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EVALUATION OF NAPHTHA HYDROTREATING UNIT (NHU) OF KADUNA REFINERY USING PINCH TECHOLOGY

***[1]Lukman, Y., [2]Yesufu, I.S., [3]Otoikhian, S.K. and [4]Yesufu, S.I.**

[1]Department of Chemical Engineering and Technology, Auchi Polytechnic, Auchi, Edo State, Nigeria
[2]Department of Quantity Surveying, School of Environmental Studies, Auchi Polytechnic, Auchi, Edo State, Nigeria
[3]Department of Chemical Engineering, Faculty of Engineering, Edo University Iyamho, Edo State, Nigeria.
[4]Servicom Unit, Auchi Polytechnic, Auchi, Edo State, Nigeria.
*yusuflukman55@yahoo.com

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ABSTRACT

Pinch analysis incorporated in Aspen energy analyzer software was used in this study in the design, optimization and identification of areas requiring improvement in the heat exchanger networks of naphtha hydrotreating units of a Kaduna Refinery naphtha hydrotreating unit (NHU) with the aim of minimizing total cost. The result obtained was an optimal total cost (OTC) of \$263.1/s from the initial target cost (ITC) of \$298.8/s. The target heating and cooling were observed to be 1.395 x10^{7}kcal/h and 1.440 x10^{7}kcal/h respectively; while the design heating and cooling were 1.228x10^7 kcal/h and 1.273x10^7 kcal/h respectively. The minimum number of heat exchanger units was found to be 23 at the optimum minimum temperature approach of 15 °C. Aspen Energy Analyzer was able to predict the OTC and it is capable of breaking any loop present as well as possible areas requiring process integration in Heat Exchanger Networks (HENs) for an optimal design.

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1. INTRODUCTION

According to Ndaman, (2012) and Chiyoda, (1980), the naphtha hydrotreating unit (NHU) is designed to provide suitable feed by treating heavy naphtha cut off sulphur contents to less than 1. ppm for the catalytic reforming unit (CRU). This is achieved by catalytic treatment of the naphtha for the removal impurity by reaction with hydrogen. Also, separation of naphtha into its fraction, this process which involved the removal of impurity such as sulphur, nitrogen and oxygen among other impurities that constitute catalyst poisoning was described as sweetening process product that are free of impurity sulphur, nitrogen and oxygen. The major reactions therefore in the unit include desulphurization, denitrification and hydrogenation reaction. The feed material to the unit is naphtha from Crude

Distillation Unit (CDU 1 and2). The naphtha is crude oil fraction which contains hydrocarbon with boiling point of up to 175 °C (Chiyoda, 1980; Ndaman, 2012).

For the efficiency of an existing process to reduce with time, it may be as a result of oversight of operating parameter, rough design or design error, impure feed materials, poor operability, degree of fouling, poor maintenance culture, climatic and environmental effects, inappropriate shutdown, preservation techniques, aging and bad warehousing." (Haske, 2004)

Pinch knowledge has now advanced to solve problems in processes industries where heating and cooling of process materials are encountered. The principle of pinch analysis has advanced over the years as a result of various research efforts made by a substantial number of researchers (Linnhoff and Flower 1978; Linnhoff 1979; Linnhoff et al., 1982; Linnhoff, 1983; Linnhoff and Parker 1984; Linnhoff and Ahmad 1990; Yee and Grossmann 1990; Ciric and Floudas 1991; Daichendt and Grossmann 1994; Floudas, 1995; Linnhoff 1998; Lewin, 1998; Hallale and Fraser 2000; Sorsak and Kravanja 2002; Smith, 2005; Krishna and Murty 2007; Akande 2007; Linnhoff and Kemp 2007; Salomeh, et al., 2008; Joe et al., 2010; Azeez et al., 2013; Dagde and Piagbo 2013; Lukman et al., 2016). The general progress that have been made to accomplish energy minimization in heat exchanger networks (HENs) and also to develop an optimal heat exchanger networks design using pinch analysis have been presented by various researchers (Linnhoff and Flower 1978; Linnhoff et al., 1982; Akande et al., 2007; Salomeh et al., 2008; Dagde and Piagbo, 2012; Ndaman, 2012; Azeez et al., 2013; Lukman, et al., 2016).

