Overall, the value of ΔT_{min} can be regarded as the determining factor in designing the optimum and feasible energy integrated distillation columns sequence.

4. CONCLUSION

In conclusion, the systematic method to determine the optimum value of ΔT_{min} in designing distillation columns sequence has been developed. The optimum ΔT_{min} value is 23°C meanwhile the Seq.3 is the best sequence amount all 14 possible sequences. Seq.3 at ΔT_{min} of 25°C has 7.72% of total energy saving, USD

1274.45MM per year of cost utility and USD 1.91MM of capital expenditure. From the data and result extracted in simulation, it is clear that Thermal Pinch Analysis can enhance the saving of energy consumption for distillation column sequence. However, in the future, better sequencing method such as the driving force method can be applied to obtain the best sequence in term of energy consumption can be further improved by thermal pinch analysis. Case study that more complex and multicomponent which involve more than five components can also be suggested to verify the proposed method.

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