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Applying Pinch Technology in the Heat Exchanger Network for an Existing Refinery

Dissertation submitted in partial fulfillment of the requirement for the degree Bachelor of engineering in Transportation and Refining Engineering

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الإستهلال

قال تعالى:

(يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ)

صدق الله العظيم

سورة المجادلة (11)

DEDICATION

We avail this opportunity to dedicate this work to our families, especially my parents, for their encouragement, patience, and assistance over the years. We are forever indebted to our parents, who have always kept me in their prayers.

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First and foremost, I would like to thank the supervisor of our project, Dr. Zeineb Abdulla Muhammad, for her support, And we greatly appreciate her cooperation airing the stage of writing up this work.

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ABSTRACT

This project uses pinch analysis techniques to analyze the heat transfer characteristics and efficiency of a typical heat exchanger network, used in Elobied. The heat exchanger network, consist of eight heat exchanger with four hot streams and one cold stream. The pinch temperature was determined to be **688 ^{o}F**, using the Problem Table method and construction of the composite curves and **652 ^{o}F** by using HEN software. And the minimum hot and cold utility requirements are founded to be **48.95999 Btu/hr** and **497.2229Btu/hr**, respectively, as determined by the HEN software and **48.96Btu/hr** and **497.85Btu/hr** as determined by hand calculations using problem table method and also by composite curve which constructed by pinch online tool . The optimum minimum temperature difference between the hot and cold streams was chosen to be **68 ^{o}F**. after that we compare these results with existing heat exchanger network and we find that there is as saving in hot utility by **70%** and for hot utility the existing is less than we calculated and thus require more field work to now the deficit, and also it save the heat transfer area by **30%** of the total area.

Key words: pinch analysis, heat exchanger network, pinch point, hot and cold utilities.

المستخلص

استخدم في هدا المشروع تقنيات -pinch technology- لتحليل المواصفات الحراريه لشبكة المبادلات الحراريه المستخدمه في مصفاة الابيض وهذه الشبكه تتكون من 8 مبادلات حراريه تحتوي غلى اربعه خطوط ساخنه من المنتجات وخط بارد من الخام وبتطبق -pinch analysis- تم تحديد -pinch point- على انها تساوي 688 °**F** باستخدام الطريقتين البيانيه والحسابيه وتساوي 652 °**F** باستخدام برنامج -HEN software- وتم ايضا تحديد اقل طاقه لازمه للتسخين تساوي**48.95999** Btu/hr واقل طاقه لازمه للتبريد تساوي **497.2229**Btu/hr وذلك باستحدام برنامج -HEN software - وباستخدام الحسابات اليدويه (طريقة الجداول) الطريقه البيانيه باستخدام -composite curve- وجد ان اقل طاقه لازمه للتسخين تساوي **48.96**Btu/hr واقل طاقه لازمه للتبريد تساويا **497.85Btu**/hr واستخدم اقل فرق يحدث عنده انتقال للحراره غلى انه يساوي 68 °**F** وتمت مقارنة هذه النتائج ووجد انها توفر مقدار 70% من الطاقه المستخدمه للتسخين اما بالنسبه للطاقه المستخدمه في تبريد وجد انها اقل من القيمه المحسوبه ويعزى ذلك الى انها تحتاج لمزيد من الدراسات الحقليه.

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DEFINITIONS

Pinch Point	The location of the smallest difference between hot and cold streams in a heat transfer network
Supply Temperature	The temperature at the inlet of a heat exchanger.
Target Temperature	The temperature goal at the outlet of the heat exchanger.
Stream	Fluid that must be heated or cooled.
Heat Capacity Flow rate	Mass flow rate multiplied by the enthalpy of the fluid for the given temperature range.
Heat Load	The maximum amount of heat that could be transferred to or from a stream.
Composite Curve.	Graph of temperature versus enthalpy for the cold and hot stream data
Utility	An external source of heating or cooling that does not use energy from the streams in the system.

Nomenclature

Symbol	Description	Unit
Cp	heat capacity Flow rate	Btu/hr/F°
ΔH	heat Load	Btu/hr
DTmin	minimum Temperature difference Between Hot and Cold	F°
TS	supply Temperature	F°
Tt	target Temperature	F°
Tcin	inlet Temperature of the cold stream	F°
Thin	inlet Temperature of the hot stream	F°
Thout	outlet Temperature of the hot stream	F°
Tcout	outlet Temperature of the hot stream	F°
$\dot{m}$	mass flow rate	lb/hr
U	the Overall Heat transfer coefficient	Btu/hr.ft2. F°
Qc	heat transferred from the cold stream	Btu/hr
Qh	heat transferred from the hot stream	Btu/hr
ΔTlm	logarithmic temperature difference	F°

Chapter 1

Introduction

1.1 Background

Energy systems are an integral and critical component of industry. They provide the process heating, cooling and power needed for conversion of raw materials and fabrication of final products. Industrial energy systems channel fuels and power into a variety of energy sources such as steam, direct heat, hot fluids and gases, and shaft power. These energy systems encompass a wide range of equipment, including boilers, furnaces, dryers, calciners, melters, smelters, coolers, and machine-driven equipment such as compressors, pumps, fans, grinders, crushers and mixers. All manufacturing processes rely to some degree on energy systems. In the very energy intensive basic industries, such as chemicals, petroleum refining, iron and steel making, and pulp and paper, energy systems are the backbone of the manufacturing process and crucial to profitability and competitiveness. For these industries, changes in the efficiency and environmental performance of critical energy systems can significantly impact the cost of production. The environment performance depends on the environmental impact of the energy system. The environmental impact of the energy industry is diverse. The use of fossil energy carriers for transportation, metal refining and the production of manufactured goods will cause depletion of fossil energy resources, climate change, and a wide range of emissions-related impacts.

Improved industrial process efficiency is of great importance to utilities. It enhances customer competitiveness and profitability, thereby fostering load retention and strategic load growth. By understanding the energy use patterns and options at an industrial site, the utility can work together with its customer to define mutually beneficial investment and operating options. The technique of choice is pinch analysis, an innovative and effective method for analyzing industrial sites. Large number of studies conducted around the world in various industries with high degree of success. [8]

Energy efficiency varies dramatically across industries and manufacturing processes, and even between plants manufacturing the same products. Efficiency can be limited by mechanical, chemical, or other physical parameters, or by the age and design of equipment. In some cases, operating and maintenance practices contribute to lower than optimum efficiency. Regardless of the reason, less than optimum energy efficiency implies that not all of the energy input is being converted to useful work – some is released as lost energy. In the manufacturing sector, these energy losses amount to several quadrillion Btus (quadrillion British Thermal Units, or quads) and billions of dollars in lost revenues every year.

Given this resource and cost perspective, it is clear that increasing the efficiency of energy use could result in substantial benefits to both industry and the nation. Unfortunately, the sheer complexity of the thousands of processes used in the manufacturing sector makes this a daunting task. A first step in understanding and assessing the opportunities for improving energy efficiency is to identify where and how industry is using energy – how much is used for various systems, how much is lost, how much goes directly to processes, and so forth. The second step is to then quantify the portion of lost energy that can be recovered technically and economically through improvements in energy efficiency, advances in technology, and other means.[1]

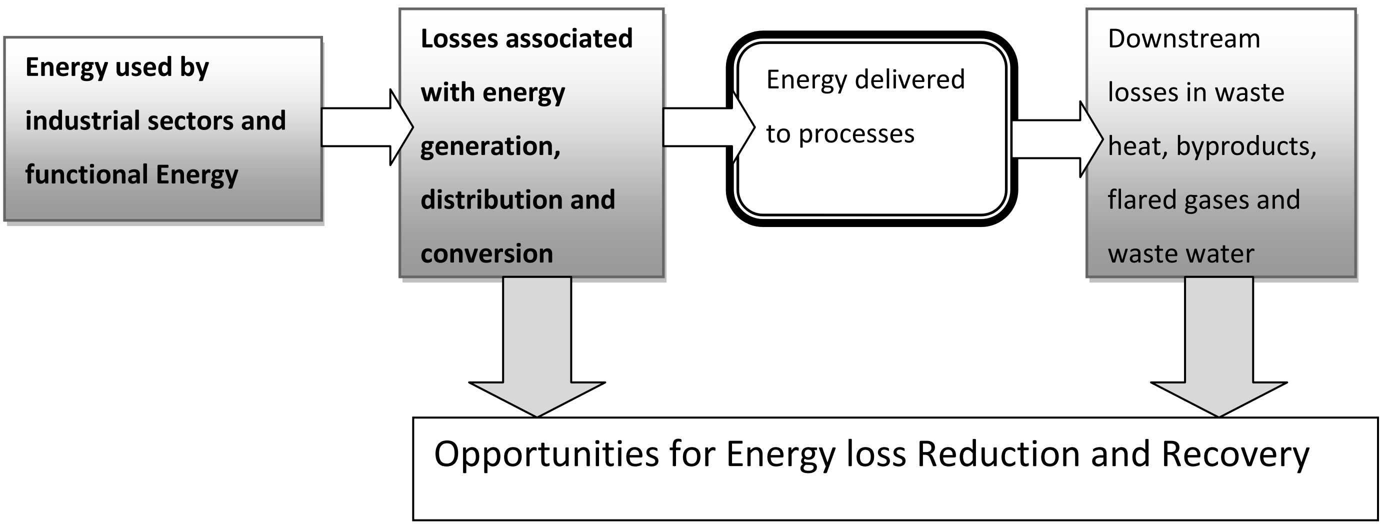


Figure (1.1): flow of multi-phase study energy use, loss and opportunities

1.2 Problem Statement

This project will analyze the heat exchanger network of Elobied refinery, using pinch analysis. The pinch point, or most constrained point in the design, will be determined, as well as the minimum external hot and cold utility requirements to meet the targeted heat exchanges. Recommendation for retrofitting the components of the power plant or improvements to increase efficiency and reduce cost will be made.

1.3 Research Objectives

In this project we identify opportunities for energy savings using pinch technology; to develop technically and economically viable projects by calculating the minimum energy targets (minimum hot and cold utilities). And the main objective of this project is:

- Calculate the minimum hot and cold utility of heat exchanger network of Elobied refinery.
- Identify the optimum heat exchanger network that will achieve the minimum energy target and save the heat transfer area.

Chapter 2

Literature review

2.1 Energy efficiency in oil and gas industry

There is a strong consensus within the oil and gas industry on the importance of saving energy by improving the efficiency of operations along the supply chain and eliminating unnecessary waste. Large investments have already been made, and oil and gas companies continue to devote considerable resources in pursuit of further energy savings. The primary strategies include implementation of energy management systems, developing energy benchmarks, identifying and introducing best management practices **(**reduce losses, proper selection of fuel **)**, enhancing communication and awareness, driving energy efficiency and GHG emission reduction projects and developing new technologies.

Companies already have a strong financial incentive to save energy. Using energy efficiently reduces costs along the whole supply chain, improving competitiveness and making end products more affordable for consumers. It is also a powerful environmental tool, reducing the carbon intensity of processes and therefore reducing carbon emissions to the atmosphere.

This is why oil and gas companies have invested heavily over the years in more efficient technologies all along the supply chain, and plan to invest more in the future.

But worldwide, opportunities still exist within the industry to make significant contributions towards reducing energy consumption and greenhouse gas emissions by taking advantage of energy efficiency improvements.

2.2 Energy losses in industrial energy systems

Not all of the energy delivered to industry is used productively. Large amounts of energy are lost in onsite energy systems prior to delivery to processes during generation, distribution, and conversion of energy. The magnitude of energy use and losses indicates that these industries are prime targets for energy efficient improvements.

The main sources of energy loss in industrial are enclosed into two major topical areas**:**

- Fluid heating and boiling.
- Melting, smelting, metal heating, agglomeration, and calcining.

Here we will discuss fluid heating and boiling only.

2.2.1 Energy losses in Fluid Heating and Boiling

Fluid heating and boiling is a critical component of many energy intensive processes used in the manufacture of chemicals, refined petroleum products, forest products, food and beverage, and textiles. Fluid heating and boiling systems include fired systems such as furnaces, evaporators, dryers, condensers, and other direct-fueled systems, as well as steam generators(mostly boilers, although a small amount of steam is produced with electric elements). Heat exchangers, steam injectors, and other auxiliary equipment are also integral components of fluid heating and boiling. Energy systems for cooling of fluids include cooling towers and ponds, heat exchangers, cryogenic equipment, chillers, and other equipment.

Waste heat embodied in hot gases or fluids is the primary source of losses from fluid heating and boiling. In petroleum refineries, for example, contaminated waste steam from fractionating and stripping processes is a major source of waste heat. In refineries and chemical manufacturing, waste gases from boilers, furnaces, vents, flares, and coolers, represent a large source of waste heat. The energy content of these waste heat sources depends primarily on temperature.

2.3 Strategies for Energy Savings in Industry

The strategies for achieving energy savings in industry are quite different to those for most other sectors. Industry is very diverse and is often controlled by very large multi-national corporations. In this context the appropriate approach needs to be carefully considered. Industry is generally receptive to efforts to cut its energy costs but it is less likely to be attracted to regulatory measures that increase its operating costs.

2.3.1 Technical Options:

The technical options available for energy savings in the industrial sector are as diverse as the industries themselves. However, they principally revolve around the saving of energy in areas such as:

2.3.1.1 Energy Savings in Steam Generation

Steam is used for a multitude of purposes in industrial plant. It can provide heat for chemical processing, hot water for cleaning purposes, steam for input to turbines for producing power and so on. Steam is generally produced by boilers. Boilers typically operate well below their optimum efficiency and savings of approximately 15% should be readily achievable.

