CHEMICAL ENGINEERING TRANSACTIONS
VOL. 56, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Jiří Jaromír Klemeš, Peng Yen Liew, Wai Shin Ho, Jeng Shiun Lim

ISBN978-88-95608-47-1; **ISSN** 2283-9216

DOI: 10.3303/CET1756027

A Simple Case Study on Application in Synthesising a Feasible Heat Exchanger Network

Suraya Hanim Abu Bakar[a,b], Mohd Kamaruddin Abd Hamid*[,a,b], Sharifah Rafidah Wan Alwi[a,b], Zainuddin Abdul Manan[a,b]

[a]Process Systems Engineering Centre (PROSPECT), Research Institute of Sustainable Environment, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
kamaruddin@cheme.utm.my

Heat exchanger network (HEN) is very important to optimise energy usage in process industry. Heat exchanger network synthesis is an important process synthesis problem where different tools and methods have been presented to solve this synthesis problem. In HEN synthesis, the feasibility of the HEN design is not taken into consideration. The HEN design may not be able to be implemented in industrial applications. It is essential to check the feasibility of a design before it is being implemented in the industry. The objective of this paper is to present the application of a new flexible and operable heat exchanger network (FNO HEN) methodology in synthesising a feasible HEN using a simple case study. The novelty of this work is to determine an optimal ΔT_{min} value that gives minimum external energy requirement (EER) and heat exchanger area (HEA) as well as simultaneously analyse the feasibility of the HEN design in an easy, systematic and efficient manner. Using the new developed FNO HEN methodology framework, HEN design target, which is the value of ΔT_{min} is determined to obtain the feasible HEN design. From process design point of view, ΔT_{min} value determines the size of heat exchanger in the network as well as energy saving. A process simulator is used to check the process feasibility of the HEN designs. With the use of the feasible HEN trade-off plot, which is a plot of EER and HEA at different value of ΔT_{min} with additional of feasibility area, the optimal feasible HEN design which satisfies external energy requirement (operability), heat exchanger area (capital) and process feasibility has been successfully determined.

1. Introductions

Supiluck and Kitipat (2015) claimed that integration of heat exchanger network (HEN) is one of causes that is able to give major impacts on energy conservation in industrial processes. Sun et al. (2013) have proposed a method of Super Targeting (ST) HEN that aims to optimise cost by considering multiple utilities with different type of heat exchanger. Akbarnia et al. (2009) studied the material piping cost and piping labour cost and they finally modified the current trade-off plot by considering the total piping cost. Yang et al. (2014) had applied Pinch Analysis to synthesis HEN with consideration of heat pump.
Feasibility of HEN synthesis has been neglected and can be questionable. The objective of this paper is to find the optimal ΔT_{min} value that gives minimum external energy requirement (EER) and heat exchanger area (HEA) as well as simultaneously analyse the feasibility of the HEN design. The basic requirement to synthesise HEN is by selecting HEN design target, which is the value of ΔT_{min}. From process design point of view, ΔT_{min} value determines the size of heat exchanger in the network.

2. Methodology

2.1 Problem statement

The feasible HEN synthesis problem in this case study can be stated as follows:

Please cite this article as: Abu Bakar S.H., Hamid M.K.A., Wan Alwi S.R., Manan Z.A., 2017, A simple case study on application in synthesizing a feasible heat exchanger network, Chemical Engineering Transactions, 56, 157-162 DOI:10.3303/CET1756027

Given two hot streams (to be cooled) and two cold streams (to be heated), it is desired to synthesis a feasible network of heat exchangers that can transfer heat from the hot streams to the cold streams. Given the heat capacity flow rate of each process hot stream, $FC_{P,u}$; its supply (inlet) temperature, T_u^s; and its target (outlet) temperature, T_u^t, where, u is 1, 2. The heat capacity, $fc_{P,v}$, and supply and target temperatures, t_v^s and t_v^t, are given for each process cold stream, where, v is 1, 2. Available for service are 2 heating utilities and 2 cooling utilities whose supply and target temperatures are known. Focus is given to synthesis a network of heat exchangers that is feasible where the control structure is assumed to be fixed. The data required for this simple case study is shown in Table 1.

