Energy Saving in Atmospheric Distillation Unit by Retrofit Design of Heat Exchanger Networks of Al –Basra Refinery

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Abstract— **Energy efficiency is a very important part in the process design because of the continuous rising in the cost of energy and the problem of global warming caused by emissions of greenhouse gases such as carbon dioxide that leads to climate change. The potential of energy saving can be significant in some industrial processes such as refinery industries. Therefore, the increase of energy efficiency leads to the decrease in the need of fossil fuel to supply the heat for the plant and thus a decrease in the emission of the carbon dioxide. This paper studies the energy saving that can be achieved in the design of optimum heat exchanger network (HEN) for atmospheric distillation unit (ADU) in the AL-Basra refinery using pinch analysis. Hint software is used in this analysis at minimum temperature different of 30°C. The results show that energy consumption for (ADU) can be reduced from 38MW to 29 MW for heating utility and from 9MW to 0.72MW for cooling utility. Also it is possible to achieve a reduction in the number of HE_s from 24 to 13 units with the area 1405.72 m^2. This means 63%, 92% and 67% reductions in heating utility, cooling utility and number of heat exchangers respectively. It has been found that the low pinch point (48°C) enables exploiting of the majority of waste heat from the ADU.**

Keywords— ***ADU, Energy Efficiency, HEN, Pinch Analysis, Pinch Point, (ΔT_{min})***

I. INTRODUCTION

A. Background

Global warming caused by emissions of greenhouse gases (GHG) such as carbon dioxide is the environmental most important issue discussed today. In the developing countries, the percentage of global energy demand consumption increased from 46 to 58% between 2004 and 2030 [1]. The important key to achieve the emission target is to reduce the consumption of fossil fuel that is considered the main source of this type of emissions.

One of many ways to reduce the problems of releasing more GHG into the environment is enhancing energy efficiency. It can save large amount of energy within industrial processes, especially refineries. Refinery plant has attracted many researchers to study and improve its energy efficiency because that approximately of 75% of energy consumption in the refining processes is achieved using furnaces and heaters [2]. Refinery processes consist of series of streams that required heating and cooling through a heat exchanger network HEN and external utilities such as steam, cooling water, air, etc. [3].

The increase of energy efficiency decreases the carbon dioxide emissions by decreasing the need for fired fossil fuel to provide the heat necessary for industrial plants. The concern about decreasing the need for fossil fuel with the climate change issue together provide an incentive to investigate and improve energy efficiencies of industrial plants [4].

The distillation section of the refinery is a major consumer of energy, its required 35 - 45% of the total demand of the refinery [5]. Therefore, the distillation section is one of the most important units to implement energy saving to modify existing plants and improve their designs.

One of effective methods in the space of integration process to increase energy efficiency and minimize fuel consumptions is called pinch analysis. Pinch analysis is a methodology for minimizing energy consumption of chemical processes by calculating the energy targets (or minimum energy consumption) and achieving them by optimizing the system of heat recovery, energy supply methods and the operating conditions of the processes [6]. The pinch analysis (or pinch technology) is an approach that used in the wide range of applications related to improvement of energy efficiencies of processes and utility.

Pinch analysis was originally introduced in the early eighties by Professor Bodo Linnhoff at University of Manchester (UK) as a method for process integration [7]. Since then, wider applications than energy analysis have been implemented using Pinch Technology.

Several studies have been done on the implementation of pinch technology for heat recovery analysis of the crude distillation unit (CDU). K.R. AJAO and H. F. Akande used pinch analysis to analyze the energy efficiency of crude pre-heat train of crude distillation unit of Kaduna refinery and petrochemical company [8]. Optimum value of minimum approach temperature of 15ºC and pinch point of 220ºC was obtained. The utilities target for minimum hot and cold utilities was also investigated. The total number of heat exchangers required for maximum energy recovery was 38.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Beabu K.Piagbo and Kenneth K.Dagde used pinch analysis of a CDU in a refinery in the Niger delta region in Nigeria, west Africa [9]. The researchers studied an optimum retrofit design that eliminating all cross-pinch heat exchangers and improving the energy performance of the CDU. The reduction in the number of heat exchangers and shells used were determined to be 84.62% and 92.31% respectively. Maximum reduction in the operating cost of 16.57% was achieved.