As with all examples of industrial energy efficiency, it is important to consider the whole steam system from generation to recovery. Heat (and thus energy) losses in the steam generation and distribution systems will result in poor heating at the location of the end use.

Energy savings in the generation side of steam use are usually the result of efficiency improvements in the operation of the boiler. In maximizing the efficiency of boilers two key principles need to be addressed: first, the level of excess air (the extra air

needed to ensure good combustion of the fuel in the boiler) and secondly the temperature of the flue gases needs to be kept as low as possible (otherwise a large part of the heat that was produced in the boiler will go up the chimney).
Good monitoring can be used to assist in achieving these outcomes. In addition, to these, the utilization of high quality water, free from contaminants, ensures that the minimum amount of heat is required to produce steam.

Boiler plants, there are typically four areas of potential savings

i. **Monitoring equipment:**

Boilers are a potential source of energy savings since they are frequently inadequately monitored, even at the simplest level, resulting in efficiency losses, and hence. Simple, but regular analysis of the flue gases, including chemical analysis of the gases and its temperature, will help determine if the boiler is operating efficiently. Care should be taken to ensure that the tests are conducted with load levels of at least 65 – 70% and that the load and gas (steam) pressures are constant. Once this level of analysis is well established, Additional monitoring equipment which can determine the gross thermal efficiency of the boiler may be required.

ii. **Load management:**

As with electric motors and air compressors, boilers do not run efficiently when they are operating at less than their recommended operating pressures. Significant cost savings can result where load management strategies, such as only operating the number of boilers to produce the required amount of gas/steam and advance warning of changes in the gas/steam load are given to boiler plant staff, are implemented.

iii. **Condensate return:**

Unfortunately, there will always be some efficiency losses in process heating due to boilers as a result of condensate. Boilers and reticulation systems which are fitted with condensate return systems are far more efficient than those where the condensate enters a waste stream. The efficiency gains are largely the result of chemical profile of the steam condensate, which is typically hot and free of oxygen. This liquid requires less energy to convert the already heated and deoxygenated liquid to gas (especially steam).

iv. **Fuel selection:**

There are seven common types of fuels available for boilers:

- Coal.
- Natural gas.
- Liquefied petroleum gas (LPG).
- Furnace Oil.
- Diesel.
- Electricity.
- Wood or wood wastes (Biomass).

In many parts of the world, coal is used as a boiler fuel as it is usually the cheapest industrial fuel source. However, many countries are looking towards natural gas and biomass as alternatives due to the increasing cost of the traditional fossil fuels, diesel,

coal and electricity as well as regulatory changes. When selecting or reviewing the fuel selection for boilers, careful consideration should be given to ensure that the full cost of the fuel, including transportation cost, is considered. For example, a boiler in a pulp and paper mill may be more cost effective if it utilized the wood waste from the pulp process than coal or natural gas, despite a supply of both nearby.
Cogeneration, the simultaneous production of heat and power is also a potential area of energy savings, through the on-site generation of heat / steam and electricity.

2.3.1.2 Energy Savings in Steam Distribution Systems

As with compressed air systems, the distribution of steam throughout an industrial facility is a potential area of energy loss, and hence increased operating costs. Steam traps are used in steam distribution systems to remove condensate as it forms. They often have the dual function of removing any entrapped air in the system. The presence of air and condensate in steam systems reduces the effectiveness of heat transfer in these systems as they tend to form insulating layers on heat transfer surfaces.

This means that temperatures have to be higher in order to achieve the same rate of heat transfer. Also the presence of air reduces the overall temperature of the system which is governed by the pressure of the steam. If part of the pressure of the system is caused by entrapped air, the net pressure of the steam is less than that read on the steam gauges and so the temperature will be lower than expected. Regular checking of steam traps and air vents is essential for the efficient operation of steam plant.

Energy is also wasted in steam distribution systems where heat is lost to the environment through inadequate insulation of the reticulation system. Care needs to be taken with valves and fittings that, if not properly insulated, lead to significant heat loss. Any heat lost in the distribution system means that additional fuel has to be consumed in the boiler to make up for this loss.

Condensate is an inevitable product of any steam system either as a result of heat loss or simply as a result of using the steam to transfer heat to a process. This condensate represents a source of hot, very pure water and so is an ideal feedstock for the boiler input. Assuming that the condensate has not been contaminated by the process, the use of condensate is a very effective example of using waste heat (or heat recovery).

2.3.1.3 Energy Savings in Furnaces

Furnaces are widely used in the manufacturing and mining industries. Although similar to boilers, they are usually used to melt metals for casting and heating crude oil in refineries. Many of the potential areas for energy savings are the result of high capital cost, or require detailed changes in the current operation of the factory or smelter. These include rescheduling to reduce the occurrence of a furnace being heated with less than an optimum load, automatic control of furnaces, insulation of the furnace as well as modifications to the furnace. Although these items require large

amounts of capital, consideration should be given to these issues, especially where the furnace is due to be replaced, or where a new furnace is to be purchased.
Cost effective, simple strategies for reducing the energy consumption of furnaces are very similar to those discussed in the section on boilers, and includes fuel selection, monitoring equipment (to ensure there is not excessive air in the melt) and load management.
Furnace systems often offer good potential for heat recovery systems where the very high temperatures in the exhaust air can be used to preheat the combustion air entering the system.

2.3.1.4 Energy savings through heat recovery

In many processes considerable amounts of waste heat are produced. Examples include the exhaust stacks of engines, boilers or furnaces, condensate in steam systems, and waste streams from washing, heating applications as well as compressed air systems.
Heat recovery involves the use of these waste heat streams to provide useful heat for another part of the plant. Heat exchangers are used to extract heat from the waste stream and transfer it to a second fluid flow. In many instances the waste heat from one part of the process can be used to preheat a fluid for use in that same process. For example the hot air in the exhaust of a furnace can be used to preheat the combustion air used in the same furnace.
Waste heat is usually best identified as part of an overall energy audit of the industrial process or facility. The audit should identify the fluid type (liquid or gas), the amount of fluid generated, either as a volume or flow rate, temperature of the fluid, the time of production (i.e. only between 10am and 2pm), its location as well as the location of heat using processes. From this information, the monetary value of the waste heat should also be determined.
Once the size and location of the waste heat product is known, a detailed analysis of the energy saving potential as well as the process of selecting an appropriate heat exchanger can be undertaken. Heat exchangers are devices which recover the waste heat from one process for use in another process.
There are a variety of heat exchangers available on the market, suitable for both batch and continuous feed operations. Recuperator type heat exchangers are able to work in continuous feed processes as the heat recovery from the fluid is steady. In regenerator type heat exchangers, heat recovery is delayed due to the storage period required for the release of heat from the fluid, and thus is best suited to batch processes. Careful consideration must also be given to the physical and mechanical performance of the proposed heat exchanger prior to purchase.
The production of onsite power and heat (or steam) through Cogeneration systems, or Combined Heat and Power (CHP) systems can also result in energy savings, through the utilization of waste energy associated with the production of power.

2.4 Heat exchangers

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air-conditioning systems in a household, to chemical processing and power production in large plants. Heat exchangers differ from mixing chambers in that they do not allow the two fluids involved to mix. Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids.[2]

The application of the principles of heat transfer to the design of equipment to accomplish a certain engineering objective is of extreme importance, for in applying the principles to design, the individual is working toward the important goal of product development for economic gain. Eventually, economics plays a key role in the design and selection of heat-exchange equipment, and the engineer should bear this in mind when embarking on any new heat-transfer design problem. The weight and size of heat exchangers used in space or aeronautical applications are very important parameters, and in these cases cost considerations are frequently subordinated insofar as material and heat-exchanger construction costs are concerned; however, the weight and size are important cost factors in the overall application in these fields and thus may still be considered as economic variables. [3]

2.4.1 Types of heat exchangers

Different heat transfer applications require different types of hardware and different configurations of heat transfer equipment. The attempt to match the heat transfer hardware to the heat transfer requirements within the specified constraints has resulted in numerous types of innovative heat exchanger designs.

1) **Double-pipe heat exchanger :**
   The simplest type of heat exchanger consists of two concentric pipes of different diameters.
2) **Compact heat exchanger :**
   Designed to realize a large heat transfer surface area per unit volume, the large surface area in compact heat exchangers is obtained by attaching closely spaced thin plate or corrugated fins to the walls separating the two fluids.
3) **Shell-and-tube heat exchanger :**
   Contain a large number of tubes (sometimes several hundred) packed in a shell with their axes parallel to that of the shell. Heat transfer takes place as one fluid flows inside the tubes while the other fluid flows outside the tubes through the shell.
4) **Plate and frame :**
   Which consists of a series of plates with corrugated flat flow passages . The hot and cold fluids flow in alternate passages and thus each cold fluid stream is surrounded by two hot fluid streams, resulting in very effective heat transfer.

5) **Regenerative heat exchanger :**

The static-type regenerative heat exchanger is basically a porous mass that has a large heat storage capacity, such as a ceramic wire mesh. Hot and cold fluids flow through this porous mass alternatively. Heat is transferred from the hot fluid to the matrix of the regenerator during the flow of the hot fluid, and from the matrix to the cold fluid during the flow of the cold fluid. Thus, the matrix serves as a temporary heat storage medium. [2]

2.4.2 Heat-exchanger networks

Energy conservation is important in process design. In industrial experience, the calculation of the minimum heating and cooling requirements reveal significant energy savings. Therefore, energy integration design procedure is a very beneficial tool and is an important phase in determining the cost of preliminary design. The transport of energy in chemical plants and petroleum refineries is accomplished by means of heat-exchanger networks (HENs). Knowing the minimum heating and cooling energy requirement and the number of heat exchangers, we can proceed with the design of heat exchanger network. The heat exchange network was recommended that appeared to be close to optimal based on qualitative observations. However, finding the feasible networks and then finding that network which maximizes the net present worth, or minimizes the present worth of all variable costs, for the application would make a preferable selection. This can be done by using pinch analysis (Pinch Technology).[4]

2.5 Pinch technology

The term "pinch technology" introduced by Linnhoff and Verdeveld to represent new set of thermodynamically based methods that guarantee minimum energy levels in the design of heat exchanger networks. Over the last two decades it has emerged as an unconventional development in process design and energy conservation. The term "pinch analysis" is often used to represent the application of tools and algorithms of pinch technology for studying the industrial processes

Pinch technology is a methodology for minimizing energy consumption of chemical processes by calculating thermodynamically feasible energy targets (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and process operating conditions. It is also known as process integration, heat integration, energy integration or pinch technology. Pinch technology presents a simple methodology for systematical analyzing chemical processes and the surrounding utility systems with the help of first and second law of thermodynamics. The first law of thermodynamic provides the energy equation for calculation the enthalpy changes in stream passing through heat exchanger. The second law determined the direction of the heat flow. That is, heat energy may only flow in the direction of hot to cold. In heat exchanger unit neither a hot stream can be cooled below cold stream supply temperature nor can cold stream be heated to temperature more than the supply temperature of the hot stream. In practice the hot stream can only be cooled to temperature defined by the "temperature approach" of the heat exchanger. The temperature approach is the minimum allowable temperature difference (DTmin) in the stream temperature profiles, for the heat exchanger unit. The temperature level at which the DTmin is observed in the process is referred to as "pinch point" or "pinch condition". The pinch defines the minimum driving force allowed in the exchanger unit.

The process data is represented as a set of energy flows, or streams, as a function of heat load (Btu/hr) against temperature (degree F). These data are combined for all the streams in the plant to give composite curves, one for all hot streams (releasing heat) and one for all cold streams (requiring heat). The point of closest approach between the hot and cold composite curves is the pinch point (or just pinch) with a hot stream pinch temperature and a cold stream pinch temperature. This is where the design is most constrained. Hence, by finding this point and starting the design there, the energy targets can be achieved using heat exchangers to recover heat between hot and cold streams in two separate systems, one for temperatures above pinch temperatures and one for temperatures below pinch temperatures. In practice, during the pinch analysis of an existing design, often cross-pinch exchanges of heat are found between a hot stream with its temperature above the pinch and a cold stream below the pinch. Removal of those exchangers by alternative matching makes the process reach its energy target.

2.6 Selection of DTmin

The process engineer generally assumes that there is a trade-off between energy and capital costs. Although there are occasions when pinch analysis can direct the engineer to savings in both energy and capital, saving energy generally implies increased capital spending, particularly in the case of retrofit. The DTmin value is determined by the overall heat transfer coefficients (U) and the geometry of the heat exchanger.

In practice, the pinch specialist often selects the DTmin value for a given process by looking at the two following factors:

a) **The shape of the composite curves.** Typically, a higher value will be chosen for composite curves that are almost parallel, than for systems that diverge sharply. This is because the temperature difference between cold and hot streams, in any heat exchanger of the process, is close to the DTmin value when the composite curves are almost parallel. In this case, a small DTmin would result in a high heat exchange area for all heat exchangers (not only for the ones that transfer heat between streams close to the pinch point) and thus, high investment costs.

b) **Experience.** In systems where fouling readily occurs or where heat transfer coefficients are low; typical DTmin values of 30–40°C are used. For chemical processes, and where utilities are used for heat transfer. A few values based in the Linnhoff March application experience are tabulated below for shell and tube heat exchangers. **[6]**

Table (2.1): linnhoff March DTmin value

No	Industrial Sector	Experience DTmin Values	Comments
1	Oil refining	20-40ºC	Relatively low heat transfer coefficients, parallel composite curves in many applications, fouling of heat exchangers
2	Petrochemical	10-20ºC	Reboiling and condensing duties provide better heat transfer coefficients, low fouling
3	Chemical	10-20ºC	As for Petrochemicals
4	Low Temperature Processes	3-5ºC	Power requirement for refrigeration system is very expensive. DTmin decreases with low refrigeration temperatures

2.7 The pinch analysis methods:

In the present crisis scenario all over the world, the target in any industrial design is to maximize the process-to-process heat recovery and to minimize the utility (energy) requirement, to meet this goal of maximum energy recovery and the minimum energy requirement.

