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PT09 - A COMPUTER PROGRAM TO INTEGRATION OF INDUSTRIAL UNITS BY PINCH TECHNOLOGY

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ABSTRACT:
According to lack of energy sources and increasing number of consumers, a need to present samples of optimization is felt. Process Integration especially Pinch Technology is a powerful analytical method for identifying and selecting concrete technical solutions to improve efficiencies and provide an optimum manufacturing solution. In this paper a computer program to obtain most of Pinch concepts such as minimum energy requirement, optimum network area, optimum minimum temperature difference and total annual cost is presented. The results record can compete with the existing soft wares. In the paper, the program ability by means of two case studies will be given.
KEYWORDS:
Process Integration, Pinch Technology, Heat exchanger network, Optimization, Energy

1. INTRODUCTION

Energy conservation is important in process design. In industrial experience, the calculation of the minimum heating and cooling requirements reveal significant energy savings. In a global context, it is essential to reduce energy consumption. Industry's share of the total energy consumption is very large, and thus reduction of energy use is highly motivated in this sector. Energy integration design procedure is a very beneficial tool and is an important phase in determining the cost of preliminary design. Chemical plants need efficient management of energy. For this purpose, an optimum integration of supply and removal of heat among the process streams is required. The most important equipment in energy integration is heat exchanger which is widely used in process industries such as gas processing and petrochemical industries, to exchange heat energy among several process streams with different supply temperature. The first step in the energy integration analysis is the calculation of the minimum heating and cooling requirements for a heat exchanger network. In any process flow sheet, there are several streams that need to be heated and there are some that need to be cooled. Based on the heat load, the heat exchanger area is determined. The exchanger is fabricated based on this area. A network of heat exchangers is usually used in a process plant. The task of the synthesis of heat exchanger networks is to find a heat exchanger network which has the minimum total annualized cost of the process. The total cost comprises of the cost of the exchanger units and the cost of utilities. Cost of the exchanger is directly related to the heat exchange area. The cost of hot and cold utilities is based on their unit cost and annual consumption.

There are two laws for heat integration analysis. The first law states that the difference between the heat available in the hot streams and the heat required for the cold streams is the net amount of heat that must be removed or supplied. The second law states that a positive temperature driving force must exist between the hot and the cold streams. For any heat exchanger networks, the second law must be satisfied as well as the first law.

2. PINCH TECHNOLOGY

A large number of applications have been made presented for the design problem of heat recovery networks. Thermodynamic approaches in the form of *Pinch Analysis* have been first introduced in the late 1970s with the idea of setting targets prior to design and were originally developed at the ETH Zurich and Leeds University (Linnhoff and flower 1978; Linnhoff 1979) [1,2]. ICI plc took note of these promising techniques and set up research and applications teams to explore and develop them [2]. Pinch analysis reports significant changes in energy savings and has established a track record of numerous successful applications in the Chemical Process Industries. Schematic workflow of Pinch Approach is shown in figure 1. Pinch analysis embeds initial economics in the early stages of design. Then, it produces rigorous targets for utilities demand. After that it follows a systematic approach to get the final design and compare it to the already established targets. Targets are set for the minimum utility consumption, the minimum heat transfer area of the network, and the minimum number of units. The targets span different driving forces for heat transfer (minimum approach temperature DT_{min}) and include shortcut calculations as available from a conceptual representation of the network. The individual targets are further composed into aggregate, “super” targets that account for the cumulative cost of the heat exchanger network. The minimum cost determines the optimal level of driving forces, DT_{min} [3].

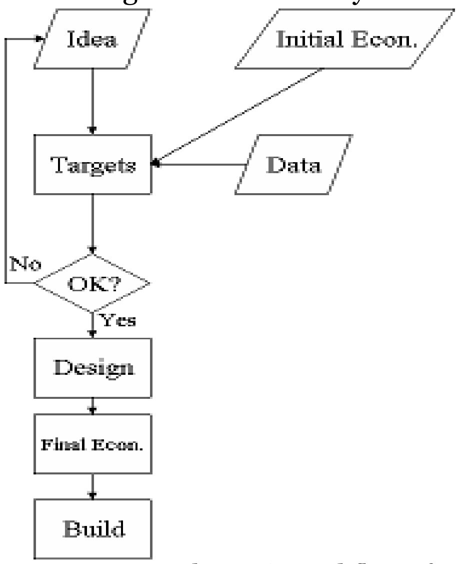

FIGURE 1. Schematic workflow of Pinch Approach

In the present work, by using pinch method, a new computer program (PT09: Pinch Technology 2009) is developed to achieving above targets. The solution was applied to calculation and synthesis of heat exchanger networks and good results were obtained. Also the results compared with SuperTarget™ exit. The program will be useful for companies which are working on optimization of chemical plants or power plants.

