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Energy integration of catalytic reforming unit (CRU) using pinch analysis

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ABSTRACT

Energy Integration of Catalytic Reforming Unit of Kaduna Refinery and Petrochemicals Company were carried out using Pinch Technology. Optimum minimum approach temperature of 20^{O}C was used to determine the energy target. The pinch point temperature was found to be 278^{O}C. The utilities targets for the minimum approach temperature were found to be 72711839.47 KJ/hr and 87105834.43 KJ/hr for hot and cold utilities respectively. Pinch analysis as an energy integration technique saves more energy and utilities cost than the traditional energy technique.

Keywords: Pinch, CRU, Energy Target, Maple, Composite Curve.

INTRODUCTION

Energy saving in the Nigerian industrial sector has several possibilities, due to the fact that, almost all the industrial equipment stock in Nigeria were imported during the era of cheap energy. Consequently, they are inherently energy inefficient [1]. 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. An additional major advantage of the Pinch approach is that, it simply analyzes the process data using its methodology, more so, energy and other design targets are predicted such that it is possible to assess the consequences of a new design or a potential modification before embarking on actual implementation. Process integration PI, is an efficient approach that allows industries to increase their profitability through reduction in energy, water and raw materials consumption, reduction in green house gas (GHG) emissions, and waste generation [2]. Process integration, combined with other tools such as process simulation, is a powerful approach that allows engineers to systematically analyze an industrial process and the interaction between its various parts [3].

PI technology may be applied to address the industrial issues such as, energy saving and green house gas emission, optimization of batch processes, optimization of hydrogen use, reactor design and operation improvement, minimization of water use and waste water production, optimization of separation sequences, waste minimization, utility system optimization and investment cost reduction [4].

The power of pinch technology lies in two factors, these includes its ability to quickly evaluate the economics of heat recovery for a given process and the guidance it provides regarding how a process can be modified in order to reduce associated utility needs and costs [5].

MATERIALS AND METHODS

The procedure involved data extraction, process simulation and pinch analysis. The methodology involves analyzing the existing Heat Exchangers Network of the unit in order to extract all the necessary information required for the analysis [6].

Data Extraction

This involved thorough study of the Process Flow Diagram (PFD) and Laboratory analysis of the feed (Whole Naphtha) and Products (Reformate) of CRU in order to extract all the necessary and available information required to carry out the process simulation, and the pinch analysis of the unit. The stream temperatures, pressures and mass flow rates, were also extracted from PFD for carrying out the process simulation [7]. The process simulation was necessary in order to determine parameters such as the stream duty and CP (Heat capacity x Flow rate) which were used in carrying out the pinch analysis with the aid of Aspen HX-NET program and maple software [8].

Methodology for Pinch Analysis

The procedure for carrying out pinch analysis is shown in figure 1.

