Report of Cooperative Education

Cold recovery in ASU process from cooling water improvement

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รายงานสหกิจศึกษาฉบับสมบูรณ์

การเพิ่มประสิทธิภาพของระบบน้ำหล่อเย็นโดยการนำความเย็นในระบบแยกอากาศมาใช้

นางสาวสุชานันท์ ตั้งทรงสุวรรณ์

รายงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรบัณฑิต

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ABSTRACT

The purpose of this cooperative project is to estimate efficiency of air cooler and to reduce power consumption of compressor by adjust the cooling water by vary % opening of valve. This work is separated into two parts, i.e., efficiency estimation of air cooler using LMTD and NTU methods and study effect of cooling water flow rate on power consumption of compressor. There are 4 heat exchangers (HE) that efficiency could be estimated by LMTD and NTU methods. The average of efficiency from LMTD and NTU methods are 0.86 and 0.64, respectively for HE20 and 0.54 and 0.61, respectively for HE21 at average flow rate of nitrogen 20.49 kNm^3/h. The average efficiency from LMTD and NTU methods are 0.5 and 0.58, respectively for HE521 and 0.75, and 0.58 for HE522. There are 32 cases were carried out in plant for study on effect of %open valve from power consumption. There are 23 and 3 cases that power consumption did not change or increase when adjust %open valve, respectively. There are only 6 cases that power consumption reduce significantly. The best scenario is %open valve of HE101, HE102, HE of C50, HE521, HE522 at 50%, 100%, 10%, 10%, and 10%. It could reduce power consumption about 98 kW.

ชื่อโครงงานสหกิจศึกษา: การเพิ่มประสิทธิภาพของระบบน้ำหล่อเย็น โดยการนำความเย็นในระบบกลั่นอากาศมาใช้
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บทคัดย่อ

โครงการสหกิจศึกษานี้วัตถุประสงค์เพื่อประเมินประสิทธิภาพของเครื่องทำความเย็นให้กับอากาศและหาวิธีลดการใช้ไฟฟ้าของเครื่องอัดอากาศโดยการปรับ % วาล์ว เพื่อปรับอัตราการไหลของของน้ำหล่อเย็น วิธีดำเนินงาน แบ่งเป็นสองส่วนคือ การประเมินประสิทธิภาพของเครื่องแลกเปลี่ยนความร้อนด้วยวิธี LMTD และ NTU และ ศึกษาเกี่ยวกับผลกระทบของอัตราการไหลของน้ำหล่อเย็นต่อการใช้ไฟฟ้าของเครื่องอัดอากาศ สามารถประเมินประสิทธิภาพของเครื่องแลกเปลี่ยนความร้อนได้ 4 เครื่อง พบว่าประสิทธิภาพโดยเฉลี่ยจากวิธี LMTD และ NTU มีค่าเท่ากับ 0.86 และ 0.64 สำหรับ HE20 และสำหรับ HE21 มีค่าเท่ากับ 0.54 และ 0.61 ที่อัตราการไหลเฉลี่ยเท่ากันคือ 20.49 kNm^3/h สำหรับ HE521 มีค่าเท่ากับ 0.5 และ 0.58 และ HE522 มีค่าเท่ากับ 0.75 และ 0.58 ในการศึกษาส่วนที่ 2 จากกรณีศึกษา 32 กรณีที่ถูกนำไปทดลองในโรงงานเพื่อศึกษาผลกระทบของเปอร์เซ็นต์การเปิดของวาล์วที่มีผลต่อการใช้ไฟฟ้าของเครื่องอัดอากาศ พบว่ามี 23 กรณี ที่การใช้ไฟฟ้าไม่เปลี่ยนแปลง และอีก 3 กรณีที่การใช้ไฟฟ้าเพิ่มขึ้น มีเพียง 6 กรณีที่การใช้ไฟฟ้าลดลง กรณีศึกษาที่ดีที่สุดคือการควบคุมการเปิดของ HE101, HE102, HE ของ C50, HE521, HE522 ที่ 50%, 100%, 10%, 10% ซึ่งสามารถลดการใช้ไฟฟ้าได้ถึง 98 kW

