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Energy Integration Of Crude Distillation Plant Using Pinch Analysis (A Case Study Of Kaduna Refinery And Petrochemical Company, Nigeria)

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Abstract: Energy integration is a subdivision of a wider field of process integration, which is an efficient approach that allows industries to increase their profitability through reduction in energy, water and raw materials consumption. Pinch analysis principally matches cold and hot process streams with a network of exchangers so that the demands for externally supplied utilities are minimized. The aim of the research is to use pinch analysis to integrate energy used in crude distillation plant of Kaduna refinery and petrochemical company. Energy integration of crude distillation plant of Kaduna refinery and petrochemical company was carried out, using pinch technology with HENSAD software. The minimum approach temperature of 20^{o}C was used, the pinch point was found to be 222^{o}C. The hot utility requirement as the result of pinch analysis approach were found to be 57.650 MW while the cold utility requirement were found to be 2.638 MW respectively. Hence pinch analysis as an energy integration technique saves more energy and utilities cost than the traditional energy technique.

Keywords: Energy Integration, HENSAD Software, Pinch Point, Crude distillation unit, KRPC

I. INTRODUCTION

Pinch analysis is a methodology for minimizing energy consumption of a process plant by maximizing the utilization of hot and cold utilities available within the process, thereby reducing the use of external utilities. It is also known as process integration, heat integration, energy integration or pinch technology. Energy conservation has become one of the most current concerns due to continuous increase in energy prices. Among process integration methodologies, pinch analysis is the most widely used. This is due to the simplicity of its underlying concepts and especially to the spectacular results it has obtained in numerous projects worldwide. Before the advent of pinch analysis, industrial equipment were designed and operated separately in terms of external utilities, with pinch analysis those process equipment can be incorporated in order to minimize the use of external utilities such as energy, hydrogen and water. Process integration when combine with other tools such as process simulation or HENSAD (Heat exchanger network, simulation and design), is a powerful approach that allows engineers to systematically analyze industrial processes and the interaction between its various parts [1, 2, 3 and 4].

Pinch technology is a complete methodology derived from simple scientific principles by which it is possible to design new plants with reduced energy and capital costs as well as where the existing processes require modification to improve performance. Pinch Analysis also analyze the process data using its methodology to predict energy and other design targets such that it's possible to assess the consequences of a new design or potential modification before embarking on actual implementation [2, 6 and 4].

Wherever heating and cooling of process materials take place, there is a potential opportunity. The technology has been employed to solve problems as diverse as improving effluent quality, reducing emission, increasing product yield and debottlenecking, increasing throughput and improving the flexibility and safety of the process. Energy saving in the Nigerian industrial sector has several opportunities, due to the fact that almost all the industrial equipment stocks in Nigeria were imported during the era of cheap energy. Consequently, they are inherently energy inefficient, the improvement of energy efficiency can provide substantial benefit in general to all sector of the economy of the process plants [1].

A. OVERVIEW OF CRUDE DISTILLATION UNIT OF KADUNA REFINERY AND PETROCHEMICAL COMPANY

Crude oil comes from the ground, which contains variety of substances like gases, water and dirt (Minerals). Pretreatment of crude oil is important if the crude is to be processed without causing fouling and corrosion in the process equipment. Pretreatment of crude takes place in two ways which are field separation and crude desalting. The Crude Distillation Unit is a unit in Fuels section of Kaduna refining and Petrochemical Company (KRPC) where distillation of local crude into Naphtha, gasoline, kerosene, diesel and bottom residue is carried out. Raw crude oil is pumped to the CDU after settling and dewatering at the tank farm. It passes through a heat exchanger train, the desalter (for removal of salt and sediments), the pre-flash column (for removal of lighter ends) and the crude furnance where it is heated up, then to the fractionating column where the crude is separated into its components. The vapours are removed from the top, condensed and sent to saturated gas concentration unit (SGCU) for further separation and production of LPG or cooking gas while the liquids are withdrawn from the sides, based on the boiling point range [5and 7].

B. SIMILAR WORKS

Studies similar to present work have been done by several people among whicha few are listed below.

