Retrofit of Heat Exchanger Network in a Paper Making Industry

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Abstract

A retrofit design procedure based on conventional Pinch Analysis was used to investigate the economic potential of retrofitting an air heating system for a paper making industry. The retrofit design procedure includes targeting and design stages. The results show that significant energy reduction can be achieved with some modifications on the existing heat recovery system. Three economically feasible alternative heat exchanger networks (HEN) were identified successfully using Pinch Analysis. Economic analysis was performed to assess the benefits of the retrofitted HEN.

Keywords:

Paper making industry, Energy system, Heat exchanger network, Retrofit design

Introduction

Rising oil prices, as well as the potential crude oil depletion have necessitated the improvement of energy management strategy beyond good housekeeping of processes and operations. Since energy constitutes approximately 25% of the overall manufacturing cost, the need for improvement on paper mill energy system becomes essential for further cost reduction [1].

Over the past few decades, many analysis tools have been developed to assist and improve the management of energy system for process plants. Pinch Analysis has been widely accepted as a powerful tool for analyzing the potential of exchanging and recovering energy in process plants including papermaking industry [1-5]. Pinch Analysis was first developed in 1970s for the optimal design of heat exchanger network (HEN). One of the key features is the use of graphical representations of the energy flows for the overall process and utility streams. The minimum amount of energy that is used to satisfy a specific processing requirement can be determined by using this approach. The Pinch Analysis can be used for grassroots design as well as retrofit purposes.

In this paper, conventional Pinch Analysis is used to retrofit the air heating system in a paper making industry. An economically feasible HEN was produced by implementing Pinch Analysis technique which involves utility targeting and network design.

Methodology

A Pinch retrofit design procedure was applied in this work [6]. In particular, the targeting prior to design was maintained. The first step in this procedure is to represent the existing HEN by using a grid diagram. The pinch location is fixed by the value of ΔT_{min} determined during retrofit targeting. The second step is to remove the exchangers, which transfer energy across the pinch temperature and cause the energy target to be exceeded. The third step is to design the network by using "Pinch Design Method". The philosophy of the Pinch Design Method is to start the design at the pinch and move away. In order to produce a minimum utility design, it is advised not to use cold utilities above the pinch temperature and not to use hot utilities below the pinch temperature.

The retrofit approach addresses most of the possible modifications available to an existing HEN as it accounts for the installation of new units, purchase of heat exchangers, reassignment of existing matches, as well as the modifications on the existing heat transfer area. The designer should fully utilise the existing exchangers and avoid any modifications as far as possible.

Case Study

Process Description: Air heating system

The purpose of the air heating system in this paper mill is to supply hot dry air required for the drying process and to remove the moist air that is produced during sheet drying within the dryer hood enclosure. The air heating system consists of a dryer hood and three hood air supply systems. In addition, there is a heat recovery unit for each hood air supply system and a turbair heat recovery unit for the air heating system. Atmospheric air is draw into the hood air supply systems where they are filtered and heated to 60 °C by dryer hood exhaust air. The atmospheric air is further heated up to 110 °C by the heat exchangers. The heat exchangers accomplish the heating took by using the recovered heat from condensate leaving dryer cylinders and, 5 bara make-up steam. The turbair heat recovery unit heats the atmospheric air by using blower air removed from the press section in the paper making process. The heated air is added to the hood air supply lines to further heat up the incoming atmospheric air. In order to supply heated air for the press pan process, atmospheric air is also drawn and heated by low-pressure steam. Figure 1 shows the simplified flow diagram of an existing air heating network system.

