Energy Integration of Atmospheric Distillation and Fluid Catalytic Cracking Units of Kaduna Refining and Petrochemical Company using Pinch Method

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Abstract: ***Energy integration of Atmospheric distillation unit (ADU)and Fluid catalytic cracking unit (FCCU) of Kaduna Refinery and Petrochemicals Company was carried out using pinch analysis with the aid of HENSAD. In order to achieve the aim of the study, cold and hot streams data of the two units in question were extracted from the plant's flow sheet and entered in to the spread sheet of the software appropriately and the following results were obtained; For the atmospheric distillation unit, the minimum temperature difference (∆Tmin) of 30°C was used and pinch point temperatures were 99°C and 69°C for hot and cold utilities respectively. Also, existing energy was25324kW, the target was 18754kW and the energy saved was 31% (6570kW) for the hot utilities; existing energy was31733kW, the target was 21722 kW and the energy saved was 26% (10, 011kW) for the cold utilities, with a total amount of $9, 582, 436.25 that could be saved annually. For the fluid catalytic cracking unit, the minimum temperature difference (∆Tmin) of 25°C was used and pinch point temperatures were 110°C and 85°C for hot and cold utilities respectively. Also, existing energy was308952.7kW, the target was 243978kW and the energy saved was 21% (64974.7kW) for the hot utilities; existing energy was310340.4kW, the target was 242590 kW and the energy saved was 21.8% (67750.4kW) for the cold utilities, with a total amount of $76, 704, 047.4 that could be saved annually.***

Keywords: Pinch analysis, Energy integration; pinch point, utility, heat exchanger

1. Introduction

Prior to the energy crisis of the 1970s, chemical plants were designed using the traditional design techniques which involve mass and energy balances, rules of the thumb, good engineering judgment and creative ability of the designers. Such designs were neither optimal in terms of energy consumption nor in capital cost invested (Linnhoff, 2000). Since then however, much attention has been directed at better process design, particularly in the area of process network design and process integration. A process integration method called the pinch design method (pinch technology) was developed in the late 1970s. The success of the pinch design method was due to the discovery of the heat recovery pinch phenomenon.

Pinch technology became available to industry about 1980 and since then its application to both new designs and retrofits has become well established. Refineries designed and installed before 1980 did not enjoy the benefit of insights from the new developments in energy saving technologies (Linnhoff, 2000).

Energy today has become the most needed and sought for resource in our world, and it is being consumed at a high rate, there is however high utilization of energy which could be minimized in some units in industries with proper management. The high utilization of energy in the atmospheric distillation unit and fluid catalytic cracking unit of kaduna Refining and Petrochemical Company as well as continuous increase in price and demand of energy and environmental pollution gives a justification to increasing energy efficiency by minimizing its consumption and improving profitability in this industry. A good number of research works on energy integration using pinch analysis has been reported in history, but these works are majorly related to comparison between pinch analysis and traditional method of energy saving of different chemical industries. However, no work has been done on the FCCU and ADU of Kaduna Refining and Petrochemical Company, especially after the shutdown of the Company in December 2015.

Energy integration is a division of process integration (Adejoh et al., 2013). It is an efficient process that allows industries to increase their profitability through reduction in energy, water and raw materials consumption, reduction in greenhouse gas (GHG) emissions, and waste generation (Adejoh et al., 2013).

Process integration (PI) as a part of process intensification is a fairly new term that emerged in the 80's and has been extensively used in the 90's to describe certain systems oriented activities related primarily to cover almost complete process design (Rossiter, 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 (Rossiter, 2012).

Fluid catalytic cracking unit without any doubt belongs to the most important refinery technologies. This process converts heavy atmospheric residues and vacuum distillates into fractions of motor fuels, mainly gasoline. The history of the beginning of the cracking of heavier crude molecules to lighter lead to the beginning of the crude oil applications in combustion engines.

The atmospheric 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.

Pinch analysis provides a systematic methodology for energy saving in processes and total sites. The methodology is based on thermodynamic principles (Linnhoff, 2000). A pinch analysis starts with the heat and material balance for the process. Using pinch technology, it is possible to identify appropriate changes in the core process conditions that can have an impact on energy savings (Linnhoff, 2000).).

This work aims at using pinch analysis to integrate the energy and to determine theoretically the amount of energy that could be recovered and reused in the process as well as financial savings in the atmospheric distillation and fluid catalytic cracking units of Kaduna Refining Petrochemical Company, Kaduna, Nigeria.