Table 1: Information for a simple case study (Abu Bakar et al., 2013)

No	Stream names	Temperature (°C)		Heat capacity flowrate, FC_p (kW/°C)	Enthalpy, ΔH (kW)
		Supply	Target		
1	H1	250	60	0.1420	-29.81
2	H2	200	80	0.1074	-12.89
3	C1	70	180	0.1971	31.53
4	C2	140	230	0.2279	20.51

In order to solve the problem statement stated in Section 2.1, method from Abu Bakar et al. (2015a) has been adapted. It should be noted here that the controller structure for this case study has been assumed to be fixed. Therefore, weight factor 2 (w_2) is set as zero. Multi-objective function from the method is redefined as shown in Eq(1).

$$\max(J) = w_1(P_{1,1}) + w_3(1/P_{3,1}) + w_3(1/P_{3,2}) \tag{1}$$

- To achieve process design objectives, $P_{1,1}$ is maximised. $P_{1,1}$ is the performance criteria for maximisation of the energy recovery of the network.
- To achieve economic objectives, $P_{3,j}$ is minimised. $P_{3,1}$ is the capital cost and $P_{3,2}$ is the operating costs.
- w_1 and w_3 are the weight factor assigned to each objective term $P_{1,1}$ and $P_{3,i\ (i=1\text{-}2)}$.

2.2 Feasibility test

There are two things to consider in feasibility test. Firstly, all the information from Design Target and HEN Design Analysis stages were transfer into Aspen HYSYS process simulator (2015). Warning sign in Aspen HYSYS such as low f_t correction factors and temperature cross are also considered in this test. A 'f_t correction factor' is defined as a ratio of the true mean temperature difference to the log-mean temperature difference (see Eq(2)). The 'f_t correction factor' value must be greater than 0.75 for a heat exchanger to be feasible. Temperature cross warning should not occur if calculation in Design Target stage has been done correctly (Abu Bakar et al., 2015b). Secondly, it is done by calculating and analysing the f_t correction factor for each heat exchanger in the network. f_t correction factors lower than 0.75 is considered as infeasible (Shah and Sekulić, 2007).

$$f_t = \Delta T_M / \Delta T_{LMTD} = q/UA\Delta T_{LMTD} \tag{2}$$

where: ΔT_M = True mean temperature difference; ΔT_{LMTD} = Log mean temperature difference; q = Heat duties U = Overall heat transfer coefficient; A = Surface area.

In Design Target and HEN Design analysis stages, HEN were synthesised at ΔT_{min} = 10 °C, 15 °C, 20 °C and 30 °C. Table 2 shows the output summary for both stages. From the information in Table 2, HENs were designed using grid diagram (see Figures 1 and 2). After grid diagram has been developed, it can be seen that HEN designs at 15 °C, 20 °C and 30 °C are producing the same network. Feasibility of these candidates is still a question and it needs to be analysed. For this reason, all results obtained in both stages have been used to simulate HEN in the Aspen HYSYS process simulator to analyse the feasibility of every single heat exchanger.

Table 2: Results Design Target and HEN Design Analysis stages for different ΔT_{min} in the case study

ΔT_{min} (°C)	Maximum Energy Recovery (MER) (kW)	External Energy Requirement (EER) (kW)	Pinch Temperature (°C)		Unit operation (unit)		
			Cold	Hot	HE	Cooler	Heater
10	28,508.4	13,680.9	140.0	150.0	4	0	2
15	27,971.2	14,755.3	70.0	85.0	3	1	1
20	27,434.0	15,829.7	70.0	90.0	3	1	1
30	26,359.6	17,978.5	70.0	100.0	3	1	1

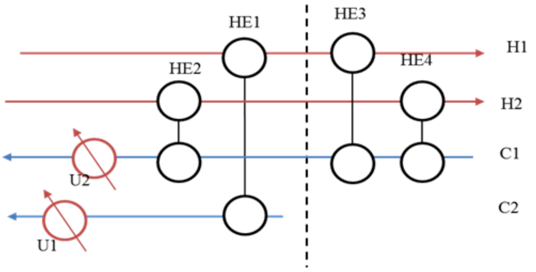

Figure 1: Grid diagram process flow diagram of HEN candidates 10 °C

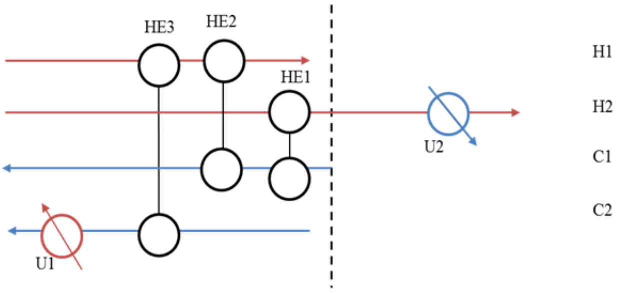

Figure 2: Grid diagram process flow diagram of HEN candidates 15 °C, 20 °C and 30 °C

