ENERGY CONSERVATION FOR PRODUCTION OF 50000 MT/A ISOBUTYLENE BY USING PINCH ANALYSIS AND EFFECT TO THE PLANT ECONOMIC

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ABSTRACT

This research shows how the application of Pinch Technology can lead towards great of heat recovery and energy saving. 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 cost and energy consumption. Since no studies have been done on minimizing energy consumption in Isobutylene Production Plant, there is a potential for energy conservation by using Pinch Analysis. The heat exchanger network of the isobutylene process plant has been studied and it was shows how the application of pinch technology makes it possible to reduce the demand of hot and cold utility. 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 10°C to 14 °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 3 different ΔT_{min} values which are 10°C, 12°C and 14 °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 three different ΔT_{min} to find the optimal ΔT_{min}. Overall analysis results in output where the optimum ΔT_{min} equal to 14 °C where the total annual cost of energy and capital costs is minimized and also a payback period of within one year of plant operation.

ABSTRAK

Kajian ini menunjukkan bagaimana aplikasi Teknologi Jepitan boleh membawa ke arah pemulihan haba dan penjimatan tenaga yang terbaik. Mengaplikasikan teknik ini membolehkan sebuah wawasan yang mendasar pada interaksi terma antara proses kimia dan sistem utility. Ini bermakna bahawa pembinaan semula dan pelaburan kewangan tertentu dalam suatu proses yang ada boleh mengurangkan modal kapital dan penggunaan tenaga. Kerana tiada kajian yang dilakukan ke atas meminimumkan penggunaan tenaga di loji penghasilan Isobutylene, terdapat potensi untuk penjimatan tenaga dengan menggunakan Analisis Jepitan. Rangkaian kerja penukar haba daripada loji proses Isobutylene telah dikaji dan ia berkemungkinan boleh mengurangkan penggunaan pemanasan dan penyejukan. Tujuan kajian ini adalah untuk mengetahui keperluan tenaga minimum dan untuk melihat kesan pemuliharaan/penjimatan tenaga kepada kos pengeluaran dan ekonomi loji. Dalam rangka mencapai tujuan tersebut, terdapat tiga analisis utama yang dipraktikkan iaitu menganalisis data diagram proses aliran, Analisis Jepitan dan Analisis Ekonomi. Setelah aliran panas dan sejuk dikenalpasti dari diagram proses aliran, data terma diambil dan direkodkan di dalam sebuah jadual. Nilai perubahan minimum suhu dipilih antara 10°C - 14°C. Kemudian Keluk Komposit dan Keluk Komposit Utama dibina berdasarkan pada data yang diekstrak. Analisis kemudian bersambung dengan mengubahsuai rangkaian penukar haba dimana rangkaian penukar haba diubahsuai pada tiga nilai perubahan minimum suhu yang berbeza iaitu pada 10°C, 12°C dan 14°C. Dari rangkaian analisis grid diagram penukar haba, keperluan tenaga minimum dapat ditentukan dan analisis dilanjutkan dengan analisis ekonomi tapak proses yang hanya fokus pada penukar haba dan kos-kos lain yang mungkin mempengaruhi selepas Jepitan dibina. Hasil yang diperolehi daripada analisis awal telah dibandingkan di antara tiga nilai perubahan minimum suhu yang berbeza untuk mencari perubahan minimum suhu yang optimum. Secara keseluruhan, keputusan analisis output perubahan minimum suhu yang optimum adalah pada 14°C di mana jumlah keseluruhan kos tenaga dan kos modal diminimumkan dan juga masa pembayaran balik dalam 1 tahun operasi loji.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENT	viii
	LIST OF TABLES	xii
	LIST OF FIGURES	xvi
	LIST OF SYMBOLS	xvii
1	**INTRODUCTION**	
	1.1 Introduction	1
	1.2 Problem statement	5
	1.2 Objective of the research	7
	1.4 Scope of the research	7
2	**LITERATURE REVIEW**	
	2.1 Background of Pinch Analysis	8
	2.2 Pinch Analysis/Technique	9
	2.2.1 Principle of Pinch Analysis	12
	2.2.2 Heat exchanger network synthesis	13
	2.2.3 Cost Optimal heat Exchanger network	15
	2.3 Water uses and general approaches to water minimization	17

within industry
2.2.3 Process change 18
2.2.4 Water reused 19
2.2.5 Regeneration reused 20
2.2.6 Regeneration recycling 20
2.3 Selection of initial ΔT_{min} value 21
2.3.1 Estimation of Optimum ΔT_{min} value by energy-capital trade off 22
2.5 Benefit and application of Pinch technology 23