2.1. Targets

2.1.1. Minimum Energy Required

In order to start pinch analysis the necessary thermal data must be extracted from the process. This involves the identification of process heating and cooling duties. The assumption in the data extraction flow-sheet is that any process cooling duty is available to match against any heating duty in the process. No existing heat exchanger is assumed unless it is extracted from pinch analysis for specific reasons. Starting from the thermal data for a process, pinch analysis provides a target for the minimum energy consumption. The energy targets are obtained a tool called “Program Table Algorithm”. In this algorithm firstly the program divides the temperature range into intervals and shifts the cold temperature scale, then makes a heat balance in each interval and cascades the heat surplus/deficit through the intervals. Finally it adds heat so that no deficit cascaded. In one point, there is no transfer of energy between intervals. This is called the *pinch point*. Minimum heating/cooling utility is derived from over/below the program table. In this stage, the computer program obtains the pinch point and hot/cold utility of the process. Also it constructs the composite curve (CC) and the grand composite curve (GCC) from analyzing of program table. The CC is the graphic mode of program table and has been used for many years to set energy targets ahead of design. In selecting utilities to be used, determining utility temperatures, and deciding on utility requirements the composite curves and program table algorithm (PTA) are not particularly useful. The introduction of a new tool, GCC, was introduced in 1982 by Itoh, Shiroko and Umeda. The GCC shows the variation of heat supply and demand with in the process.

2.1.2. Area Targeting

The surface area A required for heat exchanger is given by (figure2):

$$A_{Network} = \sum_{k}^{K} \frac{1}{\Delta T_{LMTD}} \left(\sum_{i}^{I} \frac{q_i}{h_i} + \sum_{j}^{J} \frac{q_j}{h_j} \right) \quad (1)$$

A is in m^2, Q is the heat transferred in the exchanger (kW). h (or U) is the overall heat transfer coefficient (kW/m^2K) that is given as a primary data from the user and ΔT_{LMTD} is the log mean temperature difference (K). The composite curve (figure2) can be divided into a set of adjoining enthalpy intervals such that with in each interval, the hot and cold composite curves do not change slope. The hot streams in any enthalpy intervals, at any point, exchanges heat with the cold streams at the temperature vertically below it. This schema of heat transfer is called *vertical heat transfer*. This concept is used in the computer program as a linear regression for the hot and cold curve points that are not as a braking point such as points between A_2,A_3 in figure 2.

