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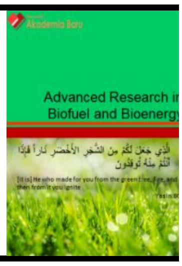

Heat Exchanger Network Design of Palm Oil Mill in Tronoh, Perak for Maximum Energy Recovery

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ABSTRACT

A palm oil mill involves energy-intensive processes. Maximizing thermal efficiency of palm oil mill is crucial for the plant profitability. Design and analysis of heat exchanger network is important to maximize heat recovery, which aims to lower the overall plant costs. This work implements a pinch analysis technique to maximize heat recovery and thermal efficiency of a palm oil mill, subject to the existing process constraints. The procedures involve setting the maximum heat recovery targets and cost-effective of the heat exchanger network (HEN). Application of the technique on a palm oil mill processes resulted in reduction of 510 kW heating and cooling load at ΔTmin of 10oC. The total annual savings in utility consumption is RM 184,735.63 giving the payback period for the investment of 2.36 years.

Keywords:
Composite curves; heat exchanger network; palm oil mill; pinch analysis; maximum heat recovery

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1. Introduction

Palm oil is one of important industry contributed to Malaysia economy and Malaysia is the second largest palm oil producer in the world. Despite of the many debatable issues, Malaysia recorded output of 19.5 mil tonnes palm oil production in 2018 which forecasted production of 20 mil tonnes in 2019 [1].

The core business of palm oil mill is revolving around the processing of fresh fruit bunches (FFB) and oil extraction process. A huge amount of energy is required to produce crude palm oil from the FFB. Energy recovery and efficiency is currently not the main practice of many mills operation. Hence, it is important to optimizing and improving the energy efficiency of process. The optimization has been proven to be beneficial to a process plant. Economizing and optimizing resource and energy consumptions can be achieved by maximizing internal recycling and usage of energy and material streams [2].

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Recycling and usage of internal energy and material streams can be materialized using Pinch Technology. Pinch Technology is based on thermodynamic principles which provide a systematic methodology for energy saving in processes [3]. The pinch concept was developed to improve the utilization of energy in grassroots HEN design [4]. Heat Exchanger Network (HEN) design using pinch technology can be developed for energy saving and cost by minimizing utilities usage in existing plant. Hence, the objectives of this study were to design HEN for the palm oil mill for maximum energy recovery and to conduct economic analysis of the HEN design.

2. Methodology

2.1 Data Collection

Process flow of palm oil mill located in Bota, Perak was obtained. Pipeline tracing and interviews with experienced operators were conducted to obtain the latest and correct process data for heat integration and network design. Data collected from the mill were mass and energy data, physical and chemical data, and costing data. Mass and energy balance, and literature search were conducted to estimate any missing information.

2.2 Data Extraction

Total of six hot and cold streams were identified and extracted as shown in Table 1. The design process was carried out in HINT v2.2 to construct composite curve, grand composite curve and HEN design according to pinch technology.

Table 1
Selected hot and cold streams data for HEN design

Steam no.	Supply temp. T_s (°C)	Target temp. T_t (°C)	Heat capacity CP (kW/K)	Heat load H (kW)
C1	35	90	0.631	34.72
C2	35	92	6.245	355.98
C3	35	95	6.287	377.21
H1	85	35	8.494	-424.68
H2	140	100	3.443	-137.70
H3	60	35	3.451	-86.28

2.3 HEN Design

Pinch technology requires identifying the “pinch”. Pinch can be identified through composite curves. Afterward, HEN design can be developed by obeying three rules to achieve the minimum energy targets for a process. The rules are; 1) heat must not be transferred across the pinch; 2) there must be no external cooling above the pinch and 3) there must be no external heating below the pinch.

