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# Pinch Analysis of Heat Exchanger Networks of an Industrial Ammonia Plant for Fertilizer Production

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***Abstract***— *The pinch analysis of the heat exchanger networks in an Industrial Ammonia Plant for the production of urea fertilizer was carried out in this work using Aspen Energy Analyzer. Process data of the heat exchanger networks (HENs) were obtained from the plant and were used to formulate a thermal table after the data were entered into the software for pinch analysis of the networks. Since energy utilization is a major factor considered in any process plant, this research aimed at ascertaining the energy efficiency and operation of the heat exchangers used in the ammonia plant. The Aspen Energy Analyzer produced the composite, balanced, grand composite curves, the grid representation and target reports for the HENs. From the results of the analysis, the following were obtained: minimum heating and cooling requirements of the entire network, the process streams not matched and the heat exchangers not properly placed. The analysis indicated that* $3.281 \times 10^{11}$ *KJ/hr cold utility and* $3.217 \times 10^{12}$ *KJ/hr hot utility were not utilized within the network, which resulted due to poor process stream matching and wrong arrangement of the heat exchangers. The heat exchangers in the ammonia plant need to be retrofitted to ensure adequate heat recovery, process-to-process integration and efficient energy utilization.*

***Key words***— *Heat Exchanger Networks, Pinch Technology, Aspen Energy Analyzer and Ammonia Plant.*

## I. INTRODUCTION

The cost of produced products largely depends on the amount of energy consumed in the plant during production of the products. The more the amount of energy consumed in a process plant, the higher the cost of products produced from the plant and vice versa. So, energy consumption is an important factor to be considered in any process plant to reduce the cost of products for consumers' sake and to gain more profit for the company. Therefore, minimization of energy is highly important in any process plant. In the reality, it is difficult to determine the minimum amount of energy required by a process plant by using the traditional chemical engineering design (mass and energy balance, rules of thumb, good engineering judgment and creative ability of designing) without including Pinch Technology. Pinch Technology was discovered in the late 1970s and was used industrially in 1980, so it is obvious that process plants before 1980 was built and designed without performing pinch analysis on them. Therefore, the amount of energy consumed in these plants will probably be higher than required, which will lead to wastage. Pinch technology is a complete methodology based on thermodynamic principles that can be used to design new plants with reduced energy and capital costs and for existing processes; to ascertain efficiency and provide potential design modifications to improve performance. A fundamental strength of pinch analysis is that it determines the most appropriate set of heat exchange stream matches. In doing so, it minimizes energy loss, reduces the cost of hot and cold utilities and can be used to determine the minimum requirement for both hot and cold utilities in a process and thus, enhance process integration (Anozie and Odejobi, 2007). Pinch Technology can also be considered in the design of a new process plant to determine the process conditions of the core equipment of a process plant in which energy can be minimized. Heat exchanger network (HEN) is a system of several heat exchangers connected together. It enables several process streams to exchange sufficient amount of thermal energy so they can attain their respective desired set temperature values (target), (Akpa and Okoroma, 2012). The production of Urea fertilizer requires reaction between ammonia ($NH_3$) and carbon dioxide ($CO_2$), therefore a urea fertilizer cannot be produced without an ammonia plant. The industrial ammonia plant has a production capacity of 2300 tons per day of ammonia from natural gas. The plant involves production of ammonia by first passing natural gas through the desulphurizing unit to reduce the sulphur content to below 280µg/m$^3$ to prevent poisoning the nickel catalyst used in the primary reformer using activated carbon or zinc oxide. The activated carbon could be regenerated by passing super-heated steam through the bed of carbon. The desulphurized natural gas is then fed into the reformer with simultaneous inflow of steam to produce carbon monoxide (CO) and hydrogen ($H_2$), CO is mixed with more steam to produce $CO_2$ and more hydrogen, the produced hydrogen from the primary reformer is then mixed with $N_2$ (air) to produce ammonia.

Some works have been done on different sections of various plants; Akpa and Okoroma, (2012) performed pinch analysis on the heat exchanger networks of the crude distillation unit of Port Harcourt refinery and discovered pinch penalty of about 98916.1 kW hot utility and 8298.7 kW cold utility. Lukman, *et al.*, (2018), performed evaluation of Naphtha Hydro treating Unit (NHU) of Kaduna refinery using pinch technology in identification of areas requiring improvement in the heat exchanger networks of the NHU with the aim of minimizing total cost and they discovered the optimal total cost to be $263.115 from the initial target cost of $298.815 and also observed the target heating and cooling to be $1.395\text{x}10^7$kcal/h and $1.440\text{x}10^7$kcal/h respectively while the design heating and cooling are $1.228\text{x}10^7$ kcal/h and $1.273\text{x}10^7$ kcal/h. In this work, Pinch Technology was used to evaluate the heat exchanger network in Industrial Ammonia plant. The analysis will ascertain design efficiency of the existing heat exchangers network; determine appropriate number of heat exchangers and identify improper stream matching within the selected network.

## II. Materials and Methods

### *2.1 Materials*

The materials used include: Aspen Energy Analyzer version 8.6 (used to produce the composite curve, balanced composite curve, grand composite curve and grid representation of the heat exchanger networks), Industrial fertilizer plant process data and process flow diagram showing the inlet and outlet temperatures, mass flow rates, specific heat capacities, enthalpy per unit temperature and enthalpy of each process streams and utilities.

