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Retrofit with Exchanger Relocation of Crude Preheating Train for Crude Distillation Unit

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Rapid population growth, increasing energy demand and consequently high crude oil price have been fundamental drivers of global economic growth which partially affect our living. The crude preheating train of the refinery in Thailand consumes high energy at the crude furnace. In this work, the optimization with graphical searching technique and the retrofit model of heat exchanger network (HEN) using stage-wise model from (Grossmann and Zamora, 1996) was applied to design the most profitable HEN of crude preheat train. The retrofit model with the relocation technique is applied to design HEN with using the existing exchangers. The design data is used for the base-case HEN of PTTAR refinery. For result, the retrofitted HEN gives hot utility saving of 13% furnace and 2.21 year of payback period with maximum profit of 391,454.62 $/year.

1. Introduction

The heat exchanger network (HEN) of CDU or the crude preheating train in oil refinery is an important aspect of energy conservation and becomes more important as energy costs continue to increase. Retrofit has attracted significant research due to energy savings achieved in utility costs. The major objectives of retrofit problems are the full utilization of the existing exchangers, reduction of the utility consumption and identification of the required structural modifications. The purpose of this work is to apply the optimization for HEN retrofit with crude preheating train of the real refinery in Thailand, PTTAR refinery. The relation between the process conditions and the heat integration options to provide an optimal structure for a retrofitted heat exchanger network is used as the method of this work. The model is based on a superstructure and stage model by (Grossmann and Zamora, 1996).

2. Stage Model

This retrofit model was modified from the stage-wise superstructure (Grossmann and Zamora, 1996) which is grassroots design as shown in Figure 1.It shows n-stage superstructure for a two hot-two cold stream synthesis problem. At each stage, hot and cold streams are split to allow the potential existence of a heat exchanger to match any hot-cold pair of streams. This concept enables the implicit inclusion of a large number

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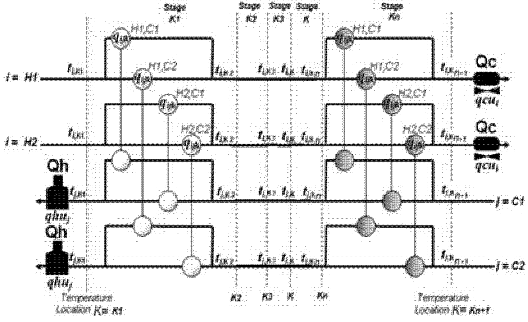
of system topologies. Before a stream enters a new stage its streams of the preceding stage are remixed isothermally. Heater and coolers are placed at the end of cold and hot streams, respectively.



Cost of Hot utility ($/kW/year)	80
Cost of Cold utility ($/kW/year)	20
Area cost ($)	1,200($A^{0.6}$), A in m^2
Fixed cost for an exchangers ($/unit)	4,000
Rate of interest	20%
Plant life time	5 years
Relocation cost ($/unit)	25,000

Figure 1: Heat Exchanger Network Superstructure (Grossmann and Zamora, 1996)(left) and Economic data (Ciric and Floudas, 1988)(right).

Generally, the number of stages in the superstructure is set equal to the maximum cardinality of the hot and cold sets of streams, although sometimes it is necessary to increase the number of stages to allow designs with minimum energy consumption. The retrofit model is to minimize number of exchangers under constraint functions of energy balance, thermodynamics, logical and retrofit constraint with non-splitting assumption.

$$\text{Retrofit constraint: } \sum_{i=1}\sum_{j=1}\sum_{k=1} Zijk \leq 1$$

Where Zijk is a binary variable of existing exchanger matches between hot (i) and cold (j) streams at stage k.

Relocation concept is to relocate the base-case exchangers to the new location of the retrofit, with small area added or removed (≤ 40% acceptable).

3. Crude Preheating Train

It always gives more advantages to have hot streams transferring their heat to the raw crude oil in the heat exchanger networks (HEN) of preheating train to preheat crude before entering the fractionation column to produce products; naphtha-minus, bulk distillate fraction, and long residue, where it is heated up from 30 to about 359 °C as shown in Figure 2. This HEN contains 19 process-to-process exchangers; E-1, E-2, E-3, E-5, E-6, E-7, E-8, E-9, E-10A, E-11, E-12, E-13, E-14, E-15, E-16, E-17, E-18, E-19, and E-20. To transfer heat from 19 hot process streams; I1 to I19, to heat the crude cold streams (divided into three parts); J1, J2, and J3.