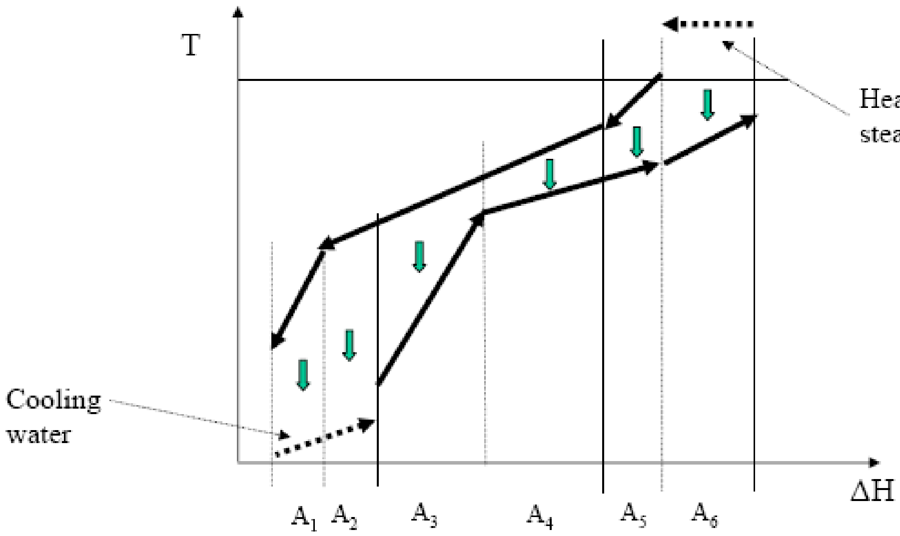

Figure 2. Vertical heat transfer

If we have a pure countercurrent heat exchanger, where the hot stream enters at T_{H1} and leaves at T_{H2}, and the cold stream enters at T_{C1} and exits at T_{C2}, so that T_{C1} and T_{H2} are the *cold end* C and T_{H1} and T_{C2} are at the *hot end* H of the exchanger (figure3), then ΔT_{LMTD} is given by:

$$\Delta T_{LMTD} = \frac{(T_{H1} - T_{C2}) - (T_{H2} - T_{C1})}{\ln \frac{(T_{H1} - T_{C2})}{(T_{H2} - T_{C1})}} \quad (2)$$

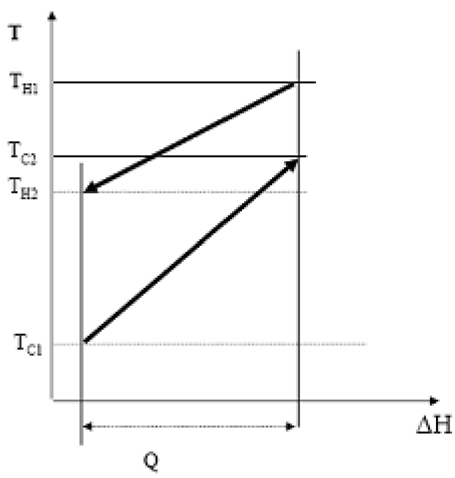

FIGURE3. Inlet/Outlet temperature in a general interval

2.1.3. Number of Units Targeting

The capital cost of chemical processes tends to be dominated by the number of items on the flow sheet. This is certainly true of heat exchanger networks and there is a strong incentive to reduce the number of matches hot and cold streams. For the minimum number of heat exchanger units (N_{min}) required for MER (minimum energy requirement or maximum energy recovery), the heat exchanger network can be evaluated prior to heat exchanger network design by using a simplified form of Euler's graph theorem. In designing for the MER, no heat transfer is allowed across the pinch and so a realistic target for the minimum number of units (N_{minMER}) is the sum of the

$$N_{minMER} = (N_h + N_c + N_u - 1)_{\text{Above the pinch}} + (N_h + N_c + N_u - 1)_{\text{Below the pinch}}$$

$$N_h = \text{Number of hot streams}$$
$$N_c = \text{Number of cold streams} \quad (3)$$
$$N_u = \text{Number of utility streams}$$

targets evaluated both above and below the pinch separately.

2.1.4. Total Annual Cost

The targets for the minimum surface area and the number of units can be combined together with the heat exchanger cost law equation such as equation 4.

$$\text{Capital Cost} = N[a + b(A_{Network}/N)^c] \quad (4)$$

where N is the number of units and a,b,c are constants in exchanger cost law. The capital cost can be super-imposed on the energy cost targets to obtain the minimum total cost target for the network. We must annualize Capital Cost by Annual Factor:

$$\text{Annual Factor} = \frac{i(i+1)^n}{(i+1)^n - 1} \quad (5)$$

where n is the plant life time (year) and i is the rate of interest (%).

2.1.5. Optimal Pinch Temperature Difference (DT_{min})

An optimal pinch approach temperature equation is derived from economic, thermodynamic, and heat transfer formulas as shown in figure 4. The problem is divided into two parts into by the pinch. The functional relations between the heat transfer area, the heat recovery duty, and ΔT_{pinch} are predicted separately above and below the pinch. The optimal pinch approach temperature corresponds to a maximum annual cost saving that is difference between the heat recovery saving and the increase annualized exchanger capital cost [4].