-K.R. Ajao and H. F. Akande worked on "Energy Integration of Crude Distillation Unit using Pinch Analysis." Pinch analysis methodology using Marple software was employed on the process streams of crude distillation unit of Kaduna refinery and petrochemical company, stream data was then extracted as hot and cold streams according to analysis procedure and all process heating and cooling duties were reviewed. As the result of the integration the hot and cold utility requirements were found to be 1.112×10^8 kJ/hr and 1.018×10^8 kJ/hr respectively. The pinch point temperature was found to be 220°C [7].

- Adejoh et al worked on "Energy Integration of Vacuum Distillation plant using Pinch Technology. (A case study of KRPC VDU Unit)" Energy integration and design approaches using pinch analysis methodology have been adopted to maximize heat recovery of VDU unit of Kaduna refinery and petrochemical company. All process heating and cooling duties were reviewed. The hot utility requirement of the process was obtained from the energy balance to be 0.32MW, however as the result of the integration it was reduced to 0.24MW while the cold utility requirement for the traditional approach and pinch analysis were found to be 0.31MW and 0.19 MW respectively [8].

II. MATERIALS AND METHODS

A. MATERIAL

The materials used include Process flow diagram, Pinch analysis software (HENSAD), Stream data of crude distillation unit of Kaduna refinery and petrochemical company and Computer set.

B. METHOD

The procedure involves process streams specification, data extraction and use of HENSAD software to simulate and design the energy process system. In streams specification, the process was divided into hot and cold streams. A hot stream is a stream that needs to be cold to satisfy the process need while cold stream is a stream that needs to be heated up to satisfy process need. In data extraction, the mass flow rate, specific heat capacity, input and output temperature and film heat transfer coefficient for each stream was extracted and finally the heat exchanger network simulation and design were carried out.

C. RUNNING OF HENSAD SOFTWARE

The HENSAD software was ran by first starting up the menu. This was done by double clicking on the HENSAD software to display the startup menu, file from the tool bar was clicked, a new command was selected and appropriate units was chosen. Hot streams data page was displayed, the hot streams data were computed then followed by the selection of cold streams from the tool bar. The cold streams data page was displayed, the cold streams data were computed and return to main menu was clicked. System from the tool bar was selected and ΔT_{min} was computed. Worksheet from the tool bar was clicked to select summary of table which displayed the summary of the data provided. Worksheet from the tool bar was clicked again to select the following commands from the tool bar one after the other:

TI Diagram which displayed the TI (temperature interval) diagram, from which the possible heat transfer intervals were obtained.

Cascade diagram which displayed the cascade diagram, from which the pattern of heat transfer from heat surplus to heat deficit intervals and the requirement of external utilities were obtained.

T-Q Diagram which displayed the T-Q (temperature-enthalpy) diagram, from which the pinch point, hot utility requirement, cold utility requirement and the possible heat recovery area were obtained.

Work sheet from the tool bar was clicked to select design above the pinch, from which the appropriate streams matching and network modification were performed. Also work sheet was clichéd again to select design below the pinch and appropriate stream matching and network modification were performed.

Figure 1 shows the procedure of pinch analysis using HENSAD software in a simple block diagram format.

