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Heat-Integrated Design for Natural Gas Processing

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Dedication

To my beloved father; then, to my dearest woman on the earth, my mother for their tender , love and great support.

To my dear siblings El Aarbi, Ahmed, Hocine, Hicham, Abd Allah, Oussama, Fatima, Yamina, Fatiha for their support, help and encouragement.

To my whole family, colleagues, friends and town chums: Brahim Khanblouche, Abd El kader, Nourddine " Radj", Lamine, El Bouti, Mohammed and Belkhir.

To all those who have never hesitated to give help whenever needed, I dedicate this modest work.

Mustapha

Dedication

I dedicate this work to my beloved parents my dear father and my lovely mother for their tender, love and encouragement.

To my dear brothers Mokhetar, Mahdi, Farouk and sisters for their help and support.

To my whole family, colleagues and friends: Elhachemi, Mahni, Zohir, A.Halim, Hamza, Fathi, Elhadi, Sid. To all friends
and to all those people whom I like.

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INTRODUCTION

GENERAL INTRODUCTION

It is predicted that the world's energy will be exhausted within a century. In this situation, the countries that have energy resources like OPECs are trying to keep their own resources for using in the emergency case. This leads to decrease in the production of oil and natural gas, which results in the petroleum price increasing everyday. Petroleum is a major source of energy in our life. The new industry countries (NICs) have very large energy consumption; the energy sources for these countries are imported from foreign country to meet the domestic consumption. All of the NICs suffer from the high price of petroleum. To resolve the problem, the energy consumption has to be reduced. Many countries have issued many energy conservation plans for reducing the energy consumption. With the latest plan, the energy consumption is being cut down in factories and buildings, and promoting the use of renewable energy. The industrial sector, which consumes a large amount of energy, is looking for the way to use the energy efficiently.

Heat integration using Pinch technology is one of the energy optimization methods. Pinch Technology is the most practical method for applying process integration. Process Integration is a very important means of improving energy efficiency of industrial and manufacturing processes while minimizing their environment impact. By analyzing the thermodynamics of a process, an engineer can qualify the thermodynamic efficiency of the process, identify the regions where energy can be better utilized and define the minimum targets for energy consumption. Pinch technology is used mostly for the Heat Exchanger Networks Synthesis (HENS). It can also be applied for Distillation Column Design, Mass Exchanger Networks Synthesis (MENS), batch scheduling, total utilities system design, etc. The process pinch point refers to the energy optimum point in the process design, the temperature level above this point acts as heat sink, and the one below acts as heat source. Based on rigorous thermodynamic principles, Pinch technology matches cold streams that need to be heated with hot streams which need to be cooled, causing high degree of energy recovery. Thus pinch technology can be used to determine the minimum requirements for both hot and cold utilities in a process.

An achievement in pinch technology crucially comes from the advancement in computer software. One essential element is process simulation software, the output from which can be used to check sensor-based data such as flow rates, pressures, temperatures, and concentrations. This research work is using HYSYS.

This study is to apply pinch technology for retrofitting the heat exchanger network to obtain the best design which prosses high degree of energy recovery. The study is separated into three parts. The first part is talking about natural gas NG. (what's NG, LNG, LGP, NG in ALGERIA). The second part is talking about Pinch Teechnology (what's Pinch Teechnology, Objectives of Pinch Analysis, Basic Concepts of Pinch Analysis. The final part is case study . (Heat-Integrated Design for Natural Gas Processing) will be chosen for this work.

CHAPTER I :

GENERAL LOOK ON NATURAL GAS

General Look On Natural Gas NG

I.1. Introduction

Natural gas, the cleanest of the fossil fuels, is the fastest growing primary energy source for the world today. Consumption of natural gas is projected to increase by nearly 70 percent between 2002 and 2025 . Liquefied natural gas (LNG) is the most economical way to transport natural gas over long distances. Reductions in costs throughout the LNG chain, advances in LNG technology, etc. have transformed LNG into an increasingly global energy option similar to oil. In only one quarter of a century, the international energy scene has witnessed a remarkable growth in LNG trade. As an alternate fuel, the demand of LNG is doubling every ten years. In 2001, world's total LNG demand was estimated to be over 100 mtpa. By 2012, it is expected to be 270 mtpa. With the expectation of increasing demand for energy with time, LNG has established itself as the fuel for the future. In 2005, the global liquefaction capacity for LNG was 150 mtpa.

I.2. What Is The Natural Gas

Natural gas is the gas obtained from natural underground reservoirs either as free gas or gas associated with crude oil. It generally contains large amounts of methane (CH4) along with decreasing amounts of other hydrocarbons. Impurities such as H2S, N2, and CO2 are often found with the gas. It also generally comes saturated with water vapor. Other information on natural gas are found in Table 1.

Table 1 Composition of Natural Gas [1]

Category	Component	Amount (%)
Paraffinic	Methane (CH_4)	70–98
	Ethane (C_2H_6)	1–10
	Propane (C_3H_8)	Trace–5
	Butane (C_4H_{10})	Trace–2
	Pentane (C_5H_{12})	Trace–1
	Hexane (C_6H_{14})	Trace–0.5
	Heptane and higher (C_{7+})	None–trace
Cyclic	Cyclopropane (C_3H_6)	Traces
	Cyclohexane (C_6H_{12})	Traces
Aromatic	Benzene (C_6H_6), others	Traces
Nonhydrocarbon	Nitrogen (N_2)	Trace–15
	Carbon dioxide (CO_2)	Trace–1
	Hydrogen sulfide (H_2S)	Trace occasionally
	Helium (He)	Trace–5
	Other sulfur and nitrogen compounds	Trace occasionally
	Water (H_2O)	Trace–5

I.3. Gas In Algeria

I.3.1. Overview

Algeria had 161.7 trillion cubic feet (Tcf) of proven natural gas reserves (the eighth-largest in the world) as of January 2007. Algeria's largest gas field is the super-giant Hassi R'Mel, discovered in 1956 and holding proven reserves of about 85 Tcf. Hassi R'Mel accounts for about a quarter of Algeria's total dry natural gas production. The remainder of Algeria's natural gas reserves center around associated (they occur alongside crude oil reserves) and non-associated fields in the south and southeast regions of the country. In southeastern Algeria, the Rhourde Nouss region holds 13 Tcf of known reserves Also in southeastern Algeria, near the Libyan border, the In Amenas region includes the Tin Fouye Tabankort (TFT; 5.1 Tcf), Alrar (4.7 Tcf), Ouan Dimeta, and Oued Noumer fields. The In Salah region in southern Algeria holds smaller, less-developed reserves (5-10 Tcf).

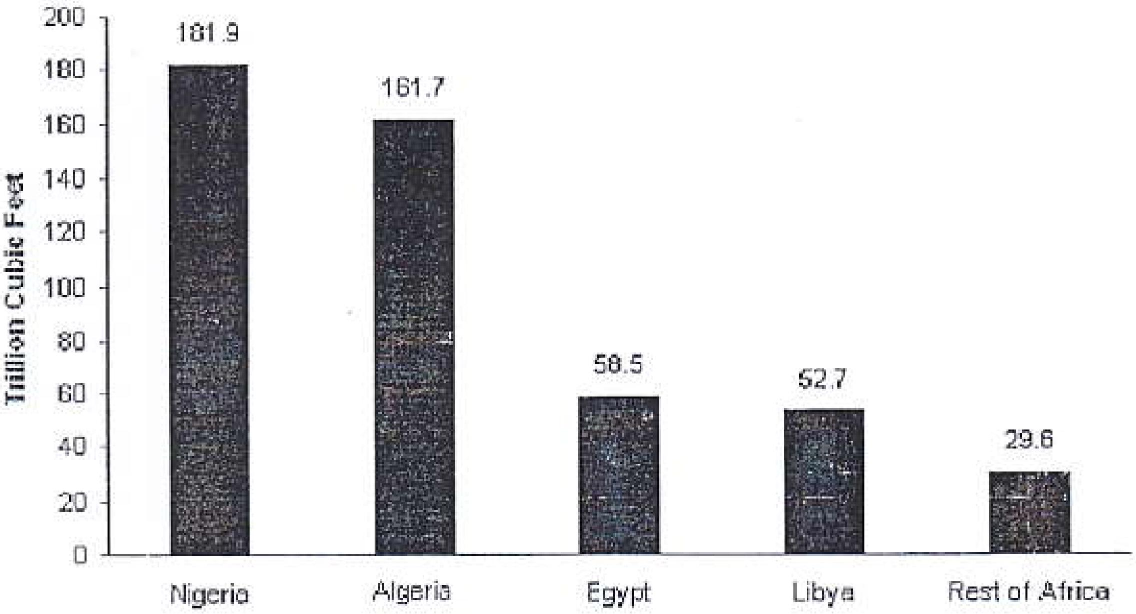

Fig 1 : Top African Natural Gas Proven Reserve Holders, 2007

The country produced 2.8 Tcf of natural gas in 2004, the eighth-largest in the world and the second largest among OPEC-member countries (behind Iran). Algeria consumed 0.68 Tcf of natural gas in 2004, some 24 percent of its production. In 1997, Algeria's natural gas production exceeded the country's crude oil production for the first time, though it has since fallen below oil production again. The Algerian government has encouraged the domestic use of natural gas, which represented 62 percent of the country's total energy consumption in 2004. The remaining natural gas is exported, with the majority going to Europe and some to the United States.

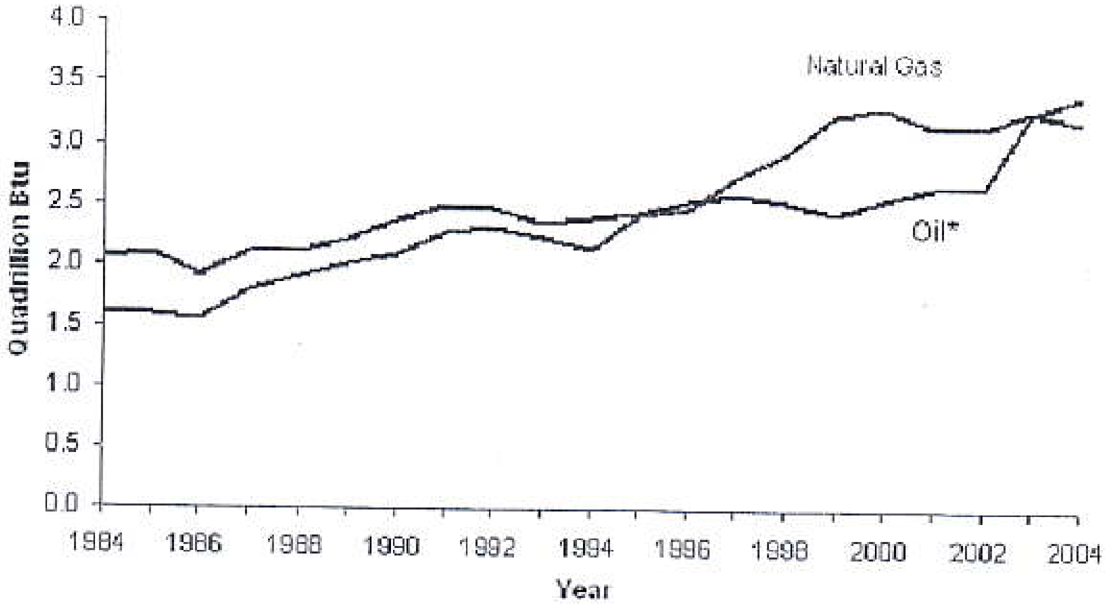

Fig 2 : Algeria's Total Hydrocarbon Producation, 1984-2004

I.3.2. Exploration and Production

Development of the In Salah region is crucial in Algeria's plan to increase its natural gas production. The In Salah Gas consortium, apartnership of Statoil, BP, and Sonatrach, was the first major natural gas partnership between Sonatrach and a foreign operator. The consortium has development rights for seven of the twelve existing fields in the In Salah region. In Salah Gas will appraise existing wells and explore for new natural gas reserves in the region. The fields controlled by the consortium contain proven reserves of 6 Tcf, with potentially 10 Tcf in total recoverable reserves. Initial production at the In Salah fields began in July 2004, and once fully online, they should produce some 880 million cubic feet per day (Mmcf/d) of natural gas. Even prior to initial startup, the consortium had already signed natural gas supply contracts with European customers. In May 1997, In Salah Gas sealed its first natural gas sales deal with Italian electricity generator Enel.

The deal enables In Salah Gas to take over an existing contract to supply Enel with 390 Mmcf/d of natural gas. In Salah Gas is also marketing natural gas to potential clients in Europe, Turkey and North Africa.

Additional Algerian natural gas projects have centered around three blocks in the Illizi province of southeast Algeria, near the Libyan border: Ohanet, In Amenas, and Gassi Touil. Ohanet, led by a consortium of BHP-Billiton and Sonatrach, is in Illizi on the northern edge of the Sahara desert. Production of natural gas, NGL, and liquified petroleum gas (LPG) at Ohanet began in October 2003. The Ohanet project includes a natural gas processing plant with capacity for 30,000 bbl/d of condensate, and 26,000 bbl/d of LPG.

In November 2004, Algeria awarded a tender to Repsol-YPF and Gas Natural for a natural gas project at Gassi Touil, a field containing 9 Tcf of proven reserves. The $2 billion integrated project will consist of 52 development wells, a 780-Mmcf/d natural gas processing facility, a 630-Mmcf/d natural gas pipeline, and a 500-Mmcf/d natural gas liquefaction terminal at Arzew. Initial production at Gassi Touil should begin in 2009, with the bulk of its gas destined for Spain and other European markets. In June 2006, Sonatrach, BP and Statoil began producing natural gas at the In Amenas field. At peak production the field should produce around 900 Mmcf/d of natural gas, plus 50,000 bbl/d of condensate and LPG. The project includes construction of three pipelines to carry the hydrocarbons to the Sonatrach distribution system at Ohanet. In 2003, Statoil purchased 50 percent of BP's stake in the project.

I.3.3. Pipelines

I.3.3.1. Domestic System

Algeria's domestic pipeline system centers around the Hassi R'Mel natural gas field. The largestpipeline systems connect Hassi R'Mel to liquefied natural gas (LNG) export terminals along theMediterranean Sea. A 315-mile, 4.38-billion-cubic-feet-per-day (Bcf/d) system connects HassiR'Mel to Arzew, while a 360-mile, 1.98-Bcf/d system connects Hassi R'Mel to Skikda. A smaller

pipeline (270 miles, 690 Mmcf/d) also runs between Hassi R'Mel and Isser, near Algiers. Hassi R'Mel is the center of Algeria's entire natural gas transport network, so pipelines connect to it fromthe country's major natural gas-producing regions. A 600-mile, 3.29-Bcf/d pipeline links the InAmenas region; a 330-mile, 774-Mmcf/d pipeline connects the In Salah region; and a 90-mile,610-Mmcf/d system runs from the natural gas fields surrounding Gassi Touil.

I.3.3.2. Export System

There are two natural gas pipeline connections between Algeria and Europe (map). The 670-mile,2.32-Bcf/d Trans-Mediterranean (Transmed, also called Enrico Mattei) line runs from Hassi R'Mel,via Tunisia and Sicily, to mainland Italy. Completed in 1983 and doubled in 1994, there are plansto construct an additional compressor station along the Transmed that could increase capacity to

3.48-Bcf/d. An international consortium, led by Spain's Enagas, Morocco's SNPP, and Sonatrach,operates the 1,000-mile, 820-Mmcf/d Maghreb-Europe Gas (MEG, also called Pedro DuranFarell). MEG, completed in 1996, connects Hassi R'mel with Cordoba, Spain via Morocco, whereit ties into the Spanish and Portuguese natural gas transmission networks. In August 2001,Sonatrach awarded ABB a $93 million contract to build a natural gas compressor station on theMEG line in order to increase the line's capacity to 1.78 Bcf/d.

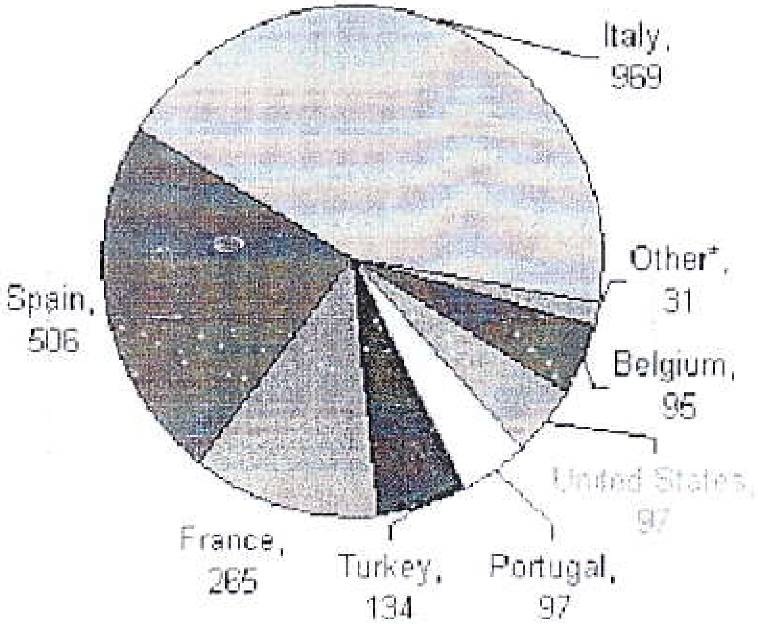

Fig 3 : Importers of Algerian Natural Gas – Billion Cubic Feet, 2005

I.3.3.3. Medgas Pipeline

In July 2001, a consortium led by Spain's Cepsa (20 percent) and Algeria's Sonatrach (20 percent) agreed to build a natural gas pipeline linking Algeria and Europe: Medgaz. The 120-mile Medgaz will link Beni Saf, Algeria to Almeria, Spain, with an eventual extension to France. In September 2002, the consortium completed a study of the line's feasibility, and initial construction on the project should begin around June 2007. The $1.2 billion Medgaz, which should be completed by 2009, will have an initial capacity of 390 Mmcf/d, increasing to a maximum of 1.55 Bcf/d. There are also plans to run a parallel power cable. In November 2002, Cepsa said that it had signed a letter of intent to purchase 35 Bcf/y of natural gas via Medgaz, and in 2004, Iberdrola also agreed to purchase 35 Bcf/y from the line.

I.3.3.4. Galsi Pipeline

In 2002, Sonatrach signed a deal with Italy's Enel and Germany's Wintershall to form Galsi, a consortium to build a natural gas pipeline from Algeria to Italy. The pipeline will run from Gass R'Mel to El Kal, Algeria, then an underwater section to Cagliari, Sardinia. This is to be followed by an onshore section to Olbia, Sardinia, then a final, offshore pipeline to C.D. Pescaia, Italy. The Galsi pipeline, which is currently under construction, will have initial capacity of 770-990 Mmcf/d and, as with Medgaz, there are plans for a parallel power cable. The Galsi project could be completed by late 2009.
Trans-Saharan Pipeline Sonatrach and the Nigerian National Petroleum Corporation (NNPC) formed the Trans-Saharan Natural Gas Consortium (NIGEL) in 2002. The NIGEL consortium aims to construct a 2,800-mile natural gas pipeline from Warri, Nigeria to Hassi R'Mel, via Niger. There are also plans to construct a road and fiber optic cable parallel to the pipeline. The NIGEL pipeline would utilize the proposed Medgaz and

existing Transmed pipeline to carry Nigerian natural gas to European markets. A feasibility study on the Trans-Saharan pipeline is underway, but practical problem such as the immense length and possible sabotage are two deterrents to the project moving forward. The Algerian government would like to see the $10 billion pipeline functioning by 2015.