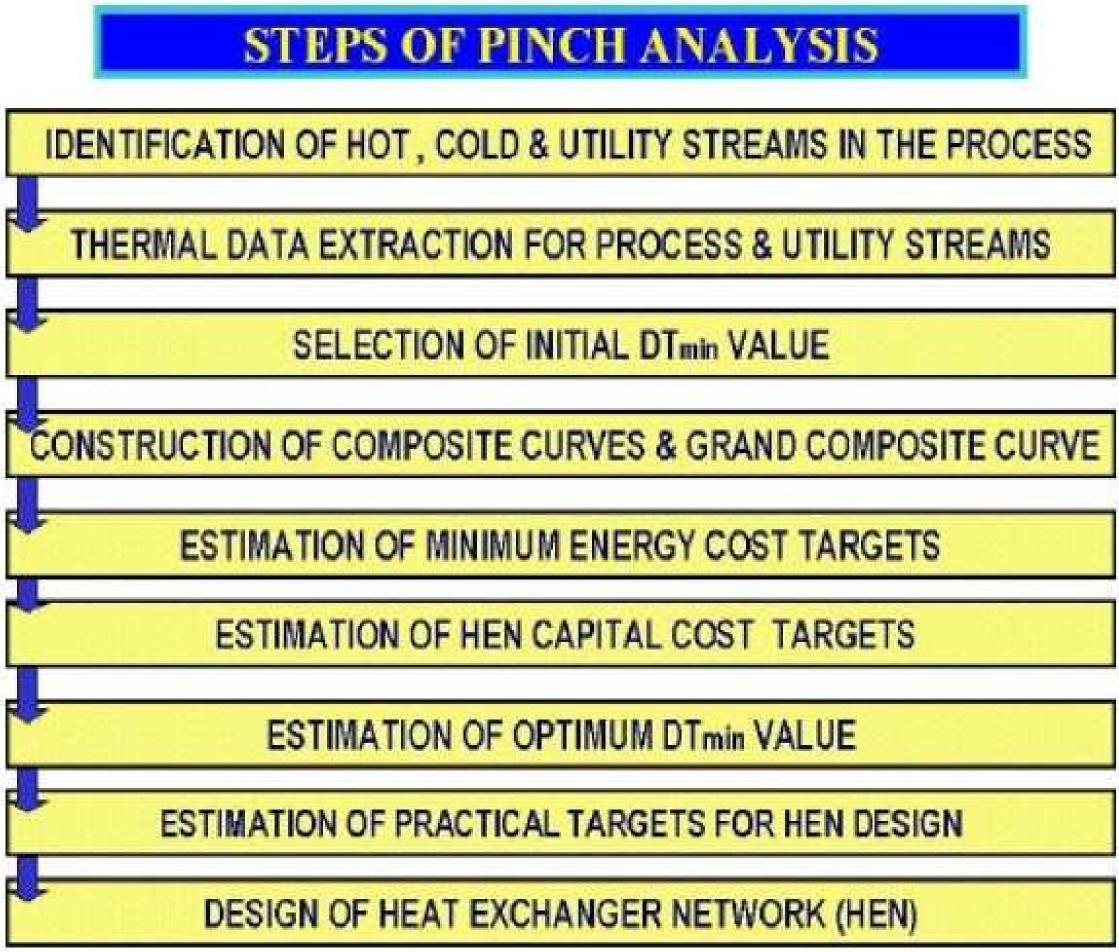

Figure 1 Steps of pinch analysis

Process Simulation Procedure

Hysys Process Simulator was used for the process simulation of the plant streams. The source and target temperatures of all the streams, mass flow rates, feed and product compositions of the feed and product of the plant were used for obtaining the specific heat capacities and enthalpies of the streams [9]. The procedure is as follows:

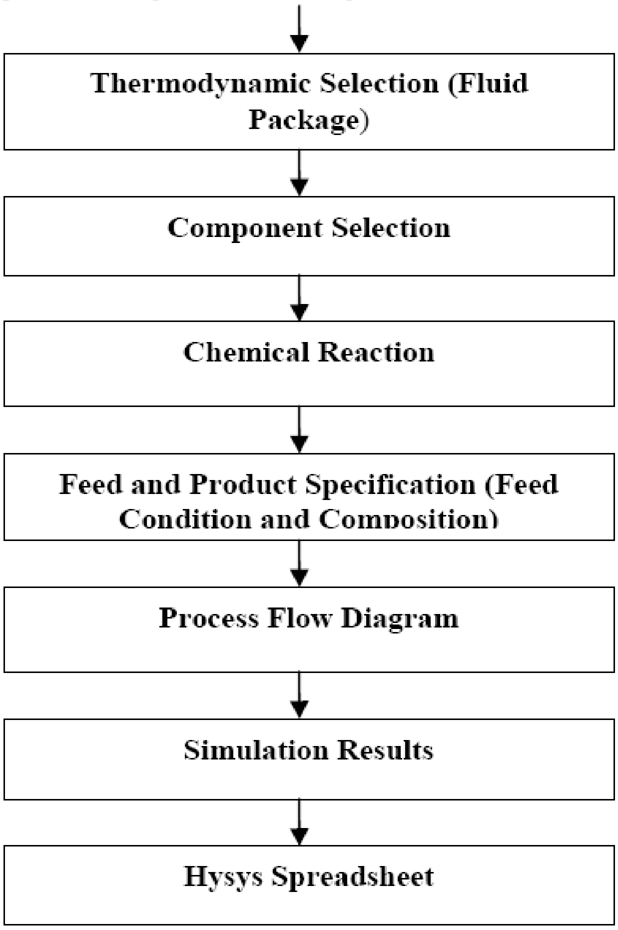

Figure 2: Process Simulation Steps using HYSYS

Table 1 Catalytic Reforming Unit Feed Specification

Feed Condition	Value
Vapour phase fraction	0.37325
Temperature (^{o}C)	93
Pressure (bar)	21.0843
Mass Flow (kg/hr)	142454
Heat Flow	-2.6E+08

Maple Simulation Procedure

The procedure for carrying out Maple Simulation is as shown in figure 3.