2. Materials and Method

2.1 Materials

The materials include Process Flow Diagrams (PFD), Operating Data of the Atmospheric Distillation Unit (ADU), Fluid Catalytic Cracking Unit (FCCU) of the KRPC, Microsoft Excel Spread sheet and the Heat Exchanger Network Synthesis and Design (HENSAD) software, Computer sets (Hp, windows 8.0).

2.2 Method

This presents all the steps involved in the analysis, designing and optimization of heat exchangers network of ADU and FCCU of Kaduna Refining and Petrochemical Company. Data such as streams temperature, pressures, flow rates, feed parameters were extracted from the process flow diagram. In performing a pinch analysis using HENSAD software the following procedures were used.

1) Pinch Analysis:

i. Run the HENSAD program on your computer system.
ii. Click on file, and after that click on new.
iii. The software will take you to a page where you can input values for mass flow rates, temperature source, temperature targets and heat transfer coefficients of the hot streams.
iv. Click on 'go to cold streams' and input the values for the cold streams.
v. Click on 'Return to main menu' and change the value for ΔTmin.
vi. Go to worksheet and click on summary table, the software will automatically calculate values for QHmin, QCmin, and the pinch point temperatures.
vii. From the worksheet, you can also view the temperature interval diagram, the cascade diagram and the composite curve diagram.
viii. Go to worksheet, click on 'design above the pinch'. Use the procedure for matching streams above the pinch and match the hot and the cold streams.
ix. The program will check for ΔT violations and calculate the exchanger duty, area and cost.
x. Return to main menu.
xi. Click on the worksheet.
xii. Go to 'design below the pinch' and repeat the procedure used above the pinch.

3. Results and Discussion

3.1 Results for Atmospheric Distillation Unit

1) Data Extraction for ADU: The ADU target and supply temperatures for the cold stream ranges from 40 – 2440C and 73 – 3470C respectively while that of hot stream are 231 – 3510C and 226 – 3450C respectively. 30°C was used as the minimum temperature approach (ΔTmin). A furnace provides utility heating in the crude pre-heat train of ADU. The furnace design which was represented for fired heaters for the pinch analysis as a heat source and as a single temperature that is hot enough to satisfy any anticipated heat load in the unit.

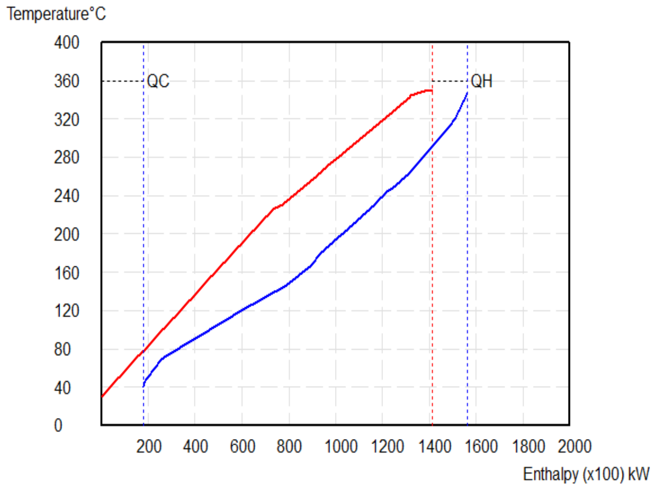

Figure 2: Composite curve diagram using HENSAD

Figure 2 is a plot of both the hot and cold against enthalpy which gave a pinch point temperature of 99oC and 69oC for the hot and cold streams respectively. The closest distance between the hot and the cold curves is the ΔTmin value. The areas where the two curves do not overlap show the minimum utility requirements. This plot illustrates the effect that the chosen value of ΔTmin has on the minimum heating and cooling utility requirements. The target heat for hot streams (QHmin) and cold stream (QCmin) obtained from the HENSAD software were 15017 kW and 17985 kW respectively.