I.4. Liquefied Natural Gas

Liquefied natural gas (LNG) is natural gas that has been cooled to about minus 162° Celsius (-260 degrees Fahrenheit) for shipment and/or storage as a liquid. The volume of the liquid is about 600 times smaller than the gaseous form. In this compact form, natural gas can be shipped in special tankers to receiving terminals. At these terminals, the LNG is returned to a gaseous form and transported by pipeline to distribution companies, industrial consumers, and power plants.

Liquefying natural gas provides a means of moving it long distances where pipeline transport is not feasible, allowing access to natural gas from regions with vast production potential that are too distant from end-use markets to be connected by pipeline

I.4.1. Liquefied Natural Gas in Algeria

With the start-up of the Arzew GL4Z plant in 1964, Algeria became the world's first producer of liquefied natural gas (LNG). Algeria is the fourth largest exporter of LNG (behind Indonesia, Malaysia and Qatar), exporting around 13 percent of the world's total. The vast majority of Algeria's LNG exports go to Western Europe, especially France, Spain and Turkey. Sonatrach has LNG export contracts with Gaz de France, Belgium's Distrigaz, Spain's Enagas, Turkey's Botas, Italy's Snam, and Greece's DEPA. During 2005, Algeria exported 97 Bcf of LNG to the United States, some 15 percent of total U.S. LNG imports for that period. Algeria's largest LNG export terminal is the Arzew facility, whose three facilities produce a combined 2.47 Bcf/d of re-gasified LNG. Other important terminals include Skikda and Algiers.

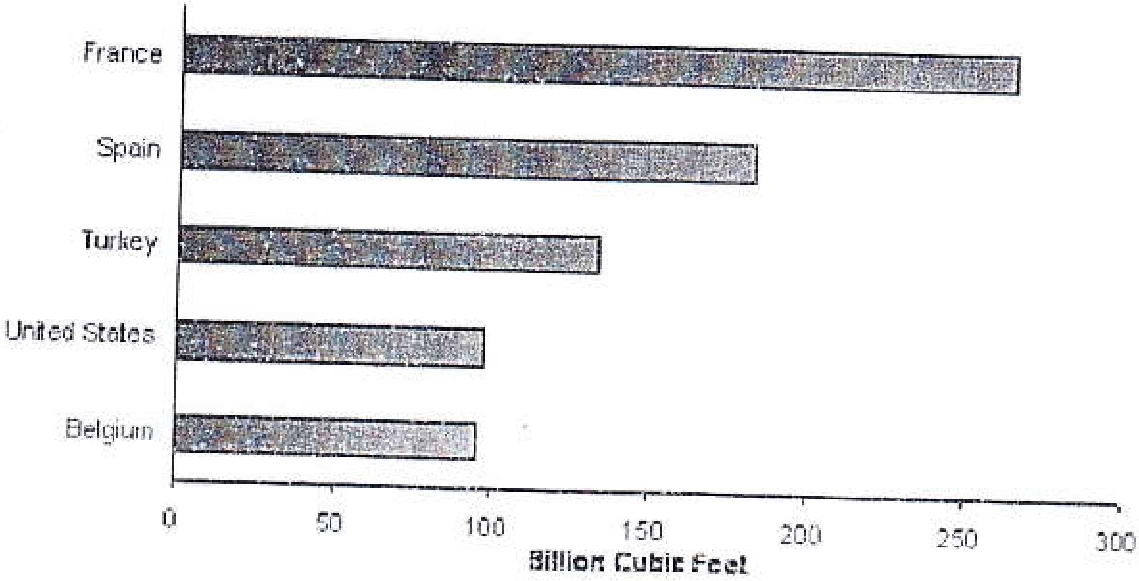

Fig 4 : Top 5 Importers of Algerian LNG, 2005

I.5. Liquefied petroleum gas

Liquefied Petroleum Gas (LPG) consists mainly of propane, butane and isobutane and it may also contain C_3 and C_4 unsaturated hydrocarbons. Its main use is as a fuel, but it is also in widespread use as an aerosol propellant, and as a chemica feedstock.

I.5.1 LPG Description

LPG is predominantly a mixture of C_3 and C_4 hydrocarbons with other hydrocarbons in the C_1-C_7 range. These are gases at normal ambient temperatures and pressures. Liquefaction of these gases by application of pressures of a few atmospheres to produce Liquefied Petroleum Gases (LPG) enables them to be conveniently and efficiently stored and transported in light pressure vessels.Refrigeration to below their boiling point is an economic method of liquefying large quantities of LPGs for bulk storage and transport.

The main constituents of LPGs produced either in petroleum refineries as the light end fractions of distillation and cracking processes, production of crude oil or purification of natural gas are mainly propane and butanes. LPGs produced by secondary refinery processing, e.g. cracking, may contain unsaturated hydrocarbons such as propylene and butenes and small traces of diolefins may also be produced. Certain specifications permit the presence of up to 10% mol. Total dienes in LPG. The level of dienes in LPG is under review and a draft CEN specification for automotive LPGs proposes a maximum level of 0.5% mol. LPGs obtained as the liquid condensate in natural gas or crude oil production (also known as natural gas liquids or NGLs) are less likely to contain appreciable amounts of these unsaturated hydrocarbons.

LPGs normally contain low concentrations of various sulphur compounds. The levels permitted are governed by the technical specification, which typically prescribes limits for total sulphur, hydrogen sulphide, and mercaptans. Depending on the base odour, odourants (also described as stench agents or denaturants) may be added in small quantities (ppm) so that gas leaks may be detected by smell. An anti-icing agent such as methanol may be added in small quantities to prevent ice and hydrate formation in valves or regulators.

LPGs are widely used as fuels and as feedstocks in chemical processes. In some countries there is also extensive use as automotive fuel. A large volume is distributed, much of it in small containers, for domestic heating and cooking use in locations where piped supplies of gas are not available. LPGs are also used as propellants in pressurized aerosol containers.

CHAPTER II :

HEAT INTEGRATION

Heat Integration Using Pinch Analysis

II.1. Introduction

Due to the close relationship between the energy and environmental problems, recovering technology and optimizing energy consumption have a major role in environment protection by minimization the atmospheric pollutants such as SOx, COx, NOx. This minimization may decrease the greenhouse effect, and the ozone layer destruction. On the other hand, optimization of Energy consumption and its recovering may minimize the water and hot oil consumption at the heat exchangers (reboilers and condensers) in petroleum distillation columns, specially. The distillation section consumes a great deal of energy in the chemical and petroleum industries, hence studying the ways in which we may decrease this consumption is of great importance. One of these retrofit solutions is the **Heat Integration**, which is going to be presented in this research with a different idea from the other previous methods.

II.2. Definition of heat integration

Heat Integration (or Pinch Technology/Process Integration) is an energy saving methodology that has been extensively used in the processing and power generating industry over the last30 years. This method examines the potential of exchanging heat between heat sources and heat sinks via the use of heat exchangers and reducing the amount of external heating and cooling required. A systematic design procedure has been developed to provide the final energy reduction design of the system. The method has further been developed to specify the source of heating and cooling required (e.g. steam, hot water, cooling water) and also the potential of power production in the form of shaftwork or electrical production. This methodology is based on the analysis and understanding of heat exchange between process streams through the use of a temperature-enthalpy diagram. The methodology first identifies sources of heat (termed hot streams) and sinks of heat (termed cold streams) in the process flowsheet.

II.3. Objectives of heat integration

The processing of crude oil and natural gas requires an enormous amount of energy, which is why we are constantly examining ways to improve energy efficiency. The advantages are twofold: not only does a more efficient energy policy serve to reduce the substantial costs, but it also does much to spare the environment.

The objectives and benefits of Heat Integraion can be summarised as follows:

- To achieve financial savings by better process heat integration (maximizing process-to-process heat recovery and reducing the external utility loads).
- Systematically designing an optimal scheme of utility exchange between producers and consumers.
- Reduce the amount of energy input for each distillation column by selecting the optimal design parameters such as reflux ration, q value,etc.
- Reduce the total amount of energy input to the entire system by heat integration.
- Change the temperature level of heat sinks and sources, one or both, required in the distillations, such as temperature or pressure.

II.4. PINCH TECHNOLOGY

II .4.1.What is Pinch Technology?

II .4.1.1.Meaning of the Term Pinch Technology

The term "Pinch Technology" was introduced by Linnhoff and Vredeveld to represent a new set of thermodynamically based methods that guarantee minimum energy levels in 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 the tools and algorithms of Pinch Technology for studying industrial processes. Developments of rigorous software programs like PinchExpress^{TM}, SuperTarget^{TM}, Aspen Pinch^{TM} have proved to be very useful in pinch analysis of complex industrial processes with speed and efficiency.

II .4.1.2.Basis of Pinch Technology

Pinch technology presents a simple methodology for systematically analysing chemical processes and the surrounding utility systems with the help of the First and Second Laws of Thermodynamics. The **First Law** of Thermodynamics provides the energy equation for calculating the enthalpy changes (H) in the streams passing through a heat exchanger. **The Second** Law determines the direction of heat flow. That is, heat energy may only flow in the direction of hot to cold. This prohibits '*temperature crossovers*' of the hot and cold stream profiles through the exchanger unit. In a heat exchanger unit neither a hot stream can be cooled below cold stream supply temperature nor a cold stream can be heated to a temperature more than the supply temperature of hot stream. In practice the hot stream can only be cooled to a 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 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.

II .4.1.3.Objectives of Pinch Analysis

Pinch Analysis is used to identify energy cost and heat exchanger network (HEN) capital cost targets for a process and recognizing the pinch point. The procedure first predicts, ahead of design, the minimum requirements of external energy, network area, and the number of units for a given process at the pinch point. Next a heat exchanger network design that satisfies these targets is synthesized. Finally the network is optimized by comparing energy cost and the capital cost of the network so that the total annual cost is minimized. **Thus, the prime objective of pinch analysis is to achieve financial savings by better process heat integration (maximizing process-to-process heat recovery and reducing the external utility loads).** The concept of process heat integration is illustrated in the example discussed below.

II .4.1.4.A Simple Example of Process Integration by Pinch Analysis

Consider the following simple process [Fig 5(a)] where feed stream to a reactor is heated before inlet to a reactor and the product stream is to be cooled. The heating and cooling are done by use of steam (Heat Exchanger -1) and cooling water (Heat Exchanger-2), respectively. The Temperature (T) vs. Enthalpy (H) plot for the feed and product streams depicts the hot (Steam) and cold (CW) utility loads when there is no vertical overlap of the hot and cold stream profiles.

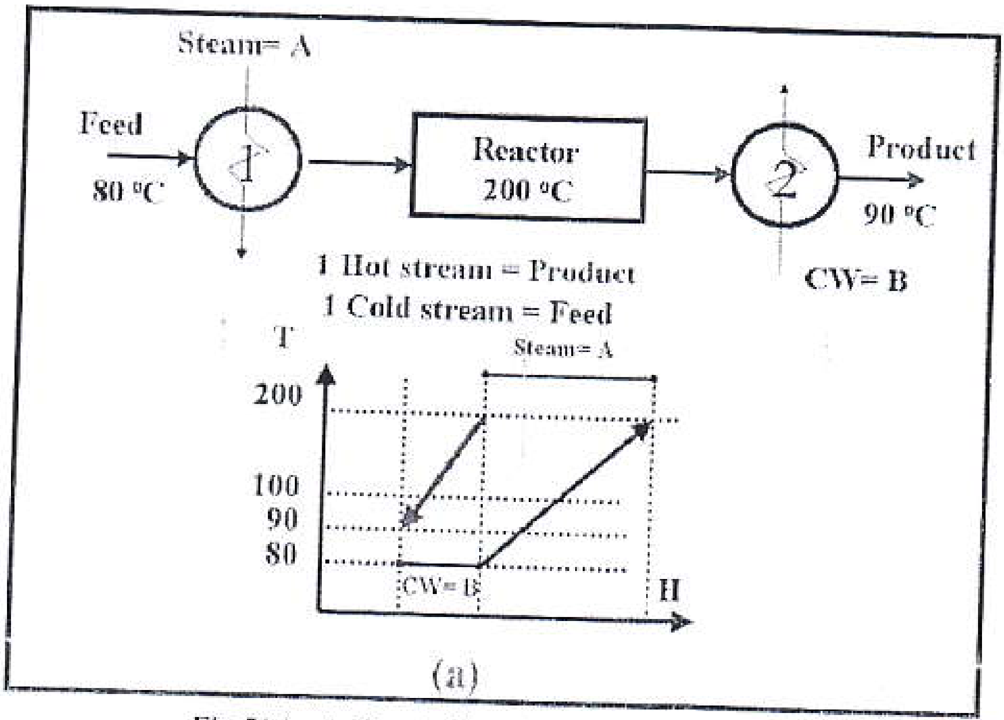

Fig 5(a): A Simple Flow Scheme with T-H profile

An alternative, improved scheme is shown in Figure 5(b) where the addition of a new 'Heat Exchanger–3' recovers product heat (X) to preheat the feed. The steam and cooling water requirements also get reduced by the same amount (X). The amount of heat recovered (X) depends on the 'minimum approach temperature' allowed for the new exchanger. The minimum temperature approach between the two curves on the vertical axis is DTmin and the point where this occurs is defined as the **"pinch"**. From the T-H plot, the X amount corresponds to a DTmin value of 20 oC. Increasing the DTmin value leads to higher utility requirements and lower area requirements.

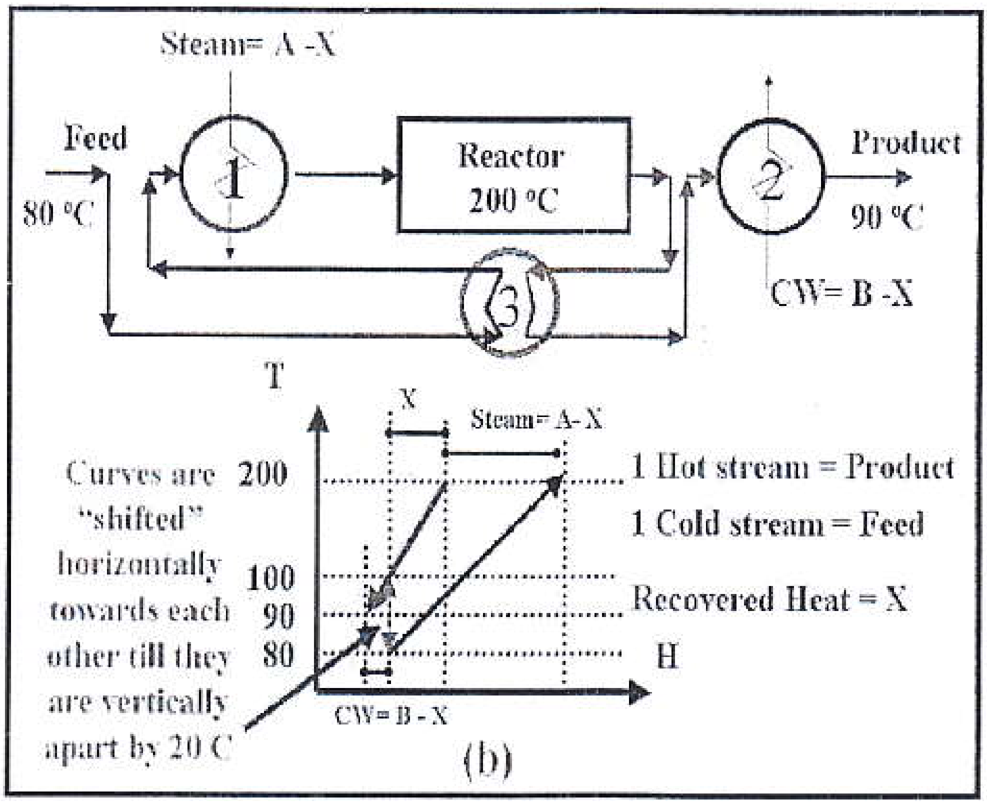

Fig 5(b): Improved Flow Scheme with T-H profile.

II .4.1.5.Development of Pinch Technology Approach

When the process involves single hot and cold streams (as in above example) it is easy to design an optimum heat recovery exchanger network intuitively by heuristic methods. In any industrial set-up the number of streams is so large that the traditional design approach has been found to be limiting in the design of a good network. With the development of pinch technology in the late 1980's, not only optimal network design was made possible, but also considerable process improvements could be discovered. Both the traditional and pinch approaches are depicted in Figure 6.

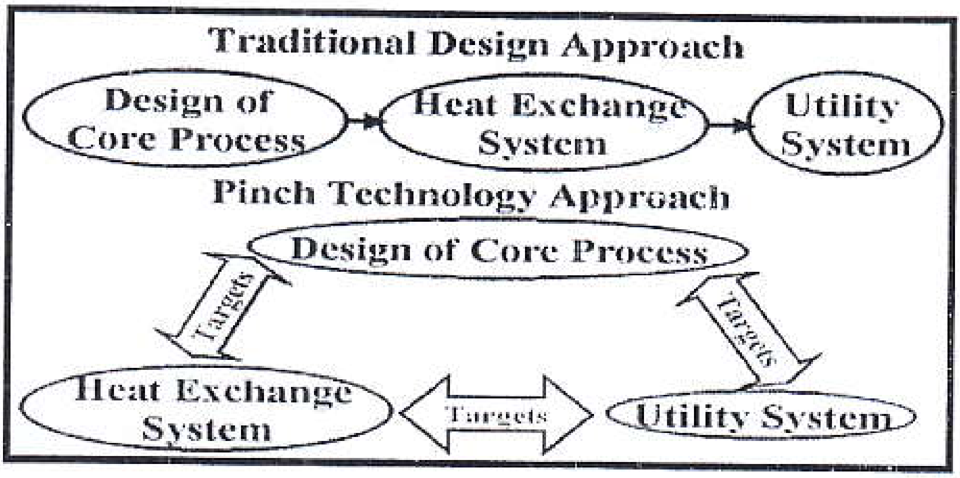

Fig 6: Graphic Representation of Traditional & Pinch Design Approaches

Traditional Design Approach: First, the core of the process is designed with fixed flow rates and temperatures yielding the heat and mass balance for the process. Then the design of a heat recovery system is completed. Next, the remaining duties are satisfied by the use of the utility system. Each of these exercises is performed independently of the others.

Pinch Technology Approach: Process integration using pinch technology offers a novel approach to generate targets for minimum energy consumption before heat recovery network design. Heat recovery and utility system constraints are then considered in the design of the core process. Interactions between the heat recovery and utility systems are also considered. The pinch design can reveal opportunities to modify the core process to improve heat integration. The pinch approach is unique because it treats all processes with multiple streams as a single, integrated system. This method helps to optimize the heat transfer equipment during the design of the equipment.

II .4.1.6.Areas of Applications of Pinch Technology

Pinch originated in the petrochemical sector and is now being applied to solve a wide range of problems in mainstream chemical engineering. Wherever heating and cooling of process materials takes places there is a potential opportunity. Thus initial applications of the technology were found in projects relating to energy saving in industries as diverse as iron and steel, food and drink, textiles, paper and cardboard, cement, base chemicals, oil, and petrochemicals.

Early emphasis on energy conservation led to the misconception that conservation is the main area of application for pinch technology. The technology, when applied with imagination, can affect reactor design, separator design, and the overall process optimization in any plant. It has been applied to processing problems that go far beyond energy conservation It has been employed to solve problems as diverse as improving effluent quality, reducing emissions, increasing product yield, debottlenecking, increasing throughput, and improving the flexibility and safety of the processes.

Since its commercial introduction, pinch technology has achieved an outstanding record of success in the design and retrofit of chemical manufacturing facilities. Documented results reported in the literature show that energy costs have been reduced by 15-40%, capacity debottlenecking achieved by 5-15% for retrofits, and capital cost reduction of 5-10% for new designs.

