CONSERVATION OF ENERGY AND ECONOMIC ANALYSIS FOR PRODUCTION OF 50000 MT/ANNUM OF TITANIUM DIOXIDE PLANT BY USING PINCH ANALYSIS

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JUDUL **CONSERVATION OF ENERGY AND ECONOMIC ANALYSIS FOR PRODUCTION OF 50000 MT/ANNUM TITANIUM DIOXIDE PLANT**

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CONSERVATION OF ENERGY AND ECONOMIC ANALYSIS FOR PRODUCTION OF 50000 MT/ ANNUM TITANIUM DIOXIDE BY USING PINCH ANALYSIS

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A thesis submitted in fulfillment of
the requirements for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical Engineering & Natural Resources
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APRIL 2010

I declare that this thesis entitled "*Conservation of Energy and Economic Analysis for Production of 50000MT/Annum Titanium Dioxide by Using Pinch Analysis*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Special dedication to my beloved
father and mother

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ABSTRACT

Energy conservation techniques based on the Pinch Analysis is a way to minimize the energy consumption in production plant at the same time to maximize the process design. Pinch Analysis also enables the maximum interface between the utilities and process systems. Since no studies have been done on minimizing energy consumption in Titanium Dioxide Production Plant, there is a potential for energy conservation by using Pinch Analysis. The objectives of this research are to find the minimum energy requirement and to observe the effect of energy conservation to production cost and plant economics. In order to achieve the objectives, there are three main analysis are practiced which are Process Flow Diagram Analysis, Pinch Analysis and Economic Analysis. As the hot and cold stream was identified from the Process Flow Diagram, the thermal data extracted and recorded in a table. The value of ΔT min was selected between 5 to 25 °C. Next the Composite Curve and Grand Composite Curve were constructed based to the data extracted. The analysis then continued with the design of Heat Exchanger Network (HEN) where the HEN was designed at 5 different ΔT min value which are 5, 10, 15 20 and 25 °C. From HEN grid diagram analysis the minimum energy requirement can be determined and the analysis proceed with plant economic analysis that only focused to the heat exchanger and another cost that might affect after the Pinch was constructed. The results obtained from the earlier analysis are compared between the five different ΔT min to find the best. Overall analysis results in output where the best ΔT min equal to 15 °C with 50075.748 kW of energy required and a payback period of within one year of plant operation. The total cost is decreased by 35.36%.

ABSTRAK

Teknik kelestarian tenaga berasakan Analisa Cubitan merupakan satu cara untuk mengurangkan penggunaan tanaga dalam pelan penghasilan pada masa yang sama untuk memaksimakan reka bentuk proses. Analisa cubitan juga membolehkan peantaramukaan antara sistem utiliti dan proses. Memandangkan tiada lagi kajian dijalankan ke atas pengurangan tenaga dalam pelan menghasilkan *Titanium Dioxide,* kelestarian tenaga berpotensi dengan menggunakan Analisa Cubitan. Tujuan kajian ini adalah untuk mencari minimum tenaga yang diperlukan dan memerhatikan kesan kelesarian tenaga pelan penghasilan dan pelan ekonomi. Demi mencapai tujuan kajian tiga langkah utama telah di ambil iaitu Analisa Gambarajah Aliran Proses, Analisa Cubitan dan Analisa Ekonomi. Kelangsungan aliran panas an sejuk telah dapat ditemtukan daripada Gambarajah Aliran Proses, data termal diekstrak dan direkodkan dalam jadual. Nilai ΔT min dipilih di antara 5 hingga 25°C. Seterusnya lengkungan komposit dan lengkungan koposit utaa dibina berdasarkan data yang telah diekstrak. Penganalisaan kemudian diteruskan dengan merekabentuk Rangkaian Penukar Haba (HEN) di mana gambarajah kekisi HEN di rekabentukk pada lima ΔT min yang berlainan iaitu 5, 10, 15, 20 dan 25 °C. Daripada analisa gambarajah kekisi HEN minima tenaga yang diperlukan dapat dikenalpasti dan analisa ekonomi dan diteruskan dengan analisa ekonomi yang hanya fokus terhadap penukar haba dan kos lain yang terlibat setelah analisa cubitan dijalankan. Hasil analisis kemidian dibandingkan antara lima ΔT min yang demi mencari yang terbaik. Keseluruhan analisis meghasilkan ooutput dimana nila ΔT min terbaik adalah pada 15 °C dengan sebanyak 50075.748 kW tenaga diperlukan dan tempoh bayar balik selama satu tahun operasi. Jumlah kos berkurangan sebanyak 35.36%.

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LIST OF ABBREVIATIONS

CC	Composite Curve
COM	Cost of Manufacturing
DMC	Direct Manufacturing Cost
FCI	Fixed Capital Cost Investment
GCC	Grand Composite Curve
HEN	Heat Exchanger Network
PTA	Problem Table Algorithm

LIST OF SYMBOLS

ΔH	Different Enthalpy
ΔT or ΔT min	Different Temperature Minimum
ΔT_{lm}	Log Mean Different Temperature
ΔT_m	Different Mean Temperature
A_o	Provisional Area
A_t	Area of Tube
C_{GR}	Grass Root Cost
C_{OL}	Cost of Operating Labor
CP	Heat Capacity
CP_{cold}	Heat Capacity for Cold Stream
CP_{hot}	Heat Capacity for Hot Stream
C_{TM}	Total Module Cost
C_{UT}	Cost of Utilities
C_{WT}	Cost of Wastewater Treatment
D_i	Inlet Tube Diameter
D_o	Outlet Tube Diameter
D_s	Shell Diameter
DT or DT min	Different Temperature Minimum
F_T	Temperature Correction Factor for Heat Exchanger
L_t	Length of Tube
N_{cold}	Number of Cold Stream
N_{hot}	Number of Hot Stream
N_{np}	Number or non-particulate Processing Steps
N_{OL}	Number of Operators per Shift
Nt	Number of Tube
Q	Heat Flow or Heat Duty
T_{cin}	Cold Stream Inlet Temperature
T_{cout}	Cold Stream Outlet Temperature
T_{hin}	Hot Stream Inlet Temperature

T_{hout}	Hot Stream Outlet Temperature
T_s	Supply Temperature
T_t	Target Temperature
U	Heat Transfer Coefficient
W	Work

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CHAPTER 1

INTRODUCTION

1.1. Introduction

Nowadays, establishing minimum energy consumption for a maximum energy recovery becomes the most important roles in many process industries. Energy cost contributes significantly to the production cost. Hence, saving and optimizing the energy usage is a promise to meet the goal of an optimum energy cost and to be more profitability. As an addition, the energy reduction can give good environmental effect. This study focuses on energy conservation in the production of 50 000 MT/Annum titanium dioxide plant.

The consumption of utilities during the production can be very significantly large. Much work has been published on the design and optimization of utility systems. While some researchers advocate the use of heuristics and thermodynamics insight, others propose mathematical optimization (P. S. Varbanov *et al*, 2004)

Utilities have to develop and recommend integrated, reliable and cost effective approaches for meeting the future demand and energy needs. Changes in the national and local energy economy and business environment presents significant uncertainty and challenge. In order to manage effectively in this uncertain environment, utilities should place great emphasis on planning.

In order to achieve the energy conservation for a chemical plant, performing optimizing study on the heat exchanger is crucial, pinch analysis; a thermodynamics principles based that offers systematic approach to a optimum energy integration in a process will be performed, which will be examine at several different minimum temperature (ΔT min) in order to identify the best ΔT min that satisfy the energy recovery of the plant.

1.2. Research Background

This research is focused the study on conservation of energy and utilities usage in titanium dioxide plant. Titanium dioxide (TiO_2) exists in a number of crystalline forms which are anatase and rutile. The white pigment is used to give color to almost all materials. TiO_2 also provides opacity and brightness to plastics and rubber.

The production of 50 000 MTA Titanium Dioxide Plant has been planned to be located at Gebeng Industrial Estate. This plant operates based on chlorite process (US Pattern 6, 229, 037, 2001). Basically, the raw materials are synthetic rutile, chlorine gas, petroleum coke, and oxygen gas. There are 2 main reactions which are chlorination process and oxidation process. During chlorination process, synthetic rutile will reacts with chlorine gas to produce titanium tetrachloride vapor with chlorine gas as an excess reactant and for oxidation process, titanium tetrachloride will react with oxygen gas to produce titanium dioxide powder.

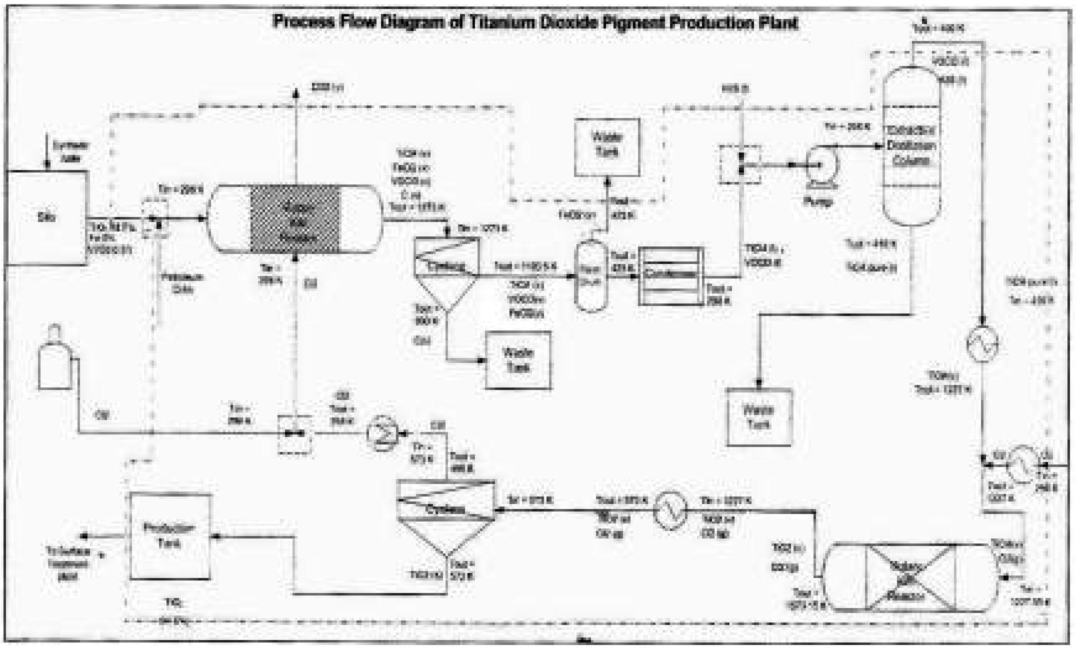


Figure 1.1: Process Flow Diagram (PFD) of Titanium Dioxide Production Plant

For the purpose of producing 50 000 MT per annum, the plant has a silo, three storage tanks, two rotary kiln reactors, two cyclones, a flash drum, a condenser, a pump, an extractive distillation column, 4 heat exchangers and a production tank for storage. There are three hot streams and two cold streams, which need utilization of energy.