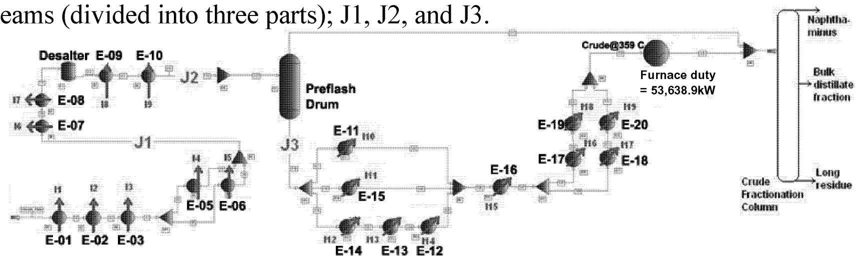


Figure 2: Base case crude preheating train from PRO/II

The base case HEN of crude preheating train can be represented by grid diagram as shown in Figure 4. And the data consists of the stream properties and thermal condition for each exchangers of base case; recovered heat (Q), area, overall heat transfer coefficient (U), and logarithm mean temperature difference (LMTD) are shown in Table 1. An economic data for exchangers and utilities are shown in Table 2.

Table 1: Stream properties of all exchangers of base case. (U= 0.3 kW/m^2 K for New exchangers)

No.HX	Matching	Q(kW)	Ufouled (kW/m^{2}C)	LMTD(C)	Area (m^2)
E-1	**I1-J1**	10,976.90	0.516	78.61	**270.60**
E-2	**I2-J1**	15,154.00	0.49	108.80	**284.24**
E-3	**I3-J1**	7,274.60	0.353	78.00	**264.22**
E-5	**I4-J1**	1,076.50	0.563	46.95	**40.73**
E-6	**I5-J1**	12,450.10	0.512	91.56	**265.57**
E-7	**I6-J1**	14,426.60	0.519	80.28	**346.24**
E-8	**I7-J1**	2,213.10	0.538	32.90	**125.04**
E-9	**I8-J2**	12,419.90	0.457	49.92	**544.41**
E-10	**I9-J2**	9,290.00	0.177	50.84	**1,032.41**
E-11	**I10-J3**	10,920.40	0.515	60.37	**351.22**
E-12	**I11-J3**	3,410.10	0.498	58.34	**117.38**
E-13	**I12-J3**	314.40	0.526	13.54	**44.15**
E-14	**I13-J3**	210.40	0.259	53.42	**15.21**
E-15	**I14-J3**	14,382.90	0.345	36.71	**1,135.66**
E-16	**I15-J3**	12,384.30	0.418	49.15	**602.85**
E-17	**I16-J3**	1,833.50	0.433	68.42	**61.89**
E-18	**I17-J3**	669.20	0.309	71.52	**30.28**
E-19	**I18-J3**	8,643.70	0.196	56.58	**779.47**
E-20	**I19-J3**	6,898.30	0.198	32.35	**1,077.02**

The annual profit of the retrofit case is calculated by equation as shown below. Assumption; repiping cost ≅ very small value.

Profit = Utility saving cost – Annualized investment cost

4. Retrofit Potential

Retrofit potential of the crude preheating train is generated by pinch analysis (1970s) using the composite curve of hot and cold process streams as shown in Figure 3

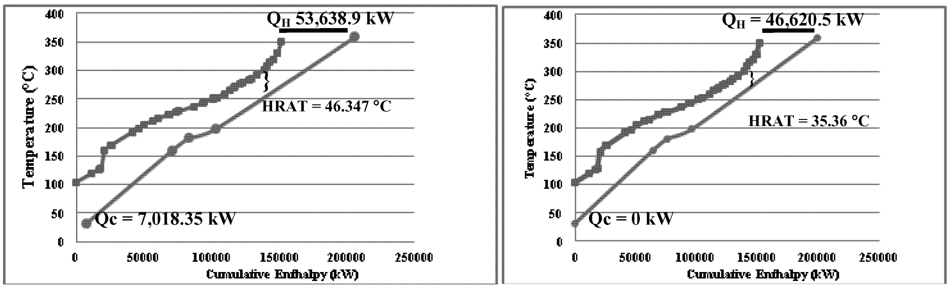


Figure 3: Composite curve of the base case (left) and retrofit (right)

The hot and cold utilities of the existing network are 53,638.9 kW and 7,018.35 kW, respectively; corresponding to heat recovery approach temperature (HRAT) of 46.347°C and exchanger minimum approach temperature (EMAT) of 5.86°C. This means that scope of energy saving on furnace duty should be less than or equal 8,773 kW. Adding or removing exchanger area and/or new exchangers help to reduce the energy usage of crude furnace.

