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Retrofit with Exchanger Relocation of Crude Preheat Train under Different Kinds of Crude Oils

Bongkoch Yimyam[a,b], Kitipat Siemanond[a,b]

[a]The Petroleum and Petrochemical College, Chulalongkorn University, Chulalongkorn Soi12, Phayathai Rd., Pathumwan, Bangkok 10330, Thailand
[b]National Center of Excellence for Petroleum, Petrochemicals and Advanced Materials, Chulalongkorn Soi12, Phayathai Rd., Pathumwan, Bangkok 10330, Thailand
bongkoch_yimyam@yahoo.com

Energy management is an important portion of controlling total operating costs for refineries throughout the world. For refinery, the crude distillation unit is one of the largest energy consumption units and also represents one of the most important areas for doing heat integration. The heat exchanger network (HEN) of crude distillation units (CDU) can be retrofitted to reduce the utility consumption. This research used the retrofit potential program, Supachai (2011) to find the optimum point in targeting step and then a mathematical programming model using General Algebraic Modelling System (GAMS) called the stage model, using the mixed integer linear programming (MILP) of Yee and Grossmann (1990) was applied to develop the retrofit model and the simulation software (PROII) was used to validate the design and to perform the total utility consumption. With using the existing exchangers, the retrofit model with the exchanger relocation technique is applied. Example problems of HEN for a crude distillation unit with light, medium and heavy crude oil feeds for a period of 100, 150 and 100 days per year, respectively, were used to demonstrate the retrofitting with the aim of finding the optimal design that would yield the highest net present value (NPV).

1. Introduction

For refineries throughout the world, energy management is an important element of controlling total operating costs. The crude distillation unit (CDU) is one of the largest energy-consuming units in a refinery, having a complex heat exchanger network (HEN) of crude preheat train which transfers heat from hot-product and pump-around streams to preheat crude before entering the crude distillation column, resulting in energy saving in crude furnace and coolers. Various applications are used to address exchanger network design and process heat integration, thus helping to identify energy-efficient process designs while minimizing operating and capital expenditure. The retrofit technique by Linnhoff and Tjoe (1985) using pinch technology or thermodynamic method applies targeting procedures to energy-area trade-offs which subsequently translate into investment savings plots. Yee and Grossmann (1984) proposed assignment-transhipment models for structural modifications and a two-stage approach with MINLP model (Yee and Grossmann, 1990). In the last two decades, the raw material fed to the refinery changes frequently the characteristics. This situation is one of the reasons to retrofit the crude distillation unit (CDU), to increase the flexibility. The major objectives of retrofit problems are the reduction of the utility consumption, the full utilization of existing exchangers and identification of the required structural modifications.

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2. Methodology

Targeting step by pinch technology

The pinch design method has been developed by Tjoe and Linnhoff (1987) and applied to optimize a HEN through the incorporation of thermodynamic properties of the process streams. In this work used a retrofit potential program (Supachai, 2011) which was developed using visual basic for application (VBA) of pinch technology which is automatically find the optimum point of ΔT_{min}. The optimum ΔT_{min} value must be determined before designing the network.

HEN retrofit step by mixed integer linear programming (MILP)

The MILP model also offers a good level of flexibility that opens room for decision making by the users. This is advantageous for the retrofit application because retrofit problems of industry are numerous and complex. Then the stream matches are generated by using a mixed integer linear programming (MILP) model using GAMS called the stage model, from Yee and Grossmann (1990). The objective function is to minimize the number of exchanger under constraint functions of energy balance, thermodynamics and logical constraint. At the pinch, use value of EMAT equal to ΔT_{min} from pinch analysis. As matches move away from the pinch, use value of EMAT equal to 5 ^{o}C.

Simulation step by PROII

PROII simulated HEN to perform the utility consumption of multiple crudes from retrofit step. The duties and the overall heat transfer coefficient of each exchanger are defined. Then PROII calculates area of each exchanger. Furthermore PROII is also used to validate the retrofit design.

HEN relocation step

After retrofit and simulation step is complete, HEN structure changes using the existing exchangers in retrofit network is not specified. It shows where the base case exchanger are used or relocated in the retrofit case, resulting in the optimal HEN with the retrofit structure. Relocation concept is to relocate the base-case exchangers to the new location of the retrofit, with small area added or removed.