3 METHODOLOGY

3.0 Methodology 25
3.1 Analysis of Process Flow Diagram data 25
3.1.1 Data Extraction Flow sheet 27
3.2 Pinch Analysis 27
3.2.1 Construction of composite curves 28
3.2.2 Problem table algorithm 29
3.2.3 Grand composite curve 32
3.2.4 Design of heat exchanger network 32
3.2.4.1 The heat exchanger network design 33
3.2.4.2 Heat exchanger area 35

3.3 Economic analysis 36
3.3.1 Total Capital Investment cost 36
3.3.2 Operating labor cost 36
3.3.3 Utilities cost 37
3.3.4 Payback Period 38

4 RESULT AND DISCUSSION

4.1 Thermal Data Extraction for Process and Utility Stream 40

    4.1.1 Temperature intervals of Hot and Cold Streams 41

4.2 Pinch Analysis 43

    4.2.1 Determination of ΔT_{min} and Construction of Composite Curves 43

    4.2.2 Construction of Grand Composite Curve 46

        4.2.2.1 Shifted Temperature Scale 46

        4.2.2.2 Problem Table Algorithm (PTA) 49

        4.2.2.3 Grand Composite Curve (GCC) 51

    4.2.3 Heat Exchanger Network 52

        4.2.3.1 Overall Analysis on Heat Exchanger Network (for ΔT_{min} = 10°C) 52

        4.2.3.2 Analysis on above and below Pinch Region (for ΔT_{min} = 10°C) 53

        4.2.3.3 Overall Analysis on Heat Exchanger Network (for ΔT_{min} = 12°C) 56

        4.2.3.4 Analysis on above and below Pinch Region (for ΔT_{min} = 12°C) 57

        4.2.3.5 Overall Analysis on Heat Exchanger Network (for ΔT_{min} = 14°C) 61

        4.2.3.6 Analysis on above and below Pinch Region (for ΔT_{min} = 14°C) 62

4.3 Equipment cost 65

4.4 Result of Manufacturing cost 66

    4.4.1 Saving cost utilities 66

    4.4.2 Investment cost 70

    4.4.3 Annualized cost 71

    4.4.3 Payback period 72

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion 75
5.2 Recommendation 76

6 REFERENCES 77

APPENDIX A

APPENDIX B

APPENDIX C

LIST OF TABLES

TABLE NO	TITLE	PAGE
2.1	Experience ΔT_{min} based on industrial sector	22
3.1	Stream data for production of 50,000MT/A	27
3.2	Problem Table Algorithm	30
3.3	Operator requirements for various process equipment	37
3.4	Utilities provide by Off sites for a plant with multiple process unit	38
4.1	Stream Process Data for Heat Exchangers	40
4.2	Stream for Hot Composite	41
4.3	Stream for Cold Composite	42
4.4	Shifting Temperature for Hot Composite (ΔT_{min} = 10°C)	46
4.5	Shifting Temperature for Cold Composite (ΔT_{min} = 10°C)	46
4.6	Shifting Temperature for Hot Composite (ΔT_{min} = 12°C)	47
4.7	Shifting Temperature for Cold Composite (ΔT_{min} = 12°C)	47
4.8	Shifting Temperature for Hot Composite (ΔT_{min} = 14°C)	48
4.9	Shifting Temperature for Cold Composite (ΔT_{min} = 14°C)	48
4.10	Problem Table Algorithm (ΔT_{min} = 10°C)	49
4.11	Problem Table Algorithm (ΔT_{min} = 12°C)	50
4.12 (a)	Summary of heat exchanger area and price before network	65
4.12 (b)	Summary of heat exchanger area and price for ΔT_{min} = 10°C	66
4.13 (a)	Energy consumption of heat exchanger network before Pinch	67
4.13 (b)	Energy consumption of heat exchanger network for ΔT_{min} = 10°C	67

4.13 (c)	Energy consumption of heat exchanger network for ΔT_{min} = 12°C	68
4.13 (d)	Energy consumption of heat exchanger network for ΔT_{min} = 14°C	68
4.14	Water Consumption of heat exchanger network	69
4.15	Cumulative of investment cost of heat exchanger network for isobutylene process	70