2.4 Economic Analysis

The estimated purchased heat exchanger cost was using Equation (1). The total installed heat exchanger cost calculated using Equation (2)

$$HE\ cost\ (RM) = (1300 + 920 \times Area(m^2)^{0.81}) \times (conversion\ factor) \quad (1)$$

$$Total\ cost = Module\ factor \times Equipment\ Cost \quad (2)$$

Cost savings of utilities and payback period were calculated using Equations (3) and (4), respectively.

$$Cost\ saving\ of\ utilities\ (RM/yr) = cost\ of\ utilities\ (RM/kJ) \times 360\ days/\ yr \times 86400\ s/day \times Heat\ load\ reduction\ (kW) \quad (3)$$

$$Pay\ Back\ Period\ (PBP) = \frac{Capital\ investment\ (RM)}{Saving\ per\ year\ (\frac{RM}{yr})} \quad (4)$$

3. Results

3.1 Palm Oil Mill Processes

Figure 1 shows process flow of the palm oil mill. FFB enters the sterilization process, which consumes the largest volumes of steam in all the milling processes. The objectives of sterilization include preventing the formation of emulsions during crude palm oil (CPO) clarification, deactivating the fruit enzyme to stop the build-up of free fatty acid, softening the mesocarp and conditioning the nut to minimize kernel breakage. The cooking pressure and temperature in sterilization are set to 300 kPa and 140 °C, respectively. Then, the cooked FFB enters the stripping process, which is a rotating drum stripper to detach the fruit from the EFB. The fruit flow to the digester where they are treated mechanically and converted into a homogeneous oily mash. Hot water is then added to facilitate this homogenization. Subsequently, the fruit is fed into a screw press where the press cake is separated from the mixture of oil, water, debris, and any other material, which is discharged as dirty crude oil. The hot water is added to reduce the viscosity of the discharged crude oil. The solid press cake including palm pressed fiber (PPF) and palm nuts is separated and fed to the depericarper. The crude oil is further clarified through solid screening (mechanical vibration) and oil sifting based on the density differences in the clarification tank. Oil from the top is then skimmed off and flows to the next process, vacuum drying. The final CPO is then cooled and stored. The lower layer of sludge is moved to the desander for removing solid waste such as sand and mud. Subsequently, the remaining oil in the sludge is separated using a centrifugal separator. The palm oil mill is generating their own electricity which is generated by burning the waste products of the fruits, fibre and shell in a boiler. The boiler generates steam which drives a steam turbine to produce electricity. Palm oil mills are located in plantations that are far away from major towns and as such they also treat their own water supply.

3.2 Economic Trade for Minimum Temperature Difference

Figure 2 shows the economic trade-off between energy (------) and capital costs (- - -), set against minimum temperature difference (ΔT_{min}). The optimum selection of the ΔT_{min} value is made by optimising the total cost of both trade-offs which minimum cost is achieved at ΔT_{min} equal to 5°C. Value of ΔT_{min} is important to find the correct setting of composite curve which has an implication on the energy target and heat exchanger network design. However, operating below 10°C should be avoided, unless under special circumstances [3]. Thus, composite and grand composite curves of hot and cold streams were plotted as respectively shown in Figures 3(a) and 3(b) at ΔT_{min} of 10°C.