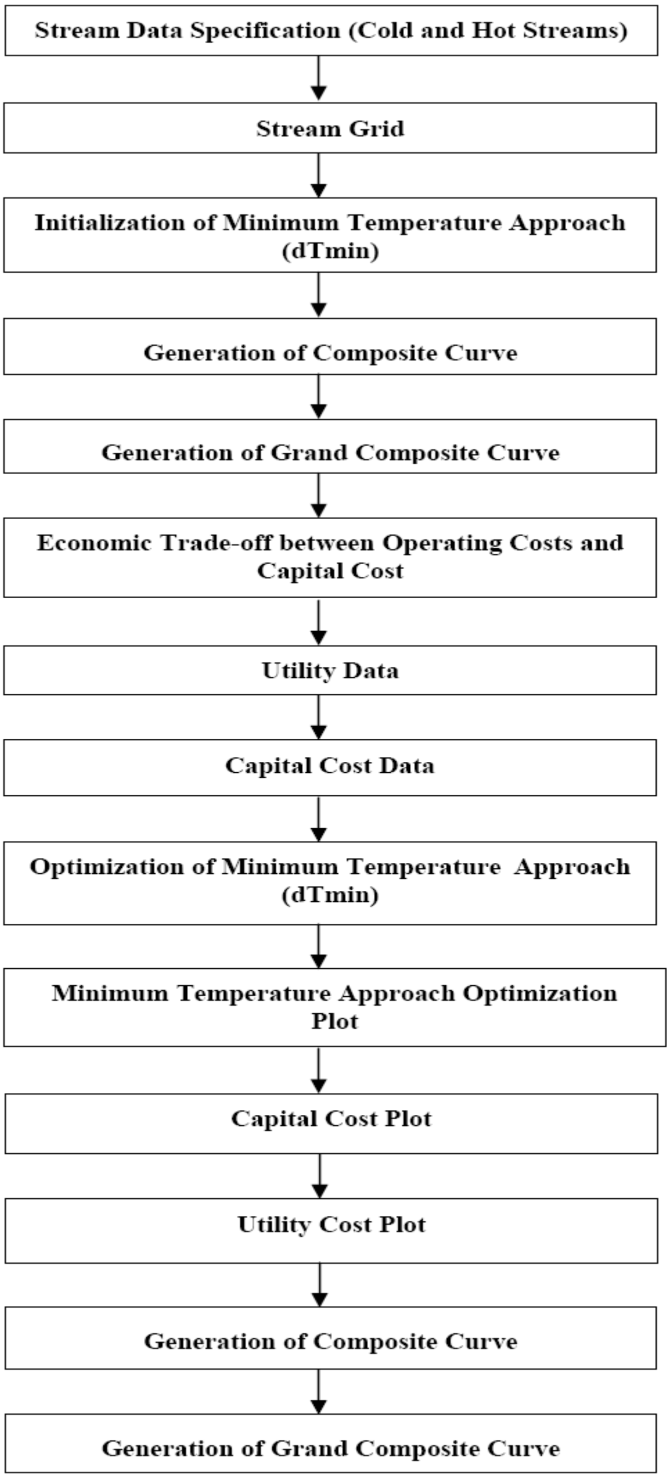

Figure 3: Pinch Analysis Simulation Procedure

RESULTS AND DISCUSSION

Data Extraction

The data extracted for catalytic reforming unit CRU feed specification, the laboratory analysis of the feed composition, the catalytic reforming unit process and utility heat exchangers inlet and outlet temperatures and enthalpies, hot minimum utility requirement unit for traditional energy approach and pinch analysis, experience and selected ΔT_{min} values, shifted composite curve of catalytic reforming unit and grand composite curve of CRU main fractionator results are shown in Tables 1,2,3,4, and figures 4 and 5 respectively [1-9].

