HEAT INTEGRATION OF FRACTIONATORS FOR LOW TEMPERATURE SEPARATION UNIT (LTSU) AND PRODUCT RECOVERY UNIT (PRU)

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ABSTRACT

Chemical processing plant typically consumes a lot of energy that used to convert raw materials to desired products. Having said that, gas processing plant (GPP) also requires intensive energy to fractionate mixture of hydrocarbons into sellable products such as sales gas, ethane, propane, butane and so on. In order to reduce the operating cost, energy recovery through Pinch Analysis need to be carried out that utilize hot and cold streams of Low Temperature Separation Unit (LTSU) and Product Recovery Unit (PRU) in GPP. In this research, typical Process Flow Diagram (PFD) of LTSU and PRU has been modeled using Aspen Hysys V7.0. Existing energy consumption provides a basis for better process improvement. Therefore, both of Composite Curve and Problem Table Algorithm were used for targeting energy that can be recovered within the process as well as to determine Q_{Hmin} and Q_{Cmin}. It shows that the values of QHmin and QCmin are 539 kW and 4644 kW respectively and the energy that can be recovered is 2854 kW. To realize these recoveries, conceptual design of heat exchanger network (HEN) has been presented. The economic trade-off between energy saving and capital investment for heat exchangers should be determined for future considerations.

ABSTRAK

Loji pemprosesan kimia lazimnya menggunakan banyak tenaga yang digunakan untuk menukarkan bahan mentah kepada produk yang diingini. Berkata tentang tersebut, loji pemprosesan gas juga memerlukan banyak tenaga untuk memecahkan campuran-campuran hidrokarbon kepada produk-produk yang boleh dijual seperti gas jualan, ethane, propane, butane dan lain-lain. Bagi mengurang kos operasi loji, pemerolehan tenaga dilakukan melalui Analisis Pinch yang menggunakan stream panas dan sejuk. Di dalam kajian ini, Gambarajah Aliran Proses Unit Pengasingan Suhu Rendah dan Unit Pemerolehan Produk telah di modelkan menggunakan Aspen Hysys v7.0. Penggunaan tenaga yang sedia ada menyediakan asas untuk pembaikan proses yang lebih baik. Lantaran itu, kedua-dua Lengkung Komposit dan Jadual Masalah Algoritmatelah digunakan untuk mensasarkan tenaga yang boleh didapatkan kembali dalam proses serta bagi menentukan Q_{Hmin} dan Q_{Cmin}. Ia menunjukkan bahawa nilai-nilai QHmin dan QCmin masing-masing adalah 539 kW dan 4644 kW dan tenaga yang boleh didapatkan kembali adalah 2854 kW. Bagi melaksanakan pemerolehan semula ini, reka bentuk konseptual rangkaian penukar haba telah disampaikan. Kesimbangan ekonomi antara penjimatan tenaga dan pelaburan modal untuk penukar-penukar haba harus di tentukan untuk pertimbangan masa hadapan.

TABLE OF CONTENTS

2 LITERATURE REVIEW

3 RESEARCH METHODOLOGY

4 RESULTS AND DISCUSSION

5 CONCLUSION AND RECOMMENDATION

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Q_{REB}	-	Heat of reboiler
Q_{COND}	-	Heat of condenser
T_s	-	Supply temperature
T_T	-	Target temperature
^0C	-	Degree celsius
ΔH	-	Enthalpy
kW	-	kiloWatt
CP	-	Heat capacity flowrate of stream
$kW/^0C$	-	kiloWatt per degree celsius
ΔT	-	Temperature difference
$\sum CP_C$	-	Sum of heat capacity flowrate of cold stream
$\sum CP_H$	-	Sum of heat capacity flowrate of hot stream
Q_{Hmin}	-	Minimum hot utility requirement
Q_{Cmin}	-	Minimum cold utility requirement
Q_{rec}	-	Heat recovery
HE	-	Heat exchanger
H	-	Heater
C		Cooler

CHAPTER 1

INTRODUCTION

1.1 Research Background

Historically, natural gas has been used as a fuel for more than 150 years ago. Although used as a fuel over a long period, natural gas has achieved prominence as an important energy supply in early 1970's. When produced as an associated gas in the oil fields, natural gas was rarely used efficiently. In most instances, oil production was considered important, and gas production a nuisance. Natural gas was used as a supply for energy requirements for the oil field, and the rest was flared. However in 1980's it shown that the demand of natural gas was increased as a important sources.