Deepa H.A. and Ravishankar used the two pinch technologies of graphical (thermal pinch diagram) and tabular (temperature interval diagrams) approaches in order to compare the minimum heating and cooling utility requirement of a process with the actual requirement [10]. The research was found that the minimum cooling utility requirement from both graphical and tabular procedures were almost identical (about 19 MW). The reduction in the minimum cooling utility requirement was 20%.

B. *Objectives of the present work*

The main objective of this work is to set targets for minimum heating and cooling utilities. The waste energy available and potential for energy saving from the process will be determined and optimum heat exchanger network is designed. Pinch analysis technique will be applied for this purpose. The ADU at Al -Basra/ Iraq of South Refineries Company will be taken as a case study

C. *Process Description*

Distillation unit is the first major unit at the refinery consist of main sections: ADU, VDU and a HEN with two Furnaces. The process flow sheet as shown in figure (1). The crude oil is firstly pumped from a storage tank at 33°C to the site of production. It is heated in the first grid of HEs (HEN -1) contained of 11 heat exchangers to reach a temperature of 148°C. The crude oil contains salt that can be harmful for equipment and must be removed. Water is mixed with crude oil to remove the salt and heated to the temperature between 148 °C to 153°C to be separated in the Desalter. Then, the crude oil is send to the second grid of HEs (HEN -2) which contains 13 Heat exchangers that heat up the crude oil to reach 210°C. This temperature is low for crude oil to vaporize which is necessary for the separation process in the AD column. Therefore, the furnace is important part in the CDU. The crude is heated in the furnace to 342°C where natural gas or fuel oil is used as energy source.

The HEN is used to maximize heat recovery from process streams and decrease energy demand of the furnace. The high flow rate and temperature difference between the inlet and outlet crude make the furnace one part of the refinery that consumes a significant amount of energy [11]. The heated crude oil enters the atmospheric distillation column (AD) where five fractions are extracted (Naphtha, Kerosene, Diesel, Light Gas Oil (LGO) and AD Residue).

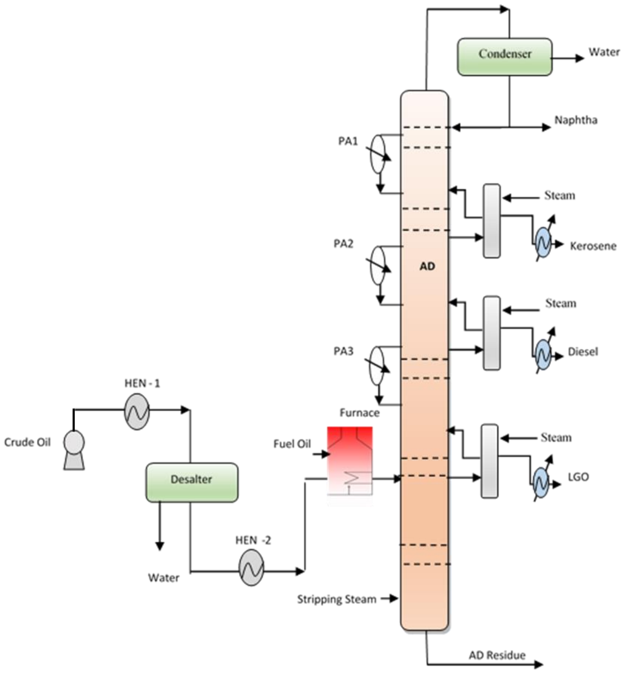

Fig.1 Process Flow Diagram of Atmospheric Distillation Column

II. METHODOLOGY AND ENERGY ANALYSIS

The plant data of the atmospheric distillation column of Al -Basrah refinery are shown in Table1. Pinch analysis is implemented using the graphical approach. A HINT software was used in the application of this technique. The Composite Curve (CC) and Grand Composite Curve (GCC) of the ADU were produced and their significant features were presented discussed. Then, the next step is the usage of the remaining problem analysis to re-design the HEN with the target being to maximize energy recovery of the process with a rearrangement HEN that makes maximum use of existing heat exchangers.

