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COMPARATIVE STUDIES OF TRADITIONAL (NON-ENERGY INTEGRATION) AND ENERGY INTEGRATION OF CATALYTIC REFORMING UNIT USING PINCH ANALYSIS

M. AUTA[1], A. S. AHMAD[2], H. F. AKANDE[3]

[1]Department of Chemical Engineering, Federal University of Technology, Minna, Niger State, Nigeria manaseuta@yahoo.com
[2]Kaduna Refining and Petrochemical Company, Kaduna, Kaduna State, Nigeria sadiqahmadfcc@yahoo.com
[3]Department of Chemical Engineering, Kaduna Polytechnic, Kaduna, Kaduna State, Nigeria akandehf@yahoo.com

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ABSTRACT

Energy Integration of Catalytic Reforming Unit (CRU) of Kaduna Refinery and Petrochemicals Company Kaduna Nigeria was carried out using Pinch Technology. The pinch analysis was carried out using Maple. Optimum minimum approach temperature of 20 °C was used to determine the energy target. The pinch point temperature was found to be 278 °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 was found to save more energy and utilities cost than the traditional energy technique.
Key words: Pinch point, CRU, Energy Target, Maple

1. INTRODUCTION

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 by simply analyzing the process data using its methodology, 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.(Adefila, 1994).

Pinch analysis originated in the petrochemical sector and is now being applied to solve a wide range of problems in mainstream chemical engineering. Wherever heating and cooling of process materials take place, there is a potential opportunity. The technology, when applied with imagination, can affect reactor design, separator design and the overall process optimization in any plant. It has been applied to process problems that go far beyond energy conservation. It 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 (Badr, 2001).

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. Furthermore, given the fact that energy prices had been kept at a low level up to 1985, energy cost has not been a significant fraction of total production cost even for energy intensive industry like refineries in Nigeria. The improvement of energy efficiency can provide substantial benefit in general to all the sectors of the economy (Dayo, 1994).

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Process integration using pinch technology offers a novel approach to generate targets for minimum energy consumption before heat recovery network design. The pinch design can reveal opportunities to modify the core process to improve heat integration: this is possible because wherever heating and cooling of process materials takes places there is a potential opportunity. (Frank and Evans. 1985).
Pinch Analysis procedure generally first predicts ahead of design the minimum requirement of external energy, network area. and the number of units for a given process at the pinch point. Thereafter, a heat exchanger network design that satisfies these targets is synthesized. The network is then finally optimized by comparing energy cost and the capital cost of the network so that the total annual cost is minimized. Thus, the prime objective of energy integration is to achieve financial savings by better process heat integration (maximizing process-to-process heat recovery and reducing the external utility loads). (Bassey, 1995).

Catalytic Reforming is a chemical process use to convert petroleum refinery naphtha, typically having low octane ratings, into high octane liquid products called reformate which are components of high octane gasoline. Basically the process re-arranges or re-structures the hydrocarbon molecules in the naphtha feedstock as well as breaking some of the molecules into smaller molecules. The overall effect is that the product reformate contains hydrocarbons with more complex molecules shapes having higher octane values than the hydrocarbons in the naphtha feedstock.(Chiyoda, 1980).

2. METHODOLOGY

This section presents all the steps involved in the analysis, designing and optimization of Heat Exchangers Network of Catalytic Reforming Unit (CRU) of Kaduna Refining and Petrochemical Company. The procedures involved data extraction, process simulation and pinch analysis which are shown under Figure 3. The procedure involved analysis of the existing Heat Exchangers Network of the Preheat train of the unit in order to extract all the necessary information required for the analysis. As mentioned earlier, the use of pinch technology in the energy conservation area remains the focus of this work.

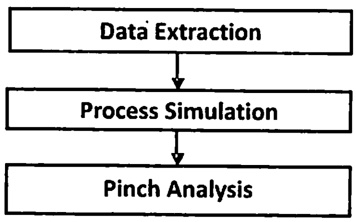

Figure 1: Steps involved in the energy integration of CRU unit of KRPC. (Brown, 1998).