The minimum energy requirement in the pinch analysis can be determined by one of these methods**:**

1. Graphical method(Composite Curves)
2. Algebraic method (Problem table or intervals).

2.7.1 Graphical method (Composite Curves)

Composite Curves consist of temperature-enthalpy (T-H) profiles 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. The composite curves provide a counter-current picture of heat transfer and can be used to indicate the minimum energy target for the process and minimum hot utility requirement (Q_{Hmin}) and the minimum cold utility requirement (Q_{Cmin}) of the process for the chosen DTmin.

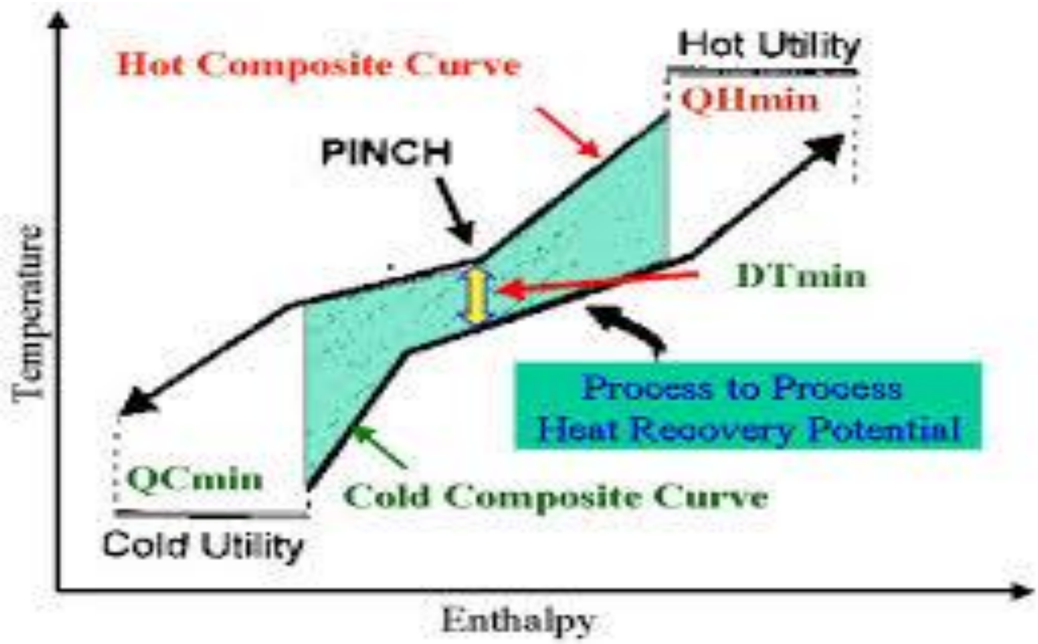


Figure (2.1): composite curve

- **The Pinch Principle**

The point where DTmin is observed is known as the “Pinch” and recognizing its implications allows energy targets to be realized in practice. Once the pinch has been identified, it is possible to consider the process as two separate systems: one above and one below the pinch, as shown in Figure (3). The system above the pinch requires a heat input and is therefore a net heat sink. Below the pinch, the system rejects heat and so is a net heat source.

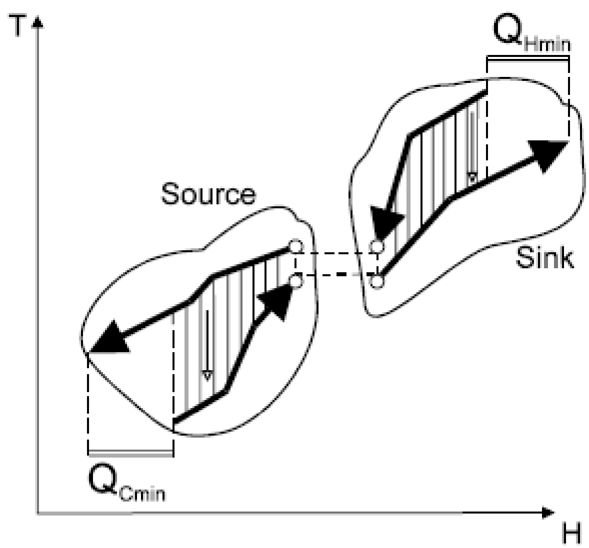


Figure (2.2): The Pinch Divides the composite curve into heat Source and Sink

The understanding of the pinch gives three rules that must be obeyed in order to achieve the minimum energy targets for a process:

• Heat must not be transferred across the pinch
• There must be no external cooling above the pinch
• There must be no external heating below the pinch

Violating any of these rules will lead to cross-pinch heat transfer resulting in an increase in the energy requirement beyond the target. The design procedure for heat exchanger networks ensures that there is no cross pinch heat transfer. For retrofit applications the design procedure "corrects" the exchangers that are passing the heat across the pinch.

2.7.2 Algebraic method or Problem table method (intervals).

Composite curves are inconvenient. Thus a method based on tables was developed. The problem table is the name given by Linnhoff and Flower to a numerical method for determining the pinch temperatures and the minimum utility requirements; Linnhoff and Flower (1978). Once understood, it is the preferred method, avoiding the need to draw the composite curves and manoeuvre the composite cooling curve using, for example, tracing paper or cut-outs, to give the chosen minimum temperature difference on the diagram.

The procedure is as follows:

STEPS:

1. Divide the temperature range into intervals.

2. Convert the actual stream temperatures (T_{act}) into interval temperatures (T_{int}).

3. Rank the interval temperatures in order of magnitude, showing the duplicated temperatures only once in the order.

4. Carry out a heat balance for the streams falling within each temperature interval.

5. "Cascade" the heat surplus from one interval to the next down the column of interval temperatures.

6. Introduce just enough heat to the top of the cascade to eliminate all the negative values **[7].**

❖ The heat introduced to the top was considered as minimum hot utility required for the heat exchanger network and the heat accumulated at the bottom was considered as minimum cold utility requirement and the point where the heat load was zero it is a pinch point.

2.8 Literature review

2.8.1 Wax extraction plant

A wax extraction plant case study demonstrates how process integration or pinch technology can identify practical and cost effective ways to substantially reduce energy costs. Suggested cost saving measures include steam and power system improvements, yield improvement, reduction of NOx emissions and optimum heat exchanger network design. Petro wax Corporation produces high grade waxes for use in a variety of commercial and consumer markets. Petro wax was keen to modernize its facilities in order to reduce operating costs, increase manufacturing flexibility, and to achieve compliance with a NOx abatement order at minimum capital cost.

The present study employed the techniques of Pinch Analysis to identify a comprehensive process improvement strategy that improved wax yield by *8%,* increased refrigeration capacity by 10% and reduced total steam demand by 22%. It is possible to boost VDU (vacuum distillation unit) wax yield by about *8%* points by making relatively minor modifications to VDU tower operation. Economics of replacing the existing bauxite process with a hydrotreater are not good and Economics of cogeneration involving gas turbines are not good. Increased energy cost in VDU is offset by additional heat recovery, and reduced energy cost in PDA area. By implementing the recommended HEN (heat exchanger network) retrofit in VDU and MEK process areas, steam savings of about 40,000 Ib/hr are possible. This will enable shut down of boilers 3 and 4, and reduce NOx emissions by 30-50%. **(Linnhoff March, Inc. (1995))**

2.8.2 Energy targeting study in Palatka plant

It carry out a water reduction study and an energy targeting study using its Successive Design Methodology in its Palatka plant in Florida; to promotes plant-wide energy efficiency assessments that will lead to improvements in industrial efficiency, waste reduction, productivity, and global competitiveness. It is use the principles of water and thermal pinch to identify water and energy conservation projects.

This will result a save in the energy of 729,000 MMBtu per year, saves a potential $2.9 million per year in operating and energy costs and reduces water use**. (Georgia-Pacific Corporation (2002))**

2.8.3 Pinch analysis in Petrochemical plant

provide a methodology to apply energy integration to retrofit (EITR) a petrochemical plant (The polyethylene production plant) using the Pinch Technology concept, building a heat exchanger network to reduce the overall consumption of hot and cold utilities. Energy savings are realized via a modification in the existing heat exchanger network and by the use of a flue gas stream to produce steam and a process stream to produce chilled water. The minimum utilities consumption target for the process, the minimum number of heat exchanger units and the minimum total surface area were determined, based on the minimum temperature difference established between hot

and cold process streams, using the heat exchanger network (HEN) synthesis software At HENS.
The results of this study indicated possible reduction in plant consumption of hot and cold utilities by 9% and 24% respectively, with a payback period estimated at 2.3 years. **(João et al)**

2.8.4 Pinch analysis chemical and gas plants

Chemical and gas plants are energy-intensive facilities so that any enhancement of their efficiency will result in abundant reduction of energy consumption and greenhouse gas emissions. Liquefied natural gas (LNG) plants consume a great amount of energy. After developing models for the LNG process using ASPEN software, four expansion loss recovery options are simulated.
When replacing conventional expansion processes with expanders the simulation results show that the compressor power reduction, expansion work recovery, and LNG production increase can be achieved as much as 2.187 MW, 3.9 MW, and 1.24%, respectively. Therefore, the expansion work recovery is an important option to be implemented in LNG plants. **(A. Mortazavi1, Y., R., S. and P. (2008))**

2.8.5 Vacuum distillation plant Process

This project studied the energy integration of vacuum distillation plant Process integration is referring 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. 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.
It has been shown that pinch analysis as an energy integration technique saves more energy and utilities cost than the traditional energy technique. The minimum approach temperature of 10°C was used to determine the energy target and pinch point discovers was 370°C. 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. **(Adejoh A. Z. *et al* (2013))**

2.8.6 Regenerative Rankine cycle

This project uses pinch analysis techniques to analyze the heat transfer characteristics and efficiency of a typical Regenerative Rankine cycle, used in the Millstone Unit III nuclear power plant. The heat exchanger network, consisting of six feed water heaters was evaluated using the data from the Millstone Unit III heat balance and software provided with. The minimum hot and cold utility requirements are 1,641 MBtu/hr and

370,852 MBtu/hr, respectively, as determined by the software and 1,642 MBtu/hr and 371,225 MBtu/hr as determined by hand calculations.

The optimum minimum temperature difference between the hot and cold streams was determined to be 50 °F. Additional cases were evaluated to determine the effect of minimum temperature difference, supply and target temperatures, and the number of heat exchangers in the network on the external utility requirements. Deleting the 5^{th} and 6_{th} point heaters decreased the cold utility requirement from 370,852 MBtu/hr to 37,228 MBtu/hr, as determined by the software, while keeping the hot utility at 1,641 MBtu/hr. This would greatly reduce the external energy costs by utilizing the most energy within the system from the turbine exhausts and waste from other components. **(Stephanie Barnes, (2013)) .**

2.8.7 Pinch analysis in a sulphonation process

Studies the application of the pinch technology analysis to a sulphonation process at Orbit Chemical industries-Nairobi; The aim was to design a heat exchanger network retrofit for energy use reduction in the sulphonation process and to develop an investment appraisal for the design.

After the retrofit could be implemented, the required external heating load could be reduced from 2.772 MW to 2.456 MW and the external cooling load from 0.329 MW to 0.014 MW. The recoverable heat was found to be 0.316 MW with estimated saving of 11.4 %.**(Musonye et al *(May- Jun. 2014)*)**

Chapter 3

Methodology

3.1 The process description

In this research we apply the pinch analysis to retrofitting an existing heat exchanger network of Elobied refinery. The prime objective is to achieve financial saving by better process heat integration (maximizing process to process heat recovery and reducing the external utility load).

Elobied refinery is a simple refinery .It was a facility which originally built in 1979 as 10,000 BPSD crude topping plant in US. In 1995 it was revamped and modified and rebuilt in Sudan with a design capacity of 10,000 bbl/day. It is located at El Obeid city, North Kordofan State, Sudan. Location coordinates are: Latitude 13.2714, Longitude 30.2362. The refinery was upgraded to15,000 bbl/day in 2002. ORC consists of one Crude Distillation Unit (CDU), therefore it is considered as single complexity refinery. It is producing wide range of products Furnace (63%), gas oil (24%), kerosene (7%) and naphtha (6%).