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
1.1	Process flow diagram for production of 50,000 MT/A of isobutylene.	2
1.2	Stream flow of heat exchanger 1 and 2	3
1.3	Stream flow of heat exchanger 3	4
1.4	Stream flow of heat exchanger 4	4
1.5	Stream flow of heat exchanger 5	5
2.1	“Onion Diagram” of hierarchy in process design	10
2.2	Flowchart of Pinch technology	11
2.3	Schematic presentation of the HENS task	14
2.4	Possible project payback period through technology technique	16
2.5	Typical water use on a process site	18
2.6	Process changes	19
2.7	Water reused	19
2.8	Regeneration reused	20
2.9	Regeneration recycling	20
2.10	Heat Transfer Equation	21
2.11	Energy-Capital Cost Trade Off (Optimum ΔT_{min})	22
3.1	Flow Analyzed PFD	25
3.2	Practical flow of pinch retrofit analysis	26
3.3	Temperature intervals of hot and cold streams	28

3.4	Shifting the composite curve modifies ΔT_{min} and utility target	29
3.5	Shifted Temperature Scale	30
3.6	Cascade Diagram	31
3.7	Grand Composite Curve	32
3.8	Grid Diagram of the HEN isobutylene process	33
3.9 (a)	Network design above pinch	34
3.9 (b)	Network design below Pinch	34
3.9 (c)	Overall heat exchanger network design	35
4.1	Temperature interval diagram	41
4.2 (a)	Composite Curve (ΔT_{min} = 10°C)	43
4.2 (b)	Composite Curve (ΔT_{min} = 12°C)	44
4.2 (c)	Composite Curve (ΔT_{min} = 14°C)	44
4.3	Shifted Temperature Scale (ΔT_{min} = 10°C)	46
4.4	Shifted Temperature Scale (ΔT_{min} = 12°C)	47
4.5	Shifted Temperature Scale (ΔT_{min} = 14°C)	48
4.6	Cascade Diagram (ΔT_{min} = 10°C)	51
4.7	Cascade Diagram (ΔT_{min} = 12°C)	51
4.8	Composite Curve with respect to the value of ΔT_{min} (ΔT_{min}= 10°C)	52
4.9	Overall stream temperature with respect to the value of ΔT_{min} (ΔT_{min} = 10°C)	52
4.10	Above Pinch Region (ΔT_{min} = 10°C)	53
4.11	Below Pinch Region (ΔT_{min} = 10°C)	53
4.12	Overall heat exchanger network for ΔT_{min} = 10°C	55
4.13	Composite Curve with respect to the value of ΔT_{min} (ΔT_{min}= 12°C)	56
4.14	Overall stream temperature with respect to the value of ΔT_{min} (ΔT_{min} = 12°C)	57
4.15	Above Pinch Region (ΔT_{min} = 12°C)	57
4.16	Below Pinch Region (ΔT_{min} = 12°C)	58
4.17	Overall heat exchanger network for ΔT_{min} = 12°C	60

4.18 Composite Curve with respect to the value of ΔT_{min} (ΔT_{min}= 14°C) 61
4.19 Overall stream temperature with respect to the value of ΔT_{min} (ΔT_{min} = 14°C) 61
4.20 Above Pinch Region (ΔT_{min} = 14°C) 62
4.21 Below Pinch Region (ΔT_{min} = 14°C) 62
4.22 Overall heat exchanger network for ΔT_{min} = 14°C 64
4.23 Graph cumulative of investment cost of heat exchanger network against ΔT_{min} 71
4.24 Graf annualized cost against ΔT_{min} 72
4.25 (a) Payback period with $\Delta T_{min} = 10^oC$ 73
4.25 (b) Payback period with $\Delta T_{min} = 12^oC$ 73
4.25 (c) Payback period with $\Delta T_{min} = 14^oC$ 74

LIST OF SYMBOLS

CC - Composite curve
CHP - Combined heat and power
CP - Heat capacity
C_{TM} - Total manufacturing cost
EAOC - Equivalent annual operating cost
FCI - Fix capital investment
GCC - Grand composite curve
HEN - Heat exchanger network
HENS - Heat exchanger network synthesis
MT/A - Metric Tonne per Annum
N_{cs} - Number of cold stream
N_{hs} - Number of hot stream
ΔT_{min} - Minimum temperature different
t_{out} - Temperature outlet
t_{in} - Temperature inlet
T_{new} - New Temperature
Q_h - Heat Duty for hot streams
Q_c - Heat Duty for cold streams