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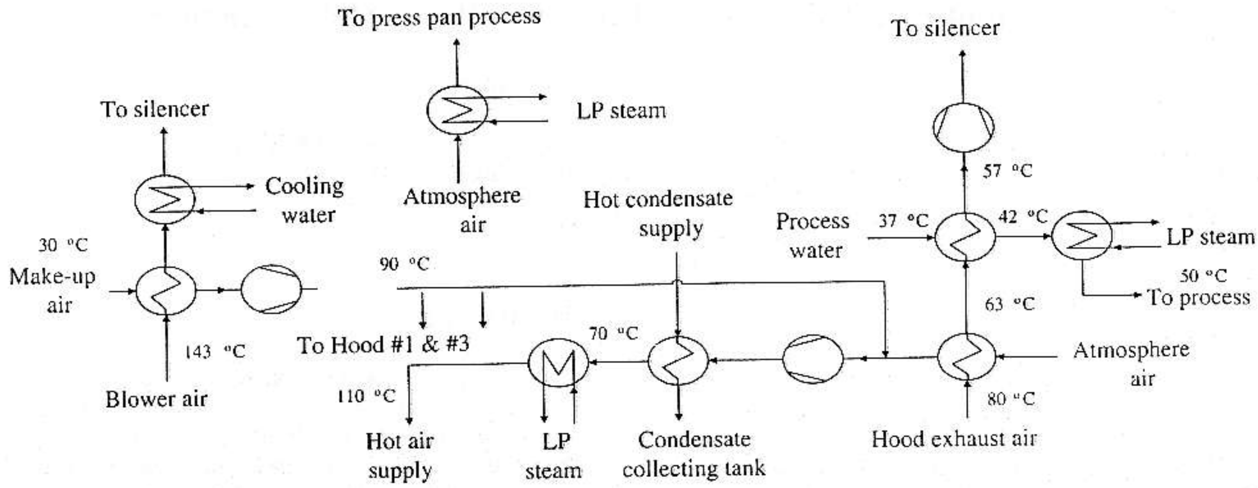

Figure 1 - Simplified Flow diagram of the Existing Air Heating Network System.

Existing HEN

There are 9 hot process streams and 12 cold process streams for the entire air heating system. Table 1 shows the stream data for the entire air heating system. Figure 2 shows the representation of the system in a HEN grid diagram. The existing HEN is analysed using pinch analysis. Note that the existing hot utility is 4.05 MW, and the cold utility is 1.11MW for the air heating system.

Targets for maximum energy recovery

At the targeting stage, targets for this maximum energy recovery were determined by constructing the Problem Table analysis [7]. Using the existing HEN data and ΔT_{min} = 10°C, the analysis gave the following results:

$Q_{H,min}$ = 2.93 MW

$Q_{C,min}$ = 0 MW

Pinch temperature = 35 °C

Hot pinch temperature = 40 °C

Cold pinch temperature = 30 °C

Table 1-Process Stream Data for Potential Heat Exchange.

Name	Stream No.	Ts (°C)	Tt (°C)	FCp (MW/°C)	Q (MW)
Hood exhaust air	H1	80	57	0.12	2.71
Blower air	H2	143	50	0.03	2.55
Hot condensate	H3	93	44	0.01	0.61
Atmospheric air	C4	30	110	0.06	4.59
Make-up air	C5	30	90	0.02	1.44
Cooling water	C6	38	50	0.21	2.51
Press pan air	C7	30	110	0.003	0.27

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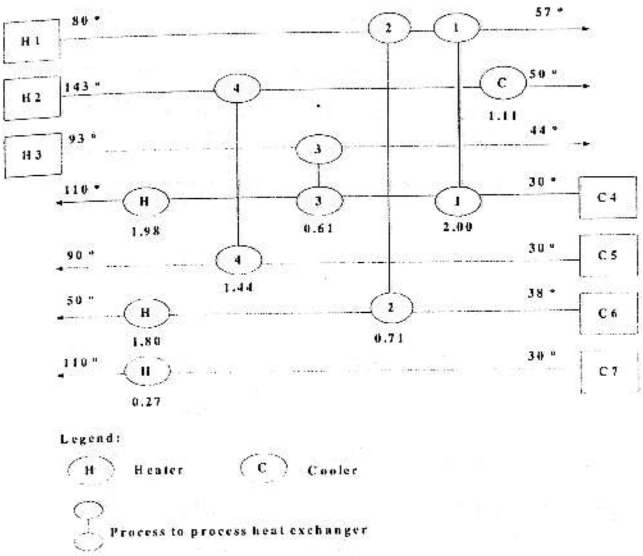

Figure 2- The Grid Diagram of the Existing Air Heating Network System.