2.1 Data Extraction

In the analysis of the existing network, a thorough study of the Process Flow Diagram (PFD), Piping and Instrumentation Diagram (P&ID) and Laboratory analysis of the CRU feed (Whole Naphtha) and product (Reformate) were carried out in order to extract all the necessary and available information required to carry out the process simulation of the CRU plant. The feed and product compositions of the laboratory analysis were used in carrying out the process simulation. The stream temperatures, mass flow rates, pressures were also extracted from PFD and P&ID for carrying out the pinch analysis as shown in Table 1, 2 and 3.

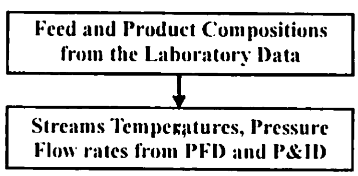

Figure 2: Data Extraction Steps (Chris and Doug, 2002)

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2.2 Process Simulation Procedure

Hysys Process Simulator version 7.1 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.

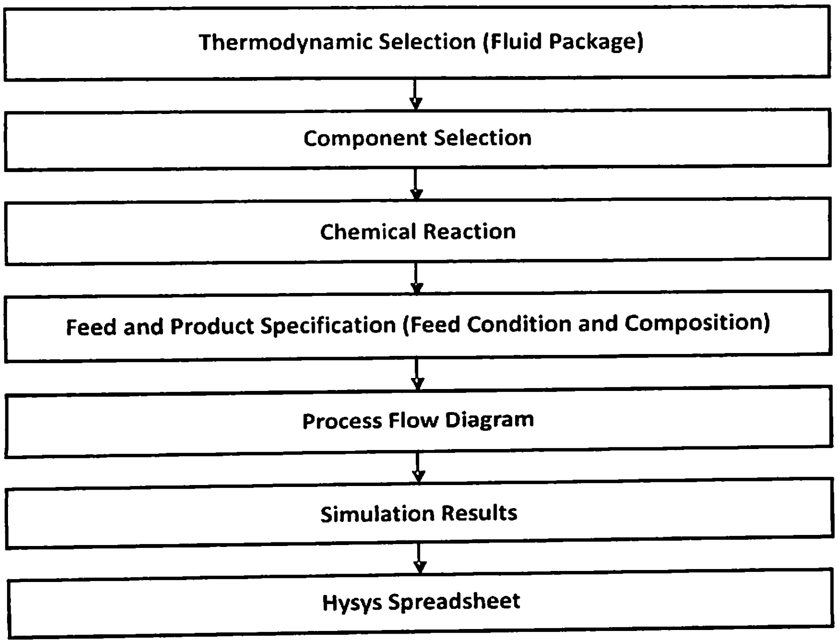

Figure 3: Process Simulation Steps using HYSYS (Callagha, 1981).

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2.3 Maple Simulation Procedure

The pinch analysis was carried out using Maple software. Maple procedure for carrying out pinch analysis is shown in figure 4.