3.1.1 The refinery facilities

1. Storage system**.**
2. Heat exchanger network (preheating)**.**
3. Crude heaters.
4. Distillation column & side strippers.
5. Water coolers & air coolers.
6. Pumps.
7. Cooling water towers.
8. Steam boilers.
9. Control room.
10. Plat forms.
11. Workshops.
12. Warehouse.
13. Plant power generation.
14. Laboratory.
15. Firefighting system.
16. Waste water treatment

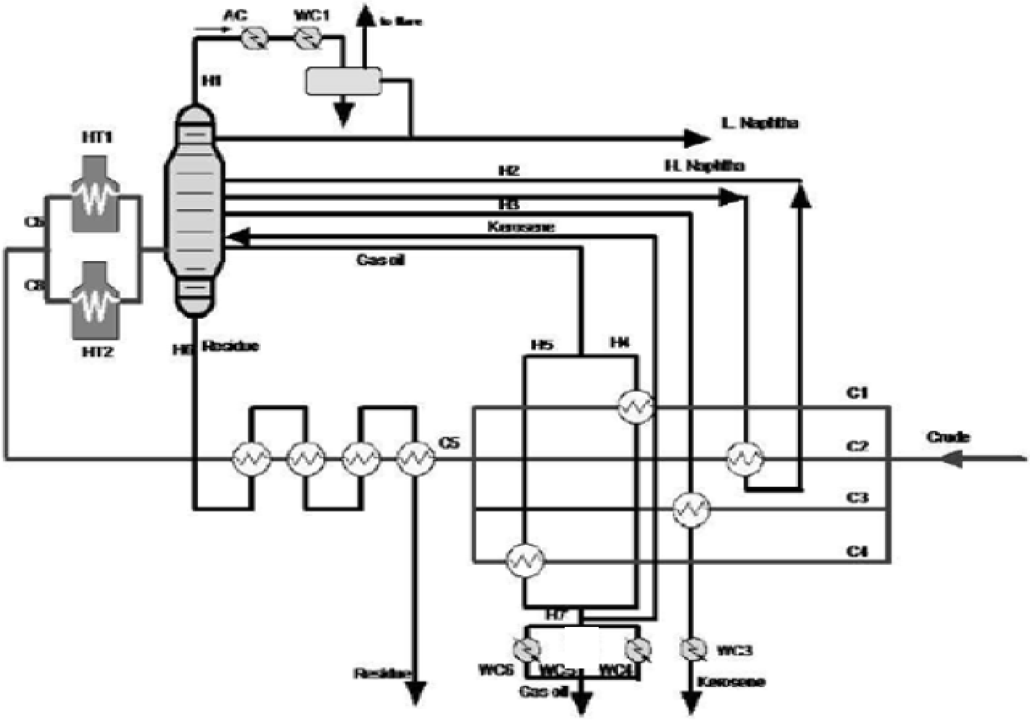


Figure (3.1): ORC process flow diagram

3.1.1.1 Storage system

- Five tanks for crude oil, 5000 cubic meter each plus tank 3000 cubic meter.
- Three tanks for heavy fuel oil, 5000 cubic meter each.
- Three tanks for gas oil, 5000 cubic meter each.
- Two tanks for kerosene, 600 cubic meter each.
- Three tanks for naphtha, 600 cubic meter each plus one tank 5000 cubic meter.
- One tank for diesel oil, 5000 cubic meter.
- Two tanks for water, 600 cubic meters.
- Two tanks for slops, 180 cubic meters.

3.1.1.2 Heat exchangers

Consist of eight heat exchangers, its function is to increase of the crude oil and decrease the temperature of the finished products, so as to reduce crude heaters load and reduce fuel consumption.

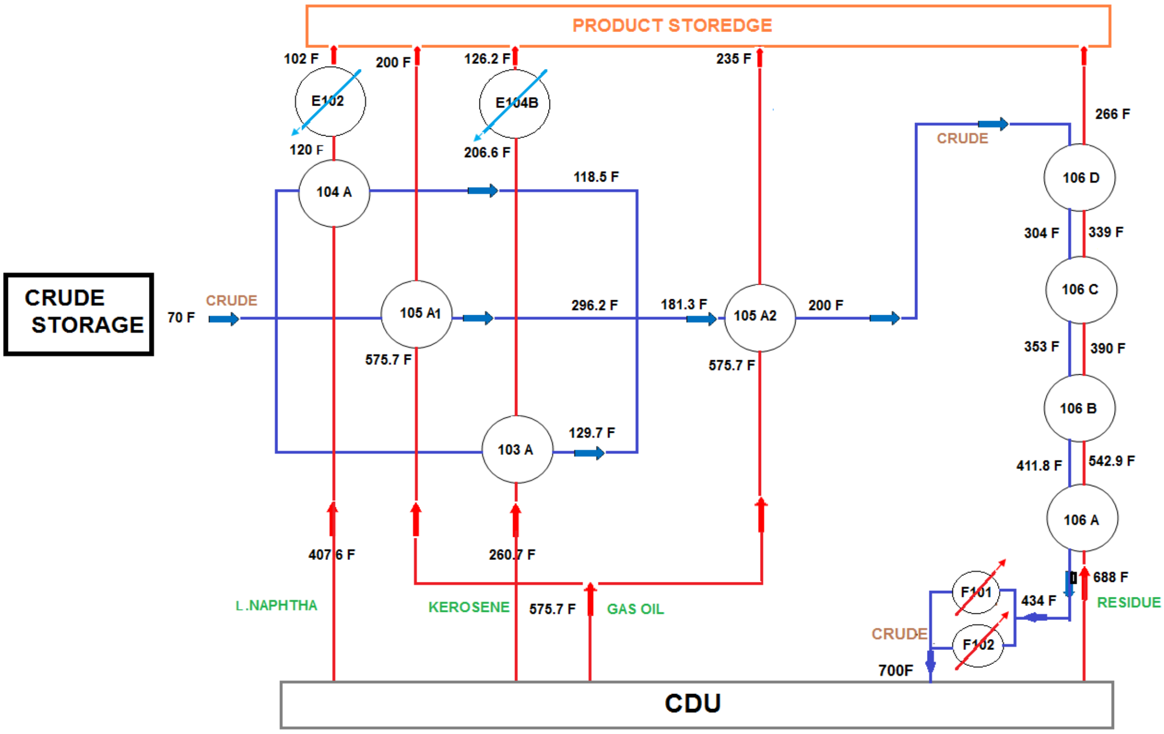
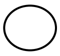
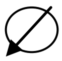
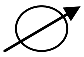


Figure (3.2): The existing heat exchanger net work

 Heat exchanger

 Cooler

 Heater

3.1.1.3 Crude heaters

It consists of two heaters, to increase crude temperature to the point that allows the fraction of the products.

3.1.1.4 main column and side strippers

After crude being heated to required temperature the crude flows to the fractionating column, where light naphtha, kerosene, Gasoil, residue are separated and purified.

3.1.1.5 Water and air coolers

Its function is to reduce the temperature of the finished products to the lowest possible figure so as to be stored safely in its storage tanks.`

3.1.1.6 Pumps

There are groups of pumps, some pumping the crude oil and finishing product to and from process unit, and the others, pumping products to loading areas.

3.1.1.7 Cooling water towers

Its function is to reduce the temperature of the circulation water from the process to cooling water tower.

3.1.1.8 Steam boiler

It produces steam which is used in heaters, stripping of the light products in the column after been superheated in the heaters, and what left is used to heat crude oil and fuel oil if needed.

3.1.1.9 The control room

This stands as director which directs the process operation automatically through (SCADA) electronic instrument.

3.1.1.10 The platforms

There are three loads out platforms, two for road trucks and the third one for the wagons loading.

3.1.1.11 work shop:

There is work shop which repairs and maintains all fixed and running equipment.

3.1.1.12 warehouse

There is warehouse for storing spare parts needed in refinery maintains.

3.1.1.13 plant power generation

There are three generators, 530 KW, 60HZ, each, beside three generators for domestic use, its average load is 250KW, 50HZ.

3.1.1.14 The laboratory

Controls product quality specification while plant is on-stream, and issues immediately reports to tune operating condition to meet the required specification.

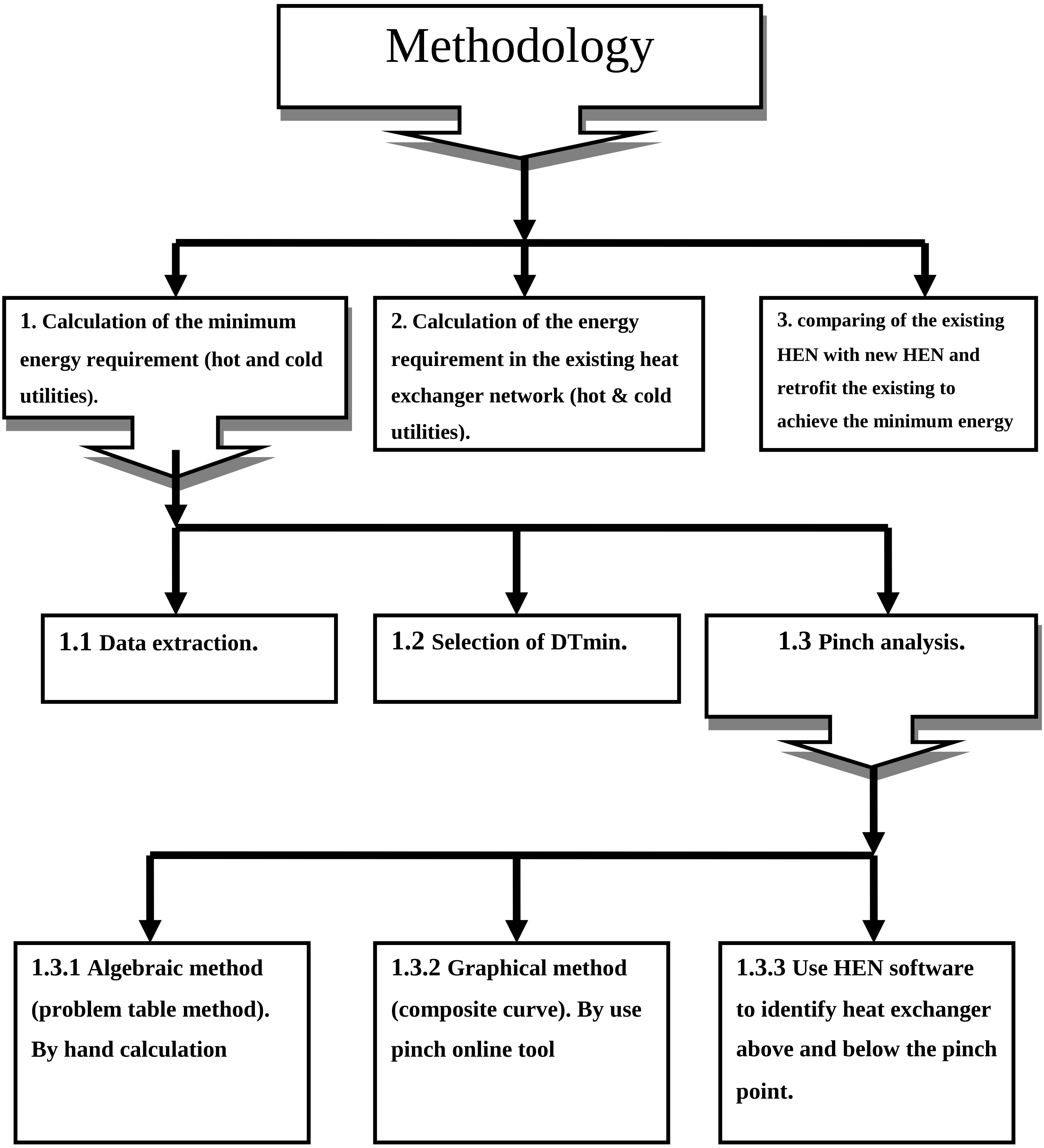
3.1.1.15 firefighting system

The firefighting system contains three firefighting pumps, cooling rings, foam system, fire trucks and fire extinguishers.

3.1.1.16 Waste and water treatment

All waste streams and waste water in refinery are accumulated and collected in large basin where is separated physically separate the oil from water the water transferred to the Lagoon which containing fishes to make biotest before it is used for irrigation, the oil transferred to storage tank. There is new laboratory for bio testing well been added in future.

3.2 Methodology



3.2.1 Calculation of minimum hot and cold utilities

3.2.1.1 Data Extraction

Data extraction relates to the extraction of information required for Pinch Analysis from a given process heat and material balance. In order to start the Pinch Analysis the necessary thermal data must be extracted from the process. This involves the identification of process heating and cooling duties. Figure shows the flow-sheet representation of process which highlights the heating and cooling demands of the streams without any reference to the existing exchangers. This is called the data extraction flow-sheet representation. The reboiler and condenser duties have been excluded from the analysis for simplicity. In an actual study however, these duties should be included. The assumption in the data extraction flow-sheet is that any process cooling duty is available to match against any heating duty in the process.