3. RESULTS AND DISCUSSION

Case Study 1. The example is a medium size problem with four process streams and two utilities. The data is shown in Table 1. The results in $DT_{min,\ optimum}$ are compared with SuperTarget™ software exit in Table 2. As it is seen the results difference between this research program (PT09) and SuperTarget™ are slightly.

The Capital cost, Energy cost and the annual cost of the process in various DT_{min} are given in Table 3. The CC and GCC of the process at $DT_{min,\ optimum}$ = 11°C is shown in figure 5 and 6, respectively.

Finally economic trade-off between energy cost and capital cost to give the optimum DT_{min} is shown in figure 7. So we can retrofit an old process

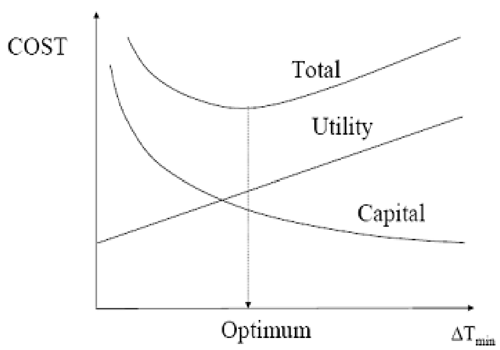

FIGURE 4. The trade-off between energy (utility) and capital cost to give the optimum DT_{min}

unit or design a new one according to economic optimization from PT09 results.

Table 1. Process stream and cost data of case study 1[a,b,c,d] [5]

Stream	FCP (kW/°C)	Tin (°C)	Tout (°C)	h (kW/m^2.°C)
H1	0.3	300	80	0.4
H2	0.45	200	40	0.4
C1	0.4	40	180	0.4
C2	0.6	140	280	0.4
HU		400	399	0.4
CU		10	11	0.4

[a] Optimal DT_{min} = 11 °C

[b] Cost model of heat exchanger ($/year): a + b.Area^c; a = 0; b = 3000, c = 0.5 (Area unit of m^2).

[c] Cost of utilities: HU(steam) = 110.0 $/kW.year; CU (cooling water) = 12.2 $/kW.year.

[d] Economic data : rate of interest (%) = 0.1; Plant life time = 5 years.

Table 2. Comparison of the results at $DT_{min,\ optimum}$ = 11 °C

Software	SuperTarget™ [5]	PT09
ΔTmin	11	11
Hot Utility (KW)	33.25	33.25
Cold Utility (KW)	31.25	31.25
Net. Area (m^2)	25.504	25.5251
No. of units	7	7
Energy cost ($/YR)	4039	4038.75
Capital cost ($/YR)	4008	3998.302
Total annual cost ($/YR)	8047	8037.052

Table 3. The Capital cost, Energy cost and the annual cost of the process in various DT_{min}

ΔTmin	Energy cost ($/YR)	Capital cost ($/YR)	Total annual cost ($/YR)
1	3122.25	6431.427	9553.677
2	3213.9	5775.288	8989.188
3	3305.55	5368.905	8674.455
4	3397.2	5071.543	8468.743
5	3488.85	4836.761	8325.611
6	3580.5	4643.056	8223.556
7	3672.15	4467.917	8140.067
8	3763.8	4336.023	8099.823
9	3855.45	4210.559	8066.009
10	3947.1	4098.802	8045.902
11	4038.75	3998.302	8037.052
12	4130.4	3907.215	8037.615
13	4222.05	3824.119	8046.169
14	4313.7	3747.897	8061.597
15	4405.35	3677.649	8082.999
16	4497	3612.642	8109.642
17	4588.65	3552.271	8140.921
18	4680.3	3496.027	8176.327
19	4771.95	3443.482	8215.432
20	4863.6	3394.271	8257.871

Case Study 2. The problem consists of 4 process streams. The relevant process data are presented in Table 4. The results in $DT_{min,\ optimum}$ are compared with SuperTarget™ software exit in Table 5. We have acceptable results from PT09 in compare SuperTarget™. The CC and GCC of the process at $DT_{min,\ optimum}$ = 2 °C is shown in figure 8 and 9, respectively. And at last, economic trade-off between energy cost and capital cost to give the optimum DT_{min} is given in figure 10. Calculation of the optimal pinch approach temperature in this heat exchanger network will help us to realize an economic trading of network exactly. Also we can decrease the cost designing of a unit easily. The Capital cost, Energy cost and the annual cost of the process in various DT_{min} are shown in Table 6.