### *2.2 Methods*

The Aspen Energy Analyzer version 8.6 process tool was employed to perform a detailed and accurate pinch analysis of the heat exchanger networks in Industrial Ammonia plant. To do this, the thermal data obtained by data extraction were fed as input to the software to construct the composite curve, balanced composite curve, grand composite curve and grid representation of all networks. The following pinch rules were employed in order to achieve the minimum energy targets for the crude preheating process.

(1) Heat must not be transferred across the pinch

(2) There must be no external cooling above the pinch and no external heating below the pinch (heaters must be placed above and coolers below the pinch).

Violating any of these rules will lead to cross-pinch heat transfer resulting in an increase in the energy requirement beyond the target. Any heat transfer across the pinch is excess heat which is wasted, and expressed as a pinch penalty.

#### *2.2.1 Steps in Pinch Analysis*

The pinch analysis of the industrial ammonia plant was achieved through the following steps:

*a) Data Extraction*

This involves extraction of the data from the process flow diagram to form thermal problem table. The data to be extracted is stated in the materials required for the work.

*b) Formation of Thermal Data Table*

The data table was formed from the extracted data by Aspen energy analyzer.

*c) The use of Aspen Energy Analyzer Software Version 8.6*

The extracted data were fed as input into Aspen energy analyzer software to complete the thermal data table.

*d) Analysis of the Composite Curves and Grid Diagrams to meet the Objective of the Work*

To formulate and complete the thermal data table, equation (1) was used:

$$Q = MCp\Delta T \quad (1)$$

where: M is the mass flow rate of the stream (kg/hr).

Cp is the specific heat capacity of the process streams ($kJ/kg$°C).

$\Delta T$ is the temperature difference between inlet (supply) temperatures and the target (outlet) temperature of each stream (°C)

$$C_P = M * c_p \quad (2)$$

Cp is the heat capacity flow rate ($kJ/kg$°C) and measured as enthalpy change per unit temperature difference (kJ/C-h).

#### *2.2.2 Configurations of the Heat Exchangers and Streams*

The preheating of the natural gas used for the reaction that leads to the production of ammonia was accomplished via thirteen (13) heat exchangers using hot streams from other units within the plant. For the purpose of this evaluation the thirteen heat exchangers were sectioned into two Heat Exchanger Networks (HENs), HEN-1 and HEN-2. The configurations of the two networks obtained from the Process Flow Diagram (PFD) are represented in Figures 1 and 2.

#### *2.2.3 Construction of Composite Curves*

A composite curve of a Heat exchanger network is a plot of enthalpy of cold streams and enthalpy of hot streams against temperature on the same graph sheet. The plot is obtained by addition of the enthalpies of the streams with respect to temperature change for both hot and cold composite curves. The composite curves determine if hot or cold utilities or both are required, and the minimum energy requirement (from the areas covered by the cold and hot composite curves) in the grand composite curves.