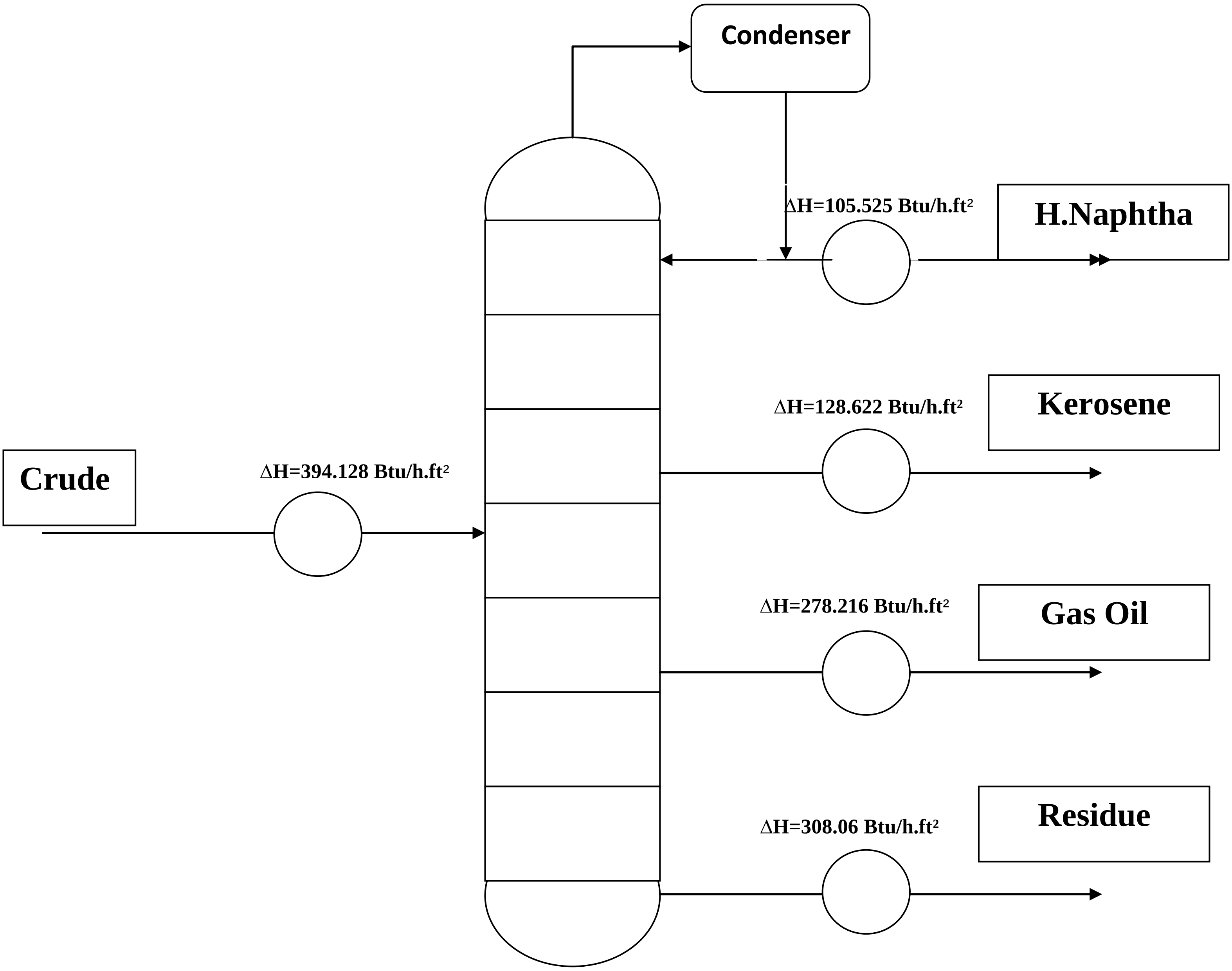


Figure (3.3): Data extraction flow sheet

❖ **Thermal data**

Table below shows the thermal data for Pinch Analysis. “Hot steams” are the streams that need cooling (i.e. heat sources) while “cold streams” are the streams that need heating (i.e. heat sinks). The supply temperature of the stream is denoted as Ts and target temperature as Tt. The heat capacity flow rate (CP) is the mass flow rate times the specific heat capacity i.e.

CP = Cp x M

Where Cp is the specific heat capacity of the stream (Btu/lb. F˚) and M is the mass flow rate (lb/h).

Table (3.1): Streams Table

Stream No	Fluid	Type of the stream	Mass flow lb/hr	Heat capacity flow rate Cp Btu/hr.ft2 F°	Source Temperature Ts F°	Target Temperature Tt F°
C1	**Crude oil**	**Cold**	**138608**	**0.612**	**85**	**700**
H4	**Residue**	**Hot**	**94304**	**0.730**	**688**	**266**
H3	**Gas oil**	**Hot**	**21078**	**0.621**	**576**	**120**
H2	**Kerosene**	**Hot**	**11930**	**0.582**	**408**	**120**
H1	**H.Naphtha**	**Hot**	**10142**	**0.525**	**261**	**117**

Table (3.2): the heat exchangers data

H.E	Hot fluid	Cold fluid	Mh	Mc	Thi	Tho	Tci	Tco	Area
Code			Lb\hr	Lb\hr	ºF	ºF	ºF	ºF	ft2
E103	H.Naphtha	Crude oil	**10142**	**28058**	**260.7**	**117**	**70**	**129.7**	**998.4**
E104	Kerosene	Crude oil	**11930**	**62796**	**407.6**	**206.6**	**70**	**18.5**	**690.9**
E105A1	Gas oil	Crude oil	**21078**	**42754**	**575.7**	**200**	**70**	**296.2**	**1320.8**
E105A2	Gas oil	Crude oil	**21078**	**42754**	**575.7**	**235**	**181.3**	**200**	**6815**
E106A	Residue	Crude oil	**94304**	**133608**	**688**	**542.9**	**411.8**	**434**	**3297.7**
E106B	Residue	Crude oil	**94304**	**133608**	**542.9**	**390**	**353**	**411.8**	**6815.9**
E106C	Residue	Crude oil	**94304**	**133608**	**390**	**339**	**304**	**353**	**6815.9**
E106D	Residue	Crude oil	**94304**	**133608**	**339**	**266**	**200**	**304**	**6815.9**
E105B	Gas oil	Water	**15809**	**62615**	**200**	**120**	**85**	**94.3**	**1533**
E105C	Gas oil	Water	**21078**	**83484**	**230**	**120**	**85**	**150**	**4741**
E104B	Kerosene	Water	**11930**	**11930**	**206.6**	**120**	**85**	**105**	**658**
F101	Flue gas	Crude oil	**21952**	**21952**	**1430**	**1080**	**420**	**700**	**1707.2**
F102	Flue gas	Crude oil	**21952**	**21952**	**1430**	**1080**	**420**	**700**	**1707.2**
F101	Flue gas	steam	**21952**	**21952**	**1030**	**973**	**305**	**744**	**131.3**
F102	Flue gas	steam	**21952**	**21952**	**1030**	**973**	**305**	**680**	**131.3**

3.2.1.2 Selection of DTmin

From Linhoff March application experience we mentioned before for the oil refining it is range from (20-40ºC). And we suppose the DTmin equal 20 ºC (68ºF).

3.2.1.3 Pinch analysis

As we mention before there are two methods for calculation the minimum energy target (minimum hot and cold utility requirement) and identify pinch point.

We were applying pinch analysis at three steps by using the two methods:

1. Use problem table method for calculating minimum energy requirement &pinch point only.
2. Use the pinch online tools using the composite curve.
3. Use the HEN software to identify the new network design plus the energy requirement.

3.2.1.3.1 The problem table or intervals method

Step One: Convert the actual stream temperatures (Tact) into interval temperatures (Tint) by subtracting half the minimum temperature difference from the hot stream temperatures, and by adding half to the cold stream temperatures:

- Hot streams $T_{int} = T_{act} - \frac{DT_{min}}{2}$
- Cold streams $T_{int} = T_{act} - \frac{DT_{min}}{2}$

The use of the interval temperature rather than the actual temperatures allows the minimum temperature difference to be taken into account. **DTmin** 68F; see Table.

Table (3.3): intervals temperature

No	fluid	Cp Btu/hr. F°	Actual Temperatures		Intervals Temperature	
			Tsource	Ttarget	Tsource	Ttarget
1 C	Crude oil	**0.612**	**70**	**700**	**104**	**734**
2 H	Residue	**0.730**	**688**	**266**	**654**	**232**
3 H	Gas oil	**0.621**	**576**	**120**	**542**	**86**
4 H	Kerosene	**0.582**	**408**	**120**	**374**	**86**
5 H	H.naphtha	**0.525**	**261**	**117**	**227**	**83**

Step two: Note any duplicated interval temperatures. These are bracketed in Table

Step three: Rank the interval temperatures in order of magnitude, showing the duplicated temperatures only once in the order; see Table.

Step four: make a heat balance in each interval: the necessary equation for the (i) interval is:

$$\Delta H = [\Sigma\ (Cp)_{cold,\ i} - \Sigma\ (Cp)_{hot,\ i}]\ \Delta Ti$$

Where**:**

ΔH = net heat required in the nth interval.

CP_{cold} = sum of the heat capacities of all the cold streams in the interval.

CP_{hot} = sum of the heat capacities of all the hot streams in the interval.

ΔTi = interval temperature difference ($T_{(i-1)}$ - T_i)

Table (3.4): Ranked order of interval temperatures

Intervals	Intervals ΔT◦F	Streams in intervals
	734	
1	654	+1
2	542	1-2
3	374	1- (2+3)
4	232	1-(2+3+4)
5	227	1-(3+4)
6	104	1-(3+4+5)
7	86	-(3+4+5)
8	83	-5

Table (3.5): problem table

No Intervals	Intervals Temperature	ΔT◦F	Σ(Cp)cold- Σ(Cp)hot	ΔH	Surplus or deficit
	734				
1	654	80	0.612	48.96	D
2	542	112	-0.118	-13.216	S
3	374	168	-0.321	-124.152	S
4	232	142	-1.321	-187.582	S
5	227	5	-0.591	-2.955	S
6	104	123	-1.116	-137.286	S
7	86	18	-1.728	-31.104	S
8	83	3	-0.525	-1575	S

Step five: "Cascade" the heat surplus from one interval to the next down the column of interval temperatures; see table below.

Cascading the heat from one interval to the next implies that the temperature difference is such that the heat can be transferred between the hot and cold streams.

Step six: Introduce just enough heat to the top of the cascade to eliminate all the negative values; see table below.

Table (3.6): cascade table

Intervals Temperature	**ΔH**		**Introduce the enough heat**
734	0		48.96
654	48.96	-48.96	0
542	-13.216	-35.744	13.216
374	-124.152	88.408	137.368
232	-187.582	275.99	324.95
227	-2.955	278.945	327.905
104	-137.286	416.213	465.173
86	-31.104	447.317	496.277
83	-1575	448.892	497.852

The minimum hot utility

Pinch point

The minimum cold utility

From the table of cascade: -

The minimum hot utility = 48.96Btu/hr.ft2

The minimum cold utility = 467.852Btu/hr.ft2

The pinch temperature for the hot stream =688 °F

The pinch temperature for the cold stream = 620 °F

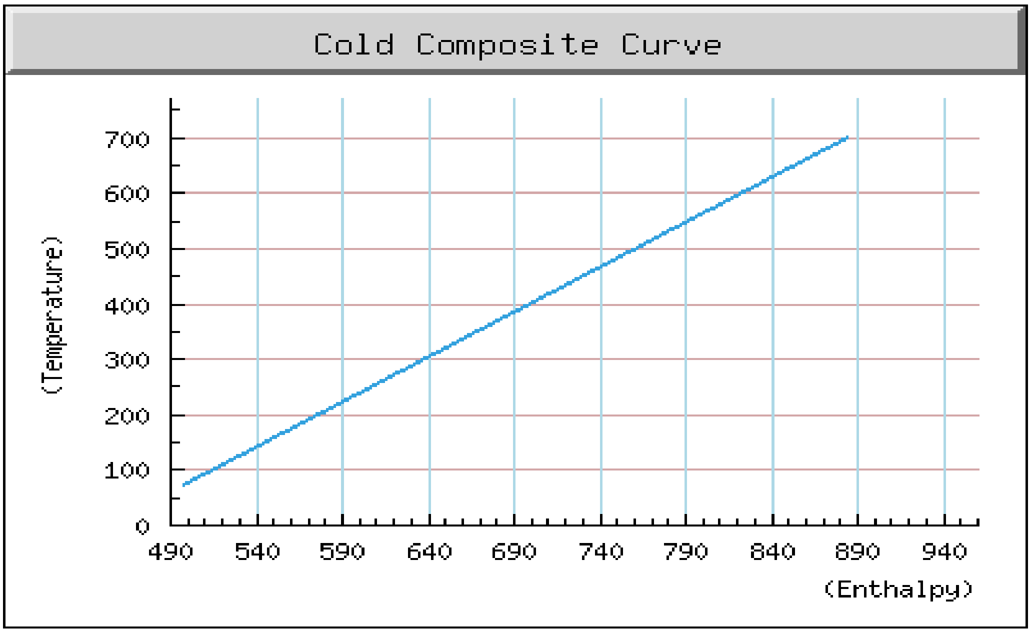
3.2.1.3.2 The composite curve: -

By using of online pinch analysis software, by entering the streams data the software give the results as follow.

