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Heat Exchanger Network Retrofit by Pinch Design Method using Stage-Model Mathematical Programming

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For refineries throughout the world, energy management is an important element for controlling total operating costs. Over the past decades there appears to be an urgent need to retrofit the existing Heat Exchanger Network (HEN) of Crude Distillation Units (CDU) to reduce the current utility consumption. A simple pinch design approach is proposed here to accomplish above-and-below-pinch HEN design by stage-model mathematical programming using GAMS software. The energy and capital costs of a heat exchanger network are both dependent on the pinch temperature or ΔT_{min} which is set as target prior to the design of a HEN. In this work, a retrofit potential program was developed using visual basic for application (VBA) to find the optimum pinch temperature in targeting step. Moreover, the program can automatically generate composite curves, and grand composite curve of the process hot and cold streams. An example; base-case HEN of crude preheat train, from Bagajewicz's paper (2010) is used to illustrate this procedure and compare the results.

1. Introduction

Heat exchanger networks (HENs) have been widely applied in industrial projects over the past decades because they provide significant energy and economic savings. Applications of HEN integration can be divided into two categories are grassroots and retrofit design. In oil refining, retrofit design are far more common than grassroots applications. Frequently, proper redesign of an existing network can reduce significantly the operating costs in a process. The major objectives of retrofit problems are the reduction of the utility consumption, the full utilization of the existing exchangers and identification of the required structural modifications.The incorporation of the optimum HENs in the retrofit design to minimizing energy consumption is a challenging problem. 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. The simplicity and flexibility of the method allows the user to optimize exchanger location as well as exchanger area. An improved pinch-technology retrofit procedure is developed in this work by using potential retrofit program or targeting program and new objective function in cost targeting step to lower the utility consumption levels of any given HEN at the cost of minimal capital investment.

2. Methodology

2.1 Targeting step by pinch analysis

This step is to develop VBA targeting program to find the optimal ΔT_{min} or heat recovery approach temperature (HRAT) of the retrofit case giving the maximum profit or net present value (NPV)

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calculated from energy saving cost minus investment cost of additional tube area and new shell of exchangers based on vertical heat transfer between hot and cold composite curves.

2.2 HEN retrofit step by n-stage model

After obtaining optimal HRAT or pinch point from VBA targeting program, the n-stage model Grossmann & Zamora (1996), as shown in Figure 1, is applied to design HEN at above and below pinch sections based on algorithm from Smith (1995) shown in Figure 2 and 3.

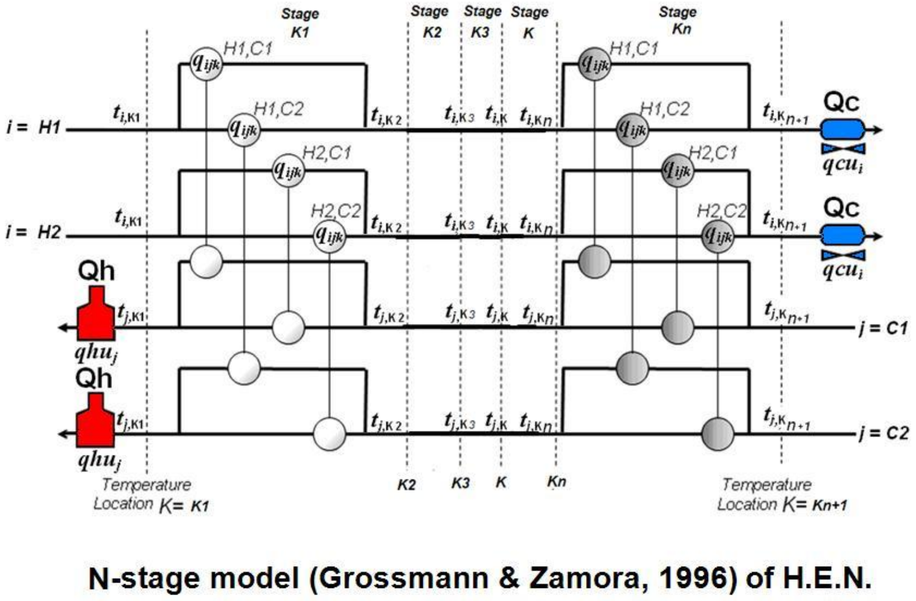
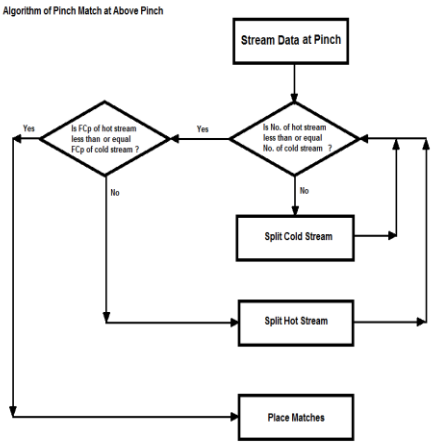