Natural gas is a gas consisting primarily of methane. It is found associated with fossil fuel in coal beds as methane clathrates and is created by methanogenic organisms in marshes, bogs and landfills. Natural gas is often referred to as non-complex when compared to the other fossil fuels such as coal and petroleum. Besides that this gas also consist other hydrocarbon components such as ethane, propane, butane, pentane and heavier hydrocarbons together with non-hydrocarbon components such as elemental sulphur, carbon dioxide, water and sometimes helium and nitrogen. The exact compositions of natural gas usually depend on the geologic conditions where the natural gas is being extracted. To ensure that the natural gas can be used as sources of energy or as well asfeed stock for petrochemical plant, treatment processes always required to remove undesired impurities at which these processes happen in a Gas Processing Plant (GPP).

1.1.1 Gas Processing Plant

Figure 1.1 shows the simplified block diagram of the treatment processes in GPP. The selection of treatment processes are usually dictated by the amount of impurities in the raw natural gas.

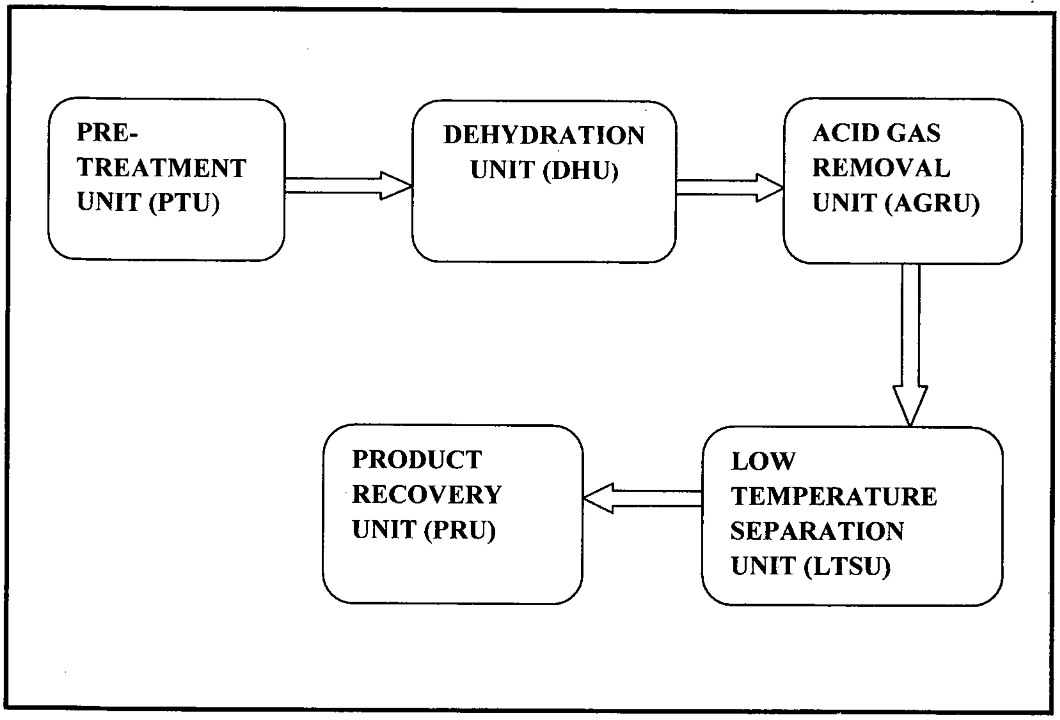


Figure 1.1: Simplified Block Diagram of Gas Processing Plant

The feed liquid and gas from the offshore fields and off gas from a crude oil terminal undergo first stage which is Feed Pre – Treatment Unit (PTU). This stage removes solid contaminants and chloride from the gas and liquid feed entering the system. The feed gas is sent to the Acid Gas Removal Unit (AGRU) where carbon dioxide is reduced to the desired level before the gas goes to the Low Temperature Separation Unit (LTSU). If the natural gas has unacceptable level of moisture then Dehydration Unit (DHU) will be installed to remove the moisture. If there is no level of moisture this gas will just goes to LTSU. In LTSU, drying of the gas and removal of mercury take place before the gas undergoes the various steps of cooling, chilling and separation. The chilled separated gas then goes into the Cold Turbo Expander for expansion to the pressure of the Demethanizer. The resulting coldest stream flows to the Demethanizer where methane or sales gas is separated from the ethane and heavier hydrocarbons which are fed to the Product Recovery Unit (PRU). The cold sales gas leaves the top of the Demethanizer and enters the Feed Gas Coolers where it is warmed up by cooling the feed gas. The warm sales gas is compressed up to product pressure by the Sales Gas Compressor. The sales gas is then sent to the sales gas pipeline and into the Peninsular Gas Utilities (PGU) system. The liquid feeds entering the PTU are dehydrated by Condensate Dryers before flowing into the Condensate Treatment Unit (CTU) where the lighter gas components are separated from the heavier liquids and mercury removed.