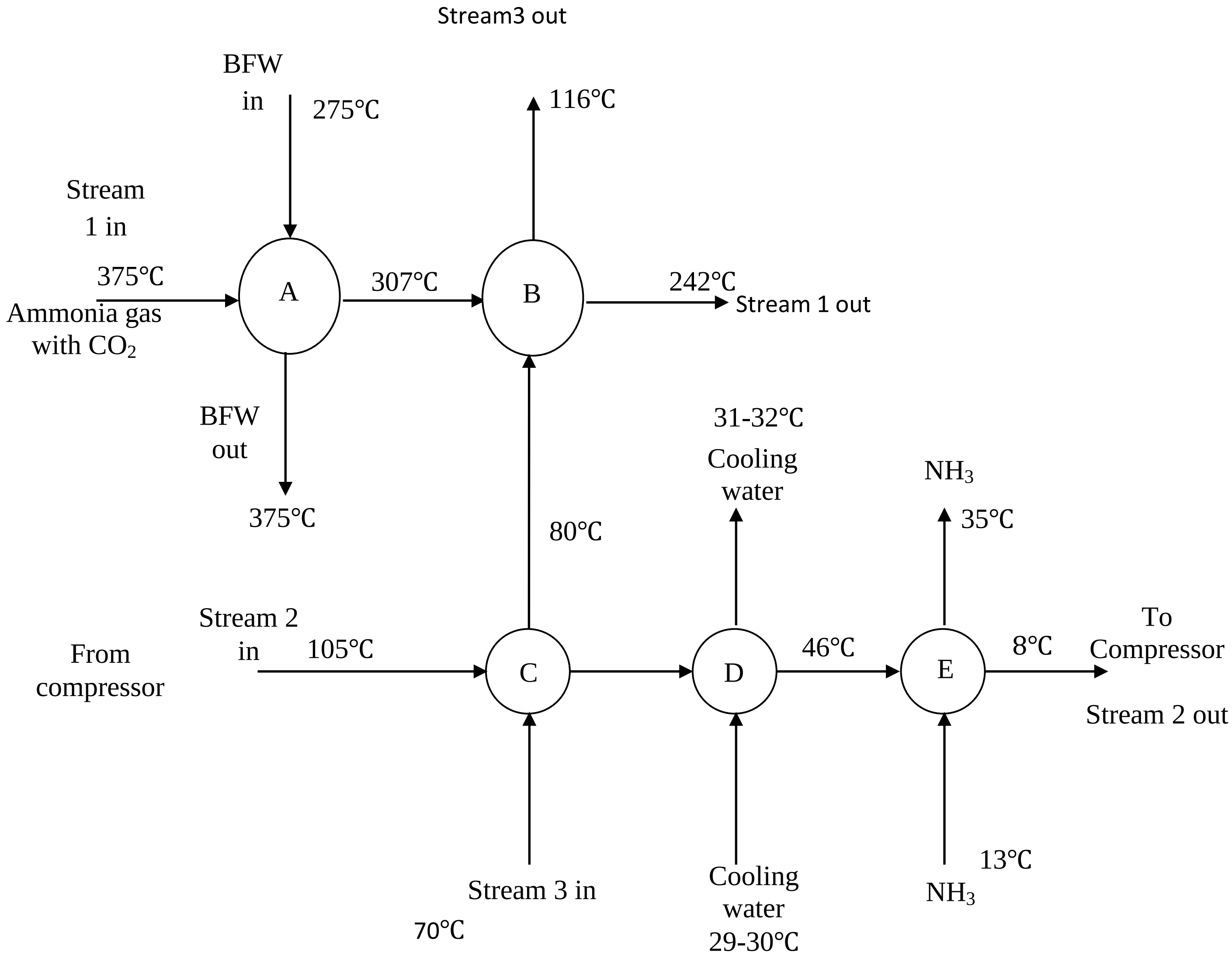


Figure 1: Flow Chart for Heat Exchanger Network 1 (HEN-1)

*2.2.4 Construction of Grid Diagram*

This involves the representation of heat exchanger network of a given process on a grid. The grid diagram shows all the streams on the heat exchanger network with the hot streams above the cold streams. It indicates hot streams with red color having direction from right to left and with their supply and target temperatures specified. In the grid representation the user merge two streams together with the aid of heat exchanger. Two streams are merged together based on two conditions above the pinch ($C_c \geq C_h$) and below the pinch ($C_h \geq C_c$). After the merging, the temperatures required by the software for the grid representation are put in by the user. Also, in the grid representation you can also check if hot utility or cold utility is the required target menu and HP/LP is commonly added for hot utility while cooling water is added as best cooling utility. This diagram serves as the proper measure for connecting process streams of heat exchanger network of process plant. Also, while connecting heat exchangers of a network on grid diagram, the three rules of pinch are applied which include; there must be no external heating below pinch (right hand side of the grid diagram) because it serves as heat source, no external cooling above pinch because it serves as heat sink and heat must not be transferred across pinch. If any of these rules is violated, there will be cross pinch heat transfer which will increase the minimum energy required beyond target.

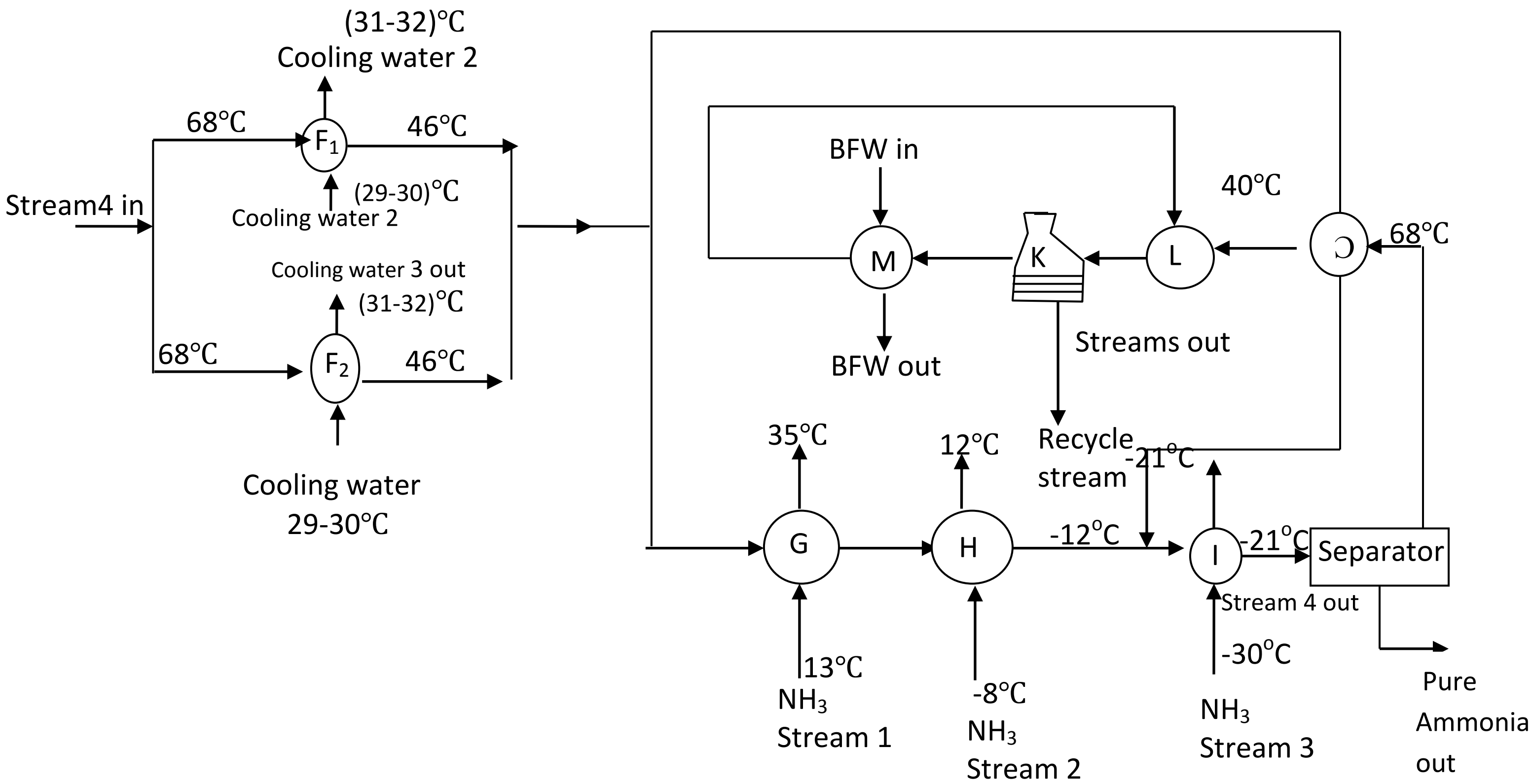


Figure 2: Flow Chart for Heat Exchanger Network 2 (HEN-2)