II .4.2.Basic Concepts of Pinch Analysis

Most industrial processes involve transfer of heat either from one process stream to another process stream (interchanging) or from a utility stream to a process stream. In the present energy crisis scenario all over the world, the target in any industrial process design is to maximize the process-to-process heat recovery and to minimize the utility (energy) requirements. To meet the goal of maximum energy recovery or minimum energy requirement (MER) an appropriate heat exchanger network (HEN) is required. The design of such a network is not an easy task considering the fact that most processes involve a large number of process and utility streams. The traditional design approach has resulted in networks with high capital and utility costs. With the advent of pinch analysis concepts, the network design has become very systematic and methodical.

A summary of the key concepts, their significance, and the nomenclature used in pinch analysis is given below:

- **Combined (Hot and Cold) Composite Curves**: Used to predict targets for
- Minimum energy (both hot and cold utility) required,
- Minimum network area required, and
- Minimum number of exchanger units required.
- **DTmin and Pinch Point**: The DTmin value determines how closely the hot and cold composite curves can be 'pinched' (or squeezed) without violating the Second Law of Thermodynamics (none of the heat exchangers can have a temperature crossover).

- **Grand Composite Curve**: Used to select appropriate levels of utilities (maximize cheaper utilities) to meet over all energy requirements

.

- **Energy and Capital Cost Targeting:** Used to calculate total annual cost of utilities and capital cost of heat exchanger network.

- **Total Cost Targeting:** determine the optimum level of heat recovery or the optimum DTmin value, by balancing energy and capital costs. Using this method, it is possible to obtain an accurate estimate (within 10 - 15%) of overall heat recovery system costs without having to design the system. The essence of the pinch approach is the speed of economic evaluation.

- **Plus/Minus and Appropriate Placement Principles:** The *"Plus/Minus" Principles* provide guidance regarding how a process can be modified in order to reduce associated utility needs and costs. The *Appropriate Placement Principles* provide insights for proper integration of key equipments like distillation columns, evaporators, furnaces, heat engines, heat pumps etc. in order to reduce the utility requirements of the combined system.

- **Total Site Analysis** : This concept enables the analysis of the energy usage for an entire plant site that consists of several processes served by a central utility system.

With further research, new topics like 'Regional Energy Analysis', 'Network Pinch', 'Top

Level Analysis', 'Optimisation of Combined Heat & Power', 'Water Pinch', 'Hydrogen Pinch' etc. Are being developed.

These basic terms and concepts have become the foundation of what we now call Pinch Technology.

II .4.3.Steps of Pinch Analysis

In any Pinch Analysis problem, whether a new project or a retrofit situation, a well-defined stepwise procedure is followed (Figure 7). It should be noted that these steps are not necessarily performed on a once-through basis, independent of one another. Additional activities such as re-simulation and data modification occur as the analysis proceeds and some iteration between the various steps is always required.

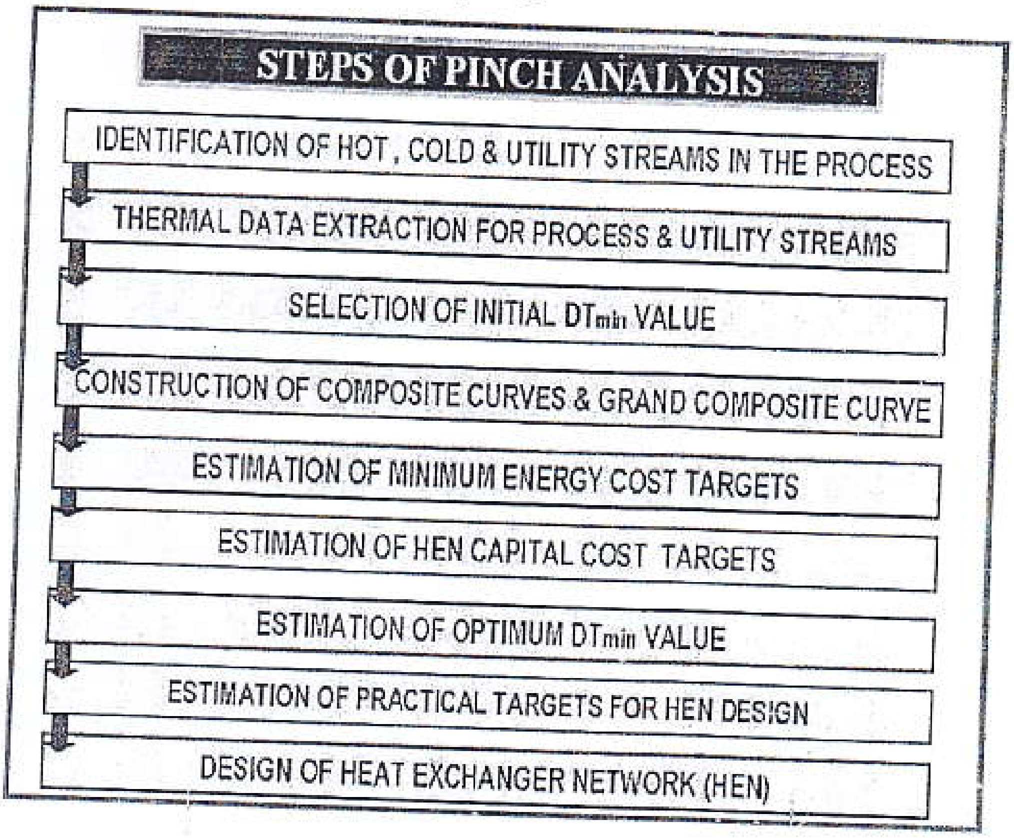

Fig 7: Steps of Pinch Analysis

II .4.3.1.Identification of Hot, Cold, and Utility Streams in the Process

- **'Hot Streams'** are those that must be cooled or are available to be cooled. e.g. product cooling before storage

- **'Cold Streams'** are those that must be heated e.g. feed preheat before a reactor.

- **'Utility Streams'** are used to heat or cool process streams, when heat exchange between process streams is not practical or economic. A number of different **hot utilities** (steam, hot water, flue gas, etc.) and **cold utilities** (cooling water, air, refrigerant, etc.) are used in industry

The identification of streams needs to be done with care as sometimes, despite undergoing changes in temperature, the stream is not available for heat exchange. For example, when a gas stream is compressed the stream temperature rises because of the conversion of mechanical energy into heat and not by any fluid to fluid heat exchange. Hence such a stream may not be available to take part in any heat exchange. In the context of pinch analysis, this stream may or may not be considered to be a process stream.

II .4.3.2.Thermal Data Extraction for Process and Utility Streams

For each hot, cold and utility stream identified, the following thermal data is extracted from the process material and heat balance flow sheet:

- **Supply temperature** (TS $_{o}$C) : the temperature at which the stream is available.

- **Target temperature** (TT $_{o}$C) : the temperature the stream must be taken to.

- **Heat capacity flow rate** (**CP** kW/ °C) : the product of flow rate (m) in kg/sec and specific heat (Cp kJ/kg°C).

$$CP = m \times Cp$$

- **Enthalpy Change (H)** associated with a stream passing through the exchanger is given by the First Law of Thermodynamics:

First Law energy equation: $U = Q \pm W$

In a heat exchanger, no mechanical work is being performed:

$$W = 0 \text{ (zero)}$$

The above equation simplifies to: where **Q** represents the heat supply or demand associated with the stream. It is given by the relationship: **Q= CP x (TS - TT)**

Enthalpy Change, $H = CP \times (TS - TT)$

*** Here the specific heat values have been assumed to be temperature independent within the operating range.*

The stream data and their potential effect on the conclusions of a pinch analysis should be considered during all steps of the analysis. Any erroneous or incorrect data can lead to false conclusions. In order to avoid mistakes, the data extraction is based on certain qualified principles. For details on principles of data extraction. The data extracted is presented in Table 2.

TABLE 2: TYPICAL STREAM DATA

STREAM NUMBER	STREAM NAME	SUPPLY TEMP. °C	TARGET TEMP. °C	HEAT CAP.FLOW kW /°C	ENTH. CHANGE kW
1	FEED	60	205	20	2900
2	REAC.OUT	270	160	18	1980
3	PRODUCT	220	70	35	5250
4	RECYCLE	160	210	50	2500

II .4.3.3.Selection of Initial DTmin Value

The design of any heat transfer equipment must always adhere to the Second Law of Thermodynamics that prohibits any temperature crossover between the hot and the cold stream i.e. a minimum heat transfer driving force must always be allowed for a feasible heat transfer design. Thus the temperature of the hot and cold streams at any point in the exchanger must always have a minimum temperature difference (DTmin). This DTmin value represents the bottleneck in the heat recovery.

In mathematical terms, at any point in the exchanger

Hot stream Temp. (T_H) (T_C) Cold stream Temp. DTmin

The value of DTmin is determined by the overall heat transfer coefficients (U) and the geometry of the heat exchanger. In a network design, the type of heat exchanger to be used at the pinch will determine the practical Dtmin for the network. For example, an initial selection for the Dtmin value for shell and tubes may be 3-5 0C (at best) while compact exchangers such as plate and frame often allow for an initial selection of 2-3°C. The heat transfer equation, which relates Q, U, A and LMTD (Log Mean Temperature Difference) is depicted in Figure 8.

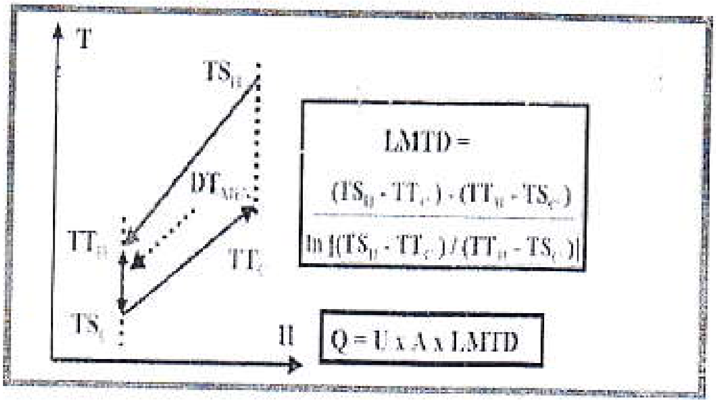

Fig 8: Heat Transfer Equation

For a given value of heat transfer load (Q), if smaller values of DTmin are chosen, the area requirements rise. If a higher value of DTmin is selected the heat recovery in the exchanger decreases and demand for external utilities increases. **Thus, the selection of DTmin value has implications for both capital and energy costs.** This concept will become clearer with the help of composite curves and total cost targeting discussed later.

Just as for a single heat exchanger, the choice of DTmin (or approach temperature) is vital in the design of a heat exchanger networks. To begin the process an initial DTmin value is chosen and pinch analysis is carried out. Typical DTmin values based on experience are available in literature for reference. A few values based on Linnoff March's application experience are tabulated below for shell and tube heat exchangers.

No	**Industrial sector**	**Experience DT_{min} values**
1	**Oil Refining**	**20-40°C**
2	**petrochemical**	**10-20°C**
3	**chemical**	**10-20°C**
4	**Low Temperature Processes**	**3-5°C**

II .4.3.4.Construction of Composite Curves and Grand Composite Curve

•COMPOSITE CURVES :

Temperature - Enthalpy (T - H) plots known as '**Composite curves**' have been used for many years to set energy targets ahead of design. Composite curves consist of temperature (T) – enthalpy (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.

In general any stream with a constant heat capacity (CP) value is represented on a T – H diagram by a straight line running from stream supply temperature to stream target temperature. When there are a number of hot and cold streams, the construction of hot and cold composite curves simply involves the addition of the enthalpy changes of the streams in the respective temperature intervals. An example of hot composite curve construction is shown in Figure 9(a) and (b). A complete hot or cold composite curve consists of a series of connected straight lines, each change in slope represents a change in overall hot stream heat capacity flow rate (CP).

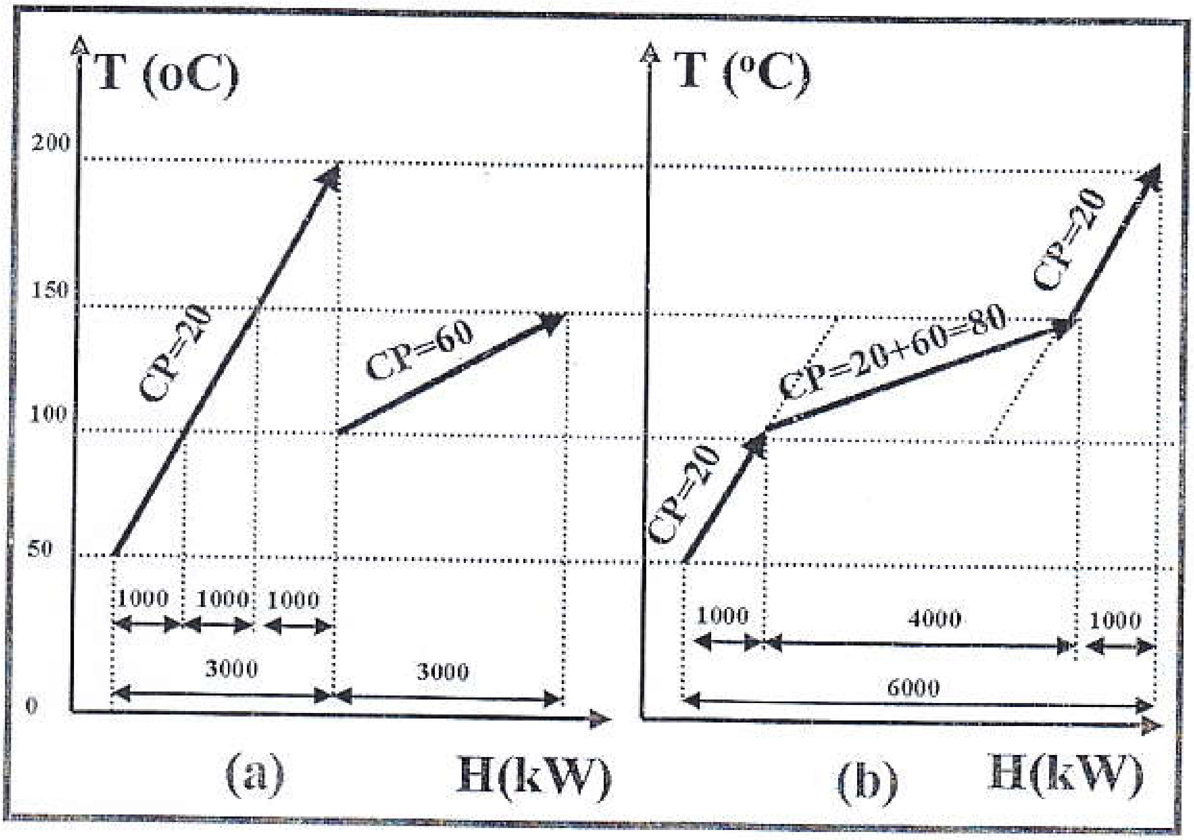

Fig 9: Temperature-Enthalpy Relations Used to Construct Composite Curves

For heat exchange to occur from the hot stream to the cold stream, the hot stream cooling curve must lie above the cold stream-heating curve. Because of the 'kinked' nature of the composite curves (Figure 10), they approach each other most closely at one point defined as the minimum approach temperature (DTmin). DTmin can be measured directly from the T-H profiles as being the minimum vertical difference between the hot and cold curves. This point of minimum temperature difference represents a bottleneck in heat recovery and is commonly referred to as the "Pinch". Increasing the DTmin value results in shifting the of the curves horizontally apart resulting in lower process to process heat exchange and higher utility requirements. At a particular DTmin value, the overlap shows the maximum possible scope for heat recovery within the process. The hot end and cold end overshoots indicate minimum hot utility requirement (QHmin) and minimum cold utility requirement (QCmin). of the process for the chosen DTmin.

Thus, the energy requirement for a process is supplied via process to process heat exchange and/or exchange with several utility levels (steam levels, refrigeration levels, hot oil circuit, furnace flue gas, etc.).

Graphical constructions are not the most convenient means of determining energy needs. A numerical approach called the "Problem Table Algorithm" (PTA) was developed by Linnhoff & Flower (1978) as a means of determining the utility needs of a process and the location of the process pinch. The PTA lends itself to hand calculations of the energy targets.

To summarize, the composite curves provide overall energy targets but do not clearly indicate how much energy must be supplied by different utility levels. The utility mix is determined by the Grand Composite Curve.

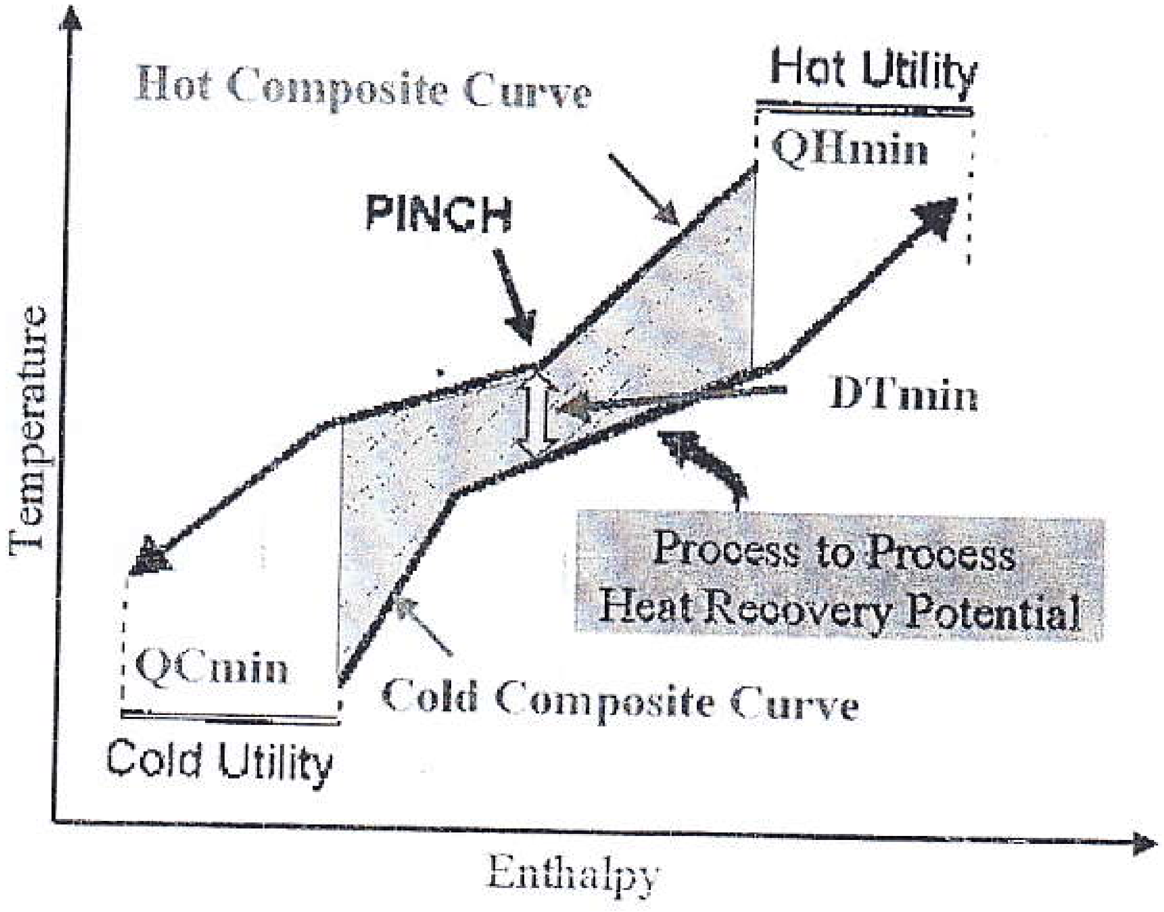

Fig 10: Combined Composite Curves

- **GRAND COMPOSITE CURVE (GCC)**

In selecting utilities to be used, determining utility temperatures, and deciding on utility requirements, the composite curves and PTA are not particularily useful. The introduction of a new tool, the Grand Composite Curve (GCC), was introduced in 1982 by Itoh, Shiroko and Umeda. The GCC (Figure 7) shows the variation of heat supply and demand within the process. Using this diagram the designer can find which utilities are to be used. The designer aims to maximize the use of the cheaper utility levels and minimize the use of the expensive utility levels. Low-pressure steam and cooling water are preferred instead of high-pressure steam and refrigeration, respectively

The information required for the construction of the GCC comes directly from the Problem Table Algorithm developed by Linnhoff & Flower (1978). The method involves shifting (along the temperature [Y] axis) of the hot composite curve down by ½ DTmin and that of cold composite curve up by ½ DTmin. The vertical axis on the shifted composite curves shows process interval temperature. In other words, the curves are shifted by subtracting part of the allowable temperature approach from the hot stream temperatures and adding the remaining part of the allowable temperature approach to the cold stream temperatures. The result is a scale based upon process temperature having an allowance for temperature approach (DTmin). The Grand Composite Curve is then constructed from the enthalpy (horizontal) differences between the shifted composite curves at different temperatures. On the GCC, the horizontal distance separating the curve from the vertical axis at the top of the temperature scale shows the overall hot utility consumption of the process.

