Pinch Analysis of Methane Derived Methanol Plant Using HINT Software

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Abstract. Methane is a highly potent greenhouse gas which contributes to the pressing global warming issue in the world. Methanol derived from methane was one of the solutions to prevent the escalating greenhouse effect. However, the process was energy intensive and hence pinch technology was used to optimize the heat efficiency in the process. This study aims to determine the optimum ΔT_{min} indicated with lowest total cost via HINT software. Results shown that the optimum heat exchanger configuration was obtained by network with ΔT_{min} 10 K, with minimum operating and capital cost of $2,729,590/year and $579,129,590/year respectively.[*]

1 Introduction

Climate change and global warming are persistent worldwide issues for the past decade. One of the factors for the occurrence is the greenhouse effect, which is a process that occurs when the gases in the atmosphere trapped the sun's heat [1]. Methane is included as one of the gases, with 84 times more greenhouse potential compared to carbon dioxide [2]. About 25% of the manmade global warming was caused by methane emissions, largely due to hydrocarbon combustion engines including natural gas and LPG fed engines, gas oil fired furnace and power plants [3]. To combat the rising global warming matter, methane could be converted to methanol, which hold various application in products, namely solvents, detergents, paints, antifreeze, acetic acid and formaldehyde. Moreover, methanol could also be used as liquid fuel or raw material for gasoline and olefin production [4]. Methanol production plants are generally considered as one of the petrochemical industries requiring intensive energy. This is due to the fact that in the whole process, including the feed preparation, natural gas desulfurization, synthesis gas production, feed gas compression, reactions and product distillation consumed huge amount of energy through heating, cooling and shaft works. Hence, researches to reduce the intensive energy consumption have been conducted, and one of the applicable solutions was to optimize the heat energy flowing in the system through pinch analysis [5]. Pinch analysis is a systematic method which optimizes the energy usage in process plants consisting of several techniques, namely heat flow analysis, energy target establishment, inefficiencies identification and process improvement determination [6,7]. The objective of this work was to determine which heat exchanger

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configuration with different ΔT_{min} (10, 15 and 20 K) would give the optimum heat efficiency indicated by the lowest cost of operation.

2 Case Study

In this study, the methanol synthesis plant design (Figure 1) was taken from Kijevcanin et al. [8]. The basic stream data of methanol synthesis was presented in Table 1. This process included 10 hot streams and 5 cold streams.

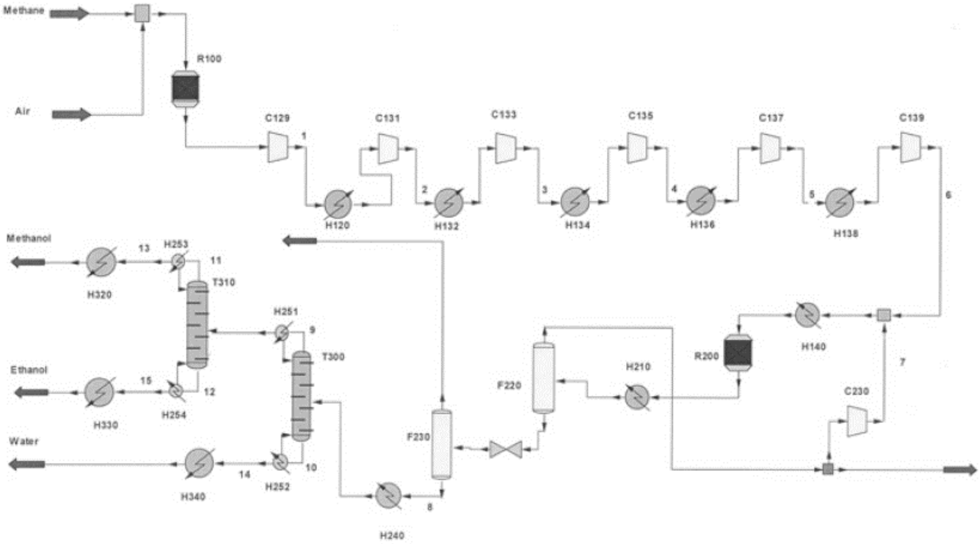

Fig. 1. Methanol plant design

Table 1. Stream table

Stream	Ts (K)	Tt (K)	H (kW)	m.Cp (kW/K)
1	424.3	120	-1521.5	5
2	342.1	120	-1110.5	5
3	342.2	120	-1111	5
4	343.1	160	-933.81	5.1
5	403.1	210	-1004.12	5.2
6	37.7	450	1896.58	4.6
7	14.5	70	227.55	4.1
8	62	62	-1108	-
9	98.9	98.9	1126	-
10	60.6	60.6	-1869	-
11	76.4	76.4	1866	-
12	60.6	30	-76.5	2.5
13	98.9	30	-75.79	1.1
14	76.4	30	-13.92	0.3
15	349.7	450	1925.76	19.2