Part of the output goes to the LTSU for Demethanization and the other part to the PRU. There, the Deethanizer extracted ethane, while propane and heavier components as feed of the Depropanizer. Ethane goes into the ethane product pipeline and to the ethylene plant nearby. The Depropanizer produce propane product and butane and heavier components as a feed of the Debutanizer. The treated propane product then flows to the Propane Surge Drum where it is the transferred to the propane pipeline for onward transmission to the Export Terminal (ET) in Tanjung Sulong Kemaman and/or MTBE Propylene/Polypropylene plants in Gebeng, Kuantan. The Debutanizer produces butane product and condensate product. The treated butane product then flows to the Butane Surge Drum, where it is then transferred to the butane pipeline and to the ET and/or MTBE plants. Condensate from the Debutanizer flows to the Condensate Storage Tank, where it is sent to refinery for blending with crude oil.

1.1.2 Low Temperature Separation Unit (LTSU)

In LTSU as shown in Figure 1.2, drying of the gas and removal mercury take place before the gas undergoes the various steps of cooling, chilling and separation. The chilled separated gas then goes into the Cold Turbo Expander for expansion to the pressure of the Demethanizer. The resulting coldest stream flows to the Demethanizer where methane or sales gas is separated from the ethane and heavier hydrocarbons which are fed to the PRU. The cold sales gas leaves the overhead of the Demethanizer and enters the Feed Gas Coolers where it is warmed up by cooling the feed gas. The warm sales gas is compressed up to product pressure by the Sales Gas Compressor. The sales gas is then sent to the sales gas pipeline and into the PGU system. The liquid feeds entering the PTU are dehydrated by Condensate Dryers before flowing into the CTU where the lighter gas components are separated from the heavier liquids and mercury removed. Part of the output goes to the LTSU for demethanization process. While the mixture of hydrocarbon components at the bottom of the Demethanizer will goes to Product Recovery Unit (PRU).

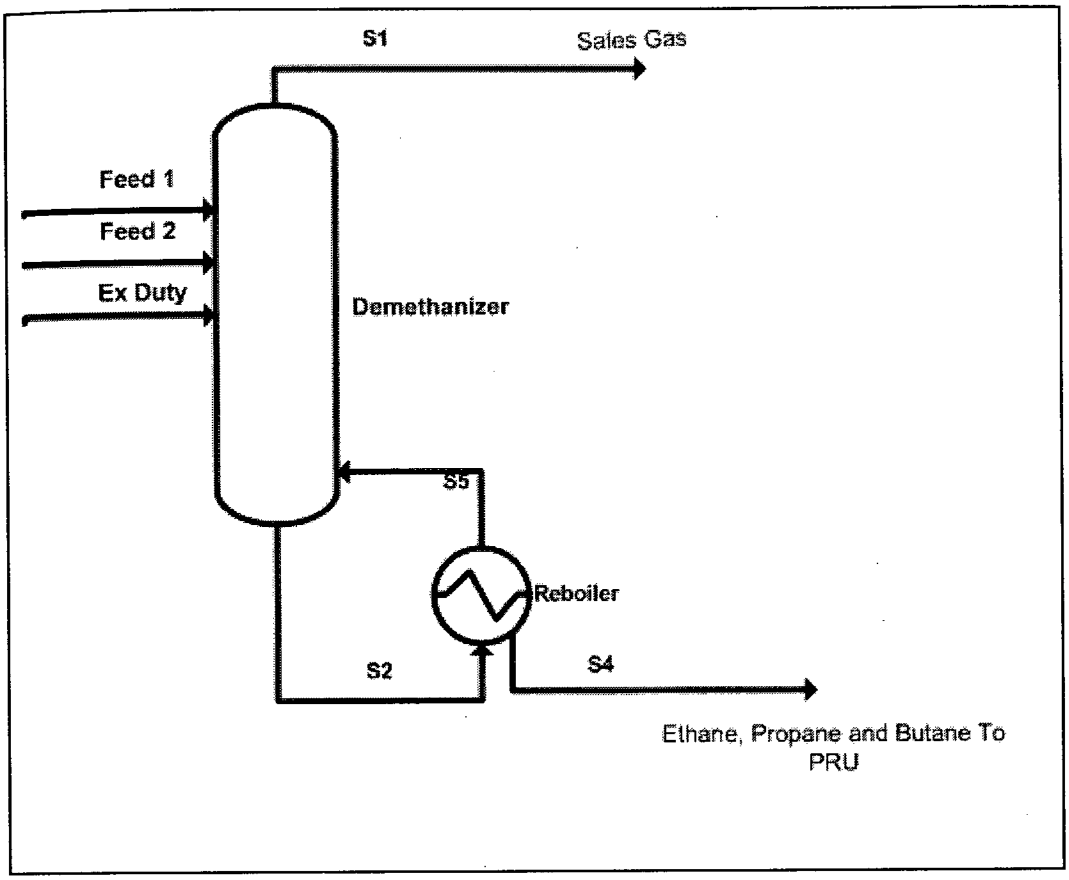


Figure 1.2: Low temperature separation unit (LTSU)