CHAPTER 1

1.0 Introduction

1.1 Current Scenario

In recent years, isobutylene has become an important product in industries because it is used as an intermediate chemical and largely used in polymerization process to produce the polisobutylene that mostly used in butyl rubber industry and also were used in the MTBE industry. More than half of the butylenes produced worldwide are utilized as alkylate and polymer gasoline. Isobutylene can be isolated from refinery streams by reaction with sulfuric acid, but the most common industrial method for its production is by catalytic dehydrogenation of isobutene. In the 1990s, the production of isobutylene increased dramatically as the demand for oxygenates such as MTBE grew. The world's butylenes markets have undergone significant changes during the last 10 years and will continue to evolve in the future. Due to the rapid demand of isobutylene, more plant of isobutylene is designed annually.

In the isobutylene plant, the heat exchanger widely used both for cooling and heating large scale processes. It is desirable to increase the temperature of one fluid while cooling another. Because of that, they become major consumers of energy in process plant. Increasing of energy in a process plant can cause of producing a large quantity of carbon emissions which contribute to global warming crisis. 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 requirement

(MER), an appropriate heat exchanger network (HEN) required. The design of such a network is not an easy considering the fact that most processes involve a large number of process and utility streams. The integration of a new process into the existing facility provides significant improvements in the design of process plants that would minimize the net cost of energy purchase. The most useful tool that enables this design advance is pinch technology. It is a comprehensive and reliable technique to be applied in order to conserve the energy usage of a chemical plant and will contribute to sustainable and environmental friendly chemical process and also has a significant economical impact on the plant's operation.

