DEVELOPMENT OF A SYSTEMATIC TECHNIQUE FOR SIMULTANEOUS REDUCTION OF ENERGY AND WATER IN CHEMICAL PROCESS PLANTS

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ABSTRACT

Water and energy are the two main operating costs in a chemical process plant. With the increase in water and fuel prices, chemical process industries are under pressure to improve their profit margin or face possible closure of plants. Pinch and exergy analyses are techniques that have been used widely for plant energy and water consumption analysis. Pinch Analysis is an energy optimisation tool that can present system information by the use simple diagrams like the Composite Curves and Grand Composite Curves, and thus, provide energy consumption targets prior to design. Exergy analysis, also known as availability analysis is a powerful thermodynamics analysis tool that can provide a quick assessment of the energy efficiency of selected equipment and processes. Both approaches have been widely used as separate tools for improving chemical processes, but have key disadvantages that can hamper practical implementation of the project. In this paper, a novel, simple and systematic approach for simultaneous reduction of water and energy in the chemical process industries is presented. This new approach for the retrofit of existing process heat recovery system is focused, and requires significantly less diagnosis effort. The procedure is also easy to use and designer is in control during process retrofit. The equipment causing the highest energy and water losses will be identified in order to reduce the utility consumption. Economic analysis will be conducted to assess the benefits of the improvement.

Keywords: Pinch and Exergy Analysis, Heat Exchanger Network. Exergetic Efficiency. Retrofit.

INTRODUCTION

The past two years (1999-2000), it has been a particularly difficult time for the chemical process industries due to the increase in the cost of fuel and water. The crude oil price had increased from the USD 25 to USD 35 per barrel. The situation became worse when the local authorities announced the significant increment in the tariff for process water and natural gas. In order to maintain the profit margin of a company, it became necessary to look for opportunities to reduce a plant's operating costs. One effective way to reduce the operating cost would be to reduce its utility consumption through the efficient utilisation of energy. This can be achieved through the optimal design and improvement of heat recovery network.

The problem of designing optimal heat exchanger system was first investigated in the mid 1960s. In the effort to optimise the heat exchanger network (HEN), several work has been reported (Nishida, 1977, Linhoff and Flower, 1978). Approaches of mathematical programming (Grossmann, 1977), heat availability diagram (Umeda et. al, 1978) and problem table analysis (Linhoff et. al., 1985) have been used for HEN design. In the 1980s, encouraging results were reported by researchers who attested the effectiveness of the method in solving industrial HEN problems for both new designs and retrofit cases. Linhoff claimed that significant improvement had been achieved, with savings up to 90% energy and 25% capital (Zainuddin and Foo, 2000).

The major limitation of Pinch Analysis is found to be that it can only deal with heat transfer process. It cannot apply for the processes involving changes in pressure or compositions, which are quite common in power plants and chemical processes (Zhu and Feng, 1996). Pinch analysis also is unable to provide a quick assessment of the efficiency of selected equipment or processes (Zainuddin and Foo, 2000). Meanwhile, exergy analysis has the ability to identify the major causes of thermodynamic imperfections of thermal and chemical processes and thus promising scope for improvement can be determined effectively. However, exergy analysis cannot provide solutions to correct the inefficiency (Zhu and Feng, 1996).

In this paper, a novel procedure is developed for simultaneous reduction of energy and process water usage for the chemical process industries. The exergy analysis is first conducted and represented in the new exergy diagram. Later, this diagram will provide the information to diagnose the potential of revamp of the existing heat exchanger network in order to improve the efficient use of energy and water of the network. A case study for a petrochemical complex is used to demonstrate the advantages of the new method over the Pinch Design Method (PDM). A simple economic analysis is conducted to compare the performance of the two methods.