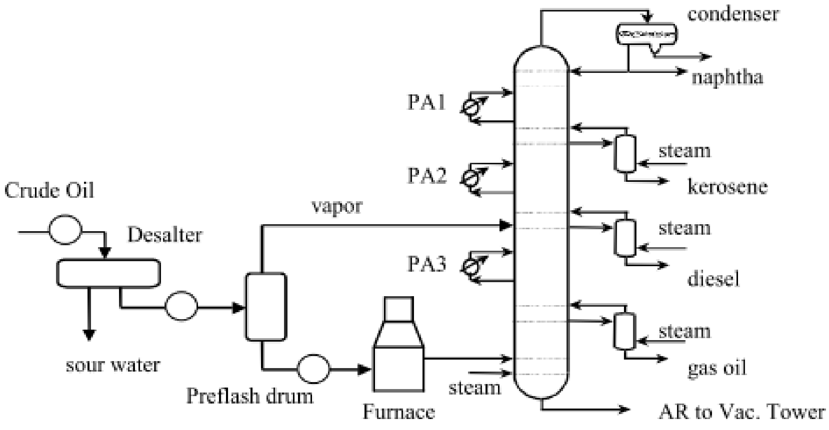


Figure 1: The crude distillation unit with pre-flash drum

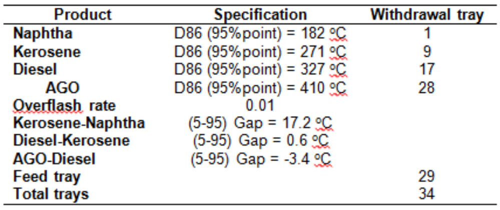
3. Case study

The case study considers the retrofit of a heat exchanger network of a crude distillation unit with pre-flash drum, as shown in Figure 1, with 11 streams and 9 exchangers, the base case of CDU is operated under TROLL (light crude), FOROZAN (medium crude) and SOUEDIE (heavy crude). Crude is preheated to a temperature of 125 ^{o}C, for desalting purposes. After that crude is preheated to 170 ^{o}C in order to preflash before heating it to 370^{o}C and sent to the distillation column. In this example, 5 - 95 gaps and ASTM D86 (95% point) of product are used as separation criteria. Table 2 indicates the specifications of the products and the product withdraw locations. The column data are shown in Table 3. Table 4 shows the set of design variables.

Table 1: Crude used for study case

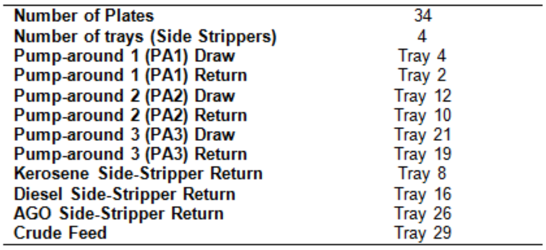
Crude	API	Throughput (m^3/h)
Light crude	35.87	795
Medium crude	30.19	795
Heavy crude	23.12	795

Table 2: Specifications of the products



Product	Specification	Withdrawal tray
Naphtha	D86 (95%point) = 182 ºC	1
Kerosene	D86 (95%point) = 271 ºC	9
Diesel	D86 (95%point) = 327 ºC	17
AGO	D86 (95%point) = 410 ºC	28
Overflash rate	0.01	
Kerosene-Naphtha	(5-95) Gap = 17.2 ºC	
Diesel-Kerosene	(5-95) Gap = 0.6 ºC	
AGO-Diesel	(5-95) Gap = -3.4 ºC	
Feed tray		29
Total trays		34

Table 3: Column data



Number of Plates	34
Number of trays (Side Strippers)	4
Pump-around 1 (PA1) Draw	Tray 4
Pump-around 1 (PA1) Return	Tray 2
Pump-around 2 (PA2) Draw	Tray 12
Pump-around 2 (PA2) Return	Tray 10
Pump-around 3 (PA3) Draw	Tray 21
Pump-around 3 (PA3) Return	Tray 19
Kerosene Side-Stripper Return	Tray 8
Diesel Side-Stripper Return	Tray 16
AGO Side-Stripper Return	Tray 26
Crude Feed	Tray 29

