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Heat Exchanger Integration and Analysis of Minimum and Maximum Energy Needed Using Pinch Technology: A Case Study in Bahir Dar Textile S.C, Ethiopia

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ABSTRACT

Global energy demand and environmental pollution due to the emission of greenhouse gas is the main problem of the world. In Ethiopia, the demand for energy is rising due to industrialization. The main application of pinch technology is optimizing the design of heat exchanger networks to get energy targets (minimum and maximum energy needed to operate the overall utilities). Finding the energy shortage through energy audits and integrating it with surplus energy supply is one of the basses of this technology. As per the analysis of this study, the thermal data for heat exchanger was collected from Bahir Dar textile factory. By considering a suitable temperature difference between hot and cold streams and by constructing the composite curves, the pinch point was evaluated. Aspen HYSYS software was employed for designing of heat exchanger network. Finally, the maximum energy of the cold stream utility at the textile factory was estimated at 287.3 kJ/h.

Keywords: Energy Audit, Pinch, Heat Integration, Heat Exchanger Network, Aspen HYSYS

1. INTRODUCTION

The demand for energy in the industrial sector has been rising, resulting in higher energy and production costs. Along with rising production costs, greater usage of fossil fuels threatens to raise carbon dioxide levels in the atmosphere. Engineers and other industry stakeholders are tasked with lowering energy use. Reduced demand will result in lower manufacturing costs and lower carbon dioxide emissions into the atmosphere. Energy-intensive businesses include petrochemical plants, cement plants, oil refineries, steel mills, paper pulp mills, and other operations that use thermo chemical processes. Different approaches may be used by companies to lower the need for fossil fuel energy. Industries may make effective use of energy or employ renewable energy to replace fossil fuels. The pinch analysis and the usage of learning curves are two energy efficiency strategies [1]. In the textile business, steam is necessary for various operations such as dyeing, hot rinsing, and so on. As a result, steam creation in the boiler necessitates a significant amount of fuel. The boiler's efficiency ranges from 50 to 75 %.As a result, heat that would normally be lost to the atmosphere may now be recovered. In the textile sector, there is a lot of wasted heat recovery potential. It is feasible to save a significant amount of fuel annually by adjusting the boiler's blowdown rate [2]. By reducing gasoline prices, the industry's profitability rises. Because condensate contains 60 % of the energy of steam, it may be used as boiler feedwater, resulting in significant fuel savings [3]. It is possible to recover heat from steam in the form of flash steam when the pressure is reduced. Wastewater may be used to heat boiler feed water, which saves money and decreases the amount of fuel used to generate steam. The process of recovering heat from waste is known as waste heat recovery is also possible from hot exhaust air & cooling water. Hot streams: - which required cooling Cold streams: - which required the presence of heat. Bahir Dar Textile S.c. is one of Ethiopia's garment manufacturing companies. One of the most important difficulties in the industry is the cost of electricity. Textile manufacture is an energy-intensive process that demands a thorough energy study. Imported fossil fuels like furnace oil, coal, and petcock meet the majority of the energy demands of landlocked nations like Ethiopia. In the present global energy crisis, every process designer's goal is to increase process-to-process heat recovery while reducing utility (energy) needs. Energy auditing management has never been done in this industry previously [4]. An appropriate device network (HEN) is the best choice for optimizing energy recovery or meeting the minimum energy requirement (MER). Pinch point Analysis was used to examine the factory's energy consumption processes to determine the minimal energy objectives for the production and to identify routes to improve energy efficiency [5]. As a result, by calculating thermodynamically possible energy using Pinch Technology, this study will show the possibility of actual energy targeting for the textile processing sector and lowering the energy consumption process. The goal of this research is to identify the process's energy objectives (minimum cold and hot utility) as well as the minimal heat exchanger demand [6]. The specific goals were to extract data from the process diagram, determine the minimum temperature difference, construct temperature interval, cascade, and composite curve diagrams, determine the hot utility requirement, cold utility requirement, and pinch point, and design a heat exchanger network for maximum heat recovery and minimal utility consumption.