Energy saving is now the driving force for many process industries. Most manufacturing processes involve an exchange of heat from supply process stream to target; otherwise, from utility stream to a process stream. Currently, the objective of every process designer is to maximize heat recovery from process to process stream as well as minimizing the utility (energy) requirements. To achieve these objectives, suitable HENs are needed with the application of process integration techniques (Salomeh et al., 2008).

Pinch analysis incorporated in Aspen energy analyzer software was employed in this study to evaluate Naphtha Hydroteating Unit (NHU) of Kaduna refinery in form of HENs using pinch investigation where there are numbers of process hot stream and cold stream that need cooling and heating respectively. Our targets are to synthesis a HENs that will be used to convey high temperature stream to a low temperature stream region respectively, to obtain a minimum TAC network. This will establish basis for attaining minimum total cost of NHU heat exchanger networks of Kaduna refinery.

This study deals with selection of data, imputing data into simulation environment of the Aspen Energy Analyzer software to investigate the potentials and application of its principle in NHU of Kaduna Refining and Petrochemical Company (KRPC) for minimum TAC using Aspen Energy Analyzer.

2. METHODOLOGY

2.1. Data Collection

Data were collected from NHU of Kaduna Refining and Petrochemical Company (KRPC) Process Flow Diagram (PFD). The stream data collected were inlet and outlet temperatures, and mass flowrate times the specific heat capacity (MCp) respectively as show in Table 1.

Table 1: Collection of streams data from PFD of NHU of KRPC (Adapted from KRPC data 1980)

Stream Name	Stream Type	Supply T^S (^OC)	Target T^T (^OC)	MCP (Kcal/C-h)	Enthalpy (Kcal/h)
NHU Reactor Effluent	H1	370	125	$9.861x10^4$	$2.416x10^6$
NHU Stripper Bottom Exchanger	H2	237	133	$6.163x10^4$	$6.410x10^6$
NHU Stripper Reboiler	H3	221	190	$1.355x10^5$	$4.200x10^6$
NHU Heavy Naphtha Cooler	H4	137	48	$2.360x10^4$	$2.100x10^6$
NHU Reactor Effluent Cooler	H5	125	48	$7.701x10^4$	$5.930x10^6$
NHU Stripper OH Condenser	H6	77	48	$1.514x10^5$	$4.390x10^6$
NHU Stripper OH Trim Condenser	H7	72	55	$2.994x10^5$	$5.090x10^6$
NHU Light Naphtha	H8	55	35	$1.150x10^4$	$2.300x10^5$
NHU Stripper Oil Condenser	H9	48	40	$7.000x10^4$	$5.600x10^5$
NHU Reactor Effluent Trim C	H10	48	40	$6.500x10^4$	$5.200x10^5$
NHU Heavy Naphtha Trim C	H11	48	40	$2.125x10^4$	$1.700x10^5$
NHU LP Separator Charge C	H12	46	40	$5.833x10^4$	$3.500x10^5$
NHU Reactor Charge Heater	C1	293	370	$8.286x10^4$	$6.380x10^6$
NHU Stripper Reboiler Heater	C2	200	237	$3.973x10^5$	$1.470x10^7$
NHU Stripper Reboiler 2	C3	137	137.2	$4.200x10^7$	$2.008x10^6$
NHU Stripper Feed	C4	40	133	$6.893x10^4$	$6.410x10^6$
NHU Reactor Feed	C5	39	293	$9.512x10^4$	$2.416x10^6$

2.2. Simulation

Aspen energy analyzer from Aspen Hysys 8.0V in computer icon was launched. The Heat Integration Manager was opened to select HI project then the process stream was selected to input various streams data as shown in Table 1. In the simulation process, streams data were inputted into the heat integration manager Project dialogue box. A minimum temperature approach difference (ΔTmin) of 20ºC was selected in the dialogue box to generate composite and grand composite curves, which subsequently generated the energy targets (Heating and cooling utility requirement), number of unit targets, cost index target, area targets, and pinch temperatures.

2.3. Grid Design Selection of KRPC-NHU

Grid design of the NHU was selected from the various possible grid design options generated and recommended by the Aspen energy analyzer. The grid design with the minimum number of unit, area target, energy target and cost target respectively was selected on the basis of least minimum total cost.

