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Energy integration of vacuum distillation plant using pinch technology (A case study of KRPC VDU Unit)

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ABSTRACT

Process integration is refer to as Energy integration if the aim is to optimized the use of energy in a process plant. Energy integration of Vacuum Distillation unit of Kaduna Refining and Petrochemical Company was carried out, using the principle of Pinch Technology. Optimum Temperature approach of 10^0C was obtained, the pinch point was found to be 370^0C. The cold utility requirement for the traditional approach and pinch analysis were found to be 0.31 and 0.19MW respectively, while the hot utility requirement were found to be 0.32 and 0.24MW respectively. Hence pinch analysis as an energy integration technique saves more energy and therefore save more cost than the traditional approach.

Keywords: *process integration, Energy integration, Pinch analysis, Optimum temperature approach.*

INTRODUCTION

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, reduction in green house gas (GHG) emissions, and waste generation. When specifically applied with the aim of optimizing energy consumption, the process is termed energy integration. Process integration when combine 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.

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 design were neither optimal in terms of energy consumption nor in capital cost invested [1]. Since then however, much attention has been directed at better process design, particularly in the area of process network design or process synthesis or 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 [2]. Pinch technology became available to industry about 1980 and since then its application to both new designs and retrofits has become well established [3]. Refineries designed and installed before 1980 did not enjoy the benefit of insights from new developments in energy saving technologies [4].

Pinch technology is a thermodynamically based method for analyzing and understanding the energy flows in process plants, and subsequently determining the absolute minimum energy requirement of the plant for a specified minimum temperature of approach [5]. It identifies practical process changes to minimize energy input to a process. It simply gives the designer a rigorous target for how much energy a process plant should be using, and how this target can be achieved.

The aim of this work is to develop an energy integration of vacuum distillation unit of Kaduna Refinery and Petrochemical Company (KRPC), using pinch technology approach.

This aim can be actualize through the realization of the following objectives: Collection of Design data, Operating Data and Piping and Instrumentation Diagram of Vacuum distillation (VDU) Unit of Kaduna Refinery and Petrochemical Company (KRPC); Identification of Hot, Cold and Utility Streams in the Process (VDU); Thermal Data Extraction for VDU Process and Utility Streams; Selection of Initial ΔT_{min} Value; Construction of Composite Curves and Grand Composite Curve; Estimation of Minimum Energy Cost Targets; Estimation of Heat Exchanger Network (HEN) Capital Cost Targets; Estimation of Optimum ΔT_{min} Value; Estimation of Economic Trade-off between Operating Costs and Capital Cost; Performing Optimization by calculating the net present cost total for utilities and capital over a range of ΔT_{min} values and obtaining the optimum; Establishing ΔT_{min} Optimization Plot, Capital Cost Plot and Utilities Cost Plot.

1.1 Description of the Vacuum Distillation Unit (VDU)

In this unit, additional liquid is recovered from the residue of atmospheric distillation at a pressure of 4.8 to 10.3 kPa. The vacuum, which is created by a vacuum pump or steam ejector, is pulled from the top of the tower. Often, instead of trays, random packing and demister pads are used. These materials are therefore distilled under vacuum because the boiling temperature decreases with a lowering of the pressure.

The residue from the vacuum contains most of the crude contaminants such as metals, salts, sediments, sulphur, nitrogen, etc.

To improve vaporization, the effective pressure is lowered even further by the addition of steam to the furnace inlet and at the bottom of the vacuum tower. Addition of steam to the furnace inlet increases the furnace tube velocity and minimizes coke formation in the furnace as well as decreasing the total hydrocarbon partial pressure in the vacuum tower. The amount of stripping steam used is a function of the boiling range of the feed and the fraction vaporized, but generally ranges from 10 to 50 Ib/bbI feed .