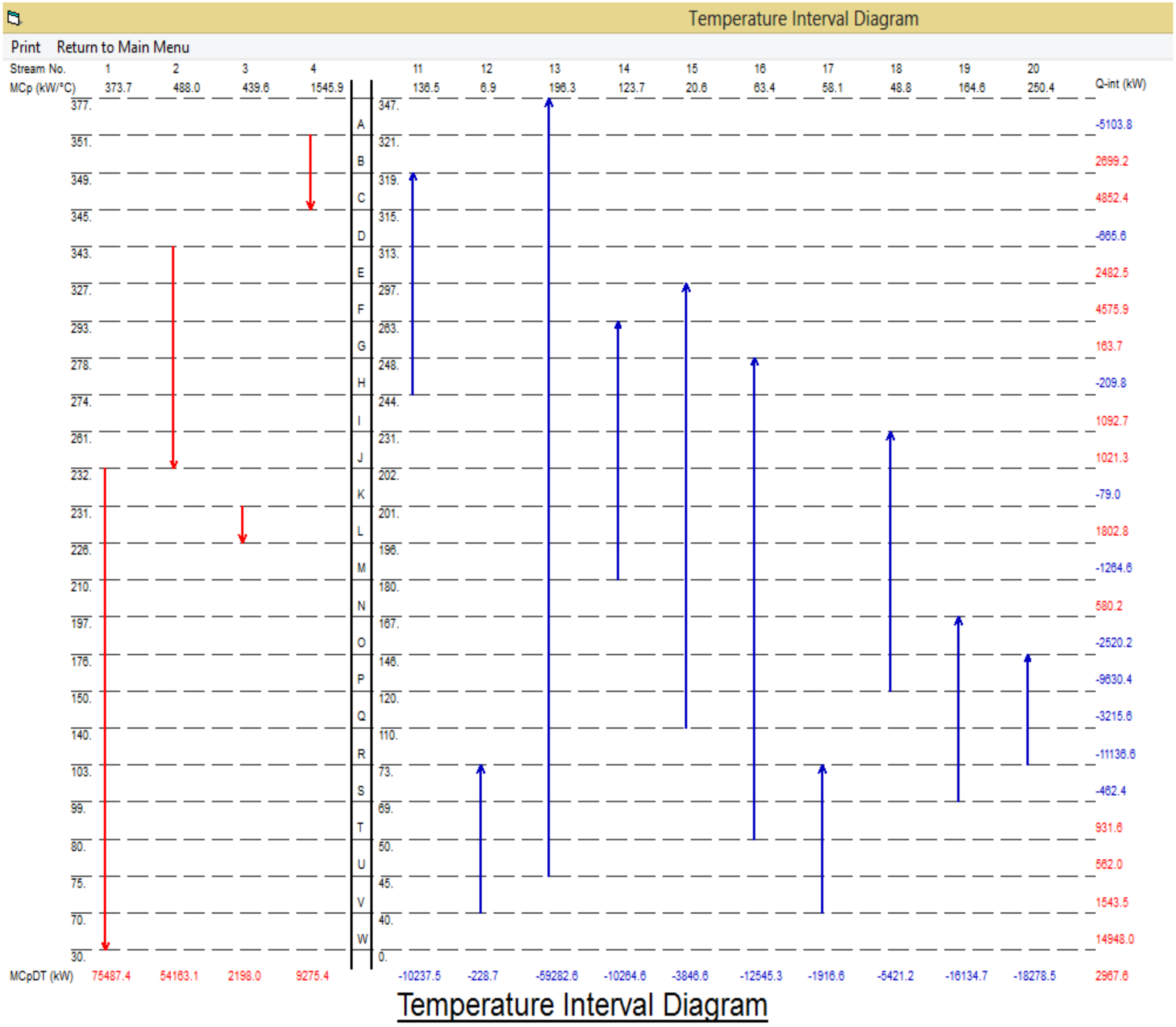

Figure 3: Temperature Interval Diagram using HENSAD

The temperature interval diagram in Figure 3 above is a visual representation of the hot and cold streams, showing their relationship in regards to the amount of heat that can be transferred (www.uic-che.org). There are hot streams and cold streams as indicated; the horizontal grid lines indicate the temperature intervals with the thickest black line indicating the pinch temperature. It shows how heat can be transferred from hot streams to cold streams without crossing the pinch. A heat exchanger is created to handle the transfer of heat from the hot stream to the cold stream.