3. Feasibility test results and discussions

3.1 HEN in Aspen HYSYS simulator

From the grid diagram, HEN designs were transferred into Aspen HYSYS simulator. HEN at ΔT_{min} of 10 °C has four heat exchangers and two heaters. Network designs of other candidates are the same with three heat exchangers, one cooler and two heaters. The simulation for HEN designs at 10 °C, 15 °C, 20 °C and 30 °C as shown in Figures 3 and 4.

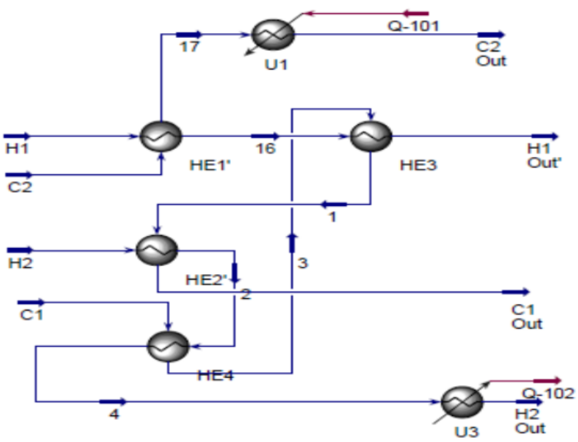

Figure 3: HEN process simulation using Aspen HYSYS at ΔT_{min} 10 °C

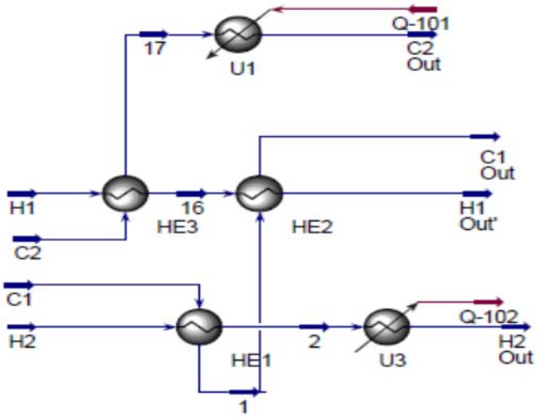

Figure 4: HEN process simulation using Aspen HYSYS at ΔT_{min} 15 °C, 20 °C and 30 °C

3.2 f_t Correction calculation results

After the feasibility test has been conducted, it can be seen that all of the designs are feasible. Table 3 shows values of f_t correction factor for all heat exchangers in the HEN candidates and results summary of the feasibility analysis. The results were in line with HEN that has been simulated in Aspen HYSYS.

Table 3: Value of f_t correction factor and status of HEN design candidates

ΔT_{min} (°C)	f_t correction factor				Feasibility
	HE1	HE2	HE3	HE4	
10	0.7915	0.7913	0.9523	0.8813	Feasible
15	0.9038	0.8777	0.9538	0.8792	Feasible
20	0.8500	0.8871	0.8971	0.8671	Feasible
30	0.7938	0.9084	0.7758	0.9084	Feasible

3.3 Multi-objectives function

All objective function values were collected from Design Target and HEN Design analysis are tabulated in Table 4. Since all the values of the objective functions have different units, therefore all objective function values need to be normalised. The normalised value, $P_{x,xs}$ were calculated by dividing it with the largest value of each objective function. Using the normalised objective function values, the value of multi-objective J is calculated using Eq(1). The best overall candidate is at ΔT_{min} of 30 °C because it has highest J value.