The feed is pre-heated in heat exchanger train and fed to fired heater, the heater outlet temperature is controlled to produce the required quality of distillate and residue. Structure parings are typically used as tower internals to achieve low flashzone pressure and hence to maximize distillates yield. Circulating reflux stream enable maximum heat recovery and reduced column diameter.

A wash section immediately above the flashzone ensures that the metal content in the lowest side draw is minimized. Heavy distillate from the wash trays is recycled to the heater inlet or withdrawn as metal cut.

The operating pressure of the column is about 0.7 to 1.5kPa, at a lower temperature than that of the atmospheric tower. The utility requirement of the unit per m^3 of feed is outlined below:-

Table 1.0: Utility Requirement of the Unit

Utility	Quantity
Electricity, kWh	5
Steam, MP, kg	15
Steam Production, LP, kg	60
Fuel oil, kg	7
Water, cooling m^3	3

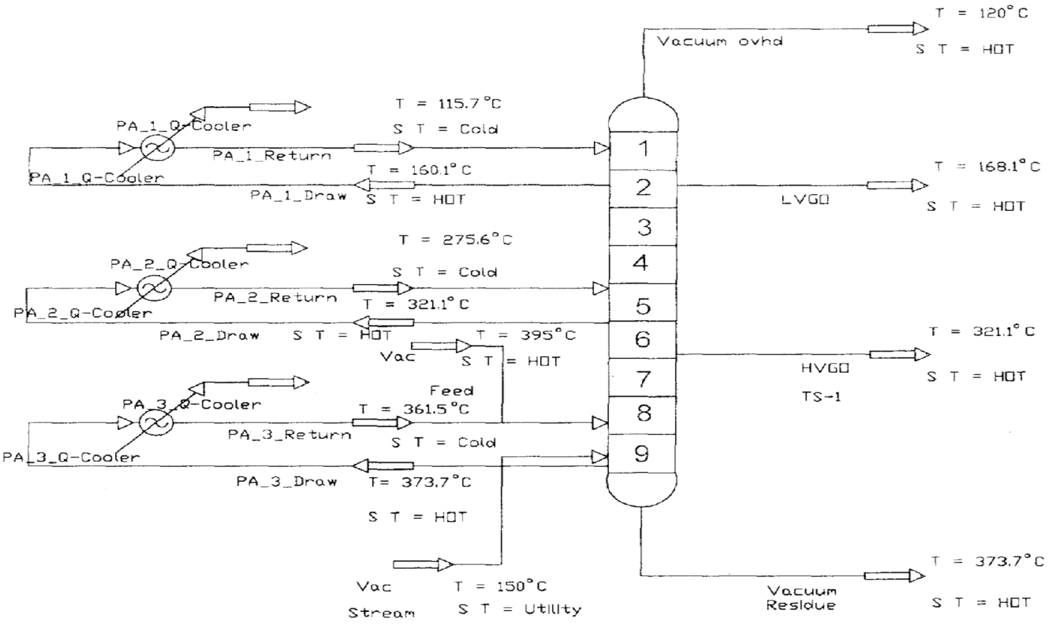

Figure 1.0 : Schematic Flow Diagram of VDU for the Purpose of Pinch Analysis

(Refining processes 2006)

The overhead stream light vacuum gas oil can be used as a lube base stock, heavy fuel oil, or as feed to a conversion unit. Heavy vacuum gas oil is pulled from a side draw. The vacuum residence can be use to make asphalt, or it can be sent to a coker or visbreaker unit for further processing.

MATERIALS AND METHODS

2.1 MATERIAL

The materials used include process flow diagrams (PFD), shown on figure 1.0 and operating data of the vacuum distillation (VDU) of the Kaduna refining and petrochemical company (KRPC), Maple program pinch application software and Microsoft Excel Spreadsheet.

2.2 METHOD

This area presents all the steps involved in the analysis, designing and optimization of Heat Exchangers Network of Vacuum Distillation Unit (VDU) of Kaduna Refining and Petrochemical Company. The procedures involved data extraction, process simulation and pinch analysis. The procedure involved analyzing 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. The use of pinch technology in the energy conservation area remains the focus of this work.