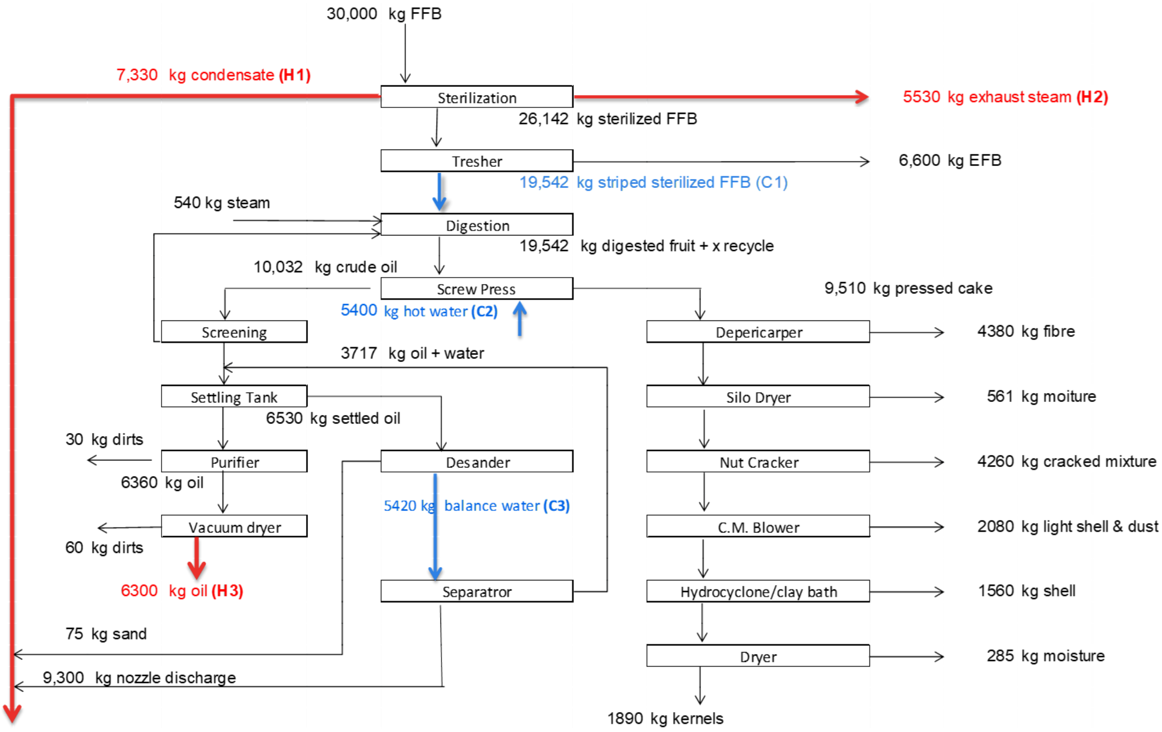

Fig. 1. Block diagram of mass balance for palm oil mill process

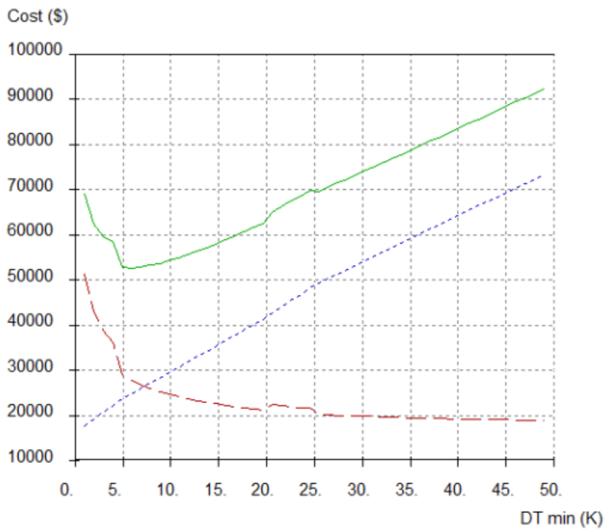

Fig. 2. Total cost plot

3.3 HEN Design

Minimum hot (Q_{Hmin}) and cold utilities (Q_{Cmin}) requirements in this case at ΔT_{min} of 10°C are 257.92kW and 138.65 kW, respectively and these are energy targeted for HEN design. The mill plant existing hot and cold utilities requirements are 767.92 kW and 648.65 kW respectively with 510 kW of heat recovered through process-to-process stream heat transfer. These can be translated to energy reduction of hot and cold utilities of 66% and 79%, respectively were expected. In addition, Figure 3(a) also shows the hot and cold pinch temperatures which are 45°C and 35°C, respectively. The pinch temperatures are essential for HEN design. The temperatures divided the streams to above and below pinch as shown in Figure 4 and following certain rules to design the HEN.