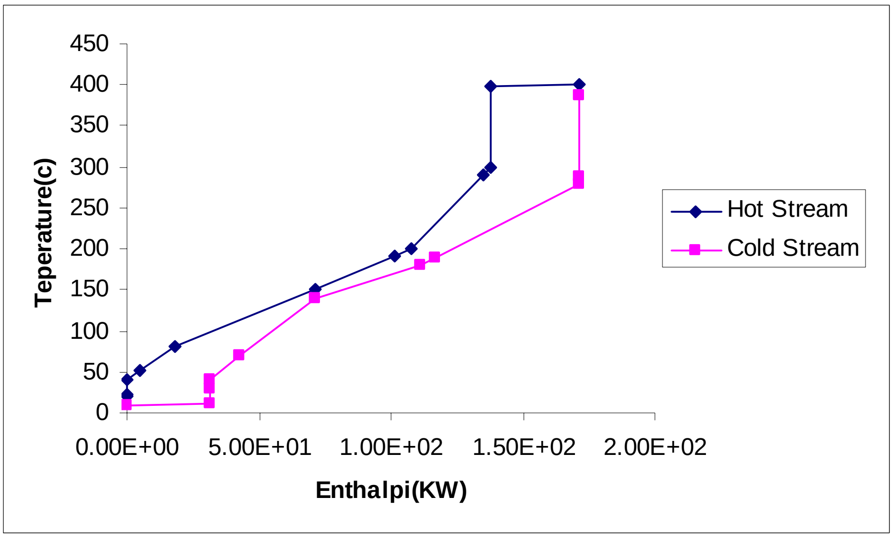

FIGURE 5. Balanced Composite curve at $DT_{min,\ optimum} = 11^{\circ}C$

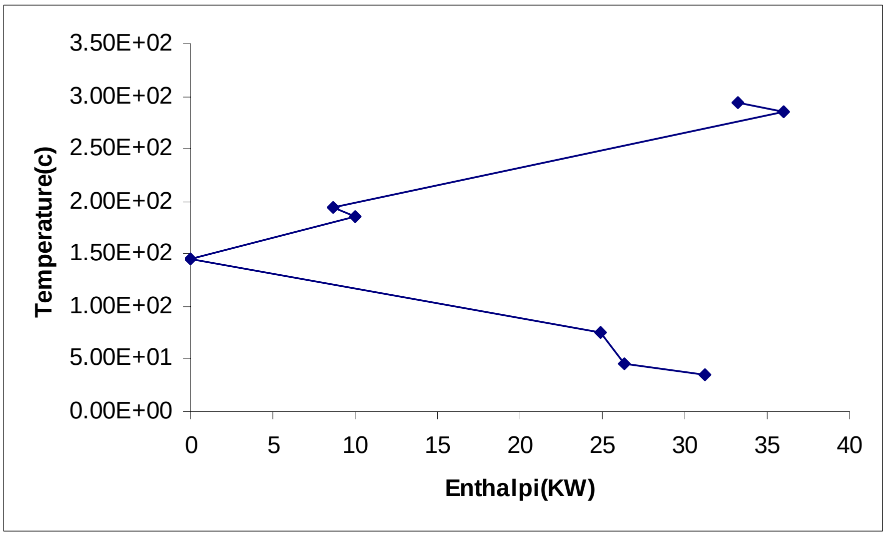

FIGURE 6. Grand Composite curve at $DT_{min,\ optimum} = 11^{\circ}C$

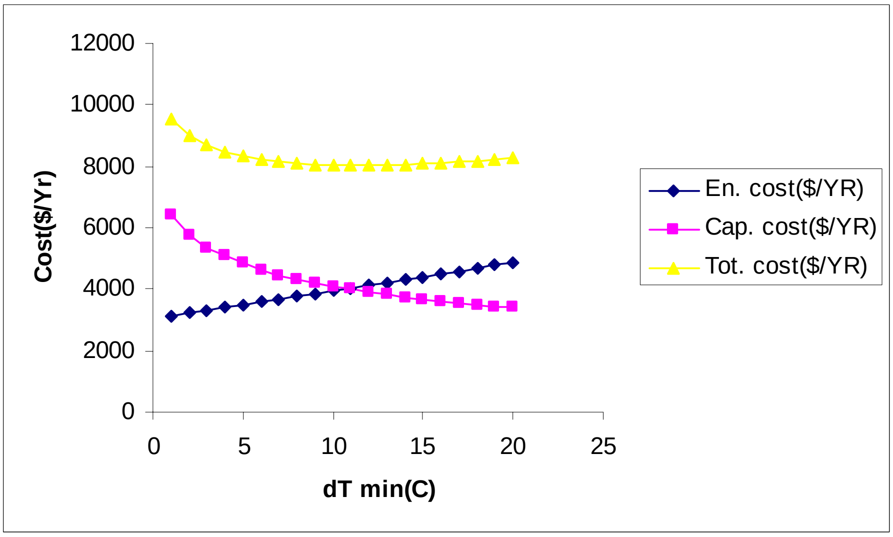

FIGURE 7. Economic trade-off between energy cost and capital cost to give the optimum DT_{min}

Table4. Process stream and cost data of case study $2^{a,b,c,d}$ [5]

Stream	FCP (kW/°C)	Tin (°C)	Tout (°C)	h (kW/m^2.°C)
H1	3	260	160	1.5
H2	1.5	250	130	1.5
C1	2	120	235	1.5
C2	4	180	240	1.5
HU		280	279	1.5
CU		30	80	1.5

[a] Optimal DT_{min} = 2 °C

[b] Cost model of heat exchanger ($/year): a + b.Area^c; a = 0; b = 3000, c = 0.5 (Area unit of m^2).

[c] Cost of utilities: HU(steam) = 110.0 $/kW.year; CU (cooling water) = 12.2 $/kW.year.

[d] Economic data: rate of interest (%) = 0.1; Plant life time = 5 years.

Table5. Comparison of the results at $DT_{min,\ optimum}$ = 2 °C

Software	SuperTarget™ [5]	PT09
ΔTmin	2	2
Hot Utility (KW)	14	14
Cold Utility (KW)	24	24
Net. Area (m^2)	70.576	70.67561
No. of units	7	7
Energy cost ($/YR)	1833	1832.8
Capital cost ($/YR)	6668	6653.14
Total annual cost ($/YR)	8501	8485.94

Table6. The Capital cost, Energy cost and the annual cost of the process in various DT_{min}

ΔTmin	Energy cost ($/YR)	Capital cost ($/YR)	Total annual cost ($/YR)
1	1282.9	7487.178	8770.078
2	1832.8	6653.14	8485.94
3	2382.7	6136.688	8519.388
4	2932.6	5759.435	8692.035
5	3482.5	5462.228	8944.728
6	4032.4	5217.652	9250.052
7	4582.3	5010.555	9592.855
8	5132.2	4831.408	9963.608
9	5682.1	4674.035	10356.135
10	6232	4534.184	10766.184