Table 2 Catalytic Reforming Unit Feed Composition

Components	Mass Composition
n-Butane	0.010
n-Pentane	0.100
i-Pentane	0.000
n-Hexane	0.100
n-Heptane	0.100
n-Octane	0.010
n-Nonane	0.010
n-Decane	0.010
Mcyclopentane	0.100
2Mpentane	0.100
Cyclohexane	0.100
Benzene	0.010
Toluene	0.010
Hydrogen	0.340

Table 3 Catalytic Reforming unit process and utility heat exchangers inlet and outlet temperatures and inlet and outlet enthalpies

Stream Name	Inlet Temperature (°C)	Outlet Temperature (°C)	Enthalpy (kJ/hr)	Flowrate (kg/hr)
LP SEP LIQ_To_STRIPPER FD C	30.99	198.62	84007940.17	215507.58
FRAC BTMS_To_HT PROD	279.22	46.11	71295403.33	125741.95
TO RB_To_Boilup@COL2	279.22	320.76	31076571.64	153684.60
COLD FEED_To_COLD FEED A	29.44	87.78	12080969.65	102861.64
REACTOR EFFLUENT IN_To_RX EFF B	361.67	28.33	249903439.02	230148.92
TOTAL H2_To_TOTAL H2 A	47.67	254.44	26068458.94	19789.62
FRAC CHG_To_FRAC CHG A	281.00	239.30	26068458.94	209471.95
TO RB_To_Boilup@COL1	281.00	309.12	61887687.16	466244.02
Rx Charge_To_HEATER OUTLET	124.61	337.78	170151289.32	230148.92
To Condenser@COL1_TO_STRIP OH VAP@COL1	85.00	35.00	15266730.50	39883.04
To Condenser@COL2_TO_ISM CHG@COL2	95.10	29.44	38572279.55	82423.25

Energy Target Results

Table 4 Hot Minimum Utility Requirement for Traditional Energy Approach and Pinch Analysis of CRU of Kaduna Refining and Petrochemicals Company [10].

Energy	Process Simulation Energy Value (Energy Value before Energy Integration)	Pinch Analysis Energy Value (Energy Value after Energy Integration)
Heating Cost Index ($/s)	8.58E-02	8.58E-02
Heating Load (kJ/hr)	192756945.9	72711839.47
Cooling Cost Index ($/s)	5.08E-03	5.08E-03
Cooling Load (kJ/hr)	989456712.4	87105834.43

Table 5 Experience and Selected ΔTmin Values

Type of heat transfer	Experience ΔTmin values (°C)	Selected ΔTmin values (°C)
Process streams against process streams	30 -40.	35
process streams against steam	10 -20.	15
Process streams against cooling water	10 -20.	10
Process streams against cooling air	15 -25	15

