Energy Optimization of Heat Exchanger Network of a Nigerian Based Naphtha Hydrotreating Unit (NHU) Using Pinch Analysis

Ismaila I. Paiko[1],O.S. Azeez[2], N. Makwashi[3]
[1] Chemical Engineering Department, Federal Polytechnic Bida.
[2] Chemical Engineering Department, Federal University of Technology, Minna
[3] Chemical and Petroleum Engineering Department, London South Bank University, UK.
ismaeel.xcal@gmail.com and +234 8030400759

ABSTRACT

The rewards for integrated energy system are eco-friendly environment, high economic profitability, reduction in excessive energy utilization; greener and cleaner technology. This paper employed one of the best acceptable global practices in the concept of energy integration, it adopted pinch technology as a tool to address some of the global problems. Also, this study applied pinch technology in designing heat exchanger network with a high degree of energy recovery and drastic minimization of total annual cost (TAC). Realistic process streams data were used as input in the NHU simulation in Aspen Plus environment to aid the extraction of necessary thermodynamic data. Using Aspen Pinch, Heat exchanger network (HEN) of the developed NHU plant was designed, followed by strict application of pinch analysis and its principle to the process plant. The minimum temperature approach was optimized to obtain the optimum ΔT_{min} of 15 °C for the minimum total annualised cost. The final heat exchanger network designed, based on this optimum ΔT_{min}, is also presented along with its composite curve, grand composite curve and total annualized cost. With analysis of the NHU plant, an improved heat exchanger network (HEN) was obtained. Nineteen heat exchangers were used to obtain a minimum annual capital cost (ACC) of $17,301.46/yr, annual operating cost (AOC) of $561,994.20/yr and total annualized cost (TAC) of **$579,295.66**/yr. Also, 240.4989 kWenergy (Emission) and $11543.94/yr were saved with 2113.6m^2 heat exchanger area utilized.

Keywords: Energy conservation, Naphtha Hydrotreating Unit (NHU), Aspen Pinch

INTRODUCTION

To resolve the problem of energy crisis and minimize the total annual cost (TAC) of a process plant, the energy consumption has to be reduced. When it becomes unavoidably to reduce the consumption, the streams are integrated thereby minimizing the use of utilities. The current trend in most developing countries is issuance of several energy conservation plans for reducing the energy consumption (Stephen, 1997; Fortune Ngwakwe, 2014). With the latest plan, the energy consumption is being cut down in factories and buildings, and promoting the use of renewable energy. The industrial sector, which consumes a large amount of energy, is looking for ways to use the energy efficiently (Manoch, 2002).

Pinch technology is one of the energy optimization methods. This technology is the most practical method for applying process integration. Process Integration is a very important means of improving energy efficiency of industrial and manufacturing processes while minimizing their environment impact (Stankiewicz, 1993). By analyzing the thermodynamics of a process, an engineer can qualify the thermodynamic efficiency of the process, identify the regions where energy can be better utilized and define the minimum targets for energy consumption (Trivedi, 1996).

Pinch Technology is one of the numerous methods of process integration. In 1993 the International Energy Agency (IEA) defined process integration as: Systematic and general methods for designing integrated production systems, ranging from individual processes to total sites, with special emphasis on the efficient use of energy and reducing environmental effects (Gundersen, 2002) . By this definition, process integration is seen as a group of methods to optimize the use of energy, but with concerns for environmental aspects (Azeez O.S, Isafiade A.J.,.Fraser D.M., 2012). Process integration is a holistic approach to process design, retrofitting, and operation of industrial plants, with applications focused on resource conservation, pollution prevention and energy management (Russell and El-Halwagi, 2003). Two main branches of process integration can be recognized as:

1. *Energy integration* that deals with the global allocation, generation, and exchange of energy throughout the process and
2. *Mass integration* that provides a fundamental understanding of the global flow of mass within the process and optimizes the allocation, separation, and generation of streams and species. (El-Halwagi, 1989)

Therefore, this paper is aimed to synthesize heat exchanger network for Naphtha Hydrotreating Unit (NHU) of a Nigerian based refinery and Petrochemical Company to minimize the total annual cost (TAC). This aim is actualized through the following objectives:

- To apply the established pinch principles in designing an alternative energy efficient HEN using Aspen Pinch 11.1
- To improve the economic performance and to minimize the generation of emissions and wastes of the plant in question.
- To evaluate the merits of advanced commercial software tools for process integration *(Aspen Pinch 11.1)* for applications to real industrial problems.

Results and Discussion

Table I: Process Cold Stream Data for NHU

S/ N	STREAM	Ts (°C)	Tt (°C)	MCp (kCal/h-°C)	Enthalpy (kCal/h)
1	NHU Reactor feed	39	293	9.512×10^4	2.416×10^6
2	NHU Reactor Charge Heater	293	370	8.286×10^4	6.380×10^6
3	NHU Stripper Feed	40	133	6.893×10^4	6.410×10^6
4	NHU Stripper Reboiler Heater	200	237	3.973×10^5	1.470×10^7
5	NHU Splitter Reboiler 2	137	137.2	4.200×10^7	4.200×10^6