Figure 1: N-Stage model



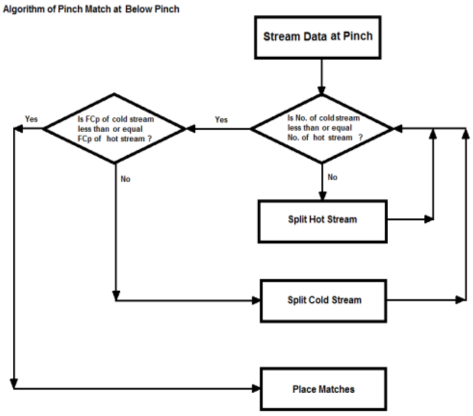


Figure 2: Algorithm of above-pinch design

Figure 3: Algorithm of below-pinch design

3. Case study

The case study is retrofitting base-case crude preheat train, as shown in Figure 4, of a crude distillation unit from Bagajewicz (2010).The network consists of ten hot and three cold process streams (H1, H2, H3, H4, H5, H6, H7, H8, H9, H10, C1, C2, and C3) with six process exchangers (No.11, 10, 6, 5, 1, and 12), three hot utility (No. 9, 18, and 17), and nine cold utility exchangers (No.15, 7, 14, 4, 8, 2, 3, 13, and 16). The current design uses two kinds of hot utilities (HU11,and HU12) and three kinds of cold utilities (CU4, CU5, and CU6). This existing network does not have splitting. The retrofit result of this study will be compared to one without heat exchanger relocation and C3 splitting from Bagajewicz's paper as shown in Figure 8 for a project life of 5 years (350 working days per year) and annual interest rate of 5.42 %. Modifications in the HEN include new exchanger addition and area addition or reduction to existing exchangers. The base-case HEN consumes 67,964 kW of hot utility and 75,051 kW of cold utility.

