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HEAT EXCHANGER NETWORK OPTIMIZATION OF NAPHTA HYDROTREATING UNIT OF A NIGERIAN REFINERY USING PINCH ANALYSIS

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ABSTRACT

Energy integration of the Naphtha hydro treating unit (NHU) of a Nigeria Refinery Company was carried out using Pinch Technology. It was revealed that the traditional requirements of utilities for heating and cooling of streams are 21,080,000Kcal/h and 19,340,000Kcal/h respectively. When pinch technology was adopted for the same process, the heating and cooling utilities requirements are 13,950,000Kcal/h and 12,210,000Kcal/h respectively. Optimum minimum temperature difference of 13°C was obtained for the determination of utility requirements. The temperature at the pinch point was found to be 205°C. For the minimum approach temperature, the utilities targets were found to be 11,940,000Kcal/hr and 10,200,000Kcal/hr for hot and cold utilities respectively. For maximum energy recovery, the total numbers of heat exchangers is 23. Pinch analysis is seen to be an efficient technique for energy integration that saves more energy and utilities cost than the traditional energy technique.

Key Words:*cold stream, hot stream, cold utilities, hot utilities, minimum approach temperature, maximum energy recovery, optimum temperature.*

1.0 INTRODUCTION

The cost of energy usage has contributed to the global cost of production in process industries. This has the tendency to affect the profit made by industries negatively. Recently, the cost of energy increased tremendously, and what happened then is still possible because of the volatility in oil market.. When the price of oil continued to climb in the recent past, the sustainability of industrial development became an issue of concern at the period. Though, the price of oil has fallen drastically at the moment, energy conservation still remains the focus of many process industries since oil price and cost of energy are very relevant to their existence. In any industrial process design, it is economical to maximize the process-to-process heat recovery and to minimize the utility usage. In order to achieve maximum energy recovery or minimum energy requirement (MER,) heat exchanger network (HEN) has been synthesized using either the pinch technology or mathematical programming (Linnhoff and Ahmad, 1989; Salomeh *et al.,* 2008; Azeez, *et al.,* 2013). Pinch technology has been widely studied for HEN synthesis (Hallale and Fraser, 1998; Linnhoff and Ahmad, 1990; Linnhoff, et al.,1982). Mathematical programming techniques have also been used as energy optimization tools (Azeez *et al.,* 2013; Isafiade and Fraser, 2008).

Therefore, efforts towards reducing energy and costs of production have been continuously explored.

Based on the thermodynamic principles, pinch technology offers the opportunity to integrate the energy in a process for optimum cost. It also helps to evolve design with reduced capital cost and energy requirements. It can as well be used for the modification of existing processes by way of retrofitting. The main advantage of pinch technology is its ability to set an energy target before starting the design. The energy target provides the minimum theoretical energy required for the process (Akande, 2007). Linnhoff et al. (1979) in their work explain the relation between the minimum temperature difference ΔTmin and energy recovery, using the composite curves in a similar manner to Huang and Elshout (1976). Linnhoff and Hindmarsh (1983) presented and use the pinch point as the most constrained region of a design. In their method, the task was divided into two at the pinch point as separate systems (above and below the pinch point). In the design of a network, it must starts at the most constrained region of the system, which is immediately above or below the pinch point (Hallale, 1998). Feasibility criteria that are normally used to decide which streams are to be matched are contained in Smith (2005).

Evaluation of maximum energy recovery and minimum number of units at ΔTmin values made it possible for a design engineer to distinguish between a good and a bad network structure before the design. Various researchers have discussed targeting for minimum heat exchanger area in relation to heat content and the composite curves. The approached is based on equal heat transfer coefficients between all matches in the network and on vertical counter-current heat transfer between the composite curves. General overviews of pinch based synthesis and design are contained in Nishida et al. (1981); Smith (2005); Westerberg (1980) along with those earlier mentioned. However, Townsend and Linnhoff (1984) in their work extended the approach to account for individual heat transfer coefficients for each streams using the Bath formula, with consideration for the spaghetti network. Their formulation is though an approximation but works well in many situations (Azeez, *et al.*, 2013).