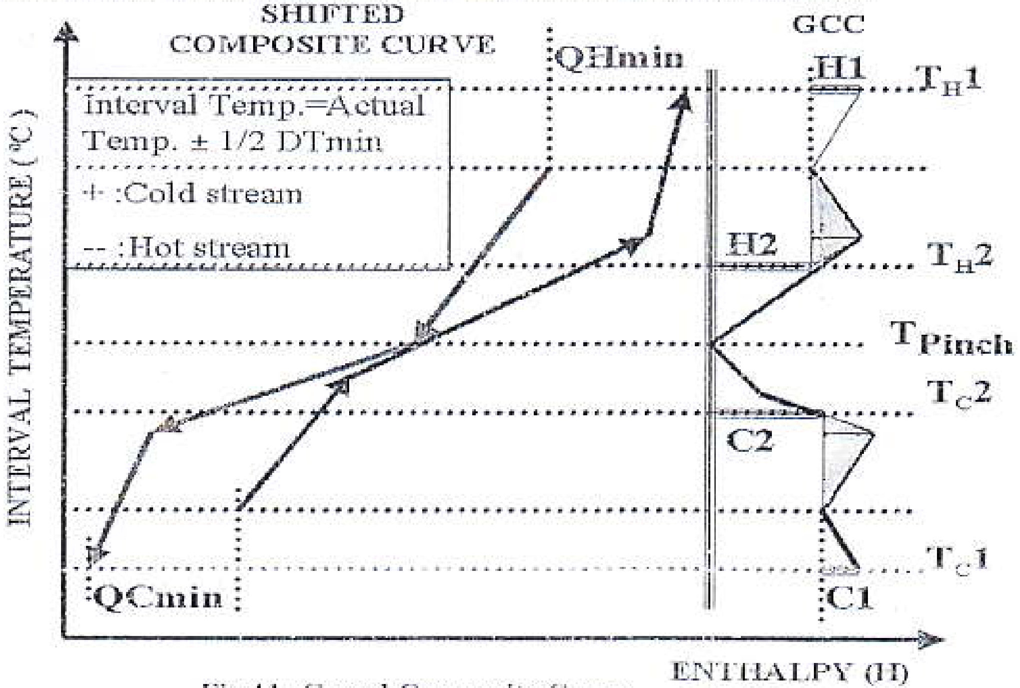

Fig 11: Grand Composite Curve

Figure 11 shows that it is not necessary to supply the hot utility at the top temperature level. The GCC indicates that we can supply the hot utility over two temperature levels TH1 (HP steam) and TH2 (LP steam). Recall that, when placing utilities in the GCC, intervals, and not actual utility temperatures, should be used. The total minimum hot utility requirement remains the same: QHmin = H1 (HP steam) + H2 (LP steam). Similarly, QCmin = C1 (Refrigerant) +C2 (CW). The points TH2 and TC2 where the H2 and C2 levels touch the grand composite curve are called the "Utility Pinches." The shaded green pockets represent the process-to-process heat exchange.

In summary, the grand composite curve is one of the most basic tools used in pinch analysis for the selection of the appropriate utility levels and for targeting of a given set of multiple utility levels. The targeting involves setting appropriate loads for the various utility levels by maximizing the least expensive utility loads and minimizing the loads on the most expensive utilities.

II .4.3.5.Estimation of Minimum Energy Cost Targets

Once the DTmin is chosen, minimum hot and cold utility requirements can be evaluated from the composite curves. The GCC provides information regarding the utility levels selected to meet QHmin and QCmin requirements.

If the unit cost of each utility is known, the total energy cost can be calculated using the energy equation given below.

$$\text{TOTAL ENERGY COST} = \sum_{U=1}^{U} Q_U \times C_U$$

Where Q_U = Duty of utility U , kW

C_U = Unit cost of utility U , \$/kW,yr

U = Total number of utilities used

II .4.3.6.Estimation of Heat Exchanger Network Capital Cost Targets

The capital cost of a heat exchanger network is dependent upon three factors:

1.the number of exchangers,

2.the overall network area,

3.the distribution of area between the exchangers

Pinch analysis enables targets for the overall heat transfer area and minimum number of units of a heat exchanger network (HEN) to be predicted prior to detailed design. It is assumed that the area is evenly distributed between the units. The area distribution cannot be predicted ahead of design.

•AREA TARGETING:

The calculation of surface area for a single counter-current heat exchanger requires the knowledge of the temperatures of streams in and out (TLMi.e. Log Mean Temperature Difference or LMTD), overall heat transfer coefficient (U-value), and total heat transferred (Q). The area is given by the relation

$$\text{Area} = Q / [\ U \times T_{LM}\ ]$$

The composite curves can be divided into a set of adjoining enthalpy intervals such that within each interval, the hot and cold composite curves do not change slope. Here the heat exchange is assumed to be "vertical" (pure counter-current heat exchange). The hot streams in any enthalpy interval, at any point, exchanges heat with the cold streams at the temperature vertically below it. The total area of the HEN (Amin) is given by the formula in Figure 12, where i denotes the ith enthalpy and interval j denotes the jth stream and TLMdenotes LMTD in the ith interval.

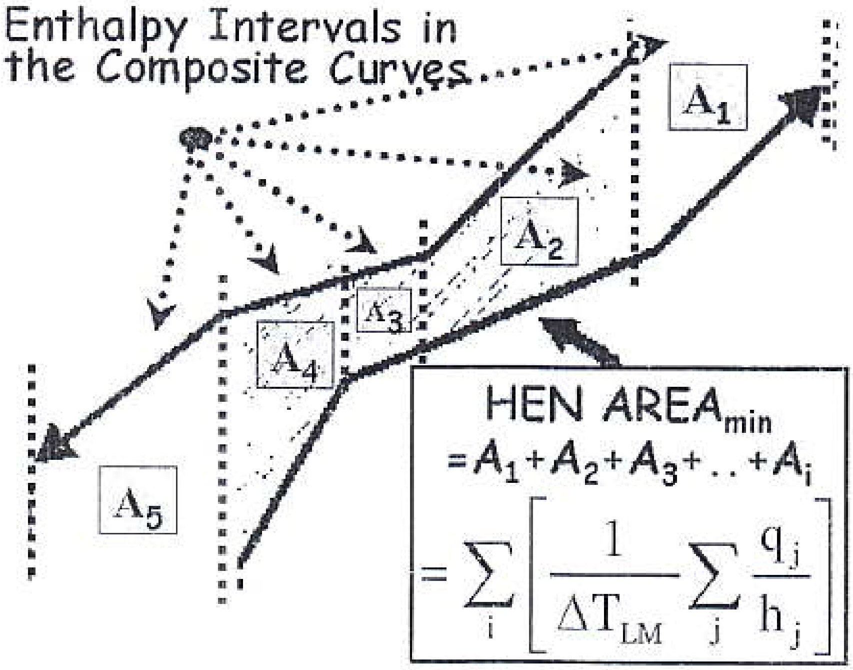

Fig 12: HEN AREA$_{min}$ Estimation from Composite Curves

The actual HEN total area required is generally within 10% of the area target as calculated above. With inclusion of temperature correction factors area targeting can be extended to non counter-current heat exchange as well.

•NUMBER OF UNITS TARGETING:

For the minimum number of heat exchanger units (Nmin) required for MER (minimum energy requirement or maximum energy recovery), the HEN can be evaluated prior to HEN design by using a simplified form of Euler's graph theorem. In designing for the minimum energy requirement (MER), no heat transfer is allowed across the pinch and so a realistic target for the minimum number of units (NminMER) is the sum of the targets evaluated both above and below the pinch separately.

$$N_{minMER}=|Nh+Nc+Nu-1|_{AP}+|Nh+Nc+Nu-1|_{BP}$$

Where :
Nh = Number of hot streams
Nc = Number of cold streams
Nu = Number of utility streams

AP / BP : Above / Below Pinch

•HEN TOTAL CAPITAL COST TARGETING:

The targets for the minimum surface area (Amin) and the number of units (Nmin) can be combined together with the heat exchanger cost law to determine the targets for HEN capital cost (CHEN).The capital cost is annualized using an annualization factor that takes into account interest payments on borrowed capital. The equation used for calculating the total capital cost and exchanger cost law is given below.

$$C(\$)_{HEN} = \left[N_{min}\left\{a + b\,(A_{min}/N_{min})^{c}\right\}\right]_{AP} + \left[N_{min}\left\{a + b\,(A_{min}/N_{min})^{c}\right\}\right]_{BP}$$

where a ,b, and c are constants in exchanger cost law

$$\text{Exchanger cost } (\$) = a + b\,(\text{Area})^{c}$$

For the Exchanger Cost Equation shown above, typical values for a carbon steel shell and tube exchnager would be a = 16,000, b = 3,200, and c = 0.7. The installed cost can be considered to be 3.5 times the purchased cost given by the Exchanger Cost Equation.

II .4.3.7.Estimation of Optimum DTmin Value

To arrive at an optimum DTmin value, the total annual cost (the sum of total annual energy and capital cost) is plotted at varying DTmin values (Figure 11). Three key observations can be made from Figure 13:

a.An increase in DTmin values result in higher energy costs and lower capital costs.

b.A decrease in DTmin values result in lower energy costs and higher capital costs.

c.An optimum DTmin exists where the total annual cost of energy and capital costs is minimized.

Thus, by systematically varying the temperature approach we can determine the optimum heat recovery level or the DTminOPTIMUM for the process.

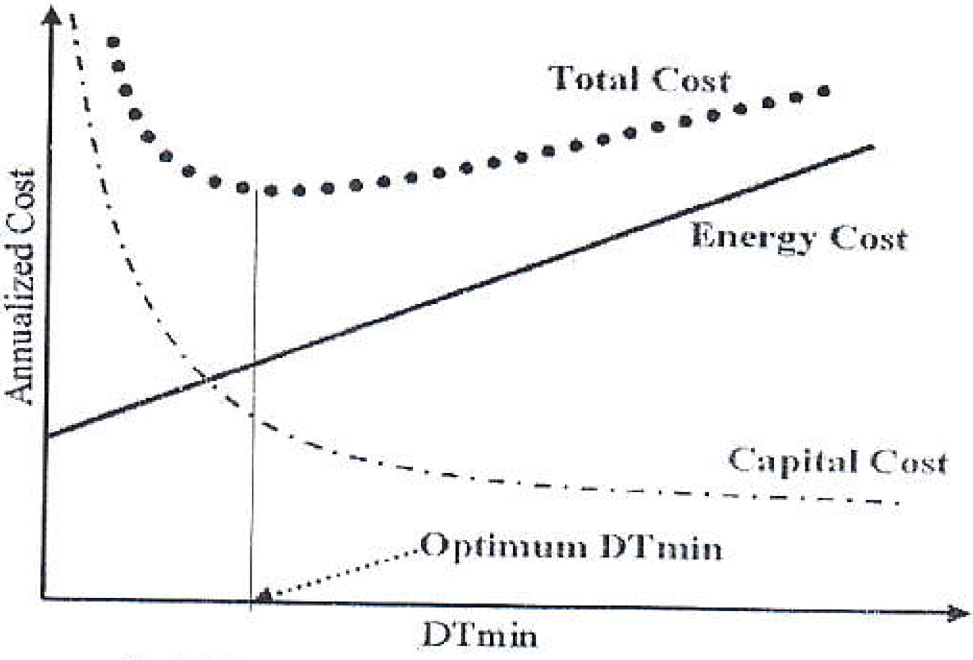

Fig 13: Energy-Capital Cost Trade Off (Optimum DTmin)

II .4.3.8.Estimation of Practical Targets for HEN Design

The heat exchanger network designed on the basis of the estimated optimum DTmin value is not always the most appropriate design. A very small DTmin value, perhaps 8 0C, can lead to a very complicated network design with a large total area due to low driving forces. The designer, in practice, selects a higher value (150C) and calculates the marginal increases in utility duties and area requirements. If the marginal cost increase is small, the higher value of DTmin is selected as the practical pinch point for the HEN design.

Recognizing the significance of the pinch temperature allows energy targets to be realized by design of appropriate heat recovery network.

So what is the significance of the pinch temperature?

The pinch divides the process into two separate systems each of which is in enthalpy balance with the utility. The pinch point is unique for each process. Above the pinch, only the hot utility is required. Below the pinch, only the cold utility is required. Hence, for an optimum design, no heat should be transferred across the pinch. This is known as the key concept in Pinch Technology.

To summarize, Pinch Technology gives three rules that form the basis for practical network design:

- No external heating below the Pinch.
- No external cooling above the Pinch.
- No heat transfer across the Pinch

Violation of any of the above rules results in higher energy requirements than the minimum requirements theoretically possible.

Plus/Minus Principle:

The overall energy needs of a process can be further reduced by introducing process changes (changes in the process heat and material balance). There are several parameters that could be changed such as reactor conversions, distillation column operating pressures and reflux ratios, feed vaporization pressures, or pump-around flow rates. The number of possible process changes is nearly infinite. By applying the pinch rules as discussed above, it is possible to identify changes in the appropriate process parameter that will have a favorable impact on energy consumption. This is called the "Plus/Minus Principle."

Applying the pinch rules to study of composite curves provide us the following guidelines:

- Increase (+) in hot stream duty above the pinch.
- Decrease (-) in cold stream duty above the pinch.

This will result in a reduced hot utility target, and any

- Decrease (-) in hot stream duty below the pinch.
- Increase (+) in cold stream duty below the pinch

will result in a reduced cold utility target.

These simple guidelines provide a definite reference for the adjustment of single heat duties such as vaporization of a recycle, pump-around condensing duty, and others. Often it is possible to change temperatures rather than the heat duties. The target should be to

•Shift hot streams from below the pinch to above and

•Shift cold streams from above the pinch to below.

The process changes that can help achieve such stream shifts essentially involve changes in following operating parameters:

•reactor pressure/temperatures

•distillation column temperatures, reflux ratios, feed conditions, pump around conditions, intermediate condensers

•evaporator pressures

•storage vessel temperatures

For example, if the pressure for a feed vaporizer is lowered, vaporization duty can shift from above to below the pinch. The leads to reduction in both hot and cold utilities.

Appropriate Placement Principles:

Apart from the changes in process parameters, proper integration of key equipment in process with respect to the pinch point should also be considered. The pinch concept of "Appropriate Placement" (integration of operations in such a way that there is reduction in the utility requirement of the combined system) is used for this purpose, Appropriate placement principles have been developed for distillation columns, evaporators, heat engines, furnaces, and heat pumps. For example, a single-effect evaporator having equal vaporization and condensation loads, should be placed such that both loads balance each other and the evaporator can be operated without any utility costs. This means that appropriate placement of the evaporator is on either side of the pinch and not across the pinch.

In addition to the above pinch rules and principles, a large number of factors must also be considered during the design of heat recovery networks. The most important are operating cost, capital cost, safety, operability, future requirements, and plant operating integrity.

Operating costs are dependent on hot and cold utility requirements as well as pumping and compressor costs. The capital cost of a network is dependent on a number of factors including the number of heat exchangers, heat transfer areas, materials of construction, piping, and the cost of supporting foundations and structures.

With a little practice, the above principles enable the designer to quickly pan through 40-50 possible modifications and choose 3 or 4 that will lead to the best overall cost effects.

The essence of the pinch approach is to explore the options of modifying the core process design, heat exchangers, and utility systems with the ultimate goal of reducing the energy and/or capital cost.

II .4.3.9.Design of Heat Exchanger Network (HEN)

The design of a new HEN is best executed using the "Pinch Design Method (PDM)". The systematic application of the PDM allows the design of a good network that achieves the energy targets within practical limits. The method incorporates two fundamentally important features: (1) it recognizes that the pinch region is the most constrained part of the problem (consequently it starts the design at the pinch and develops by moving away) and (2) it allows the designer to choose between match options.

In effect, the design of network examines which "hot" streams can be matched to "cold" streams via heat recovery. This can be achieved by employing "tick off" heuristics to identify the heat loads on the pinch exchanger. Every match brings one stream to it target temperature. As the pinch divides the heat exchange system into two thermally independent regions, HENs for both above and below pinch regions are designed separately. When the heat recovery is maximized the remaining thermal needs must be supplied by hot utility.

The graphical method of representing flow streams and heat recovery matches is called a 'grid diagram' (Figure 14).

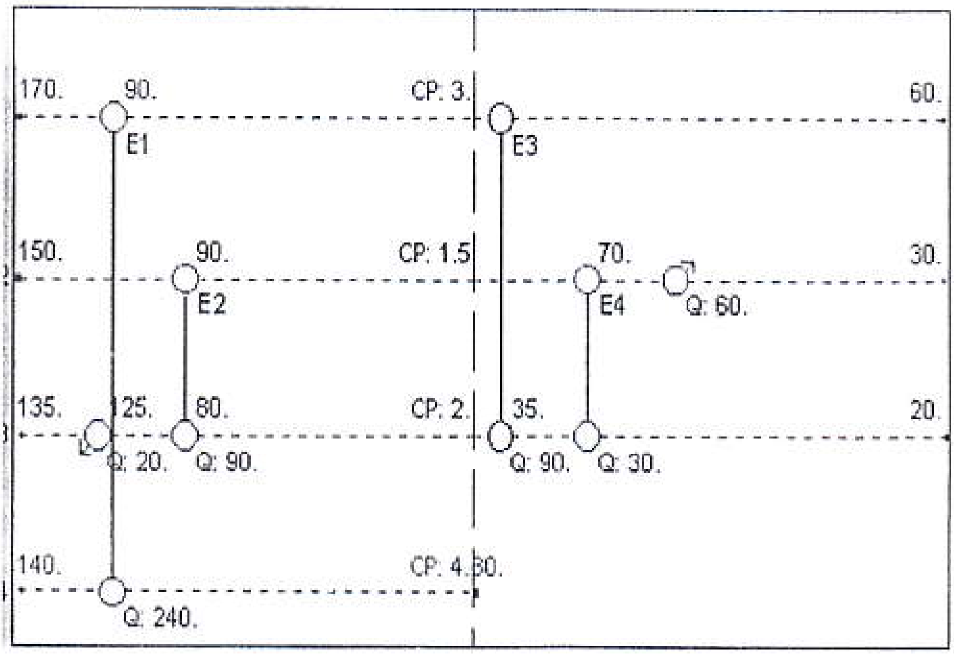

Fig 14: Typical Grid Diagram

All the cold (blue lines) and hot (red line) streams are represented by horizontal lines. The entrance and exit temperatures are shown at either end. The vertical line in the middle represents the pinch temperature. The circles represent heat exchangers. Unconnected circles represent exchangers using utility heating and cooling.

