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COST-EFFECTIVE RETROFIT OF A PALM OIL REFINERY USING PINCH ANALYSIS

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Abstract. A palm oil refinery involves energy-intensive processes. Maximizing thermal efficiency of palm oil refinery is crucial for the plant profitability. This work implements a pinch analysis retrofit technique to maximize heat recovery and thermal efficiency of a palm oil refinery, subject to the existing process constraints. The procedures involve setting the maximum heat recovery targets and cost-effective retrofit of the heat exchanger network (HEN). Application of the technique on a palm oil refinery results in reduction of 700 kW (21%) heating and cooling loads or a saving of RM370,787, incurring a capital investment of about RM656,293 and a payback period of 1.77 years.

Keywords: Pinch analysis; palm oil; retrofit; heat exchanger network; maximum heat recovery

Abstrak. Kilang penapisan minyak sawit lazimnya melibatkan proses penggunaan tenaga yang tinggi. Peningkatan kecekapan tenaga adalah amat penting bagi memastikan keuntungan tercapai. Kertas kerja ini menggunakan teknik analisis jepit bagi memaksimumkan penggunaan semula haba dan meningkatkan kecekapan sistem rangkaian haba sedia ada di kilang penghasilan minyak sawit, tertakluk kepada kekangan-kekangan proses. Langkah-langkah yang terlibat ialah penetapan sasaran guna semula haba maksimum diikuti dengan reka bentuk rangkaian haba yang ekonomik. Aplikasi teknik berkenaan kepada kilang penghasilan minyak sawit telah menghasilkan pengurangan penggunaan haba panas dan sejuk sebanyak 700 kW (21%), atau penjimatan kos utiliti sebanyak RM370,787, dengan pelaburan kapital sebanyak RM656,293 dan jangka pulangan balik selama 1.77 tahun.

Kata kunci: Analisis jepit; minyak kelapa sawit; sedia ada; rangkaian pemindahan haba; kitar semula haba maksimum

1.0 INTRODUCTION

Efforts to increase plant energy efficiency have intensified with recent years due to fuel price volatility and the global concern on environmental emissions. As new processes and technologies emerge, existing processes are under pressure to increase efficiency and to maintain profitability in order to remain competitive. Many existing energy-

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intensive facilities have focused on thermal energy efficiency upgrading, including retrofit of heat exchanger network (HEN) in order to increase profitability. Pinch Analysis has been a very well established and powerful tool for HEN design and retrofit to maximize energy efficiency.

Pinch Technology is a systematic procedure for the design and retrofit (improvement) of process systems for optimum energy and resource utilisation. Until the last decade, energy was the main focus of new developments in the area. Now, it has been used to optimise solvent, water as well as hydrogen utilisation networks [1, 2 and 3].

In the beginning, the pinch concept was developed to improve the utilization of energy in grassroots HEN design. Technique for HEN retrofits based on pinch analysis was first introduced by Tjoe and Linnhoff [4]. Many recent works focus on improved HEN targeting and optimization techniques [5, 6 and 7].

This work implements a pinch analysis retrofit technique to maximize heat recovery and thermal efficiency of a palm oil refinery, subject to the existing process constraints. The objective of this work is to establish the maximum heat recovery targets for the existing palm oil refinery and to retrofit the HEN cost effectively.

2.0 APPLICATION OF PINCH ANALYSIS FOR RETROFIT OF A PALM OIL PROCESSING PLANT

Palm-oil processing typically consists of three main sections for processing crude palm oil to refined bleached and deodorized (RBD) olein and stearin. The physical refining process begins at the pretreatment plant, followed by deodorization and crystallization plants. Note that most of the heat exchangers are located at the pretreatment and deodorization plants due to the energy-intensive nature of these sections of the plant. These sections are very crucial and are therefore the focus of this study.

2.1 Data Collection

2.1.1 Thermal Data

Data extraction is the most crucial part of a process integration study. The data collected may include the material and energy balances data, physical and chemical properties of the materials and costing data that is used to estimate the capital investment and payback period. The piping and instrumentation diagram (P&ID) provided by the company is usually not up-to-date. Therefore, pipeline tracing and interviews with experienced operators were conducted to get the latest and correct process data for heat integration. Tables 1 and 2 show the hot and cold stream data collected from the plant.