The data extractions are obtained from feed and product compositions from the laboratory data and streams temperature, pressures, flow rates from PFD. The feed parameters and True Boiling point (TBP) obtained by laboratory analysis shown in table 3.1 and 3.2 were used in carrying out the process simulation. The stream temperatures, mass flow rates, and pressures were also useful in carrying out the process simulation.

The process simulation was necessary in order to determine the stream duty and CP (Heat capacity x Flow rate). These parameters were used in carrying out the pinch analysis.

Maple program was used in carrying out pinch analysis, and the maple procedure for running the maple calculation is shown in figure 2.0 below:-

2.3 Maple Procedure for Running Pinch Calculation

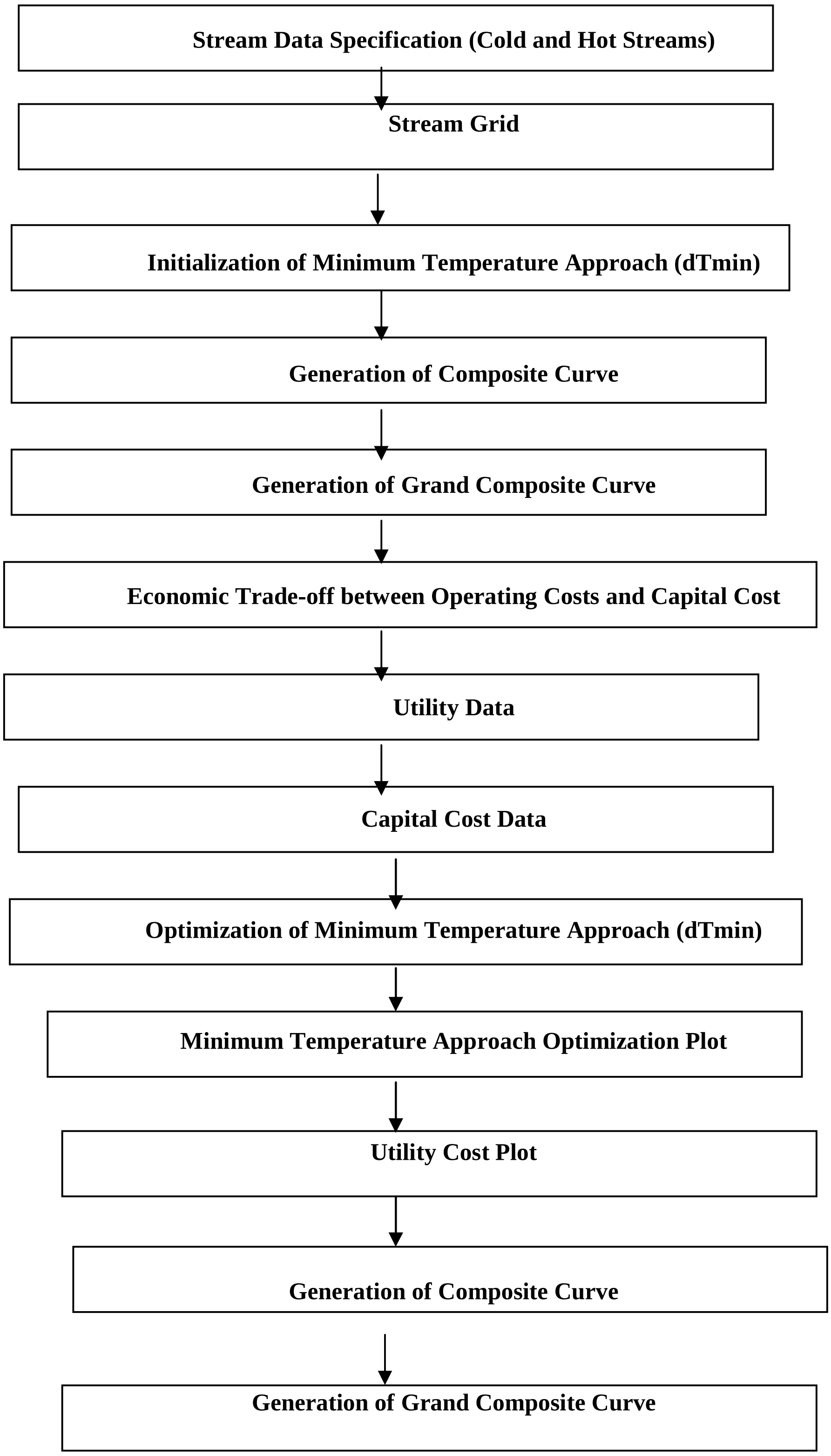

Figure 2.0: Pinch Analysis Procedural Steps using Maple

The heat exchanger network has the task of heating and/or cooling a collection of process streams. The stream data specification were carried out for cold and hot sreams.

The cold stream data arrays were defined as follows:

Stream ID, CP (kW/K), Tsupply (K), Ttarget(K), H (kW)

The hot stream data arrays were defined as follows:-

Stream ID, CP (kW/K), Tsupply (K), Ttarget (K), H(kW)

The stream grid gives a visual representation of the heating and cooling requirements. The following command is typed under stream grid in maple code to display the Stream Grid:

```
> Stream Grid ();
```

The following command is typed in the maple program to display the composite curves:

```
> p1: = plots [point plot] (HC data, connect = true, color = red):
P2: = plots [point plot] (CC data, connect = true, color = blue):

Plots [display] (p1, p2, title =CC title, labels = [‘H(kW)’,’Tshifted(K)’]
```

The following command is typed in the maple program to display the grand composite curves.

```
> plots[pointplot](GCCdata,title= GCC title, connect=true,