2. MATERIEALS AND METHODS

2.1 Data Collection from Plant

Over two weeks, data was collected in various areas of the Bahir Dar textile factory. The data from the three heating and cooling loads were gathered, and a schematic of the methods was made. For each load, the absolute temperatures, as well as the mass flow rates, were measured. The temperature and mass flow rate were determined using a mercury thermometer and mass flow rate sensor, respectively. After that, the results were averaged.

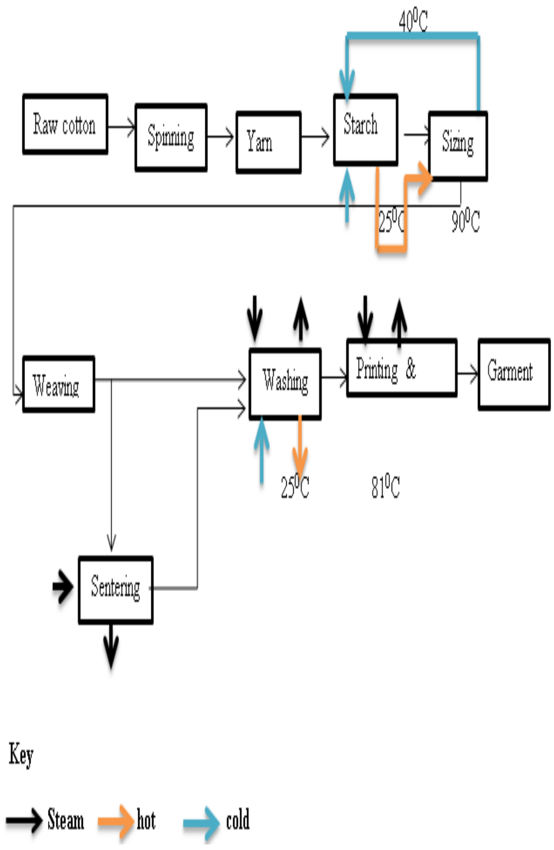


Fig. 1 Stream data for the process and Process flow diagram of Bahir Dar textile factory

Temperature data and mass flow rates were also acquired by a digital display device in the production control room. The data was used to establish the plant's total heating and cooling needs, set energy objectives, and construct the heat recovery network.

2.1 Heat Exchanger's Paramours for the Study

This entails extracting pertinent stream and cost information from the process flow diagram. The input and output temperatures, the heat capacities flow rate, and the specific heat capacities of all streams in the operation, including the utility streams, are among the data retrieved [7]. These dates were measured directly from the streams line as well as on the specification manual.

$$Q = Cp \times F \times \Delta T_1 \quad (1)$$

Where F= mass flow rate of the stream (Kg/s), ΔT =Temperature difference (^{0}C), Q = Heat duty (kW), and C_p = Specific heat capacity of the stream.

Table 1.Parameters of hot and cold streams of heat exchanger measured form the textile factory

S.No	Stream name	Type	Ts (°C)	Tt (°C)	mC_p (KJ/^{0}C.h)
1	Starch cooking	Cold	25	95	3
2	Sizing of yarn	Hot	90	40	2.5
3	Washing water	Cold	35	80	4.180

2.1.1 Minimum Approach Temperature for the Study

The minimum approach temperature is the smallest temperature difference between two streams leaving or entering a heat exchanger. Temperatures typically range from 5 °C to 20 °C. For this scenario, the temperature was set at 10°C. Thereafter, alternative temperature methods provide different outcomes i.e, the minimum temperature difference [8].

Based on Table 2, the pinch temperature was chosen to be 10-20 °C, since it is a chemical industry.