2.4. Optimization of Selected Grid Design

The selected minimum total cost grid design was optimized using the Aspen Energy Analyzer optimization tool with objective function of minimizing Total Annual Cost (TAC) and constraints such as heat exchanger loads, split flow ratios. The appropriateness of the optimization command was observed in the optimization wizard displayed after the objective function and constraints were confirmed to be satisfactory. The optimal result was obtained when the simulation convergence bar shows no error and degree of freedom; infeasibilities, untied streams and temperature specifications were OK. Clicking RUN on the optimization wizard allow generation of the network cost indexes and the network performance.

2.5. Loop and Path Verification

Presence of loop in the optimal design of the heat exchanger network was verified and if found, the network requires additional heat exchanger (s), to break the loop with consequences of extra cost. The optimal design of NHU exchanger networks was verified by right clicking on the empty spot of the grid diagram environment and subsequently clicking of show loop button. Loop was found in the grid design and the heat exchanger involved was traced in the simulation work sheet and its load was reduced to zero to break the loop. The relaxation path was trace by right clicking on the empty spot of the grid diagram environment and subsequent clicking of show path button to trace heat path from heater to cooler to determine the violation of ΔTmin from the heater to a cooler by shifting heat loads along paths and ΔT was brought close to the ΔTmin.

3. RESULTS AND DISCUSSION

Table 2: Comparison of results for target and design of the HEN

Parameter	Target Report	Utility Target Cost index ($/s)	Network Performance	Network Cost Index	% of Target
Energy					
Heating (kcal/h)	1.395x10^{7}	270.79	1.228x10^{7}	238.4	88.04
Cooling (kcal/h)	1.440x10^{7}	27.96	1.273x10^{7}	24.73	88.41
Cost indexes					
Operating ($/s)	298.8	-	-	263.1	88.07
Capital (Cost)	2.068 x10^{6}	-	-	2.845x10^{6}	137.6
Total Cost ($/s)	298.8	-	-	263.1	88.08
Total annual ($/s)	-	-	-	-	
Number of Units					
Total Minimum	18	-	23	-	109.5
No of shell	67	-	66	-	98.51
Area					
Counter current (m^{2})	1.453 x10^{4}		-		
1-2 Shell and Tube (m^{2})	1.585 x10^{4}		-		
Total area (m^{2})	3.037 x10^{4}	-	2.489x10^{4}	-	157.1

The result obtained as in Table 2 shows the performance of the parameters of the network design and the percentage of target obtained showed that the optimal design performance minimum number of unit was 23 compared to the set target of 18. For energy target, a reduction was achieved requiring only about 88.04 % and 88.41 % of the target. The OTC of $263.1 /s was reduced from the initial target TAC of $298.8 /s at Minimum Temperature Approach (ΔT_{min}) of 15 ^{o}C and was obtained after optimization of the selected grid design and loop breakage.

The modified grid diagram is presented in Figure1 while Figure 2 and Figure 3 illustrate the composite curve grand composite curve of the hot utilities and cold utilities. The total cost of $263.1/s was obtained at the optimal temperature (ΔTmin) of 15 ^{o}C as shown in Figure 4, which falls within the range of values reported for petrochemical process utility matches (Linnhoff, 1998).