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Chapter I

INTRODUCTION

1.1 Background [1]

Air separation units (ASUs) are used mainly to produce high purity of nitrogen, oxygen and argon from air. These gases are widely used in several major manufacturing industries and usually called industrial gases. For example, nitrogen is mainly used in food packaging and stainless-steel manufacturing, while oxygen is used as raw material in many oxidation processes and metal production, and argon is used in welding industry and semiconductor manufacturing process. Air separation processes are classified in 2 type, i.e., is cryogenic and non-cryogenic air separation units. Cryogenic air separation units are used for large production of nitrogen, oxygen and argon because it has the most efficient and cost-effective technology. This technology could produce of oxygen, nitrogen, and argon as gaseous or liquid products. Process of cryogenic air separation could be divided 5 steps, i.e., air compression, pre-cooling and purification with molecular sieve, cooling of air, cryogenic rectification of air, and cryogenic rectification of argon.

Air compression unit is a unit that consumed a lot of power to produces air at high pressure, so air compressed air is typically one of the most expensive utilities in an industrial facility. From survey of US department of energy, the operating cost is about 88% of the total lifetime cost is (electricity (76%) and maintenance (12%)), the remaining 12% of the total lifetime cost is installation. Thus, the better management of air compression unit is will lead to cost saving in ASUs.

A typical air compression unit consists of various equipment such as air compressor, air coolers, air dryers, filters, and piping system. Each of equipment shows potential for energy loss in form of flow or pressure loss in system. Since approximately 80% of the electrical energy going to compressor is converted into heat, and heat that generated this must be removed by air cooler. Typical compressor in ASUs are multistage so they required both of intercooler and aftercooler. These air coolers should be cleaned periodically to maximize the heat transfer capability for energy efficiency.

In this study, air coolers in air separation unit of Air Liquide company at Laem Chabang site are investigated to find efficiency and solution to improve efficiency and cost saving This work is separated into two parts. Part 1 is to estimate efficiency of air cooler necessary information and prioritize unit that need to be cleaned. Part 2 is to study the effect of cooling water flow rate on power consumption of compressors for air coolers that no data available foe calculation.

1.2 Objectives

1) To study air separation units (ASUs) process and create process flow diagram (PFD)
2) To estimate efficiency of air cooler in air compressor unit
3) To reduce power consumption of compressor by adjust the cooling water by vary %opening of valve.

1.3 Scopes of work

1) The main units that are invested are air cooler in main air compressor (C10), Nitrogen compressor (C50,51,52), Recycle compressor (C30/60), Warm booster (C20), Cold booster (C21), Oxygen compressor (C41,42) is estimated
2) The study on vary % of opening of valve are consider only valve of air cooler in main compressor (C10), Nitrogen compressor (C50,52) is adjusted to study power consumption cost.

1.4 Expected Outputs

Estimate efficiency of air coolers in compressor and from units with necessary information and options for %valve of opening in main compressor that lead to significantly reduce power of consumption.

Chapter II

THEORY AND LITERATURE REVIEW

In this chapter, the theory and literature review associate with this project are mentioned. They are separated into 5 parts. Part 1 is introduction about air. Part 2 is air separation technologies. Part 3 focus on cryogenic air separation. Part 4 is introduction compressed air systems. Part 5 is introduction about heat exchanger and methodology of estimation efficiency of heat exchanger.

2.1 Properties of air[2]

Air is mixture of many gases which is made up mostly by nitrogen (78.08 %), oxygen (20.95 %), and the inert gas argon (0.93 %). The remaining gases are carbon dioxide (0.03 %), and other inert gas is such as neon, helium, krypton and xenon, methane, and hydrogen. Water vapor is also a constituted of air in varying amounts along with dust particles depending on the temperature. Air that contains water vapor is called moist air. If air doesn't contain water, it is called dry air. Physicals of air are colorless, odorless and tasteless gas mixture. Some properties of dry air components show in Table 2.1.