1.1.3 Product Recovery Unit (PRU)

The bottom products of Demethanizer will go to the other fractionation steps such as Deethanizer, Depropanizer and Debutanizer. All of this fractionators found in PRU. Typical fractionation trains are shown in Figure 1.3. It consists of series of distillation columns which are De-ethanizer. Depropanizer and Debutanizer. Each of these fractionators are designed to produce and to purify single component such as ethane, propane, normal butane and isobutene that called as natural gas liquids (NGLs). A parts from economic benefits of selling these NGLs, fractionation process are necessarily important to prevent hydrocarbons condensation during transportation.

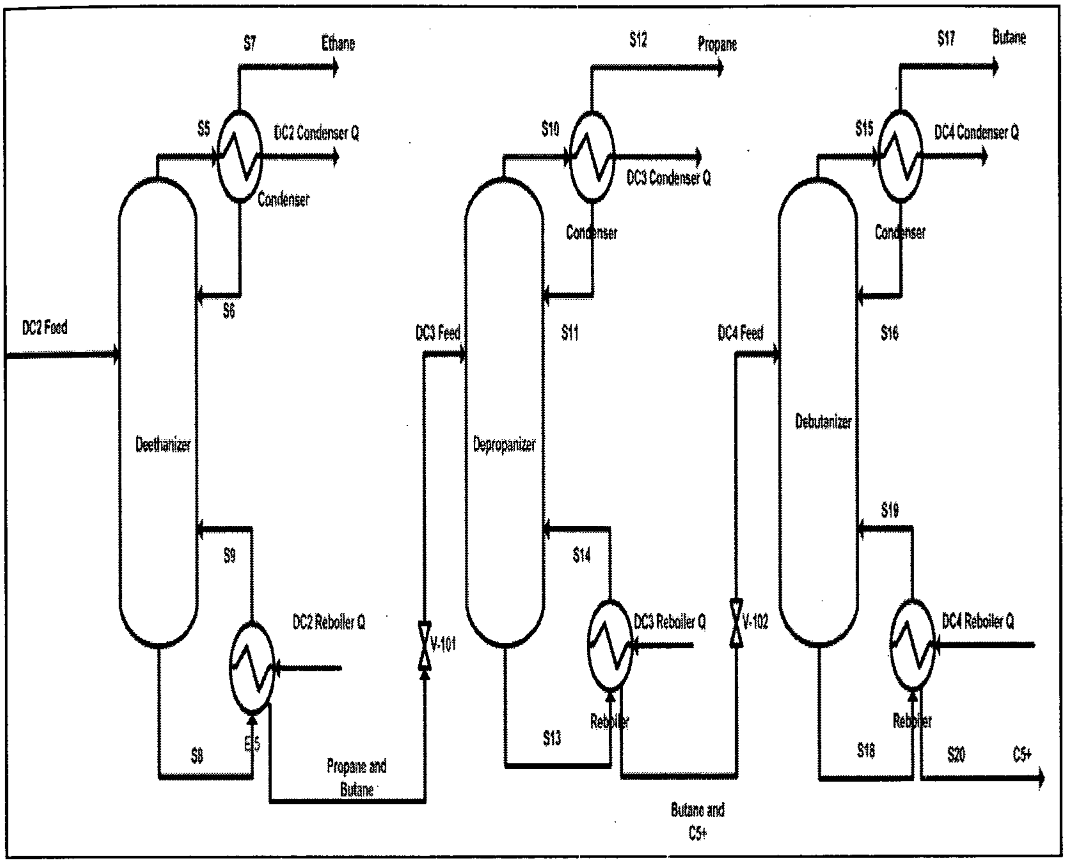


Figure 1.3: Product Recovery Unit

The NGL liquid enters the de-ethanizer, which separates the ethane from the mixed NGL liquid. The column operates with a partial condenser and produces a cold ethane gas product. The bottom product from the de-ethanizer feeds the de-propanizer. A propane stream is taken from the de-propanizer reflux drum. The de-butanizer removes the butane from the remaining NGL liquid. Pentane plus, or natural gasoline, is taken as a bottom product from the de-butanizer.