METHODOLOGY

The procedure for the new method can be summarised into the flow chart as shown below:

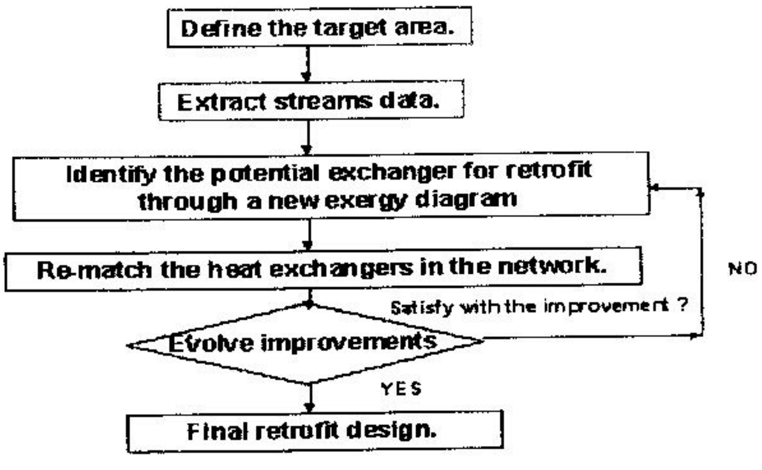

Figure 1: Flow Chart of the Exergy Blocks Diagram Procedure.

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As illustrated in Figure 1, first, one should define the target area for retrofit. Normally, the plant owner would like to invest less in capital but gain much saving through the reduction of utility costs. Therefore, the target area for retrofit will focus on the potential area for heat integration with minimal hardware modifications to the plant. Next, the necessary data must be extracted from the process. These data includes stream type (e.g. hot/cold stream), supply temperature (Ts), target temperature (Tt) and duty (heat load) of the exchangers. Then, the data is presented in a newly developed exergy diagram. A θ (*tita*) versus temperature graph is plotted. θ will be the exergy of the particular stream divided by the temperature difference of the same stream. Exchangers will be matched according to the rules proposed in this paper in order to match the quality of the source to the quality demanded by the task (sink). Further improvement can be made to achieve higher exergetic efficiency before coming to the final retrofit design.

The case study in this paper (Linnhof et. al., 1985) is related to a crude oil fractionation facility, need to be upgraded to handle increase demand. The initial retrofit design was performed by a contractor. It was suggested that it was impossible to increase the throughput without installing a new-fired heater with a 13.9 MW duty. The comparisons between the base case, retrofit design using PDM, and that using this method is discussed.

The first step is to determine the target area. The target area is defined according to the specific needs and conditions of the plant. Since it is undesirable for the plant to implement a new heater, the target area should then focus on the area where the new heater is proposed, the downstream process and the affected utility section. This is to ensure any changes of the exchanger will bring only minimal effect to the upstream process as shown in Figure 1. The thermal data was then extracted from the grid diagram in Figure 2 and information needed for the exergy diagram was calculated as tabulated in Table 1.The exergy blocks diagram was plotted as illustrated in Figure 3.

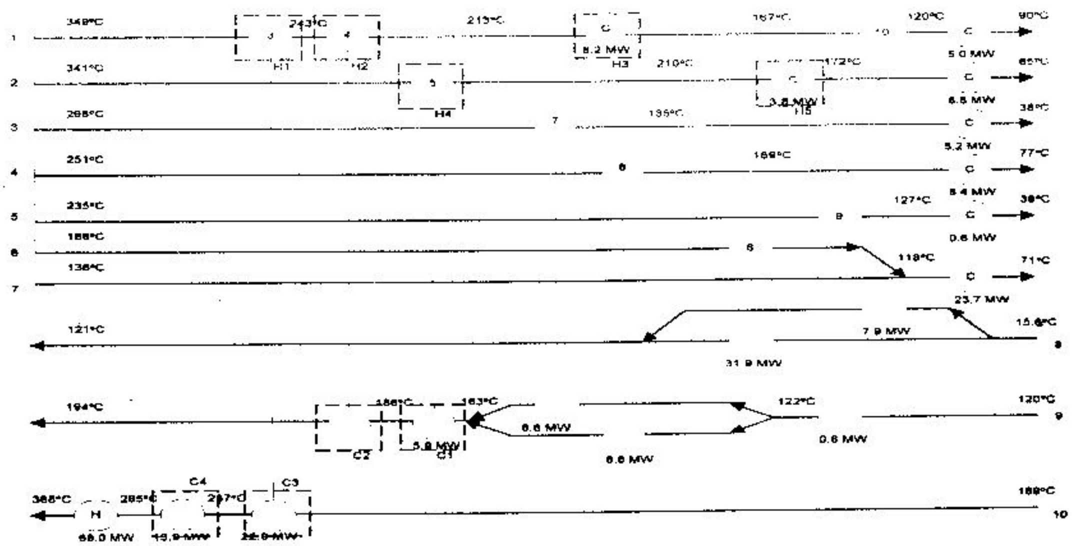

Figure 2: Cold Blocks and Hot Blocks of the Case Study.