2.1 Heat exchanger network design

The design of the heat exchanger network (HEN) usually started at the pinch, since this is the most constrained region. The acceptable minimum temperature difference is called the pinch temperature. Pinch divided the entire temperature interval into two regions, above the pinch which contain the hot utility region and below pinch which belonged to the cold utility region [9]. Furthermore, to design a HEN, several feasibility criteria should also be followed, namely stream population and heat capacity flowrate difference. Stream population stated that at the hot region of the pinch, the number of cold streams must be higher or equal to the number of hot streams available ($N_{cold} > N_{hot}$). While at the cold region of the pinch, the opposite was expected ($N_{hot} > N_{cold}$). The heat capacity flowrate difference also stated that at the hot region of the pinch, the heat capacity flowrate of the cold stream must be higher than that of the hot stream ($Cp_{cold} > Cp_{hot}$), and the opposite was true for the cold region of the pinch ($Cp_{hot} > Cp_{cold}$) [10].

In designing a HEN, the most helpful representation is the grid diagram introduced by Linhoff and Flower (1978). The streams were drawn as horizontal lines, with the high temperature on the left-hand side and the hot streams at the top. Heat exchanger matches are represented by two circles joined together with a vertical line. Grid diagram represents the counter current nature of the heat exchange, making it easier to check the feasibility of exchange temperature [11]. The HEN diagrams of the methanol synthesis illustrated in Figure 2-4 was obtained by HINT, a non-commercial software for HEN designing. The minimum temperature difference (ΔT_{min}) gave some implications to the energy and cost efficiency. In this study, in order to determine the optimum ΔT_{min}, variations of said value was made to be 10, 15 and 20 K.