Table 2. Minimum temperature difference for various industry sectors

S.No	Industrial sector	Experienced ΔT_{min} (° C)
1	Oil refining	20-40
2	Petrochemical	10-20
3	Chemical	10-20
4	Low temperature process	3-5

Any value larger than zero will result in a functional heat-exchanger network. In a subsequent section, the impact of varying minimum approach temperatures on the economics of the process was studied. The economic trade-offs, on the other hand, are obvious [9] . The heat transfer area for the heat exchangers reduces, if the minimum approach temperature increases. Up till now the loads on the hot and cold utilities raised. As a result, capital investment increases due to increase in operational cost. In a subsequent section, methods for determining the total surface area of the exchanger network and the equivalent network's annual running cost were estimated. Subtracting T_{min} / 2 from the hot stream and adding T_{min} / 2 to the cool stream, the suitable minimum temperature difference between the source and goal temperatures were created. The strategy of the above shifting method is useful for calculating maximum heat transfer rates [2].

Table 2.Measured values of shift temperatures for different streams

S.No	Stream name	Type of stream	Ts (° C)	Tt(° C)	Ts shift (° C)	Tt shift	Cp (KJ/kg-K
1	Sizing of yarn	Hot	90	40	85	35	2.5
2	Starch cooking	Cold	25	95	30	10 0	3
3	Washing water	Cold	35	80	40	85	4.180

2.2.2 Shifted Temperature Determination

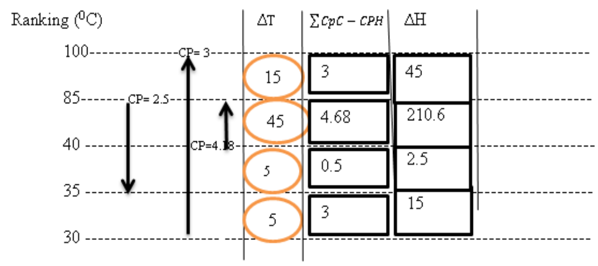
The energy balance equation 2, was applied for each shifted temperature interval to calculate the net heat exchange rates.

$$\Delta Hi = [\sum_{Cold\ streams} CPc - \sum_{Hot\ streams} CPh]\Delta Ti \quad (2)$$

Where, Hi is the rate of heat transfer due to shifted temperature difference Ti.

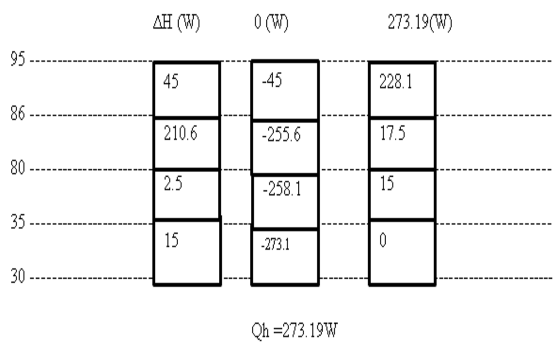
If the cold stream's shift temperature outnumbers the hot stream's range, the interval is said to have the heat deficit, and therefore, H becomes positive. Or else, If hot stream's shift temperature outnumbers the cold streams' range , the system will have a net excess of heat rates in the interval, and H will thus become negative. It agrees with the principles of thermodynamic exothermic process [10].

Table 3. Temperature interval diagram



The temperature interval diagram presented in Table 3 was converted into a formal algorithm, which can convey possibilities of excess heat flux. Heat can be added to the utility to make the net heat flux zero or positive [11].

Table 4. Problem table algorithm

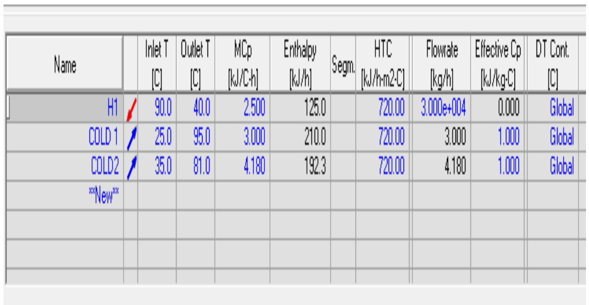


3. RESULTS AND DISCUSSIONS

In this study, the data was collected from the three heating and cooling loads. For each load, the initial and final temperatures of hot and cold streams along with mass flow rates were recorded. The Aspen HYSYS software has been used for the analysis.