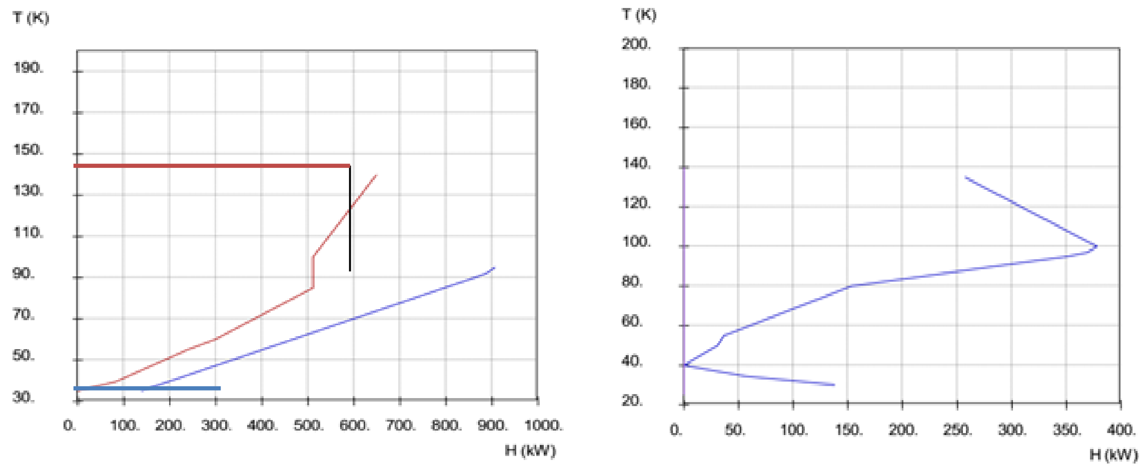

Fig. 3. (a) Composite curves and (b) grand composite curve for hot and cold streams of the palm oil mill plant

The Grand Composite Curve (GCC) (Figure 3(b)) is a plot of the difference in enthalpies between cold and hot composite curves. It is commonly used in determining the temperature levels required for the hot and cold utilities. The mill produced one level of steam at temperature and pressure of 140°C and 300 kPa, respectively. However, according to Figure 3(b) the selected streams can use lower steam temperature (<140°C) if heat from hot process streams is transferred to colder process streams as indicated by the pocket of the GCC.

Figure 4 shows the grid diagram of the HEN design. Total of 12 heat exchangers resulted from the design. This includes 5 process-to-process heat exchangers (1, 3, 8, 9 and 10), four for cold utility (C2, C5, C11and C12) and three for hot utility from steam (H4, H6 and H7). The existing hot and cold utility requirements are 767.92 kW and –648.65 kW respectively, with a total heat recovery of 510 kW by process-to-process heat exchangers. The minimum temperature difference (ΔT_{min}) of the existing HEN is 10°C. The types of heat exchangers used include 7 spiral heat exchangers, 5 tube & shell tube heat exchangers, which all five are for process-to-process streams.