Table 1 Hot stream data

Stream No.	T_{supply} (°C)	T_{target} (°C)	Heat Capacity Flow-rate (kJ/s.C)	Heat Duty (kW)
H1	240.1	172.1	10.30	–700.06
H2	172.1	128.4	9.04	–394.85
H3.1	128.4	85.7	4.46	–190.48
H3.2	128.4	85.4	1.41	–60.65
H3.3	128.4	89.1	2.72	–107.10
H4	242.1	195.2	20.82	–976.60
H5	195.2	168.3	18.42	–495.58
H6	168.3	150.4	17.52	–313.78
H7	150.4	87.1	17.26	–1092.34
H8	248.6	192.2	10.40	–586.62
H9	192.2	163.3	9.20	–265.88
H10	163.3	118.8	8.69	–387.01
H11	118.8	82.4	3.35	–121.90
H12	121.4	72.5	0.92	–45.10
H13	126.2	73.1	0.62	–32.66

Table 2 Cold stream data

Stream No.	T_{supply} (°C)	T_{target} (°C)	Heat Capacity Flow-rate (kJ/s.C)	Heat Duty (kW)
C1	149.2	90.5	11.92	700.06
C2	73.1	42.0	12.70	394.85
C3.1	96.1	73.1	6.47	148.87
C3.2	95.3	73.1	6.49	144.06
C4	188.8	138.6	19.45	976.60
C5	116.2	87.8	17.45	495.58
C6	79.0	42.2	8.53	313.78
C7	138.6	116.2	17.73	397.06
C8	91.7	79.0	8.75	111.14
C9	185.1	119.2	8.91	586.62
C10	119.2	86.4	8.11	265.88
C11	71.2	42.2	13.35	387.01
C12	92.1	71.2	13.70	286.41
C13	262.1	174.4	45.98	4034.15

2.1.2 Cost Data

The cost data is obtained from the *Daily Production and Production Cost* worksheet provided by the company. The hot utilities used in this palm-oil processing plant are steam generated from a boiler and a fired heater which use natural gas as combustion fuel. Steam is utilized at medium pressure (16 bar) and the cold utility is supplied by

Table 3 Utility cost table for existing heat exchanger network

Utilities	Medium	Heat duty (kW)	Cost (RM/kJ)
Hot utility	Steam	1087.54	1.197E-5
	Natural gas	4034.15	8.313E-6
Cold utility	Cooling water	1650.22	5.134E-6
TOTAL		6771.91	2.541E-5

water recirculated from cooling tower. The cost data shown in Table 3 is obtained from Al-Riyami *et al.* [8].

2.2 Analysis of the Existing Heat Exchanger Network

From **Tables 1** and **2**, the existing heat exchanger network (HEN) is found to have 13 hot and 13 cold streams. **Figure 1** shows the grid diagram for the existing HENs. There are a total of 21 heat exchangers in the existing process. This includes 8 process-to-process heat exchangers, 7 coolers (C), 5 steam heaters (MP) and a single fired heater (H). The existing hot and cold utility requirements are 9535 kW and –6129 kW respectively, with a total heat recovery of 4413 kW by process-to-process heat exchangers. The minimum temperature difference (ΔT_{min}) of the existing HEN is 33.1°C.

The types of heat exchangers used include 8 spiral heat exchangers (S), 4 tube heat exchangers (T), and 8 plate-frame type heat exchangers (P). Of these numbers, 5 are process-to-process spiral heat exchangers and the other 3 are plate-heat exchangers. The coolers consist of 2 spiral heat exchanger, 3 plate-frame and 2 tube heat exchangers. The heaters consist of 3 plate-frames, 2 tube type and 1 spiral heat exchanger.

2.3 HEN Improvement

A set of composite curves were constructed from the stream data from Table 1 and 2. Figure 2 shows that the system is a threshold problem. The minimum hot utility (Q_{Hmin}) target is 3469.3 kW and no minimum cold utility (Q_{Cmin}) is required. For ΔT_{min} of 33.1°C, the pinch point temperatures were located at 42°C (cold) to 75.1°C (hot).