Table II: Process Hot Stream Data for NHU

STREAMS		Ts (°C)	Tt (°C)	MCp (kCal/h-°C)	Enthalpy (kCal/h)
1	NHU Reactor Effluent	370	125	9.861×10^4	2.416×10^6
2	NHU Reactor Effluent Cooler	125	48	7.701×10^4	5.930×10^6
3	NHU React. Eff. Trim Cooler	48	40	6.500×10^4	5.200×10^5
4	NHU LP Sep. Charge Cooler	46	40	5.833×10^4	3.500×10^5
5	NHU Stripper Bottom Exch.	237	133	6.163×10^4	6.410×10^6
6	NHU Stripper OH Condenser	77	48	1.514×10^5	4.390×10^6
7	NHU Stripper OH Trim Cond.	48	40	7.000×10^4	5.600×10^5
8	NHU Splitter Reboiler	221	190	1.355×10^5	4.200×10^6
9	NHU Splitter OH Condenser	72	55	2.994×10^5	5.090×10^6
10	NHU Light Naphtha Cooler	55	35	1.150×10^4	2.300×10^5
11	NHU Heavy Naphtha Cooler	137	48	2.360×10^4	2.100×10^6
12	NHU Heavy Naph. Trim Cooler	48	40	2.125×10^4	1.700×10^5

Table I and II represent the cold and hot streams data for the Naphtha Hydrotreating Unit (NHU) respectively. These data are separated for easy analysis. As it can be seen on these tables, the data comprises of twelve hot streams and five cold streams making a total sum of seventeen streams. The supply and target temperature and enthalpy was directly traced from the process flow diagram in appendix A.

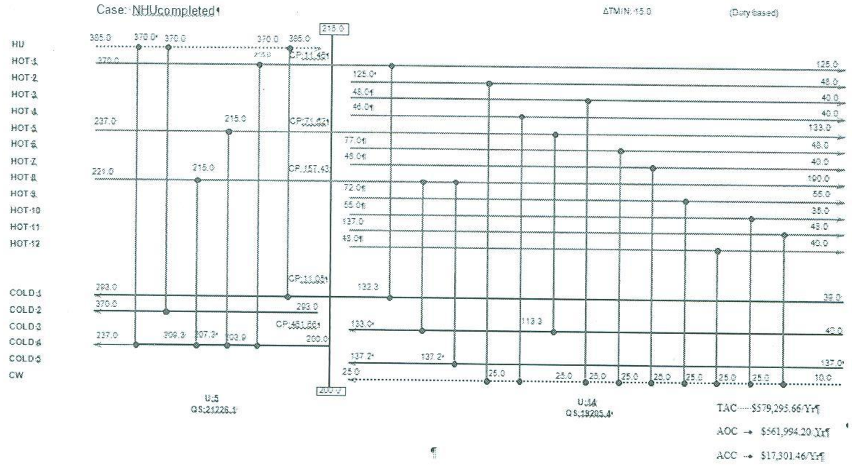
Table III: Summary of Cost and Quantity of Energy Incurred/Consumed in the Design of KRPC NHU

	Kw	US$/Yr	US$/Yr	US$/Yr
Total Hot Utility Energy Usage	21226.1	319,999.49		
Total Cold Utility Energy Usage	22473.2	241,994.70		
Annualized Energy cost ($\sum H\&C\ UTY\ Energy$)			**561,994.20**	
Annualized Capital cost			**17,301.46**	
Total Annualized Cost ($\sum AEC\ and\ ACC$)				**579,295.66**

Table III displays the economic implications and energy used in form of utility returned in the NHU design. This table comprises of five columns five rows. 21226.1 kW at a cost $319,999.49/Yr and 22473.2 kW at $241,994.70Yr for hot and cold utility utilized respectively were incurred. The summation of the cost for the hot and cold utility energy used yield the annualized energy cost i.e. annual operating cost (AOC) of $561,994.20/Yr while $17,301.46/Yr is for the annualized capital cost of the final design. In this design, $579,295.66/yr of total annual cost (TAC) was featured which is the sum of Annualized Energy cost (AOC) and Annualized Capital cost (ACC).

Table IV: Comparison between Used to Targeted values

Utility Energy Targets				Shell and Area Ratio				Utility Area Target Based on Units				Utility Area Target Based on Shell			
	Used	Target	Diff.		Used (m²)	Target (m²)	Ratio		Used (m²)	Target (m²)	Ratio		Used (m²)	Target (m²)	Ratio
Number of Units	19	21	2	Unit Area	2156.3	2113.6	1.02	CW	1096.9	925.4	1.19	CW	1096.9	962.2	1.09
Number of Shells	19	25	6	No. of Shell	2156.3	2154.2	1.00	HU	382.1	348.7	1.10	HU	382.1	348.7	1.10
Hot Utility Load (kW)	21226.1	21226.1	0.01												
Cold Utility Load (kW)	22473.2	19205.4	3267.83												



Conclusions

This study stresses on the use of Pinch technology as a tool for energy integration and minimisation of TAC in heat exchanger network synthesis (HENS) using Aspen Pinch 11.1 (*commercial software*). This application functions on the basis of pinch technology and its governing rules in designing superstructures for heat exchanger network (HEN), for the minimization of total annual cost (TAC). Some of the findings from this study include;

1. The implication of proper combination of matches between hot and cold streams results to the following;

- Reduction of waste and minimization of emission in form of heat thereby giving room for a eco-friendlier operations.
- The research shows that its actually possible to completely avoid the use of utilities in process plants.
- Cut down in the accumulation of operating cost thereby minimizing total annual cost (TAC)

2. The cost and energy predictive ability of pinch technology especially using Aspen Pinch 11.1 software gives room for conceptual budgetary evaluation before the proper design

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