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

A. *Methodology and energy analysis*

The plant data of the atmospheric distillation column of Al -Basrah refinery are shown in Table1. Pinch analysis is implemented using the graphical approach. HINT software was used in the application of this technique. The Composite Curve (CC) and Grand Composite Curve (GCC) of the ADU were produced and their significant features were presented and discussed. Then, the remaining problem analysis is applied to re-design the HEN with a target of maximize energy recovery that makes maximum use of existing heat exchangers.

B. *Simulation and data extraction*

The most important step is collection of information from flow sheet representation of material and heat balances for the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Table 1. hot and cold streams data

	Name	type	T^s °C	T^t °C	Sp.gr	Cp (kw/°C)
1	crude from storage	cold	33	148	0.856	**219.6317**
2	desalted crude	cold	153	210	0.856	**253.692**
3	Furnace crude	cold	210	342	0.856	**289.0624**
4	Naphtha	hot	125	54	0.710	**34.48412**
5	Kerosene	hot	190	45	0.790	**22.87289**
6	Diesel	hot	102	75	0.879	**25.6087**
7	LGO	hot	250	85	0.839	**52.79417**
8	AD Residue	hot	330	100	0.957	**163.0492**

processes which are required for the application of pinch analysis. The process consists of 8 streams: 3 cold and 5 hot streams. Hot streams are streams that need cooling (heat sources) while cold streams are streams that need heating (heat sinks). The crude oil is firstly heated by heat exchangers and then by a furnace from about 33ºC to 342ºC before it enters the atmospheric column where the crude oil is fractionated into its products. The crude oil represents the only cold stream at the system which is heated by 24 of HE_S. The crude stream divided into three cold streams; the crude from storage, the desalted crude stream and furnace cold stream. Five hot process streams are used to preheat the cold streams. These hot streams include the distillate product of naphtha, kerosene, Diesel, (LGO) and (AD Res.).

The basic information needed for the simulation includes; supply temperature (T^s °C), target temperature (T^t °C) and Heat Capacity Flow Rate (Cp kW/°C). The specific heat capacity of petroleum can be calculated using empirical formula below **[9]**:

$$Cp = [0.402 + 0.00081\,t]/\sqrt{d}$$

Where d is the specific gravity of the stream at 15ºC, t is the mean temperature in ºC and C_p is the specific heat in kcal/kg.ºC.

Therefore, the heat capacity was calculated according the following equation:

$$Cp = m^{\cdot} \times cp$$

The minimum temperature difference between the hot and cold composite curves is known as the minimum temperature approach (ΔT_{min}). The optimum value of ΔT_{min} for refinery processes has been determined by Linnhoff (1998) to be in the range of 20 to 40ºC. Hence a value of 30ºC was used in this work.

C. The Number of Units Targets

The next logical step in the design of HEN is setting targets for the fewest number of heat Exchangers. The minimum number of units (*N_{min}*) depends on the total number of process (hot, *N_h and cold, N_c*) and utility, *N_u*, streams in the HEN. This can be obtained by using the equation below:

$$\mathbf{N_{min} = (N_h+N_c+N_u-1)_{\,above\ pinch} + (N_h+N_c+N_u-1)_{\,below\ pinch}}$$

HEN is the most important part in the chemical process design. It is consisting of many HE worked together to satisfy the energy conservation target. The aim of HEN is to heat and/or cool streams with the least utilities. The main target in any process design is to maximum process to process heat recovery and minimize utility requirements.

D. Feasible network configurations

The feasible network formation consists of two parts [13]:

- Hot end design (above pinch)
- Cold end design (below pinch)

By doing this, the design of HEN becomes simple and easier than the original single–task problem. The following conditions must be achieved when designing a HEs beside avoiding heat transfer across the pinch [14].