The purpose of the silo is for raw material of synthetic rutile storage before undergoing the production process of Titanium Dioxide. Synthetic rutile in solid form stored in the silo at the beginning of the process at atmospheric pressure. The silo stores the synthetic rutile for daily start up process that is sufficient enough for 24 hours.

One of the storage tanks is for the raw material of petroleum coke storage before mixed with synthetic rutile at the mixing point. The second storage tank is for storing oxygen gas before entering reactor for combustion process. The oxygen gas is stored in gaseous form at room temperature and standard environmental pressure. The other storage tank is to store chlorine gas that needed to make sure oxygen supply sufficient for every reaction in rotary kiln 1 for combustion process. All of the storage tanks are also stores product for daily needs of process.

Cyclone is used for gas – solid separation process for gas cleaning; to remove dispersed finely divided solid (dust) and liquid mist from gas stream. Process gas must be cleaned up to prevent contamination of catalyst or product, and to avoid damage to equipment such as compressor. Flash column is used for separation of two phase mixture such as vapor – liquid mixture. The separation of the different phases of a heterogeneous mixture should be carried out before homogeneous separation.

Both heat exchanger and condenser are used to transfer the heat between two fluids. The transfer of heat is accomplish from the hot fluid to the wall or tube surface by convection, through the tube wall or plate by conduction and then by convection to the cold fluid.

The basic concept of a heat exchanger is based on the premise that the loss of heat on the high temperature side is exactly the same as the heat gained in the low temperature side after the heat and mass flows through the heat exchanger. (www.heatexchangersgamma.com)

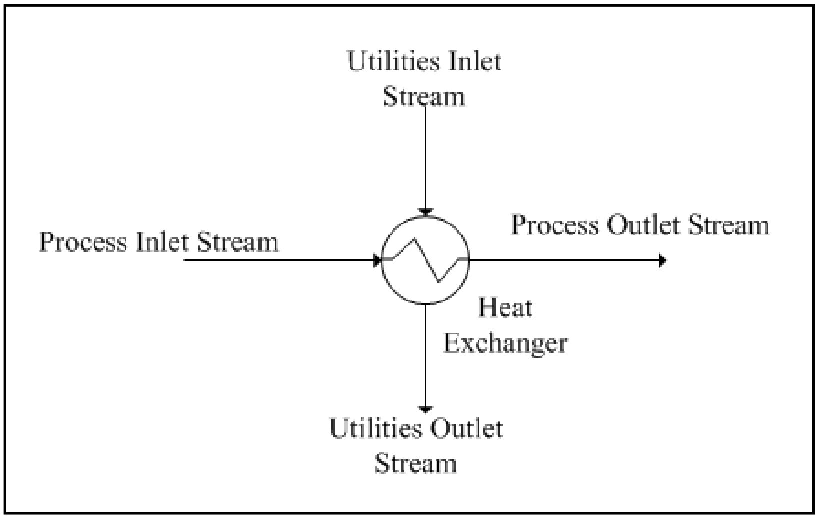


Figure 1.2: Heat Exchanger Streams Flow

Figure 1.2 shows both process stream and utility stream in the heat exchanger. As the temperature in the process streams is needed to be increase or decrease, the utility streams will provide the medium for heat transfer to occur.

The overall energy usage in the heat exchanger is summarized in the following table:

Table 1.1: Energy Usages of the Heat Exchangers

No. of heat exchanger	**Product**		**Utility stream**		**Energy (kW)**
	T_{in} (°C)	**T_{out} (°C)**	**T_{in} (°C)**	**T_{out} (°C)**	
Heat exchanger 1	137	954	234	981	-92.62
Heat exchanger 2	25	954	246	981	41870.00
Heat exchanger 3	954	300	100	410	12720.00
Heat exchanger 4	300	25	10	137	-3284.00
Condenser	150	25	10	20	-1215.00

Along with the overall energy consumption information as shown in Table 1.1 above also include both products and utilities' inlet and outlet temperature for each of the heat exchangers and condenser.

The utility must develop its best estimate of growth in future demand and energy requirement for their customers. Because of the uncertain nature of this forecast, utilities define reasonable upper and lower bounds of potential growth. (A. S Farag *et al*, 1999)

1.3. Problem Statement

The main purpose of business is to gain profit. Changes in the national and local energy economy and the business environment present significant uncertainties and challenges. In order to manage this uncertain environment, utilities usage should have great planning. The energy plan should be considerate with the overall operating expense requirement of the utilities to ensure the ongoing great financial management.

The overall heat exchanger and utilities usage costing in the plant is summarized in the following table.

Table 1.2: Overall Heat Exchanger Costing

Equipment	Bare Module Equipment Cost (RM)
Heat Exchanger 1	359,936.00
Heat Exchanger 2	899,480.00
Heat Exchanger 3	1,012,320.00
Heat Exchanger 4	501,098.40
Condenser	140,692.83

Table 1.3: Overall Utilities Usage and Costing

Utility	Usage	Operation (hr/yr)	Cost (RM/yr)
Electricity	15633.44 kW	8322	25,760,098.13
Water	2201.665 m^3/hr	8322	15,390,695.15

The water consumption shows above is the 5% of water consumed in the first run of operation. The plant has high cost in heat exchanger installation and its utilities usage. As the plant is yet to be optimized, the production cost has potential to be reduced.

1.4. Objectives

The objectives of the study are as follows:

1.4.1. To find minimum energy requirement of the plant.

1.4.2. To observe the effects of energy conservation to the production cost and plant economics

1.5. Scope of Study

In order to achieve the objectives the scope of the study are identified as follow:

1.5.1. Process Flow Diagram (PFD)

To identify potential energy recovery from hot stream and cold stream of Titanium Dioxide plant stream data.

1.5.2. Heat exchanger and stream data

To study the energy requirement for all heat exchangers with the respective stream data.

1.5.3. Pinch Point Analysis

Performing Pinch Point Analysis to every heat exchanger to determine the target of energy saving.

1.5.4. Production Cost and Economics Analysis

Production cost is the combination of raw material cost and labor incurred in producing goods, but for this research it will be focused on utility cost instead of the raw material cost.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter will focused on the explanation of Pinch Analysis and its principles as well as further insight and investigation into previous research about energy conservation and its effect to the plant economics.

Heat exchanger network design may depend on the heat pinch targeting stage in an approach whereby the hot and cold composite curves (CCs) are used to determine the heat energy targets (heat recovery, cold utility, and hot utility) at a specified minimum temperature differential DTmin (R. Smith, 1995)

Pinch Technology is a tool for optimization of a plant's heat recovery. Pinch Analysis application requires extensive process mass and energy balance data and are able to provide engineers with a systematic approach to improve heat recovery in a process through optimal exchange of heat at the appropriate temperature levels. Since its inception during the late 60s, Pinch Technology has been applied successfully optimization of energy usage in the chemical process industries, resulting it up to 90% energy and 25% capital saving said by Linholf B *et al*, (1982) (Zainuddin Abul Manaf & Foo Sheek Hia, 2000)

Great economic and energy savings were realized by the pinch analysis in comparison to the existing plant. In order to produce new Heat Exchanger Network

(HEN), the capital cost had to be increase but the total cost trade-off between the capital and energy cost will be decrease by 30% (Mirjana Kijevčanin *et al.* 2004)

2.2. Pinch Analysis

Pinch technology, methodology of analyzing heat use, has progressed since it was first developed in the 1970s onwards at the ETH Zurich and Leeds University (Linholf and Flower 1978; Linholf, 1979). ICI plc took note of these promising techniques and set up research and applications teams to explore and develop them (Ian C Kemp., 2007).

A Pinch Analysis starts with the heat and material balance for the process. Using Pinch Technology, it is possible to identify appropriate changes in the core process conditions that can have an impact on energy savings (onion layers one and two).

The onion layer is the process design hierarchy that can be represented by the "onion diagram" as shown below. The design of a process starts with the reactors (in the "core" of the onion). Once feeds products, recycle concentrations and flow rates are known, the separators (the second layer of the onion) can be designed. The basic process heat and material balance is now in place, and the heat exchanger network (the third layer) can be designed. The remaining heating and cooling duties are handled by the utility system (the fourth layer). The process utility system may be a part of a centralized site-wide utility system.