The matching process starts with C4 (the major concern in this case study). Since only one hot block fits the requirements, C4-H1. When H1 is being matched with C4, we eliminate H1 from the "possibility list" of

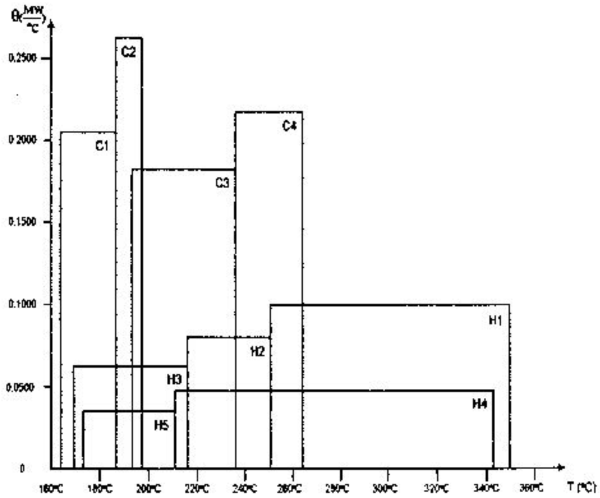

Figure 3: The Exergy Blocks Diagram (EBD) of the case study.

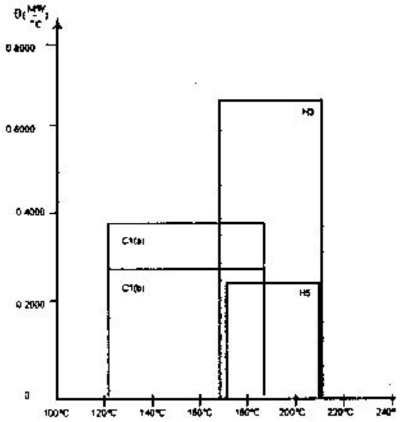

Figure 4: Exergy Diagram Shows Stream Splitting of Cold Block C1.

matching with C1, C2 and C3. For C3, the match selection is done according to a "tick-off" heuristic, where C3 is matched with H4, the largest heat source. We then filter out H4 from matching with the remaining cold blocks. Only H2 is left to match with C2, so we choose C2-H2 match. Finally, C1 is left to be matched with H3 or H5.

However, a thermodynamically feasible C1-H5 match cannot be obtained without stream splitting. Therefore, stream split technique is introduced and the C1 block is split into two portions of C1a (8.2 MW) and C1b (5.6 MW). C1 can be matched easily with H3 and H5.

Table 1: Selection of Cold-Hot Block Match.

Cold Block/ Heat Load(MW)	Hot block / Heat Load(MW)				
C1 (13.8)	H1 (22.9)	H2 (5.9)	H3 (8.2)	H4 (13.8)	H5 (3.8)
C2 (5.9)	H1 (22.9)	H2 (5.9)		H4 (13.8)	
C3 (22.9)	H1 (22.9)	H2 (5.9)		H4 (13.8)	
C4 (13.9)	H1 (22.9)				

RESULTS AND DISCUSSIONS

From Table 2 and Table 3, one will have the impression that PDM still provides the best option for the retrofit design. However, an analysis of the grid diagram in Figure 5 and Figure 6 clearly shows that design using the new method proposed involves less stream split while yielding results comparable to the one claimed by Pinch Design Method.

Table 2: Comparison of UA Values

Match	Contractor Design(Base Case)	4 way split (Pinch Design Method)		4 way split (Exergy Blocks Diagram)	
	UA (MW/K)	UA (MW/K)	UA Increment (MW/K)	UA (MW/K)	UA Increment (MW/K)
N1	-----	0.332 (New)	0.332	0.256 (New but reuse HX 3)	0.1847
N2	-----	-----	-----	0.220 (New)	0.220
3	0.288	0.337 (Mod.)	0.049	0.217	-----
4	0.159	0.412 (Mod.)	0.253	0.393 (Mod.)	0.233
5	0.152	0.147	-----	0.245 (Mod.)	0.093
6	0.462	0.462	-----	0.462	-----
7	0.196	0.198 (Mod.)	0.002	0.230 (Mod.)	0.034
8	0.132	0.241 (Mod.)	0.109	0.155 (Mod.)	0.023
9	0.022	0.022	-----	0.022	-----
10	0.111	0.111	-----	0.111	------
Total	1.522	1.930	0.413	2.055	0.603

By examining Table 3, we will notice the estimated capital cost of this work is only 5.6 % and cold utility consumption is 0.6 % higher than the PDM design. We must however bear in mind the investment does not cover the re-piping cost for splitting streams 9 and 10.