- Above the pinch, Cp cold ≥ Cp hot.
- Below The pinch, Cp cold ≤ Cp hot.

III. RESULT AND DISCUSSION

A. The *Composite Curve (CC)*

The CC is constructed by combination hot composite curve HCC, the heat availability of the process, and the cold composite curve CCC, the heat demand in the process, see Figure 2. At chosen ΔT_{min} of the process of 30°C, the pinch temperature of hot and cold streams were found 63°C and 33°C respectively. The CC shows that the minimum heating demand was 28.927 MW while the cooling demand was found 0.722 MW.

B. The *Grand Composite Curve (GCC)*

The GCC shows the amount of heat available in various temperature levels and the net heat of the process, see figure 3. The pinch point indicates zero heat transfer (H=0) which is called pinch temperature. The pinch of the process is found at 48°C. This means that cooling should be avoided above 48°C and heating should be avoided below this temperature. The GCC also shows the required temperature for heating and cooling. The process has a large heating demand up to 357°C and a low cooling demand down to 30°C which means that the heating utility of the plant is higher than the cooling utility.

The comparison between the minimum utility demand and the present utility demand of the unit and the potential saving of energy are shown in Table 2.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

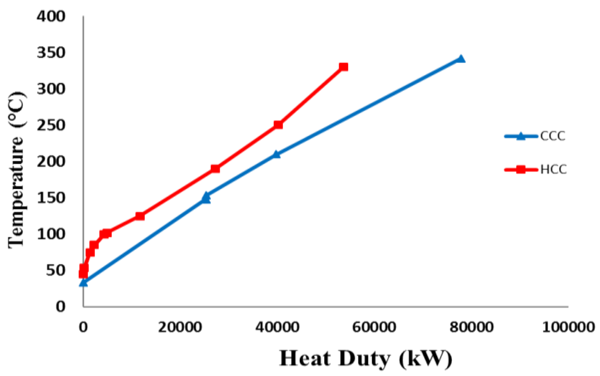

Fig. 2 The CC for ADU

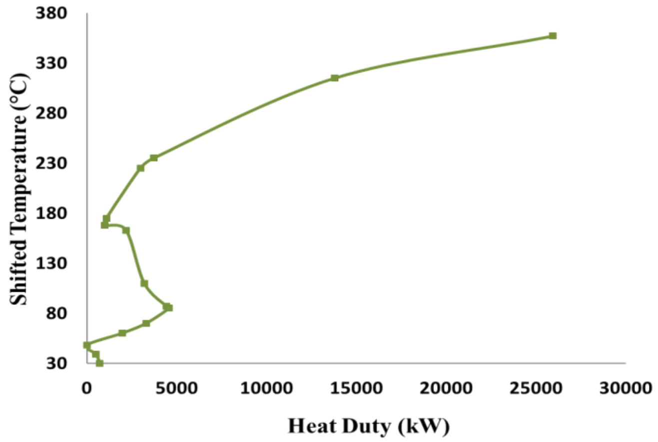

Fig. 3 The GCC for ADU

Table 2 potential saving for heating and cooling demand in ADU

	Present Demand (MW)	Minimum Demand (MW)	Potential Saving (MW)	Potential for Saving %
Heating	38.156	28.927	24.185	63%
Cooling	9.216	0.722	8.494	92%

C. Retrofit design of HEN

In retrofit design, the existing ADU and associated HEN are consider. The new design of HEN is done by rearrangement the HEs to find the optimum network and changing in operating conditions of the furnace. the design objectives are set toward minimum energy consumption.

Above the Pinch

In this region, there are five hot streams and three cold streams, Figure 4. The rule for this section is $\mathbf{Cp_c \geq Cp_h}$. The primary step is to setup process-to-process HEs for maximum energy recovery. Different configurations of HE can be used depending on the decrease of its number in the network. There are eight heat exchangers and three heaters have been used in the design of this section without using any cooler. Furthermore, the new design required stream splitting (the cold stream) because the number of hot and cold streams are not equal. The cold stream (8C1) was suitable for splitting because its supply temperature (33°C) gives minimum temperature difference of 30°C when match with any hot streams. it was need for Four split of this cold stream to complete the design of this region.