Before any design calculations can be made on a fractionation train, the column operating pressure must be fixed and these in turn will depend on the cooling medium used for the overhead condensers. Typical cooling media are air, water and refrigerant. Air cooling is the least expensive but process temperatures are limited to between 45°C and 50°C. With cooling water, process temperature of between 35°C and 40°C are possible. Below 35°C, refrigeration will be required and this is the most expensive option. Generally, it is best to operate at as low a pressure as possible in order to improve the relative volatility between key components. However, it will be necessary to carry out a life cycle economic analysis between the costs of the cooling system against the cost of adequate separation.

The reboilers of the fractionation columns can be steam or hot oil heated or they can be fired heaters. Steam heating is more commonly used. Increased steam pressure provides a greater temperature driving force, which reduces the surface area of the reboilers. The choice will depend on the availability of utilities and economic considerations. Another decision to be made is whether products are to be generated as a vapour and subsequently liquefied in the rundown system or whether total condensers are to be used again. Again, an economic analysis will dictate which the best option is. The type of processing will depend on the required state of the products and this will be dictated by market requirements and the export mode. The light products such as ethane can be exported as pressurized gas if there is a local market such as an ethylene cracker. Alternatively, a refrigerated product can be generated although this is likely to be costly because of the very low temperatures required. Products in the middle of the range such as propane, butane and LPG can be stored and exported in the totally refrigerated state at atmospheric pressure or as a pressurized fluid at ambient temperature. The heavy products such as gasoline are normally stabilized so that they can be stored and exported at ambient temperature and atmospheric pressure.

The NGL fractionation unit can be modified to improve the heat integration, thus reducing the heating and cooling demands. Some of the most common heat integrations are De-propanizer condenser linked to de-ethanizer reboiler, De-butanizer condenser linked to the de-propanizer reboiler, De-propanizer and de-butanizer feed/bottom exchangers, De-ethanizer overheads linked to de-propanizer and de-butanizer overhead product cooler.

1.2 Problem Statement

In chemical processing plant such as GPP, it typically consumes a lot of energy to fractionate mixture of hydrocarbons into sellable products such as sales gas, ethane, propane, butane and so on. To ensure the operating costs are kept at minimum value, which is the similar desire of purchasing costs by users, energy recovery through Pinch Analysis is recognized as one of practical and reliable approach From the previous research, energy recovery exercises through Pinch Analysis have been established for ethylbenzene plant while for a process which involve LTSU and PRU of GPP yet to be done.

1.3 Objectives of Research

In this research, there are two main objectives which are firstly; to model and evaluate the LTSU and PRU of GPP using Aspen Hysys v7.0. Secondly; once the Aspen Hysys model is converged, existing energy performance is used for targeting and recovering available energy within the fractionators in LTSU and PRU.

1.4 Scope of Research

The research is conducted to analyze the heat integration that will be used in LTSU and PRU. This research uses the simulation which called Aspen Hysys. Aspen Hysys is a process modelling tool for steady state simulation, design, performance monitoring, optimization and business planning for oil and gas production, gas processing and petroleum refining industries. The program built upon proven technologies with more than 25 years experience supplying process simulation tools to the oil, gas and refining industries. It proves an interactive process modelling solution that enables engineers to create steady state models of plant design, performance monitoring, troubleshooting, operational improvement and business planning and asset management. Hysys helps process industries improve productivity and profitability throughout the plant lifecycle. The powerful simulation and analysis tools, real time applications and the integrated approach to the engineering solutions enable the user to improve design, optimize production and enhance decision making (Aspen Tech, 2004). Hysys offer a high degree of flexibility because there are multiple ways to accomplish specific tasks. This flexibility combined with consistent and logical approachto how these capabilities are delivered makes Hysys a versatile process simulation tool (Aspen Tech, 2004).

In this research, it involves the modelling and improvement of existing Process Flow Diagram (PFD) of LTSU and PRU.

1.5 Benefits and Significances of Study

Using the heat integration potential analysis is one way to recover the waste and to reduce the heating and cooling demand of plant. The waste that has been recover can be use back, thus amount of the steam need to generated heat in order to supply heating demand can be reduced.

The GPP is the largest of production sales gas and other by product; therefore the heat integration analysis will make the big improvement in the industries. This research also can be used as a reference for the companies for their future development in this field. This research also will be the way and strategy to reduce the operating costs of the plant. Besides that, the heat integration makes the waste heat profitable instead of being waste.