The composite curves in Figure 2 show a threshold problem at the cold end of the process. This indicates that no cooling is needed. Figure 1 however shows that several coolers exist above the pinch in the current plant layout, indicating that the fundamental rules for maximum heat recovery have been violated (refer to streams H3, H7 and H11-H12). Looking at the difference between the targeted and the actual utility usages, clearly, there are opportunities for further heat recoveries. However, for a retrofit problem, it may not be possible to achieve the minimum utility targets without incurring significant modifications on the existing plant. Additional heat may be recovered through integration of streams H3, H7, H11 to H13, C3, C7, C8, C12 and C13. The

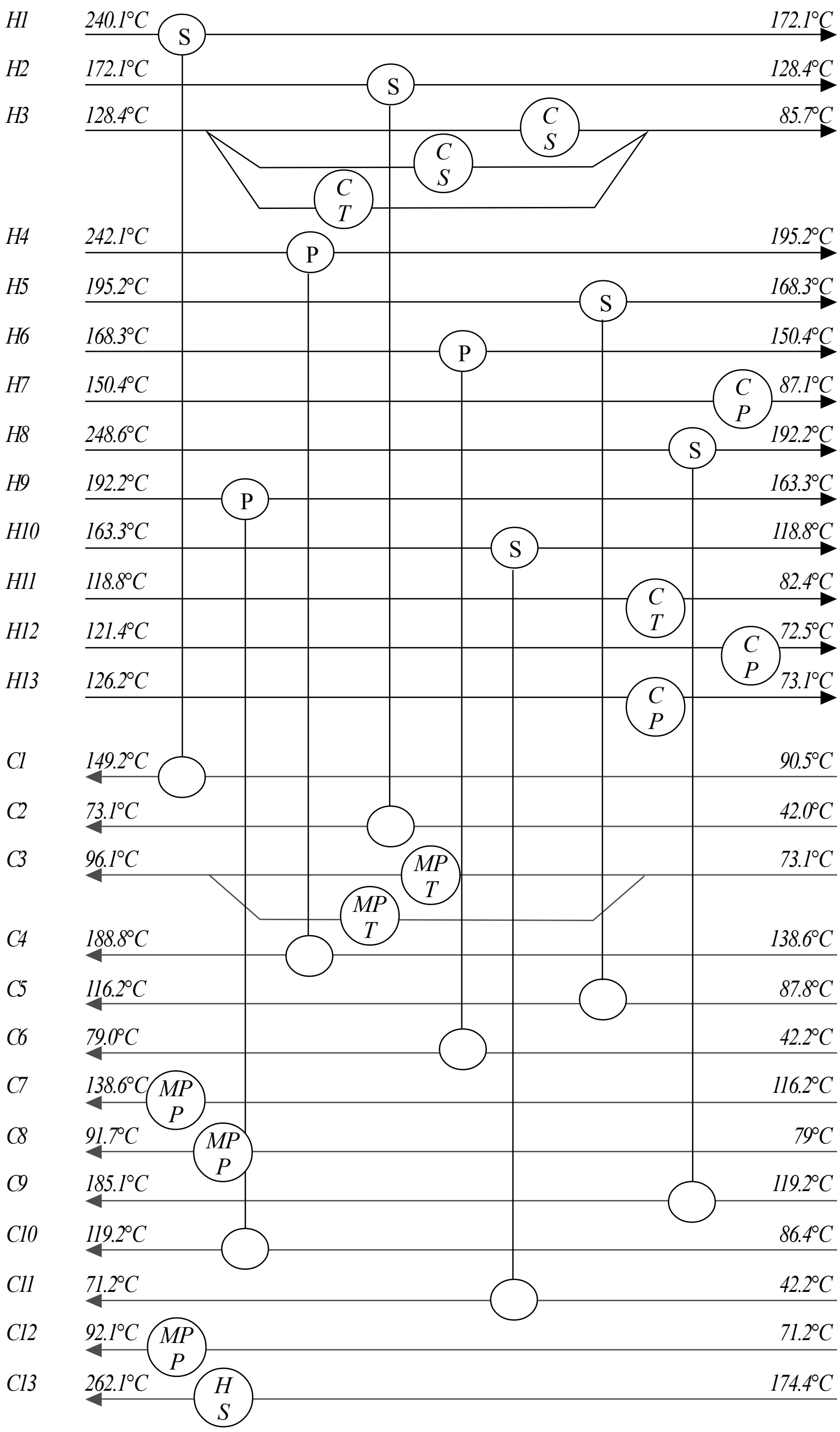

Figure 1 Existing heat network diagram

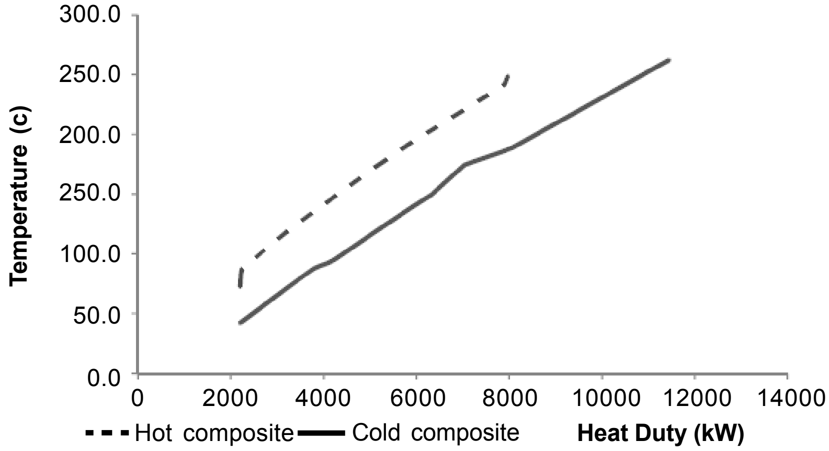

Figure 2 Composite curve for palm oil production plant