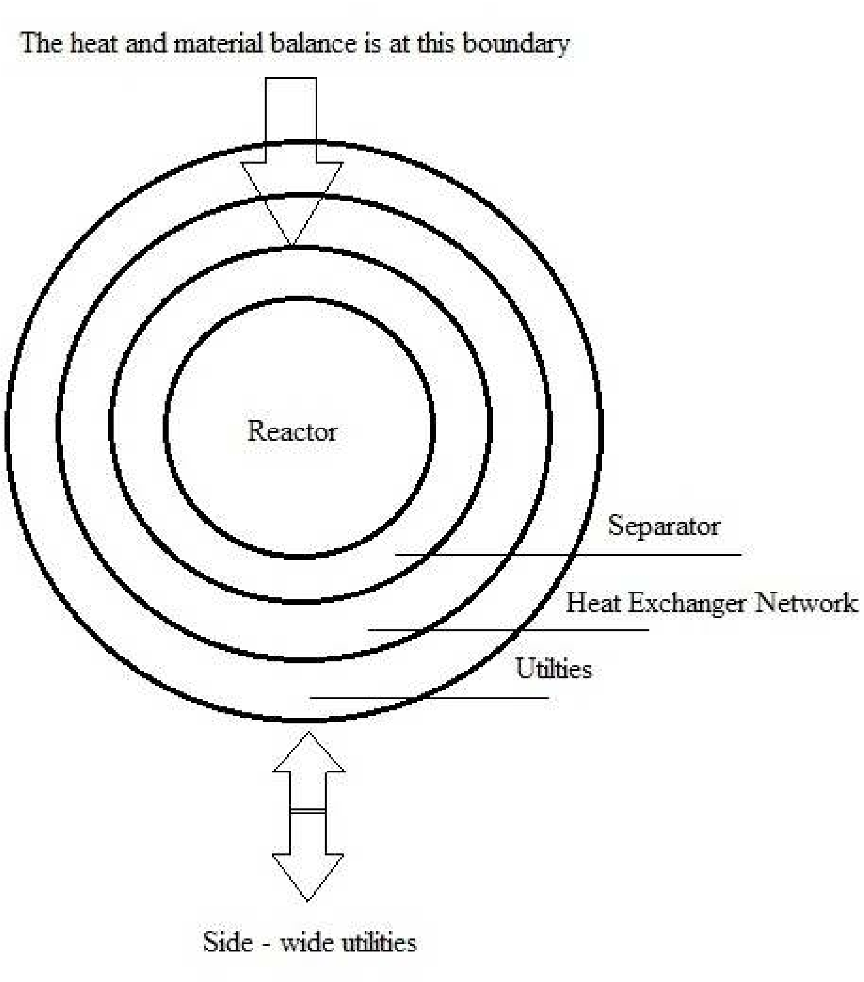


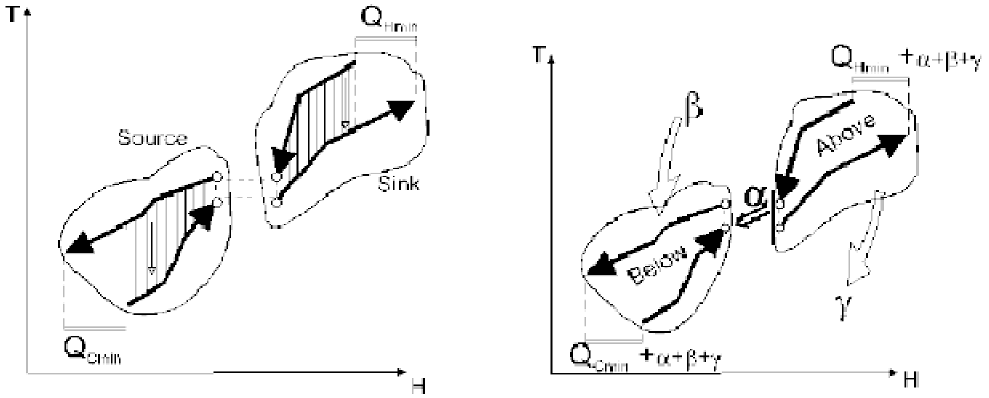
Figure 2.1: The "Onion Diagram" of Hierarchy of Process Design

After the heat and material balance is established, targets for energy saving can be set prior to the design of the heat exchanger network. The Pinch Design Method ensures that these targets are achieved during the network design. Targets can also be set for the utility loads at various levels (e.g. steam and refrigeration levels). The utility levels supplied to the process may be a part of a centralized site-wide utility system (e.g. site steam system). Pinch Technology extends to the site level, wherein appropriate loads on the various steam mains can be identified in order to minimize the site wide energy consumption. Pinch Technology therefore provides a consistent methodology for energy saving, from the basic heat and material balance to the total site utility system.

One tool in the area-wide pinch technology analyzes the transfer of heat among the energy systems of an industrial area (among multiple plants). This can show that there is excess heat recovered from the exhaust heat that can be given to the heat demand side, which will lead to energy saving (Chiyoda Corporation, External Affairs Section).

2.2.1. The Pinch Principles

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



i. The Pinch divides the problem into source and sink

ii. By violating the three golden rules Q_{Hmin} and Q_{Cmin} are each increase by $\alpha + \beta + \gamma$

Figure 2.2: The Pinch Principles

In Figure (ii), an amount of heat is transferred from above the pinch to below the pinch. The system above the pinch, which was before in heat balance with Q_{Hmin}, now loses a unit of heat to the system below the pinch. To restore the heat balance, the hot utility must be increased by the same amount, that is, a unit. Below the pinch, a unit of heat is added to the system that had an excess of heat, therefore the cold utility requirement also increases by a units. In conclusion, the consequence of a cross-pinch heat transfer (i) is that both the hot and cold utility will increase by the cross-pinch duty (i).

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

i. Heat must not be transferred across the pinch

ii. There must be no external cooling above the pinch

iii. There must be no external heating below the pinch

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

2.2.2. Pinch Effect to Plant Economic Saving

BASF, Germany, reported completing over 150 projects and achieving site-wide energy saving of over 25% in retrofits in their main factory in Ludwigshafen (Korner 1988). Based from existing research, the Energy and economy savings in the process of methanol synthesis using Pinch technology an important aspect of energy conservation is the establishment of an optional heat exchanger network (HEN) during the design of a plant.

The problem of designing an optimal HEN synthesizing has received significant attention and an extensive review of the papers be found in the current literature. (1. I. E. Grossmann *et al*,1996, T. Gundersen, *et al*,1988,Je`owski *et al*,1994,B. Linnhoff,1993,R. Smith, 2000, F. X. X. Zhu etal,2000,K. C. Furman *et al* 2002) (Mirjana Kijevčanin *et al.* 2004)

It also state that by the principles of the pinch technology used for energy integration will be applied to the heat exchanger network of a plant form ethanol synthesis. Pinch technology is an attractive and practical methodology for the systematic application of thermodynamics laws. The application of this technique enables a fundamental insight into the thermal interactions between a chemical process and the utility systems to be gained. This means that a certain reconstruction and financial investment in an existing process can considerably reduce capital and energy consumption. This has great significance not just from an economic point of view but also from the aspect of environment preservation and reduction of heat pollution is achieved.

The experience of multi-national petrochemical corporations like shell, Exxon, BP, Dow, Mitsubishi, JGC & Union Carbide in Europe, USA & Japan have shown that Pinch Analysis has led to energy saving in the range 15-90% & capital saving of up to 30% (Linholf, B *et al.* 1986).

The alternative Heat Exchanger Network (HEN) is achieved by adding a new heat exchanger and changing operating conditions. It reduces the annual energy cost by 5.6%. In order to achieve it, the capital investment is necessary but the annual cost saving will be enough to recover the cost in less than one year (Sung-Geun Yoon *et al*. 2007).

2.3. The Pinch Steps

The first two steps have been considered, namely, data extraction and analysis. Data extraction involves translation of flow-sheet information into relevant thermal and cost information required for the application of pinch technology. For more information on the principles of converting flow sheet data to pinch analysis data see Data Extraction Principles. The second step in pinch technology is pinch analysis based on targets. This involves targeting for energy, trade-offs in targeting mode between capital and energy, targeting for process modifications and targeting for multiple utility levels and placement of heat engines and heat pumps.

In the analysis stage the objective is to explore various options for process improvement quickly and easily using targeting, without getting into the detail of specific flow-sheet changes. This allows quick screening of various options for process improvement such as energy recovery, process modifications, and utility system integration.

The key improvement options identified in the analysis stage need to be implemented in design. In this section the focus is on the design aspect of pinch technology. This translates the ideas for improvement obtained during the analysis/targeting stage into specific modifications of the heat exchanger network.

The heat exchanger network design procedure is based upon pinch analysis principles and is called the Pinch Design Method. The method systematically leads the engineer to good network designs that achieve the energy targets within practical limits. The network design procedure uses a special representation for heat exchanger networks called the Grid Diagram. The network design procedures for new design and retrofit design are discussed separately in the following sections. Before this however, some further consideration is given to network representation

2.4. Relationship to The Cost Manufacturing

There are many factors that influence the cost of manufacturing chemicals. (Richard T. *et al.* 2009). The cost information is divided into three categories.

i. **Direct manufacturing cost**: These costs represent operating expenses that vary with production rate. When product demand drops, production rate is reduced to less than the design capacity

ii. **Fixed manufacturing cost**: These costs are independent of changes in production rate.

iii. **General expenses**: These costs represent an overhead burden that is necessary to carry out business functions

The utilities cost is under the direct manufacturing cost category. The cost of manufacturing can be determined when the following costs are known or can be estimated:

i. Fixed Capital Cost Investment FCI: (C_{TM} or C_{GR})

ii. Cost of Operating Labor (C_{OL})

iii. Cost of Utilities (C_{UT})

iv. Cost of Waste Treatment (C_{WT})

v. Cost of Raw Material (C_{RM})

The direct manufacturing cost can be calculated by implement the equation below:

$$DMC = C_{RM} + C_{WT} + C_{UT} + 1.33C_{OL} + 0.069FCI + 0.03COM \qquad (2\text{-}1)$$

Where

$$COM = 0.280FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \qquad (2\text{-}2)$$

Therefore, any changes in the utilities cost will affect the production or manufacturing cost of the plant.

Energy saving is the most important issue in the petrochemical industry associated with cost, regulations, and social relationships. The petrochemical industry is a capital intensive industry consuming much energy (Sung-Geun Yoon *et al*. 2007).

CHAPTER 3

METHODOLOGY

3.1. Introduction

Pinch analysis is based on straightforward thermodynamics, and uses it in a practical way. However, the approach is largely non-mathematical. Although (classical) thermodynamics itself may be thoroughly developed subject, we need to apply it the context of practical design and operation (Ian C Kemp, 2007)

3.2. Process Flow Diagram (PFD)Analysis

The Process Flow Diagram will be analyzed based to the Process flow Diagram of Titanium Dioxide Production Plant. All the equipment that has energy changes will be considered.

3.3. Pinch Analysis

3.3.1. Steps of Pinch Analysis

Pinch technology presents a simple methodology for systematically analyzing chemical process and the surrounding utility systems with the help of the 1st and 2nd

Laws of Thermodynamics. The 1st Law of Thermodynamics provides the energy equation for calculating the enthalpy changes in the stream passing through a heat exchanger. The 2nd Law determines the direction of heat flow.