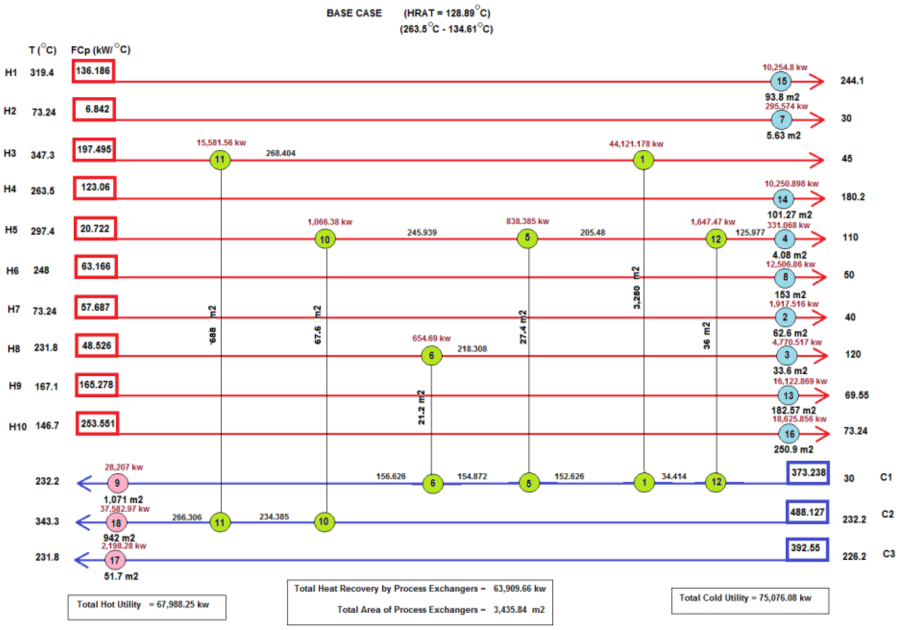


Figure 4: The grid diagram of the base-case HEN from Bagajewicz (2010) with corrected area

For HEN modification the maximum area addition and reduction to existing shells for all exchangers are 10 % and 40% of existing area, respectively, except exchangers No.5 and 12. Exchanger No.5 and 12 with H5-C1 match have maximum area addition and reduction of 20% and 30% of the existing area, respectively. The maximum area per shell is 5,000 m^2. The maximum number of shells per exchanger is 4. The investment cost equations for exchanger modification are shown in equation 1, 2, 3 and 4. A fixed cost for splitting streams is $20,000 per one split.

$$\text{Heat exchanger cost (\$)} = 26,460 + [389 \times \text{Area } (m^2)] \quad (1)$$

$$\text{Area addition cost (\$)} = 13,230 + [389 \times \text{Area}_{\text{added}} (m^2)] \quad (2)$$

$$\text{Area reduction cost (\$)} = 13,230 + [0.5 \times \text{Area}_{\text{reduced}} (m^2)] \quad (3)$$

$$\text{New shell (\$)} = 26,460 + [389 \times \text{Area}_{\text{shell}} (m^2)] \quad (4)$$

The utility cost for HU11, HU12 , CU4, CU5, and CU6 are shown in Table 1. The film coefficients for all streams are shown in Table 2.

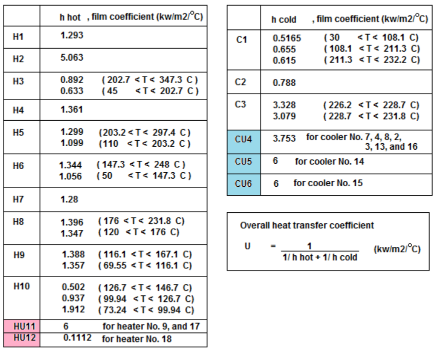
4. Results and Discussion

The VBA targeting program requires data of the existing exchanger area, stream property (flow rate, specific heat capacity, supply and target temperatures), and economic data to estimate the optimal HRAT of 16.48 °C , and optimal retrofit exchanger area of 12,414 m^2 , as shown in Table 3 and Figure 5. The program also calculates the optimal NPV of 11,770,841 $, as shown in Figure 6.

Table 1: Utility cost of hot and cold utilities

Hot/Cold Utility	Cost ($/kj) per year	h, film coefficient (kw/m2/C)	Supply Temperature (C)	Target Temperature(C)
HU11	71.09	6	250	249
HU12	134	0.111	1000	500
CU4	6.713	3.75	20	25
CU5	23.4	6	124	125
CU6	45.9	6	174	175