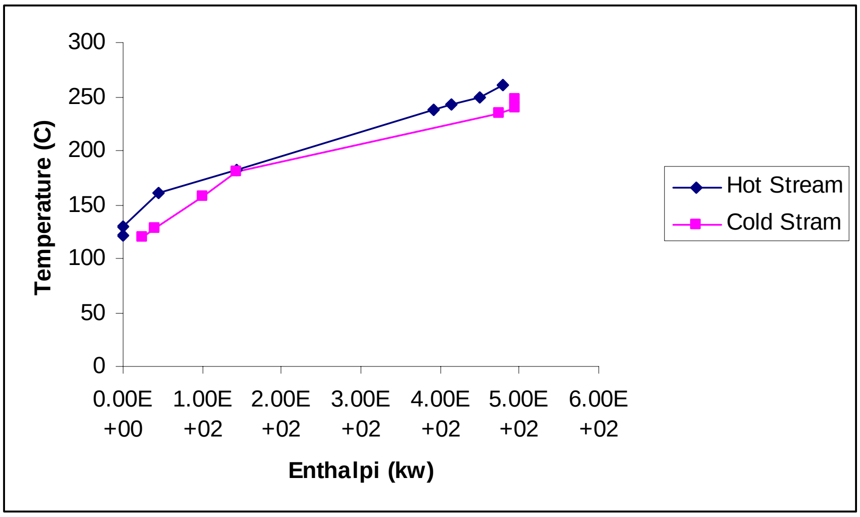

FIGURE 8. Composite curve at $DT_{min,\ optimum}$ = 2°C

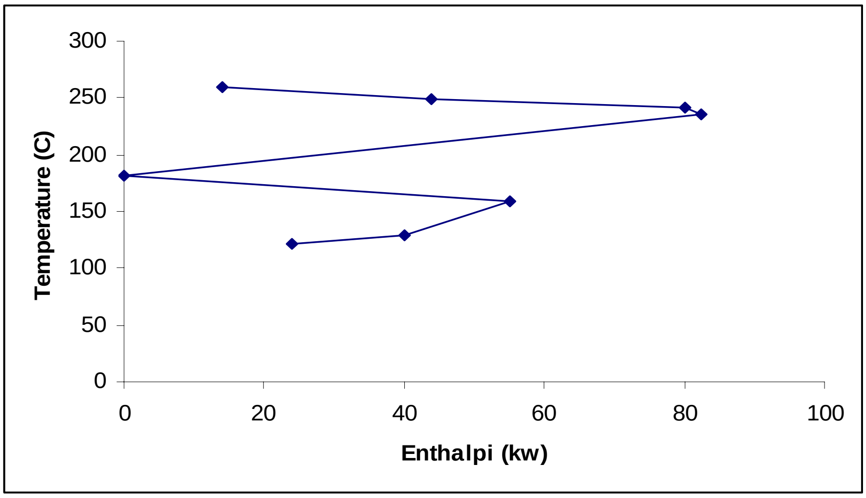

FIGURE 9. Grand Composite curve at $DT_{min,\ optimum} = 2^{\circ}C$

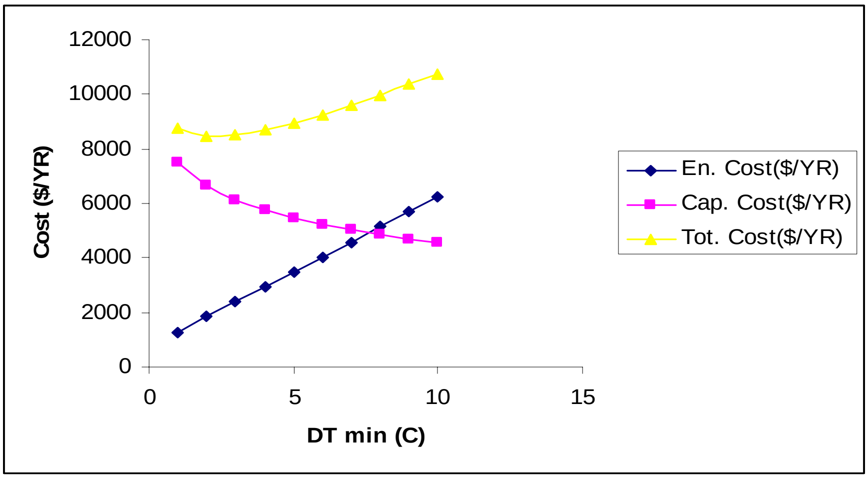

FIGURE 10. Economic trade-off between energy cost and capital cost to give the optimum DT_{min}

4. CONCLUSION

Synthesis of an optimal heat exchanger network with any one of the targets like minimization of utility, the number of exchanger, or the annual cost, to bring each process stream from its inlet to target temperature, is a combinatorial optimization problem. This paper represents an attempt to develop a computer program (that is named PT09) to researchers, student universities and companies that are working on industrial unit optimization and they can't reach to commercial soft wares in Pinch Technology. In two case studies, we obtained all important optimization design target of heat exchanger networks. The results were compared with SuperTarget™ exit. As it was seen, the difference results of two soft wares were acceptable. So we can use PT09 for different plants in different condition, successfully.

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