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Initial Analysis on Heat Exchanger Networks of Fatty Acid Fractionation Plant to Optimize Energy Recovery and Controllability

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The objective of this paper is to present the initial analysis on the energy recovery and controllability of the existing heat integrated fatty acid fractionation plant. From this initial analysis, the existing heat integrated fatty acid fractionation plant is analysed to know the either the existing heat exchanger networks (HENs) satisfied the design criteria, or controllability criteria by using trade-off plot. According to the trade-off plot, if the existing HENs is better in terms of design criteria, then more efforts need to be invested to control the network. On the other hand, if the existing HENs is better in terms of controllability criteria, then more efforts need to be invested to reduce the energy consumption. In this study, the initial analysis means the value of the ΔT_{min} used for the current HENs is investigated and the controllability of the network is predicted by using trade-off plot. In order to investigate the value of the ΔT_{min} used for the current HENs, only the first two stages of the model-based flexible and operable HENs is used. In the Stage 1, the value of the ΔT_{min} is investigated by selecting the value of the ΔT_{min} ranging from 10 °C to 40 °C with the increment of 10 °C. Then, HEN is synthesized for the selected value of the ΔT_{min}. Once the networks have been synthesized, all candidates are transferred into a process simulator to test their process feasibility in Stage 2 where the unfeasible candidates will be eliminated. Then all feasible candidates will be predicted in terms of their controllability performance by using trade-off plot. Energy integrated fatty acid fractionation plant is used as a case study for this initial analysis. This paper only considers steady state controllability test without considering process dynamics.

1. Introductions

Heat exchanger networks (HENs) are very important in the process industries. HENs links the process flowsheet with the utility system and generally involves a large fraction of both the overall plant capital cost, and operating cost in terms of energy requirements, which is a key factor for a profitable process. The aim of the HENs synthesis consists of finding a network design that minimizes the total annualized cost. The existing HENs synthesis is performed under the assumption of fixed operating parameters at nominal conditions. If the network is not properly designed, the HENs configuration may impose control limitations, such as competitive effects, inverse response, time delay and interaction. These limitation associated with the disturbance propagation through the network and may make the control of the network extremely difficult.

Researchers study on HEN optimality and aiming to design networks that have higher energy recovery with lower operating cost and implement the researches into real industries. Siemanond and Kosol (2012) focus on developing visual basic for application to find the optimum Pinch Temperature in targeting step to solve retrofit the existing HENs based on cost in optimising HENs. (Tan et al. 2014) have proposed a revised floating pinch method. This method is to address real process industries to consider streams conditions such as flowrates and temperatures that are not fixed. (Ponce-Ortega et al. 2008) have

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proposed MINLP model to synthesis HEN synthesis that include isothermal streams. This method has adapted superstructure for heat integration proper placement. Although there are much researches in HEN, however there are less research activities that consider combination of higher energy efficiency with practicality operation of HENs.
The objective of this paper is to present the initial analysis on the energy recovery and steady state controllability of the existing heat integrated fatty acid fractionation plant. From this initial analysis, the existing heat integrated fatty acid fractionation plant is analysed to know the either the existing HENs satisfied the design criteria, or steady state controllability criteria by using trade-off plot (see Figure 1) (Bakar et al. 2014). According to the trade-off plot, if the existing HENs are better in terms of design criteria, then more efforts need to be invested to control the network. On the other hand, if the existing HENs is better in terms of controllability criteria, then more efforts need to be invested to reduce the energy consumption. In this paper, the initial analysis means the value of the ΔT_{min} used for the current HENs is investigated and the controllability of the network is predicted by using trade-off plot. In order to investigate the value of the ΔT_{min} used for the current HENs, only the first two stages of the model-based flexible and operable HENs is used (Bakar et al. 2013). Energy integrated fatty acid fractionation plant is used as a case study for this initial analysis.