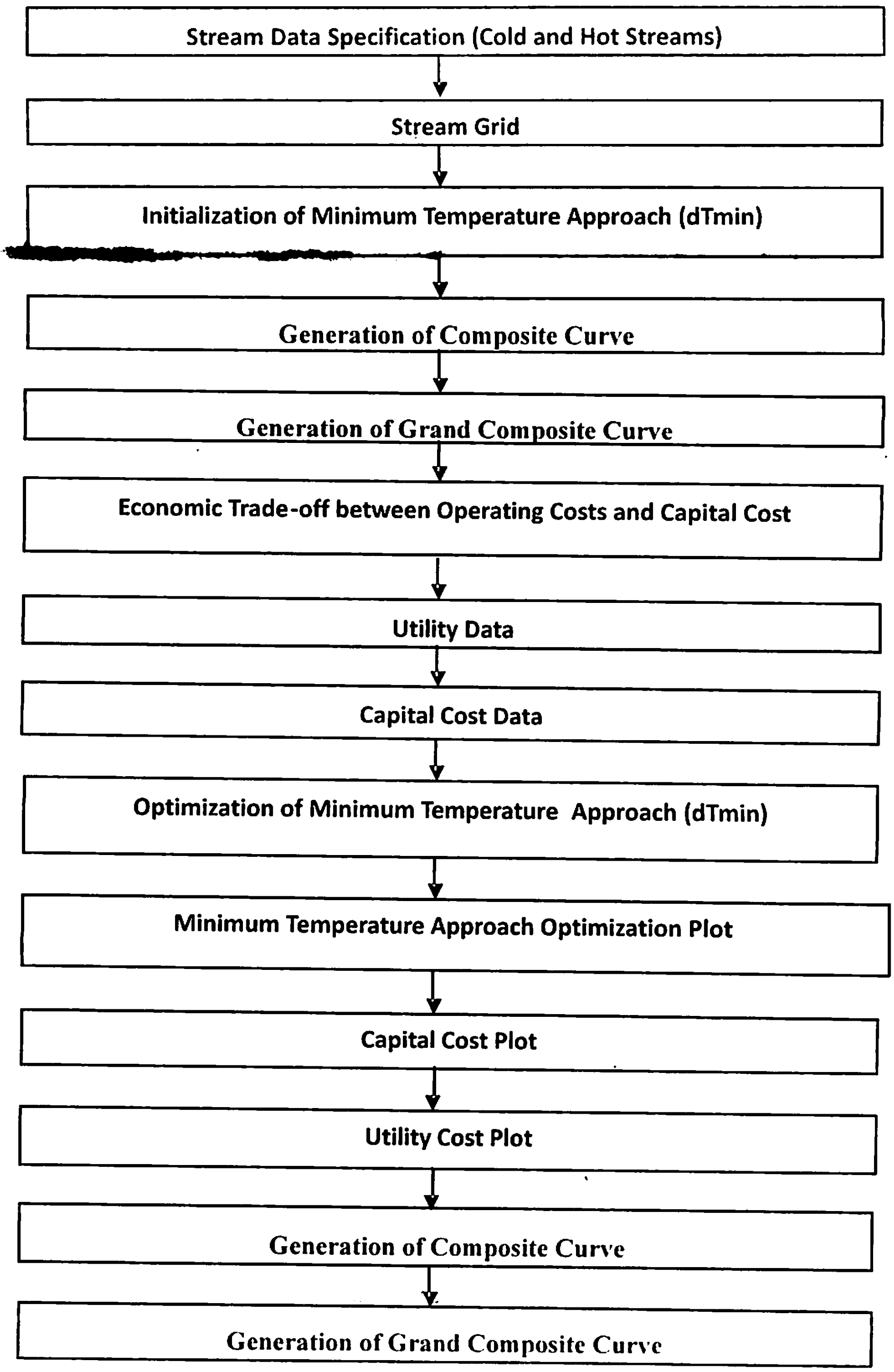

Figure 4: Maple Pinch Analysis Simulation (Akande, 2008) Procedure

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3 RESULTS AND DISCUSSION

3.1 Data Extraction

Table 1 revealed that the feed temperature, pressure and flow rates were 93°C, 21.0843 bar and 142454 kg/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 other components in the feed. Heat loads and temperatures for all the streams in the process were used for the heat integration carried out in this project. The catalytic reforming unit process and utility heat exchangers inlet and outlet temperatures and inlet and outlet enthalpies were also used and they are shown in Table 1. The furnace design which was represented for fired heaters for the Pinch analysis as a heat sources as a single temperature that is hot enough to satisfy any anticipated heat load in the Unit. The air-cooling and water-cooling likewise were also represented as heat sinks at a single temperature.