Table 2.1. Properties of dry air components.[3]

Components in dry air		Concentration of each component in dry air		Atmospheric boiling point	
Name	Formula	vol%	wt%	°C	K
Nitrogen	N_2	78.084	75.52	-195.8	77.4
Oxygen	O_2	20.946	23.14	-183.0	90.2
Argon	Ar	0.934	1.29	-185.8	87.3
Carbon dioxide	CO_2	0.033	0.051	-78.5	194.7
Neon	Ne	1.818×10^{-3}	1.3×10^{-3}	-246.0	27.2
Helium	He	5.24×10^{-4}	7×10^{-5}	-269.0	4.2
Methane	CH_4	1.79×10^{-4}	1×10^{-4}	-161.5	111.7

Components in dry air		Concentration of each component in dry air		Atmospheric boiling point	
Name	Formula	vol%	wt%	$^{\circ}C$	K
Krypton	Kr	1×10^{-4}	2.9×10^{-4}	-153.4	119.8
Hydrogen	H_2	5×10^{-5}	3×10^{-6}	-252.9	20.3
Xenon	Xe	9×10^{-6}	4×10^{-5}	-108.1	165.1

2.2 Air separation technologies

The basic of air separation technology is divided 2 type, i.e., cryogenic or non-cryogenic technology. Each of technologies are applied depend on the number of products that must be supplied, the required production rates for each gas and liquid product and required product purities.

2.2.1 Cryogenic air separation

Cryogenic air separation is a process by which highly purified gases or liquids are produced. This is achieved by taking large volumes of air from the atmosphere, which are then compressed, cooled, and liquefied. The air is then separated into its major components by a process of distillation. After the air is compressed, impurities must be removed.

In cryogenic gas processing, various equipment is used in cryogenic air separation such as distillation column, heat exchangers, cold interconnecting piping etc. These equipment are operate at very low temperatures, so there are located inside sealed or "cold boxes" and must be well insulated. The structure of cold box is tall with either a round or width rectangular cross section. The height of cold boxes may be varied from 15-60 meters and 2-4 meters depending on the plant type, size and capacity. A cryogenic unit as described above is commonly described as an "air separation unit" ("ASU").

2.2.2 Non-cryogenic air separation

For non-cryogenic air separation, there are two available technologies, i.e., adsorption and membrane air separation.

2.2.2.1 Adsorption air separation [4][5]

In air separation process using adsorption, it can be classified in 2 types including pressure swing adsorption (PSA) and vacuum swing adsorption (VSA). For pressure swing adsorption, zeolites and carbon molecular sieves (CMS) are commonly used as adsorbent which used to separate component in air. When use zeolite in air separation process, non-uniform electrical fields in the void space causing the favorable of polarize molecule. Nitrogen molecules are more polarizable than oxygen and argon molecules, so nitrogen molecules are more preferable absorbed than oxygen and argon molecules. The oxygen-rich stream is sent out of the beds. For carbon molecular sieve, components in air are separated by pore size of materials. The oxygen molecules are much smaller than nitrogen molecules, so oxygen can diffuse into cavities of the adsorbent faster than nitrogen molecules. Thus, zeolites are used for oxygen production and carbon molecular sieves (CMS) are used for nitrogen production. From flowsheet in figure 2.1, it shows the oxygen production process using zeolite as adsorbent. Pressured air enters a vessel containing the zeolite and nitrogen molecules are adsorbed. The oxygen-rich stream is produced after adsorbent is saturated. The saturated adsorbent must be regenerated by heating the bed and reducing the pressure in the bed. Then feed air is switch to a fresh vessel. For vacuum swing adsorption (VSA), it differs from pressure swing adsorption (PSA) techniques as the air is separated with a vacuum which a faster cycle time.