Below Pinch

In this region, there are only two hot streams see Figure 4. Therefore, this part does not contain process to process heat exchangers. Two cooler were used in the new design that enough to supply the cooling for the system.

After obtaining the optimum designs both above and below pinch point, the two designs were combined to get a grid diagram. The results show that optimum design contains 13 units; 7 HE_s, 3 heaters and 2 coolers.

The minimum area is 1405.72m^2. The heating and cooling demand were reached are 28926.6 kW and 722.069 kW respectively. There were not any HE_s cross the pinch which leads to improve heat recovery of the unit. This design minimizes the number of utilities. Furthermore, splitting was needed in the hot end section due to that the number of cold streams was less than the number of hot streams. The design of the network included a change in the target temperature for the fifth hot stream (H_5). The target temperature was 118.4°C instead of 100°C because it has higher enthalpy. The minimum temperature difference of 30°C has not reached, see figure 5.

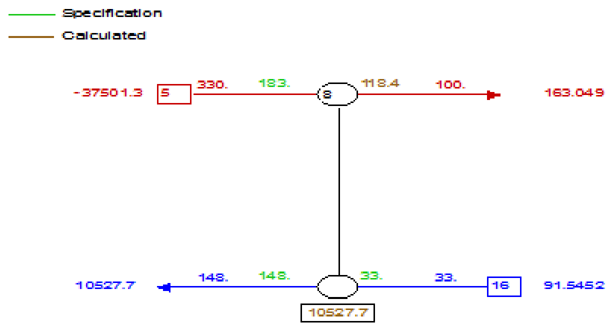

Fig.5 The Fifth Hot Stream in HEN for ADU

After optimization, the temperature of crude oil entering into the furnace increased to 260.8°C instead of 210°C, this leads to a decrease in the heat duty from 38.156 MW to 23.482 MW, with a reduction 38% in the energy consumption

D. Comparison Between the Current Case and the Optimum Design in ADU

A steady state operating data has been compared to optimum design data. These comparison is shown in Table 3. The data shows the change in the operating conditions including the furnace and the hot stream of AD Residue.

Table 3 operation condition before and after optimum design

Item	Before	After
Crude Oil Inlet(°C)	33	33
Crude Oil Inlet Desalter (°C)	148	148
Crude Oil from Desalter (°C)	153	153
Crude Oil before Furnace (°C)	210	260.8
Crude Oil after Furnace (°C)	342	342
Outlet Temperature of AD Residue	100	118.4

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

The HEN data of the current and optimum ADU also have been obtained for comparison in Table 4.

The results that have achieved after the application of pinch analysis in ADU show that it is possible to achieve a reduction in the number HE_S by 67% and 39% in the energy consumption of the furnace. Furthermore, optimum HEN design can be achieved with the splitting of the cold stream in the optimum grid design.

Table 4 Comparison of Base Case Design and Optimum Design

Item	Current design	Optimum design
ΔT_{min} (°C)	-	30
Furnace Energy Consumption (MW)	38.156	23.481
No. of HE_s	24	8
No. of Heaters	1	4
No. of Coolers	4	2
No. of Split	-	4

E. Effect of ΔTmin on the Area Target

Figure 6 shows that the area target decreases with the increase of ΔT_{min}. A decrease of 50% in the area target can be achieved by increasing the ΔT_{min} by 45ºC.

Figure 7 shows the effects of ΔT_{min} on the minimum number of heat exchangers. The figure shows that when ΔT_{min} increases from 5 to10°C, the number of heat exchangers stabilize on the 11. The minimum number of HEs changes to 12 when the value of ΔTmin changes from 10 to 15°C and changes to 13 units when ΔT_{min} becomes 25°C. Between 35-40°C, the number of HEs reaches 14, but returns to 13 for the value of ΔT_{min} above 50°C.