CHAPTER 2

LITERATURE REVIEW

2.1 Pinch Technology

In the 1980s, Linnhoff *et al.* introduced the concept of ''target before design'' using pinch technology for the design of individual processes. Pinch technology for Heat Exchanger Network (HEN) design was developed by Linnhoff and Hindmarsh . Linnhoff and Ahmad, Ahmad *et al.* evolved the methodologies to incorporate total cost targeting and block-decomposition based HEN synthesis. Later an HEN retrofit framework, based on the ''process pinch'' (Tjoe and Linnhoff) and ''network pinch'' (Asante and Zhu) concepts was established. Over time pinch technology has been applied to increasingly large and complex sites. To facilitate this, a variety of tools and techniques have been developed to enhance the methodology and simplify the analysis. This case study considered one of the largest energy consuming areas yet subjected to ''Area-wide pinch technology''. The above-mentioned developments provide the background to the successful application of pinch technology to industrial area.

2.2 The Heat Integration Characteristics of Distillation

The dominant heating and cooling duties associated with a distillation column are the reboiler and condenser duties. In general, however, there will be other duties associated with heating and cooling of feed and product streams. These sensible heat duties usually will be small in comparison with the latent heat changes in reboilers and condensers. Both the reboiling and condensing process normally take place over a range of temperature. Practical considerations, however, usually dictate that the heat to the reboiler must be supplied at a temperature above the dew point of the vapour leaving the reboiler and that the heat removed in the condenser must be removed at a temperature lower than the bubble point of the liquid. Hence, in preliminary design at least, both reboiling and condensing can be assumed to take place at constant temperatures.

2.3 The Appropriate Placement of Distillation

There are two possible ways in which the column can be integrated with the rest of the process. The reboiler and condenser can be integrated either across, or not across the heat recovery pinch.

2.3.1 Distillation Across The Pinch

This arrangement is shown in Figure 2.1a. The background process, which does not include the reboiler and condenser, is represented simply as a heat sink and heat source divided by the pinch. Heat, Q_{REB} is taken into the reboiler above the pinch temperature and heat, Q_{COND} rejected from the condenser below pinch temperature. Because the process sink above the pinch requires at least Q_{Hmin} to satisfy its enthalpy balance, the Q_{REB} removed by the reboiler must be compensated for by introducing an extra Q_{REB} from hot utility. Below the pinch, the process needs to reject Q_{Cmin} anyway; an extra heat load Q_{COND} from the condenser has been introduced.

By heat integration the distillation column with the process and by considering only the reboiler, it might be concluded that energy has been saved. The reboiler has its requirements provided by heat recovery. However, the overall situation is that heat is being transferred across the heat recovery pinch technology through the distillation column and the consumption of hot and cold utility in the process must increase correspondingly. There are fundamentally no savings available from the separator across the pinch.

2.3.1 Distillation Not Cross The Pinch

This situation is somewhat different. Figure 2.1b shows a distillation column entirely above the pinch. The distillation column takes heat Q_{REB} from the process and returns Q_{COND} at a temperature above the pinch. The hot utility consumption changes by (Q_{REB} – Q_{COND}). The cold utility consumption is unchanged. Usually, Q_{REB} and Q_{COND} have a similar magnitude. If $Q_{REB} \cong Q_{COND}$, then the hot utility consumption is QHmin, and there is no additional hot utility required to run the column. It takes a "free ride" from the process. Heat integration below the pinch is illustrated in Figure 2.1c. Now the hot utility is unchanged, but the cold utility consumption changes by (Q_{COND} – Q_{REB}). Again, given that Q_{REB} and Q_{COND} usually have similar magnitudes, the result is similar to heat integration above the pinch. If both the reboiler and condenser are integrated with the process, this can make the column difficult to start up and control. However, when the integration is considered more closely, it becomes clear that both the reboiler and condenser do not need to be integrated. Above the pinch the reboiler can be serviced directly from the hot utility with the condenser integrated above the pinch. In this case the overall utility consumption will be the same as shown in Figure 2.1b. Below the pinch, the condenser can be serviced directly by cold utility with the reboiler integrated below the pinch. Now the overall utility consumption will be the same as that shown in Figure 2.1c.