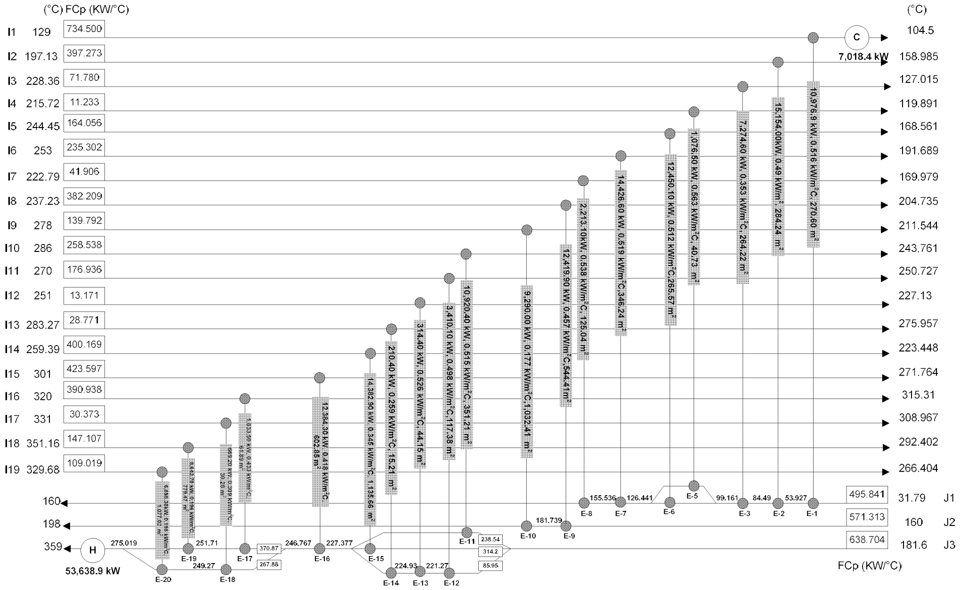


Figure 4: The grid diagram of the base case

5. Retrofit Design of HEN

The base-case HEN is retrofitted by using optimization with graphical searching technique with retrofit model of 19-stage model to maximize the total utility saving cost and minimize fixed/variable costs of exchangers. There are three splitting sections; located at stage no. 5, 10, 15. The other stages are for additional/removal exchanger area or new exchangers needed after retrofitting.