Step one: construction of the cold composite curve

Table (3.7): the data of the cold composite curve:-

Temperature °F	Enthalpy
70.00	**497.8520**
700.00	**883.4120**



Figure(3.4) The cold composite curve

Step two: construction of the hot composite curve :-

Table(3.8): the data of the hot composite currve

Temperature °F	Enthalpy Btu/hr
117.00	**0.0000**
120.00	**1.5750**
261.00	**245.2230**
266.00	**251.2380**
408.00	**525.7240**
576.00	**752.6920**
688.00	**834.4520**

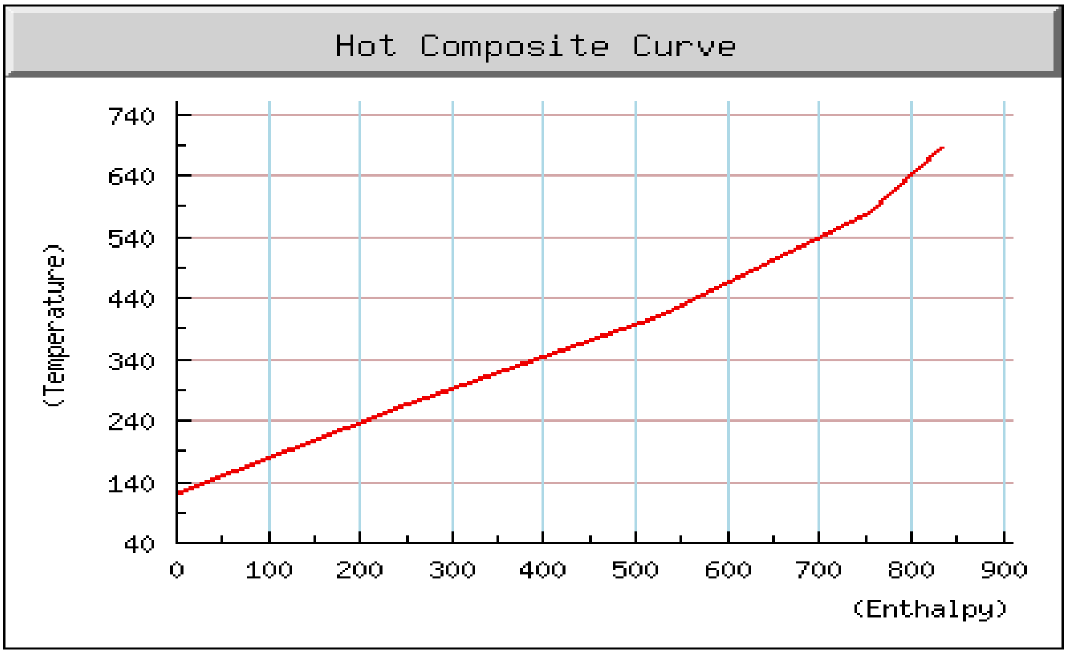


Figure (3.5): the hot composite curve

Step three: The combined composite curve: -

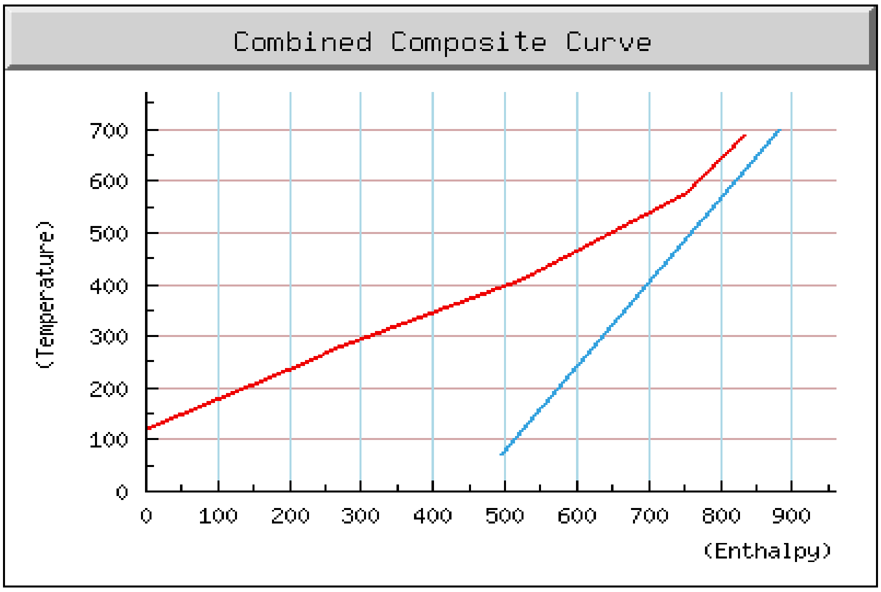


Figure (3.6): The combined composite curve

❖ **The result from the combined composite curve: -**

Table (3.9): result from the combined composite curve

Parameter Value	Parameter Value
DT min (°F)	68.0000
Pinch Temperature (°F)	688.0000
Mini Cooling (Btu/hr)	497.8520
Mini Heating (Btu/hr)	48.9600

3.2.1.3.3 The heat exchanger network design:-

When using HEN software the result will be as follow:

- Pinch temperature = 654 °**F**
- The minimum hot utility = 48.959990 **Btu/hr**
- The minimum cold utility = 497.222900 **Btu/hr**

The heat exchanger network design:

When identifying the pinch point the system is divided into above and below the pinch and steam matching (heat exchange between the streams) is done according to this. Above the pinch is considered as heat sink heat flowing into it (only hot utilities are required), below the pinch is considered as heat source heat flows out from it.

No heat transferred across the pinch this will lead to increase the hot and the cold utility by the same amount.

1) **Above the pinch point:-**

The rule for streams matching above the pinch the specific heat capacity of the cold stream (Cpc) must be greater than the specific heat capacity of the hot stream (Cph). Here there is no heat exchanger above the pinch because there is only one cold stream and that cannot be matching with any hot streams.

The hot utility required:

Table (3.10): the hot utility needed

HEATER	Stream	HEAT Btu/hr	TCIN ºF	TCOUT ºF	CPC
1.0	crude	49.0	620.0	700.0	**0 .6**

2) **Below the pinch point**:-

The rule for stream matching below the pinch the specific heat capacity of the hot stream (Cph) must be greater than the specific heat capacity of the cold stream (Cpc), and there is no hot utility needed.

Table (3.11): The heat exchanger below the pinch

H.E	Cold	Hot	HEAT Btu/hr	Thin F°	Thout F°	Tcin F°	Tcout F°
1	crude	Residue	**308**	**688**	**266**	**116.63**	**620**
2	crude	H.naphtha	**28.5**	**260.7**	**206.34**	**70**	**116.63**

Table (3.12): The cooler below the pinch:-

COOLER	Stream	HEAT Btu/hr	Thin F°	Thout F°	CPh F°
1	H.naphtha	**46.8**	**206.34**	**117.1**	**0.5**
2	kerosene	**167.4**	**407.6**	**120.0**	**0.6**
3	Gas oil	**283.0**	**575.7**	**120.0**	**0.6**

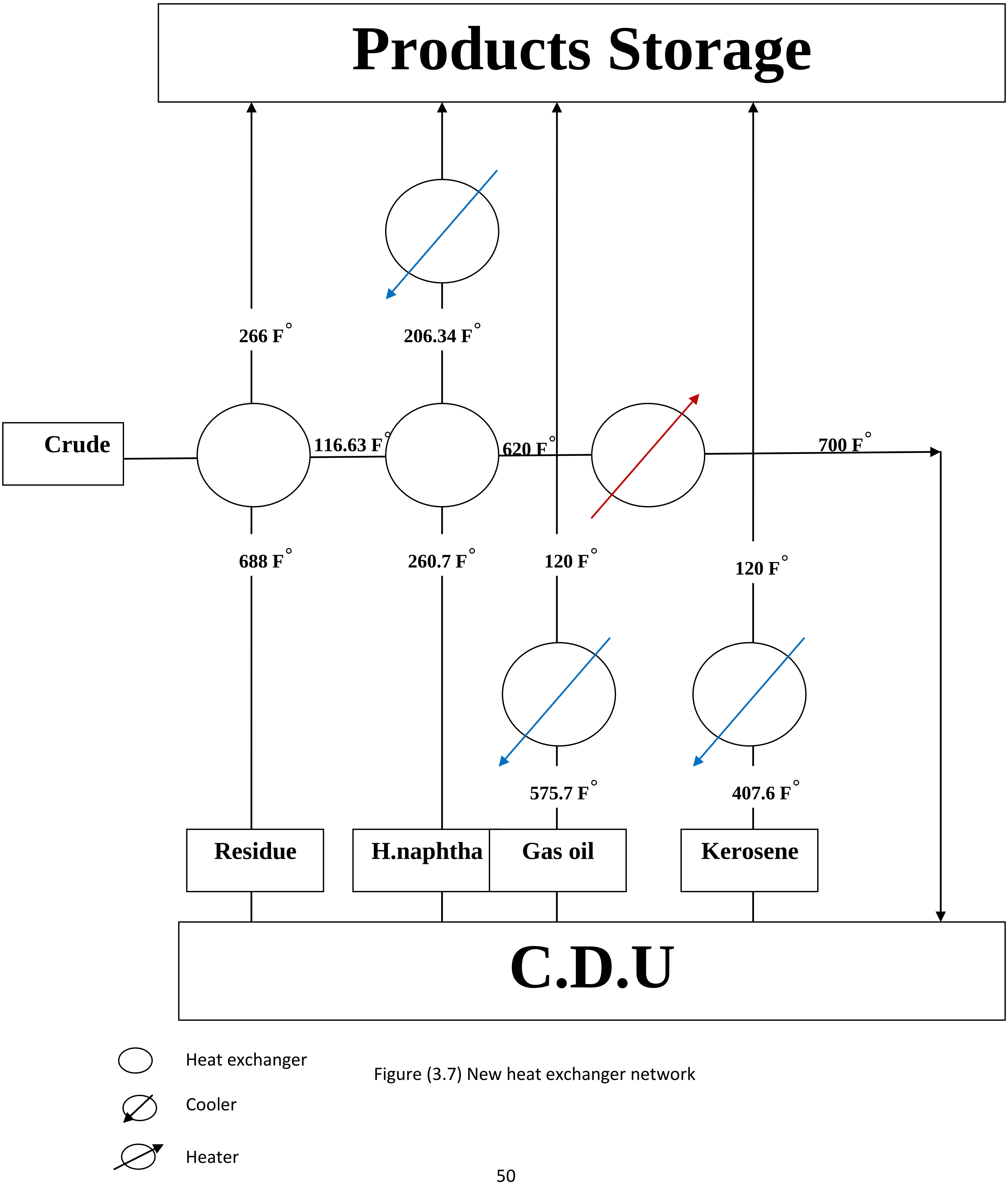


Figure (3.7) New heat exchanger network

Chapter 4

Results

4.1 Results of minimum hot and cold utilities

The results here presented are obtained applying the proposed methodology of pinch technology in Elobied refinery for calculating the minimum hot and cold utilities. The results are showing in table below:

Table (4.1): the results of pinch analysis

Parameter Value	Pinch online Tool Values	Hand calculation values	The HEN software values
DTmin(^oF)	**68.0000**	**68.0000**	**68.000**
Pinch point(^oF)	**688.0000**	**688.0000**	**652.000**
Min Cooling (Btu/hr)	**497.8520**	**497.8520**	**497.2229**
Min Heating (Btu/hr)	**48.9600**	**48.9600**	**48.95999**

- The results are obtained from the different method are similar, and the results from the HEN software we see the new heat exchanger network will be containing two heat exchanger one for the crude with the heavy naphtha and the other with residue and the heat recovered from the two heat exchanger is (28 Btu/hr) and the hot utility is (49 Btu/hr) and the cold utilities are as follow

Table (4.2): cold utilities

COOLER	Stream	Heat Btu/hr	Thin ^oF	Thout ^oF	CPh Btu/hr. ^oF
1	H.naphtha	**46.8**	**206.34**	**117.1**	**0.5**
2	Kerosene	**167.4**	**407.6**	**120.0**	**0.6**
3	Gas oil	**283.0**	**575.7**	**120.0**	**0.6**

4.2The hot and cold utilities for the existing heat exchanger network:-

As we see in the figure there are three cooled utilities and two hot utilities, the heat load of each utility it can be calculated by use the equation:

$$\Delta H = (Cp)\ \Delta Ti$$

ΔH= Heat load

ΔTi= Temperature deference $(T_{source}-T_{target})$ for each component.

4.2.1 The cold utilities:-

i. For the kerosene:

ΔH= 0.582 (206.6-120) = <u>50.4012 Btu/hr</u>

ii. For the gas oil:

ΔH (105 A1) = 0.621(200-120) = <u>49.68 Btu/hr</u>

ΔH (105 A2) = 0.621(235-120) = <u>71.415 Btu/hr</u>

The heat load for the cold utilities = 50.4012+4968+71.415 = <u>171.4962 Btu/hr</u>

4.2.2 The hot utilities:-

There is one cold stream; for the crude oil the heat load will be:

ΔH = 0.612(434-700) = <u>162.792 Btu/hr</u>

4.3 The comparing between existing design and the new design:-

Table (4.3): The comparing between existing design and the new design

Utilities	New design	Existing design
hot utility (Btu/hr)	**48.9600**	**162.792**
cold utility (Btu/hr)	**497.8520**	**171.4962**
Number of H.E	**2**	**8**
Total H.E area ft2	**16222.79**	**23016.8**
Crude temperature after HEN	**620**	**434**

- From the result table(4.3) above for the hot utility can save 70% of the energy used in heating the crude oil that means save in the fuel used, for Elobied refinery saving in the crude used in the furnace, For the cold utility we see the existing is better.
- For the heat exchanger area we see that for the new design is better and we can save 30% of the total area used now.
- From the table we see that the number of heat exchanger decreased to two heat exchangers, and for the crude oil temperature after the heat exchanger network (HEN) the new design the crude oil can leave the heat exchanger network with 620 **ºF** that will save the hot utility by 70% compared with existing design in which the crude leaving with 434 **ºF.**

Chapter 5

Conclusion & Recommendations

5.1 Conclusion

By the application of the pinch analysis in Elobied refinery heat exchanger network the minimum heating and cooling requirements were found and compared with actual existing network which summarized as follow:

- The minimum hot utility for the new design after pinch analysis from algebraic (problem table) and graphic (composite curve) were found to be (48.9600Btu/hr) and actually for the existing design is (162.792Btu/hr), and hence there is a reduction in the minimum hot utility by 70%.
- And that meaning the crude will leaving the heat exchanger network with a temperature greater than that in the actual design 620 ºF rather than 434 ºF for the actual design, and with saving in the heat exchanger area 30%.
- The minimum cooling utility for the new design after applying pinch analysis was found to be (497.8520) greater than the existing design and that means the it require more field study to now where the deficit.