2. Methodology

The model-based flexible and operable HENs (Bakar et al. 2013) is used to perform the initial analysis. The initial analysis means the value of the ΔT_{min} used for the current HENs is investigated and the controllability of the network is predicted by using trade-off plot. In order to investigate the value of the ΔT_{min} used for the current HENs, only the first two stages of the model-based flexible and operable HENs is used. In the Stage 1, the value of the ΔT_{min} is investigated by selecting the value of the ΔT_{min} ranging from 10 ^{o}C to 40 ^{o}C with the increment of 10 ^{o}C. HEN is synthesized for the selected value of the ΔT_{min}. Once the networks have been synthesized, all candidates are transferred into a process simulator to test their process feasibility in Stage 2 where the unfeasible candidates will be eliminated. Then all feasible candidates will be predicted in terms of their controllability performance by using trade-off plot. See Figure 1.

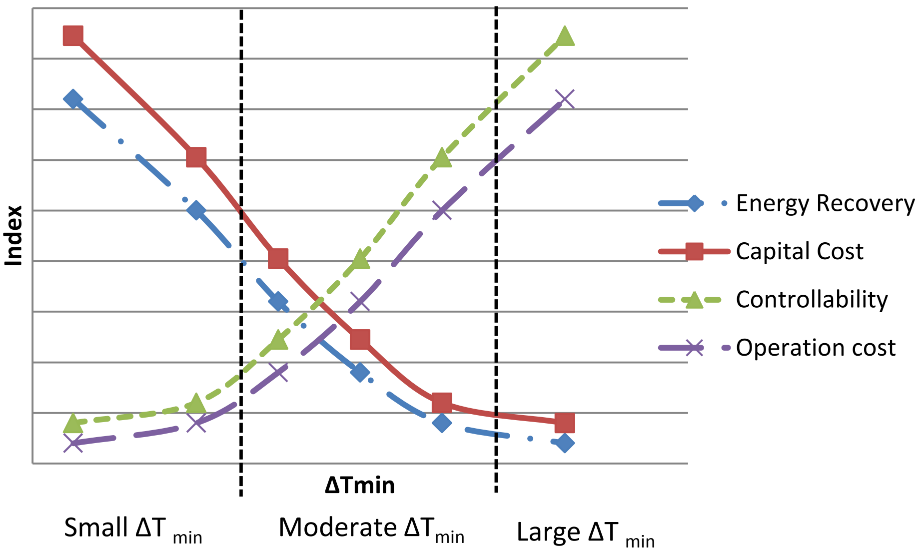

Figure 1: Trade-off plot Heat exchanger network (HEN) consider four important criteria

The trade-off plot in Figure 1 has been proposed in (Bakar et al. 2014). It has four different criteria, which are the value of ΔT_{min}, energy recovery, controllability and cost. Where, energy recovery is to analyse HEN design criteria. Controllability is being analyse only for steady state study. It is with the HEN flexibility and sensitivity tests. HEN with highly flexible and low sensitivity is good for controllability. According to this diagram, smaller ΔT_{min} has better in term of energy recovery with lower operating cost however lower in term of controllability. On the other hand, bigger value of ΔT_{min} will have lower performance in terms of energy saving with higher operating cost. However, the controllability and flexibility of this network will be much better. The controllability in this figure is only steady state controllability. Energy integrated fatty acid fractionation plant is used as a case study for this initial analysis.

2.1 Process Descriptions

Fatty acid fractionation plant used to recover several desired fatty acid fraction with certain purity. Before it enters the separator (Column 1) and fractionation column (Column 2), the feed stream needs to undergo several series of heat exchangers and heaters to heat the feed stream up. Figure 2 shows the process flow diagram of the fatty acid fractionation plant.