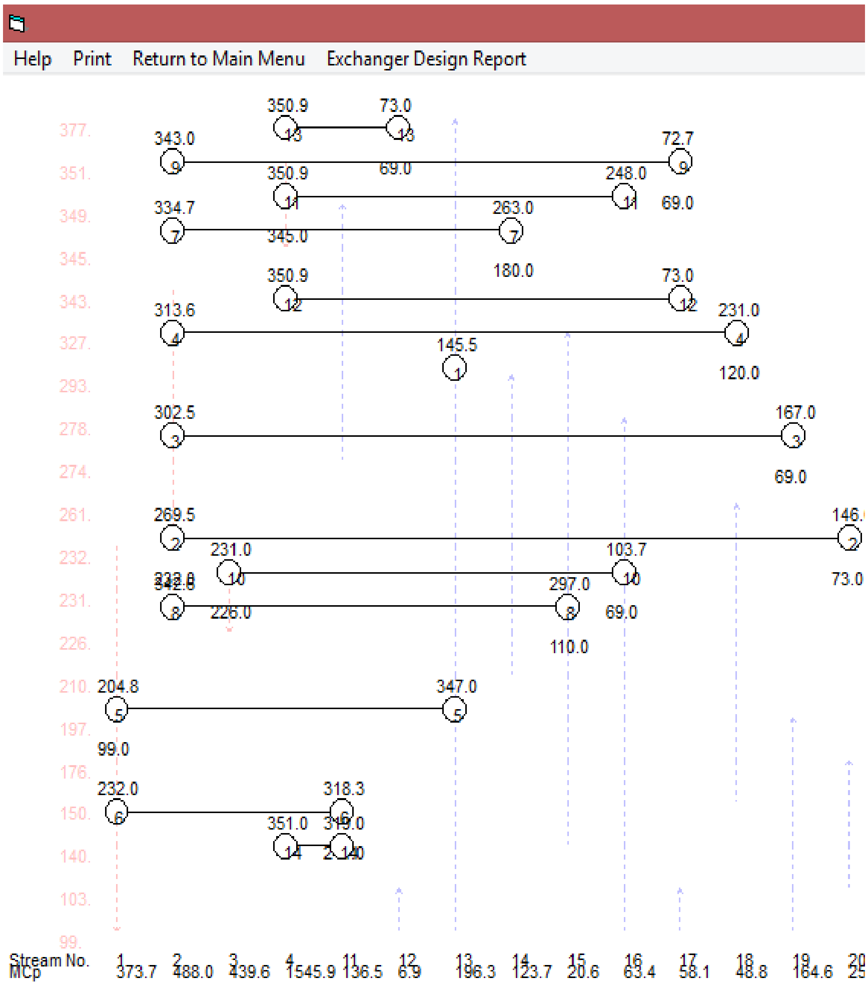

Figure 4: HENSAD (Above the pinch)

The heat exchanger network design in Figure 4 above with minimum allowable approach temperature of 30°C shows a total number of 17 process heat exchangers and 2 utility heat exchangers. The results show that the utility heating of the plant is slightly higher than the utility cooling of the plant. Therefore, any utility cooling supplied to the process above the pinch temperature cannot be absorbed and will be rejected by the process to the heating utility, increasing the amount of heating utility required (Linnhoff and Ahmad 1983), hence waste of energy (hot utilities) by the crude pre-heat train.

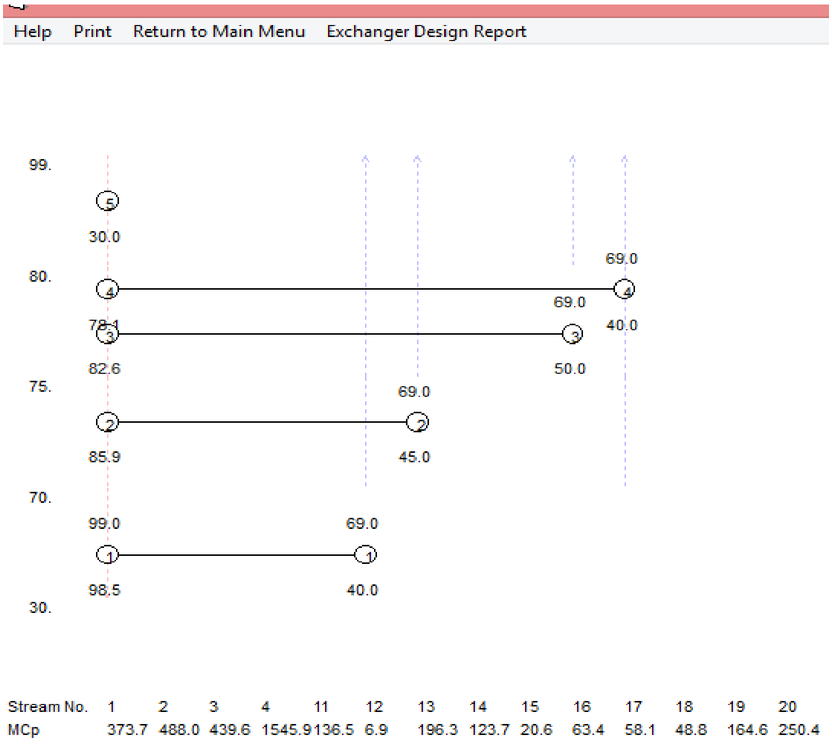

Figure 5: HENSAD (below the pinch)

The heat exchanger network design in Figure 5 above with minimum allowable approach temperature of 30^{o}C shows a total number of 17 process heat exchangers and 2 utility heat exchangers. The results show that the utility heating of the plant is slightly higher than the utility cooling of the plant. Therefore, any utility cooling supplied to the process above the pinch temperature cannot be absorbed and will be rejected by the process to the heating utility, increasing the amount of heating utility required (Linnhoff and Ahmad 1983), hence waste of energy by the crude pre-heat train.