Steps of pinch analysis from (The Chemical Engineers' Resource Page) is summarized and followed by a brief explanation of each step as below:

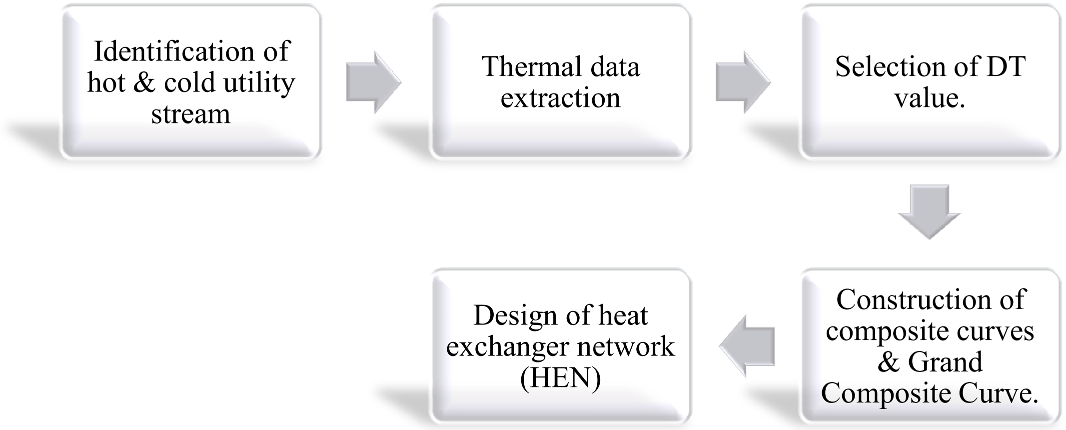


Figure 3.1: Pinch Analysis Steps

3.3.1.1. Identification of Hot & Cold Utility Stream

i. **Hot Stream** are those that must be cooled or are available to be cooled

ii. **Cold stream** are those that must be heated

iii. **Utility Stream** are used to eat or cool process streams, when heat exchange between process streams is not practical economic.

The identification of stream needs to be done with care as sometimes, despite undergoing changes in temperature, the stream is not available for heat exchange.

3.3.1.2. Thermal Data Extraction

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

i. Supply temperature (TS): the temperature at which the stream is available.

ii. Target temperature (TT): the temperature the stream must be taken to.

iii. Heat capacity flow rate (CP): the product of flow rate (m) in kg/s and specific heat (Cp kJ/kg ˚C)

$$CP = m \times Cp \tag{3-1}$$

Enthalpy change (ΔH) associated with a stream passing through the exchanger is given by the First Law of Thermodynamics

$$First\ Law\ of\ Thermodynamics: H = \pm W \tag{3-2}$$

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

$$W = 0 \tag{3-3}$$

The above equation simplifies to: H=Q where Q represents the heat supply or demand associated with the stream. It is give by the relationship:

$$Q = CP \times (T_s - T_t) \tag{3-4}$$

Enthalpy change,

$$\Delta H = CP \times (T_s - T_t) \tag{3-5}$$

*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 conclusion 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 mistake, the data extraction is based on certain qualified principles.

Table 3.1: Stream Data

Stream	Name		T_s (C)	T_t (C)	CP	ΔH (kW)
1	Condenser	hot 1	150	25	0.7409888	-92.62
2	HE 1	cold 1	137	954	51.24847001	41870.00
3	HE 2	cold 2	25	954	13.69214209	12720.00
4	HE 3	hot 2	954	300	5.021406728	-3284.00
5	HE 4	hot 3	300	25	4.418181818	-1215.00

Table 3.1 above shows the process stream data extracted for heat exchanger and condenser. The red colored row is for the hot stream while blue colored row is for cold stream. The table consists of information on supply temperature T_s and target temperature T_t, heat capacity of each stream; defined as CP = ΔH/ΔT where ΔH is the enthalpy variation over the temperature interval ΔT.

3.3.1.3. Selection of DT min 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. This DT min value represent bottleneck in the heat recovery.

The value of DT min 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 be determined the practical DT min for the network

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

Table 3.2: Typical DT min Value

No	Industrial Sector	Experience DT min values (˚C)
1	Oil refining	20-40
2	Petrochemical	10-20
3	Chemical	10-20
4	Low temperature process	3-5

For this project, the production of 50,000 MT/Annum is under the petrochemical industrial sector, thus the range of experience DT min value is between 10-20 ˚C. For this research, the DT min value used is 5, 10, 15, 20 and 25 ˚C.

3.3.1.4. Construction of Composite Curves and Grand Composite Curve.

The composite curve provides 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.

The composite curves consist of Temperature – Enthalpy 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.

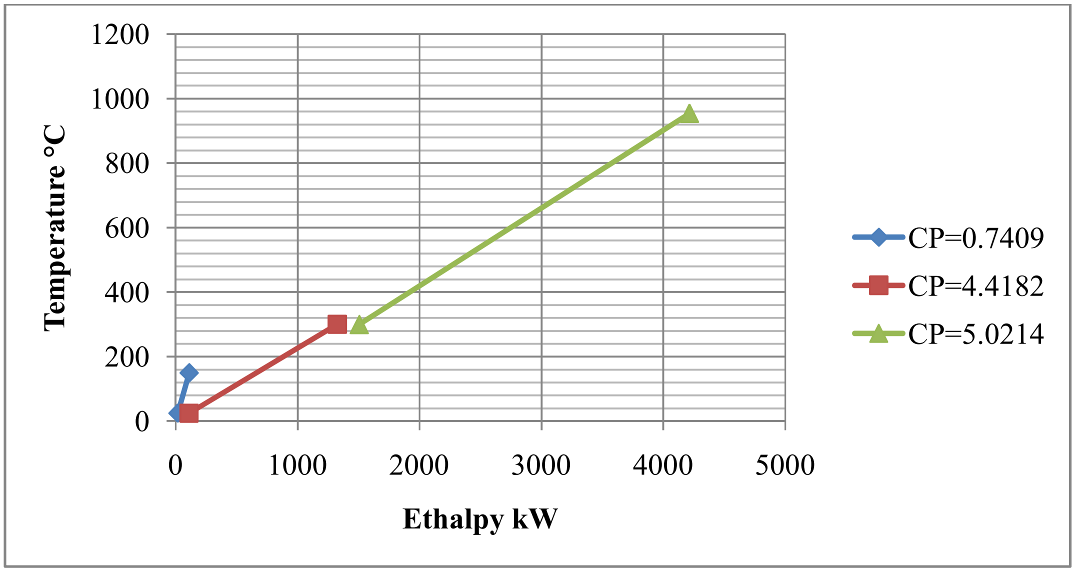


Figure 3.2: Construction of Composite Curve for Hot Stream

Figure 3.2 above illustrates the construction of the hot composite curve for the stream process which has 3 hot streams (stream hot 1, hot 2 and hot 3). The data for the hot composite curves above are based to the stream data as shown in Table 3.1

As shown in the figure below, a complete hot or cold composite curve consist a series of connected straight lines, each change in slope represents a change in overall hot stream heat capacity flow rate (CP).

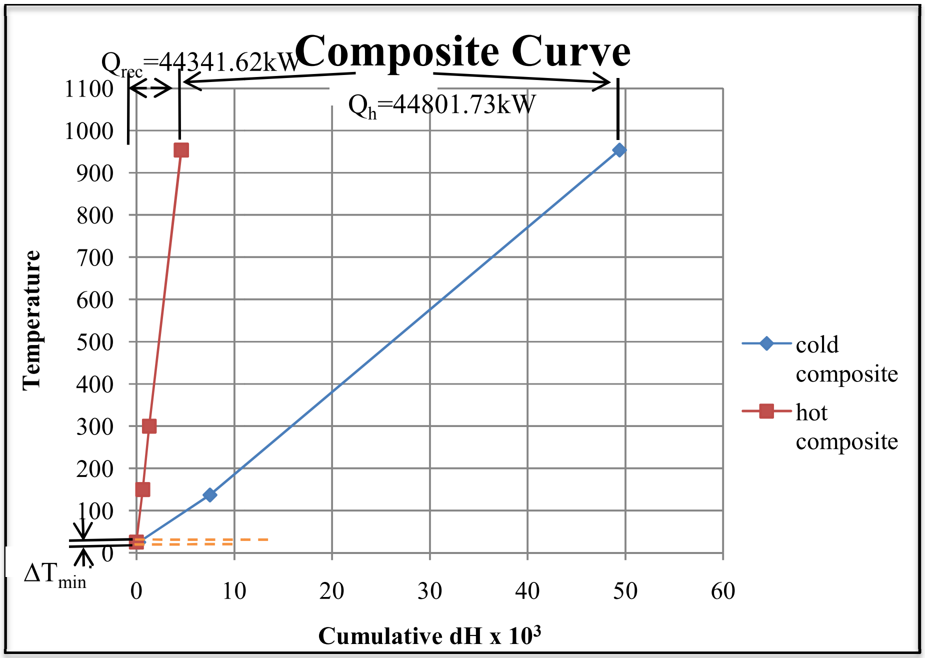


Figure 3.3: Composite Curve

The composite curve above displays the cumulated enthalpy of all streams, hot or cold, available in a temperature interval between the supply and targets temperatures and the location of DT min (ΔT min). For this case, the plant will only have region above the pinch as there no longer any enthalpy change below the pinch point.

The Grant 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.

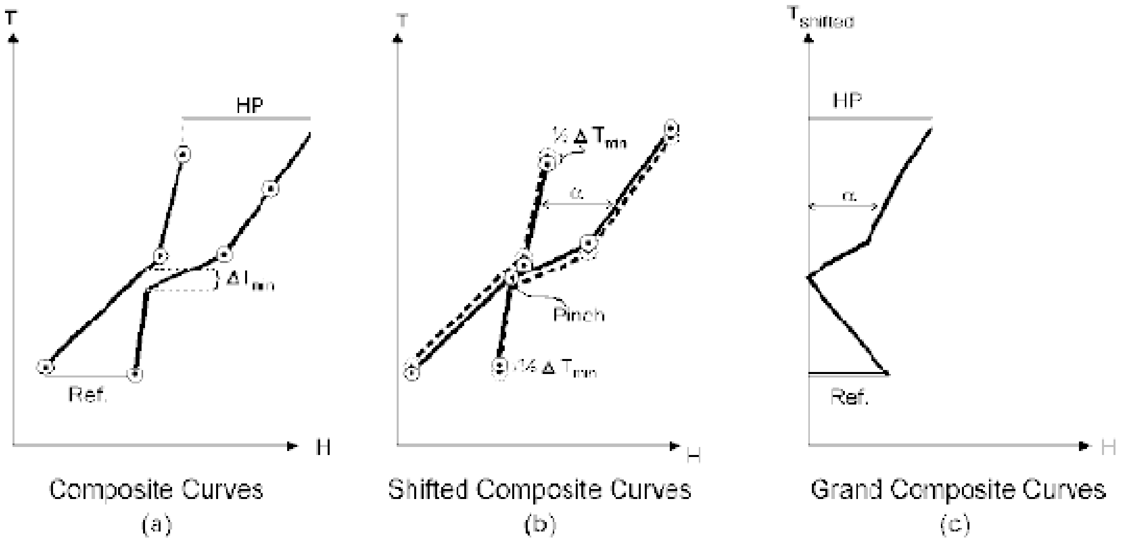


Figure 3.4: Grand Composite Curve (from Introduction to Pinch by Linholf March)

3.3.1.5. Design of Heat Exchanger Network (HEN)

The design of network examines which ‘hot’ streams can be matched to ‘cold’ streams via heat recovery. Every match brings one stream to it target temperature. As 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 Pinch split the grid diagram two region; above (at the left) and below (at he right) the Pinch. The design starts at Pinch, where the heat transfer is the most constrained. The match procedure has to respect some feasibility rules

For the match above the Pinch, the following heuristic has to be respected.

$$CP_{hot} \leq CP_{cold} \qquad (3.6)$$

Intuitively, the rule can be justified by the fact that above the Pinch there is need only for ho utility, such as the CP's of cold streams must be greater than the CP's of hot streams.