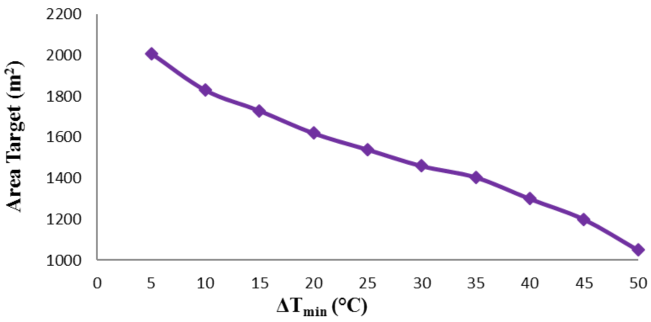

Fig.6 Effect of ΔT_{min} on the Area Target

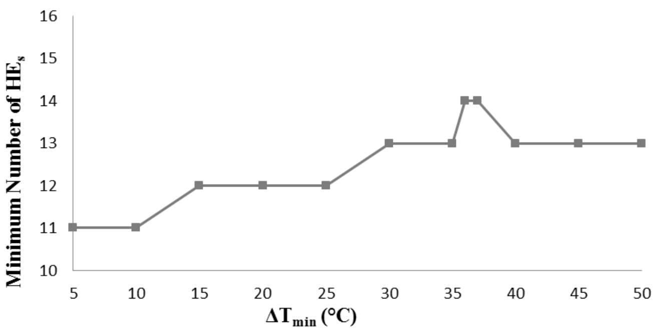

Fig. 7 Effect of ΔT_{min} on the Minimum Number of HE_s

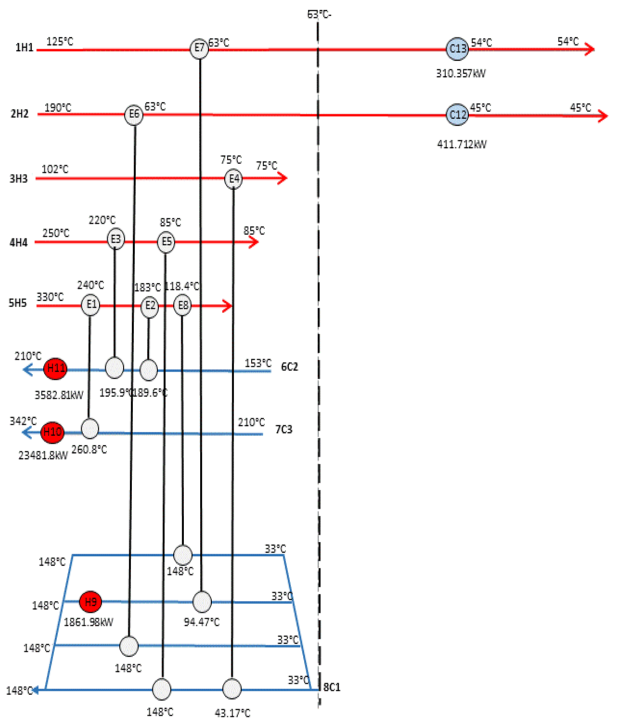

Fig. 4 The HEN for ADU

IV. CONCLUSION

A fundamental method of increasing the energy saving is by designing effective HEN. Pinch analysis techniques was applied to design the optimal HEN to minimize the energy consumption in ADU of AL– Basra refinery.

The existing energy consumption for heating and cooling utilities was 38 and 9 MW respectively with 24 of HE_s and utilities. Pinch analysis was applied assuming ΔT_{min} of 30°C the minimum heating and cooling demand are determined as 29 MW and 0.7 MW respectively. Above the pinch, the grid design consists of 8 process to process heat exchangers and 3 heaters. Below the pinch, no heat exchangers were used while 2 coolers were introduced. The optimum HEN are designed to recover 46% of waste energy with the area 1405.72m^2

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