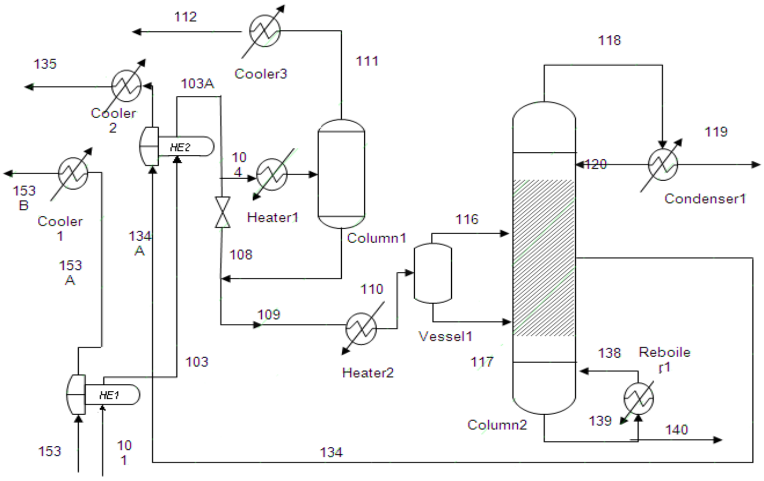

Figure 2: Heat exchanger network (HEN) for fatty acid fractionation plant

2.2 Problem Definitions

HEN model calculations used in this research are shown in Eq(1) to Eq(9). Eq(1) defines the multi-objective function in terms of performance objective with respect to design ($P_{1,1}$), controllability comprising of flexibility ($P_{2,1}$), and sensitivity ($P_{2,2}$), and capital cost ($P_{3,1}$) and operational cost ($P_{3,2}$). The capital and operation cost are for design and controllability. $w_{i,j(i=1\text{-}3,j=1,2)}$ is the weight factor assigned to all objective function terms. Temperature hot stream, T_{hot} is the stream that needs to be cool down. Temperature for cold stream, T_{cold} is the stream that need to be heated up. T_s is the supply temperature and T_t is the target temperature of hot and/or cold streams. Minimum temperature difference, ΔT_{min} is the value the needs to be selected in order to design HEN. F is the fluid flowrate, Cp is the heat capacity of the fluid and Q is the heat exchange duty.

$$\max(J) = w_{1,1}(P_{1,1}) + w_{2,1}(P_{2,1}) + w_{2,2}\left(\frac{1}{P_{2,2}}\right) + w_{3,1}\left(\frac{1}{P_{3,1}}\right) + w_{3,2}\left(\frac{1}{P_{3,2}}\right) \tag{1}$$

Subjected to:
Process constraints

$$T_s - \frac{\Delta T_{min}}{2} < T_{hot} < T_t - \frac{\Delta T_{min}}{2} \tag{2}$$

$$T_s + \frac{\Delta T_{min}}{2} < T_{cold} < T_t + \frac{\Delta T_{min}}{2} \tag{3}$$

$$Q = (FCp\Delta T)_{hot} = (FCp\Delta T)_{cold} = ftUA\Delta T_{LMTD} \tag{4}$$

$$\Delta T_{hot} = (T_{in} - T_{out})_{hot} \tag{5}$$

$$\Delta T_{cold} = (T_{in} - T_{out})_{cold} \tag{6}$$

$$ft \geq 0.75 \tag{7}$$

ft is correction factor in heat exchanger

Flexibility index, $F = \frac{\sum_{i=1}^{i=n} u\%}{n}$

Constraints:

u = percentage of maximum manipulated variables
Heat exchanger ≠ temperature crosses

n = number of manipulated variable
Heat exchanger ≠ ft correction factors

Sensitivity index, $s = \frac{\sum_{i=1}^{i=n} \frac{dy_i}{dd_i}}{n}$

y = disturbances effect
n= number of streams affected by disturbance

d = disturbances

3. Results and Discussions

3.1 Data extractions

From the process flow diagram and information obtained from the industry, information was extracted from the process flow diagram by using method proposed by Klemeš et al., 2010. Table 1 shows the extracted data.