1.1.1 Plant Descriptions – Production of 50,000 MT/A isobutylene

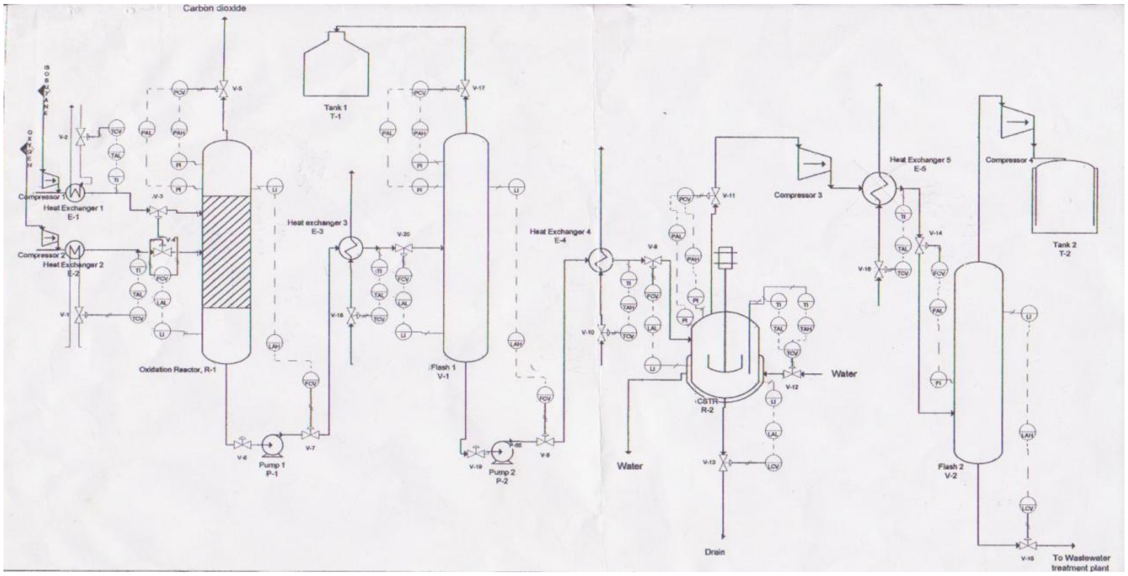

Figure 1.1: Process flow diagram for production of 50,000 MT/A of isobutylene

In this isobutylene plant, it consists of five heat exchangers. Heat exchanger is the most important equipment in chemical process industries. In the process industries, the transfer of heat between two fluids is generally done in heat exchanger. The large flows of fluid are involved in the process so the most suitable type of heat exchanger for this process is shell and tube exchanger. For the heat exchanger that has the area below $50m^2$ the use of double pipe of heat exchanger is preferred. The transfer of heat and from process fluids is an essential part of most chemical processes. It can transfer the heat between two fluids. The most common type is one in which the hot and the cold fluid do not come into direct contact with each another but are separated by a tube wall or flat or curved. The transfer of heat accomplished from the hot fluid to the wall or tube surface by convection through tube wall or plate conduction and the by convection to the cold fluid. Figure below shows the description of the heat exchangers:

Heat Exchanger 1 and Heat Exchanger 2

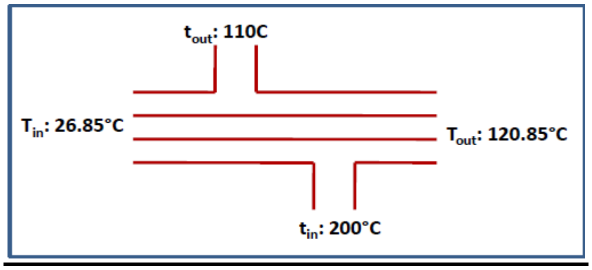

Figure 1.2: Stream flow of heat exchanger 1

Based on Figure 1.2 it indicates the temperature of inlet in stream process of 26.85°C. The process for the oxidation reactor requires higher temperature of 120.85°C in order to proceed with the oxidation process. There are two heat exchanger involve before proceeding into the reactor process. In the heat exchanger 1, isobutane gases are heated from the room temperature to the desired temperature. The heat exchanger 1 was applied on that stream to achieve the target of temperature. The inlet flowrate of the heat exchanger 1 is 28728 kg/hr of water steam at 200°C. As the result, the outlet temperature of the process stream increase to 120.85°C with decreasing the t_{out} of the heat exchanger 1 to 110°C. In the second of heat exchanger, the oxygen gases are heated to the similar temperature as in heat exchanger 1. The inlet flowrate of the heat exchanger 2 is 7596kg/hr of water steam at 200°C. Therefore, the outlet temperature of the process stream increases to 120.85°C with decreasing the t_{out} of the heat exchanger 1 to 110°C.

Heat Exchanger 3

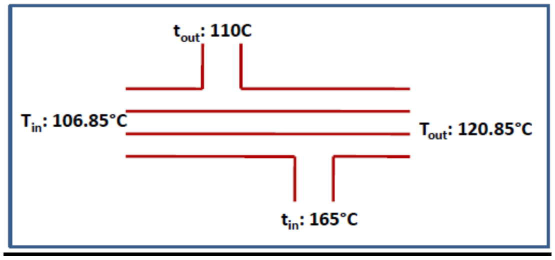

Figure 1.3: Stream flow of heat exchanger 3

Based on the Figure 1.3 above shows the temperature of inlet in stream process is 106.85°C. The process for the flash distillation column 1 requires higher temperature of 120.85°C in order to proceed with the separation homogeneous mixture process. The third heat exchanger was applied on that stream to achieve the target of temperature. The inlet flowrate of the heat exchanger 3 is 281520 kg/hr of water steam at 165°C. As the result, the outlet temperature of the process stream increases to 120.85°C with decreasing the t_{out} of the heat exchanger 3 to 110°C.

Heat Exchanger 4

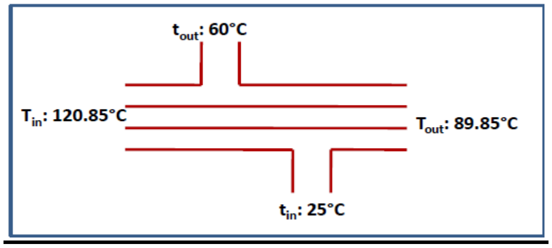

Figure 1.4: Stream flow of heat exchanger 4

Based on the figure 1.4 above shows the temperature of inlet in stream process is 120.85°C. The process for the continuous stirred reactor (CSTR) requires lower temperature of 89.85°C in order to proceed with the dehydration process. The fourth heat exchanger was applied on that stream to achieve the target of temperature. The inlet flowrate of the heat exchanger 4 is 165194.172 kg/hr of cooling water at 25°C. Thus, the outlet temperature of the process stream decreases to 89.85°C with increasing the t_{out} of the heat exchanger 4 to 60°C.