The design of a network is based on certain guidelines like the "CP Inequality Rule", "Stream Splitting", "Driving Force Plot" and "Remaining Problem Analysis".

Having made all the possible matches, the two designs above and below the pinch are then brought together and usually refined to further minimize the capital cost. After the network has been designed according to the pinch rules, it can be further subjected to energy optimization. Optimizing the network involves both topological and parametric changes of the initial design in order to minimize the total cost.

II .4.4.Benefits and Applications of Pinch Technology

One of the main advantages of Pinch Technology over conventional design methods is the ability to set energy and capital cost targets for an individual process or for an entire production site ahead of design. Therefore, in advance of identifying any projects, we know the scope for energy savings and investment requirements.

II .4.4.1.General Process Improvements

In addition to energy conservation studies, Pinch Technology enables process engineers to achieve the following general process improvements:

•Update or Modify Process Flow Diagrams (PFDs):

Pinch quantifies the savings available by changing the process itself. It shows where process changes reduce the overall energy target, not just local energy consumption.

•Conduct Process Simulation Studies:

Pinch replaces the old energy studies with information that can be easily updated using simulation. Such simulation studies can help avoid unnecessary capital costs by identifying energy savings with a smaller investment before the projects are implemented.

•Set Practical Targets :

By taking into account practical constraints (difficult fluids, layout, safety, etc.), theoretical targets are modified so that they can be realistically achieved. Comparing practical with theoretical targets quantifies opportunities "lost" by constraints - a vital insight for long-term development.

•Debottlenecking:

Pinch Analysis, when specifically applied to debottlenecking studies, can lead to the following benefits compared to a conventional revamp:

•Reduction in capital costs

•Decrease in specific energy demand giving a more competitive production facility

For example, debottlenecking of distillation columns by Column Targeting can be used to identify less expensive alternatives to column retraying or installation of a new column.

•Determine Opportunities for Combined Heat and Power (CHP) Generation:

A well- designed CHP system significantly reduces power costs. Pinch shows the best type of CHP system that matches the inherent thermodynamic opportunities on the site. Unnecessary investments and operating costs can be avoided by sizing plants to supply energy that takes heat recovery into consideration. Heat recovery should be optimized by Pinch Analysis before specifying CHP systems.

•Decide what to do with low-grade waste heat:

Pinch shows, which waste heat streams, can be recovered and lends insight into the most effective means of recovery.

II .4.4.2.Industrial Applications

The application of Pinch Technology has resulted in significant improvements in the energy and capital efficiency of industrial facilities worldwide. It has been successfully applied in many different industries from petroleum and base chemicals to food and paper. Both continuous and batch processes have been successfully analyzed on an individual unit and site-wide basis. Pinch technology has been extensively used to capitalize on the mistakes of the past. It identifies the existence of built-in spare heat transfer areas and presents the designer with opportunities for cheap retrofits. In case of the design of new plants, Pinch Analysis has played a very important role and minimized capital costs.

A Case Study: When Pennzoil was adding a residual catalytic cracking (RCC) unit, the gas plant associated with the RCC and an alkylation unit at its Atlas Refining facility in Shreveport, energy efficiency was one of their major considerations in engineering the refinery expansion. Electric Power Research Institute (EPRI) and Pennzoil's energy provider, SWEPCO, used pinch technology to carry out an optimization study of the new units and the utility systems that serve them rather than simply incorporating standard process packages provided by licensors. The pinch study identified opportunities for saving up to 23.7% of the process heating through improved heat integration. Net savings for Pennzoil were estimated at $13.7 million over 10 years.

II .4.5.The Future Outlook Of Pinch Technology

The development of Pinch Technology started in the late 1970s and still continues. Besides applications in energy conservation, new developments in Pinch Analysis are being made in the areas of water use minimization, waste minimization, hydrogen management, plastics manufacturing, and others. A few of key areas of research are mentioned decribed below.

II .4.5.1.Regional Energy Analysis

By examining the net energy demands of different companies combined, the potential for sharing heat between companies can be identified. These analyses can lend insight into the amount and temperature of waste heat in an industrial area that is available for export. Depending on the temperature of this waste heat, it can be used for district heating or power generation.

II .4.5.2.Total Site Analysis

Typically, refinery and petrochemical processes operate as parts of large sites or factories. These sites have several processes serviced by a centralized utility system. There is both consumption and recovery of process steam via the steam mains. The site imports or exports power to balance the on-site power generation. The process stream heating and cooling demands, and co-generation potential, dictate the site-wide fuel demand via the utility system. In such large sites, usually the individual production processes and the central services are controlled by different departments which operate independently. The site infrastructure usually suffers from inadequate integration. To improve integration, a simultaneous approach to consider individual process issues alongside sitewide utility planning is necessary. Similar to a single process, a Total Site Analysis using Pinch Technology can be used to calculate energy targets for the entire site. For example, how much low pressure, medium pressure, and high pressure steam should the site be using? How much steam can be raised and how much power it can generate? This also helps to identify key process changes that will lower the overall site utility consumption.

II .4.5.3.Network Pinch

When optimizing energy consumption in an existing industrial process, a number of practical constraints must be recognized. Traditional Pinch Technology focuses on new network designs. Network Pinch addresses the additional constraints in problems associated with existing facilities. This analysis identifies the heat exchanger forming the bottleneck to increasing heat recovery. Then provides a systematic approach to remove this bottleneck. This step-by-step method provides an approach for implementing energy savings in a series of consecutive projects.

II .4.5.4.Top Level Analysis

Gathering the required data in industrial areas is not an easy task. With a Top Level Analysis, only efficiencies and constraints of the utility system are used to determine which utility is worth saving. Data can be gathered from those processes or units that use these utilities. A pinch analysis can then be performed on this equipment.

II .4.5.5.Optimization of Combined Heat and Power

Typically, multiple steam turbines are used in complex steam systems. CHP optimization gives a way to determine the load distribution in a network of turbines with a given total load.

II .4.5.5.Water Pinch

In view of rising fresh water costs and more stringent discharge regulations, Pinch Analysis is helping companies to systematically minimize freshwater and wastewater volumes. Water Pinch is a systematic technique for analyzing water networks and reducing water costs for processes. It uses advanced algorithms to identify and optimize the best water reuse, regeneration, and effluent treatment opportunities. It has also helped to reduce losses of both feedstock and valuable products in effluent streams.

II .4.5.6.Hydrogen Pinch

The Pinch Technology approach applied to hydrogen management is called Hydrogen Pinch. Hydrogen Pinch enables a designer to set targets for the minimum hydrogen plant production and/or imports without the need for any process design. Methods have also been developed for the design of hydrogen distribution networks in order to achieve the targets. Hydrogen Pinch also lends insight into the effective use of hydrogen purification units.

II .6.Conclusions

With all of the tools that pinch analysis provides, one of the most important challenges before process engineers is to properly integrate pinch tools into the conceptual process design phase. Decisions made in this phase of planning affect the entire life cycle of a process facility. Using pinch technology tools and understanding the process does not ensure the desired results. These tools must be applied at the right point in the process design phase. Just as it would be incorrect to conduct a Pinch Analysis after completion of the process design phase, wherein critical process parameters have been fixed, it is just as incorrect to conduct a Pinch Analysis without direct interaction with the process specialists and downstream engineering disciplines. **It is Pinch Technology's role to identify "what might be". However, input from other engineering disciplines ultimately determines "what can be".**

CHAPTER III :
CASE STUDY

HEAT-INTEGRATED DESIGN
FOR NATUREL GAS PROCESSING

Case Study

III.1 Process description

Natural gas has to be processed before it is transported or delivered to the consumer. Technology of gas processing depends on composition of crude gas. Natural gas from high-pressure wells is usually passed through field separators at the well to remove hydrocarbon condensate and water. Then the hydrogen sulfide must be removed (called sweetening the gas). Natural gasoline, butane, and propane are usually present in the gas, and gas processing plants are required for the recovery of these liquefiable constituents. In our case study we have created simulation model of recovery of natural gas liquids from gas that can bring significant additional profit.

It is required to process natural gas stream at 4536 kgmole/h, 21 °C, 1 MPa and composition in Tab. 1. The gaseous product is required to be at 1 MPa, with at least 4472 kgmole/h of nC4 and lighter species, and a combined mole percentage at least 99.5 %. The liquid product is required to be at least 1 MPa, with at least 30.6 kgmole/h of nC5 and nC6 and a combined mole percentage at least 75 %.

Tab 3: Molar Flow Rates of the Feed, Gas, and Liquid Product Streams (in kgmole/h)

X Component	**Feed (stream SZP)**	**Gas (stream ZP)**	**Liquid (stream S11)**
N2	95.7	95.7	0
C1	3754	3754	0
C2	395.1	395.1	0
C3	186.4	186.1	0.3
nC4	64	41.9	22.0
nC5	25.9	5.2	20.7
nC6	15	0.9	14.1
Total	4536	4478.9	57.1

Instead of technological scheme we can show structure of the simulated process on the process flow diagram we have created in HYSYS (Fig. 1). The feed is compressed to 2.3 MPa, cooled to 38 °C using cooling water (E-1A), and to -26 °C using refrigerant (E-1B), before entering the flash vessel, (S-1), at 2.1 MPa. Its vapor effluent and liquid product are heated (E-2A, E-2B), to 27 °C. The latter enters the flash vessel, (S-2), at 2.05 MPa. Its liquid effluent is fed to the distillation column, K-1, which is designed to remove most of the propane in the overhead stream. It has twelve theoretical trays (not counting reboiler and condenser), with the feed to the fourth tray from the top, and recovers 99 % of nC5 in the bottom products and 99 % of nC3 in the distillate.

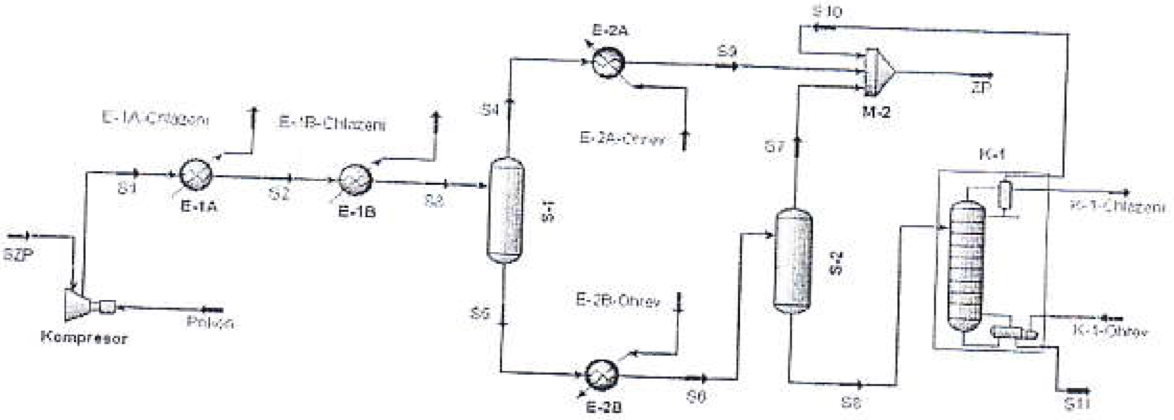

Fig 15 : Process flow diagram for the natural gas processing

III.2 Stream data extraction

Becuse of we can not deal with simple HEAT EXCHANGER in Figure 15 and obtain Pinch Results using HYSYS Simulator , we modified the flowsheet in Figure 15 to flowsheet in Figure 16 using cooling water instead of simple cooler, cooling with propan instead of simple refrigerant, heating with steam instead of simple heater.

Instead of technological scheme we can show structure of the simulated process on the process flow diagram we have created in HYSYS (Fig. 1). The feed is compressed to 2.3 MPa, cooled to 38 °C using cooling water (E-1A), and to -26 °C using refrigerant (E-1B), before entering the flash vessel, (S-1), at 2.1 MPa. Its vapor effluent and liquid product are heated (E-2A, E-2B), to 27 °C. The latter enters the flash vessel, (S-2), at 2.05 MPa. Its liquid effluent is fed to the distillation column, K-1, which is designed to remove most of the propane in the overhead stream. It has twelve theoretical trays (not counting reboiler and condenser), with the feed to the fourth tray from the top, and recovers 99 % of nC5 in the bottom products and 99 % of nC3 in the distillate.

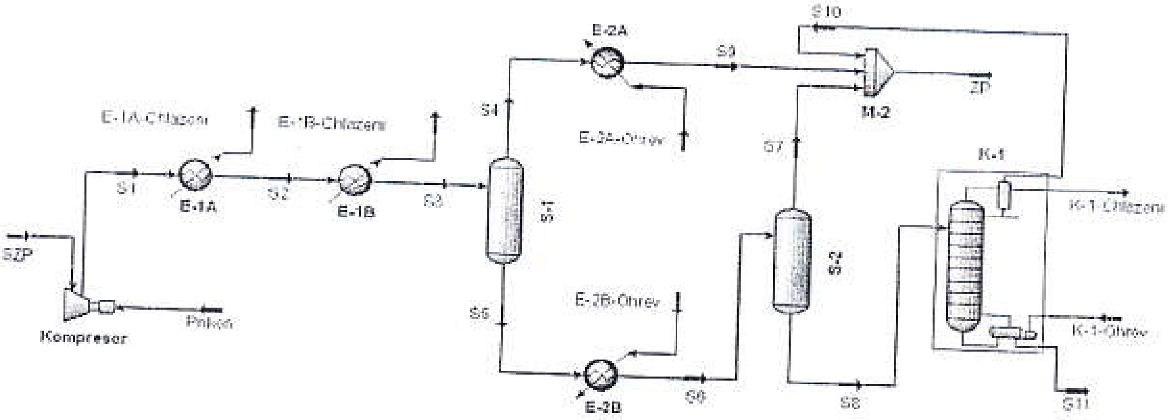

Fig 15 : Process flow diagram for the natural gas processing

III.2 Stream data extraction

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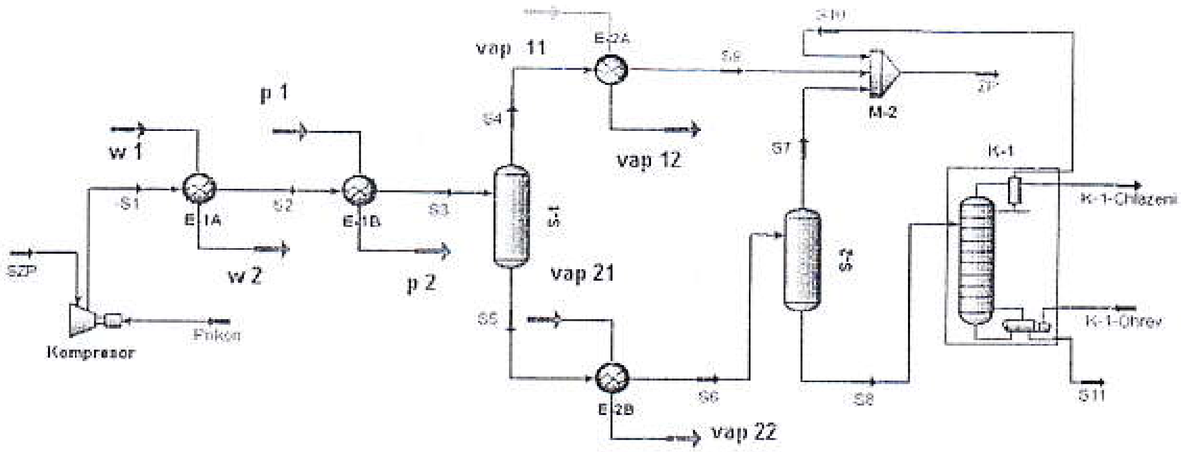

Fig 16 : Alternative Process flow diagram for the natural gas processing

To use Pinch Analysis and get data extraction and energy targeting from the flowsheet in Figure 16, we will deal with each Heat Exchanger separately and define its hot and cold streams, constructe composte curve (CC) and grand composite curve (GCC).

III.3 Without Heat Integration

We have four Heat Exchangers:

1- E-1A COOLER using cooling water.

2- E-1B REFRIGERANT using propan.

3- E-2A HEATER using steam.

4- E-2B HEATER using steam.

III.3.1 E-1A Heat Exchanger

III.3.1.1 Data Extraction And Energy Targeting For (E-1A)

The hot and cold stream data extracted from the flowsheet in Figure 16 for (E-1A) are given in Table 4. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 4 : Data for E-1A heat exchangers

	W1-W2	S1-S2
Inlet Temp. (C)	25.00	91.84
Outlet Temp. (C)	71.33	38.00
Molar Flow (kgmole/h)	3000	4536

The pinch results for E-1A heat exchangers are given in Table 5 after determine Hot Pinch Temperature, the Minimum Aproach and Avg. Temerature at Pinch are calculated

Tab 5 : pinch results for E-1A heat exchangers

Hot Pinch Temperature (C)	38.00	Cold Utility (kJ/h	0.0000
Cold Pinch Temperature (C)	25.00	Hot Utility (kJ/h	0.0000
Minimum Approach (C)	13.00	Number of Points	5
Avg. Temperature at Pinch (C)	31.50	Minimum Approach Target (C	---
Enthalpy Change at Pinch (kJ/h)	0.0000	Cold Utility Target (kJ/h	---
		Hot Utility Target (kJ/h	---

Tab 6 : Tabular Results for E-1A

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
25.00	38.00	---	0.0000
34.27	48.97	13.83	2.223e+006
43.55	59.85	15.49	4.445e+006
52.82	70.63	17.05	6.668e+006
62.08	81.29	18.50	8.891e+006
71.33	91.84	19.85	1.111e+007

III.3.1.2 Composite Curve for E-1A Heat Exchanger

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. Figure 17 illustrates the construction of the composite curve for the E-1A Heat Exchanger.

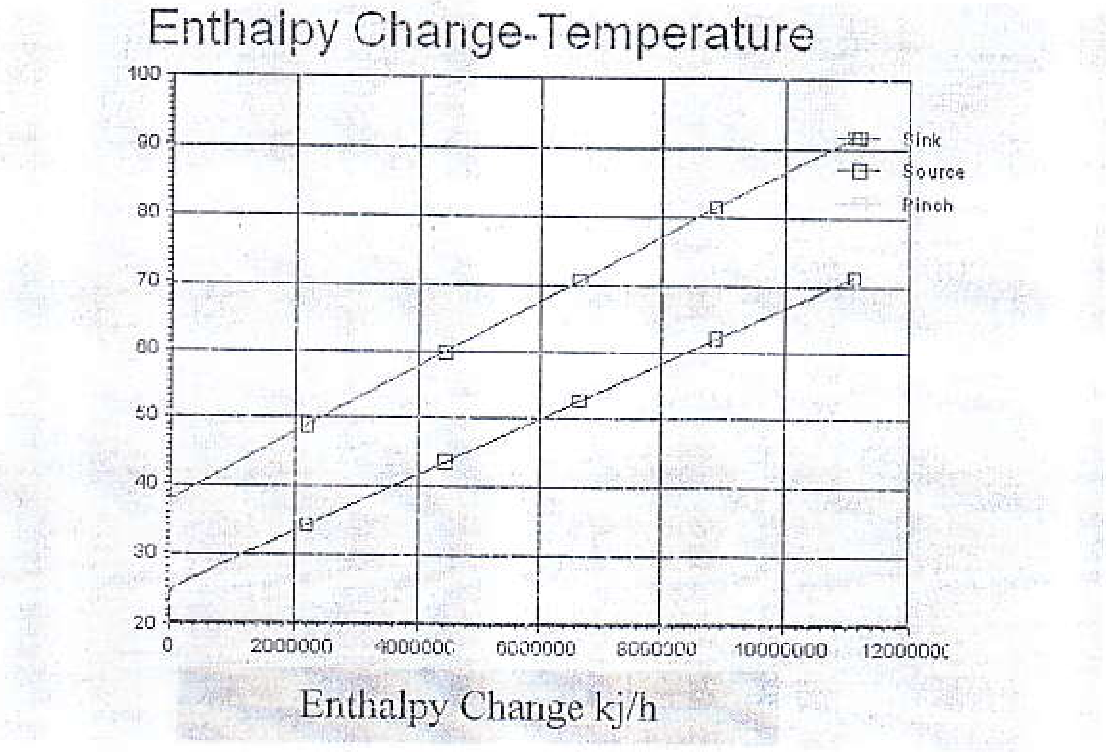

Fig 17 :Composite Curve for E-1A Heat Exchanger

III.3.1.3 The Grand Composite Curve for E-1A Heat Exchanger

The tool that is used for setting multiple utility targets is called the Grand Composite Curve, the construction of which is illustrated in Figure 18. This starts with the composite curves . The first step is to make adjustments in the temperatures of the composite curves. This involves increasing the cold composite temperature by ½ DTmin and decreasing the hot composite temperature by ½ DTmin . This temperature shifting of the process streams and utility levels ensures that even when theutility levels touch the grand composite curve, the minimum temperature difference of DTmin is maintained between the utility levels and the process streams. The temperature shifting therefore makes it easier to target for multiple utilities. As a result of this temperature shift, the composite curves touch each other at the pinch. The curves are called the "shifted composite curves". The grand composite curve is then constructed from the enthalpy (horizontal) differences between the shifted composite curves at different temperatures. The grand composite curve provides the same overall energy target as the composite curves.