Table 1: Extracted data from the fatty acid fractionation plant.

Streams	Stream types		Temp.					
Type	Inlet	Outlet	Supply	Target	C_p (kJ/kg.K)	Flowrate (kg/h)	ΔTemp. (°C)	FC_p (kJ/K)
H1	111	105	128	60	1.882	101	68	190.08
H2	153	153	140	65	2.176	14,657	75	31,893.63
H3	134	135	209	65	2.553	7,000	144	17,871.00
C1	101	105	70	130	2.053	37,000	60	75,961.00
C2	109	110	128	193	2.205	22,817	65	50,311.49

3.2 Stage 1: Target Selection

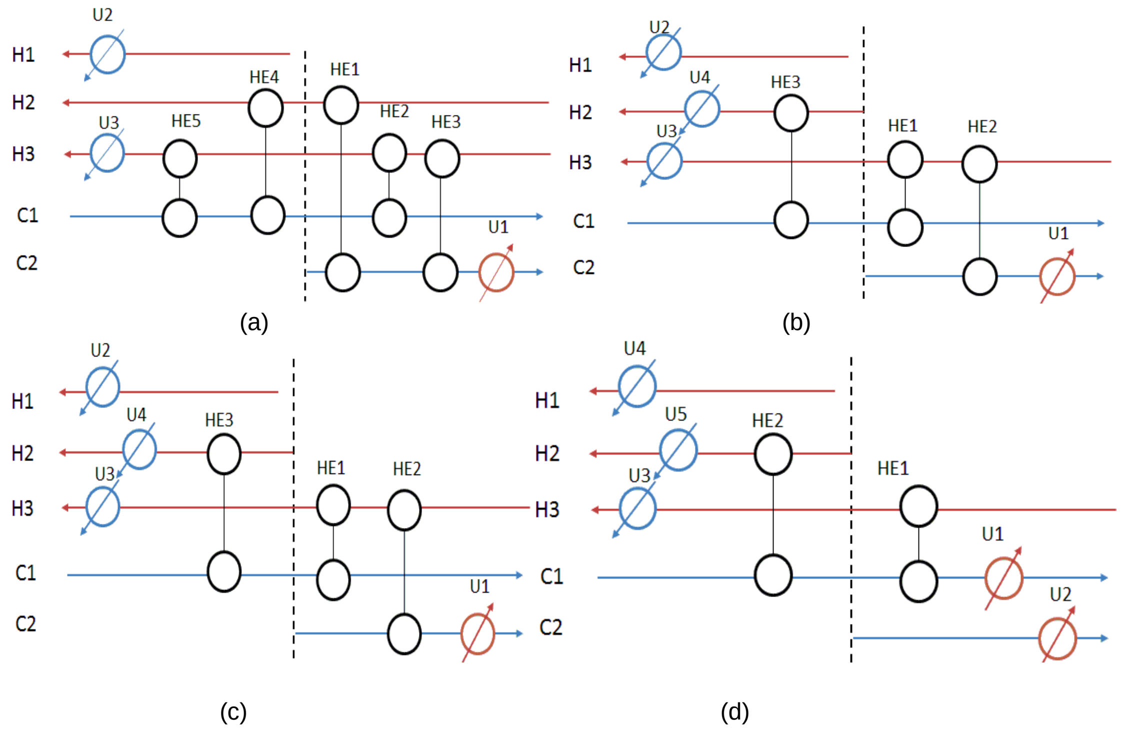

Figure 1: Grid Diagram of heat exchanger network at different ΔT_{min} a) ΔT_{min} = 10 °C, b) ΔT_{min} = 20 °C, c) ΔT_{min} = 30 °C and d) ΔT_{min} = 40 °C.