Heat Exchanger 5

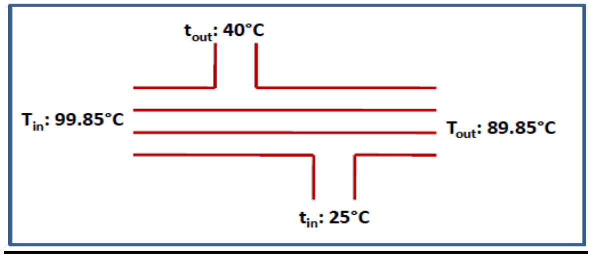

Figure 1.5: Stream flow of heat exchanger 5

Based on the figure 1.5 above indicate the temperature of inlet in stream process is 99.85°C. The process for the flash distillation column 1 requires higher temperature of 89.85°C in order to proceed with the separation homogeneous mixture process. The third heat exchanger was applied on that stream to achieve the target of temperature. The inlet flowrate of the heat exchanger 3 is 25771.1688 kg/hr of water at 25°C. As the result, the outlet temperature of the process stream decreases to 89.85°C with increasing the t_{out} of the heat exchanger 3 to 40°C.

1.2 Problem Statement

In any industrial processes, many researchers and engineers do a lot of efforts in order to minimize the cost of utilities. This can be achieved by optimizing the energy requirements in the plant. The excessive energy that is used in any production of the plant will also have a significant impact to the environmental problem. The increasing concern for the environmental impacts of human activities has stimulated the development of new methods for the analysis of industrial processes and the implementation of energy conservation measures. Various methods aiming at a better energy integration of processes have been proposed and among them, one particularly powerful method is called pinch technology method.

This project is aimed to recovery energy to the maximum and to see the effects of energy optimization to the plant economy. This can be done through heat exchanger integration which will involve the usage of Pinch analysis technology. Energy saving reflects itself in many ways, for example reduced fuel consumption or reduce maintenance cost due to the lower load on various items of plant equipment. In plant design, there is always a trade-off between energy costs and the capital costs of heat exchangers and other equipment required to optimize energy efficiency. The high number of heat exchanger in the plant can achieve very high energy efficiency, but at the same time it will increase the exchange cost. Due to this fact, eliminating some heat exchanger may help lower costs, but it will also reduce overall energy efficiency.

Energy saving in process plant equipment has essentially been a trial-and-error procedure between changes in structure and simulation until satisfactory reductions are achieved. It was very important to optimize the use of energy in the plant so that we can decrease the number of total capital cost. In order to achieve optimum heat recovery, this research will also be focusing to find the optimum ΔT_{min} for heat energy recovery in the heat exchanger process. The selection of ΔT_{min} value has implications for both capital and energy costs.

For the petrochemical industries, the ΔT_{min} value is between 10^oC - 20^oC and isobutylene is one of the petrochemical industries in the world. Based on that, the focusing is to analyze the heat recovery with different ΔT_{min} which are 10^oC, 12^oC and 14^oC. By using the different of ΔT_{min}, we want to analyze which are the best of ΔT_{min} that can give the maximum of the energy recovery to this plant. In the late 1970s, pinch technology emerged as a tool for the design of heat exchanger networks against the backdrop of energy crisis. Its key contribution was to provide the engineers with simple concept of heat, power and thermodynamics, which can be used interactively in each stage of design. In 1980s, pinch technology received prime attention as a heat exchanger network design tool and it was found that this technology could save around 20–40% of energy bills of the industry.

1.3 Objectives of this research

This aim of the study is to minimize the cost utility for a production of 50,000 MT/A isobutylene plant. The objectives of the study were:

i) To minimize the energy usage of the plant.
ii) To study the effect of heat exchanger network to the plant economic.