Analysis of existing HEN

In order to achieve the targets for maximum energy recovery, the existing HEN is analysed. Figure 3 (a) shows a T/H plot and Figure 3(b) shows a grid diagram of Match 3 for the existing air heating network system. The match mentioned is referred to process-to-process heat exchanger for stream H3 and C4. Note that current ΔT in the exchanger is less than ΔT_{min} at its hot end. The exchanger is clearly infeasible and it gives an opportunity of modification for a feasible streams matching.

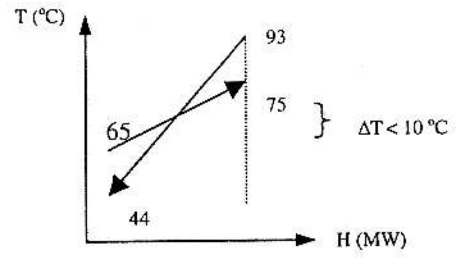

Figure 3(a):Temperature vs enthalpy plot for Match 3.

According to Pinch Design Method, FCp $_{hot}$ must be less than or equal to FCp $_{cold}$ for network above the pinch temperature [7]. It is note that the Match 4 violates the criterion. FCp of H2 is higher than FCp of C5. The current hot utility is 4.05 MW representing a 38 % of excess energy usage if comparing with the targeted minimum hot utility of 2.93 MW. In addition, the current cold utility is 1.11 MW representing a 100% of excess energy usage if comparing with the targeted minimum cold utility of 0 MW.

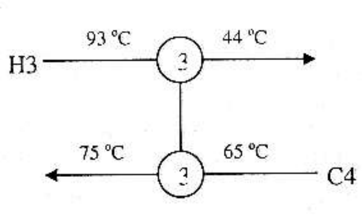

Figure 3(b) Grid diagram showing Match 3.

Design evolution

After the targeting stage, a few HEN alternatives were identified in order to achieve the best energy recovery targets. The philosophy of maximising the reuse of existing heat exchanger (HE) and minimising modifications were applied. The modifications included re-piping and addition of new heat exchangers. Since the overall process existed above the pinch temperature, effort of searching for changes, which would increase energy saving by shifting streams from below to above the network pinch, were not carried out.

The three alternative schemes identified through the Pinch Design Method are described next. All modifications of process-to-process heat exchanger matches are referred to the grid diagram of the existing air heating network system in Figure 2.

Alternative 1

- Re-piping modifications are applied to Match 1, 2, 3, and 4. For Match 1, H1 is integrated with C6. As for Match 2, H1 is integrated with C4. In addition, for Match 3, H2 is integrated with C5 and for Match 4, H3 is integrated with C4.
- Existing cooler duty is eliminated from the design to achieve the minimum cold utility target. No cooler is added.
- Two existing heaters for C4 and C7 are maintained with reduction of duty. Heater for C6 is eliminated followed by an addition of a heater for C5.

Alternative 2

- Matches 1 and 2 are maintained. Re-piping modifications are considered for Matches 3 and 4. Additional heat exchanger is added between H2 and H4 with a heat load of 1.11 MW and named as Match 5.
- Existing cooler is eliminated from this design to achieve the minimum cold utility target. No cooler is added.
- Three existing heaters for C4, C6, and C7 are maintained with changes of duty to achieve the energy target. The changes of duty for heaters can be achieved by adding or reducing heat transfer area of heaters.