Ahmed and Linnhoff (1984) studied cost targeting for the cost effective ΔTmin before design. The cost of energy, cost of minimum number of units, and cost of heat exchanger area at different values of ΔTmin were evaluated and drawn in a cost -ΔTmin plot, from which the cost-effective ΔTmin was selected. Ahmed and Smith (1989) further worked on cost targeting where they developed a technique that enabled capital cost targets to take into account different materials of construction, pressure ratings, and heat exchanger type. Concept of supertargeting was presented by Hallale and Fraser (2000) where they used pinch-based techniques for mass exchanger networks.

In this research, pinch technology has been used to evaluate the hot and cold utility requirement of a naphtha hydrotreating unit (NHU) of a Nigerian refinery. In the research, it was assumed that traditional method can as well be used to effect energy need in the process. A comparison between the traditional method and the pinch analysis for energy usage was then made to know the amount of energy savings that is possible for the process.

The need for the reduction in total annual cost (TAC) in refineries production process through the reduction in energy usage in terms of utility is the motivation for this research.

2.0 METHODOLOGY

Materials

The material used for this research work is sourced from the Process Flow Diagram (PFD) of NHU of the refinery.

Methodology

Below is the necessary steps taken in the analysis, designing and optimization of any heat integration problem:

2.1 Data Extraction:

Data extraction is time consuming in the task of pinch analysis. It involves the identification of the hot and cold process streams as well as utilities in the process line. That is, those streams that need to be cooled and those that need to be heated alongside their thermal properties, flowrates, phase changes and the temperature through which they must be cooled or heated. The information above can be available in the PFD, in the field (from the plant personnel) or using of modeling tools such as simulation and data reconciliation for set of consistent and reliable data. As shown in Table 1, the extracted data of the NHU is from the PFD.

Table 1: Data of NHU extracted fro PFD

Stream no	Stream Type	Supply Tempe-rature (°C)	Target Tempe-rature (°C)	Heat Duty (Kcal/hr)
1	Cold	39	293	2.416×10^6
2	Hot	370	125	2.416×10^6
3	Cold	293	370	6.38×10^6
4	Hot	125	48	5.93×10^6
5	Hot	48	40	5.20×10^5
6	Hot	46	40	3.50×10^5
7	Cold	40	133	6.41×10^6
8	Hot	237	133	6.41×10^6
9	Hot	77	48	4.39×10^6
10	Hot	48	40	5.60×10^5
11	Cold	200	237	1.47×10^7
12	Hot	221	190	4.20×10^6
13	Cold	137	137.2	4.20×10^6
14	Hot	72	55	5.09×10^6
15	Hot	55	35	2.30×10^5
16	Hot	137	48	2.10×10^6

17	Hot	48	40	1.70 x 10^5

3.0 RESULT AND DISCUSSION

The data extracted from the Process Flow Diagram (PFD) were inputted into the "Aspen Energy Analyzer" software and the results obtained are d-iscussed as follows:

3.1 The Composite Curve of NHU

The composite curve of NHU is plotted as the temperature against enthalpy for hot and cold streams as shown in Figure 1. It determines the minimum targets for energy requirement.