Table 2: The film coefficient of all streams



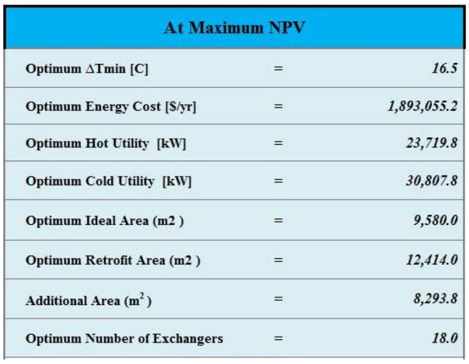
	h hot , film coefficient (kw/m2/°C)
H1	1.293
H2	5.063
H3	0.892 (202.7 < T < 347.3 C) 0.633 (45 < T < 202.7 C)
H4	1.361
H5	1.299 (203.2 < T < 297.4 C) 1.099 (110 < T < 203.2 C)
H6	1.344 (147.3 < T < 248 C) 1.056 (50 < T < 147.3 C)
H7	1.28
H8	1.396 (176 < T < 231.8 C) 1.347 (120 < T < 176 C)
H9	1.388 (116.1 < T < 167.1 C) 1.357 (69.55 < T < 116.1 C)
H10	0.502 (126.7 < T < 146.7 C) 0.937 (99.94 < T < 126.7 C) 1.912 (73.24 < T < 99.94 C)
HU11	6 for heater No. 9, and 17
HU12	0.1112 for heater No. 18

	h cold , film coefficient (kw/m2/°C)
C1	0.5165 (30 < T < 108.1 C) 0.655 (108.1 < T < 211.3 C) 0.615 (211.3 < T < 232.2 C)
C2	0.788
C3	3.328 (226.2 < T < 228.7 C) 3.079 (228.7 < T < 231.8 C)
CU4	3.753 for cooler No. 7, 4, 8, 2, 3, 13, and 16
CU5	6 for cooler No. 14
CU6	6 for cooler No. 15

Overall heat transfer coefficient

$$U = \frac{1}{1/\text{h hot} + 1/\text{h cold}} \quad (\text{kw/m2/}^{\circ}\text{C})$$

Table 3: The retrofit results from targeting program



At Maximum NPV		
Optimum ΔTmin [C]	=	*16.5*
Optimum Energy Cost [$/yr]	=	*1,893,055.2*
Optimum Hot Utility [kW]	=	*23,719.8*
Optimum Cold Utility [kW]	=	*30,807.8*
Optimum Ideal Area (m2)	=	*9,580.0*
Optimum Retrofit Area (m2)	=	*12,414.0*
Additional Area (m^2)	=	*8,293.8*
Optimum Number of Exchangers	=	*18.0*

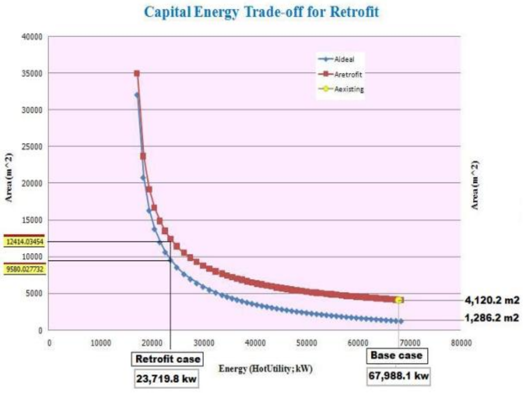


Figure 5: Retrofit curve from targeting program

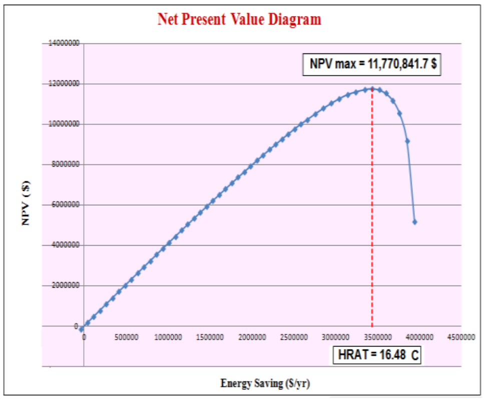


Figure 6: The optimal HRAT from targeting program

At the optimal HRAT of 16.48 °C between hot and cold composite curves, shown in Figure 9, the 10-stage model is applied to design HEN at above and below pinch sections, by keeping the old process exchanger as much as possible. There are three and two alternative designs of HEN at above and below pinch sections, respectively. Therefore, there are six combinations of HEN designs, HEN 1, HEN 2, HEN 3, HEN 4, HEN 5, and HEN 6, as shown in Table 4. The optimal design is HEN 2, as shown in Figure 7, with the maximum NPV of 16,542,682 $.