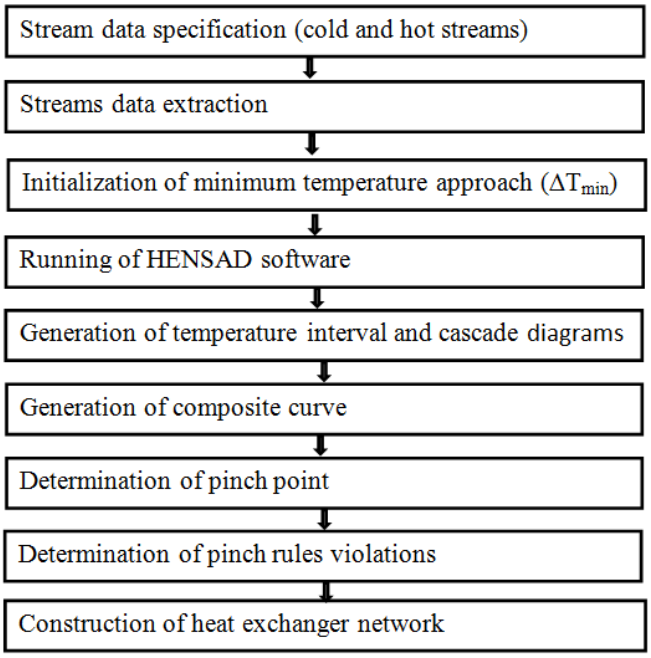

Figure 1: Procedure of Pinch Analysis Using HENSAD Software

III. RESULTS AND DISCUSSIONS

This section present the results obtained using the streams data of crude distillation unit of Kaduna refinery and petrochemical company Kaduna, Nigeria. The stream specification and data collection from the streams of crude distillation unit of Kaduna refinery and petrochemical company Kaduna, Nigeria were carried out for cold and hot steams as presented in Table 1.

S/N	Stream Type	Stream specification	Mass flow rates (kg/s)	Specific Heat cap (kJ/kg/°C)	Temp in (°C)	Temp out (°C)	Film Heat transfer coef (W/m² °C)
1	Hot	PA_3_Draw_To_PA_3_Return@COL1	48.67	2.810	319.0	244.0	45.00
2	Hot	WasteH₂O_To_Cooled WasteH₂O	20.13	2.200	73.00	40.00	680.0
3	Hot	Residue_To_Cooled Residue	32.41	2.830	347.0	45.00	643.0
4	Hot	PA_2_Draw_To_PA_2_Return@COL1	44.57	2.740	264.0	180.0	648.0
5	Hot	AGO_To_Cooled AGO	22.47	2.780	297.0	110.0	652.0
6	Hot	Diesel_To_Cooled Diesel	22.56	2.800	248.0	50.00	596.0
7	Hot	Naphtha_To_Cooled Naphtha	26.41	2.200	73.00	40.00	589.0
8	Hot	Kerosene_To_Cooled Kerosene	22.39	2.770	232.0	120.0	646.0
9	Hot	PA_1_Draw_To_PA_1_Return@COL1	46.24	2.690	167.0	70.00	700.0
10	Hot	To Condenser@COL1_TO_OffGas@COL1	28.54	2.680	147.0	73.00	420.0
11	Cold	Lowtemp crude_To_PreheatCrude1	78.0	2.100	30.00	232.0	740.0
12	Cold	PreFlashLiq_To_HotCrude1	70.0	2.790	232.0	343.0	752.0
13	Cold	KeroSS_To_Reb@COL1_TO_Kero@COL1	58.24	2.700	226.0	232.0	784.0
14	Cold	TrimDuty@COL1	170.0	2.820	343.0	398.0	810.0

Table 1: Data collected from the streams of crude distillation unit of Kaduna refinery and petrochemical company Kaduna, Nigeria

Table 1 present the streams data of crude distillation unit of Kaduna refinery and petrochemical company which was used to simulate and design the heat exchanger networks.

A. OUTCOME FROM HENSAD SOFTWARE

Table 2 and 3 present data for construction of temperature interval diagram and composite enthalpy temperature diagram respectively using 20°C as ΔTmin.

Number of Temperature Intervals = 20

Interval	Temperature Range °C	°C	Excess Heat kW	Cummulative Q kW
A	418.0	363.0	-26367	-26367
B	363.0	347.0	-7588.	-33955
C	347.0	319.0	-10712	-44668
D	319.0	297.0	-5407.	-50076
E	297.0	264.0	-6050.	-56126
F	264.0	252.0	-734.7	-56861
G	252.0	248.0	-471.9	-57333
H	248.0	246.0	-109.6	-57442
I	246.0	244.0	204.8	-57237
J	244.0	232.0	-411.8	-57649
K	232.0	180.0	1440.	-56209
L	180.0	167.0	-1227.	-57437
M	167.0	147.0	599.2	-56837
N	147.0	120.0	2874.	-53963
O	120.0	110.0	444.2	-53519
P	110.0	73.00	-667.4	-54186
Q	73.00	70.00	23.58	-54163
R	70.00	50.00	-2330.	-56493
S	50.00	45.00	970.5	-55523
T	45.00	40.00	511.9	-55011