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Alternative 3

- Match 3 is maintained. Re-piping modification is considered for match 1, 2, and 4. Duty of heat exchangers 1 and 2 is remained with re-piping modifications. H1 is integrated with C5 for Match 1 and H1 is then integrated with C6 for Match 2.
- Existing cooler duty is eliminated from this design to achieve the minimum cold utility target.
- Three existing heaters for C4, C6, and C7 are maintained with changes of duty to achieve the energy target. A new heater is added to C5.

The next step is to make a crude evaluation of all the alternatives produced, comparing them to the base case. At this stage, ΔT_{min} is abandoned and the effect of the network changes on the individual units is assessed. This is most simply done by "UA-analysis". By applying the equation $UA = Q/\Delta T_{LM}$ to each unit, the effect of network changes on the total area of each unit is assessed, on the assumption that U remains constant. Results for the UA-analysis of the existing HEN and of the synthesized alternatives are shown in Table 2.

It can be seen that Alternative 3 pays a heavy penalty in terms of additional area and number of matches in need for modification. It was also noted that only the total UA value of Alternative 1 was smaller than UA of the existing design. Next, economic analysis is conducted to identify and determine the most promising alternative.

Table 2- Comparison of UA ($Q/\Delta T_{LM}$) values in (MW/°C).

Match	Existing Design	Alternative 1	Alternative 2	Alternative 3
1	0.035	0.108	0.035	0.062
2	0.087	0.042	0.087	0.070
3	*	0.028	0.026	0.021
4	0.025	0.064	0.058	0.095
5	-	-	0.024	-
Heater 1	0.057	0.054	0.057	0.0572
Heater 2	0.209	-	0.212	0.213
Heater 3	0.003	0.003	0.003	0.003
Heater 4	-	0.028	0.024	0.024
Total UA	0.418	0.327	0.527	0.546

* Heat exchange with infeasible heat transfer

Economic analysis

Economic analysis was performed for each alternatives including utility and investment cost. Utility costs were calculated using the internal plant cost data. Table 3 shows the utility costs comparison for grassroots (base case) air heating system without HEN, existing HEN and retrofitted HEN (using Pinch Analysis).

The assumptions used during the economic analysis included:

- The investment cost considered only the cost of extra area required to achieve the energy recovery target. No piping or other costs were considered.
- For the existing network, the area was calculated for a counter-current shell and tube heat exchanger.

The investment cost is estimated as updated bare module cost [8]. Total utility cost is comprised of hot and cold utility costs. A simple payback period calculation has been done to compare the performance of the proposed alternatives. It is estimated by dividing the investment cost with the total utility saving per year. Table 4 shows that Alternative 2 gives the shortest payback period due to the least modification and new heat exchanger addition to the existing HEN.

Table 3- Utility Costs for the Base Case, the Existing HEN and the Retrofitted HEN for Air Heating Network

	Base Case	Existing HEN	Retrofitted HEN
Hot utility (MW)	8.81	4.05	2.94
Cost of hot utility (RM/yr)	3,807,281	1,750,226	1,270,534
Saving of hot utility (RM/yr)	0	2,057,055	2,536,747
% hot utility savings	0	54	66
	Base Case	**Existing HEN**	**Retrofitted HEN**
Cold utility (MW)	5.87	1.11	0
Cost of cold utility (RM/yr)	176,405	30,584	0
Saving of cold utility (RM/yr)	0	145,821	176,405
% cold utility savings	0	81	100

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Table 4 - Economic Analysis and Payback Period for the Proposed Alternatives.

	Alternative 1	Alternative 2	Alternative 3
Total utility saving (RM/yr)	2,713,000	2,713,000	2,713,000
Investment Cost (RM)	7,155,000	5,174,000	5,868,000
Payback period (yr)	2.64	1.91	2.16

Results

The results show that all proposed alternatives would give the same potential saving of utility cost saving. Alternative 2 requires the least investment cost among all. From the economic analysis, Alternative 1 is not a preferred selection in terms of payback period although it gives the smallest value in UA-analysis. Alternative 2 is recommended since it involves the least modifications and results in the shortest payback period. Figure 4 shows the grid diagram for Alternative 2.