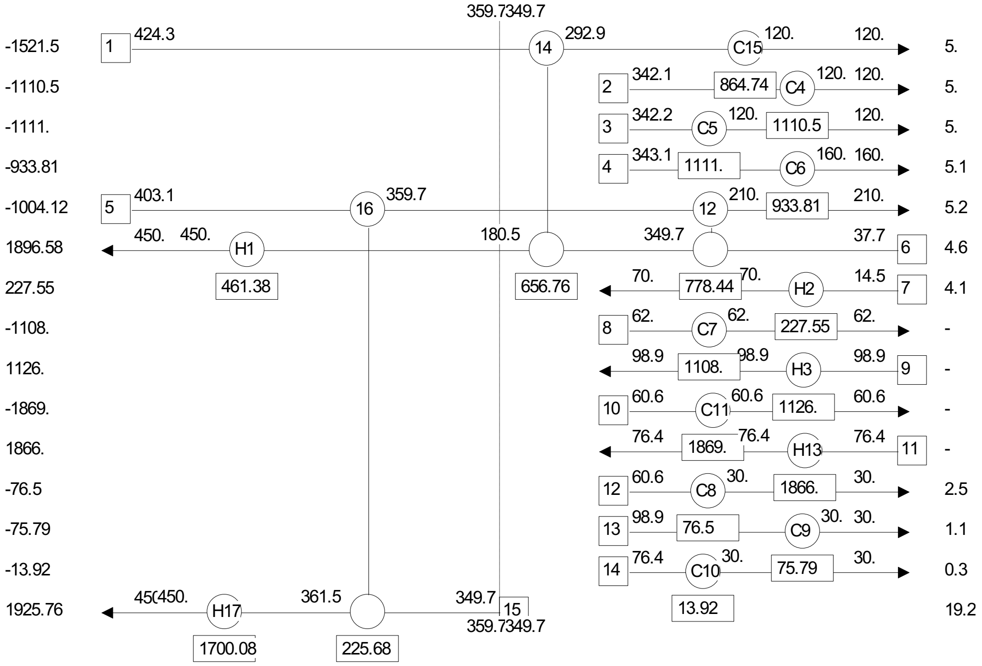

Fig. 2. HEN of methanol synthesis with ΔT_{min} 10 K

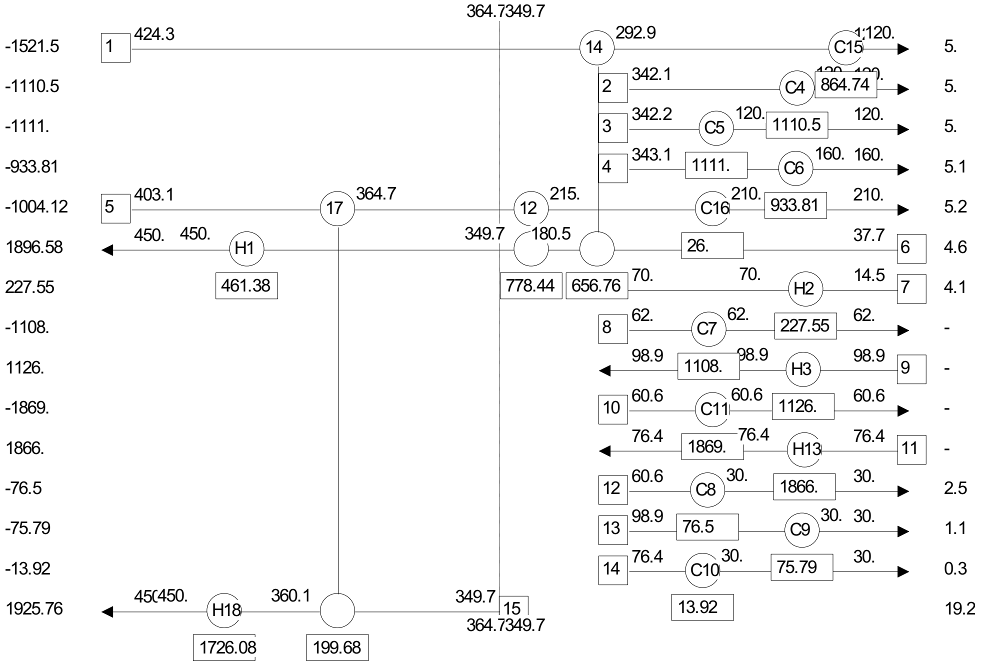

Fig. 3. HEN of methanol synthesis with ΔT_{min} 15 K

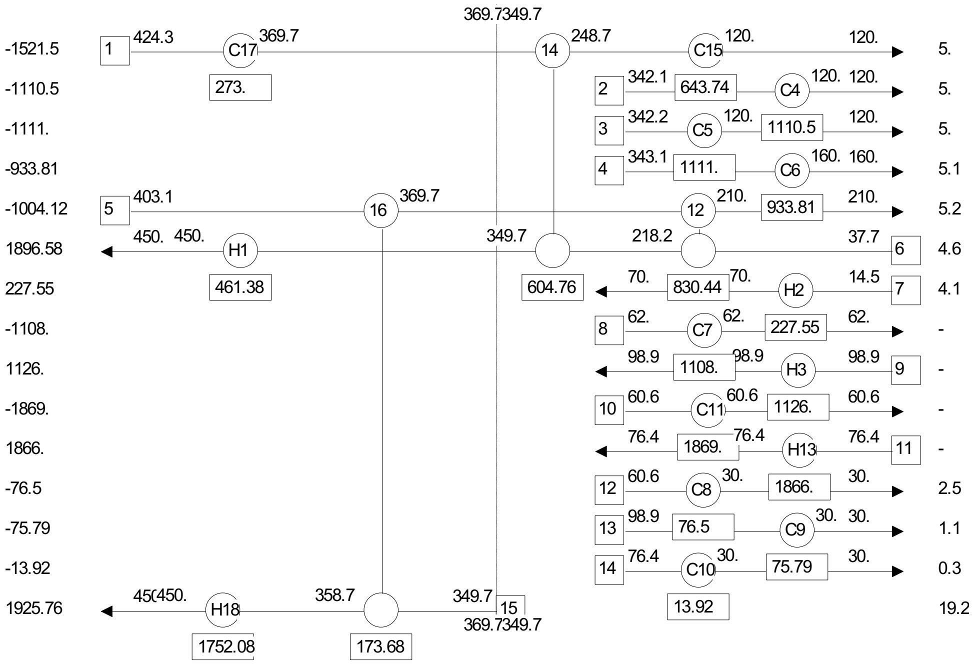

Fig. 3. HEN of methanol synthesis with ΔT_{min} 20 K

Table 2. Heating and cooling duty

	ΔT_{min} 10 K	**ΔT_{min} 15 K**	**ΔT_{min} 20 K**
Heating duty (kW)	1838.46	1889.46	1940.46
Cooling duty (kW)	3620.71	7189.26	3722.71