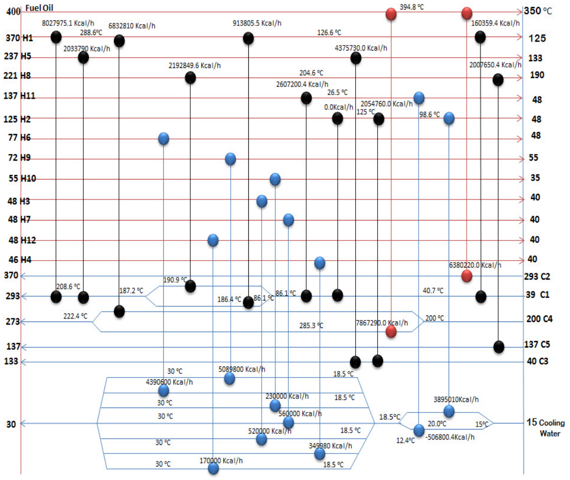

Figure 1: Modified grid diagram of NHU

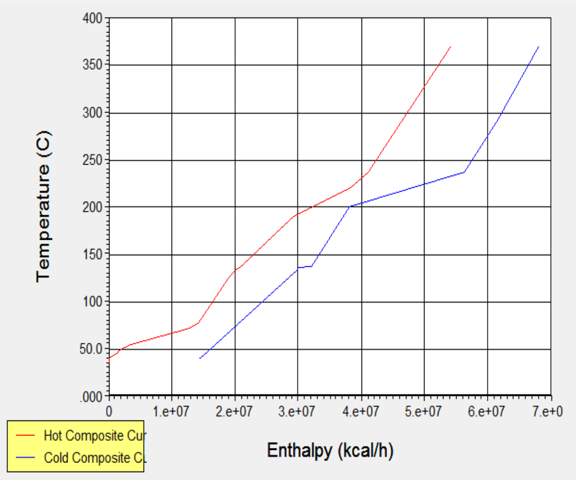

Figure 2: Composite curves for NHU

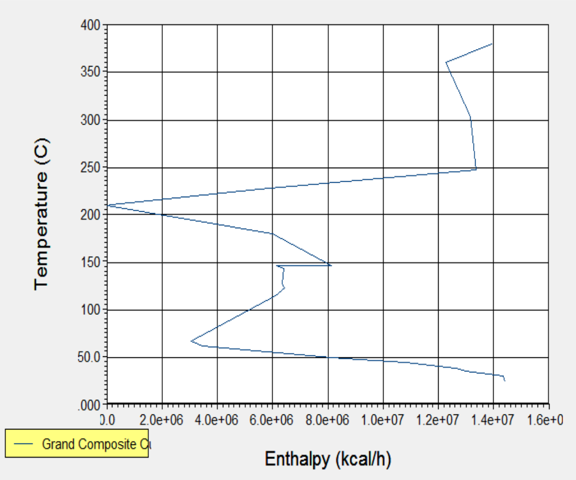

Figure 3: Grand composite curves for NHU

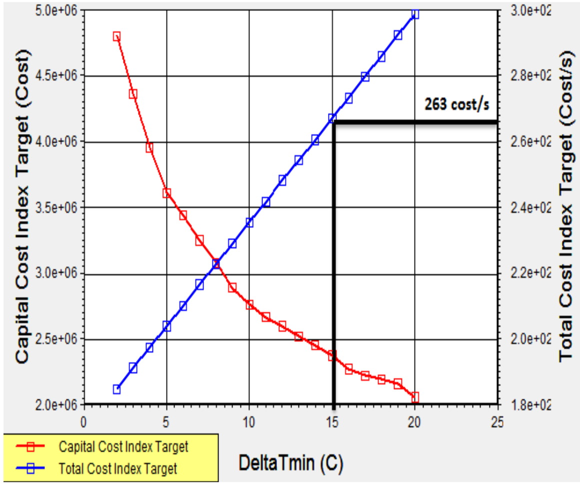

Figure 4: Tradeoff between capital and total costs and ΔTmin

It was found that the NHU deviation from the set target can be linked to a substantial number of deviations in the driving force plot as can be seen in the driving force plot in Figure 5. This shows the violation of pinch rules; stream transverse the pinch and cold utility over the pinch. This will lead to excess utility requirement for both hot and cold stream which lead to increase in the HENs size beyond the target.

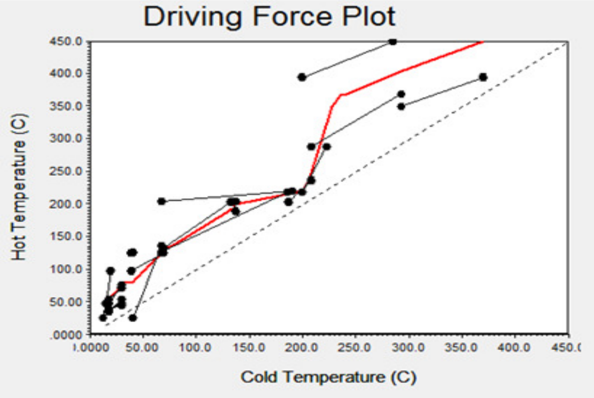

Figure 5: Hot stream and cold stream driving force

4. CONCLUSION

Comparison between the HENs of NHU of KRPC Target total cost with that of the design total cost shows a difference of $35.7/s with the selection of minimum approach temperature of 20 ^{O}C the optimum approach temperature was found to be 15 ^{O}C which is within the specified temperature range values of petrochemical company (Linnhoff, 1998).

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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