target is to reduce the cold utilities from 1650.22 kW to 0 kW and hot utilities from 5121.69 kW to 3469.3 kW as targeted in the composite curves.

Each of the shortlisted streams was carefully assessed as a candidate for heat integration. From the analysis, cold stream C13 had to be eliminated from the list. This is because C13 is heated from 174.4°C to 262.1°C using fired heater having a large heat duty of 4034.15 kW which cannot be provided by any of the available hot streams. Elimination of C13 increased the minimum cold utility target from 0 kW to 562.68 kW. The new stream data for integration is shown in Figure 3.

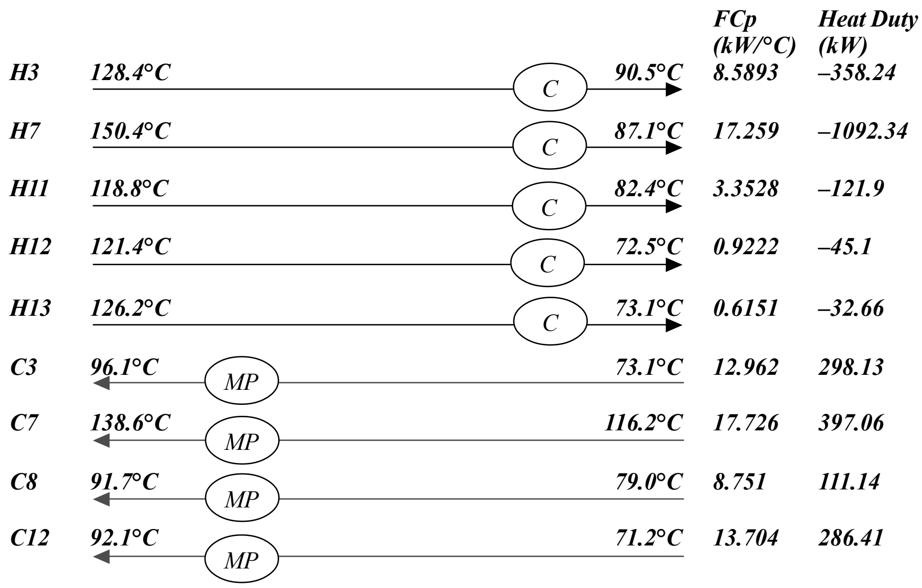

Figure 3 Stream data after excluding C13

From the revised data, a new set of composite curves is constructed as shown in Figure 4 (ΔT_{min} is maintained at 33.1°C). The hot and cold pinch temperatures are 149.3°C and 116.2°C. The new minimum cold utility requirement is 950.4199 kW and hot utility requirement is 378.0773 kW. Figure 5 shows the new heat exchanger network design with the revised stream data.