Another rule for the region above the pinch regarding the pairing of streams at pinch must be satisfied.

$$N_{cold} \leq N_{hot} \tag{3.7}$$

If not, the stream splitting needs to be constructed, therefore to match the stream become possible. However in this research, there is no need for stream splitting.

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 total cost.

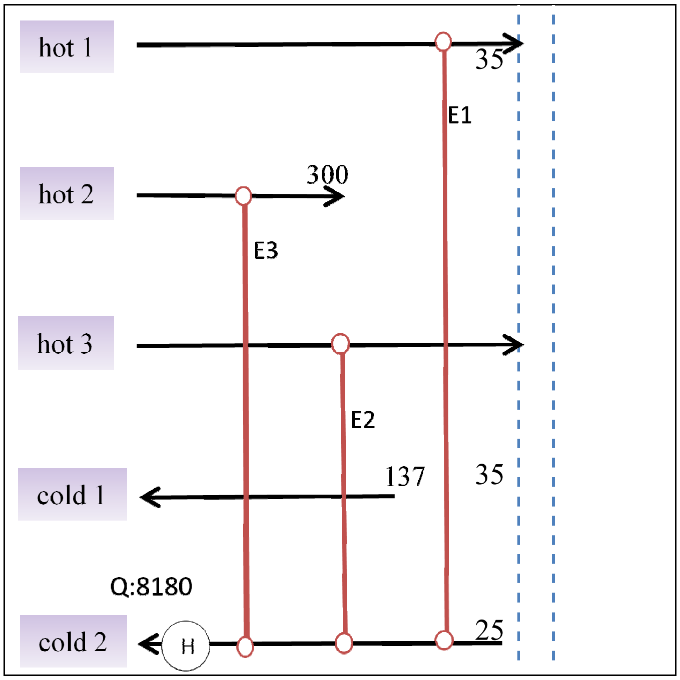


Figure 3.5: Grid Diagram for HEN

The Grid Diagram for the HEN as shown in figure 3.5 above illustrates the Overall Heat Exchanger Network for Pinch at ΔT min equal to 10. As mentioned earlier, the plant for production of 50000 MT/Annum will be only have region above the Pinch.

3.4. Production Cost Analysis

The production cost will be calculated for the energy usage in the production of 50,000 MT/Annum Titanium Dioxide plan after the pinch analysis is done. Then the new calculated production cost will be compared to the existence production cost.

3.4.1. Cost of Operating Labor

To estimate labor – related operations, it is necessary to estimate the number of operators for the plant per shift (W. D. Seider and J. D Seader, 2nd edition). The technique used to estimate operating labor requirements is based on data obtained from five chemical companies and correlated by Alkayat and Gerrard (R. Turton *et al*, 2009). According to this method, the operating labor requirement for chemical processing plant is given by equation;

$$N_{OL} = (6.29 + 31.7P^2 + 0.23N_{np})^{0.5} \qquad (3\text{-}8)$$

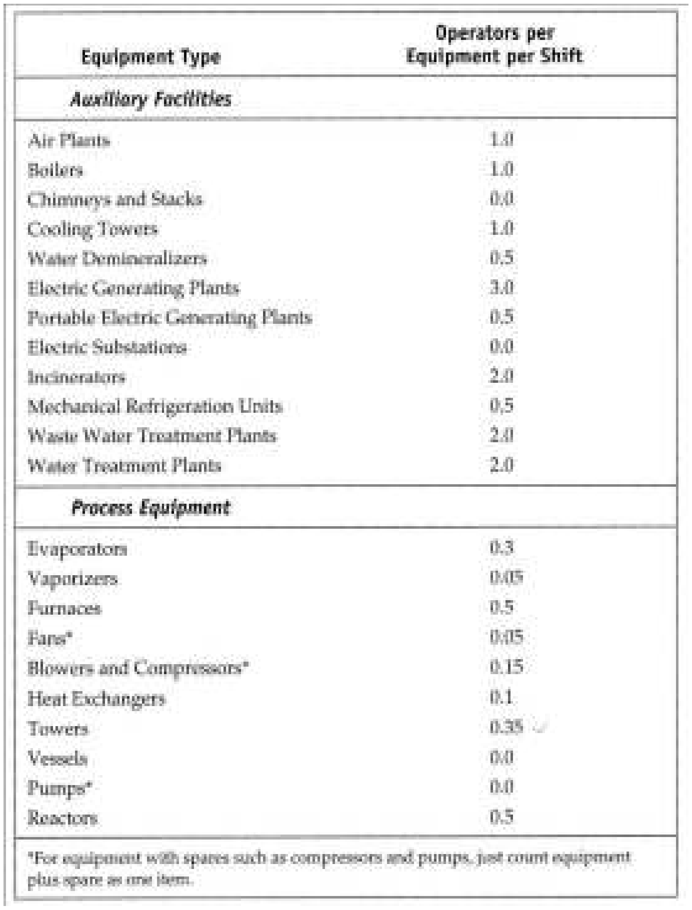
Where N_{OL} is the number of operators per shift, P is the number of processing steps involving the handling of particulate solids. N_{np} is is the number of non-particulate processing steps and includes compression, heating and cooling, mixing and reaction. In general for the process considered in this text, the value of P is zero, and the value of N_{np} is given by:

$$N_{np} = \sum equipment \qquad (3\text{-}9)$$

A single operator works on the average 49 weeks a year (3 week's time off for vacation and sick leave), fie 8 – hours shift a week. This amount (49 week/year x 5 shifts /week) makes 245 shifts per operator per year. A chemical plant normally operates 24 hours / day. This requires (365 days / year x 3 shifts / day) 1095 operating shifts per year. The number of operators needed to provide this number of shifts is [(1095 shifts / yr) / (245 shifts / operator / yr)] or approximately 4.5 operators.

The calculation on the number of operators require per shift is also can be referred to Table 3.2 below

Table 3.2: Operator Requirements for Various Process Equipments



Equipment Type	Operators per Equipment per Shift
Auxiliary Facilities	
Air Plants	1.0
Boilers	1.0
Chimneys and Stacks	0.0
Cooling Towers	1.0
Water Demineralizers	0.5
Electric Generating Plants	3.0
Portable Electric Generating Plants	0.5
Electric Substations	0.0
Incinerators	2.0
Mechanical Refrigeration Units	0.5
Waste Water Treatment Plants	2.0
Water Treatment Plants	2.0
Process Equipment	
Evaporators	0.3
Vaporizers	0.05
Furnaces	0.5
Fans*	0.05
Blowers and Compressors*	0.15
Heat Exchangers	0.1
Towers	0.35
Vessels	0.0
Pumps*	0.0
Reactors	0.5

*For equipment with spares such as compressors and pumps, just count equipment plus spare as one item.

(From D. G. Newnan *Engineering Economics Analysis*)

3.4.2. Cost of Utilities

Utilities that used in this plant are water and electricity. The calculation of those usages is based to the local utilities price multiply with the usage. Both cost of operating labor and cost of utilities is under the direct manufacturing cost category. The direct manufacturing cost can be calculated by implement the equation below:

$$DMC = C_{RM} + C_{WT} + C_{UT} + 1.33C_{OL} + 0.069FCI + 0.03COM \qquad (2\text{-}1)$$

Where

$$COM = 0.280FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \qquad (2\text{-}2)$$

Therefore, any changes in the utilities cost will affect the production or manufacturing cost of the plant.

The utilities used in the heat exchanger and condenser in this plant are cooling water for coolant, and superheated steam for heating element. From both cooling water and steam used will be calculated heir total consumption and converted to volume flow rate of water required.

Meanwhile, total saving utilities was calculated from the matched stream in the HEN grid diagram. This is because, when two streams is matched, heat transfer occur between process stream therefore the utilities consumption for both stream is eliminated.

The results on the new total cost (cost of heat exchanger, utilities cost and operating labor) was then analyzed at different value of DT min and compared by using total cost flow analysis.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The conservation of energy for the production of 50000 MT/Annum Titanium Dioxide Plant is constructed by using Pinch Analysis. From the observation on the results obtained it shows that the best ΔT min value is 15 for constructing the Pinch Analysis for this plant with an amount of 50075.748 kW energy required and a payback period of within one year of plant operation.. Comparison of the original HEN of this process plant and those obtained by Pinch at its best ΔT min value shows that total cost are about 35.36% lower. However, there is only conservation of energy from region above the Pinch for this plant. This improvement in energy utilization leading to increase in plant efficiency and profitability.