Table 4: Multi-objective function calculation of the designed HEN candidates

	Maximum Energy Recovery (MER) (kW)	Heat Exchanger Area (HEA) (m^2)	External Energy Recovery (EER) (kW)	
Design/Control value, $P_{x,x}$	$P_{1,1}$	$P_{3,1}$	$P_{3,2}$	
ΔT_{min} 10 °C	28,508.00	2,946.30	13,680.90	
ΔT_{min} 15 °C	27,971.20	2,661.40	14,755.30	
ΔT_{min} 20 °C	27,434.00	2,294.30	15,829.70	
ΔT_{min} 30 °C	26,359.60	1,601.30	17,978.50	
Normalise value, $P_{x,xs}$	$P_{1,1s}$	$P_{3,1s}$	$P_{3,2s}$	
ΔT_{min} 10 °C	1.000	1.000	0.761	
ΔT_{min} 15 °C	0.981	0.903	0.821	
ΔT_{min} 20 °C	0.962	0.779	0.880	
ΔT_{min} 30 °C	1.000	1.000	0.761	
Multi-objective function value	$P_{1,1}$	$1/P_{3,1s}$	$1/P_{3,2s}$	J
ΔT_{min} 10 °C	1.000	1.000	1.314	3.314
ΔT_{min} 15 °C	0.981	1.107	1.218	3.308
ΔT_{min} 20 °C	0.962	1.284	1.138	3.382
ΔT_{min} 30 °C	0.925	1.840	1.000	3.765

3.4 F-HEN Trade-off Plot

The F-HEN trade-off plot is a plot of EER and HEA at different value of ΔT_{min} with additional of feasibility area. The plot is important to show at which ΔT_{min} the HENs are feasible. To construct F-HEN trade-off plot, EER versus ΔT_{min} was constructed first as shown in Figure 5. Then, plot of HEA versus ΔT_{min} was plotted in the same graph as shown in Figure 6. Finally, the feasibility area was drawn in the same graph as presented in Figure 7. The figure shows the best HEN candidate (in terms of EER and HEA) that satisfies the design criteria can be identified at the intersection point between EER and HEA lines, which is approximately at ΔT_{min} of 20 °C. The similar concept also has been used by Dimian et al. (2014) to identify the optimal HEN design using common trade-off plot which energy and capital cost versus ΔT_{min}.

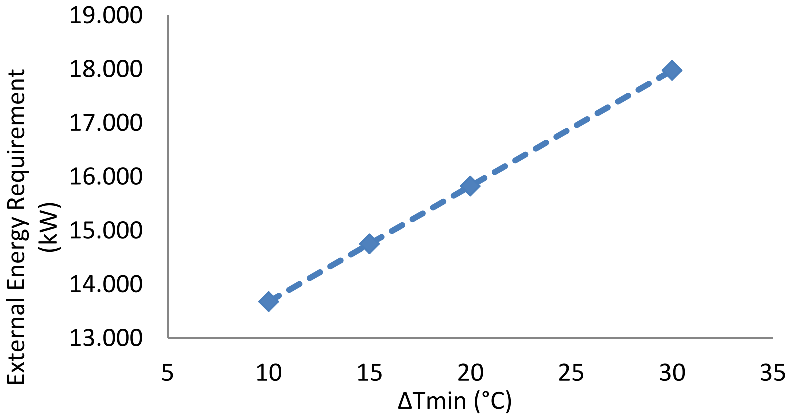

Figure 5: External energy requirement at different HEN design of ΔT_{min}

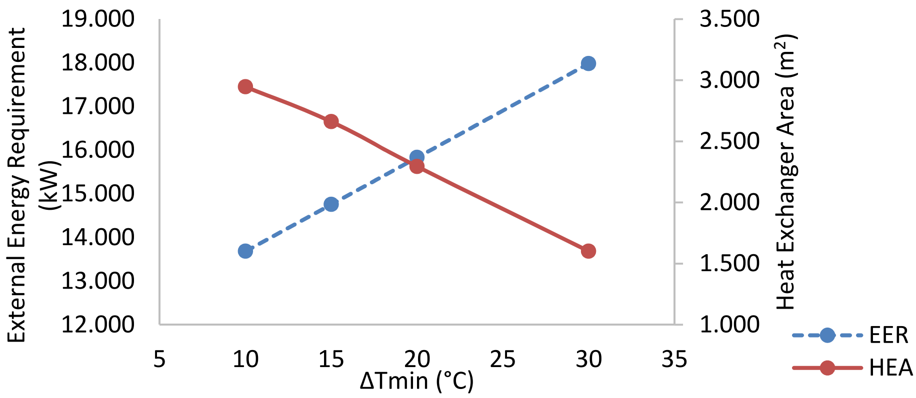

Figure 6: External energy requirement and heat exchanger area at different HEN design of ΔT_{min}