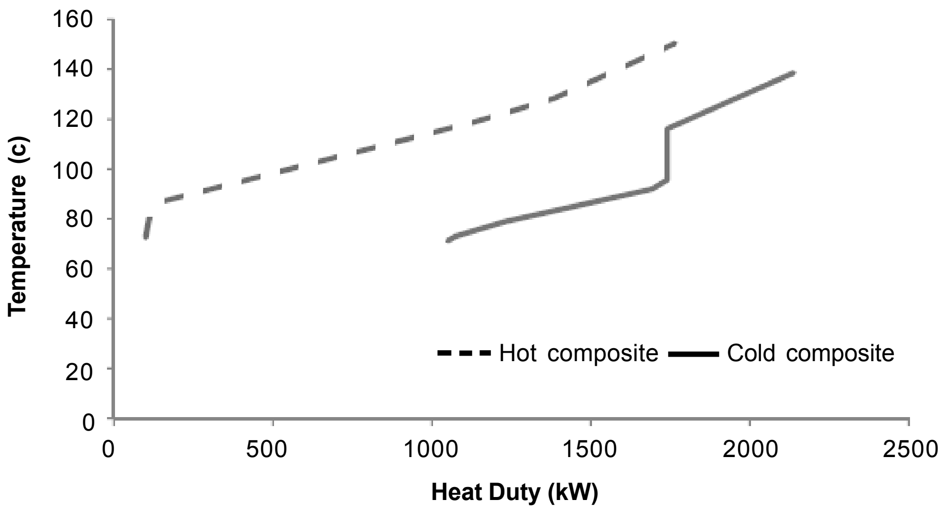

Figure 4 The composite curves for the revised stream data

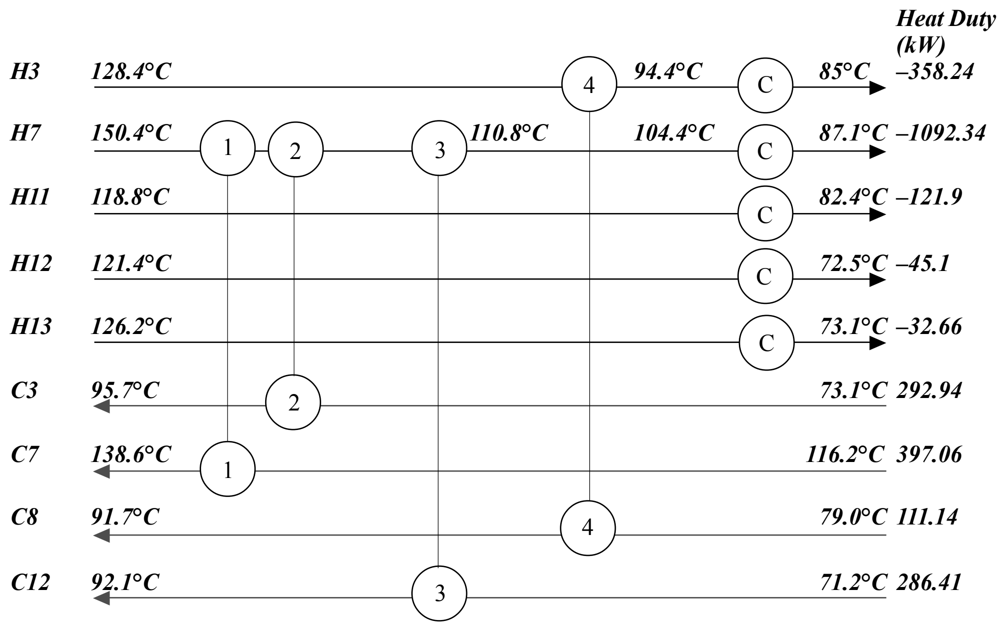

Figure 5 New retrofitted heat exchanger network for the revised stream data

Figure 5 shows that 4 additional process-to-process heat exchangers needs to be installed to achieve the minimum utility targets. Table 4 shows the new heat exchangers and the corresponding heat transfer areas calculated for use in estimation of capital investment. The estimated value of heat transfer coefficient for palm-oil processes obtained from the literature is about 600 W/m^2/°C [9].