5.2. Recommendations

From the results and conclusions stated, it is recommended that the further research in conservation of energy by using Pinch Analysis should be continued by considering matters that follows:

i. Compare the manual calculation with simulated calculation using simulation software like Aspen Pinch. Since in this research consists of many trial and error calculations, excel calculations are also considered as manual calculation.

ii. The Economic Analysis done in this research is only for the payback period. Further economic analysis is recommended since it will give a comprehensive economic analysis.

iii. There should be verification on the stream data since it's from plant design project. Thus the data is assured to be accurate.

iv. Apply the energy conservation in the real case study since the data are more reliable and convincing compared to the design projects.

v. More study on the effect of the excessive energy consumption to environment

REFERENCES

A. S. Farag, A. E Mousa, T. C. Cheng, M. Beshir. (1999) *Cost Effective Utilities Energy Plans Optimization and Management.* Energy Conversion & Management.(40):527-543

Aleksandra Anastasovsli, Liljana Markovska, Vera Meshko (2007). *Heat Integration of Ethanol and Yeast Manufacture*. Macedonian Journal of Chemistry and Chemical Engineering Vol 26, 135 - 146

Alexandre C. Dimian (2003). *Integrated Design and Simulation of Chemical Process*. Amsterdam: Elsevier Science B.V

Chiyoda Corporation, External Affairs Section. Article of Pinch Analysis

Ian C Kemp. (2007) *Pinch Analysis and Process Integration: A User Guide on Process Integration for The Efficient Use of Energy*, 2nd Edition. ICheme, BH, Britain. Revised 1st Edition 1994

Linholf March. *Introduction to Pinch*

Linholf, B et al. (1986) *Process Integration Monograph*, ICI

Mirjana Kijevčanin, Bojan Djordjević, Ozren Ocić, Mladen Crnomarković, Maja Marić, Slobodan Šerbanović. *Energy and Economy Savings in The Process of Methanol Syntesis Using Pinch Technology.* J.Serb..Chem.Soc 2004. 69(10) 827-837

P.S.Varbanov, S. Doyle, R. Smith (2004) *Modeling and Optimization of Utility Systems.* Chemical Engineering Researchand Design, 82(A5): 561–578

R. Smith, (1995) *Chemical Process Design*, McGraw Hill Inc., New York

Richard Turton, Richard C. Bailie, Wallace B Whiting, Joseph A Shaeiwitz, (2009) *Analysis, Synthesis and Design of Chemical Process*, 3rd Edition, Boston: Eason Education Inc,

Sung-Geun Yoon, Jeongseok Lee, Sunwon Park, (2007). *Heat integration analysis for an industrial ethylbenzene plant using pinch analysis*. 2006 Applied Thermal Engineering 27 886–893

Thane Brown (2007). *Engineering Economics and Economic Design for Process Engineers.* New York: Taylor & Francis Group

The Chemical Engineers' Resource Page. *Pinch Technology: Basics for Beginners*.

Theory of Heat Exchangers. Internet .www.heatexchangersgamma.com/Theory

Zainuddin Abul Manaf & Foo Sheek Hia. (2000) Combining Pinch Exergy Analysis for Process Improvement – A Casa Study on an Aromatics Complex. Journal Teknologi,33(F). 9-16 © Universiti Teknologi Malaysia

APPENDICES

Appendix A: Heat Exchanger Equipment Sizing

Table A.1: Excel Calculation for Heat Exchanger Sizing

ΔT=5	Th in °C	Th out °C	Tcin °C	Tcout °C	y	z	ΔTlm	F_T	ΔTm	Q (W)	U	Ao	Lt	Do	Di	At	Nt	Pt	K1	n	Db	Db/Pt	clearance	Ds	Lt/Ds
E1	300	30	25	112.24	0.317236	3.094911	50.40645	1	50.40645	1192914	50	473.318	4.88	0.05	0.0468	0.766549	617	0.0625	0.249	2.207	1.725805	27.61288	0.78	2.505805	1.947478
E2	954	300	112.24	351.97	0.284796	2.728069	355.553	1	355.553	3283996	50	184.7261	4.88	0.01905	0.01656	0.292055	633	0.023813	0.249	2.207	0.66474	27.91559	0.64	1.30474	3.740209
E3	1154	883	351.97	954	0.750633	0.450144	338.996	0.8	271.1968	8243051	50	607.9018	4.88	0.01905	0.01656	0.292055	2081	0.023813	0.249	2.207	1.140367	47.88943	0.74	1.880367	2.595238
E4	150	30	25	35	0.08	12	35.08219	1	35.08219	88920	2000	12.6731	2.44	0.01905	0.01656	0.146028	87	0.023813	0.249	2.207	0.27027	11.34991	0.54	0.81027	3.011343
E5	1154	813	137	954	0.803343	0.417381	390.8445	0.5	195.4222	41870025	30	714.1805	4.88	0.05	0.0468	0.766549	932	0.0625	0.249	2.207	2.079414	33.27062	0.78	2.859414	1.706643

											0														
ΔT=10																									
E1	150	35	25	31.224	0.049792	18.47686	43.95604	1	43.95604	85215	40	48.46604	2.44	0.01905	0.01656	0.146028	332	0.023813	0.249	2.207	0.496312	20.84252	0.58	1.076312	2.267
E2	300	35	31.224	116.735	0.31815	3.099017	46.23303	0.85	39.29807	1170823	50	595.8679	4.88	0.05	0.0468	0.766549	777	0.0625	0.249	2.207	1.915582	30.64931	0.78	2.695582	1.81037
E3	954	300	116.735	365.581	0.297213	2.628131	347.3227	0.85	295.2243	3283996	50	222.4746	4.88	0.01905	0.01656	0.292055	762	0.023813	0.249	2.207	0.723171	30.36938	0.65	1.373171	3.553818
E4	1154	897	365.581	954	0.746328	0.436764	339.1401	0.82	278.0948	8179927	200	147.0708	4.88	0.01905	0.01656	0.292055	504	0.023813	0.249	2.207	0.599506	25.17611	0.7	1.299506	3.755272
E5	1154	813	137	954	0.803343	0.417381	390.8445	0.5	195.4222	41870025	300	714.1805	4.88	0.05	0.0468	0.766549	932	0.0625	0.249	2.207	2.079414	33.27062	0.78	2.859414	1.706643
ΔT=15																									
E1	150	40	25	30.95	0.0476	18.48739	50.22946	1	50.22946	81510	40	40.56882	2.44	0.01905	0.01656	0.146028	278	0.023813	0.249	2.207	0.457884	19.22871	0.56	1.017884	2.397131
E2	300	40	30.95	114.85	0.311838	3.098927	58.34214	1	58.34214	1148732	50	393.7915	4.88	0.05	0.0468	0.766549	514	0.0625	0.249	2.207	1.587796	25.40474	0.78	2.367796	2.060988
E3	954	300	114.85	354.696	0.28582	2.72675	352.5907	0.9	317.3316	3283996	50	206.9756	4.88	0.01905	0.01656	0.292055	709	0.023813	0.249	2.207	0.699892	29.39179	0.64	1.339892	3.642085
E4	1154	886	354.696	954	0.749782	0.447185	339.0975	0.8	271.278	8205723	200	151.242	4.88	0.01905	0.01656	0.292055	518	0.023813	0.249	2.207	0.607151	25.49717	0.64	1.247151	3.912917
E5	11	813	137	954	0.803	0.417	390.8	0.	195.4	41870	3	714.1	4.	0.05	0.04	0.766	93	0.062	0.2	2.2	2.079	33.27	0.78	2.859	1.706

	54				343	381	445	5	222	025	00	805	88		68	549	2	5	49	07	414	062		414	643
ΔT=20																								
E1	150	45	25	30.68	0.04544	18.48592	55.60791	1	55.60791	77805	40	34.97928	2.44	0.01905	0.01656	0.146028	240	0.023813	0.249	2.207	0.428138	17.97954	0.55	0.978138	2.494536
E2	300	45	30.68	112.966	0.305532	3.098948	67.21348	1	67.21348	1126641	50	335.2426	4.88	0.05	0.0468	0.766549	437	0.0625	0.249	2.207	1.476113	23.61781	0.78	2.256113	2.163012
E3	954	300	112.966	352.81	0.285178	2.726772	354.7008	0.8	283.7607	3283996	50	231.4624	4.88	0.01905	0.01656	0.292055	793	0.023813	0.249	2.207	0.736265	30.91927	0.66	1.396265	3.495038
E4	1154	884	352.81	954	0.750371	0.449109	339.0553	0.8	271.2442	8231519	200	151.7363	4.88	0.01905	0.01656	0.292055	520	0.023813	0.249	2.207	0.60805	25.5349	0.62	1.22805	3.97378
E5	1154	813	137	954	0.803343	0.417381	390.8445	0.5	195.4222	41870025	300	714.1805	4.88	0.05	0.0468	0.766549	932	0.0625	0.249	2.207	2.079414	33.27062	0.78	2.859414	1.706643
ΔT=25																								
E1	150	50	25	30.41	0.04328	18.48429	60.43343	1	60.43343	74100	40	30.65357	2.44	0.01905	0.01656	0.146028	210	0.023813	0.249	2.207	0.403281	16.93566	0.55	0.953281	2.559582
E2	300	50	30.41	111.08	0.299232	3.099045	74.71635	1	74.71635	1104550	50	295.6649	4.88	0.05	0.0468	0.766549	386	0.0625	0.249	2.207	1.394436	22.31097	0.78	2.174436	2.24426
E3	954	300	111.08	350.93	0.284547	2.726704	356.8076	0.78	278.3099	3283996	50	235.9956	4.88	0.01905	0.01656	0.292055	808	0.023813	0.249	2.207	0.742764	31.1922	0.66	1.402764	3.478846
E4	1154	882	350.93	954	0.750956	0.451026	339.0108	0.8	271.2087	8257315	200	152.2318	4.88	0.01905	0.01656	0.292055	521	0.023813	0.249	2.207	0.608949	25.57265	0.62	1.228949	3.970874

E5	1154	813	137	954	0.803343	0.417381	390.8445	0.5	195.4222	41870025	300	714.1805	4.88	0.05	0.0468	0.766549	932	0.0625	0.249	2.207	2.079414	33.27062	0.78	2.859414	1.706643

Appendix B: Heat Exchanger Equipment Costing

Table B.1: Excel Calculation for Cost of Heat Exchanger before Pinch

Equipment	Purchased Cost, C_p 1996 ($)	Material of construction	F_p	F_m	F_pF_m	$F°_{BM}$	$C°_{BM}$ 1996 ($)
Heat Exchanger 1	16000	CS - SS	1	1.7	1.7	4.3	68800
Heat Exchanger 2	51000	SS - SS	1	3	3	5.2	265200
Heat Exchanger 3	56250	SS - SS	1	3	3	5.2	292500
Heat Exchanger 4	48000	CS - SS	1	1.7	1.7	4.3	206400
Condenser	16000	CS	1	1	1	3.2	51200
Total							884100
						C_{TM}	1043238

Table B.2: Excel Calculation for Cost of Heat Exchanger after Pinch for ΔT = 5

ΔT=5	Area $A_o(m^2)$	Type HE	Purchased Cost, C_p 1996 ($)	Material of Construction	F_p	F_m	F_pF_m	$F°_{BM}$	$C°_{BM}$ 1996 ($)
E1	473.32	floating head	32000	CS - CS	1	1	1	3.2	102400
E2	184.73	floating head	18000	CS - SS	1	1.7	1.7	4.3	77400
E3	607.90	floating head	45000	SS - SS	1	3	3	5.2	234000
E4	12.67	floating head	8000	CS - CS	1	1	1	3.2	25600
E5	714.18	floating head	50000	SS - SS	1	3	3	5.2	260000
		total	153000						699400
								C_{TM}	825292