In Stage 1, target is selected by using trade-off diagram proposed by (Bakar et al. 2014). In order to get the overview on the flexibility and operability of the current case study, HENs was designed at the value of ΔT_{min} between 10 °C to 40 °C with 10 °C increment. According to (Shenoy 1995), the optimum range of ΔT_{min} is between 5 °C to 40 °C. However we start at 10 °C to reduce the design tightness. Eq(2) and Eq(3) used to calculate the shifted supply temperature and the shifted target temperature. The objective of this stage is to investigate ΔT_{min} value of the current HEN design. From data extractions, the grid diagram was constructed at different value of ΔT_{min}. Figure 1 shows the grid diagram of HEN design at different ΔT_{min}.

3.3 Stage 2: Heat Exchanger Design Analysis

Information from Stage 1, such as the network, utility duties, energy recovery, stream matching and heat exchanger temperature in and out were simulated in process simulator tool, Aspen HYSYS. Temperature in and out for all heat exchangers can be calculated by using Eq(4), Eq(5) and Eq(6).

Then, the feasibility test was done to all heat exchangers in the network by calculating the ft correction factor by using Eq(7), Eq(8) and Eq(9). Heat exchanger that has ft correction factor value lowers than 0.75 is infeasible. Therefore, the entire network is infeasible. From the simulation results, the network that has low ft correction factor were the designed HEN at ΔT_{min} at 10 °C, 20 °C and 30 °C. However the HEN designed at ΔT_{min} value of 40 °C, is feasible since all the heat exchangers have higher *ft* correction factors. The simulation of all HEN candidates in the Aspen HYSYS is shown in Figure 2. Table 2 summarizes all the results from Stage 1 and Stage 2.