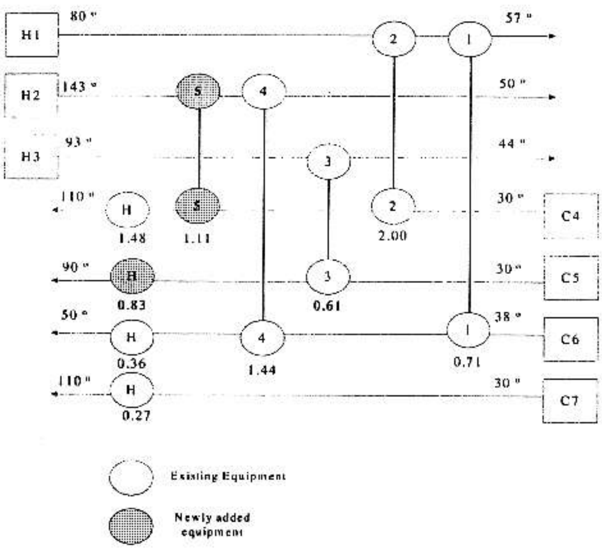

Figure 4 - Grid Diagram for the Retrofitted Air Heating Network System.

Conclusion

A retrofitted HEN of air heating system for a paper making industry was developed using This research proves that significant reduction in energy can be achieved by using Pinch Analysis to retrofit an existing HEN for retrofit purpose. It has been shown that the selected alternative can achieve savings of up to RM 2,537,000 (66%) in hot utility and RM 176,000 (100%) in cold utility. With some modifications, an investment of RM 5,174,000 in heat transfer area is required to realise the projected savings at a payback period of 1.91 years.

Nomenclature

FCp	heat capacity flowrate of hot/cold process streams
Ts	supplied temperature of process streams
Tt	targeted temperature of process streams
Q	heat to be transferred
$Q_{H,min}$	minimum hot utility target
$Q_{C,min}$	minimum cold utility target
ΔT_{LM}	logarithmic mean temperature difference
ΔT_{min}	minimum approach temperature for heat exchanger

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References

[1] Lim, K.G. 2002. Implementation of the Pinch Analysis Technique for the Performance Assessment and Energy Efficiency Improvement of MNI Combined Heat and Power (CHP) Plant. Department of Chemical and Natural Resources Engineering, Universiti Teknologi Malaysia: M.Sc. Dissertation.

[2] De Beer, J., Worrell, Ernst, & Blok, K. 1998. Long-term Energy-efficiency Improvements in the Paper and Board Industry. *Energy*. 23 (1). 21-42.

[3] Bengtsson, C., Nordman, R., & Berntsson, T. 2002. Utilization of Excess Heat in the Pulp and Paper Industry- A Case Study of Technical and Economic Opportunities. *Applied Thermal Engineering*. 22. 1069-1081.

[4] Bengtsson, C., Nordman, R., & Berntsson, T. 2002. Co-ordination of Pinch Technology and the MIND Method- Applied to a Swedish Board Mill. *Applied Thermal Engineering*. 22. 133-144.

[5] Manninen, J., Puumalainen, T., and Talja, R. 2002. Energy Aspects in Paper Mills Utilising Future Technology. *Applied Thermal Engineering*. 22. 929-937.

[6] Tjoe, T. J., & Linnhoff. B. 1986. Using Pinch Technology for Process Retrofit. *Chemical Engineering*, 98 (8). 47-60.

[7] Linnoff, B., et al., 1982. User Guide on Process Integration for the Effective Use of Energy. Institution of Chemical Engineers, London.

[8] Biegler, L., Grossmann, E. I., and Westerberg, A.W. 1997. Systematic Methods of Chemical Process Design. Prentice Hall, New Jersey

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