Table B.3: Excel Calculation for Cost of Heat Exchanger after Pinch for ΔT = 10

ΔT=10	Area $A_o(m^2)$	Type HE	Purchased Cost, C_p 1996 ($)	Material of Construction	F_p	F_m	F_pF_m	$F°_{BM}$	$C°_{BM}$ 1996 ($)
E1	48.47	floating head	11000	CS - CS	1	1	1	3.2	35200
E2	595.87	floating head	39000	CS - CS	1	1	1	3.2	124800
E3	222.47	floating head	22000	CS - SS	1	1.7	1.7	4.3	94600
E4	147.07	floating head	16000	SS - SS	1	3	3	5.2	83200
E5	714.18	floating head	50000	SS - SS	1	3	3	5.2	260000
		total	138000						597800
								C_{TM}	705404

Table B.4: Excel Calculation for Cost of Heat Exchanger after Pinch for ΔT = 15

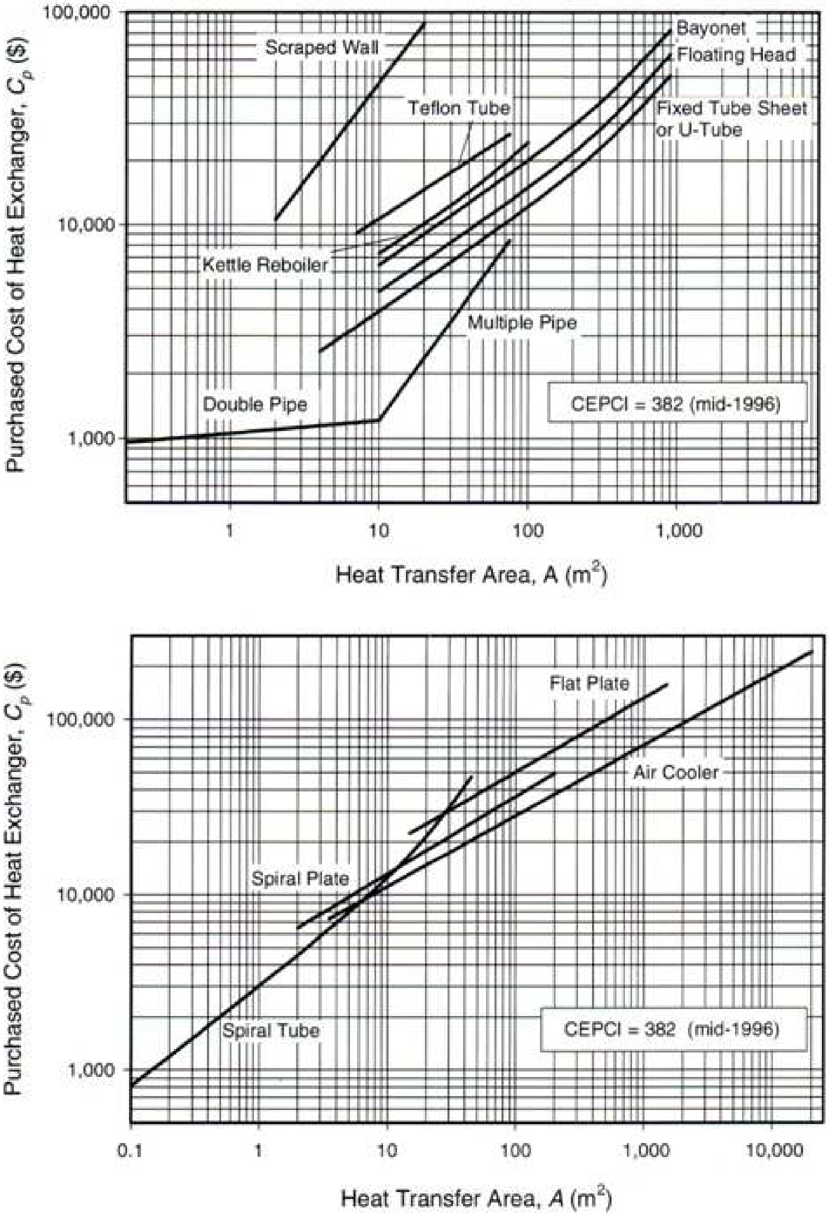
ΔT=15	Area $A_o(m^2)$	Type HE	Purchased Cost, C_p 1996 ($)	Material of Construction	F_p	F_m	F_pF_m	$F°_{BM}$	$C°_{BM}$ 1996 ($)
E1	40.57	floating head	9500	CS - CS	1	1	1	3.2	30400
E2	393.79	floating head	32000	CS - CS	1	1	1	3.2	102400
E3	206.98	floating head	21000	CS - SS	1	1.7	1.7	4.3	90300
E4	151.24	floating head	17000	SS - SS	1	3	3	5.2	88400
E5	714.18	floating head	50000	SS - SS	1	3	3	5.2	260000
		total	129500						571500
								C_{TM}	674370

Table B.5: Excel Calculation for Cost of Heat Exchanger after Pinch for ΔT = 20

ΔT=20	Area $A_o(m^2)$	Type HE	Purchased Cost, C_p 1996 ($)	Material of Construction	F_p	F_m	F_pF_m	$F°_{BM}$	$C°_{BM}$ 1996 ($)
E1	34.98	floating head	10000	CS - CS	1	1	1	3.2	32000
E2	335.24	floating head	28000	CS - CS	1	1	1	3.2	89600
E3	231.46	floating head	24000	CS - SS	1	1.7	1.7	4.3	103200
E4	151.74	floating head	17000	SS - SS	1	3	3	5.2	88400
E5	714.18	floating head	50000	SS - SS	1	3	3	5.2	260000
		total	129000						573200
								C_{TM}	676376

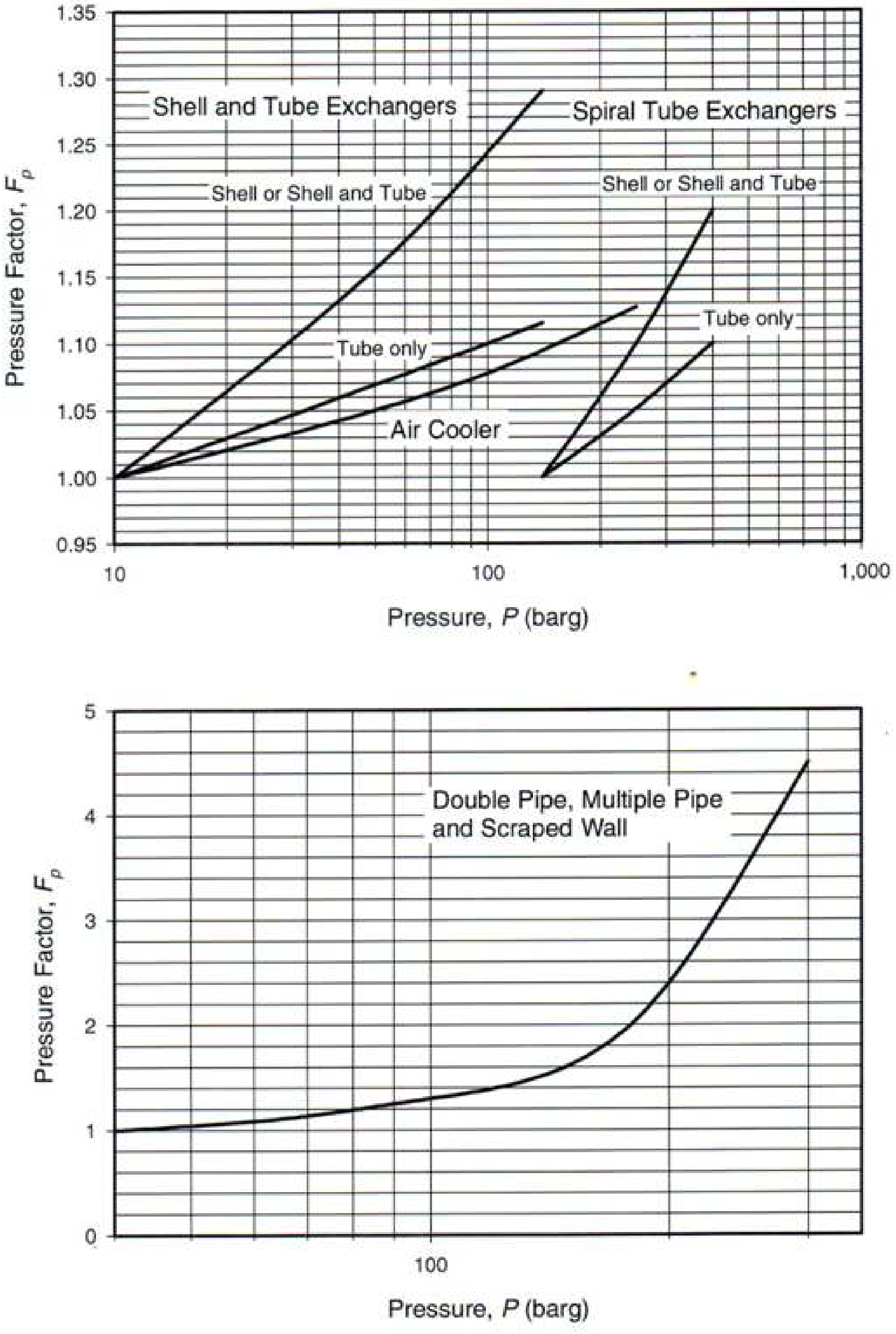
Table B.6: Excel Calculation for Cost of Heat Exchanger after Pinch for ΔT = 25

ΔT=25	Area $A_o(m_2)$	Type HE	Purchased Cost, C_p 1996 ($)	Material of Construction	F_p	F_m	F_pF_m	$F°_{BM}$	$C°_{BM}$ 1996 ($)
E1	30.65	floating head	8200	CS - CS	1	1	1	3.2	26240
E2	295.66	floating head	27500	CS - CS	1	1	1	3.2	88000
E3	236.00	floating head	25000	CS - SS	1	1.7	1.7	4.3	107500
E4	152.23	floating head	17000	SS - SS	1	3	3	5.2	88400
E5	714.18	floating head	50000	SS - SS	1	3	3	5.2	260000
		total	127700						570140
								C_{TM}	672765.2