The process streams, their properties and temperatures were identified as presented in Figure 1.

Table 5. Process streams



Name		Inlet T [C]	Outlet T [C]	MCp [kJ/C-h]	Enthalpy [kJ/h]	Segm.	HTC [kJ/h-m2-C]	Flowrate [kg/h]	Effective Cp [kJ/kg-C]	DT Cont. [C]
H1		90.0	40.0	2.500	125.0		720.00	3.000e+004	0.000	Global
COLD 1		25.0	95.0	3.000	210.0		720.00	3.000	1.000	Global
COLD2		35.0	81.0	4.180	192.3		720.00	4.180	1.000	Global
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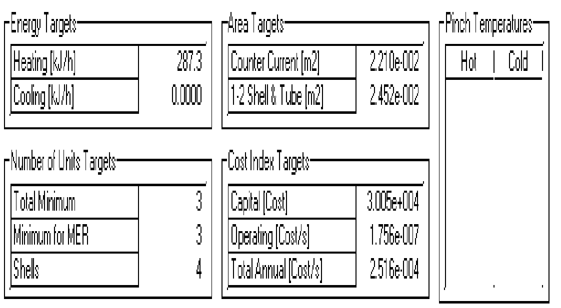
The simulation was run using ASPEN heat exchanger simulation software, and the proposed heat exchanger at the textile factory yielded the following findings. The hot side (A) of the utility supplies the heat without any heat losses. The entire heat was supplied only to sink. The proper energy balance was found within the system. The minimal cold utility (Q_{Cmin}) was found below the pinch point temperature. It was found that heat was rejected from the cold utility without receiving it.

Table 6.Energy and area targets of the heat exchanger



Energy Targets	
Heating [kJ/h]	287.3
Cooling [kJ/h]	0.0000

Area Targets	
Counter Current [m2]	2.210e-002
1-2 Shell & Tube [m2]	2.452e-002

Pinch Temperatures	
Hot	Cold

Number of Units Targets	
Total Minimum	3
Minimum for MER	3
Shells	4

Cost Index Targets	
Capital [Cost]	3.005e+004
Operating [Cost/s]	1.756e-007
Total Annual [Cost/s]	2.516e-004

The simulation resulted in the minimum supply of hot utility being 287.3 kJ/h. Whereas, the minimum cold utility studies were not required for the simulation [5],[10]. In addition to this, the targeted area of the heat exchanger was carried out and was depicted in Table 6.

3.1 Pinch Temperature

The significance of pinch point is to select the minimum possible temperature difference. For finding stream properties such as C_p, the property table has been used. Low streams of steam and cold water were employed in the utility and calculated the suitable value of C_p. ΔT_{min} between the hot and cold streams was assumed initially to be 10 ^{0}C and started the analysis of heat exchanger network.