1.4 Scopes of the research

i) Conservation of energy using Pinch Point in isobutylene plant
ii) To analyze the heat recovery with different ΔT_{min} which are 10°C, 14°C, 16°C and 20°C
iii) Target temperature, heat capacity, and mass flow rate of the process stream in the plant
iv) The study was done on reducing energy usage of the heat exchangers

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Background of Pinch Analysis

In the late 1978, Bodo Linnhoff a Ph.D student from the corporate laboratory, Imperial Chemical Industries Limited, ICI, under the supervision of professor John Flower, University of Leeds, devised a new approach to describe energy flows in process heat exchanger networks. It was an introduction of thermodynamic principles into what was then called ‘process synthesis’ and heat exchanger network design. Today, pinch technology has an established industrial track record. There are over 500 projects undertaken worldwide. The BASF Company alone has undertaken over 150 of these 500 projects. They have been able to achieve a saving of over 25 % of energy in their main factory at Ludwigshafen, Germany, by adopting this technique (Mubarak, E. Al- Kawari, 2000).

Pinch technology is a complete methodology derived from simple scientific principles by which it is possible to design new plants with reduced energy and capital costs as well as where the existing processes require modification to improve performance. An additional major advantage of the Pinch approach is that by simply analyzing the process data using its methodology, energy and other design targets are predicted such that it is possible to assess the consequences of a new design or a potential modification before embarking on actual implementation. Pinch analysis 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 take place, there is a potential opportunity. 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 process problems that go far beyond energy conservation. It has been employed to solve problems as diverse as improving effluent quality, reducing emission, increasing product yield and debottlenecking, increasing throughput and improving the flexibility and safety of the process (K.*R.* Ajao and H.F. Akande, 2009).

2.2 Pinch Analysis/Technique

Pinch technology is originally developed as a tool for the design of energy efficient heat exchange networks during the petroleum crises in the late 1970s and the early 1980s, in response to the sharp increase in the price of energy. Before that time, energy costs were usually represented around 5% of the total cost, but after that it rose to around 20% (P.Raskovic and S.Stoiljkovic, 2009). For a given project, it is based on identifying energy targets and identifies the minimum driving force across any of the heat exchanger's inlet/outlet streams. Recently, the technique has been extended to address capital cost, in which the capital-cost targets have been developed ahead of the design stage. An overall thermodynamic method has emerged which brings together energy and capital costs. In the beginning, the technique was applied for grass-root designs and subsequently it has been extended for the retrofits of old designs. Applying the pinch principle leads to promising, accurate results. These levels of temperature, which for the hot and cold composite curves are a means of separating the plant into two parts, are called streams above and below the pinch. This separation is important to indicate to the process engineer whether the locations of heaters and coolers are correct or not. Wrong positions will cause energy losses (Mubarak Ebrahim and Al-Kawari, 2000).

Pinch technology provides a systematic methodology for energy saving in processes and total sites. The methodology is based on thermodynamic principles. Figure 2.1 illustrates the role of pinch technology in the overall process design. The process design hierarchy 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 flowrates 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.

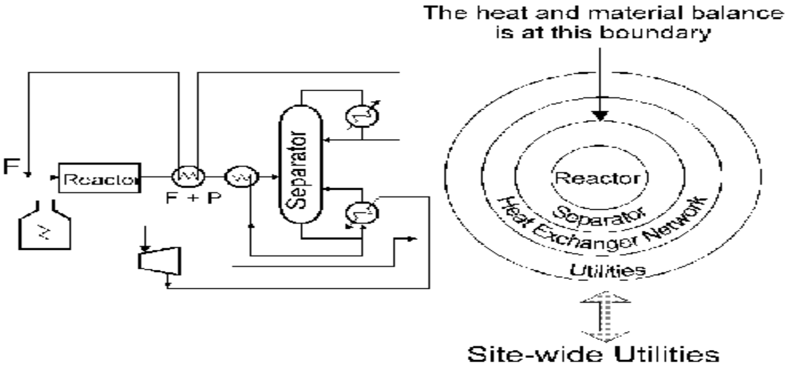

Figure 2.1: "Onion Diagram" of hierarchy in process design

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). 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 centralised 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 minimise 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 (Anonymous, date unknown)

The procedure for Pinch Technology consists of five phases: 1. Data extraction phase, 2. Simulation phase, 3. Phase of targeting and removing additional utilities, 4. Evaluation phase, 5. Design phase.