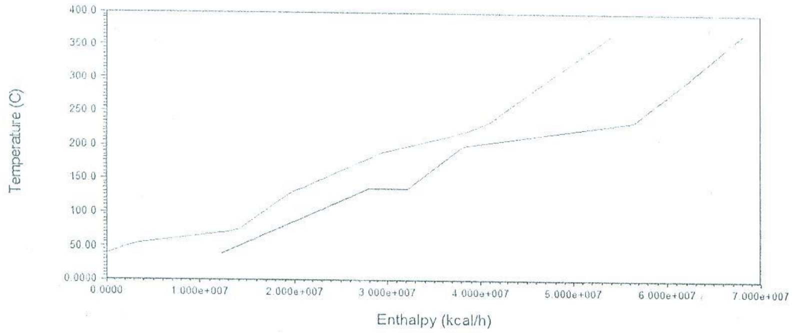

Figure 1: The composite curve of NHU

The composite curve plot of NHU as generated by the package is shown in Figure 1 having the hot composite curve represented in red while the cold composite curve is represented in blue. The maximum heat recovery possible for the process is represented by the overlap between the hot and the cold composite curves. The composite curves are closest to each other at the hot stream temperature of 220°C and cold stream temperature of 200°C (that is, they are 20°C apart which is the initial ΔTmin taken). It equally reveals the minimum hot utility (Q_{HMIN}) and minimum cold utility (Q_{CMIN}) requirements as an overshoot of the cold composite curve and the hot composite curve to be 13,950,000Kcal/h and 12,210,000Kcal/h respectively

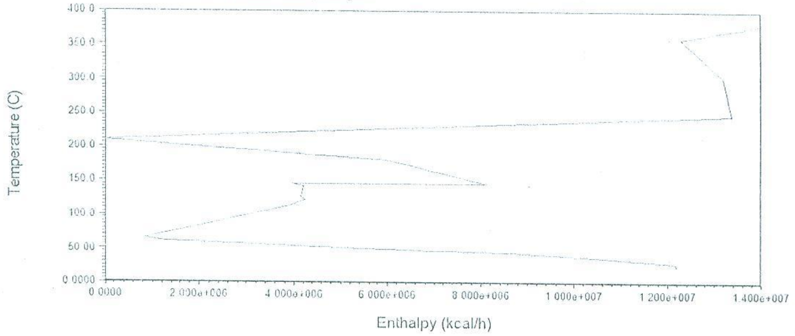

Figure 2: The Grand Composite Curve of NHU

3.2 The Grand Composite Curve of NHU

In the Grand Composite curve shown in Figure 2, the pinch occur at a point where the curve touches the temperature 220°C and it divides the curve into two regions, that is, above pinch and below pinch. The minimum utility requirement for both hot and cold are represented by the distance between the end of the above and the below curves regions and the temperature

3.3 Energy Requirement Results of NHU

The results obtained are shown in Tables 2 to 5. The traditional energy requirements are calculated result from the process flow diagram while the energy target values are from the analysis using the program

Table 4: Comparison of Energy Requirement between traditional approach and pinch analysis

	Energy Requirement (Kcal/h)		Saving (%)
	Traditional	Pinch Analysis	
Energy Target	21,080,000	13,950,000	33.82
Energy Target	19,340,000	12,210,000	36.87
Total Energ	40,420,000	26,160,000	35.28

Table 2: Traditional Energy Requirement values

Minimum hot Utility Requirements (Kcal/h)	Minimum cold Utility Requirements (Kcal/h)
21,080,000	19,340,000

Table 3: Energy Target Values of NHU based on pinch Analysis

Initial ΔTmin (°C)	Pinch Tempe-rature (°C)	Energy Target (Q_{Hmin}) (Kcal/h)	Energy Target (Q_{Cmin}) (Kcal/h)
20	220	13,950,000	12,210,000

Table 5 shows the energy requirements at optimum ΔTmin values where a further reduction in energy usage was observed. At optimum ΔTmin , minimum number of heat exchange units targeted is 23 which is higher than that obtained for initial ΔTmin which is 17 units. Azeez, *et al.* (2013) however, observed that lower number of units does not eventually translate to lower TAC. The network design for this NHU is shown in Figure 3 while Figure 4 indicates the pinch position in the network.