Table 2: Data for construction of temperature interval diagram of CDU unit of KRPC

Temperature °C	Hot Stream Enthalpy kW	Temperature °C	Cold Stream Enthalpy kW
40.00	.0000	20.00	2638.
45.00	511.9	25.00	2638.
50.00	1482.	30.00	2638.
70.00	6628.	50.00	10114
73.00	7772.	53.00	11235
110.0	20936	90.00	25066
120.0	25118	100.0	28804
147.0	38085	127.0	38897
167.0	46160	147.0	46373
180.0	49792	160.0	51232
232.0	70670	212.0	70670
244.0	74743	224.0	75155
246.0	75696	226.0	75903
248.0	76648	228.0	76965
252.0	78301	232.0	79089
264.0	83257	244.0	84781
297.0	92859	277.0	10043
319.0	97885	299.0	11086
347.0	10045	327.0	12414
363.0	10045	343.0	13173
418.0	10045	398.0	15810

Table 3: Data for construction of composite-enthalpy - temperature diagram of CDU unit of KRPC

Figure 2, 3 and 4 are the temperature interval diagram, cascade diagram and composite enthalpy diagram of CDU Unit of KRPC respectively.

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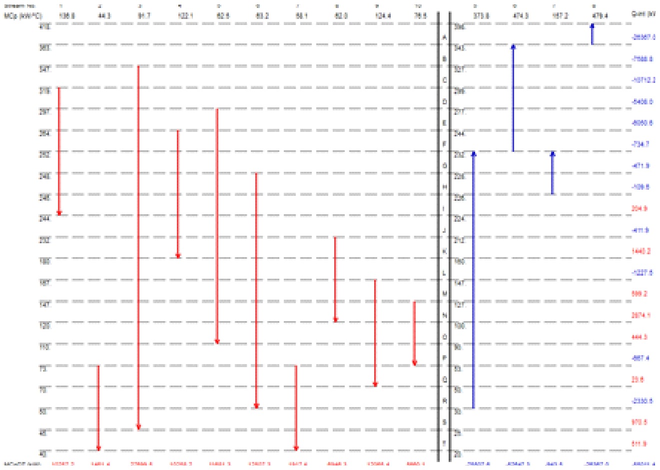