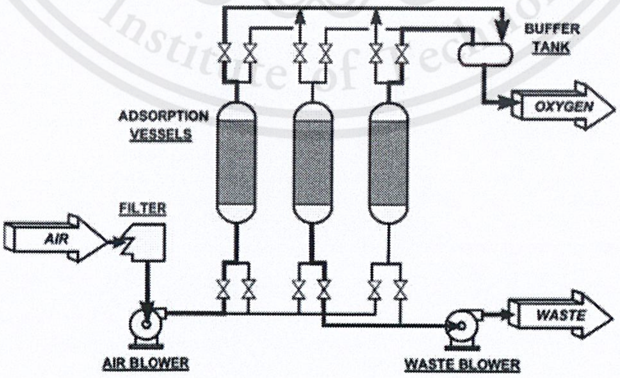


Figure 2.1. Adsorption-based air separation process.

2.2.2.2 Membrane air separation[4][5]

In membrane processes, the principle of air separation is base on different permeation rate of each component in air through a membrane. Because oxygen molecules are smaller than nitrogen and argon, so most membrane materials are more permeable to oxygen than nitrogen. From flowsheet in Figure 2.2, air sent to air blower to supply enough head pressure to overcome pressure drop in a filter, membrane tubes and piping. Oxygen is permeated through a fiber (hollow fiber type) or sheet (spiral wound type) and is remove as product. Carbon dioxide and water appear in oxygen-rich product since these components are more permeable than oxygen molecule. The advantage of membrane process is fast start-up time, simply, continuous process and operating at near ambient conditions but the weak point is also appealing

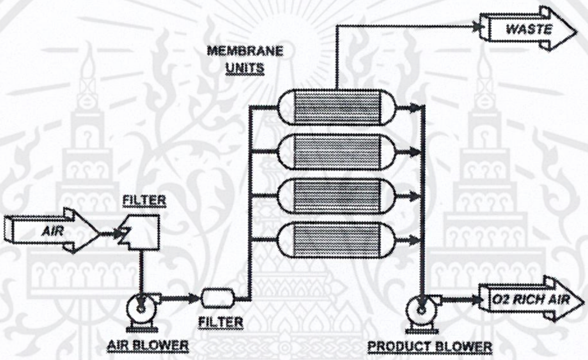


Figure 2.2. Membrane air separation process.

2.2.2.3 Comparisons of process alternatives[5]

The comparison of different methods of oxygen process selection on purity of oxygen and production rate are represented in Figure 2.3. For low volume of gaseous production, adsorption process may be recommended process. For liquid product, large volume gaseous products with high purity product. Cryogenic processes is more suitable.

Adsorption and membrane processes are technologies that developed continuously to energy efficiency by developing new adsorbents and membrane materials. Both of technology are expected to replace cryogenics in large tonnage production of oxygen, and high purity. Adsorption and membrane processes are less complex and more passive than cryogenic technology.