Table 1: CRU Feed Specification (Chiyoda, 1985)

Feed Condition	Value
Vapour/Phase Fraction	0.37325
Temperature (°C)	93
Pressure (bar)	21.0843
Mass Flow (kg/hr)	142454
Heat Flow	-2.6E+08

Table 2: CRU 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
Mcyclopentan	0.100
2Mpentane	0.100
Cyclohexane	0.100
Benzene	0.010
Toluene	0.010
Hydrogen	0.340

Table 3: Hot Minimum Utility Requirement for Traditional Energy Approach and Pinch Analysis of CRU of Kaduna Refining and Petrochemicals Company

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

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Table 4: 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

Table 5: 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

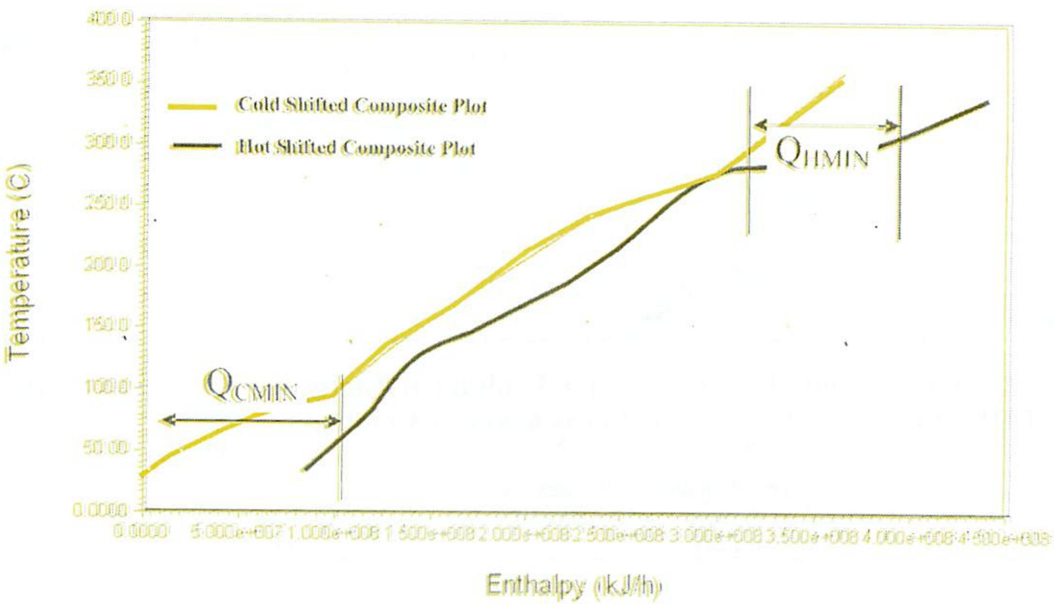

Figure 5: Shifted Composite Curve of Catalytic Reforming Unit

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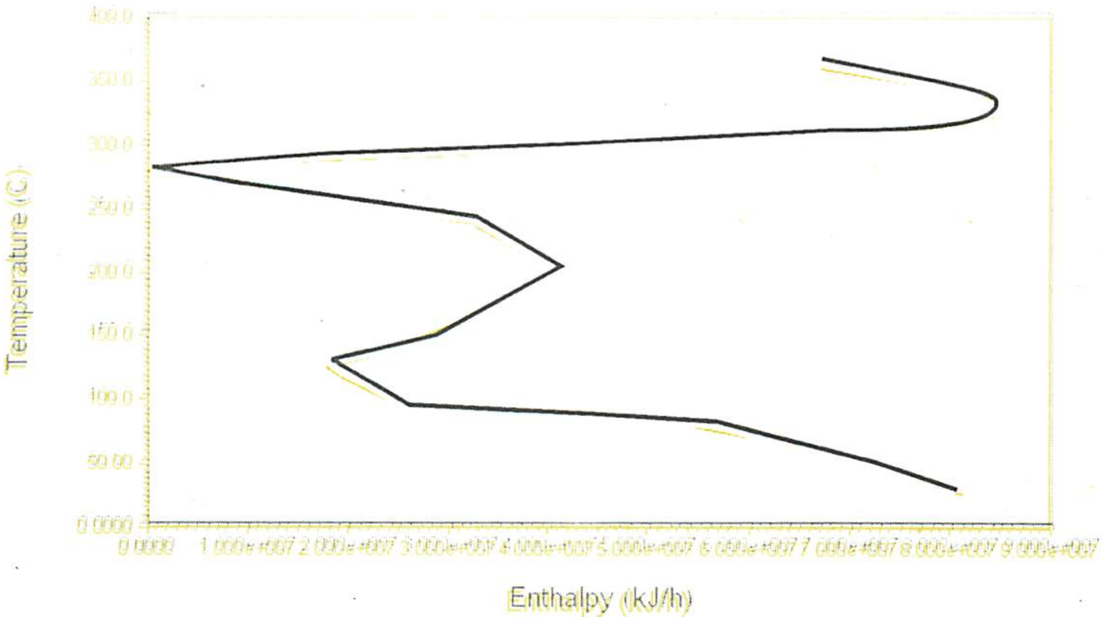

Figure 6: Grand Composite Curve of CRU Main Fractionator

3.2 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 counter-current flow was assumed. This parameter reflects the trade-off 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) (Akande, 2008). For the purpose of this project, typical ranges of ΔT_{min} values that have been found to represent the trade-off for each class of process have been used. Table 3 shows typical numbers that are appropriate for many refinery units such as CRU Units, cokers, crude units, hydrotreaters and reformers. In this study a ΔT_{min} value of 20 °C was used, which is fairly aggressive for CRUs. This is applied to all process-to-process heat exchanger matches. Rather different trade-offs apply for heat transfer between process streams and utilities, so we typically define separate ΔT_{min} values for each utility.

3.3 Energy 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") together in a graphical representation. Figure 5 show 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 6 (Grand composite Curve) show that the Pinch temperature of the process is 278 °C.

The results show that the hot/heating utility of the plant (72711839.47 kJ/hr) is far less than the cold/cooling utility of the plant (87105834.43 kJ/hr). 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.