Figure 2: Temperature interval diagram of CDU unit of KRPC

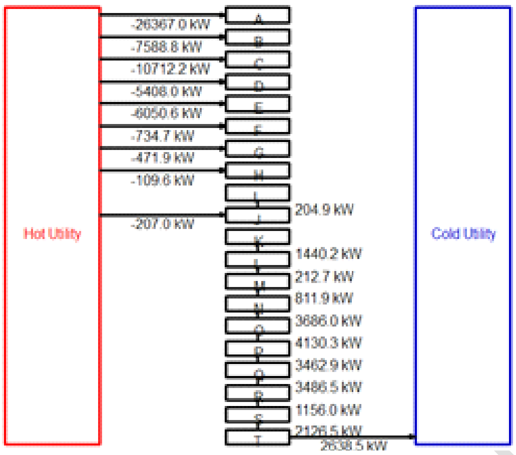

Figure 3: Cascade diagram of CDU unit of KRPC

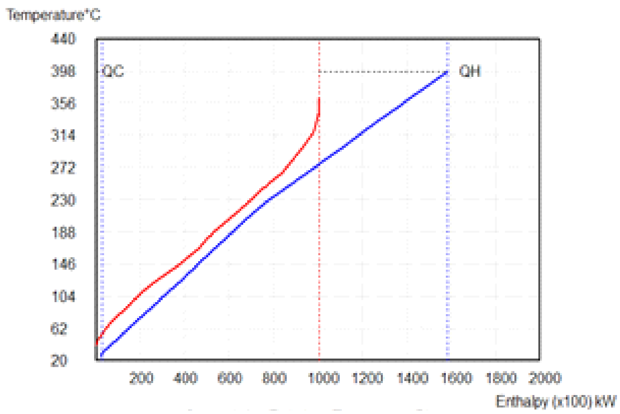

Figure 4: Composite curve diagram of CDU unit of KRPC

B. TEMPERATURE INTERVAL DIAGRAM AND CASCADE DIAGRAM

The minimum driving force of 20°C between the hot and cold streams were used. A graph showing the temperature intervals for hot and cold streams were established (Figure 2). The left side is for the hot streams while the right side is for the cold streams. 20 intervals were used, which means there are 20 points from A to T with possibilities of heat transfer within the system. The streams with arrow pointed downward are hot streams, which mean they have to be cooled to satisfy the process need. The streams with arrow pointed upward are cold streams. They have to be heated up to satisfy the process need. Table 2 tabulates the data for constructing temperature interval diagram.

The intervals were gotten by shifted temperatures. The shifted temperatures were gotten by subtracting the ΔTmin from the input and output temperatures of the hot streams and maintaining the input and output temperatures of the cold streams. The temperatures were arranged in descending order. In each interval heat from any hot streams were transferred to any of the cold streams in he interval. In interval A, only stream 14 at the cool side were present and there is no any stream on the hot side to transfer heat to stream 14 and also in interval B, only stream 12 at the cool side were present and there is no any stream on the hot side to transfer heat to it. From the cascade diagram it can be seen that from cascade A to I there is no heat transfer between the cascades and also between cascade J and K, but from cascade K down to cascade T there is possibility of heat transfer between the cascades.

The sum of the heat demand from cascade A down to cascade M and that of cascade J is the minimum hot utility requirement of the system which can only be externally supplied to satisfy the system need. The heat rejected by cascade T is the minimum cold utility requirement as there is no any cascade below cascade T that can absorb the rejected heat.

C. COMPOSITE CURVE

Table 3 tabulates the data for construction of the hot and cold composite curve. From Figure 4 the upper curve represents the hot streams composite curve while the lower curve represents the cold streams composite curve. The part of the hot streams composite curve that extends beyond the start of the cold streams composite curve cannot be cooled by heat recovery. Therefore is minimum cold utility requirement (2.638 MW). The part of the cold streams composite curve that extends beyond the start of the hot streams composite curve cannot be heated by heat recovery. Therefore is the minimum hot utility requirement (57.65 MW). The point where the two curves are closest is the pinch point and the corresponding temperature is the pinch temperature (222°C). Also from Figure 4 the hot pinch temperature was found to be 232°C and the cold pinch temperature was found to be 212°C. The minimum hot utility requirement, minimum cold utility requirement and the pinch point temperature were found to be 2.638 MW, 57.65 MW and 222°C respectively from both the cascade diagram and composite curve diagram.

D. DESIGN ABOVE AND BELOW THE PINCH

Figure 5 and 6 presents the heat exchanger network for design above and below the pinch respectively.