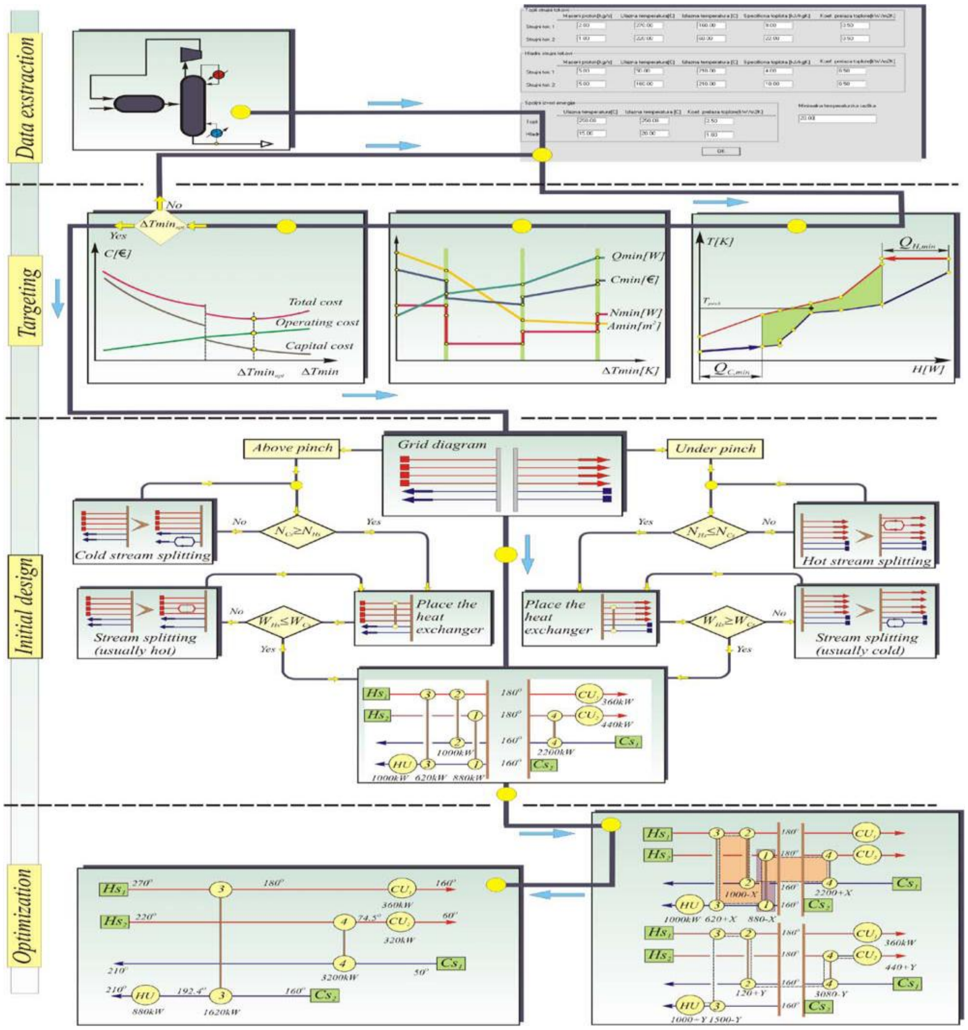

Figure 2.2: Flowchart of Pinch technology

2.2.1 Principle of Pinch Analysis

Consequently, a Pinch Point principle can be formulated as follows (Linnhoff and Hindmarsh, 1982).

- Do not transfer heat across the pinch
- Do not used cold utility above the Pinch
- Do not used hot utility below the Pinch

If there is heat flow across the pinch, then the energy consumption is higher than minimum necessary. Both hot and cold utility consumption will increase with the same amount XP above the minimum target. The Pinch equation is:

Actual energy (A) = target (T) + Cross-Pinch Energy Flow (XP)

Thus transferring heat across the pinch is a double loss in energy. However, during the effective design of the heat exchanger network, the initial target must be revised to accommodate constrains, as for example smaller number of units, or some imposed loads. The actual energy consumption could increase above the minimum targets, but the designer should try to keep the pinch violation as small as possible. Beside the stream data, supplementary information is needed as type, temperature and cost of utilities, partial heat transfer coefficients of stream and utilities, and also maximum heat transfer area of the heat exchanger. Because of the energy target increase linearly with ΔT_{min}, the cost of utilities follows the same trend. On the contrary, the capital cost decrease non-linearly with ΔT_{min}. The cost function exhibits a jump when the number of units changes. Therefore, the reduction in the number of units is by far more important overall cost optimization than the incremental reduction of heat transfer area.