Labels [‘H(kW)’,‘Tshifted(K)’];
```

The optimum selection of the dTmin value is made by optimizing the trade-off between operating costs and the installation cost of the network. The installation of larger heat exchangers can reduce operating costs for utilities but at the expenses of a higher capital cost for the network. The trade-off is best made by minimizing the net present cost of capital and operating costs.

For utility data, the calculations need information about the available utilities.

Cold and hot utilities constants were entered in Maple code as:

```
> Cold UtilityNPC factor: = 70:
Cold utility T (K)
Cold utility heat transfer coefficient (kW/sqm-K)
>hColdUtility:=.4:
Hot utility usage net present cost factor ($NPC/kW)
>hHotUtilityNPCfactor:=500:
Hot utility T (K)
>hHotUtility:=2.:
```

The heat exchanger cost formula ($) used for capital cost data is:
In (cost) = capA + capB x In(area,m^2) + capC x In(area,m^2)^2

The capital costs were entered into the Maple code as follows:

```
>capA:= 7.5:
capB: = 0.24:
capC:= 0.06:
```

The heat exchanger capital costs are adjusted to the purchase year by a factor.

```
>CostAdjust:=1.2:
```

The sum of heat exchanger costs are scaled to the installed network cost by a Lang factor.

```
>LangFactor: = 5.:
```

The capital NPC factor is needed to convert the capital cost to net present cost terms.
($NPC/$capital)

```
>CapitalNPCfactor:=90.:
```

The optimization is performed by calculating the net present cost total for utilities and capital over a range of dTmin values. The following optimization starting value, range and increment were entered in Maple code as

```
>dTstart:=10:
Range:=20:
Increment:=2:

ans:=OptimizeData(dTstart,Range,Increment);
```

The optimization plot was generated at minimum temperature approach (dTmin) in Maple code by entering the following command:

```
Plots[pointplot](NPCvalues,title=NPC vs.dTmin:

‘[[ans.connect=true,labels=[‘dTmin(K)’,‘NPC($M)’]);
```