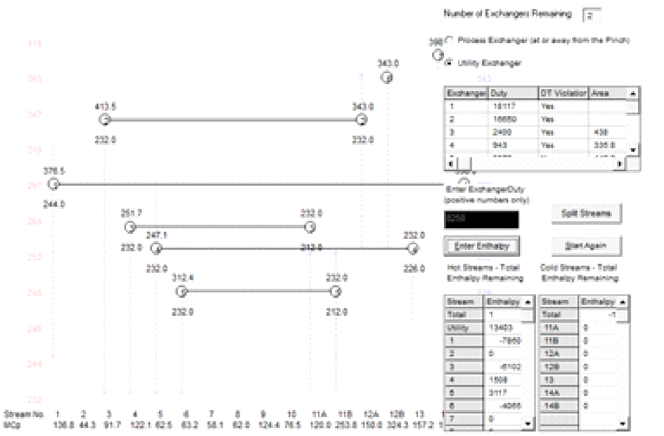

Figure 5: Heat exchanger network for design above the pinch

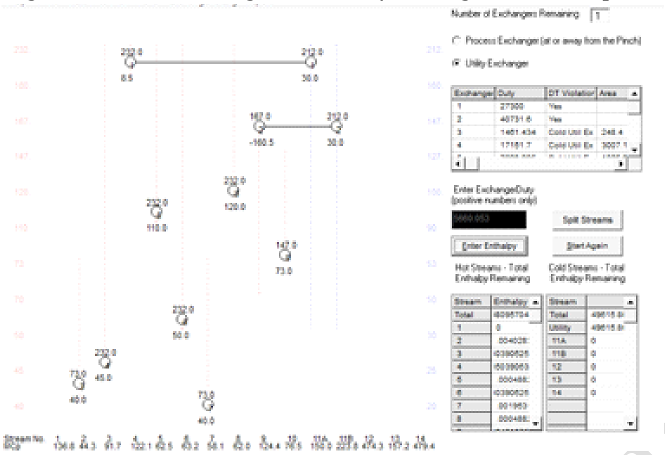

Figure 6: Heat exchanger network for design below the pinch

Figure 5 and 6 shows how heat transfers between streams were established for the design above and below the pinch respectively. From figure 5 streams 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 have heat surplus while streams 11, 12, 13 and 14 have heat deficit. Therefore the streams with heat surplus are rationally matched with streams with heat deficit. Streams 11, 12 and 14 were divided into A and B, one portion of the heat deficit of the divided streams was satisfied by heat transfer with the heat surplus streams while the other portion was satisfied by utility exchangers.

Figure 5 shows how the heat transfer between the streams were established, stream 1 was matched with stream 14B, stream 3 was matched with stream 12A, stream 4 was matched with stream 11A, stream 5 was matched with stream 13 and stream 6 was matched with stream 11B. Streams 12B and 14A were satisfied by utility exchangers.

From figure 6 it can be seen that stream 4 was matched with stream 11A and stream 9 was matched with stream 11B and streams 2, 3, 5, 6, 7, 8 and 10 were satisfied by utility exchangers.

IV. CONCLUSIONS

Energy integration of CDU unit of Kaduna refinery and petrochemical company was carried out using 20^{o}C as ΔTmin and the following conclusions were drawn The temperature interval, cascade and composite curve diagrams were constructed using the data obtained from the operating manual of CDU unit of Kaduna refinery and petrochemical company. The hot utility requirement, cold utility requirement and pinch point were found to be 57.65 MW, 2.638 MW and222^{o}C respectively from the cascade and composite curve diagrams. This research concentrated on energy integration of CDU unit of KRPC only. It is recommended to include VDU and FCCU units in the energy integration so that the excess heat rejected by one unit will be absorbed by the other unit, this can surely reduce the overall utility demand.

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REFERENCES

[1] Dayo F.B. (2000). Auditing Energy Use in an Operating Plant, Industrial Energy Management. Pp.34.

[2] Linnhoff B. (1983). New Concept of Thermodynamics for better Chemical Process Design, Royal Society Esso Energy Award Lecture, Chemical Research and Development. 61: 207-223.

[3] Linnhoff B. and Hindmarch E. (1983). Pinch Design Method of Heat Exchanger Network, Chemical Engineering Science 38: (5) Pp. 745-763

[4] Linnhoff B. and Vredeveld D. R. (1984). Pinch Technology has come of Age. Chemical Engineering Progress 33-40.

[5] Liebmann K. and Dhole V. R. (1995).Integrated Crude Distillation Design. European Symposium on Computer aided Process Engineering. Vol. 5, pp. 119-124, New Jersey.

[6] Akande H. F. (2007). Energy Integration of Thermal Hydro-dealkylation plant, M, Eng. Thesis, FUT Minna, Minna, Nigeria. Pp 2.

[7] Ajao K. R and Akande H.F. (2009). Energy Integration of crude distillation unit using pinch analysis. Science research publication. Vol 1(2), pp 54-66.

[8] Adejoh A. Z., Aloko D. F and Muhammad I. J. (2013). Energy Integration of Vacuum Distillation Plant Using Pinch Technology (A Case Study of KRPC VDU unit). Advances in Applied Science Research. Vol 4(2), pp 262-271.