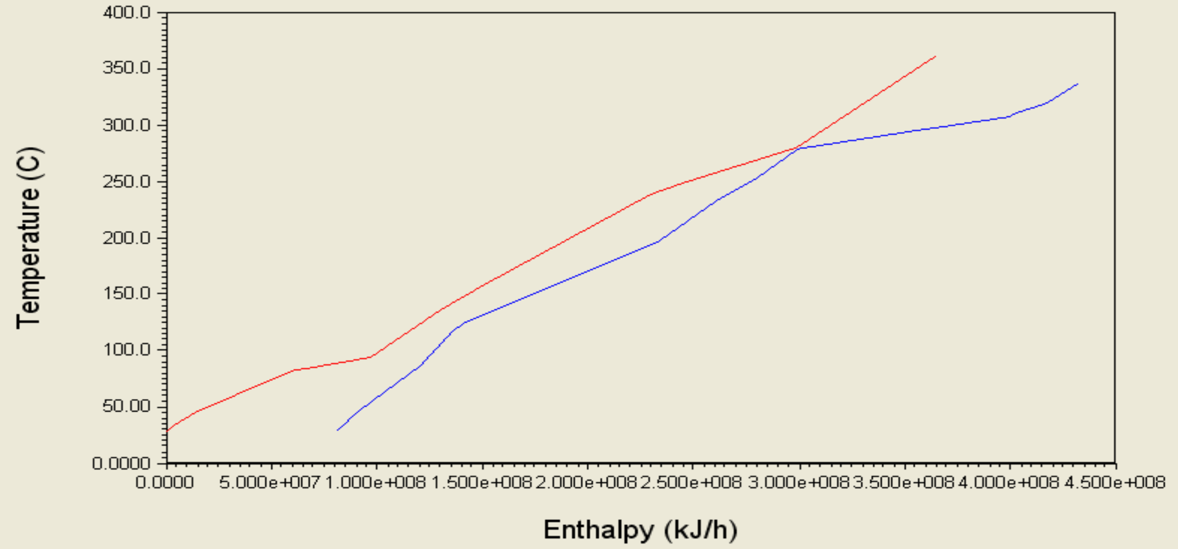

Figure 4 Shifted Composite Curve of Catalytic Reforming Unit

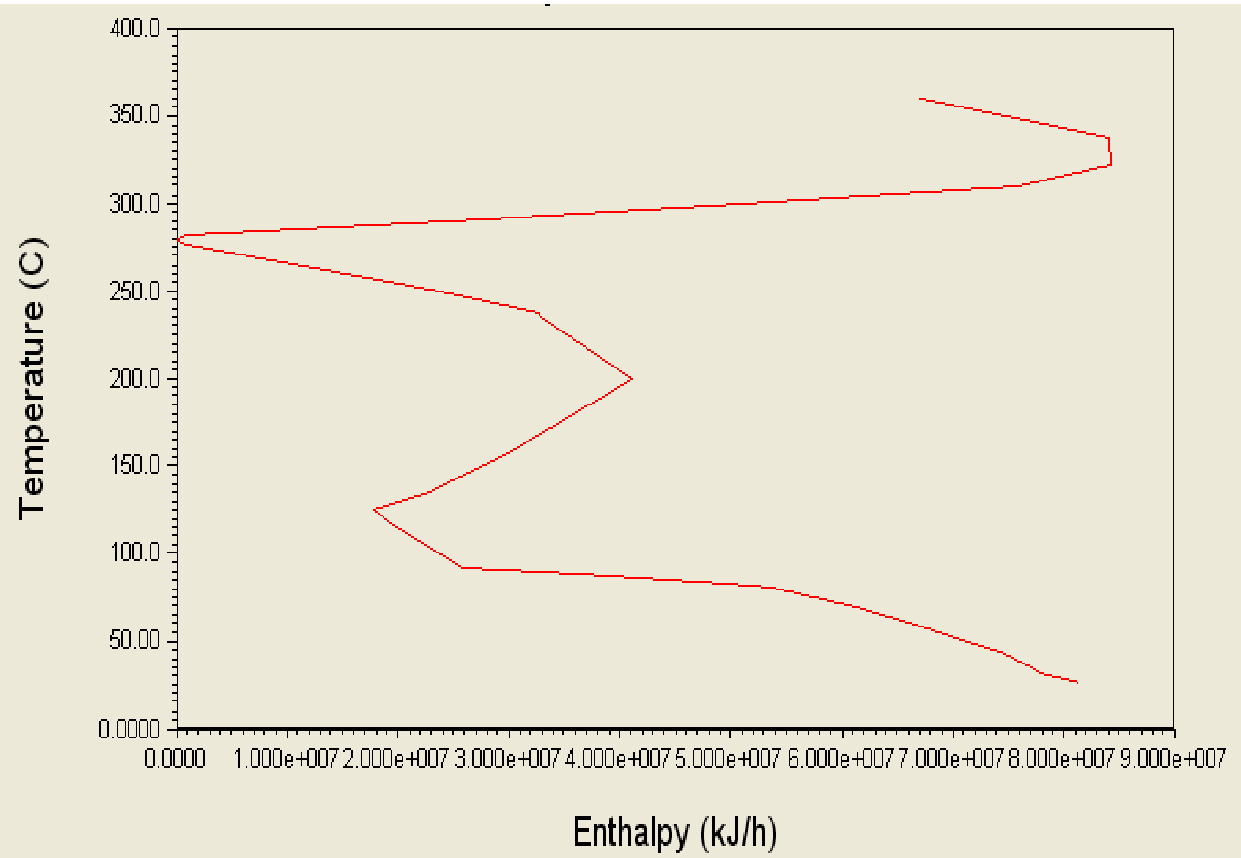

Figure 5 Grand Composite Curve of Catalytic Reforming Unit

Data Extraction

Table 1 revealed that the feed temperature, pressure and flow rates were 93^{O}C, 21.0843bar and 142454kg/hr respectively. The laboratory analysis of the feed composition in Table 2 showed that hydrogen has the highest composition of 0.340 as compared with results of other components of the feed. Heat loads and temperatures for all the streams in the process were required for the heat integration carried out; this is shown on Table 3. Furnaces which provide utility heating in the Catalytic Reforming Unit had its design represented for fired heaters for the pinch analysis as a heat source of a single temperature that is hot enough to satisfy any anticipated heat load in the unit. The air cooling and water cooling likewise represented heat sinks at a single temperature [11].

Minimum Temperature Approach

In order to generate targets for minimum energy targets the ΔT_{min} value was set for the problem. ΔT_{min} or minimum temperature approach, is the smallest temperature difference that was allowed between hot and cold streams in the heat exchanger where countercurrent flow was assumed. This parameter reflects the tradeoff between capital investment (which increases as the ΔT_{min} value gets smaller) and energy cost (which goes down as the ΔT_{min} value gets smaller). For the purpose of this study, typical ranges of ΔT_{min} values that have been found to represent the trade off for each class of process were used. Table 4 shows typical numbers that are appropriate for many refinery units such as CRU, cokers, crude units, hydrotreaters and reformers. In this study a ΔT_{min} value of $20^{O}C$ was used which is fairly aggressive for CRUs; this is applied to all process to process heat exchanger matches. Rather than different tradeoffs application for heat transfer between process streams and utilities, separate ΔT_{min} values for each utility were defined.

Pinch analysis Target Results