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3.4 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 in Table 3 are 989456712.4 kJ/hr and 87105834.43 kJ/hr respectively. The hot utility requirements of process simulation and pinch analysis shown in Table 3 are 72711839.47 kJ/hr and 192756945.9 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 (Bassey, 1995) which states that pinch analysis as an energy integration technique saves more energy than the traditional energy technique.

Table 6: 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)	Flow Rate (kg/hr)
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To Condenser@COL2_TO_ISM CHG@COL2	95.10	29.44	38572279.55	82423.25

3.5 Energy Target Results

Table 7: Hot Minimum Utility Requirement for Traditional Energy Approach and Pinch Analysis of CRU of Kaduna Refining and Petrochemicals Company

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Table 8: Experience and Selected ΔTmin Values

Type of heat transfer	Experience values (°C)	ΔTmin	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	

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3.6 Pinch Analysis Target Results

Figure 4.1 is 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") together in a graphical representation. Figure 4.1 show 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 4.2 (Grand composite Curve) show that the Pinch temperature of the process is 278 °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.

3.7 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 in Table 4.3 are 989456712.4 kJ/hr and 87105834.43 kJ/hr respectively. The hot utility requirements of process simulation and pinch analysis shown in Table 4.3 are 72711839.47 kJ/hr and 192756945.9 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 (Smith, 2005) which states that pinch analysis as an energy integration technique saves more energy than the traditional energy technique.

4. CONCLUSIONS

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. Therefore a difference of 37.7% and 8.8% for hot and cold utilities were achieved. Minimum approach temperature of 20°C was used to determine the energy target and the pinch point was found to be 278°C. Therefore this work conclude that energy integration technique saves more energy than the traditional energy technique.

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