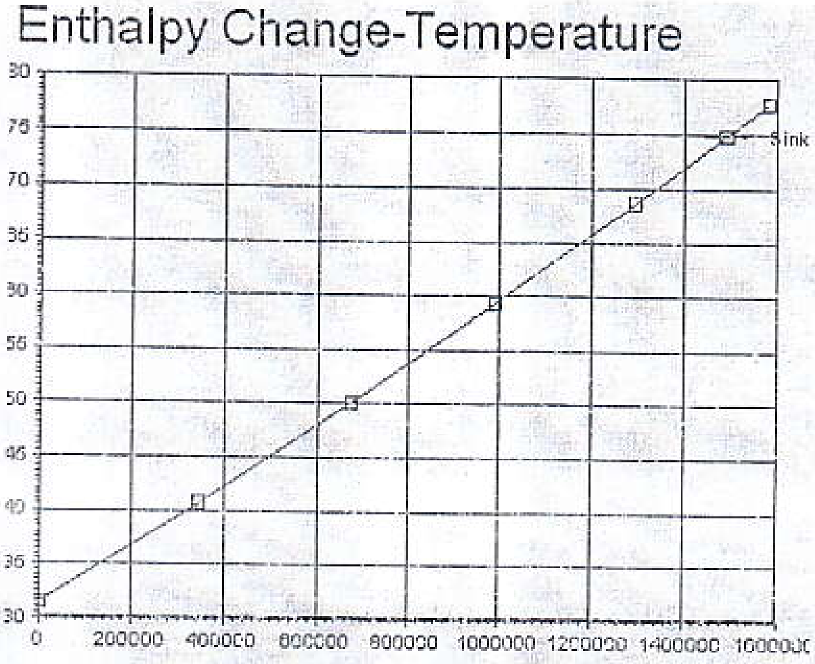

Fig 18 :The Grand Composite Curve for E-1A Heat Exchanger

III.3.2 E-1B Heat Exchanger

III.3.2.1 Data Extraction And Energy Targeting For (E-1B)

The hot and cold stream data extracted from the flowsheet in Figure 19 for (E-1B) are given in Table 7. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 7 : Data for E-1B heat exchangers

	P-P2	S2-S3
Inlet Temp. (C)	-30.00 *	38.00 *
Outlet Temp. (C)	23.98 *	-26.00 *
Molar Flow (kgmole/h)	2500 *	4536 *

The pinch results for E-1B heat exchangers are given in Table 8 after determine Hot Pinch Temperature, the Minimum Aproach and Avg. Temerature at Pinch are calculated

Tab 8 : pinch results for E-1B heat exchangers

Hot Pinch Temperature (C)	-15.39	Cold Utility (kJ/h)	0.0000
Cold Pinch Temperature (C)	-18.30	Hot Utility (kJ/h)	0.0000
Minimum Approach (C)	2.912	Number of Points	5 *
Avg. Temperature at Pinch (C)	-16.85	Minimum Approach Target (C)	---
Enthalpy Change at Pinch (kJ/h)	3.082e+006	Cold Utility Target (kJ/h)	---
		Hot Utility Target (kJ/h)	---

Tab 9 : Tabular Results for E-1B

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
-30.00	-26.00	---	0.0000
-18.30	-15.39	3.427 *	3.082e+006
-7.053	-4.096	2.935 *	6.164e+006
3.754	7.711	3.433 *	9.247e+006
14.09	22.65	5.962 *	1.233e+007
23.97	38.00	11.06 *	1.541e+007

III.3.2.2 Composite Curve for E-1B Heat Exchanger

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. Figure 19 illustrates the construction of the composite curve for the E-1A Heat Exchanger.

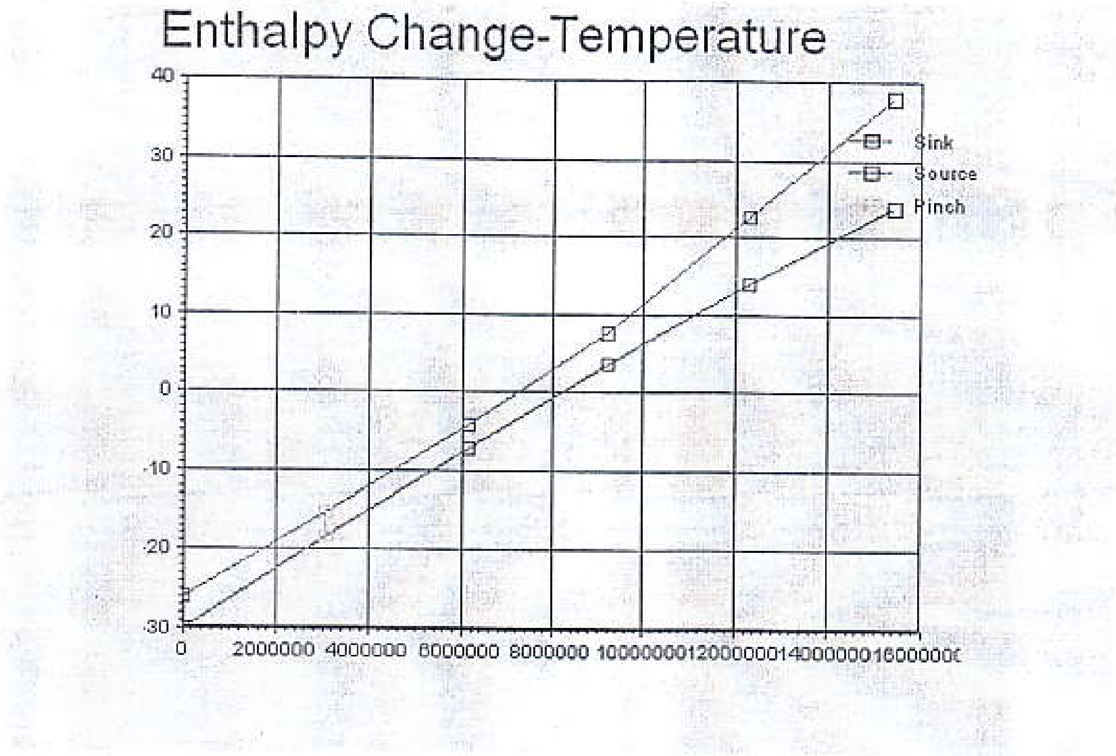

Fig 19 : Composite Curve for E-1B Heat Exchanger

III.3.2.3 The Grand Composite Curve for E-1B Heat Exchanger

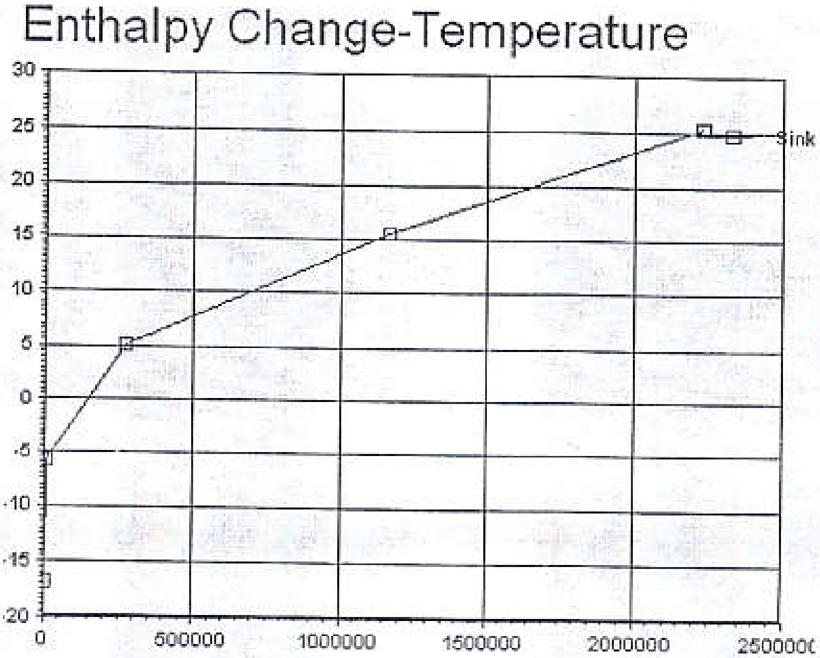

Fig 20 : The Grand Composite Curve for E-1B Heat Exchanger

III.3.3 E-2A Heat Exchanger

III.3.3.1 Data Extraction And Energy Targeting For (E-2A)

The hot and cold stream data extracted from the flowsheet in Figure 6 for (E-2A) are given in Table 10. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 10 : Data for E-2A heat exchangers

	Vap11-Vap12	S4-S9
Inlet Temp. (C)	120.0	-26.00
Outlet Temp. (C)	79.85	27.00
Molar Flow (kgmole/h)	3000	4378

Tab 11 : pinch results for E-2A heat exchangers

Hot Pinch Temperature (C)	120.0	Cold Utility (kJ/h)	0.0000
Cold Pinch Temperature (C)	27.00	Hot Utility (kJ/h)	0.0000
Minimum Approach (C)	93.00	Number of Points	5
Avg. Temperature at Pinch (C)	73.50	Minimum Approach Target (C)	---
Enthalpy Change at Pinch (kJ/h)	9.760e+006	Cold Utility Target (kJ/h)	---
		Hot Utility Target (kJ/h)	---

Tab 12 :Tabular Results for E-2A

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
-26.00	79.85	---	0.0000
-15.43	87.94	104.6 *	1.952e+006
-4.818	96.00	102.1 *	3.904e+006
5.812	104.0	99.51 *	5.856e+006
16.43	112.0	96.91 *	7.808e+006
27.00	120.0	94.30 *	9.760e+006

III.3.3.2 Composite Curve for E-2A Heat Exchanger

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. Figure 21 illustrates the construction of the composite curve for the E-2A Heat Exchanger.

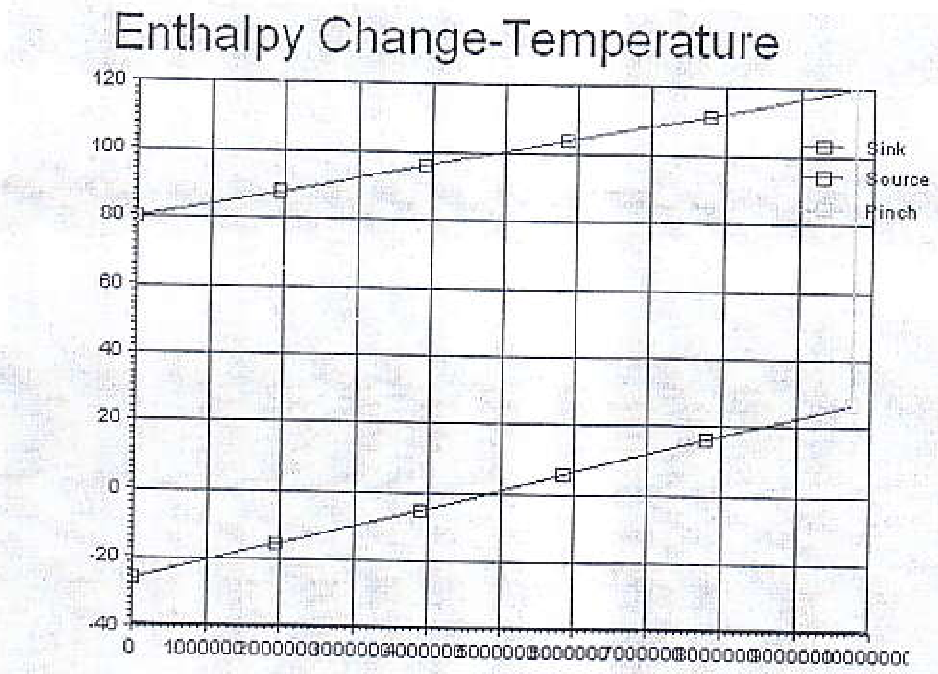

Fig 21 : Composite Curve for E-2A Heat Exchanger

III.3.3.3The Grand Composite Curve for E-2A Heat Exchanger

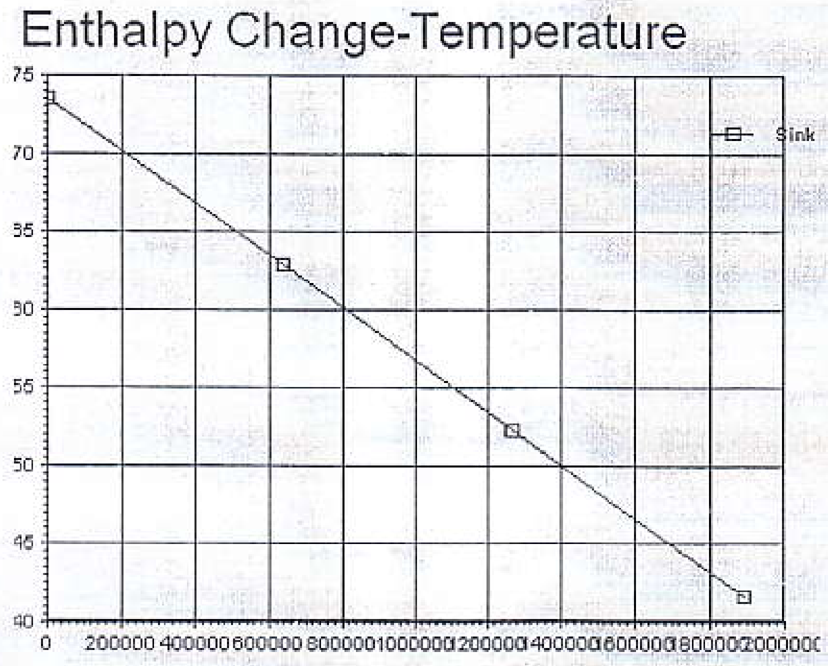

Fig 22 : The Grand Composite Curve for E-2A Heat Exchanger

III.3.4 E-2B Heat Exchanger

III.3.4.1 Data Extraction And Energy Targeting For (E-2B)

The hot and cold stream data extracted from the flowsheet in Figure 2 for (E-1A) are given in Table 1. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 13 : Data for E-2B heat exchangers

	Vap21- vap22	S5-S6
Inlet Temp. (C)	120.0	-26.00 *
Outlet Temp. (C)	106.3	27.00 *
Molar Flow (kgmole/h)	2500	158.2 *

Tab 14 : pinch results for E-2B heat exchangers

Hot Pinch Temperature (C)	120.0	Cold Utility (kJ/h)	0.0000
Cold Pinch Temperature (C)	27.00	Hot Utility (kJ/h)	0.0000
Minimum Approach (C)	93.00	Number of Points	5 *
Avg. Temperature at Pinch (C)	73.50	Minimum Approach Target (C)	---
Enthalpy Change at Pinch (kJ/h)	1.168e+006	Cold Utility Target (kJ/h)	---
		Hot Utility Target (kJ/h)	---

Tab 15 :Tabular Results for E-2B heat exchangers

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
-26.00	106.3	---	0.0000
-14.46	109.1	127.9	2.335e+005
-3.319	111.8	119.3	4.671e+005
7.347	114.5	111.1	7.006e+005
17.46	117.3	103.5	9.341e+005
27.00	120.0	96.37	1.168e+006

III.3.3.2 Composite Curve for E-2B Heat Exchanger

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. Figure 6 illustrates the construction of the composite curve for the E-1A Heat Exchanger.

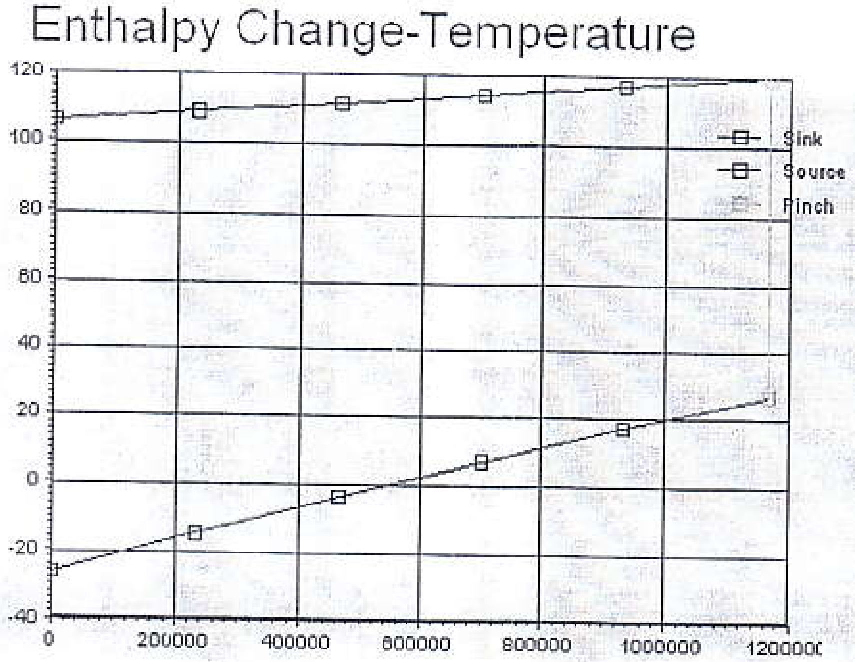

Fig 23 : Composite Curve for E-1B Heat Exchanger

III.3.3.3The Grand Composite Curve for E-2A Heat Exchanger

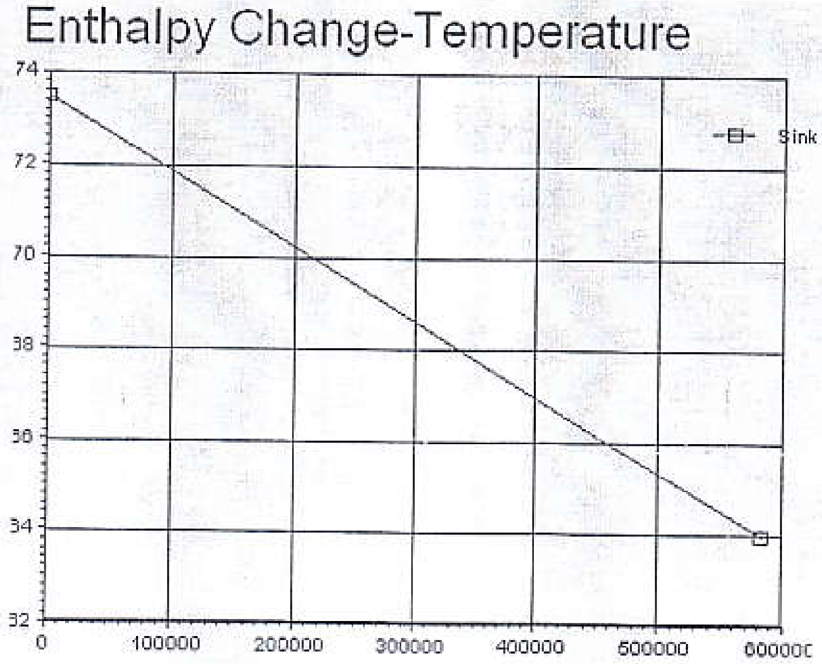

Fig 24 : The Grand Composite Curve for E-2A Heat Exchanger

III.4 Heat-Integrated Process

Process flow diagram of heat-integrated process we have created in HYSYS is shown in Fig. 25. Structure of the process was modified so that heat exchangers for heating of outlet streams of the first separator S-1 economize heat of gas heated in compressor. It was necessary to use the full value HEAT EXCHANGER weighed design model that calculates the overall exchanger UA (product of the overall heat transfer coefficient and the total area available for heat transfer). In this configuration, the hot stream, S2, has supply and target temperatures of 73 oC and - 26 oC, and the two cold streams, each have supply and target temperatures of - 26 oC to 27 oC, respectively. The hot stream is split and used to heat two cold streams, with a minimum approach temperature difference of 10 oC. The split ratio is chosen to obtain isothermal mixing in the mixer, M-1 with the help of ADJUST operation that varies the ratio of the outlet stream flow of TEE operation D-1 to meet the required zero temperature difference that is calculated in HYSYS SPREADSHEET operation.