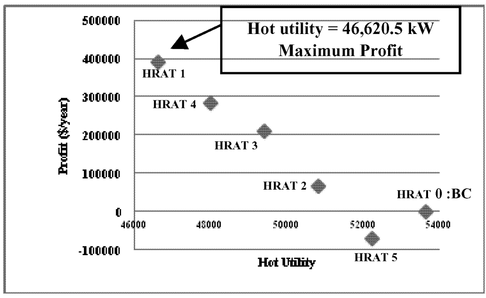


Figure 5: Total profit as a function of hot utility

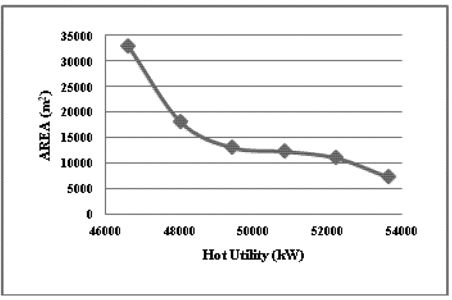


Figure 6: Area of retrofit case vs. HRAT

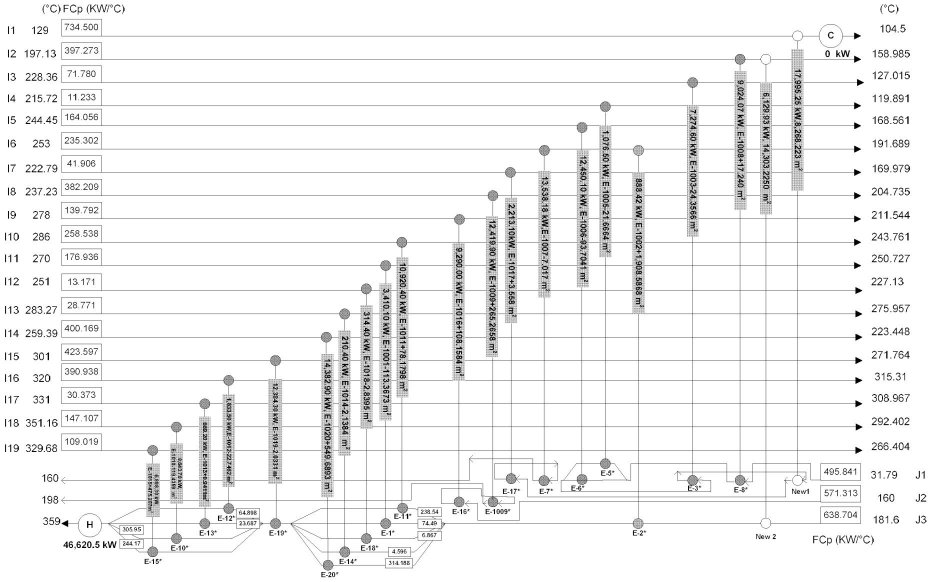


Figure 7: The grid diagram of the retrofit case with relocation

The optimal retrofit HEN with relocation is shown in Figure 7. The retrofit HEN with HRAT of 35.36 °C as shown in the composite curves in Figure 5. consumes hot utility of 46,620.5 kW and cold utility of 0 kW with hot utility saving at the crude furnace of 7,018.4 kW. The retrofit results include the relocation of the base case exchangers and repiping, with addition of 2 new exchangers with area of 22,571.45 m^2 and the additional/removal area of the existing exchangers as shown in Table 3 and 4. Utility cost of existing network is 4,431,480 \$/year. For retrofit with relocation, it is reduced to 3,729,640 \$/year, resulting in maximum profit of 391,454.62 \$/year as shown in Figure 5.

Table 3: Result of the optimal retrofitted case with relocation *(* = relocated exchangers, New = new exchanger)*

Base case exchanger number	Matching	Add (+) or Remove (-) areas to existing/new exchangers	Area(m^2)	%Add/Remove	Relocation
E-1*	**I11-J3**	**E-1-113.3673**	**157.233**	**-41.89**	**-**
E-2*	**I6-J3**	**E-2+1,908.5868**	**2,192.825**	**671.47**	**-**
E-3*	**I3-J1**	**E-3-24.3566**	**239.861**	**-9.21**	**Relocation**
E-5*	**I4-J1**	**E-5-21.6664**	**19.063**	**-53.19**	**-**
E-6*	**I5-J1**	**E-6-93.7041**	**171.865**	**-35.28**	**Relocation**
E-7*	**I6-J1**	**E-7-7.017**	**339.225**	**-2.02**	**Relocation**
E-8*	**I2-J1**	**E-8+17.240**	**142.278**	**13.78**	**-**
E-9*	**I8-J2**	**E-9+265.2658**	**809.677**	**48.72**	**-**
E-10*	**I18-J3**	**E-10-119.4359**	**912.976**	**-11.56**	**Relocation**
E-11*	**I10-J3**	**E-11+78.1798**	**429.397**	**22.25**	**Relocation**
E-12*	**I16-J3**	**E-12-22.7462**	**94.636**	**-19.37**	**Relocation**
E-13*	**I17-J3**	**E-13+0.9411**	**45.086**	**2.13**	**Relocation**
E-14*	**I13-J3**	**E-14-2.1384**	**13.067**	**-14.06**	**-**
E-15*	**I19-J3**	**E-15+475.207**	**1,610.866**	**41.84**	**-**
E-16*	**I9-J2**	**E-16+108.1584**	**711.008**	**17.94**	**Relocation**
E-17*	**I7-J1**	**E-17+3.558**	**65.450**	**5.74**	**Relocation**
E-18*	**I12-J3**	**E-18-2.8395**	**27.440**	**-9.37**	**Relocation**
E-19*	**I15-J3**	**E-19-2.0331**	**777.436**	**-0.26**	**Relocation**
E-20*	**I14-J3**	**E-20+549.6893**	**1,626.707**	**51.03**	**-**

Table 4: Details of 4 new exchangers from the retrofit case

Number of exchangers	Matching	Recovery Energy (kW)	Area(m^2)
New1	I1-J1	888.42	8,268.223
New2	I2-J3	6,129.93	14,303.225

6. Conclusion

This model simultaneously considers the saving cost utility, structural modification, new area cost and additional area cost. To overcome the retrofit HEN problems, a two-step approach is presented. In the first step, retrofit step finds the optimum network. The second step indicates heat exchanger relocation and investment cost. The retrofitted HEN with 19 stages model is carried out by relocating existing exchangers and adding 2 new exchangers, resulting in the 13 % energy saving at the furnace, and 100 % energy saving at the cooler, as shown in Table 6. and 2.21 year of payback period.

Table 5: Comparison of the retrofit results in optimal retrofit case with base-case

Data	Base case	Retrofit case	Economic result of retrofit case
Overall area(m^2)	7,388.58	32,957.55	Total Annualized Cost (\$/year)= 310,385.38
Overall recovery energy(kW)	144,948.9	151,967.25	Total Addition area(m^2)= 22,571.45
Number of exchangers	19	21	Annualized cost(\$)in 5 years= 1,551,926.9

Table 6: Comparison of energy usage between base-case and retrofit case

Cases	Hot utility		Cold utility		Utility Saving Cost (\$/year)	Profit (\$/year)	Payback Period(yr)
	Q_H (kW)	Saving(%)	Q_C(kW)	Saving (%)			
Base case	53,638.9	0	7,018.4	0	0	0	-
Retrofit case	46,620.5	13	0	100	701,840	391,454.62	2.21

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