5.2 Recommendation

1. As we see in the result the minimum cold utility is greater than the existing cold utility that means the it is require more field studies to now where the deficit.
2. We can apply the pinch technology to retrofit the existing heat exchanger network without introduce any new heat transfer area only by relocation of the heat exchanger and re-matching between the streams.
3. Also can increase efficient use of the heat transfer area in the table below we see the comparing between the area designed and the area used and we find there is 6% of the designed area is not used. By the equation below:

$$Q = U * A * \Delta T_m$$

Where:
U = overall heat-transfer coefficient
A = surface area for heat transfer consistent with definition of U
ΔT_m = suitable mean temperature difference across heat exchanger

Table (5.1): Heat transfer area

H.E code	Hot fluid	Cold fluid	Qh (Btu/hr)	Qc (Btu/hr)	U (Btu/h.ft2.F°)	DT_{lm}	Area used (ft2)	Area design
103A1	**H.naphtha**	**crude oil**	**764605.4**	**775889**	**10**	**82.01975**	**945.9782**	**998.4**
104A1	**Kerosene**	**crude oil**	**1395595**	**1400979**	**10**	**203.4104**	**688.7448**	**690.9**
105A1	**gas oil**	**crude oil**	**4915326**	**4923483**	**11**	**195.3054**	**2291.741**	**1320.8**
105A2	**gas oil**	**crude oil**	**4457417**	**489533.7**	**11**	**165.5205**	**268.8673**	**6815.9**
106A	**Residue**	**crude oil**	**9990331**	**1816142**	**13**	**185.8253**	**751.7986**	**3297.7**
106B	**Residue**	**crude oil**	**9499291**	**4278460**	**13**	**74.38485**	**4424.453**	**6815.9**
106C	**Residue**	**crude oil**	**3511419**	**4008601**	**13**	**35.99074**	**8567.59**	**6815.9**
106D	**Residue**	**crude oil**	**5026149**	**8508051**	**13**	**48.87226**	**13391.35**	**6815.9**
						Total area	**31330.52**	**33571.4**

References:

1- Energy Use, Loss and Opportunities Analysis December 2004 Prepared by Energetics, Incorporated and E3M, Incorporated for the U.S. Department of Energy Efficiency and Renewable Energy Industrial Technologies Program

2- Cengel, et.al, Heat and Mass Transfer A Practical Approach 2nd Edition

3- J.P. Holman, Heat Transfer Tenth Edition

4- Douglas, J.M., (1988) Conceptual Design of Chemical Engineering, McGraw-Hill, New York,

5- N. Hallale, (2001) Chem. Eng. Prog, 97(7): 30

6- Linnhoff March, (1998), Introduction to Pinch Technology, Targeting House Gadbrook Park Northwich, Cheshire CW9 7UZ, England

7- R. K. SINNOTT, Coulson & Richardson s, (2005) Chemical Engineering. Vol. 6 Chemical Engineering Design 4th Ed, Elsevier, New York, USA.

8- website:
American Council for an Energy-Efficient Economy: www.aceee.org

9- website:
"Online Pinch analysis Tool" copyright 2010, Jeffery

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Appendix

HEAT EXCHANGER SPECIFICATION SHEET(E-103A)

	CUSTOMER CHEMEX			Job No, REDD # 94035 Ref. No .	
	Address BAKERSF LELD , CA .			Proposal No .	
	Plant Location EL OBIED , SUDAN			Date 03 / 28 / 95 Rev . 2	
	Service of unit CRUDE /HEAVY NAPHTHA. HEAT EXCHANGER			Item No . E- 103A	
1	Size 19.0 in x 20 ft Type AFS (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 998.4 f t 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 998.4 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Heavy Naphtha		Crude	
6	Fluid Quantity Total I b / h r	10142		28058	
7	Vapor (In / out) I b / h r				
8	Liquid (I n / out) I b / h r	10142	10142	28058	28058
9	Liquid Evaporated I b / h r	0			
10	Vapor Condensed I b / h r				
11	Non condensable I b / h r				
12	Temperature (I n / Out) F	260.7	117.1	70	129.7
13	Density , Vapor I b / f t 3				
14	Density , Liquid I b / f t 3	43.0609	45.7505	56.9423	55.7454
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	0.2985	0.6349	55.7820	22.6120
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	141.0548	141.0548	369.5774	369.5774
19	Spec Heat , Vapor B t u / I b F				
20	Spec Heat , Liquid B t u / I b F	0.5698	0.4802	0.4463	0.4801
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0655	0.0755	0.0741	0.0714
23	Latent Heat B t u / I b F				
24	I n let Pressure Psig	45		240	
25	Velocity f t / s e c	0.17		1.14	
26	Pressure Drop , Allow / Calc Psig	3.00/ 0.02		5.00/ 9.28	
27	Fouling Resistance (Min)	0.0010		0.0050	
28	Heat exchanged 775000 B t u / h r ; MTD / CMTD (F) 83.74 / 78.04				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2 F) 9.95 / 9.29 / 8.68				
30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)	
31		Shell Side`	Tube Side		
32	Design / Test Pressure P s i g	75/115	300/450		
33	Design / Test Pressure F	/ 535	/535		
34	N o . Passes Per Shell	2	4		

35	Corrosion Allowance In			
36	Connections Inlet / Rating	/6	/4	
37	Size (In) Out let / Rating	4/	4/	
38	& Rating Intermediate / Rating	/	/	
39	Tube No . 258 OD 0 . 750 In ; Thk / B WG 0 . 0830 /14 ; leng 20.0 f t ; Pitch 0.900 , 30 Tria.			
40	Tube Type	Material Tubes / Fins : Carbon steel /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	00/0Shell ID (In) 19.0		
43	Shell Cover	Channel ID / OD (I N) /		
44	Channel or Bonnet	Channel Cover		
45	Tube Sheet --stationary	Tube Sheet Floating		
46	Floating Head Cover	Impingement Protection No		
47	Baffles – Cross 10 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 23.88 , Inlet 6.6			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0010 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (lb) Water Filled Bundle			

HEAT EXCHANGER SPECIFICATION SHEET(E-104A)

CUSTOMER CHEMEX				Job No, REDD # 94035 Ref. No .	
Address BAKERSF LELD , CA .				Proposal No .	
Plant Location EL OBIED , SUDAN				Date 03 / 08 / 95 Rev . 2	
Service of unit CRUDE / KEROSENE. HEAT EXCHANGER				Item No . E- 104A	
1	Size 17.0 in x 16 ft Type AFS (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 690.9 ft 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 690.9 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Kerosene		Crude	
6	Fluid Quantity Total l b / h r	11930		62796	
7	Vapor (In / out) l b / h r				
8	Liquid (I n / out) l b / h r	11930	11930	62796	62796
9	Liquid Evaporated l b / h r				
10	Vapor Condensed l b / h r	0			
11	Non condensable l b / h r	-0			
12	Temperature (I n / Out) F	407.6	206.6	70.0	118.5
13	Density , Vapor l b / f t 3				
14	Density , Liquid l b / f t 3	42.6395	47.5958	56.9423	55.9706
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	0.2874	0.7942	55.7820	29.3030
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	203.5761	203.5761	369.5774	369.5774
19	Spec Heat , Vapor B t u / l b F				
20	Spec Heat , Liquid B t u / l b F	0.6413	0.5234	0.4463	0.4738
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0587	0.0699	0.0741	0.0719
23	Latent Heat B t u / l b F				
24	I n let Pressure Psig	45		240	
25	Velocity f t / s e c	0.21		1.47	
26	Pressure Drop , Allow / Calc Psig	3.00/ 0.11		5.00/ 7.09	
27	Fouling Resistance (Min)	0.0010		0.0050	
28	Heat exchanged 1400000 B t u / h r ; MTD / CMTD (F) 206.35 / 202.73				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2 F) 10.00 / 11.35 / 10.46				

30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)
31		Shell Side`	Tube Side	
32	Design / Test Pressure P s i g	75/115	300/450	
33	Design / Test Pressure F	/425	/350	
34	N o . Passes Per Shell	2	2	

35	Corrosion Allowance In			
36	Connections Inlet / Rating	3/	4/	
37	Size (In) Out let / Rating	3/	4/	
38	& Rating Intermediate / Rating	/	/	
39	Tube No. 224 OD 0.750 In ; Thk / BWG 0.0830 /14 ; leng 16.0 ft ; Pit ch 0.900 , 30 Tria.			
40	Tube Type	Material Tubes / Fins : Carbon steel /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	Shell I D/OD (In) 17.0000/		
43	Shell Cover	Channel I D / OD (I N) /		
44	Channel or Bonnet		Channel Cover	
45	Tube Sheet --stationary		Tube Sheet Floating	
46	Floating Head Cover		Impingement Protection No	
47	Baffles – Cross 8 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 24.64 , Inlet 3.3			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0231 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (lb) Water Filled Bundle			

)1HEAT EXCHANGER SPECIFICATION SHEET(E-105A

CUSTOMER CHEMEX				Job No, REDD # 94035	
				Ref. No . E-106A	
Address BAKERSF LELD , CA .				Proposal No .	
Plant Location EL OBIED , SUDAN				Date 03 / 28 / 95 Rev . 1	
Service of unit CRUDE / DIESEL. HEAT EXCHANGER				Item No . E- 105A	
1	Size 18.0 in x 20 ft Type AFU (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 1320.8 f t 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 1320.8 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Crude		Diesel	
6	Fluid Quantity Total I b / h r	42754		21078	
7	Vapor (In / out) I b / h r				
8	Liquid (I n / out) I b / h r	42754	42754	21078	21078
9	Liquid Evaporated I b / h r				
10	Vapor Condensed I b / h r				
11	Non condensable I b / h r				
12	Temperature (I n / Out) F	70.0	296.2	575.7	200.0
13	Density , Vapor I b / f t 3				
14	Density , Liquid I b / f t 3	56.9423	52.2913	42.0729	51.0171
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	55.7820	2.3089	0.4757	2.5380
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	369.5774	369.5774	303.7238	303.7238
19	Spec Heat , Vapor B t u / I b F				
20	Spec Heat , Liquid B t u / I b F	0.4463	0.572	0.7214	0.5200
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0741	0.0638	0.0511	0.0691
23	Latent Heat B t u / I b F				
24	I n let Pressure Psig	240		45	
25	Velocity f t / s e c	2.73		0.94	
26	Pressure Drop , Allow / Calc Psig	5.00/ 3.03		1.50/ 0.34	
27	Fouling Resistance (Min)	0.0050		0.0020	
28	Heat exchanged 4927695 B t u / h r ; MTD / CMTD (F) 200.67 / 176.81				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2F) 21.11 / 25.87 / 21.59				
30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)	
31		Shell Side`	Tube Side		
32	Design / Test Pressure P s i g	/	/		
33	Design / Test Pressure F	/	/		
34	N o . Passes Per Shell	2	4		

35	Corrosion Allowance In			
36	Connections Inlet / Rating	6/	6/	
37	Size (In) Out let / Rating	6/	6/	
38	& Rating Intermediate / Rating	/	/	
39	Tube N o . 160 U's OD 0 . 750 In ; Thk / BWG 0 . 0830 /14 ; leng 20.0 f t ; Pitch 0.800 , 30 Tria.			
40	Tube Type	Material Tubes / Fins : Carbon steel /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	Shell ID (In) 18.0000/		
43	Shell Cover	Channel ID / OD (In) /		
44	Channel or Bonnet	Channel Cover		
45	Tube Sheet --stationary	Tube Sheet Floating		
46	Floating Head Cover	Impingement Protection N o		
47	Baffles – Cross 18 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 13.33 , Inlet 6.6			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0139 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (Ib) Water Filled Bundle			

HEAT EXCHANGER SPECIFICATION SHEET(E-105A2)

CUSTOMER CHEMEX				Job No, REDD # 94035 Ref. No .	
Address BAKERSF LELD , CA .				Proposal No .	
Plant Location EL OBIED , SUDAN				Date 03 / 28 / 95 Rev . 1	
Service of unit CRUDE / RESID. HEAT EXCHANGER				2A05Item No . E- 1	
1	Size 38.0 in x 20 ft Type AEU (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 3297.7 f t 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 3297.7 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Resid		Crude	
6	Fluid Quantity Total I b / h r	94304		133608	
7	Vapor (In / out) I b / h r				
8	Liquid (I n / out) I b / h r	94304	94304	133608	133608
9	Liquid Evaporated I b / h r				
10	Vapor Condensed I b / h r				
11	Non condensable I b / h r				
12	Temperature (I n / Out) F	688.0	542.9	311.8	434.0
13	Density , Vapor I b / f t 3				
14	Density , Liquid I b / f t 3	46.4262	49.8210	51.9557	49.2505
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	1.2970	1.5264	2.0316	0.9287
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	572.9266	572.9266	369.5774	369.5774
19	Spec Heat , Vapor B t u / I b F				
20	Spec Heat , Liquid B t u / I b F	0.7636	0.6966	0.5803	0.6443
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0460	0.0526	0.0631	0.0575
23	Latent Heat B t u / I b F				
24	I n let Pressure Psig	45		235	
25	Velocity f t / s e c	0.69		0.80	
26	Pressure Drop , Allow / Calc Psig	3.00/ 0.22		1.00/ 0.10	
27	Fouling Resistance (Min)	0.0050		0.0050	
28	Heat exchanged 10000000 B t u / h r ; MTD / CMTD (F) 242.38 / 229.64				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2 F) 13.21 / 16.57 / 13.90				
30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)	
31		Shell Side`	Tube Side		
32	Design / Test Pressure P s i g	925/	1000/		
33	Design / Test Pressure F	/700	/600		
34	N o . Passes Per Shell	1	2		