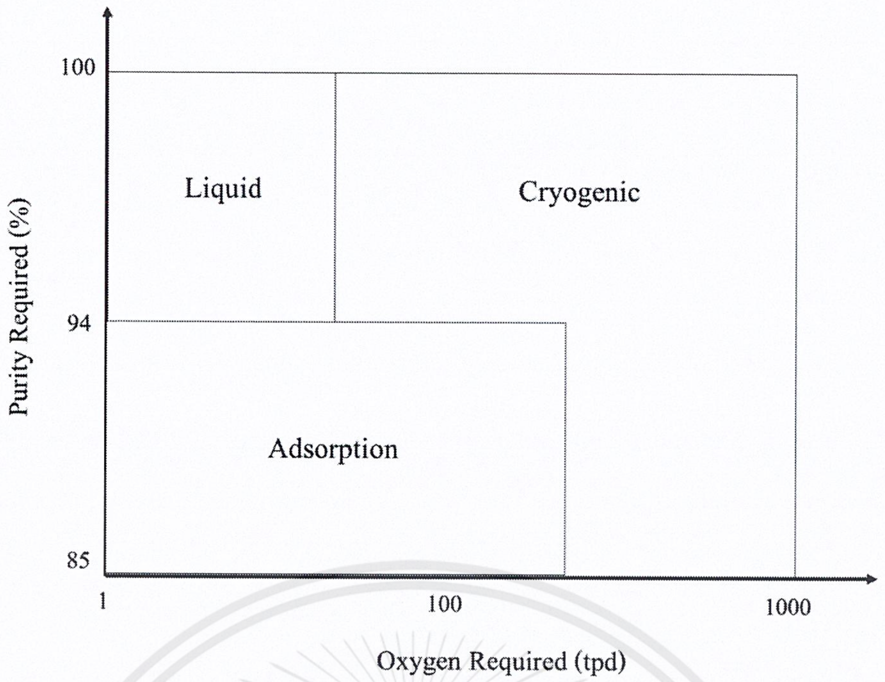


Figure 2.3. Oxygen production process selection.

Table 2.2 compares the various technologies based on the following categories. Status is the degree to which the technology has been commercialized. Byproduct Capability is a measure of the ability of the process to produce relatively pure nitrogen or argon streams. Purity Limit is the maximum purity that can be economically produced using the specific technology. Start-up Time is a measure of the time required to restart the process and reach purity after a shutdown. Thus, cryogenic air separation is applied in air separation unit because of the mature of technology, excellent capacity of product, high purity and hours to start up. Process description of cryogenic air separation will be extensively explained in the next topic.[5]

Table 2.2. Comparing of ASUs technology based on technology status and other.

Process	Status	Byproduct capability	Purity limit (vol%)	Start-up time
Adsorption	Semi-mature	Poor	95	Minutes
Cryogenic	mature	Excellent	99+	Hours
Membrane	Semi-mature	Poor	~ 40	Minutes

2.3 Cryogenic air separation[5]

Cryogenic air separation is the most efficient and cost-effective technology for producing large quantities of oxygen, nitrogen, and argon as gaseous or liquid products. An air separation unit ASU using a conventional, multi-column cryogenic distillation process to produce oxygen from compressed air at high recoveries and purities. Cryogenic technology can also produce high-purity nitrogen as a useful byproduct stream at relatively low cost. In addition, liquid argon, liquid oxygen, and liquid nitrogen can be added to the product slate for stored product backup or byproduct sales at low incremental capital and power costs.

2.3.1 Process description

Process flow diagram of cryogenic air separation unit is presented in Figure 2.4. It could be divided into 5 sections, i.e., preliminary air purification and air compression, Preliminary air cooling and purification, air cooling, air separation, gaseous and liquid storage.