Table 1: Thermal Data Table for Heat Exchanger Network 1 (HEN-1)

| Name | Inlet Temperature ℃ | Outlet Temperature ℃ | MCp $\frac{kJ}{h℃}$ | Flowrate $\frac{kg}{h}$ |
|---|---|---|---|---|
| Stream 1 | 375.0 | 242.0 | 2.467*10^9 | 1.479*10^9 |
| Stream 2 | 105.0 | 8.0 | 3.125*10^9 | 1.479*10^9 |
| Stream 3 | 70.0 | 116.0 | 7.133*10^9 | 1.479*10^9 |
| $NH_3$ | 13.0 | 35.0 | 5.681*10^7 | 2.594*10^7 |
| Stream 4 | 68.0 | -21.0 | 1.808*10^10 | - |
| Stream 5 | 68.0 | 40.0 | 5.74*10^10 | - |
| $NH_3$ 1 | 68.0 | 35.0 | 5.185*10^10 | - |
| $NH_3$ 2 | 13 | 12.0 | 5.681*10^7 | 2.594*10^7 |
| $NH_3$ 3 | -8 | -12.0 | 5.450*10^7 | 2.433*10^7 |

## III. Results and Discussion

The results of the heat exchanger networks 1 and 2 are presented in this section. The results are shown in the composite, balance and grand composite curves for the HENs. The plots show the variation of the enthalpy at varying temperature. The red line represents the hot stream while the blue line represents the cold stream.

### *3.1 Analysis of Heat Exchanger Network-1 (HEN-1)*

From Figure 3, the left end of the cold composite and hot composite curve matches at the same enthalpy values showing that no heating utility is needed and right end of the composite curves (cold and hot) does not match at the same enthalpy value showing that cooling utility is required. The difference between the right end enthalpy value of both the hot and cold composite curves gives the minimum amount of heating utility $Q_{H,min}$ required and the difference between the left end enthalpy value of both hot and cold composite curve gives the minimum amount of cooling utility $Q_{C,min}$. From the curve, it could be seen that excess of $3.019 \times 10^{11}$ KJ/hr hot duty were not utilized and all the cold duty were fully utilized in the HEN-1, these values could also be seen in the utility targets of the software where the cooling utility was the hot duty not utilized and the required heating utility was the cold duty not utilized. The minimum allowable temperature difference is found to be 10°C.