Table 3: The Marginal UA values and Capital Costs

	Additional UA (MW/K)	Capital Cost ($\le$)	Hot Utility (MW)	Cold Utility (MW)	Hot Utility Savings (%)	Cold Utility Savings (%)
Base Case	-----	-----	81.9	63.7	-----	-----
4 way split (Pinch Design Method)	0.745	77107.5	68.0	49.8	17.0	21.8
4 way split (Exergy Blocks Diagram)	0.787	81454.5	68.0	49.4	17.0	22.4

EBD and PDM both come to the conclusion of 4-way split at stream 9 as shown in Figure 5 and 6. However, EBD provides a cheaper way to retrofit comparatively because it does not involve repiping work for stream 10 (i.e. no stream split at stream 10). For the control issue, the retrofit design produced by using EBD is less constraint in the sense of control because it involves less stream splitting.

CONCLUSIONS

A new method for the simultaneous reduction of energy and process water consumption has been developed. To date, this is the only *retrofit* method with a graphical exergy analysis representation. In this paper, it has been shown that the new method is quick and simple to use for retrofit purposes. With significantly less effort,the method is capable of producing optimal solution for retrofit that is comparable to conventional Pinch Design Method.

Furthermore, the method allows a designer to be in complete control during retrofit. The procedure is much simpler and easier to understand as designers can apply this method without the knowledge of PDM. It has been proven that the method results in a retrofit design with less complex modifications compared to PDM, for example, by avoiding unnecessary stream splits.

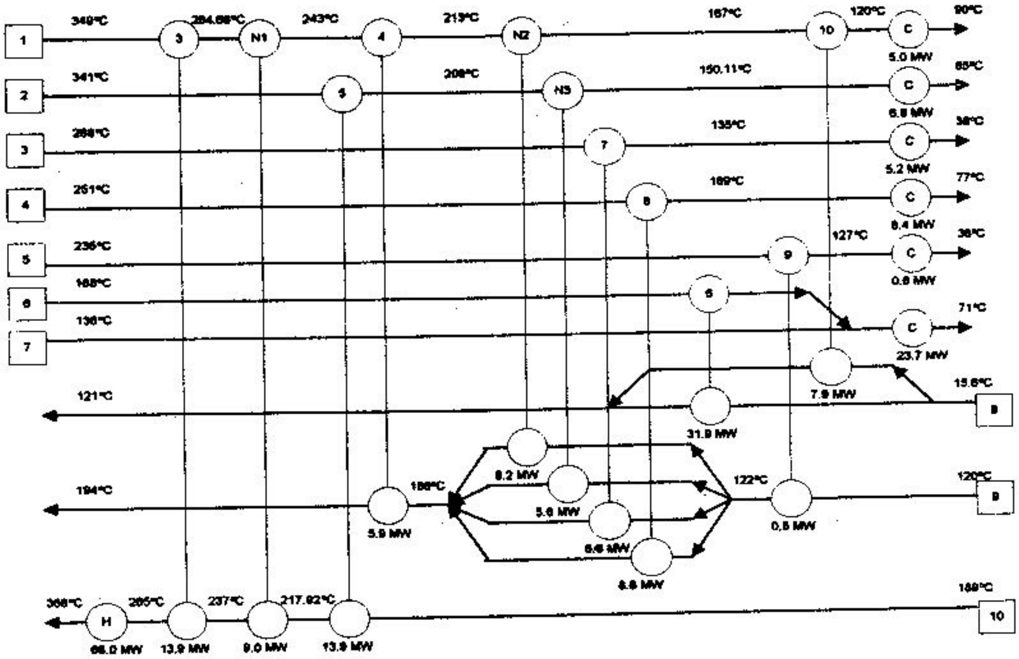

Figure 5: Retrofit Design Using the Exergy Blocks Diagram.