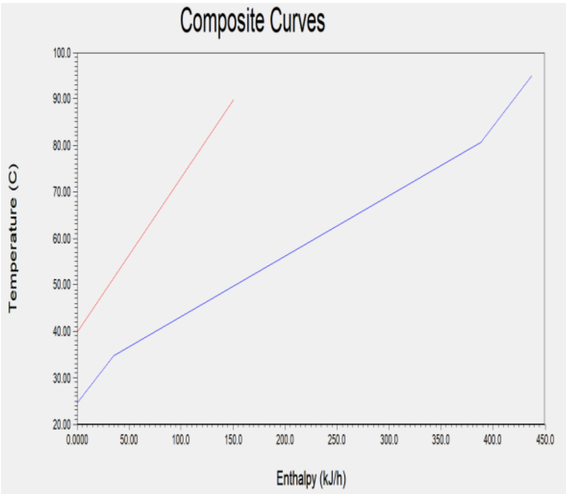


Fig. 2(a) Profiles of composite curve

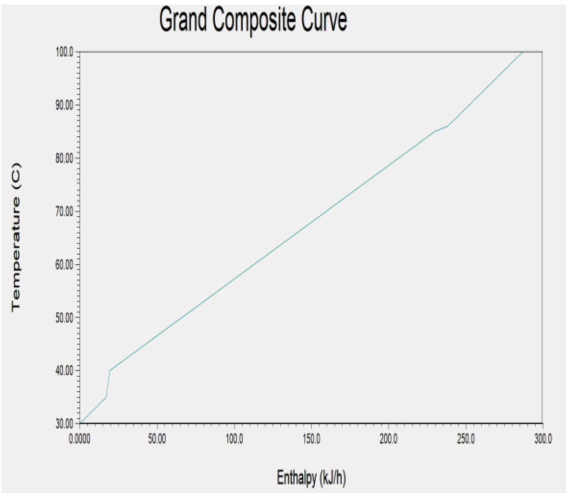


Fig. 2(b) Profiles of grand composite curve

The composite curve and grand composite curves were obtained using the software and shown in Figure 2(a) and 2(b). The position of the pinch point in these Figures is not precise due to the following reason.

It is due to the system's threshold problem against the cold stream of the utility [8]. As a result, shift temperature with respect to stream energy was deviated significantly from the zero axis and shown in Figure 2(b).

In the heat exchanger, the medium of heat transfer were hot and cold streams. Based on the information provided in the composite curves, the targets of minimum energy-consumption was determined.

The profiles of the composite curve represent the heat availability (hot composite curve) and heat demand (cold composite curve).The degree to which the occurrence of profile's overlap indicates the occurrence of ΔT_{min}. This possible minimum occurrence (closest approach) is the pinch point. The heat recovery of the system will be maximum at the pinch point,

The effect of different operations and process modifications can be studied using pinch analysis. The position of ΔT_{min} (pinch point) in the composite curves is the determining factor in the analysis.

3.2 Heat Exchanger Network

The design of the heat exchanger network was done and presented in Figure 3. In its design, the method of linking hot and cold streams was shown. This linkage is essential for heat recovery from the system via splitting of the streamline [11].

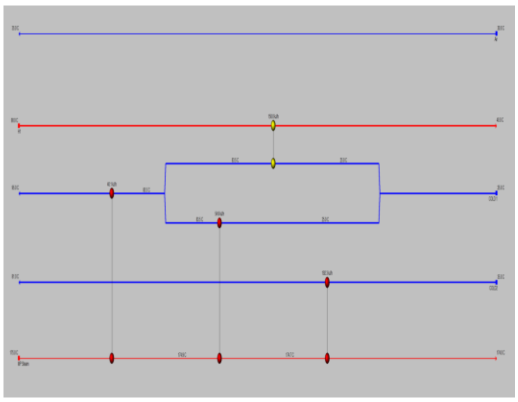


Fig.3 Heat exchanger networking

Finding the minimum requirements for hot and cold streams of the utility from the grand composite curve gives the scope for energy saving. From the analysis, the energy demand for heating and cooling loads of the utility were optimized.

4. CONCLUSION

In this study, the pinch technology and related principles were employed to optimize the rate of heat transfer in the heat exchanger system at Bahir Dar textile factory. The experiments were conducted by designing the heat exchanger network and by constructing composite curves using Aspen HYSYS software. The data analysis of this study revealed that for the initial ΔT_{min} assumption of 10°C, the maximum heat gain between hot and cold streams of utilities was found to be 287.3 kJ/h.

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