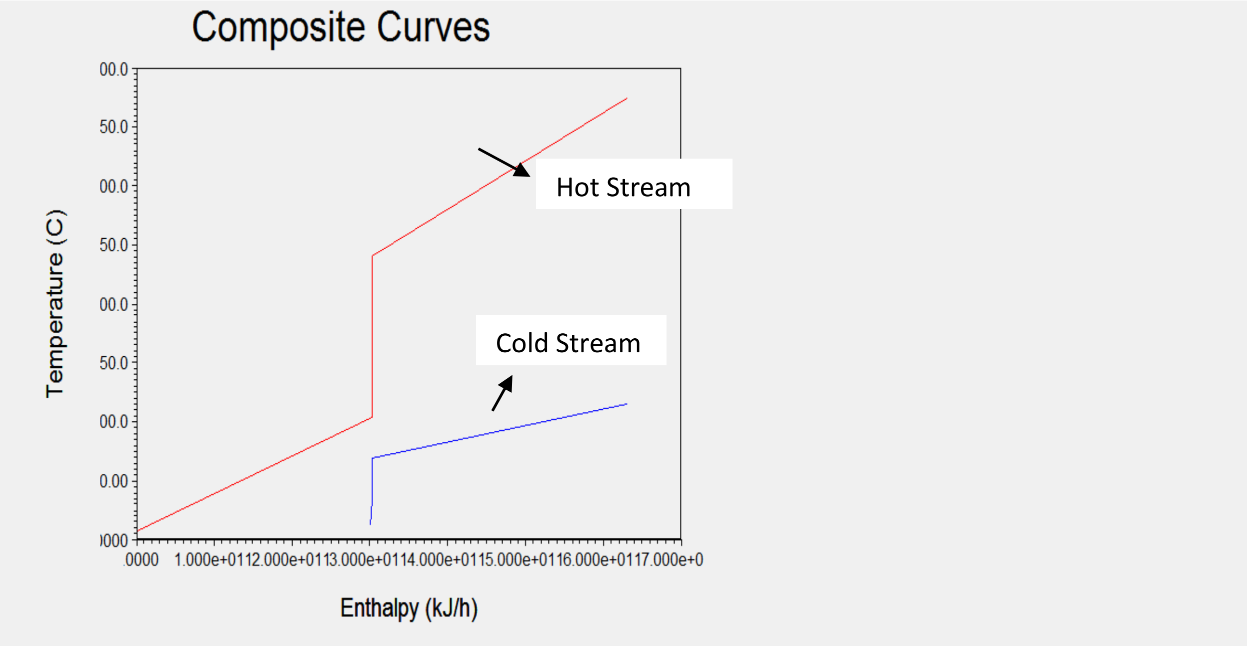


Figure 3: Composite Curve for HEN-1

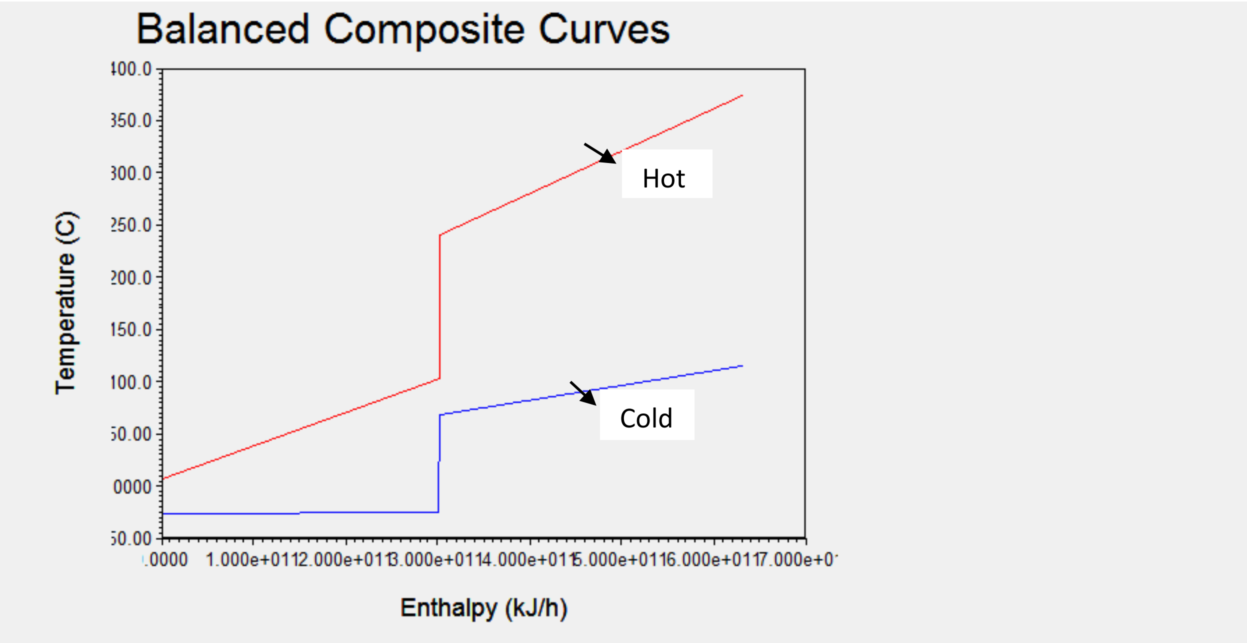


Figure 4: Balanced Composite Curve for HEN-1

Figure 4 shows the balanced composite curve of the heat exchanger network when both hot and cold utilities have been added. The both ends of the cold and hot composite curves have the same enthalpy value in the curve meaning the cold utility required in the composite curve have been accounted for.

Figure 5 shows the amount of energy that is efficiently utilized. When a straight line is drawn from the upper end of the curve downward, the area to the right of this curve shows the amount of heat energy that was efficiently utilized while the area to the left of this curve shows the total amount of heat energy that was not utilized in the heat exchanger network.

From Figure 6, Heat Integration (HI) Project is used to design the grid diagram because it was discovered that there were no cold and hot pinch temperatures, so it will be so hard to design it manually or without using HI project. Since pinch temperatures were not found it shows that the streams in the network cannot be matched. HI project provides more designs near optimum design but the design that gives the lowest cost and lowest heat exchanger area is the best grid representation.

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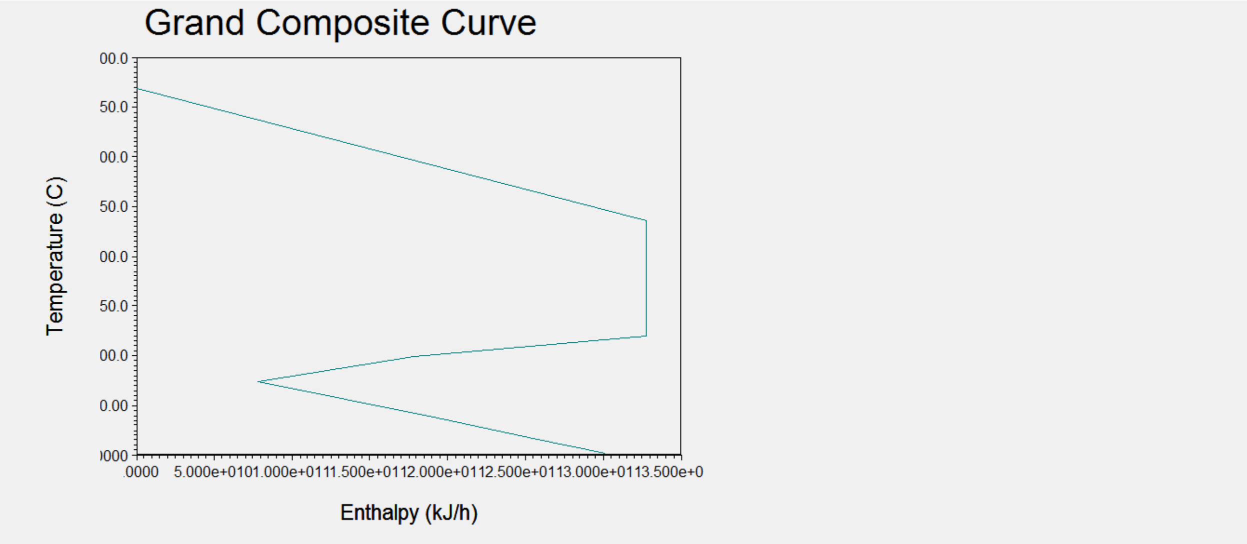