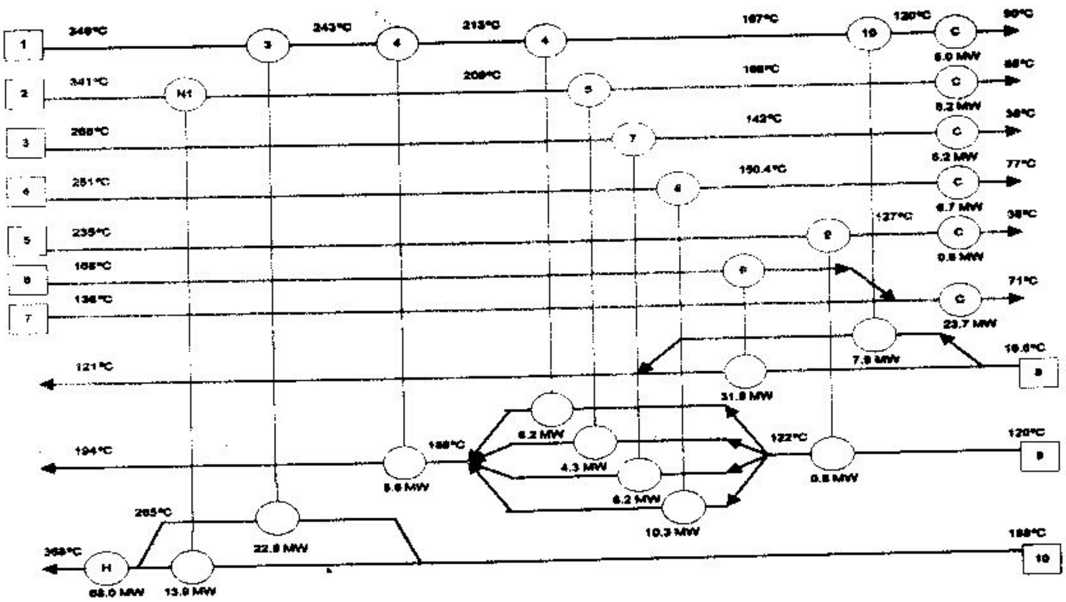

Figure 6: Retrofit Design Using the Pinch Design Method.

NOTATION

A	Area (m^2)
Cp	Specific heat capacity (J/Kg.K)
Ts	Supply temperature (°C),
Tt	Target temperature (°C)
Q	Heat load or heat duty (MW)
θ	Exergertic Factor (MW/°C)
C	Capital Cost (≤)

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REFERENCE

1. B. Linnhoff,. and G.T. Polley, Stepping beyond the pinch., The Chemical Engineer, February, 25-31, (1988).
2. X. Feng. and X.X, Zhu, Combining pinch and exergy analysis for process modifications, Applied Thermal Engineering,. July, 249-261, (1996).
3. B Linhoff, and E.Hindmarsh, The pinch design method for heat exchanger networks, Chemical Engineering Science, Vol. 38, No.5, 745-763 (1983).
4. Zainuddin Manan, Combining pinch and exergy analysis for process improvement- A cases study on an aromatics complex, Proceedings of 14th Symposium of Malaysian Chemical Engineers, Putrajaya, Malaysia, Oct. 30-31, (2000).
5. B Linnhoff,, Townsend, D.W., Boland, D. and et. al, A user guide on process integration for the efficient use of energy, Rugby, The Institution of Chemical Engineers, (1985).
6. I.E. Grossmann and R.W. H. Sargent, Optimum design of heat exchanger network, Computer and Chemical Engineering, Vol. 2, 1-7 (1978).
7. N. Nishida, Y.A. Liu and L. Lapidus, Studies in chemical process design and synthesis III: A simple and practical approach to the optimal synthesis of heat exchanger networks. AIChE J Vol. 24, 77-93. (1977).
8. B Linhoff, and J. R. Flower, Synthesis of heat exchanger networks I Systematic generation of energy optimal networks, II. Evolutionary generation of networks with various criteria of optimality, AIChE J., 24, 634-654 (1978).
9. J. Van Reisent, P.J.T. Verheijen and G.T. Polley, Potential Benefits of Using Compact Multi-stream heat exchangeers in integrated process plant, 1st International Conference on Process Intensification for the Chemical Industry, Antwerp, Belgium, 83-93, 6-8 Dec, (1995).