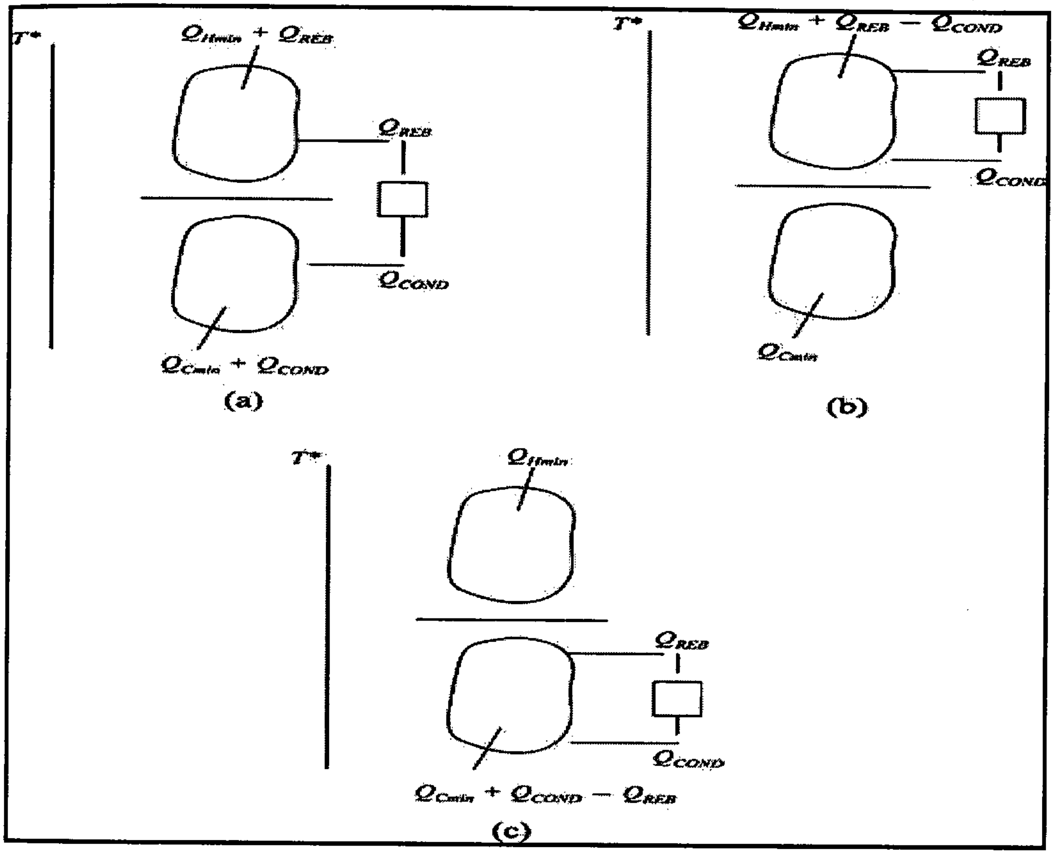
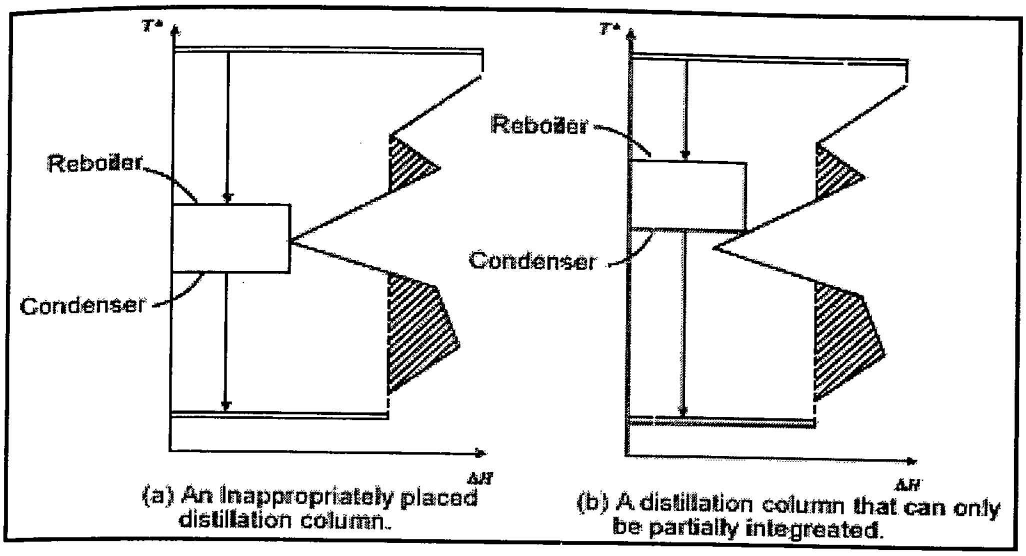


Figure 2.1: Reprinted from Chemical Process Design and Integration Book, The Appropriate placement of distillation columns, (From Smith R and Linnhoff B, 1988, Trans IChemE CheRD, 66:195, reproduced by permission of the Institution of Chemical Engineers)