Figure 5: Grand Composite Curve for HEN-1

Table 2: Utilities used for Analysis

| Name | Inlet Temperature ℃ | Outlet Temperature ℃ | Cost index | HTC | Target load |
|---|---|---|---|---|---|
| Refrigerant 1 | -25 | -24.0 | 2.739*10^6 | 4680 | 3.019*10^11 |

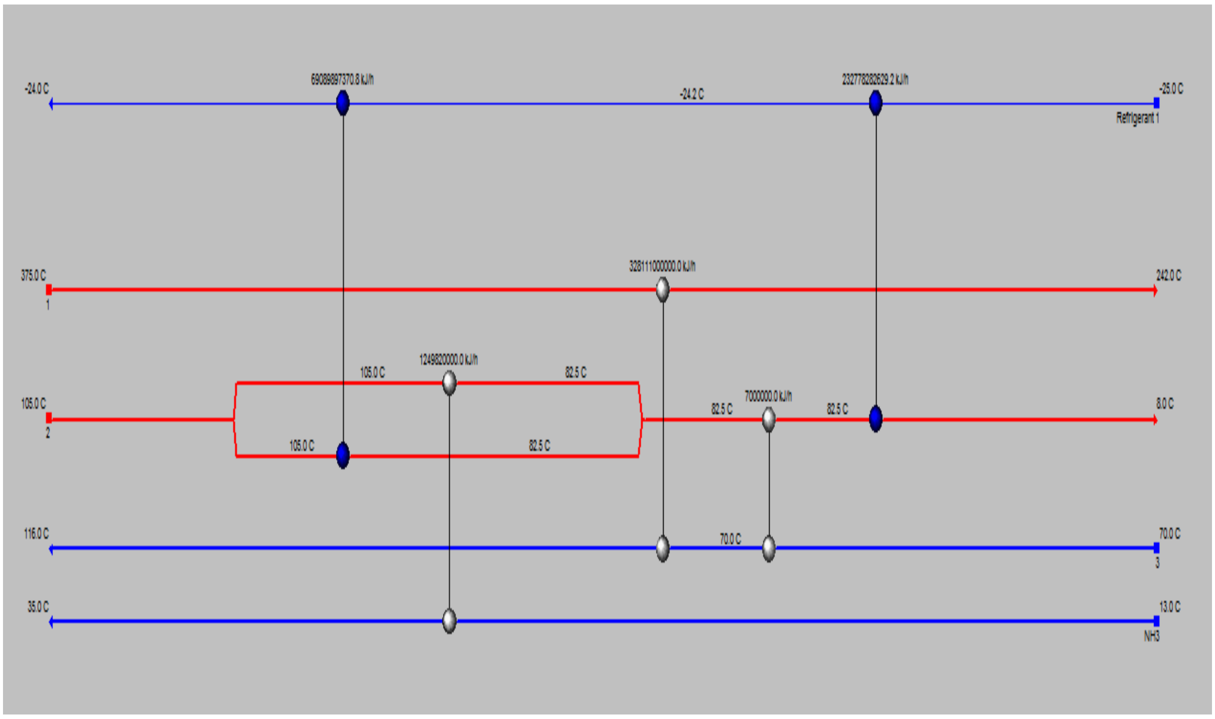


Figure 6: Grid Representation of HEN-1

### *3.2 Analysis of Heat Exchanger Network-2*

From Figure 7, the curve shows that no heating utility was required since the right end of both hot and cold composite curves have the same enthalpy value and also that large amount of cooling utilities was required since the left end of the hot composite curve was far from the cold composite curve while enthalpy difference between the left ends gave the minimum amount of cooling duty required in the heat exchanger network. Also, from the composite curve, it could be seen that all the cold duty was fully used up in the network and excess of $3.215 \times 10^{12}$ KJ/hr hot duty was not utilized. The minimum allowable temperature difference is found to be 10°C.