2) Economic Analysis:

Table 3: Existing and target hot and cold demand for Atmospheric distillation unit

Atmospheric distillation unit	Existing plant	Target	Amount saved
Hot utility (kW)	25324	18754	6570
Cold utility (kW)	31733	21722	10011

$$\%Hot\,Utility = \frac{(25324-18754)}{25324} \times 100 = 26\%$$

$$\%Cold\,Utility = \frac{(31733-21722)}{31733} \times 100 = 31.5\%$$

Assuming plant attainment = 95%

$$Per\,annum = 365 \times 95\% = 346.75\,days = 346.75 \times 24\,hrs = 8322\,hrs$$

Hot utility:

$$Energy\,saved\,in\,kWH = 6570 \times 8322 = 54675540\,kWH$$

Cost of energy saved:

1kWH = N25

$$Cost\ of\ energy\ saved = 25 \times 54675540 = N1{,}366{,}888{,}500$$

Cold utility:

$$Energy\ saved\ in\ kWH = 10011 \times 8322 = 83311542\ kWH$$

Cost of energy saved:

1kWH = N25

$$Cost\ of\ energy\ saved = 25 \times 83311542 = N2{,}082{,}788{,}550$$

3.2 Results for fluid catalytic cracking unit (FCCU)

1) Data Extraction for FCCU:

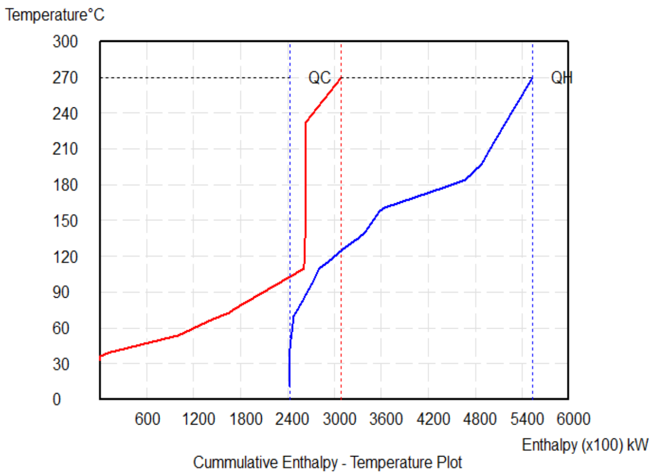

Figure 6: Composite curve for FCCU

From the composite curve in Figure 6 above it was found that the minimum utilities requirements are 308952.7 kW and 310340.4 kW for the hot and cold utility respectively.

The above figure identifies the possible pinch site of the two hot and cold streams and the minimum temperature difference, ΔT_{min} between these two streams. The major use of this traditional composite is to determine the heat energy targets such as heat recovery, cold utility and hot utility requirements at the denoted ΔT_{min} of 25^{o}C

The composite curve in Figure 3 also reveals that there is only one pinch point which 270^{o}C. This makes this study viable because the bottleneck can be controlled by adjusting the ΔT_{min}. The hot and cold utilities can also be determined from the composite curve.