Table 4: Design variables

Variable	Value		
	Light crude	Medium crude	Heavy crude
Kerosene Stripper Steam @ 260 ^{o}C, 4.4 atm (kg/h)	522.5	832.5	818.6
Diesel Stripper Steam @ 260 ^{o}C, 4.4 atm (kg/h)	2616.5	2080.6	2217.5
AGO Stripper Steam @ 260 ^{o}C, 4.4 atm (kg/h)	2843.0	1860.0	1696.0
Main Steam @ 260 ^{o}C, 4.4 atm (kg/h)		3493	
Overflash		1%	
Condensor Temperature		32.22 ^{o}C	
Pump-around 1 (PA1) Return Temperature		104.44 ^{o}C	
Pump-around 2 (PA2) Return Temperature		148.89 ^{o}C	
Pump-around 3 (PA3) Return Temperature		232.22 ^{o}C	
Pump-around 1 (PA1) Heat Rate		11.7 MW	
Pump-around 2 (PA2) Heat Rate		8.8 MW	
Pump-around 3 (PA3) Heat Rate		8.8 MW	

The existing exchanger network configuration is shown in Figure 2. The existing network does not have splitters. The stream properties are shown in Table 5, 6 and 7, the existing heat exchangers areas and heat load are shown in Table 8.The original HEN consumes 315539 MW/h of hot utility and 149255 MW/h of cold utility. The results will be compared for a project life of 5 y, 10 % annual interest rate and presented in the discussion section. 350 working days per year is assumed. The costs of hot and cold utilities are 0.4431 and 0.0222 cent/MJ.

The maximum values of area addition and reduction that can be made to existing shells are 20 % and 50% of the corresponding existing area. The maximum area per shell is 5,000 (m^2); the maximum number of shells per exchanger is4.The model was run for maximizing the net present value (NPV).The cost relations for area adjustment are shown Equation 1, 2, 3 and 4. Costs are assigned to splitting of $20,000 and to relocation of $25,000.

Exchanger (\$) = 8,600 + [670×Area$^{0.83}$ (m^2)] (1)

Area addition (\$) = 4,300 + [1476× Added Area$^{0.83}$ (m^2)] (2)

Area reduction (\$) = 4,300 + [9× Reduced Area$^{0.83}$ (m^2)] (3)

New shell (\$) = 8,600 + [1476×Area of shell $^{0.83}$(m^2)] (4)

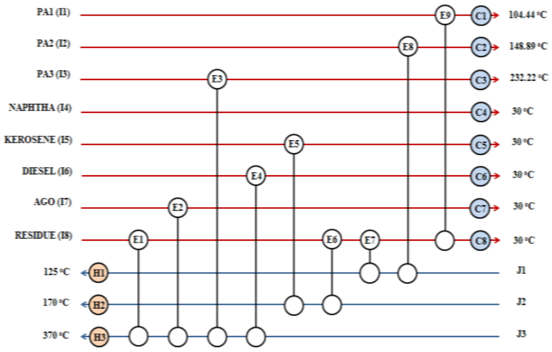


Figure 2: Existing heat exchanger network

Table 5: Stream properties of Light crude

Stream	FCp (kW/ °C)	T_{in} (°C)	T_{out} (°C)	h (kW/m²°C)	H (kW)
I1	121.02	201.17	104.44	1.293	11707
I2	69.91	274.71	148.89	1.318	8796
I3	98.60	321.17	232.22	1.298	8771
I4	105.22	32.22	30	1.058	234
I5	67.76	234.40	30	1.395	13850
I6	49.64	273.17	30	1.423	12072
I7	59.98	326.40	30	1.343	17779
I8	135.33	341.73	30	0.892	42186
J1	380.57	25	125	0.654	38057
J2	434.32	125	170	0.632	19544
J3	585.63	166.64	370	0.788	119092

Table 6: Stream properties of Medium crude

Stream	FCp (kW/ °C)	T_{in} (°C)	T_{out} (°C)	h (kW/m²°C)	H (kW)
I1	125.28	198.28	104.44	1.092	11756
I2	71.80	271.63	148.89	1.235	8812
I3	101.36	319.12	232.22	1.270	8808
I4	92.01	32.22	30	1.253	204
I5	56.28	225.57	30	1.394	11007
I6	34.77	269.78	30	1.431	8338
I7	41.91	326.26	30	1.413	12415
I8	210.12	357.39	30	0.888	68791
J1	387.57	25	125	0.652	38757
J2	443.70	125	170	0.630	19967
J3	587.80	168.84	370	0.782	118241