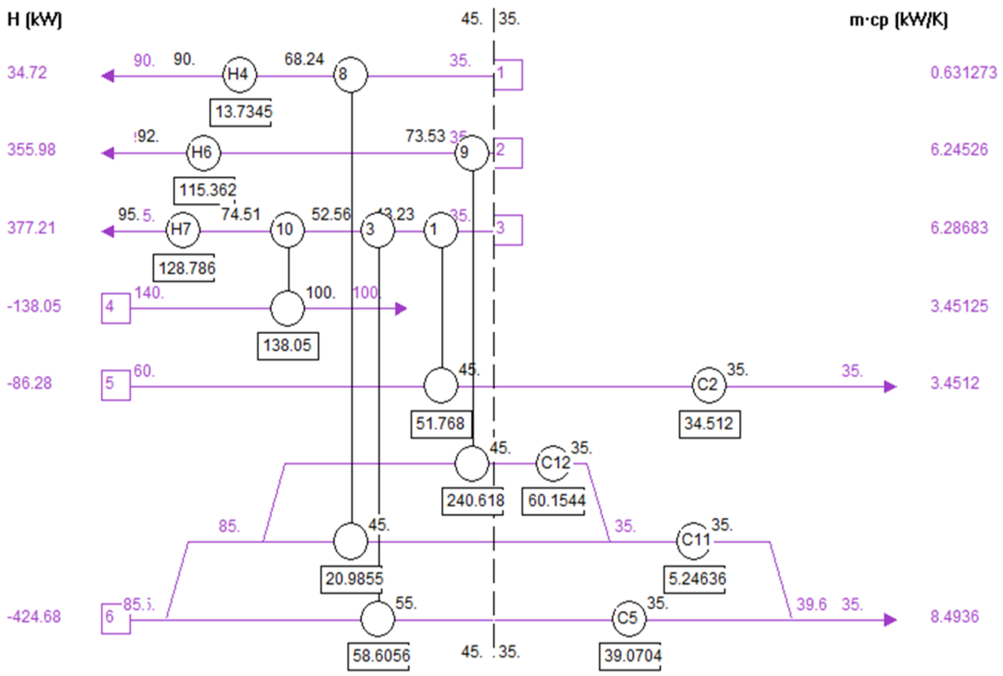

Fig.4. HEN design for the palm oil mill

3.4 Economic Analysis

Table 2 shows the characteristics of each of the 12 heat exchangers. The heat transfer coefficient was estimated using the HINT program with the following correlation Nu = 0.26 $Re^{0.6}Pr^{0.3}$, taking into account the following factors; thermal conductivity, heat capacity, density, viscosity, surface tension, velocity, tube diameter.

Table 2
Heat transfer coefficient estimation with HE area and heat duty

HE	1	3	8	9	10	H4	H6	H7	C2	C5	C11	C12
Hot stream coeff. ($kW/m^2.K$)	0.37	0.48	1.82	1.82	0.39	2.00	2.00	2.00	0.10	1.82	1.82	1.82
Cold steam coeff. ($kW/m^2.K$)	1.84	1.84	1.84	1.84	1.84	1.84	1.84	1.84	2.00	2.00	2.00	2.00
Heat duty (kW)	51.77	58.61	20.99	240.62	138.05	13.73	115.36	128.79	34.51	39.07	5.25	60.15
Area (m^2)	12.80	7.60	1.75	10.72	7.69	2.00	1.95	2.25	17.75	2.39	0.28	3.23

The total heat transfer area calculated is 70.4 m^2. Cold and hot utilities costs were 5.134 $\times 10^{-6}$ (RM/kJ) and 1.197$\times 10^{-5}$ (RM/kJ), respectively. The estimated purchased heat exchanger cost is RM 436,689.44 calculated using Equation (1). The total installed heat exchanger cost calculated using Equation (2) is RM 519,660.96, using a module factor of 1.19 [5].

Equation (3) was used to calculate the cost savings of utilities. The total estimated cost savings is RM 184,735 per year. For cold utilities, the cooling water savings is about 36% or RM65,156 per year. The total hot utility savings is also about 36% or RM119,579 per year. This gives a payback period of 2.36 years calculated using Equation (4). Thus, it can be concluded that the HEN design based on pinch technology approach is an effective means for a process plant to further reduce energy consumption.

$$\text{Cost saving of utilities (RM/yr)} = \text{cost of utilities (RM/kJ)} \times 360 \text{ days} \times \times \text{ Heat load reduction (kW)} \quad (3)$$

$$Pay\ Back\ Period\ (PBP) = \frac{Capital\ investment\ (RM)}{Saving\ per\ year\ (\frac{RM}{yr})} \quad (4)$$

4. Conclusions

In this study, a crude palm oil mill located at Bota, Perak, is processing 30 ton/h of FFB was assessed for HEN design and economic analysis. Pinch method has been applied to the palm-oil processing plant. Total of 12 heat exchangers (5 process to process streams, 3 heaters and 5 coolers) are needed to fully target the heat demand. The total cold and hot utilities required at the beginning were 767.92 kW and 648.65 kW, respectively. After the HEN design, the hot and cold utilities requirements were respectively reduced to 257.92 kW and 138.65kW. The result shows that the HEN is able to recover up to 510 kW of heating and cooling loads with a capital investment of about RM 519,660.96. The total annual savings in utility consumption is RM 184,735.63 giving the payback period for the investment of 2.36 years.

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