The capital cost plot was generated in Maple code by entering the following command:

```
> plots[pointplot](NPCvalues,title=NPC      vs dTmin;

[[ans.connect=true,labels=[dTmin(K)’,’NPC($M)’]);
```

The utility cost plot was generated in Maple code by entering the following command:

```
> plots[pointplot](UtilityNPCvalues,title=Target Utility Costs ($M) vs dTmin’,
connect=true,labels=[‘dTmin(K)’,‘NPC($M)’]);
```

RESULTS

Laboratory Data

The laboratory data includes the data from the TBP analysis, which is required in running the simulation.

Table 3.1: True Boiling Point (TBP) from Laboratory Analysis

Feed % vol. distilled	**0**	**4**	**9**	**14**	**20**	**30**	**40**	**50**	**60**	**70**	**76**	**80**
Temperature^{0}C	**-12**	**32**	**74**	**116**	**154**	**224**	**273**	**327**	**393**	**450**	**490**	**516**

3.2 Extracted Data

The Extracted data includes data obtained from the PFD, such as the feed stock density, feed condition and flow rate and the supply and target temperature of all the streams in the unit. The result of the data extraction is tabulated below:-

Table 3.2a: Feed Stock Density

Feed Stock Density	879.8kg/m^3

Table 3.2b: Data Extracted from Operating Manual

Parameter	Feed Temperature (^{0}C)
Feed Flow rate (kgmole/hr)	637.2
Feed Temperature (^{0}C)	395
Feed Pressure (kPa)	15

Table 3.2.c: Data Extracted from Process Flow Diagram

Sream ID	**1**	**2**	**3**	**4**	**5**	**6**
T supply(^{0}C)	**168.1**	**115.1**	**321.1**	**275.6**	**373.7**	**361.5**
T target(^{0}C)	**115.7**	**120**	**275.6**	**168.1**	**361.5**	**321.1**

3.3 Simulation Result

After running the simulation the following results were obtained for the CP and the heat Duty (H).

Table 3.3: Simulation Results

Stream ID	**CP(kj/kg)**	**Duty(kW)**
1	2.386	4.620×10^8
2	2.177	4.918×10^8
3	2.889	3.653×10^8
4	2.737	3.972×10^8
5	2.990	4.309×10^8
6	2.954	4.429×10^8

3.4 Energy Target Results

Table 3.4a: Hot Minimum Utility Requirement for Traditional Energy Approach and Pinch Analysis of VDU Main fractionators of Kaduna Refining and Petrochemical Company

Hot Utility (MW) Traditional Energy Approach	**Hot Utility (MW) Pinch Analysis**
0.32	0.24

Table 3.4b: Cold Minimum Requirement for Traditional Energy Approach and Pinch analysis of VDU Main Fractionators of Kaduna Refining and Petrochemical Company

Cold Utility (MW) Traditional Energy Approach	**Cold Utility (MW) Pinch Analysis**
0.31	0.19

Table 3.5: Experience and Selected ΔTmin Values

Types of heat transfer	**Experience ΔTmin Values (^{0}C)**	**Selected ΔTmin Values(^{0}C)**
Process streams against process streams	30-40	35
Process streams against stream	10-20	15
Process streams against cooling water	10-20	10
Process streams against cooling air	15-25	15