35	Corrosion Allowance In			
36	Connections Inlet / Rating	10/	10/	
37	Size (In) Out let / Rating	12/	12/	
38	& Rating Intermediate / Rating	/	/	
39	Tube No . 284 OD 1.000 In ; Thk / BWG 0.1200/11 ; leng 20.0 ft ; Pitch 1.250 , 90. Square			
40	Tube Type	Material Tubes / Fins : 5cr-1 / 2Mo-Si /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	Shell ID/OD (In) 38.0000/		
43	Shell Cover	Channel ID / OD (IN) /		
44	Channel or Bonnet		Channel Cover	
45	Tube Sheet --stationary		Tube Sheet - Floating	
46	Floating Head Cover		Impingement Protection No	
47	Baffles – Cross 16 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 14.98 , Inlet 11.0			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0107 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (lb) Water Filled Bundle			

HEAT EXCHANGER SPECIFICATION SHEET(E-106B)

	CUSTOMER CHEMEX			Job No, REDD # 94035 Ref. No .	
	Address BAKERSF LELD , CA .			Proposal No .	
	Plant Location EL OBIED , SUDAN			Date 03 / 28 / 95 Rev . 2	
	Service of unit CRUDE / RESID HEAT EXCHANGER			Item No . E- 106B	
1	Size 55.0 in x 18 ft Type AES (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 6815.9 f t 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 6815.9 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Resid		Crude	
6	Fluid Quantity Total I b / h r	94304		133608	
7	Vapor (In / out) I b / h r				
8	Liquid (I n / out) I b / h r	94304	94304	133608	133608
9	Liquid Evaporated I b / h r				
10	Vapor Condensed I b / h r				
11	Non condensable I b / h r				
12	Temperature (I n / Out) F	542.9	390.0	181.3	311.8
13	Density , Vapor I b / f t 3				
14	Density , Liquid I b / f t 3	49.8210	53.1684	54.6950	51.9557
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	1.5264	5.0262	8.6313	2.0316
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	572.9266	572.9266	369.5774	369.5774
19	Spec Heat , Vapor B t u / I b F				
20	Spec Heat , Liquid B t u / I b F	0.6966	0.6210	0.5090	0.5803
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0526	0.0595	0.0690	0.0631
23	Latent Heat B t u / I b F				
24	I n let Pressure Psig	42		235	
25	Velocity f t / s e c	0.17		0.36	
26	Pressure Drop , Allow / Calc Psig	0.00 / 0.11		0.00 / 0.10	
27	Fouling Resistance (Min)	0.0050		0.0050	
28	Heat exchanged 9500000 B t u / h r ; MTD / CMTD (F) 219.73 / 203.65				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2f) 6.85 / 7.55 / 6.95				
30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)	
31		Shell Side`	Tube Side		
32	Design / Test Pressure P s i g	150/	450/		
33	Design / Test Pressure F	/565	/650		
34	N o . Passes Per Shell	1	2		

35	Corrosion Allowance In			
36	Connections Inlet / Rating	12/	12/	
37	Size (In) Out let / Rating	12/	12/	
38	& Rating Intermediate / Rating	/	/	
39	Tube No . 2032 OD 0 . 750 In ; Thk / BWG 0 . 0830 /14 ; leng 18.0 f t ; Pitch 1.000 90 Tria.			
40	Tube Type	Material Tubes / Fins : Carbon steel /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	Shell I D/OD (In) 55.0000/		
43	Shell Cover	Channel I D / OD (In) /		
44	Channel or Bonnet	Channel Cover		
45	Tube Sheet --stationary	Tube Sheet Floating		
46	Floating Head Cover	Impingement Protection No		
47	Baffles – Cross 7 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 28.89 , Inlet 13.2			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0048 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (lb) Water Filled Bundle			

HEAT EXCHANGER SPECIFICATION SHEET(E-106A)

	CUSTOMER	CHEMEX		Job No, REDD # 94035	Ref. No .
	Address	BAKERSF LELD , CA.		Proposal No .	
	Plant Location	EL OBIED , SUDAN		Date 03 / 28 / 95 Rev . 1	
	Service of unit	CRUDE / RESID. HEAT EXCHANGER		Item No . E- 106A	
1	Size 38.0 in x 20 ft Type AEU (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 3297.7 f t 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 3297.7 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Resid		Crude	
6	Fluid Quantity Total l b / h r	94304		133608	
7	Vapor (In / out) l b / h r				
8	Liquid (I n / out) l b / h r	94304	94304	133608	133608
9	Liquid Evaporated l b / h r				
10	Vapor Condensed l b / h r				
11	Non condensable l b / h r				
12	Temperature (I n / Out) F	688.0	542.9	311.8	434.0
13	Density , Vapor l b / f t 3				
14	Density , Liquid l b / f t 3	46.4262	49.8210	51.9557	49.2505
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	1.2970	1.5264	2.0316	0.9287
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	572.9266	572.9266	369.5774	369.5774
19	Spec Heat , Vapor B t u / l b F				
20	Spec Heat , Liquid B t u / l b F	0.7636	0.6966	0.5803	0.6443
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0460	0.0526	0.0631	0.0575
23	Latent Heat B t u / l b F				
24	I n let Pressure Psig	45		235	
25	Velocity f t / s e c	0.69		0.80	
26	Pressure Drop , Allow / Calc Psig	3.00/ 0.22		1.00/ 0.10	
27	Fouling Resistance (Min)	0.0050		0.0050	
28	Heat exchanged 10000000 B t u / h r ; MTD / CMTD (F) 242.38 / 229.64				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2 F) 13.21 / 16.57 / 13.90				
30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)	
31		Shell Side`	Tube Side		
32	Design / Test Pressure P s i g	925/	1000/		
33	Design / Test Pressure F	/700	/600		
34	N o . Passes Per Shell	1	2		

35	Corrosion Allowance In			
36	Connections Inlet / Rating	10/	10/	
37	Size (In) Out let / Rating	12/	12/	
38	& Rating Intermediate / Rating	/	/	
39	Tube No . 284 OD 1.000 In ; Thk / BWG 0.1200/11 ; leng 20.0 ft ; Pitch 1.250 , 90. Square			
40	Tube Type	Material Tubes / Fins : 5cr-1 / 2Mo-Si /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	Shell I D/OD (In) 38.0000/		
43	Shell Cover	Channel I D / OD (I N) /		
44	Channel or Bonnet		Channel Cover	
45	Tube Sheet --stationary		Tube Sheet - Floating	
46	Floating Head Cover		Impingement Protection No	
47	Baffles – Cross 16 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 14.98 , Inlet 11.0			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0107 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (lb) Water Filled Bundle			

HEAT EXCHANGER SPECIFICATION SHEET(E-106C)

	CUSTOMER CHEMEX			Job No, REDD # 94035 Ref. No .	
	Address BAKERSF LELD , CA .			Proposal No .	
	Plant Location EL OBIED , SUDAN			Date 03 / 28 / 95 Rev . 1	
	Service of unit CRUDE / RESID. HEAT EXCHANGER			Item No . E- 106C	
1	Size 38.0 in x 20 ft Type AEU (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 3297.7 f t 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 3297.7 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Resid		Crude	
6	Fluid Quantity Total I b / h r	94304		133608	
7	Vapor (In / out) I b / h r				
8	Liquid (I n / out) I b / h r	94304	94304	133608	133608
9	Liquid Evaporated I b / h r				
10	Vapor Condensed I b / h r				
11	Non condensable I b / h r				
12	Temperature (I n / Out) F	688.0	542.9	311.8	434.0
13	Density , Vapor I b / f t 3				
14	Density , Liquid I b / f t 3	46.4262	49.8210	51.9557	49.2505
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	1.2970	1.5264	2.0316	0.9287
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	572.9266	572.9266	369.5774	369.5774
19	Spec Heat , Vapor B t u / I b F				
20	Spec Heat , Liquid B t u / I b F	0.7636	0.6966	0.5803	0.6443
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0460	0.0526	0.0631	0.0575
23	Latent Heat B t u / I b F				
24	I n let Pressure Psig	45		235	
25	Velocity f t / s e c	0.69		0.80	
26	Pressure Drop , Allow / Calc Psig	3.00/ 0.22		1.00/ 0.10	
27	Fouling Resistance (Min)	0.0050		0.0050	
28	Heat exchanged 10000000 B t u / h r ; MTD / CMTD (F) 242.38 / 229.64				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2 F) 13.21 / 16.57 / 13.90				
30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)	
31		Shell Side`	Tube Side		
32	Design / Test Pressure P s i g	925/	1000/		
33	Design / Test Pressure F	/700	/600		
34	N o . Passes Per Shell	1	2		

35	Corrosion Allowance In			
36	Connections Inlet / Rating	10/	10/	
37	Size (In) Out let / Rating	12/	12/	
38	& Rating Intermediate / Rating	/	/	
39	Tube No . 284 OD 1.000 In ; Thk / BWG 0.1200/11 ; leng 20.0 ft ; Pitch 1.250 , 90. Square			
40	Tube Type	Material Tubes / Fins : 5cr-1 / 2Mo-Si /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	Shell I D/OD (In) 38.0000/		
43	Shell Cover	Channel I D / OD (I N) /		
44	Channel or Bonnet		Channel Cover	
45	Tube Sheet --stationary		Tube Sheet - Floating	
46	Floating Head Cover		Impingement Protection No	
47	Baffles – Cross 16 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 14.98 , Inlet 11.0			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0107 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (Ib) Water Filled Bundle			

HEAT EXCHANGER SPECIFICATION SHEET(E-106D)

CUSTOMER CHEMEX				Job No, REDD # 94035	
				Ref. No .	
Address BAKERSF LELD , CA .				Proposal No .	
Plant Location EL OBIED , SUDAN				Date 03 / 28 / 95 Rev . 1	
Service of unit CRUDE / RESID. HEAT EXCHANGER				Item No . E- 106D	
1	Size 38.0 in x 20 ft Type AEU (Horz) Connected : 1 Parallel 1 Series				
2	Surf / Unit (Gross / Eff) 3297.7 f t 2 ; Shells / Unit 1 ; Surf / Shell (Gross / Eff) 3297.7 f t 2				
3	PERFORMANCE OF ONE UNIT				
4	Fluid Allocation	Shell side		Tube side	
5	Fluid Name	Resid		Crude	
6	Fluid Quantity Total I b / h r	94304		133608	
7	Vapor (In / out) I b / h r				
8	Liquid (I n / out) I b / h r	94304	94304	133608	133608
9	Liquid Evaporated I b / h r				
10	Vapor Condensed I b / h r				
11	Non condensable I b / h r				
12	Temperature (I n / Out) F	688.0	542.9	311.8	434.0
13	Density , Vapor I b / f t 3				
14	Density , Liquid I b / f t 3	46.4262	49.8210	51.9557	49.2505
15	Viscosity , Vapor cp				
16	Viscosity , Liquid cp	1.2970	1.5264	2.0316	0.9287
17	Molecular Weight , Vapor				
18	Molecular Weight , Liquid	572.9266	572.9266	369.5774	369.5774
19	Spec Heat , Vapor B t u / I b F				
20	Spec Heat , Liquid B t u / I b F	0.7636	0.6966	0.5803	0.6443
21	Thermal Cond . Vapor B t u / h r ft F				
22	Thermal Con . Liquid B t u / h r ft F	0.0460	0.0526	0.0631	0.0575
23	Latent Heat B t u / I b F				
24	I n let Pressure Psig	45		235	
25	Velocity f t / s e c	0.69		0.80	
26	Pressure Drop , Allow / Calc Psig	3.00/ 0.22		1.00/ 0.10	
27	Fouling Resistance (Min)	0.0050		0.0050	
28	Heat exchanged 10000000 B t u / h r ; MTD / CMTD (F) 242.38 / 229.64				
29	Transfer Rate , Serv / Clean / calc (B t u / h r f t 2 F) 13.21 / 16.57 / 13.90				
30	CONSTRUCTION OF ONE SHELL			Sketch (Bundle / Nozzle)	
31		Shell Side`	Tube Side		
32	Design / Test Pressure P s i g	925/	1000/		
33	Design / Test Pressure F	/700	/600		
34	N o . Passes Per Shell	1	2		

35	Corrosion Allowance In			
36	Connections Inlet / Rating	10/	10/	
37	Size (In) Out let / Rating	12/	12/	
38	& Rating Intermediate / Rating	/	/	
39	Tube No . 284 OD 1.000 In ; Thk / BWG 0.1200/11 ; leng 20.0 ft ; Pitch 1.250 , 90. Square			
40	Tube Type	Material Tubes / Fins : 5cr-1 / 2Mo-Si /		
41	No . Fin s Per Tube	Fin Thk / Height (In) /		
42	Shell	Shell I D/OD (In) 38.0000/		
43	Shell Cover	Channel I D / OD (I N) /		
44	Channel or Bonnet		Channel Cover	
45	Tube Sheet --stationary		Tube Sheet - Floating	
46	Floating Head Cover		Impingement Protection No	
47	Baffles – Cross 16 Segmental ; Diam Cut : 40 % Vert ; Spacing (in) : C / C 14.98 , Inlet 11.0			
48	Baffles – Long Seal Type			
49	Supports - Tube U – Bend Type			
50	Bypass Seal Arrngmt . Tube - Tube sheet Joint			
51	Expansion Joint Type			
52	Rho v2 -Inlet Nozzle 0.0107 Bundle Enter. Bundle Exit			
53	Gaskets- Shell side Tube side Float. Head			
54	Code Requirements : TEMA Class : U - Stamp :			
55	Weight / Shell (Ib) Water Filled Bundle			