2.4 Use of the Grand Composite Curve For Heat Integration of Distillation

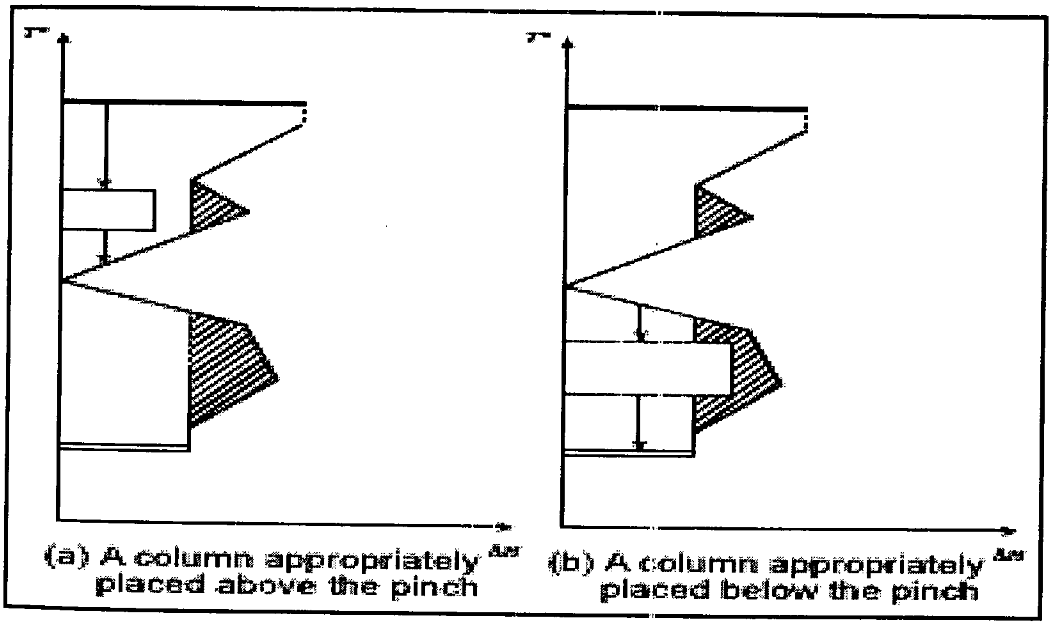
The appropriate placement principle can only be applied if the process has the capacity to provide or accept the required heat duties. A quantitative tool is needed to assess the sources and sink capacities of any given background process. For this purpose, the grand composite curve (GCC) can be used. Given that the dominant heating and cooling duties associated with the distillation column are the reboiler and condenser duties, a convenient representation of the column is therefore a simple "box" representing the reboiler and condenser loads. This "box" can be matched with the GCC representing the remainder of the process. The GCC would include all heating and cooling duties for the process, including those associated with separator feed and product heating and cooling, but excluding reboiler and condenser loads. Consider now a few examples of use this simple representation. A GCC is shown in Figure 2.2a. The distillation column reboiler and condenser duties are shown separately and are matched against it. The reboiler and condenser duties are on opposite sides of the heat recovery pinch and the column does not fit. In Figure 2.2b, although the reboiler and condenser duties are above the pinch, the heat duties prevent a fit. Part of duties can be accommodated, and if heat integrated that would be saving, but less than the full reboiler and condenser duties. The distillation columns shown in Figure 2.3 both fit. Figure 2.3a shows a case in which the reboiler duty can be supplied by hot utility. The condenser duty must be integrated with the rest of the process. Another example is shown in Figure 2.3b. This distillation column also fit. The reboiler duty must be supplied by integration with the process. Part of the condenser duty in Figure 2.3b must also be integrated, while the remainder of the condenser duty can be rejected to cold utility.



(a) An inappropriately placed distillation column.

(b) A distillation column that can only be partially integreated.

Figure 2.2: Distillation column that does not fit against the grand composite curve, (From Smith R and Linhoff B, 1988, *Trans IChemE ChERD*, 66: 195, reproduced by permission of the Institution of Chemical Engineers)



(a) A column appropriately placed above the pinch

(b) A column appropriately placed below the pinch

Figure 2.3: Distillation column that fit against the grand composite curve, (From Smith R and Linhoff B, 1988, *Trans IChemE ChERD*, 66: 195, reproduced by permission of the Institution of Chemical Engineers)

2.5 Previous Research

From the previous done by by Sung-Geun Yoon *et al.* heat integration has been conducted to a ethylbenzene plant. The target process in this research is the ethylbenzene process of LG chemicals in Yeosu, Korea. It focused to recover the waste heat by design heat exchanger network (HEN). After the ethylbenzene process study, the HEN of the current process can be extracted. The necessary data for this research are temperatures, heat duty, and heat capacity of each stream and available utility data. This study uses real operating data of the plant to extract the temperature and flow data of the process streams. Heat duty of each stream is calculated by Aspen Plus^{TM} using the real operating data. After analysis, an alternative HEN is proposed to save the energy. The alternative HEN is achieved by adding a new heat exchanger and changing operating conditions. It reduces the annual energy cost by 5.6%.