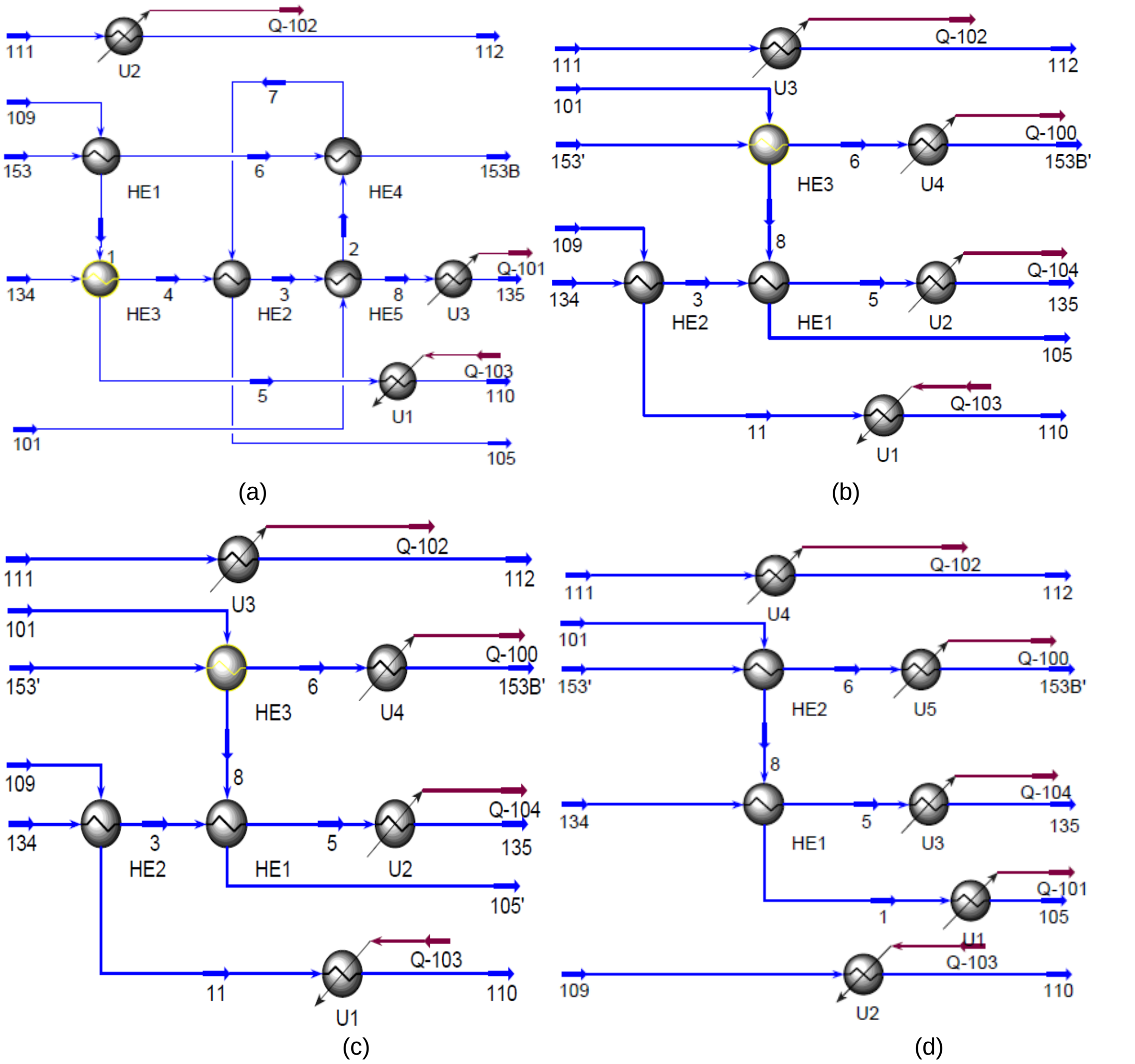

Figure 2: Heat exchanger network in the Aspen HYSYS process simulator at different value of ΔT_{min} a) ΔT_{min} = 10 °C, b) ΔT_{min} = 20 °C, c) ΔT_{min} = 30 °C and d) ΔT_{min} = 40 °C

Table 2: Summary of results of Stage 1 and Stage 2

ΔT_{min}(^oC)	Unit Operation		Heat Exchanger	External Utility		Energy Recovery (kW)	Feasibility
	Cooler	Heater		Q_{hot} (kW)	Q_{cold} (kW)		
10	2	1	5	564.48	254.73	1,128.28	No
20	3	1	3	696.70	386.95	996.07	No
30	3	1	3	827.41	517.66	865.36	No
40	3	2	2	958.11	648.37	734.65	Yes

There are four HEN design candidates that were tested in this initial analysis. In Stage 1, four different design targets, ΔT_{min} were selected to study the energy recovery. Results from Stage 1 can be seen in the Table 2 (external utility and energy recovery). It can be seen that all four HEN candidates are designedly feasible. Then, the information from Stage 1 were transferred into Aspen HYSYS process simulator in Stage 2 to check their process feasibility. Results from Stage 2 can be seen in the Table 2 (feasibility). It can be seen that only one HEN candidate that is feasible in terms of design and process, which is HEN design at ΔT_{min} = 40 °C. This HEN design is similar with the existing heat integrated fatty acid fractionation plant. The other HEN candidates are not feasible in terms of process although their energy recovery values are better. According to trade-off plot, HEN design at the smaller value of ΔT_{min} may face some difficulty in the operation (Bakar at al., 2014). It is shown in this initial analysis that three HEN candidates which are designed at the smaller values of ΔT_{min} (10 °C to 30 °C) are not feasible once tested in the process simulator compare to the one that designed at the higher value of ΔT_{min}.

4. Conclusions

The initial analysis on the energy recovery and steady state controllability of the existing heat integrated fatty acid fractionation plant has been successfully performed. From this initial analysis, the existing heat integrated fatty acid fractionation plant is analysed to know the either the existing heat exchanger networks (*HEN*s) satisfied the design criteria, or controllability criteria by using trade-off plot. It was found out that the existing network is satisfying the controllability criteria predicted by the trade-off plot. The future work will deal with the controllability verification and cost calculation of the existing network to proof the prediction of the trade-off plot.

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