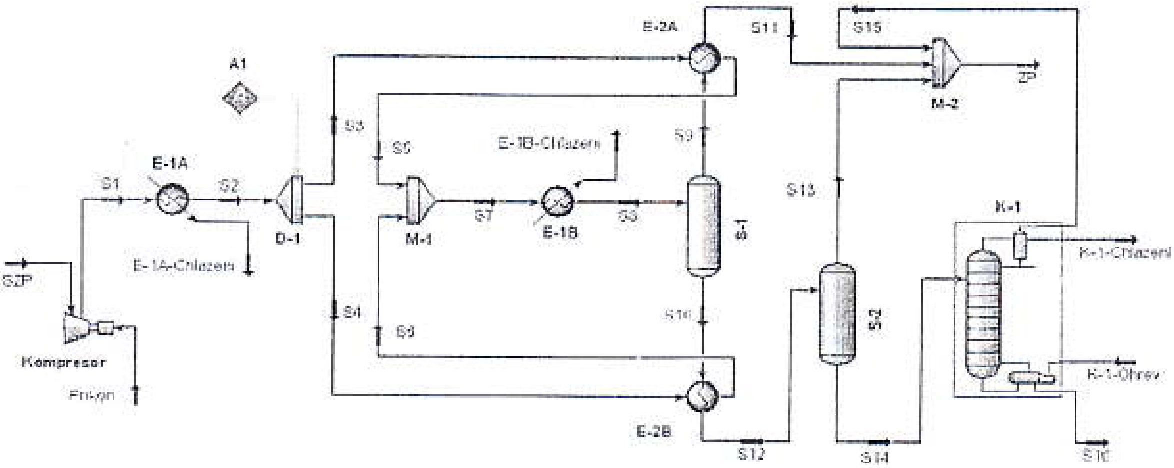

Fig 25 Process flow diagram for heat-integrated process

III.4.1 E-1A Heat Exchanger

III.4.1.1 Data Extraction And Energy Targeting For (E-1A)

The hot and cold stream data extracted from the flowsheet in Figure 25 for (E-1A) are given in Table 16. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 16 : Data for E-1A heat exchangers

	W1-W2	S1-S2
Inlet Temp. (C)	25.00 *	91.84 *
Outlet Temp. (C)	41.50 *	73.00 *
Molar Flow (kgmole/h)	3000 *	4536 *

Tab 17 : pinch results for E-1A heat exchangers

Hot Pinch Temperature (C)	73.00	Cold Utility (kJ/h)	0.0000
Cold Pinch Temperature (C)	25.00	Hot Utility (kJ/h)	0.0000
Minimum Approach (C)	48.00	Number of Points	5 *
Avg. Temperature at Pinch (C)	49.00	Minimum Approach Target (C)	---
Enthalpy Change at Pinch (kJ/h)	0.0000	Cold Utility Target (kJ/h)	---
		Hot Utility Target (kJ/h)	---

Tab 18 : Tabular Results for E-1A heat exchangers

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
25.00	73.00	---	0.0000
28.30	76.80	48.25 *	7.907e+005
31.60	80.58	48.74 *	1.581e+006
34.90	84.35	49.22 *	2.372e+006
38.20	88.10	49.68 *	3.163e+006
41.50	91.84	50.13 *	3.954e+006

III.4.1.2 Composite Curve for E-1A Heat Exchanger

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. Figure 26 illustrates the construction of the composite curve for the E-1A Heat Exchanger.

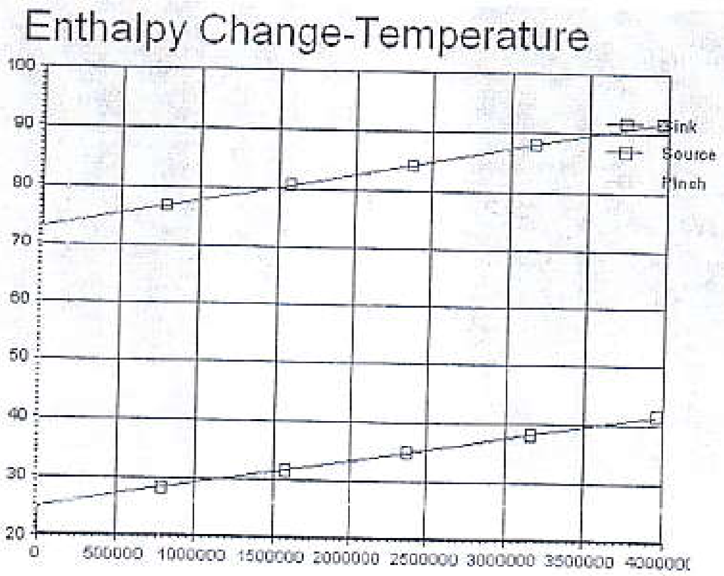

Fig 26: Composite Curve for E-1A Heat Exchanger

III.4.1.3The Grand Composite Curve for E-1A Heat Exchanger

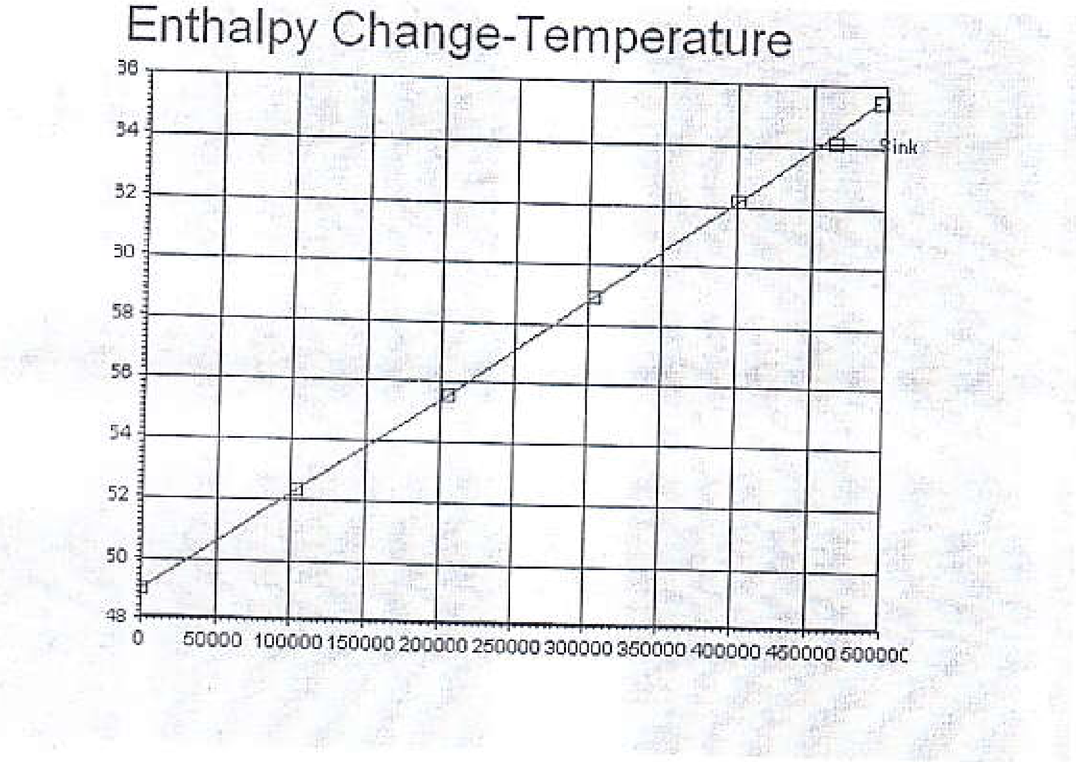

Fig 27: The Grand Composite Curve for E-1A Heat Exchanger

III.4.2 E-1B Heat Exchanger

III.4.2.1 Data Extraction And Energy Targeting For (E-1B)

The hot and cold stream data extracted from the flowsheet in Figure 25 for (E-1B) are given in Table 19. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 19 : Data for E-1B heat exchangers

	P-P2	S2_M-S3
Inlet Temp. (C)	-30.00	19.22
Outlet Temp. (C)	11.86	-26.00
Molar Flow (kgmole/h)	2500	4536

Tab 20 : pinch results for E-1B heat exchangers

Hot Pinch Temperature (C)	-9.708	Cold Utility (kJ/h)	0.0000
Cold Pinch Temperature (C)	-12.49	Hot Utility (kJ/h)	0.0000
Minimum Approach (C)	2.786	Number of Points	5
Avg. Temperature at Pinch (C)	-11.10	Minimum Approach Target (C)	---
Enthalpy Change at Pinch (kJ/h)	4.658e+006	Cold Utility Target (kJ/h)	---
		Hot Utility Target (kJ/h)	---

Tab 21 : Tabular Results for E-1B heat exchangers

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
-30.00	-26.00	---	0.0000
-21.12	-18.05	3.512	2.329e+006
-12.49	-9.708	2.924	4.658e+006
-4.122	-0.9805	2.960	6.987e+006
3.995	7.978	3.545	9.315e+006
11.86	19.22	5.501	1.164e+007

III.4.2.2 Composite Curve for E-1B Heat Exchanger

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. Figure 25 illustrates the construction of the composite curve for the E-1B Heat Exchanger

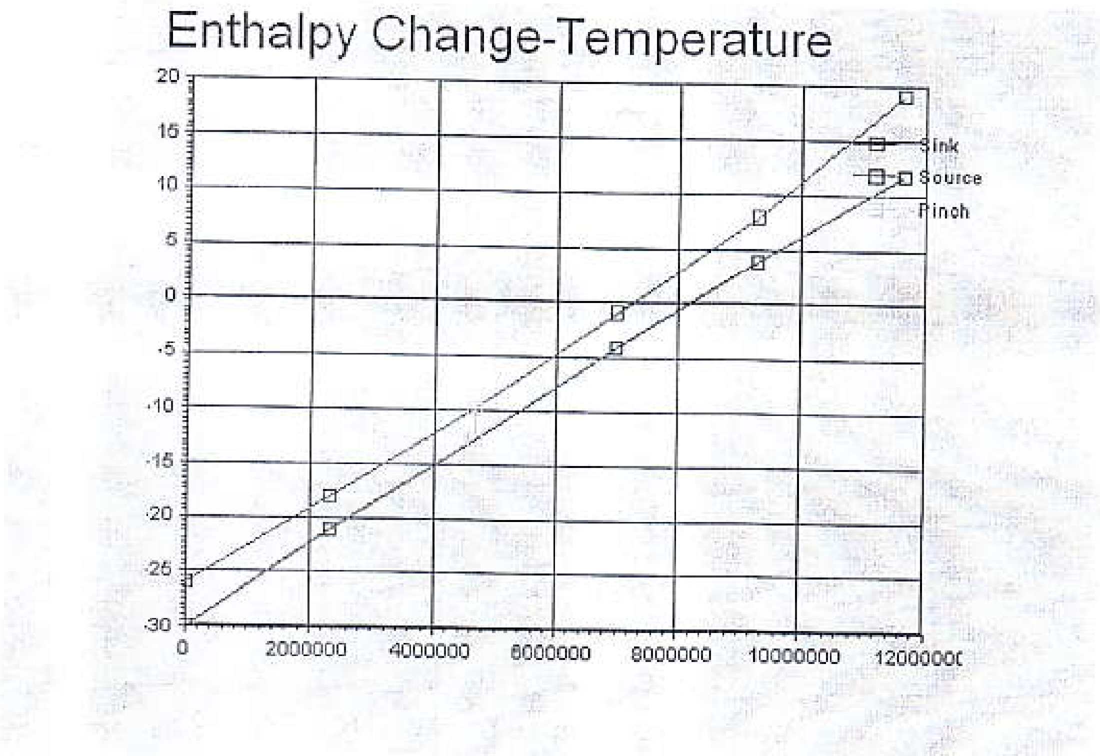

Fig 28 Composite Curve for E-1B Heat Exchanger

III.4.2.3The Grand Composite Curve for E-1B Heat Exchanger

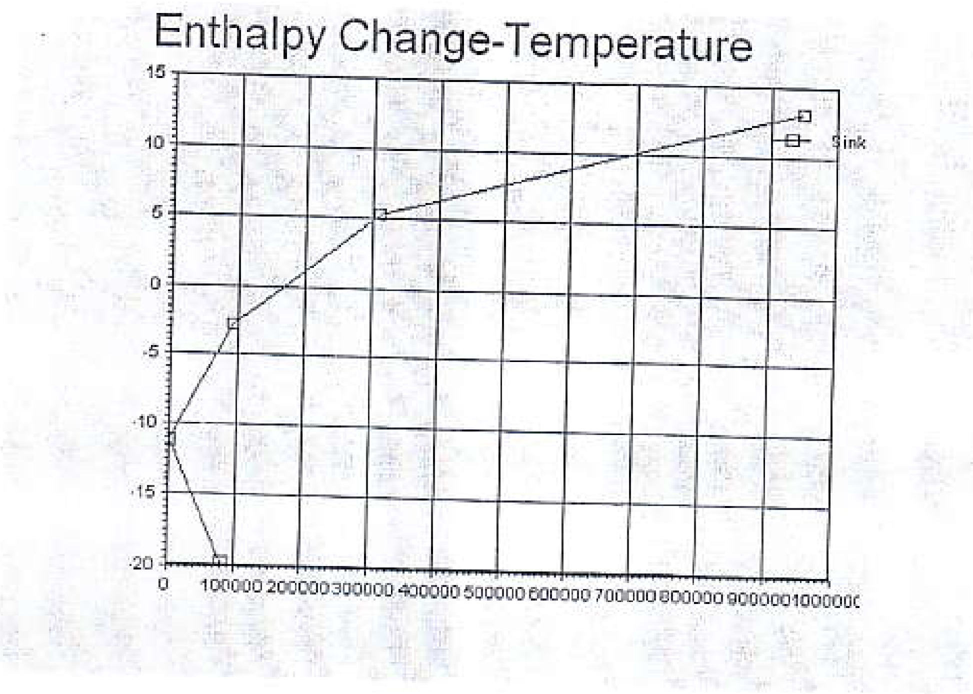

Fig 29 :The Grand Composite Curve for E-1B Heat Exchanger

III.4.3 E-2A Heat Exchanger

III.4.3.1 Data Extraction And Energy Targeting For (E-2A)

The hot and cold stream data extracted from the flowsheet in Figure 25 for (E-2A) are given in Table 22. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 22 : Data for E-2A heat exchangers

	S2_1-S2_1_1	S4-S9
Inlet Temp. (C)	73.00 *	-26.00 *
Outlet Temp. (C)	-15.51 *	27.00 *
Molar Flow (kgmole/h)	2268 *	4378 *

Tab 23 : pinch results for E-2A heat exchangers

Hot Pinch Temperature (C)	-15.51	Cold Utility (kJ/h)	0.0000
Cold Pinch Temperature (C)	-26.00	Hot Utility (kJ/h)	0.0000
Minimum Approach (C)	10.49	Number of Points	5 *
Avg. Temperature at Pinch (C)	-20.76	Minimum Approach Target (C)	---
Enthalpy Change at Pinch (kJ/h)	0.0000	Cold Utility Target (kJ/h)	---
		Hot Utility Target (kJ/h)	---

Tab 24 :Tabular Results for E-2A heat exchangers

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
-26.00	-15.51	---	0.0000
-15.43	-1.091	12.31 *	1.952e+006
-4.818	15.29	17.06 *	3.904e+006
5.812	34.78	24.27 *	5.856e+006
16.43	54.05	33.11 *	7.808e+006
27.00	73.00	41.67 *	9.760e+006

III.4.3.2 Composite Curve for E-2A Heat Exchanger

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. Figure 3 illustrates the construction of the composite curve for the E-2A Heat Exchanger.