As could be seen from the HEN diagrams of ΔT_{min} 10, 15 and 20 K, the pinch temperature obtained were 359.7, 364.7 and 369.7 K respectively. Based on Table 2, it could be seen that the heating duty, cooling duty and maximum energy recovery values all strongly depended on the value of ΔT_{min}. The network on the above pinch region contained two hot and two cold streams, which shown that streams 5 and 6 were linked. Both of said streams had fulfilled the criteria of the heat capacity flowrate ($Cp_{cold} > Cp_{hot}$). Hence, there was a heat exchanger in stream 6 (H_1) and stream 5 (H_{18}). While in HEN with ΔT_{min} 20 K (Figure 4), there was a heat exchanger in stream 1 (C17) which was functioned to cool the process.

Whereas for the network below the pinch region contained 8 hot and 2 cold streams, with some streams were of latent heat. The only stream that managed to fulfill the feasibility criteria ($Cp_{hot} > Cp_{cold}$) were streams 1, 5 and 6. Stream 6 had enough energy to be used for heat recovery in stream 1 and 5. While latent heat could not be used to recover other streams, due to the fact that it would cause the crossing of temperature across the streams. In total, there were 13 heat exchangers located in the below pinch region, which consisted of 10 coolers and 3 heaters.

2.2 Economic analysis

Table 3. Cost of HEN configuration on methanol synthesis

	Operating cost ($/y)	**Capital cost ($/y)**		**Total cost**	
		Original HEN	**Pinch tech HEN**	**Original HEN**	**Pinch tech HEN**
ΔT_{min} 10 K	2.729.590	645.600.000	576.400.000	648.329.590	579.129.590
ΔT_{min} 15 K	2.780.590	679.100.000	584.000.000	681.880.590	586.780.590
ΔT_{min} 20 K	2.831.590	653.100.000	626.400.000	655.931.590	629.231.590

Table 3 compared the cost required on methanol synthesis with the orginal heat exchanger network configuration and the configuration after pinch analysis. The capital cost was calculated using the following equation:

$$C = a + bA^c \tag{1}$$

where values of a, b and c were parameters based on the type of heat exchanger. Calculation was done automatically using the HINT software. It could be concluded from the results that the total cost of HEN configuration after the pinch analysis for all ΔT_{min} were lower compared to the original HEN configuration. Therefore, it could be said that there was energy conservation in the process, as the number of heater and/or cooler installation were less than before. With less heat exchanger, the capital cost would also decrease. Based on Table 3, the lowest total cost was obtained from HEN configuration with ΔT_{min} 10 K.

3 Conclusion

The heating and cooling duty were dependent and directly proportional to the ΔT_{min}. The total cost of methanol synthesis with HEN configuration using pinch technology were lower compared to the original configuration. The optimum ΔT_{min} was estimated to be 10 K, which generated operating cost $2.729.590/year and capital cost $579.129.590/year.

References

Authors should use the forms shown in Table 3 in the final reference list.

Table 3. Font styles for a reference.

Element	Style
Authors	Reference Body (Initials followed by last name)
Journal title	Reference Body (Abbreviated)
Book title, Proceedings title	Reference Body - Book/Proceedings title
Volume number	Reference Volume Bold
Page number	Reference Body
Year	Reference Body (In brackets)

Here are some examples:

1. NASA, What is the Greenhouse Effect? (2020). Accessed on 24 June 2020 from https://climatekids.nasa.gov/greenhouse-effect/
2. EDF, Methane: The Other Important Greenhouse Gas. (2020). Accessed on 24 June 2020 from https://www.edf.org/climate/methane-other-important-greenhouse-gas#:~:text=If%20methane%20leaks%20into%20the,greenhouse%20gas%2C%20like%20carbon%20dioxide.
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