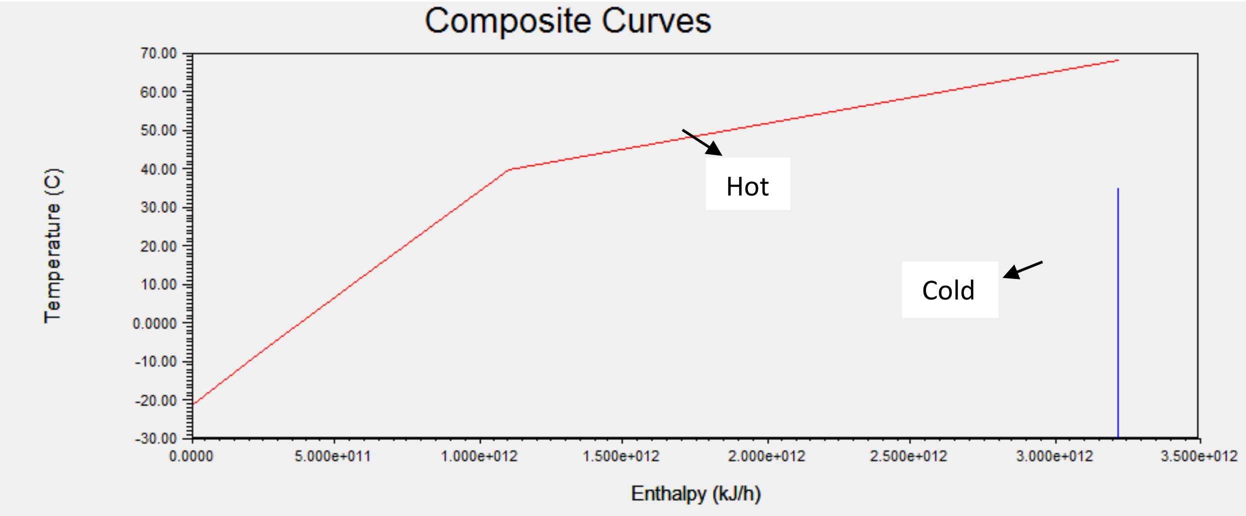


Figure 7: Composite Curve for HEN-2

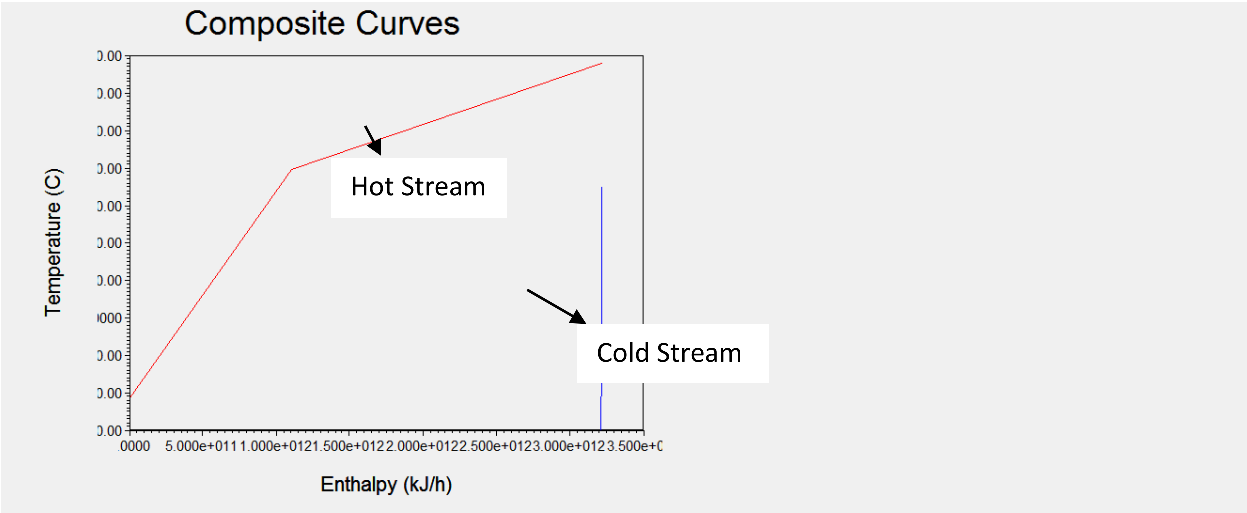


Figure 8: Balanced Composite Curve for HEN-2

Figure 8 shows the balanced composite curve of the heat exchanger network 2 when both hot and cold utilities have been added. The both ends of the cold and hot composite curves have the same enthalpy value in the curve meaning no utility requirements.

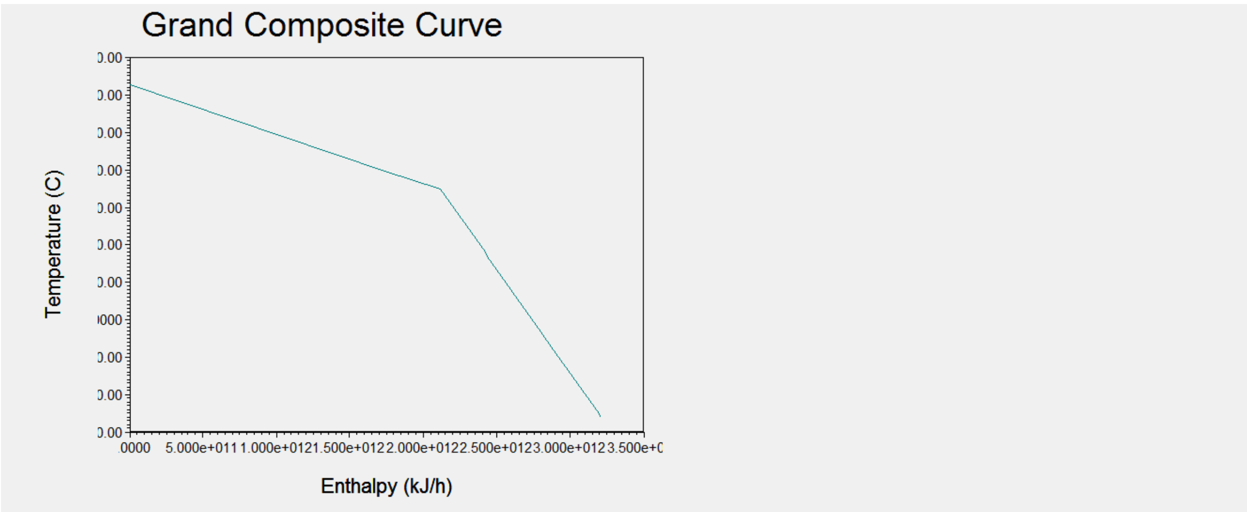


Figure 9: Grand Composite Curve for HEN-2



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Figure 9 is a plot of the grand composite curve and depicts that little amount of heat energy was efficiently utilized in the heat exchanger network.