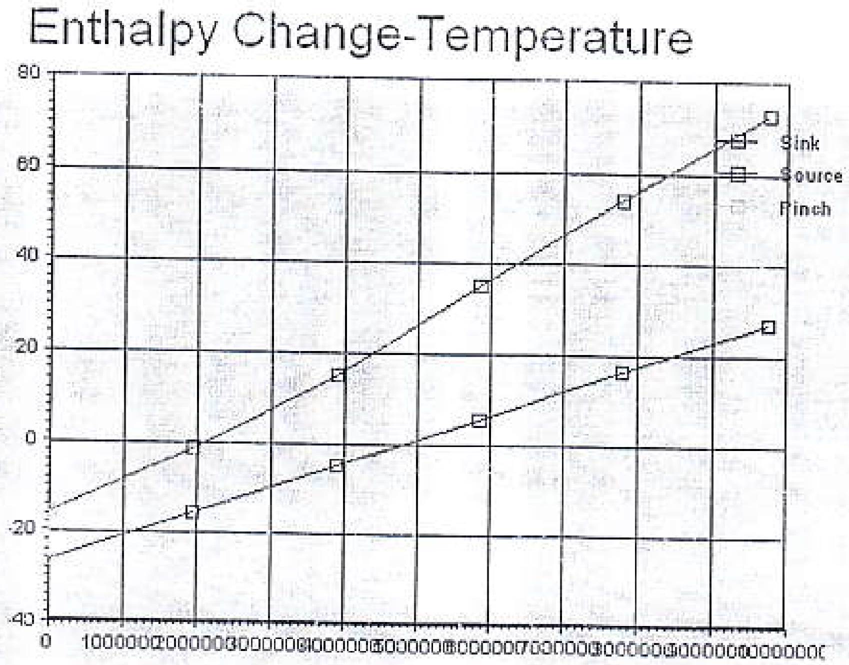

Fig 30 : Composite Curve for E-2A Heat Exchanger

III.4.3.3The Grand Composite Curve for E-2A Heat Exchanger

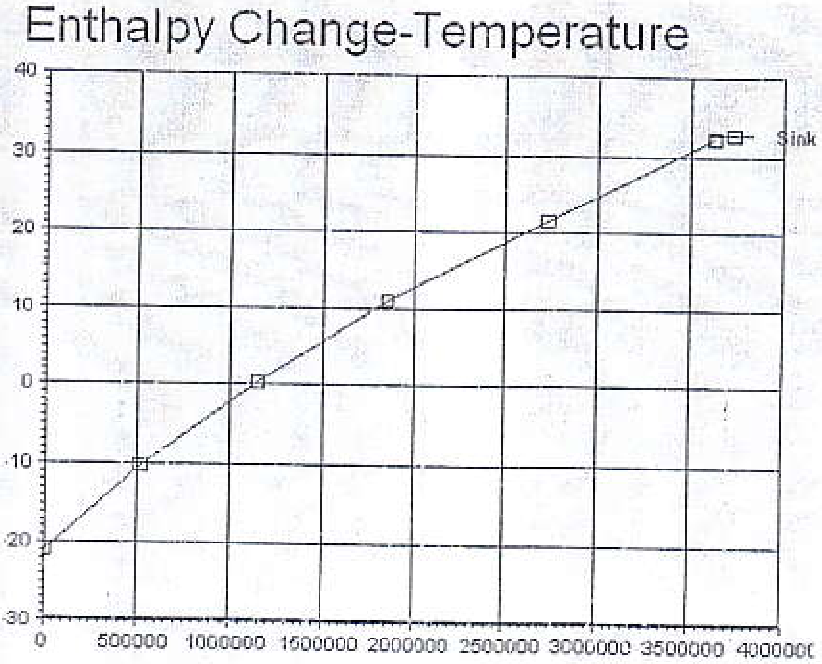

Fig 31 :The Grand Composite Curve for E-2A Heat Exchanger

III.4.4 E-2B Heat Exchanger

III.4.4.1 Data Extraction And Energy Targeting For (E-2B)

The hot and cold stream data extracted from the flowsheet in Figure 25 for (E-2A) are given in Table 1. Which contain Supply Temperature (Ts), Target Temperature (Tt), Molar Flow

Tab 25 : Data for E-2B heat exchangers

	S2_2-S2_2_2	S5-S6
Inlet Temp. (C)	73.00 *	-26.00 *
Outlet Temp. (C)	61.70 *	27.00 *
Molar Flow (kgmole/h)	2268 *	158.2 *

Tab 26 : pinch results for E-2B heat exchangers

Hot Pinch Temperature (C)	73.00	Cold Utility (kJ/h)	0.0000
Cold Pinch Temperature (C)	27.00	Hot Utility (kJ/h)	0.0000
Minimum Approach (C)	46.00	Number of Points	5 *
Avg. Temperature at Pinch (C)	50.00	Minimum Approach Target (C)	---
Enthalpy Change at Pinch (kJ/h)	1.168e+006	Cold Utility Target (kJ/h)	---
		Hot Utility Target (kJ/h)	---

Tab 27 :Tabular Results for E-2B heat exchangers

Temperature (Sink) (C)	Temperature (Source) (C)	LMTD (C)	Enthalpy Change (kJ/h)
-26.00	61.70	---	0.0000
-14.46	63.97	82.98 *	2.335e+005
-3.319	66.23	73.91 *	4.671e+005
7.347	68.49	65.26 *	7.006e+005
17.46	70.75	57.13 *	9.341e+005
27.00	73.00	49.56 *	1.168e+006

III.4.4.2 Composite Curve for E-2B Heat Exchanger

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. Figure 32 illustrates the construction of the composite curve for the E-2B Heat Exchanger.

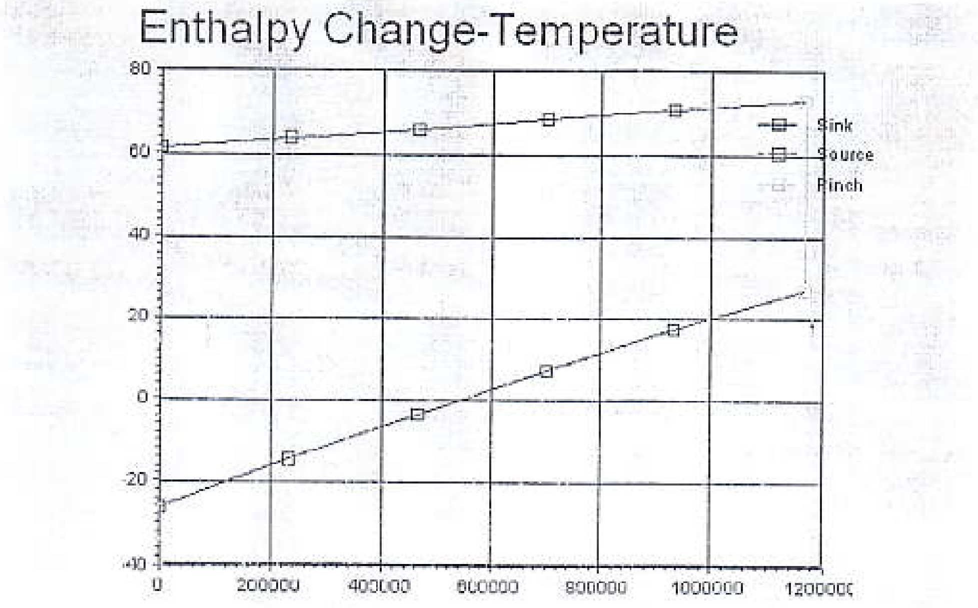

Fig 32 : Composite Curve for E-2B Heat Exchanger

III.4.4.3The Grand Composite Curve for E-2B Heat Exchanger

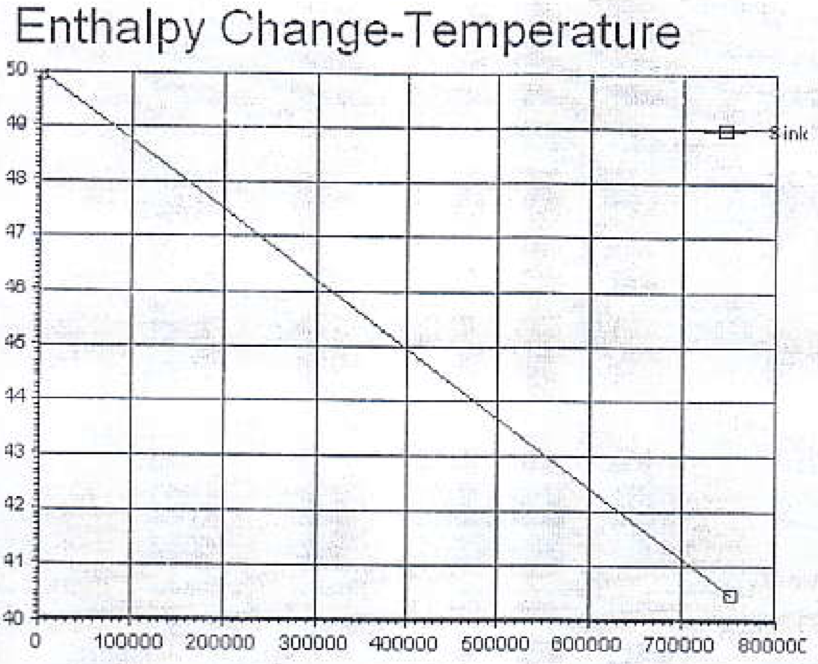

Fig 33 :The Grand Composite Curve for E-2B Heat Exchanger

Tab 28 compares the energy requirements of the original design with the heat integrated design. The latter has no external heating requirements (apart from the column K-1), and its refrigeration load is only 76 % of that of the original design. Energy saving makes up approx..3.73e+005 refrigeration.

Tab 28 comparison of the energy requirements in kj/h of the original design with the heat integrated design

	Initial Design			Heat-Integrated Design		
	Refrigerant	Cooling Water	Steam	Refrigerant	Cooling Water	Steam
E-1A	-	1.117e+007	-	-	3.98e+006	-
E-1B	1.54e+007	-	-	1.167e+007	-	-
E-2A	-	-	9.760e+006	-	-	-
E-2B	-	-	1.168e+006	-	-	-
Total	1.54e+007	1.117e+007	10.92e+006	1.167e+007	3.98e+006	0

Tab 28 compares the energy requirements of the original design with the heat integrated design. The latter has no external heating requirements (apart from the column K-1), and its refrigeration load is 76 % of that of the original design. Energy saving makes up approx.3.73e+005 refrigeration

Tab 29 comparison of the refrigeration load in kj/h of the original design with the heat integrated design

	Initial Design	Heat-Integrated Design
	Refrigerant	Refrigerant
E-1A	-	-
E-1B	1.54e+007	1.167e+007
E-2A	-	-
E-2B	-	-
Total	1.54e+007	1.167e+007

Tab 30 compares the energy requirements of the original design with the heat integrated design. The latter has no external heating requirements (apart from the column K-1), and its refrigeration load is only 35.63 % of that of the original design. Energy saving makes up approx. 7.19e+006 Cooling Water.

Tab 30 comparison of the Cooling Water in kj/h of the original design with the heat integrated design

	Initial Design	Heat-Integrated Design
	Cooling Water	Cooling Water
E-1A	1.117e+007	3.98e+006
E-1B	-	-
E-2A	-	-
E-2B	-	-
Total	1.117e+007	3.98e+006

Tab 31 compares the energy requirements of the original design with the heat integrated design. The latter has no external heating requirements (apart from the column K-1), and its refrigeration load is only 00 % of that of the original design. In the original design we need 9.760e+006 kj/h for E-2A Heat Exchanger and 1.168e+006 kj/h for E-2B. So 10.92e+006 for the whole design Energy saving makes up approx. 10.92e+006 Steam.

Tab 31 comparison of Steam in kj/h of the original design with the heat integrated design

	Initial Design	Heat-Integrated Design
	Steam	Steam
E-1A	-	-
E-1B	-	-
E-2A	9.760e+006	-
E-2B	1.168e+006	-
Total	10.92e+006	0

CONCLUSION

CONCLUSIONS

Heat Integration (or Pinch Technology) has been used for 20 years in industry throughout the world to increase energy efficiency of any processing plants that have heating or cooling requirements, and also have needs for power to provide electricity or directly drive machinery. Energy savings of over 30% have been recorded, and the methodologies developed have been incorporated into the design offices of all major producing companies. The same methodologies and design rules can also be applied in buildings or their complexes. Examples of two complexes have been given. It is clear that as energy efficiency in buildings and the reduction of emissions becomes a standard issue in existing and new complexes, further examples of heat integration application will be carried out.

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APPENDIX

Notation

List of Symbols and Units

A	Heat transfer area (m^2)
C_P	Specific heat capacity (kJ/kg K)
COP_p	Coefficient of performance for a heat pump (-)
COP_r	Coefficient of performance for a refrigerator (-)
CP	Heat capacity flowrate (kW/K)
H	Flow enthalpy (kW)
ΔH	Change in flow enthalpy (kW)
ΔH_{com}	Heat of combustion (kJ/kg)
h	Specific enthalpy (kJ/kg)
h	Film heat transfer coefficient of an individual stream ($kW/m^2 K$)
k, K	Number of temperature intervals or segments (-)
L	Number of loops in a network (-)
m, $\dot{m}$	Mass flowrate (kg/s)
N	Number of process streams plus utilities, or process stream branches (-)
Q	Heat flow (kW)
Q_{Hmin}	Minimum feasible hot utility (kW)
Q_{Cmin}	Minimum feasible cold utility (kW)
q	Heat flow of an individual stream (kW)
S	Entropy (kJ/kg K)
s	Number of separate components (subsets) in a network (-)
S	Shifted temperature (°C or K)
S_S	Shifted supply temperature of process stream (°C or K)
S_T	Shifted target temperature of process stream (°C or K)
T	Temperature (°C or K)
T_S	Supply temperature of process stream (°C or K)
T_T	Target temperature of process stream (°C or K)
ΔT	Temperature difference (K)
ΔT_{cont}	ΔT_{min} contribution of an individual stream (K)
ΔT_{min}	Minimum allowed temperature difference (K)
$\Delta T_{threshold}$	Boundary value of ΔT_{min} between a threshold and pinched problem (K)
ΔT_{LM}	Log mean temperature difference (K)
t	Time (s)
U	Overall heat transfer coefficient ($kW/m^2 K$)
u	Number of heat exchange units (i.e. heaters, coolers, exchangers) (-)

u_{min}	Minimum number of units (-)
W	Shaft work for heat engine or heat pump (kW)
w	Work per unit mass flow (kJ/kg)
X	Heat load shifted around a loop or along a path (kW)
α	Heat flow across the pinch (kW)
η	Heat engine efficiency (-)
η_c	Reversible (Carnot) heat engine efficiency (-)
η_{mech}	Mechanical efficiency (-)

Subscripts

C, COLD	Relating to cold stream
H, HOT	Relating to hot stream
MER	At maximum energy recovery or minimum energy requirement
1, 2, ... A, B, ... i, n,	counters

Glossary of terms

Appropriate placement Positioning of utilities, heat engines, heat pumps or an extracted process (e.g. separation system) above or below the pinch and grand composite curve for best overall energy performance.

Background process The stream data for the remainder of the process after the extracted streams have been removed.

Balanced composite curves Composite curves including the hot and cold utility streams.

Balanced grand composite curves Grand composite curves including the hot and cold utility streams.

Balanced grid Network grid diagram including the hot and cold utility streams.

Cascade Set of heat flows through a heat recovery problem, in strict descending temperature order (as calculated in Problem Table analysis – see **Problem Table**).

Cascade analysis The method of batch process analysis based on breaking the process into time intervals and developing time-dependent heat cascades.

Cold stream Process stream requiring heating.

Composite curve Combined temperature-enthalpy plot of all hot or cold streams in a problem.

***CP*-Table** Tabulated values of stream heat capacity flowrates, immediately above or below the pinch.

Cycle time The total duration of a batch.

Cyclic matching Repeated matching of pairs of process streams.

Data extraction Definition of data for energy integration studies, from a given flowsheet.

Debottlenecking Increasing the production capacity of a plant by identifying and removing rate-limiting steps, such as slow processing stages or heavily occupied equipment items.

Direct heat exchange Heat exchanged between two streams in the same time interval of a batch process.

Direct contact heat transfer Heat exchanged by two streams which mix directly (e.g. steam injection).

Energy relaxation Process of reducing energy recovery in a heat exchanger network for the purpose of design simplification.

Extracted streams or **extracted process** A set of streams removed from the process stream data to test them for appropriate placement.

Feasible cascade Heat cascade in which net heat flow never becomes negative and is zero at the pinch.

Flowing stream A stream which receives or releases heat as it flows through a heat exchanger.

Gantt chart A representation of which streams exist in given time intervals of a batch process, also called a **time event chart**.

Grand composite curve (GCC) Plot of heat flow vs. temperature from a heat cascade (see **Cascade** and **Problem Table**).

Grid System of horizontal and vertical lines with nodes, for representing heat exchanger networks.

Heat cascade A table of the net heat flow from high to low temperatures divided up into temperature intervals.

Heat engine System converting high-grade heat to lower-grade heat and producing power.

Heat exchanger network (HEN) System of utility heaters and coolers and process interchangers.

Heat pump System upgrading heat from a lower to a higher temperature using power or high-grade heat.

Heat storage Heat recovery by taking heat out of one time interval in a batch or time-dependent process and supplying it to a later time interval.

Hot stream Process stream requiring cooling.

Individual heat cascades Heat cascades for a time interval considered in isolation from all other time intervals.

Infeasible cascade Heat cascade with zero hot utility and some negative values of net heat flow.

***In-situ* heating/cooling** A stream which is heated or cooled in a vessel over a period of time.

Intermediate condenser An additional condenser in a column working above the main condenser temperature.

Intermediate reboiler An additional evaporation stage in a column working above the main reboiler temperature.

Interval temperature Obsolete name for **shifted temperature**.

Loop System of connections in a heat exchanger network which form a closed pathway.

Maximum energy recovery (MER) Best possible energy recovery in a heat exchanger network for a given value of ΔT_{min}; also known as minimum energy requirement.

Maximum heat exchange (MHX) The maximum amount of heat which can be recovered by direct heat exchange in a batch process.

Maximum heat recovery (MHR) The maximum amount of heat which can be recovered for a batch process at given process conditions by direct heat exchange and heat storage added together.

MHR or MHX network A heat exchanger network achieving the MHR or MHX target.

Multiple utilities Utility or utility system whose temperature or temperature range falls within the temperature range of the process stream data.

Near-pinch Point in a heat cascade where net heat flow is very small but increases at temperatures on either side.

Network optimisation Evolution of a heat exchanger network to give most convenient heat exchanger sizes, allowing for existing area.

Network pinch Point in heat exchanger network where temperature driving force is lowest.

Overall heat cascade A time-dependent heat cascade for a batch process which includes the effects of heat storage.

Path System of connections in a heat exchanger network forming a continuous pathway between the utility heater and a utility cooler.

Pinch Point of zero heat flow in a cascade (alternatively, point of closest approach of composite curves in a "heating and cooling" problem).

Pinch design method Method of heat exchanger network design which exploits the constraints inherent at the pinch.

Pinch match Process interchanger which brings a stream to its pinch temperature (i.e. hot streams above the pinch, cold streams below).

Pinch region Range of temperatures over which cascade net heat flow is zero (or very low).

Pocket Region in the grand composite curve where neither external heating nor cooling is required.

Problem Table System of analysing process stream data for a heat recovery problem which exploits **temperature interval** sectioning of the problem, and predicts minimum utilities consumptions, pinch location, and cascade heat flows.

Process change Altering the stream data by changing the temperature and/or heat load of one or more streams.

Process sink profile Section of the grand composite curve above pinch temperature.

Process source profile Section of the grand composite curve below pinch temperature.

Profile Temperature-enthalpy plot of a stream or a composite stream.

Pumparound Liquid drawn from a distillation column which releases sensible heat and is returned to the column.

Rescheduling Altering the time period during which a stream exists.

Retrofit or **Revamp** Any change to an existing chemical process, but in this context, mostly changes for improvement in energy efficiency.

Shifted composite curves Plots of combined enthalpy of all hot and all cold streams against shifted temperature, touching at the pinch.

Shifted temperature Stream temperatures altered to include the effect of the required ΔT_{min}, usually by reducing hot stream temperatures by $\Delta T_{min}/2$ and increasing cold stream temperatures by $\Delta T_{min}/2$.

Site sink profile Plot of heat required by all processes on a site at given temperatures.

Site source profile Plot of heat released by all processes on a site at given temperatures.

Split grand composite curve Plot of the grand composite curve for the background process and the extracted streams on the same graph.

Stream splitting Division of a process stream into two or more parallel branches.

Subset Set of process streams or process streams, plus utilities, within a heat recovery problem which are in overall enthalpy balance.

Supply temperature Temperature at which a process stream enters a heat recovery problem.

Target A design performance limit, determined prior to design.

Target temperature Temperature at which a process stream leaves a heat recovery problem.

Temperature interval Section of a heat recovery problem between two temperatures which contains a fixed stream population.

Threshold problem Heat recovery problem that shows the characteristic of requiring either only hot or only cold utility, over a range of ΔT_{min} values from zero up to a threshold (or throughout).

Tick-off rule Heuristic of maximising the heat load on an interchanger by completely satisfying the heat load on one stream.

Time average model (TAM) Averaging heat flows by dividing the total heat load over the batch period by the total batch cycle time.

Time-dependent heat cascade A set of heat cascades for different time intervals, forming a matrix.

Time event chart A Gantt chart, plotting the time periods when different streams exist.

Time interval A period of time during which stream conditions do not change appreciably and for which a target can be obtained.

Time slice model (TSM) Division of a batch problem into time intervals and finding the targets for the individual cascades, with zero heat storage.

Top level analysis Study of a site's heat and power needs using existing utility consumption of plants, rather than targets.

***UA* analysis** Procedure of calculating *UA* values ($=Q/\Delta T_{LM}$) for matches in a heat exchanger network, for the purposes of preliminary costing and optimisation.

Utility System of process heating or process cooling.

Unit Process interchanger, heater or cooler.

ΔT_{min} Minimum temperature difference allowed in the process between hot and cold streams.

ΔT_{min} contribution (ΔT_{cont}) Temperature difference value assigned to individual process streams. Match-dependent ΔT_{min} values are given by the sum of the contributions in a match.