Table 7: Stream properties of Heavy crude

Stream	FCp (kW/ °C)	T_{in} (°C)	T_{out} (°C)	h (kW/m²°C)	H (kW)
I1	132.07	193.31	104.44	1.075	11737
I2	74.03	267.77	148.89	1.221	8801
I3	104.43	316.69	232.22	1.270	8821
I4	70.64	32.22	30	1.309	157
I5	46.81	221.36	30	1.393	8957
I6	29.33	263.57	30	1.438	6851
I7	32.46	322.00	30	1.419	9478
I8	268.65	353.52	30	0.826	86914
J1	392.24	25	125	0.651	39224
J2	449.76	125	170	0.630	20239
J3	555.77	167.81	370	0.780	112370

Table 8: The existing heat exchangers areas and heat load

Exchanger	Area (m²)	Heat Load (kW)		
		Light crude	Medium crude	Heavy crude
E1	1218	18866	29963	33546
E2	1035	9229	6574	5021
E3	75	4231	4223	4240
E4	435	5737	3894	3125
E5	485	6094	4354	3291
E6	484	8827	11906	13948
E7	461	6914	10888	13639
E8	142	8796	8697	8644
E9	182	9616	9151	8962

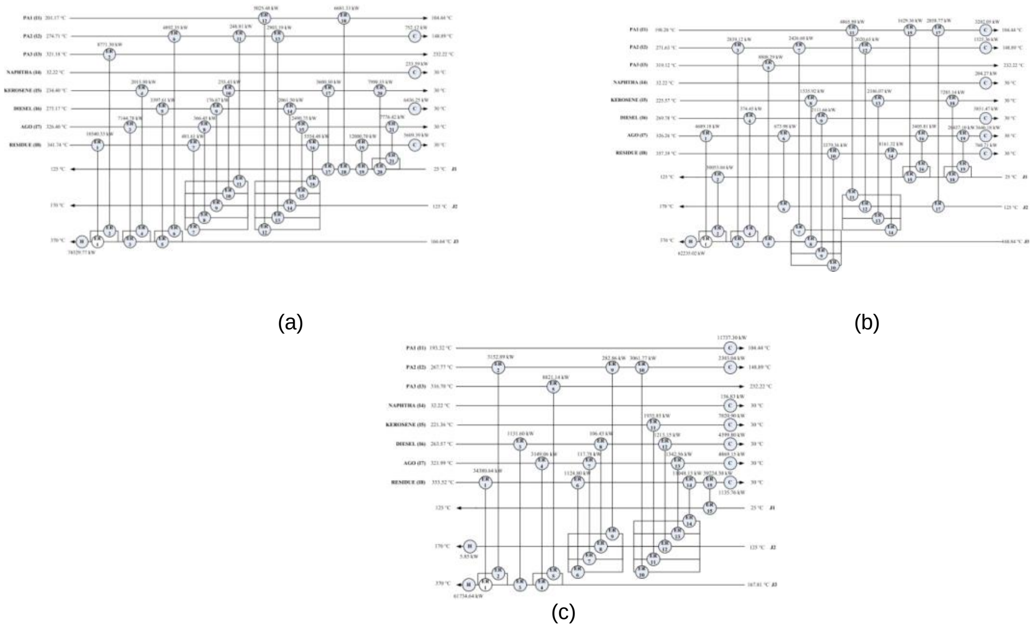
4. Results and discussion

In this section the results for each retrofitted designs are compared to find the optimum retrofitted design which gives the maximum NPV. Each retrofitted design was performed using the specified constraints and cost functions. The relocation concept was used to manipulate the area of existing exchangers as well as adding new exchangers and introducing split streams.