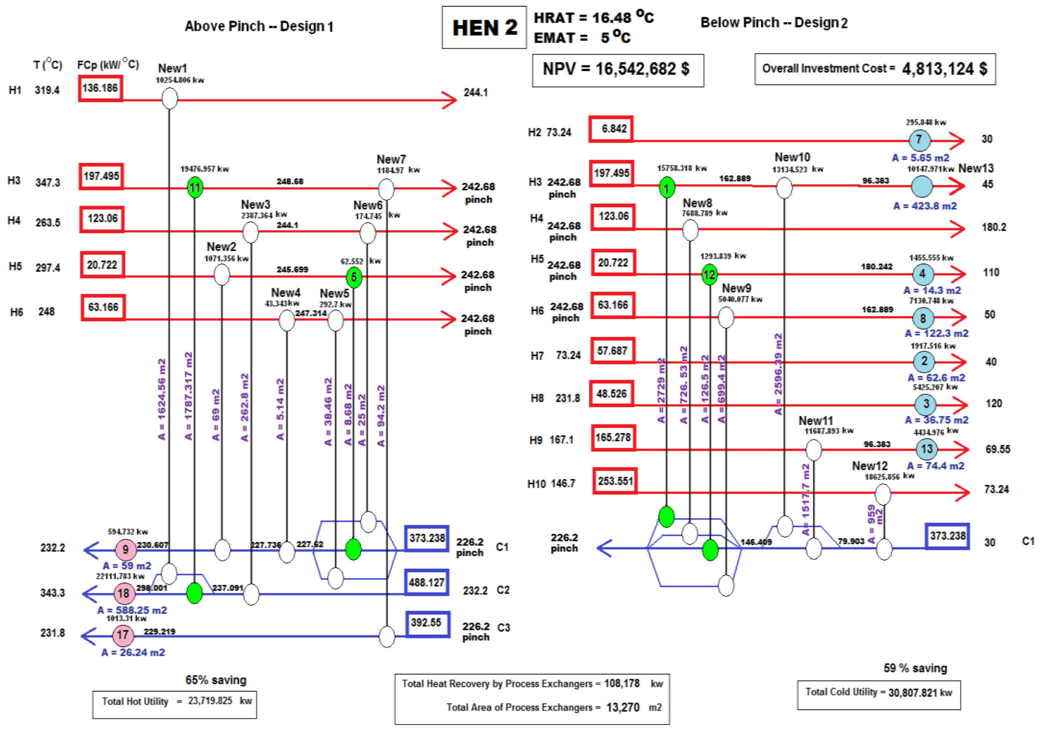


Figure 7: The grid diagram of retrofit case from this study

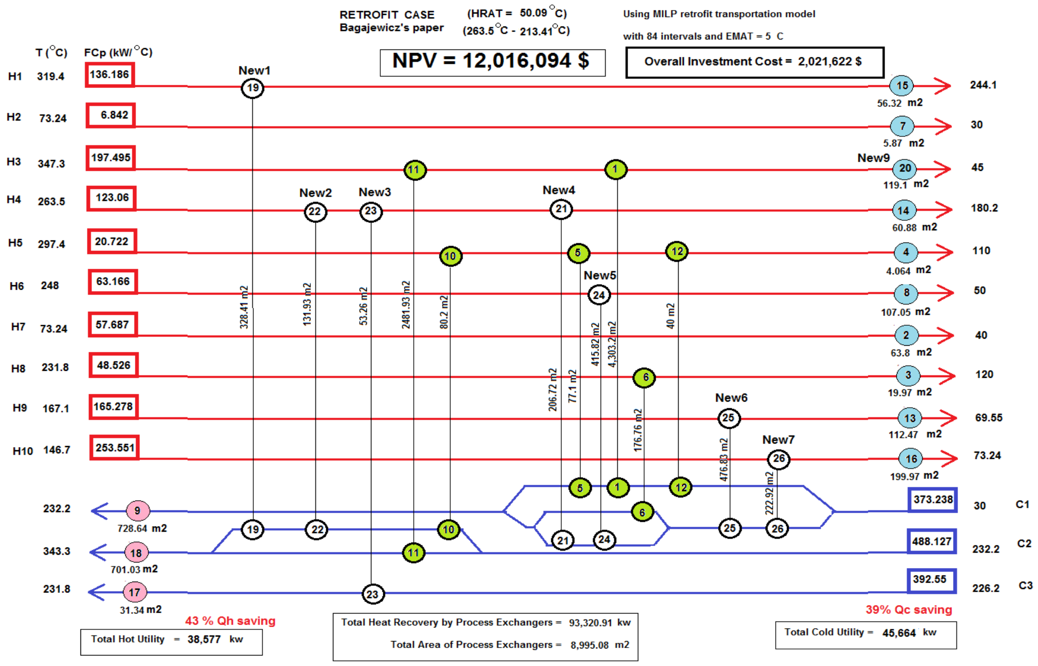


Figure 8: The grid diagram of retrofit case from Bagajewicz (2010)

Table 4: Economic results of six retrofit cases

Retrofit Case	NPV ($)	Total Investment Cost ($)
HEN 1	16,426,458	4,929,348
HEN 2	16,542,682	4,813,124
HEN 3	16,346,907	4,832,211
HEN 4	16,524,172	4,654,947
HEN 5	16,285,810	4,647,451
HEN 6	16,437,549	4,495,712

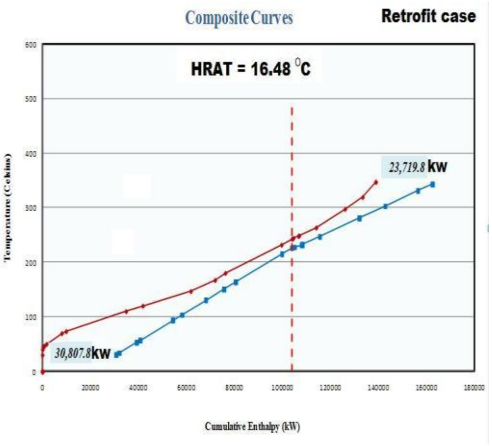


Figure 9: The retrofit-case composite curves

5. Conclusion

The retrofit case from this study, shown in Figure 7, is compared to one from Bagajewicz (2010), shown in Figure 8. Our result gives more NPV, however his work gives less total investment cost in exchanger area and new shell. That is because his work uses all six existing process exchangers while our design uses only four from six existing exchangers. Our VBA targeting program can estimate the optimal HRAT based on retrofit area calculation but the stage model designs HEN without retrofit constraint keeping the old exchangers. For the future work, the retrofit constraints will be added to the stage model, and stream repiping might be occurred in the network.

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References

Tjoe T.N., Linnhoff B., 1986, Using Pinch Technology for Process Retrofit. Chemical Engineering Journal, 28, 47-60.
Yee T.F., Grossmann I.E., 1990, Simultaneous Optimization Models for Heat Integration. Computers and Chemical Engineering,14, 1151.
Nguyen D.Q., Barbaro A., Vipanurat N., Bagajewicz M. J., 2010, All-At-Once and Step-Wise Detailed Retrofit of Heat Exchanger Networks using an MILP Model, Industrial and Engineering Chemistry Research, 49, 6080-6130.
Smith R.,1995, Chemical Process Design, McGraw-Hill, Inc., New York.
Promvitak P., Siemanond K., Bunluesriruang S., Raghareutai V., 2009, Retrofit Design of Heat Exchanger Networks of Crude Oil Distillation Unit, Chemical Engineering Transactions, 18, 99-104, DOI: 10.3303/CET0918014.