Table 5: Energy Target Result Based on optimum ΔTmin

Optimun ΔTmin (°C)	Pinch Temperature (°C)	Energy Targ (QH min) (Kcal/h)	Energy Targ (QCmin) Kcal/h)
13	205	1.194×10^7	1.020×10^7

The minimum heating and cooling requirements for the traditional approach is shown in Table 2 while Table 3 shows the pinch analysis energy requirement. A table of comparison for the values is shown in Table 4 and from observation; a significant savings of energy requirement is noticed. Saving of 33.82% and 36.87% for hot and cold respectively and the overall savings is found to be 35.28% which is a good saving for refineries.

3.4 Design of Heat Exchanger Network for NHU

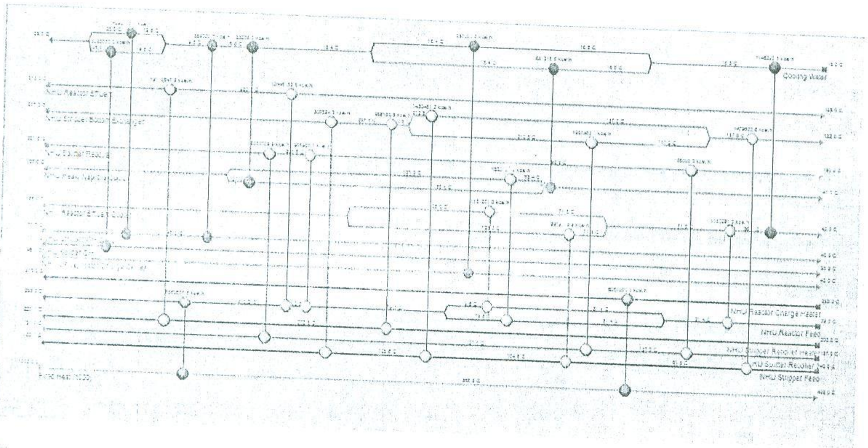

Figure 3: Complete HEN Design of NHU

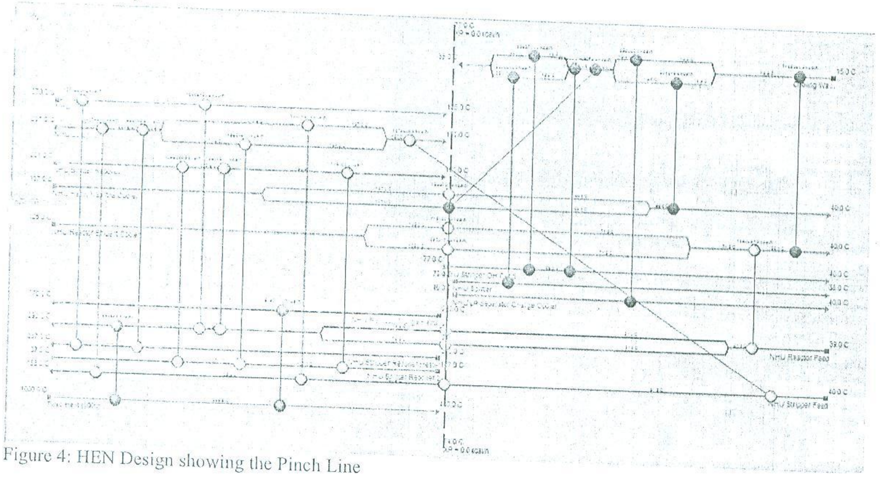

Figure 4: HEN Design showing the Pinch Line

4.0 Conclusions

The following conclusions were drawn from the result of the analysis:

1. The pinch point for the analysis was found to be 220°C and the minimum temperature approach of 20°C was used to determine the energy target.
2. For minimum approach temperature of 20°C, the utilities targets were found to be 13,950,000Kcal/h and 12,210,000Kcal/h for hot and cold utilities respectively.
3. The optimum ΔTmin was found to be 13°C, and the utilities targets were found to be

11,940,000Kcal/h and 10,200,000Kcal/h for hot and cold utilities.

4. Energy savings were found to be more using pinch analysis as an energy integration technique than the traditional energy technique.

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