Table 3: Utility used for the Analysis

| Name | Inlet Temperature ℃ | Outlet Temperature ℃ | Cost index | HTC | Target load |
|---|---|---|---|---|---|
| Refrigerant 1 | -40 | -39.0 | 3.739*10^6 | 4680 | 3.019*10^11 |

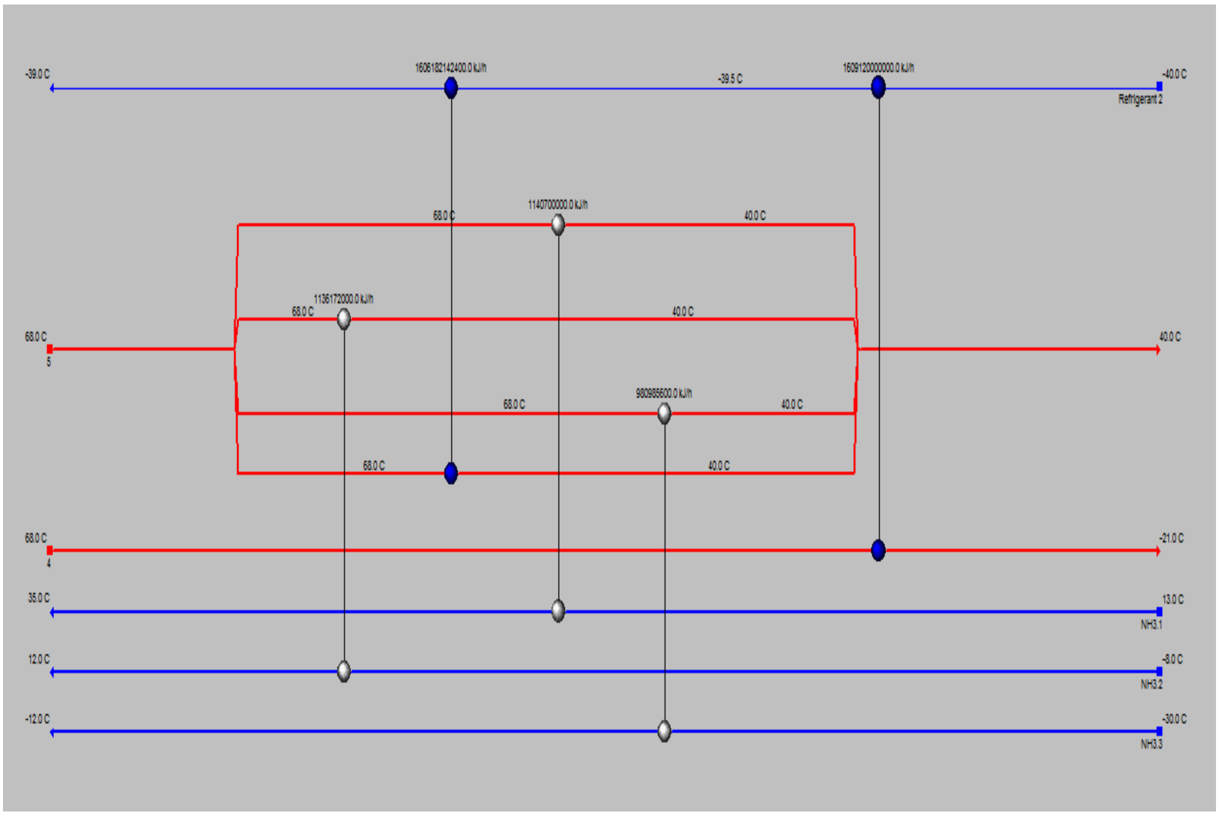


Figure 10: Grid Representation HEN-2

In designing the heat exchanger network 2, Heat Integration (HI) project was used and it gave different scenarios close to optimum design. Showing the pinch lines for all the scenarios, the stated rules of pinch principles was violated which would increase the energy requirement beyond target for the network. The grid diagram shown in Figure 10 shows the scenarios that minimally violate the rules of pinch principle and with optimal cost. Therefore, it can be concluded that the streams in heat exchanger network 2 cannot also be matched.

## IV. CONCLUSION

Pinch analysis using Aspen Energy Analyzer has been carried out on Industrial Ammonia Plant to ascertain the efficient energy utilization and process-process heat integration. The heat exchangers in the ammonia plant was divided into two heat exchanger networks (HEN-1 & HEN-2) to ascertain efficiency of heat exchanger arrangement and effective process to process heat integration and energy utilization in the networks. It was discovered that the process streams in the heat exchanger networks could not be matched because their matching violated the rules of pinch principles. The results from the analysis showed that an excess of $3.019 \times 10^{11}$ KJ/hr hot duty was not utilized and all cold duty was utilized in the HEN-1 and excess of $3.215 \times 10^{12}$ KJ/hr hot duty was not utilized in the HEN-2. Proper design of the heat exchanger network can ensure efficient utilization of energy in the plant. The results from this research showed that, high-energy efficiency and utilization can be achieved using the grid representation techniques, which gave the best arrangement of heat exchangers in any process plant. Retrofit should be carried out for both heat exchanger network 1 and heat exchanger network 2 to properly match process streams so as to reduce the minimum energy requirement which would thereby reduce cost of production of product.

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