The shifted composite curve (temperature-enthalpy) profile of heat availability in the process (the “hot composite curve”) and heat demands in the process (the “cold composite curve”) were represented graphically as shown in Figure 4. It shows that the heat available in the process is 72711839.47 kJ/hr while the heat demand in the process is 87105834.43 kJ/hr. This shows that more heat is to be supplied from the process than heat to be removed from the system. Figure 5, Grand composite Curve of CRU showed that the Pinch temperature of the process was $278^{O}C$.

The results show that the utility heating of the plant is far less than the utility cooling of the plant. Therefore any utility heating supplied to the process below the pinch temperature cannot be absorbed and will be rejected by the process to the cooling utility, increasing the amount of cooling utility required, hence waste of energy (cold utilities) by the CRU.

Energy Saving between the Process Simulation (Non Energy Integration) and Pinch Analysis (Energy Integration) for CRU

The cold utility requirements of traditional energy approach and pinch analysis obtained as shown in Table 4 were 989456712.4 kJ/hr and 87105834.43 kJ/hr respectively. The hot utility requirements of process simulation and pinch analysis shown in Table 4 are 192756945.9 kJ/hr and 72711839.47 kJ/hr respectively. This shows that pinch analysis energy integration saves more energy and utilities cost than the traditional energy approach. This statement is in agreement with literature [11-17] which states that pinch analysis as an energy integration technique saves more energy than the traditional energy technique [18-19].

CONCLUSION

The research carried out shows that the utilities demand after energy integration using pinch technology gave a minimum approach temperature of 72711839.47 KJ/hr and 87105834.43 KJ/hr for hot and cold utilities respectively; whereas the traditional energy technique gave 192756945.9 KJ/hr and 989436712.4 KJ/hr for hot and cold streams respectively. Therefore a difference of 37.7% and 8.8% for hot and cold utilities were achieved. Minimum temperature approach of $20^{O}C$ was used to determine the energy target and the pinch point was found to be $278^{O}C$. Therefore, it can be said that pinch analysis as an energy integration technique saves more energy utilities cost than the traditional energy technique.

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