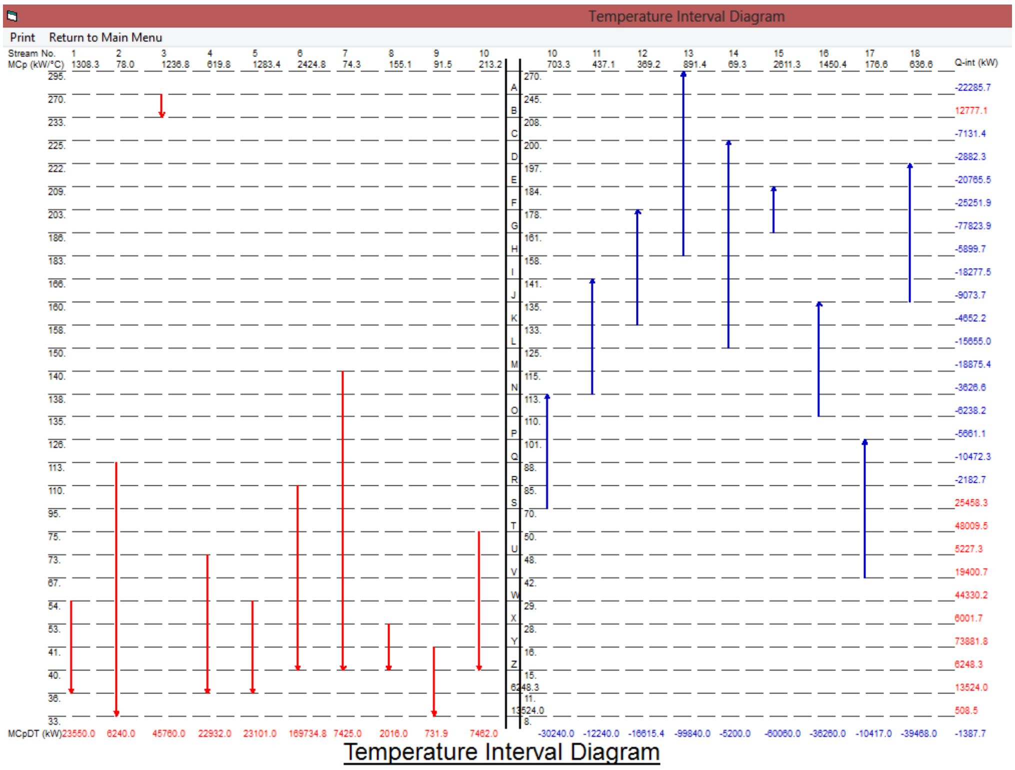

Figure 7: Temperature Interval Diagram for FCCU using HENSAD

The temperature interval diagram in Figure 7 above is a visual representation of the hot and cold streams, showing their relationship in regards to the amount of heat that can be transferred (www.uic-che.org). There are hot streams and cold streams as indicated; the horizontal grid lines indicate the temperature intervals with the thickest black line indicating the pinch temperature. It shows how heat can be transferred from hot streams to cold streams without crossing the pinch. A heat exchanger is created to handle the transfer of heat from the hot stream to the cold stream.

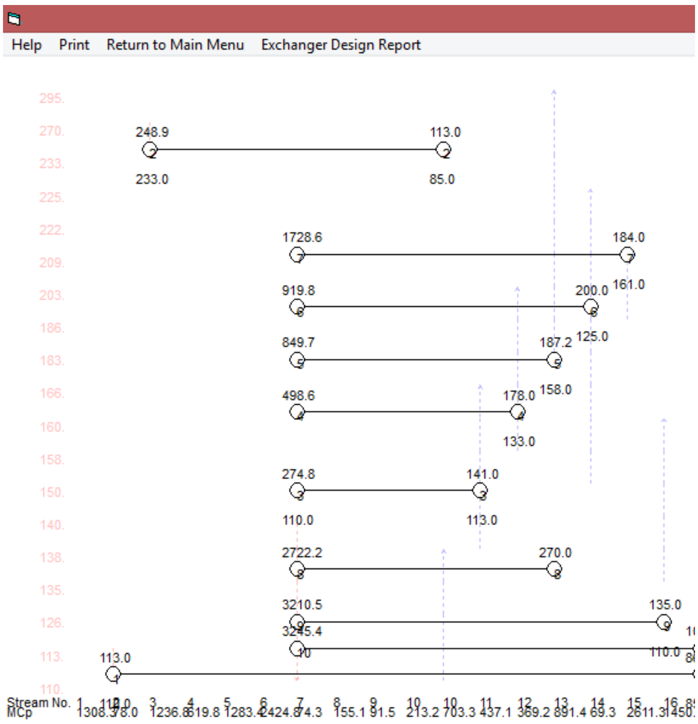

Figure 8: HENSAD (above the pinch)

The above the pinch region has five hot streams, and two cold streams. Only hot utilities can be used in this region, the hot utility used in the study is a fired heater operating at a temperature of 1000°C. The above the pinch design as shown in figure 19 shows all the hot streams satisfied by heat exchanger networks with the nine cold streams.

Figure shows the Heat Exchanger Network Design (above the pinch) using HENSAD software.