From process pinch analysis by the retrofit potential program the maximum NPV of retrofitted Light crude, Medium crude and Heavy crude design occur at ΔT_{min} of 34.65 ^{o}C, 29.80 ^{o}C and 55.0 ^{o}C respectively. Now that the optimum ΔT_{min} value has been defined, Table 9 shows the optimum ΔT_{min} and the pinch temperature of each retrofit case. The retrofitted design of Light crude base, Medium crude base and Heavy crude base are shown in Figure 3. Table 10, 11 and 12 show the area of each exchanger from PROII simulation

Table 9: The optimum ΔT_{min} and the pinch temperature of each retrofit case

	Light Crude	Medium Crude	Heavy Crude
Optimum ΔT_{min}(^oC)	34.65	29.80	55.00
Pinch temperature of hot stream(^oC)	198.28	201.17	221.36
Pinch temperature of cold stream(^oC)	168.48	166.53	166.36



(a)

(b)

(c)

Figure 3: Retrofit design of base case (a) Light crude, (b) Medium crude and (c) Heavy crude

Table 10: Exchangers areas of Light crude from PROII simulation

Exchanger	Area (m^2)	Exchanger	Area (m^2)
ER1	1169.35	**ER12**	333.36
ER2	465.76	**ER13**	186.04
ER3	208.13	**ER14**	138.16
ER4	166.18	**ER15**	113.19
ER5	137.73	**ER16**	281.61
ER6	160.22	**ER17**	139.54
ER7	24.79	**ER18**	867.83
ER8	16.53	**ER19**	855.32
ER9	12.24	**ER20**	623.12
ER10	13.99	**ER21**	832.65
ER11	15.51		

Table 11: Exchangers areas of Medium crude from PROII simulation

Exchanger	Area (m^2)	Exchanger	Area (m^2)
ER1	348.64	**ER11**	398.58
ER2	1773.35	**ER12**	130.83
ER3	149.86	**ER13**	144.67
ER4	13.80	**ER14**	442.82
ER5	254.70	**ER15**	111.95
ER6	29.60	**ER16**	165.43
ER7	132.65	**ER17**	451.50
ER8	89.01	**ER18**	804.57
ER9	78.60	**ER19**	2355.63
ER10	174.03		

Table 12: Exchangers areas of Heavy crude from PROII simulation

Exchanger	Area (m^2)	Exchanger	Area (m^2)
ER1	1377.43	**ER9**	11.85
ER2	518.49	**ER10**	128.83
ER3	44.61	**ER11**	77.63
ER4	64.78	**ER12**	44.10
ER5	201.95	**ER13**	43.84
ER6	42.86	**ER14**	415.66
ER7	3.93	**ER15**	3220.47
ER8	4.01		

Table 13: Utility consumption of retrofit designs

	Light crude	Medium crude	Heavy crude
Hot utility (MJ/h)	241069	234224	302620
Cold utility (MJ/h)	39666	68022	136418

Table 14: Cost summary

	Retrofit Design		
	Light crude Base	Medium crude Base	Heavy crude Base
no.of new exchanger	12	10	8
Area of new exchanger	2601.31	3445.49	272.83
no. of used existing exchanger	9	9	7
Added Area	0	3.6	179.38
Removed area	533.37	471.21	559.24
no.of new shell	2	1	1
Area of new shell	176.31	555.35	2735.47
Investment cost for 5 years life time ($)	771,578	1,042,097	1,385,774
Annualize investment cost ($/y)	154,316	208,419	277,155
Heating Utility (MJ/y)	2,024,982,526	1,967,478,709	2,542,007,559
Cooling Utility (MJ/y)	333,194,353	571,382,662	1,145,910,849
Energy saving ($/y)	2,976,183	3,178,105	504,822
Splitting cost ($)	20,000	20,000	20,000
Relocation cost ($)	25,000	25,000	25,000
NPV ($)	10,510,498	11,005,420	527,899
Total Utility consumption (MJ/y)	2,358,176,905	2,538,861,370	3,687,918,407

5. Conclusion

This model simultaneously considers the saving cost utility, structural modification, new area cost and added/removed area cost. To overcome the problems, a three main step approach is presented. In the first step, targeting step finds the optimum ΔT_{min}, the second step or retrofit step indicates optimum HEN for each ΔT_{min} and the last step, relocation step indicates heat exchanger matching and investment cost. From three alternative retrofit design which are based on light crude, medium crude and heavy crude, respectively, the retrofit HEN of medium crude with multiple crude feed with applying 11 stages model is carried out by relocating some existing exchangers and adding 10 new exchangers and 1 new shell to the base-case HEN and old exchangers are relocated, gives 35% total utility saving and maximum NPV of 11,005,420 $.

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