Purchased Costs of Heat Exchangers

Figure B.1: Purchased Cost of Heat Exchanger



Pressure Factors for Heat Exchangers

Figure B.2: Pressure Factors for Heat Exchanger

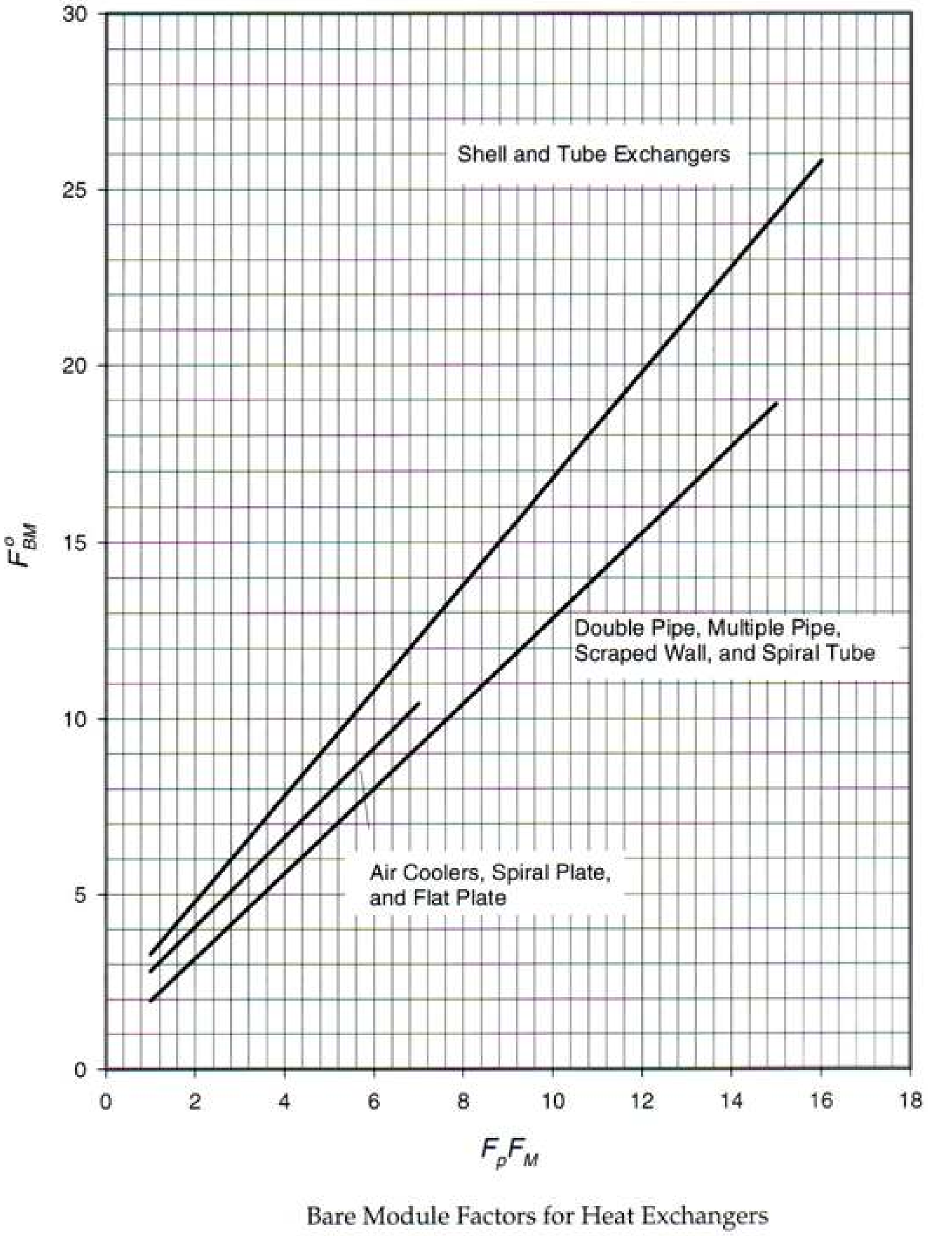
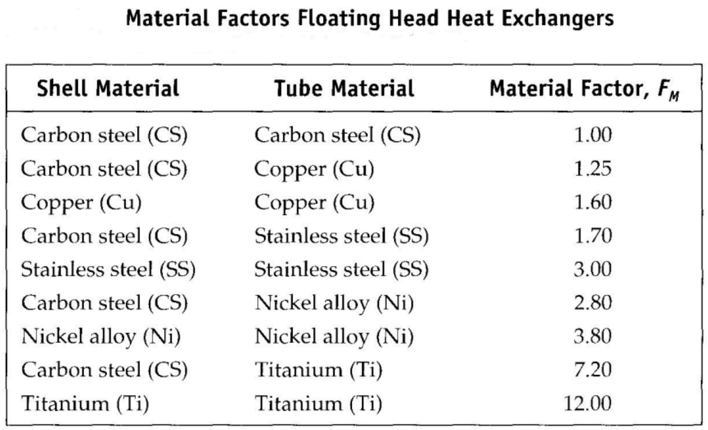


Figure B.3: Bare Module Factors for Heat Exchanger

Table B.7: Material Factors Floating Head Heat Exchanger



Material Factors Floating Head Heat Exchangers

Shell Material	Tube Material	Material Factor, F_M
Carbon steel (CS)	Carbon steel (CS)	1.00
Carbon steel (CS)	Copper (Cu)	1.25
Copper (Cu)	Copper (Cu)	1.60
Carbon steel (CS)	Stainless steel (SS)	1.70
Stainless steel (SS)	Stainless steel (SS)	3.00
Carbon steel (CS)	Nickel alloy (Ni)	2.80
Nickel alloy (Ni)	Nickel alloy (Ni)	3.80
Carbon steel (CS)	Titanium (Ti)	7.20
Titanium (Ti)	Titanium (Ti)	12.00

Table B.8: CEPCI and Marshall & Swift Cost Index

Year	Marshall & Swift Equipment Cost Index	Chemical Engineering Plant Cost Index
1978	552	219
1979	607	239
1980	675	261
1981	745	297
1982	774	314
1983	786	317
1984	806	323
1985	813	325
1986	817	318
1987	814	324
1988	852	343
1989	895	355
1990	915	358
1991	931	361
1992	943	358
1993	964	359
1994	993	368
1995	1028	381
1996	1039	382
1997	1057	387
1998	1061	390
1999	1068	391
2000	1089	394
2001	1094	395
2002	1104	396
2003	1124	402
2004	1179	444
2005	1245	468
2006	1302	500
2007	1373	525
2008	1449	575

Appendix C: Utilities Consumption

Table C.1: Excel Calculation for Utilities Consumption before Pinch

Equipment	Q (kW)	utility	ΔH (kJ/kg)	Cp	ΔT	m (kg/s)	m (kg/hr)
HE 1	41870.00	steam	4593.412			9.115	32814.823
HE 2	12720.00	steam	4593.412			2.769	9969.060
HE 3	3284.00	c.water		4.182	310	2.533	9119.267
HE 4	1215.00	c.water		4.182	127	2.288	8235.520
Condenser	92.6236	c.water		4.182	10	2.215	7973.337
						18.920	68112.007

Where

C. water = cooling water

Table C.2: Excel Calculation for Utilities Consumption after Pinch for ΔT = 5°C

ΔT=5°C	Q (kW)	utility	ΔH (kJ/kg)	Cp	ΔT	m (kg/s)
E3	8243.051	steam	5030.45			1.638630997
E4	88.92	c.water		4.182	10	2.12625538
E5	41870.02	steam	5030.45			8.323315906
						12.08820228

Table C.3: Excel Calculation for Utilities Consumption after Pinch for ΔT = 10°C

ΔT=10°C	Q (kW)	utility	ΔH (kJ/kg)	m (kg/s)
E4	8179.927	steam	5030.45	1.626082617
E5	41870.02	steam	5030.45	8.323315906
				9.949398523

Table C.4: Excel Calculation for Utilities Consumption after Pinch for ΔT = 15°C

ΔT=15°C	Q (kW)	utility	ΔH (kJ/kg)	m (kg/s)
E4	8205.723	steam	5030.45	1.631210588
E5	41870.02	steam	5030.45	8.323315906
				9.954526494

Table C.5: Excel Calculation for Utilities Consumption after Pinch for ΔT = 20°C

ΔT=20°C	Q (kW)	utility	ΔH (kJ/kg)	m (kg/s)
E4	8231.519	steam	5030.45	1.636338558
E5	41870.02	steam	5030.45	8.323315906
				9.959654464

Table C.6: Excel Calculation for Utilities Consumption after Pinch for ΔT = 25°C

ΔT=25°C	Q (kW)	utility	ΔH (kJ/kg)	m (kg/s)
E4	8257.315	steam	5030.45	1.641466529
E5	41870.02	steam	5030.45	8.323315906
				9.964782435

Table C.7: Excel Calculation for Saving Cost and Cost of Water for ΔT = 5°C

ΔT =5°C	before	after	saving
Volume Flow rate	68.31	43.65	24.67
cost (RM)	78.56	50.19	28.37
% saving cost			36.11
5% v (m3/yr)	28425.55	18161.40	10264.14
cost (RM/yr)	32689.38	20885.61	11803.77
% saving cost			36.11

Table C.8: Excel Calculation for Saving Cost and Cost of Water for ΔT = 10°C

ΔT =10°C	before	after	saving
Volume Flow rate	68.31	35.92	32.39
cost (RM)	78.56	41.31	37.25
% saving			47.41
5% v (m3/yr)	28425.55	14948.05	13477.50
cost (RM/yr)	32689.38	17190.25	15499.12
% saving			47.41

Table C.9: Excel Calculation for Saving Cost and Cost of Water for ΔT =15°C

ΔT =15°C	before	after	saving
Volume Flow rate	68.31	35.94	32.37
cost (RM)	78.56	41.33	37.23
% saving			47.39
5% v (m3/yr)	28425.55	14955.75	13469.79
cost (RM/yr)	32689.38	17199.11	15490.26
% saving			47.39

Table C.10: Excel Calculation for Saving Cost and Cost of Water for ΔT = 20°C

ΔT =20°C	before	after	saving
Volume Flow rate	68.31	35.96	32.35
cost (RM)	78.56	41.36	37.21
% saving			47.36
5% v (m3/yr)	28425.55	14963.46	13462.09
cost (RM/yr)	32689.38	17207.97	15481.40
% saving			47.36

Table C.11: Excel Calculation for Saving Cost and Cost of Water for ΔT = 25°C

ΔT =25°C	before	after	saving
Volume Flow rate	68.31	35.98	32.33
cost (RM)	78.56	41.38	37.18
% saving			47.33
5% v (m3/yr)	28425.55	14971.16	13454.39
cost (RM/yr)	32689.38	17216.83	15472.54
% saving			47.33