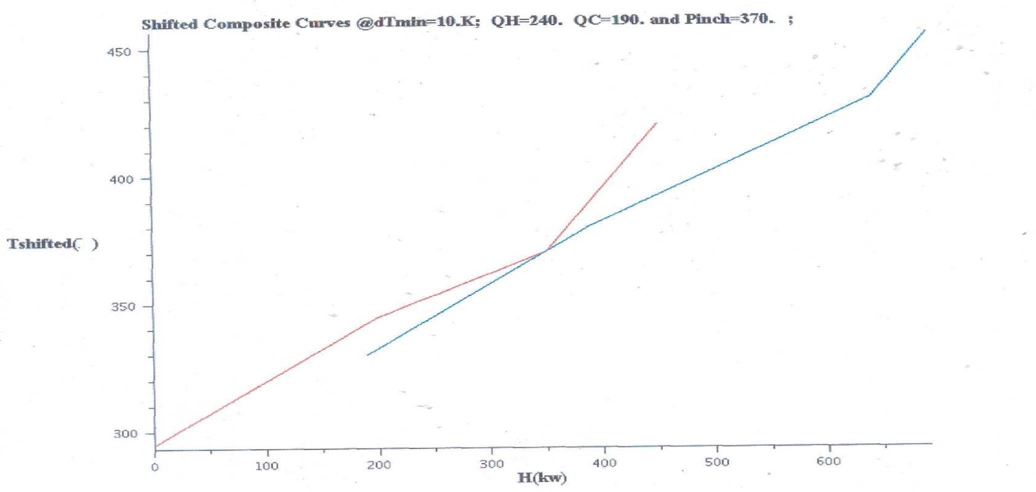

Figure 3.1: Shifted Composite Curve of VDU Main Fractionator
Grand Composite Curve @dTmin = 10.K; QH=240. QC=190. and Pinch =370.;