Table 4 New heat exchangers design data

Heat Exchanger no.	Temperature(°C)					Heat duty (kW)	Heat transfer area (m^2)
	Th_i	Th_o	Tc_o	Tc_i	T_{lm}		
1	150.4	149.3	117.2	116.2	33.15	16.3	0.81951
2	149.3	132.0	95.7	73.1	56.2084	298.13	8.84003
3	132.0	115.4	71.2	92.1	42.0133	286.41	11.3619
4	128.4	115.5	79.0	91.7	36.5999	111.14	5.06103

*T - temperature; h - hot stream; c - cold stream; i - input; o - output

Referring to Table 4, note that heat exchanger 1 only involve a very small amount of heat transfer with a corresponding 1.1°C temperature drop for hot stream and 1°C temperature rise for cold stream. For reasons of practicality, heat exchanger 1 is to be eliminated. Figure 6 shows the final retrofit design which includes 3 new process-to-process heat exchangers to replace 3 steam heaters.

2.4 Capital Cost

The total heat transfer area calculated is 25.26 m^2. By using equation 1 [10], the estimated purchased heat exchanger cost is RM199,481. Using a module factor of 3.29, the total installed heat exchanger cost calculated using equation 2 is RM 656,293.

$$HE \text{ cost (RM)} = (33422 + 1784 \times \text{Area(m}^2)^{0.81}).(\textit{conversion} \text{ factor}) \quad (1)$$

$$\text{Total cost} = \text{Module factor} \times \text{Equiment Cost} \quad (2)$$

2.5 Comparison Study

Equation 3 is used to calculate the cost savings of utilities based on the cost data in Table 3. From Tables 5 and 6, the total estimated cost savings is RM 370,787 per year. For cold utilities, the cooling water savings is about 42.41% or RM111,775 per year. The total hot utility savings is about 13% or RM259,012 per year. This gives a payback period of 1.77 year calculated using equation 4. Thus, it can be concluded that the HEN retrofit based on pinch design approach is an effective means for a process plant to further reduce energy consumption.

$$\text{Cost saving of utilities (RM/year)} \quad (3)$$
$$= \text{cost of utilities (RM/kj)} \times 360 \text{ days} \times 86400\text{s/day} \times \text{Heat load reduction (kW)}$$