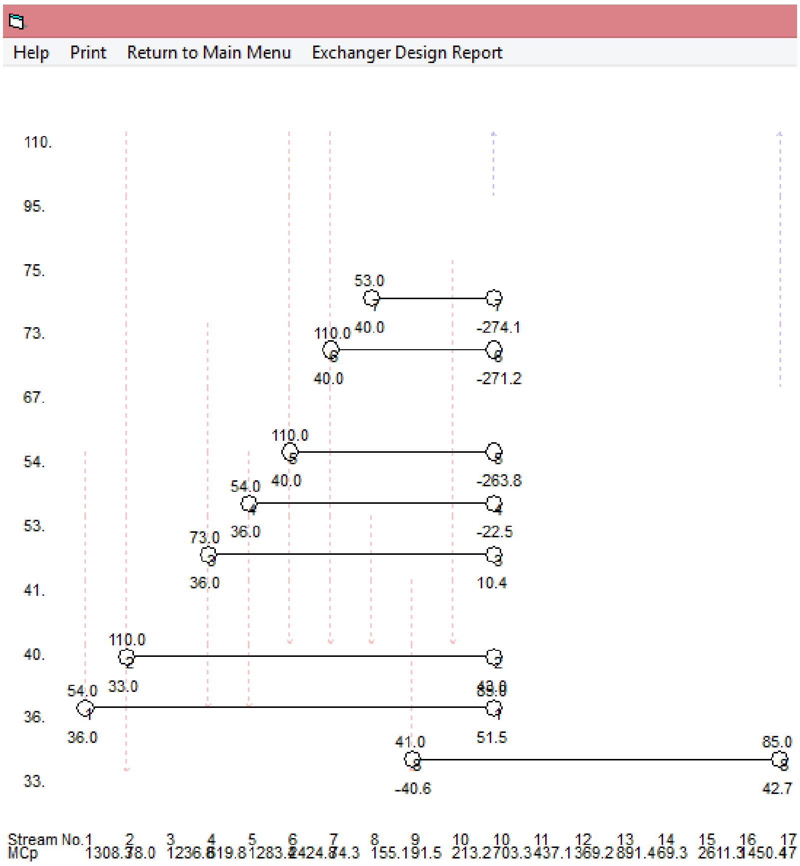

Figure 9: HENSAD (below the pinch)

The below the pinch region has four hot streams and eleven cold streams. Only cold utilities can be used in this region. There are eleven cold utility matches required to satisfy all the hot streams that was not satisfied by the matches in this region. The below the pinch design as shown in Figure 9 shows all the cold streams satisfied by heat exchanger networks with the available hot streams.

2) Economic Analysis:

Table 13: Existing and target hot and cold demand for fluid catalytic cracking unit

Fluid catalytic cracking unit	Existing plant	Target	Amount saved
Hot utility (kW)	308952.7	243978	64974.7
Cold utility (kW)	310340.4	242590	67750.4

$$\%Hot\,Utility=\frac{(308952.7-243978)}{308952.7}\times 100=21\%$$

$$\%Cold\,Utility=\frac{(310340-242590)}{310340}\times 100=21.8\%$$

Assuming plant attainment = 95%

$$Per\,annum=365\times 95\%=346.75\,days=346.75\times 24\,hrs=8322\,hrs$$

Per annum = 365×95%
= 346.75 days
Converting to hours = 346.75 × 24
= 8322 hrs

Hot utility:

$$Energy\, saved\, in\, kWH = 64974.7 \times 8322 = 540719453.4\, kWH$$

Cost of energy saved:
1kWH = N25

$$Cost\, of\, energy\, saved = 25 \times 540719453.4 = N13,517,986,335$$

Cold utility:

$$Energy\, saved\, in\, kWH = 67750.4 \times 8322 = 563818828.8\, kWH$$

Cost of energy saved:
1kWH = N25

$$Cost\, of\, energy\, saved = 25 \times 563818821.8 = N14,095,470,720$$

4. Conclusions

The following are points in concluding the energy integration of the fluid catalytic cracking unit and the atmospheric distillation unit of Kaduna Refining and Petrochemical Company using pinch analysis.

For the atmospheric distillation unit, the energy saved was 10, 011 kW and 6, 570 kW for the cold and hot utilities respectively. For the fluid catalytic cracking unit, the energy saved was 64974.7 kW and 67750.4 kW for hot and cold utilities respectively.
For the atmospheric distillation unit, N3, 449, 677, 050 could be saved annually and N27, 613, 457, 055 per year could be saved for fluid catalytic cracking unit.

For the atmospheric distillation unit, ΔT min value of 30oC was used and pinch point temperatures were 99oC and 69oC for hot and cold utilities respectively.

For fluid catalytic cracking unit ΔT min value of 25oC was used and pinch point temperatures were 110oC and 85oC for hot and cold utilities respectively.

Composite curves were developed and used to determine the pinch points of both units.

Pinch analysis is an effective method for saving energy.