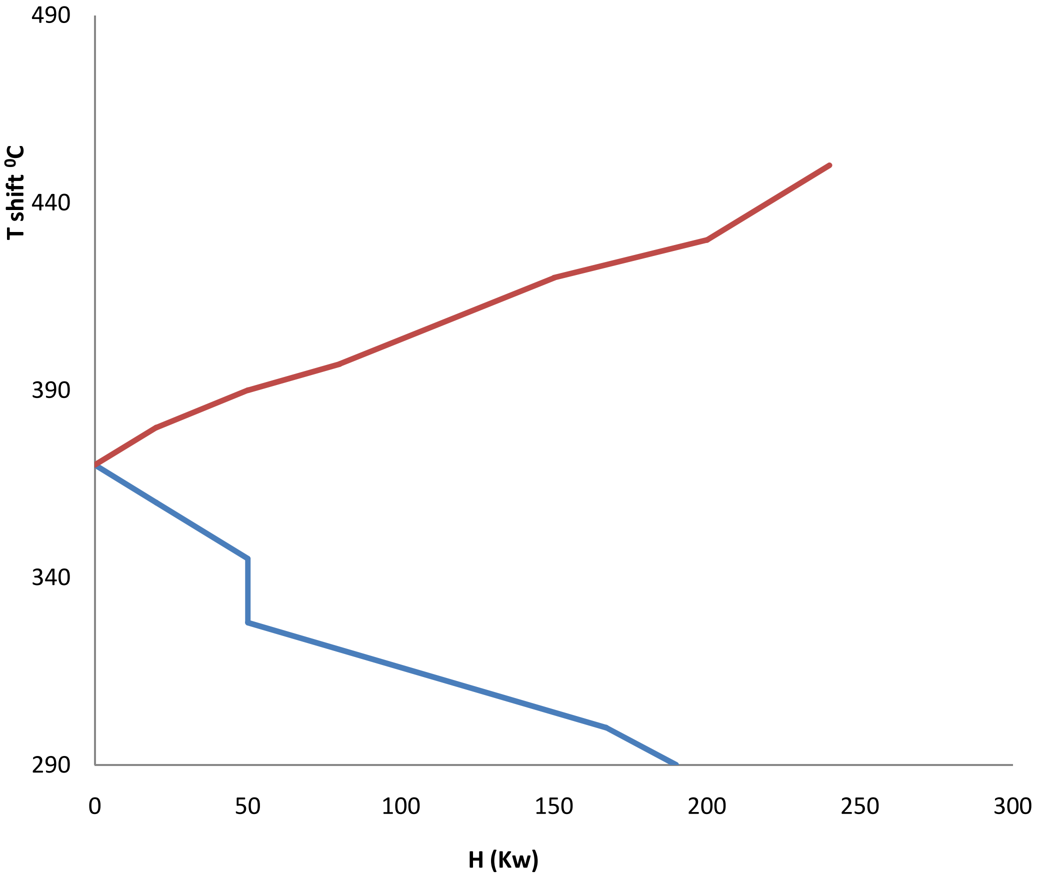

Figure 3.2: Grand Composite Curve of VDU main Fractionator

DISCUSSION

The result obtained from the laboratory analysis, and the data extracted from the process flow diagram and the operating manual is discussed as follows:-

3.2.1 Laboratory analysis result

The result obtained from the True Boiling Point analysis as indicated in table 3.1 shows that the true boiling point of the feed ranges from 32^{o}C to 516 ^{0}C, and the volume of distilled at those points was 4% and 80% of the feed respectively. This analysis was necessary because the TBP result was required in running the simulation.

3.2.2 Data Extraction results

The result extracted from the process flow diagram and the operating manual is shown in table 3.2a-c show that the density of the feed is 879.8g/m^{3}, while the feed flow rate and temperature are respectively 637.2kmole/h and 395^{0}C. The feed stock density, the feed temperature, pressure and flow rate were also necessary in order to carry out the process simulation. The simulation was carried out to obtain the CP and the heat duty of the streams. The CP, Heat Duty T supply and T target were used in carrying out the pinch analysis. From the result of the pinch analysis, the cold and hot utility requirement of the unit was obtained. These requirements were compared with that of the traditional units.

3.2.3 Simulation results

The simulation was run to compute heat capacities and heat duties, which are required in carrying out the pinch analysis, (energy integration in this case). Hysys was used in carrying out the simulation. As shows in table 3.3, the heat capacities of the six streams range from 2.386 to 2.954 JK/kg and the heat duty range from 4.620 x 10^{8} to 4.429 x 10^{8}.

3.2.1 Energy target results

Figure 3.1 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 3.1 show that the heat available in the process is 0.24 MW while the heat demand in the process is 0.19 MW. This shows that more heat is to be removed from the process than heat to be supplied to the system. Figure 3.2 (Grand Composite Curve) also confirmed this results while at the same time giving the pinch temperature of the process as 370^{0}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 utilities, increasing the amount of cooling utility required, hence waste of energy (cold utilities) by the VDU Main Fractionator.

3.2.2 Energy saving between the traditional energy approach and pinch technology for VDU main fractionator

The hot utility requirements of traditional energy approach and pinch analysis obtained in Table 3.4a are 0.32 MW and 0.24 MW respectively. The cold utility requirements of traditional energy approach and pinch analysis shown in Table 3.4b are 0.31 MW and 0.19MW 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, which states that pinch analysis as an energy integration technique saves more energy than the traditional energy technique [6].

3.2.1 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). For the purpose of this work, an initial value of ΔT_{min} was assumed, and the maple program calculated an optimum value for the ΔT_{min}. Typical ranges of ΔT_{min} values that have been found to represent the trade-off for each class of process have been used. Table 3.3 shows typical numbers that are appropriate for many refinery units such as VDU Units, cokers, crude units, hydrotreaters and reformers.

In this study a ΔT_{min} value of 10^0C was used, which is fairly aggressive for VDUs. This is applied to all process-to-process heat exchanger matches. Rather different trade-off apply for heat transfer between process streams and utilities, so typically separate ΔT_{min} was define for each utility.

CONCLUSION

It has been shown that pinch analysis as an energy integration technique saves more energy and utilities cost than the traditional energy technique, and this means utility and capital cost saving. The minimum approach temperature of 10^0C was used to determine the energy target and pinch point discover was 370^0C. There is, therefore, urgent need to carryout retrofit of vacuum distillation unit main fractionators of Kaduna Refinery and petrochemical company in order to increase its profitability.

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