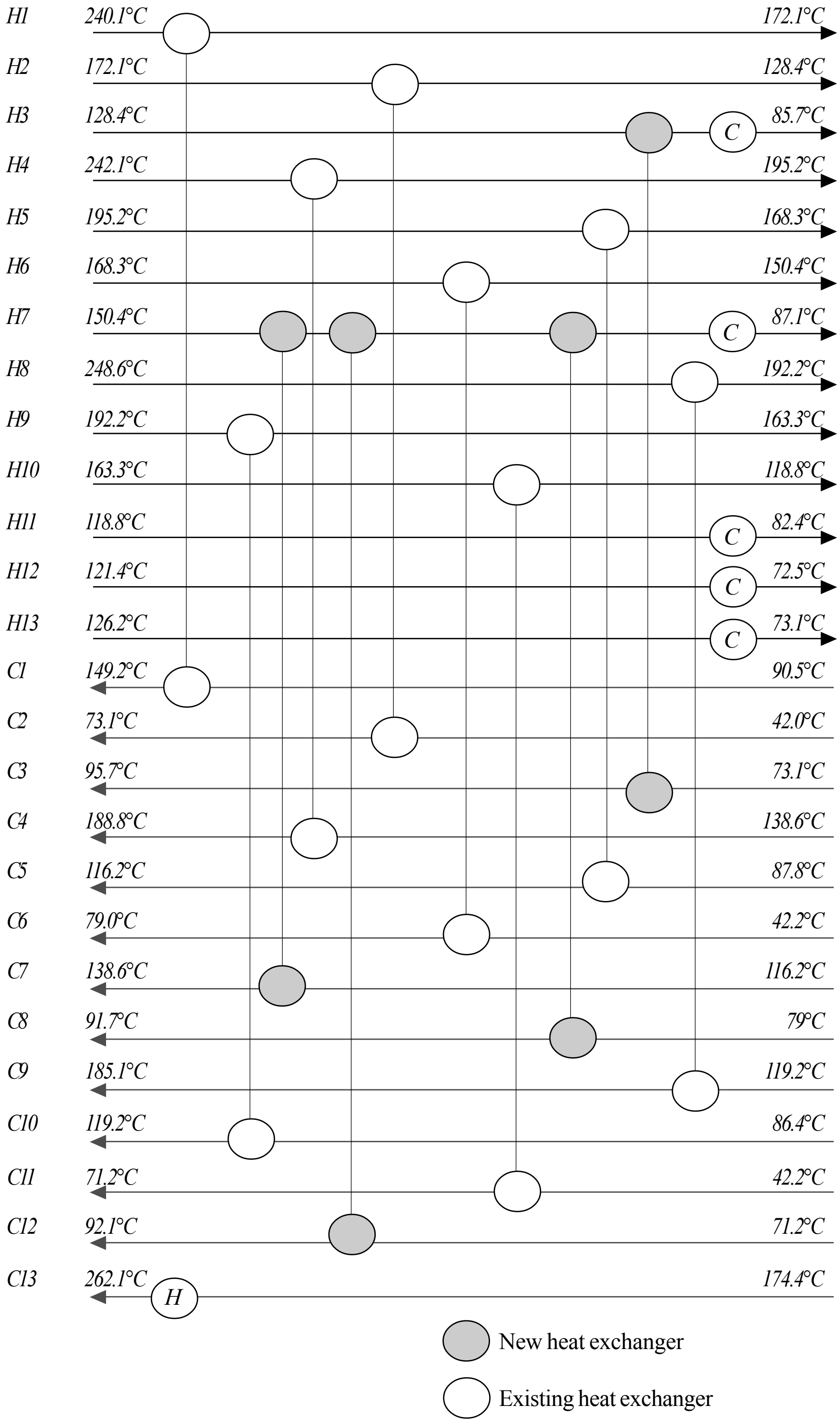

Figure 6 Final retrofitted HEN for FOP

$$PBP = \frac{\text{Capital Investment(RM)}}{\textit{Saving} \text{ per year}\left(\frac{\text{RM}}{\text{year}}\right)} \quad (4)$$

Table 5 Savings in cold utilities

Stream No.	Utility consumption before retrofit (kW)	Utility consumption after retrofit (kW)	Percentage of savings (%)	Cost savings per year (RM)
H3	358.24	261.64	27.0 (96.6 kW)	15,425
H7	1092.34	488.98	55.2 (603.36 kW)	96,349
H11	121.9	121.9	0	0
H12	45.1	45.1	0	0
H13	32.66	32.66	0	0
Total cooling water	1650.22	950.28	42.4 (699.94 kW)	111,775

Table 6 Savings in hot utilities

Stream No.	Utility consumption before retrofit (kW)	Utility consumption after retrofit (kW)	Percentage of savings (%)	Cost savings per year (RM)
C3	298.13	0	100 (298.13 kW)	110,998
C7	397.06	397.06	0	0
C8	111.14	0	100 (111.14 kW)	41,379
C12	286.41	0	100 (286.41 kW)	106,634
Total steam heating	1087.55	397.06	63.5(699.94 kW)	259,012
C13 (fired heater)	4034.15	4034.15	0	0
Total heating utilities	5121.70	4431.21	13.0 (699.94 kW)	259,012

3.0 CONCLUSION

Pinch retrofit method has been applied to a palm-oil processing plant. The result shows that the retrofitted heat exchanger network is able to recover up to 700 kW of heating and cooling loads with a capital investment of about RM656,293. The total annual savings in utility consumption is RM370,787 or 20.7%, giving the payback period for the investment of 1.77 year.

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NOMENCLATURE

ΔT_{min}	Minimum temperature difference
C	Cooler
C*i*	Cold stream
H	Fired heater
HE	Heat exchanger
HEN	Heat exchanger network
H*i*	Hot stream
MP	Medium pressure steam heater
P	Plate-frame type heat exchangers
PBP	Payback period
Q_{Cmin}	Minimum cold utility
Q_{Hmin}	Minimum hot utility
S	Spiral heat exchangers
T	Tube heat exchangers
Tc_i	Cold stream temperature inlet
Tc_o	Cold stream temperature outlet
Th_i	Hot stream temperature inlet
Th_o	Hot stream temperature outlet
T_{lm}	Log mean temperature
T_{supply}	Supply temperature
T_{target}	Target temperature

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