References

[1] Abtin A., (2011), Application of combined pinch and exergy analysis in retrofit of an Olefin Plant for Energy Conservation, Scientific Research and Essays, vol.6, 2437
[2] Ajao K.R and Akande H.F (2009); Energy Integration of Crude Distillation Unit using Pinch Analysis, Researcher, 1(2) 54-65
[3] Adejoh A.Z., Aloko D. F., Muhammad I.J., (2013); Energy Integration of Vacuum Distillation Plant Technology, Advances in Applied Science Research, 4(2) 262-271
[4] Babatope O., Kayode L, Ayokunle O., (2013), Riser Reactor Simulation in a Fluid Catalytic Cracking Unit, Chemical and Process Engineering Research (7), 12
[5] Barnes S. (2013), Using pinch analysis to optimize the Heat Exchanger Network of Regenerative Rankine Cycle for an Existing Modern Nuclear Power Plant, Rensselaer, p.6
[6] Beninca M., Trierweiler J. O. and Secchi A. R. (2011), Heat Integration of an Olefins Plant: Pinch Analysis and Mathematical Optimization Working Together, Brazilian Journal of Chemical Engineering, 98
[7] Ernst Worrell, Mariëlle Corsten, and Christina Galitsk, (2015), Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries An Energy Star Guide for Energy and Plant Managers, Lawrence Berkeley National Laboratory, p. 11
[8] Elamurugan P and Dinesh K. D., (2010), Modeling and Control Of Fluid Catalytic Cracking Unit in Petroleum Refinery, International Journal of Computer Communication and Information System, Vol.2, 55
[9] Emerson J., (2012), Improving Refinery Fluid Catalytic Cracking Unit with Process Gas Chromatographs, Emerson Process Management, pp.1-2
[10] Galitsky C, Ernst W., Lynn P., Nathan M. and Michael R., (2006), Energy Efficiency Improvement Opportunities for the Petroleum Refining Industry, Environment Energy Technologies Division, 1-3
[11] Gorica R. Ivaniš I, Lazarević M, Ivona R. R., Mirjana L. K (2015). Energy Integration of Nitric Acid Production using Pinch Methodology, Professional Paper Hem. Ind. (69)
[12] Gupta R. S., (2006), Modeling and Simulation of Fluid Catalytic Cracking Unit, pp.1-6
[13] Gunnarsson A. and Magnusson C., (2011), Pinch Analysis of Nynas Refinery, an Energy Efficiency Study Chalmers University of Technology Göteborg SE-412, 1-6
[14] Hudec P., (2011), FCC Catalyst-key Element in Refinery Technology, 45th International Petroleum Conference, pp. 1-2
[15] Ignacio E. G., Mariano M. and Linlin Y. (2013); Review of Optimization Models for Integrated Process Water Networks and their Application to Biofuel Processes
[16] John J. (2015); Fluidized Catalytic Cracking: Colorado School of Mines, JJechura[at]mines.edu, p.2
[17] Johnson P. W. and Tim A.G.L. (2006); Pinch and Exergy Analysis in Drying: A Thermodynamic Backbone for Process Optimization and Environmental Assessment, University of Sydney, pp1-4
[18] Kemp I.C (2007), Pinch Analysis and Process Integration, a user guide on Process Integration for the efficient use of energy, second edition, pp. 15-97

[19] Kuldeep P., (2012), Simulation of Fluid Catalytic Cracker, National Institute of Technology Rourkela, pp.1-6
[20] Linnhoff B., (2000), Introduction to Pinch technology, pp. 4-10
[21] Linnhoff B., (1983), Design of Heat Exchanger Networks – a short course. Department of Chemical Engineering, UMIST, Manchester, 8-20
[22] Linnhoff B, D.W. Townsend, D. Boland, G.F. Hewitt, B.E.A. Thomas, A. R. Guy, and R.H. Marsland (1983). "User Guide on Process Integration for the Efficient Use of Energy", IChemE, Rugby, U.K, 742-748
[23] Linnhoff B., and D. R. Vredeveld (1984). "Pinch Technology Has Come Of Age", Chem. Eng. Progress, 80 (7), pp. 33-40.
[24] Mehran H, Habib A. and Bahram D., (2010), Study of Seven lump kinetic Model in the Fluid Catalytic Cracking Unit, American Journal of Applied Sciences, p.71
[25] Olsen D. and Wellig B. (2011); Practical Heat Integration Analysis in the Process Industries Lucerne School of Engineering and Architecture, Switzerland, World Engineers Convention.
[26] Rossiter P.A. 2010, Improved energy efficiency through Heat Integration, American Institute of Chemical Engineers p.33
[27] Rossiter P.A (2012), Pinch analysis: for the efficient use of energy, water and Hydrogen, Energy recovery at a Fluid Catalytic Cracking Unit, pp.7-15
[28] Wang, Y., Smith, R. and Kim, J.-K. 2012. Heat Exchanger Network Retrofit Optimization Involving Heat Transfer Enhancement. Applied Thermal Engineering. 43: 7-13.
[29] Weijin L., Ali A. and Rajab K., (2010); Pinch Analysis for Integration of Coal-Fired Power Plants with Carbon Capture,20th European Symposium on Computer Aided Process Engineering