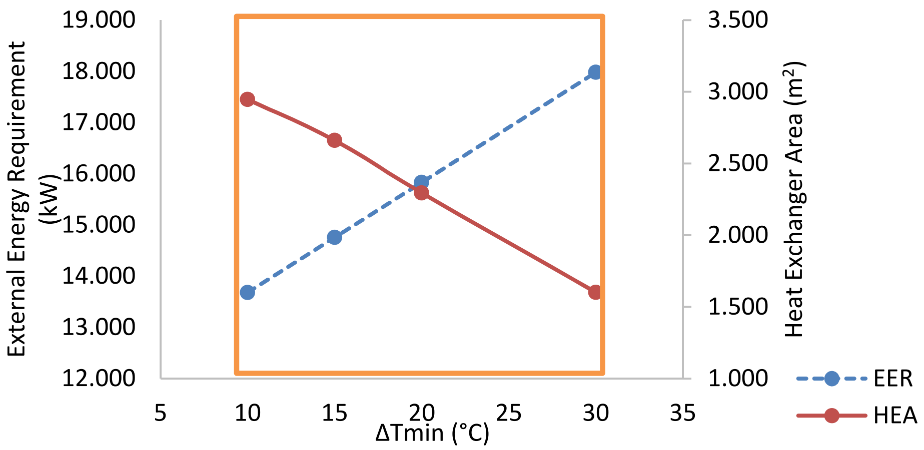

Figure 7: HEN trade-off plot with feasibility area for this case study

4. Conclusions

The optimal solution for the feasible HEN design of this case study which satisfies external energy requirement (operability), heat exchanger area (capital) and process feasibility has been successfully analysed. FNO HEN methodology framework has been successfully developed. The new trade-off plot which incorporates the feasibility area has been successfully developed and tested using a simple case study. The use of feasible trade-off plot helps in obtaining the optimal and feasible HEN design in an efficient and systematic manner.

Acknowledgments

The financial support from Research University Grant (RUG) Tier 1 (Q.J130000.2546.12H67), Universiti Teknologi Malaysia (UTM) is acknowledged.

Reference

Abu Bakar S.H., Hamid M.K.A., Wan Alwi S.R., Manan Z.A., 2013, Flexible and Operable Heat Exchanger Networks, Chemical Engineering Transactions 32, 1297-1303.

Abu Bakar S.H., Hamid M.K.A., Wan Alwi S.R., Manan Z.A., 2015a, Selection of minimum temperature difference (ΔTmin) for heat exchanger network synthesis based on trade-off plot, Applied Energy 162, 1259-1271.

Abu Bakar S.H., Hamid M.K.A., Wan Alwi S.R., Manan Z.A., 2015b, Effect of Delta Temperature Minimum Contribution in Obtaining an Operable and Flexible Heat Exchanger Network, Energy Procedia 75, 3142-3147.

Akbarnia M., Amidpour M., Shadaram A., 2009, A new approach in pinch technology considering piping costs in total cost targeting for heat exchanger network, Chemical Engineering Research and Design 87 (3), 357-365.

Aspen HYSIS V8.8, 2008, Aspen Technology Inc., Houston, United States.

Dimian A.C., Bildea C.S., Anton A.K., 2014, Integrated Design and Simulation of Chemical Processes, Computer Aided Chemical Engineering 35, 1-33.

Shah R.K., Sekulić D.P., 2007. Fundamentals of Heat Exchanger Design, Wiley, Canada.

Sun K.N., Wan Alwi S.R., Manan Z.A., 2013, Heat exchanger network cost optimization considering multiple utilities and different types of heat exchangers,Computers and Chemical Engineering 49, 194-204.

Supiluck K., Kitipat S., 2015, Heat Exchanger Network Synthesis/Retrofit using MINLP Stage-wise Superstructure with Non-isothermal Mixing, Chemical Engineering Transactions 43, 1273-1278.

Yang M., Xiao F., Liu G., 2014, Heat exchanger network design considering heat pump performance, Chemical Engineering Transactions 39, 1099-1104.