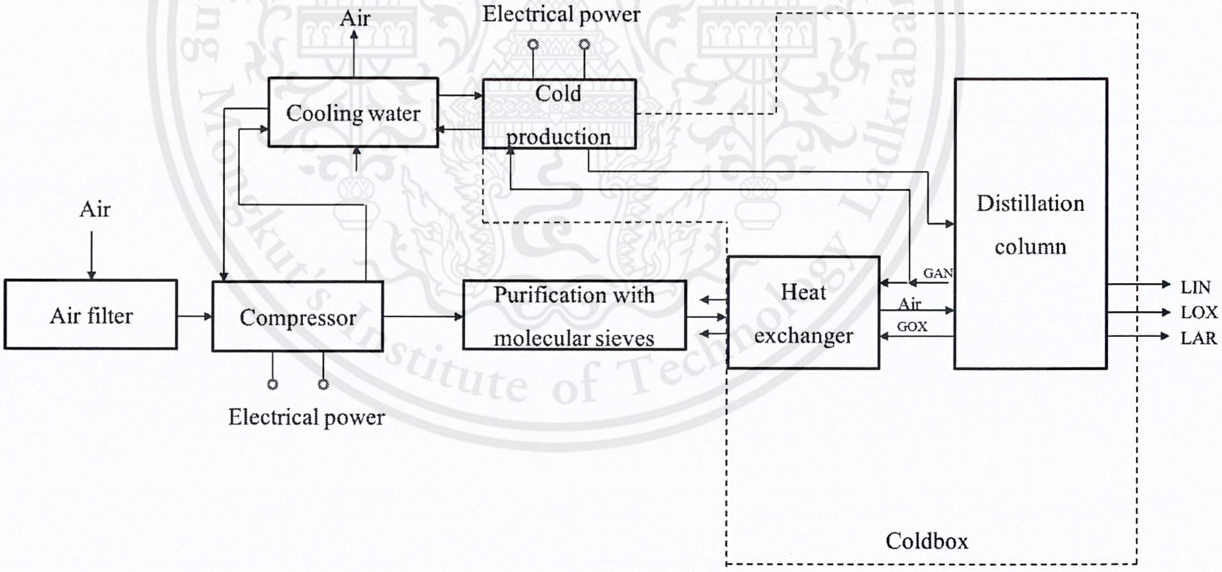


Figure 2.4. Process diagram of cryogenic air separation unit.

2.3.1.1 Preliminary air purification and air compression[6][7][8]

The first step of cryogenic air separation is filtering due to air in atmosphere compose of fine solid particles as known as dust particles. Dust or particulate matter are suspended tiny, solid particles in the air. It can be generated and released into air by natural and man-made activities. The natural erosion of soil, sand and rock is mainly source of dust. Pollen, microscopic organisms and plant material are also part of the dust in the environment. Man-made, dust are generated from household activities to industrial activities.[6] Thus, air must be filtered before to remove fine solid particle. After that, air is compressed to increase pressure of air to about 5-10 bar to saving energy during liquefaction process of air. From vapor pressure curves of atmospheric gases in Figure 2.5, it indicates that air at atmospheric pressure could be liquified at temperature 81.5 K (-191.65°C). If air is compressed to 5-10 bar, air could be liquified at temperature about 101 K (-172.15 °C).[7]

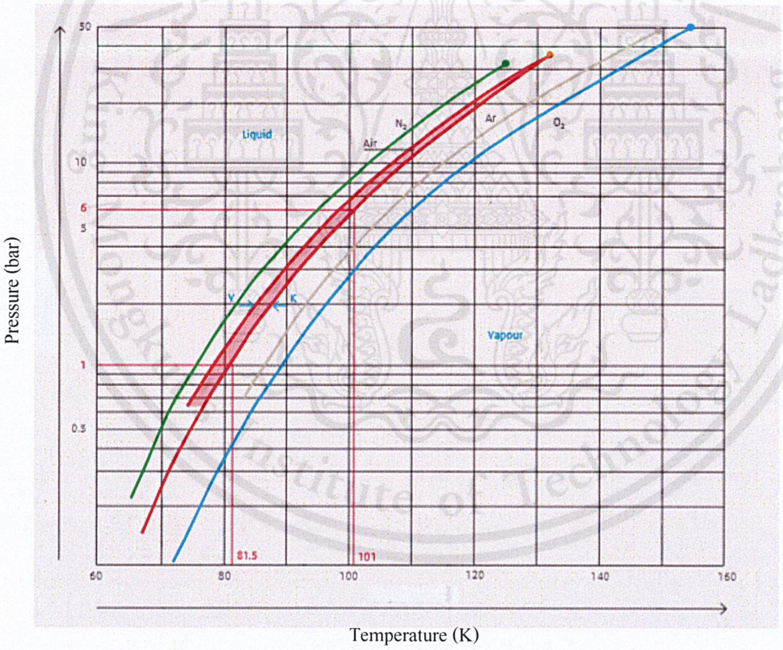


Figure 2.5. Vapor pressure curves of atmospheric gases.

In air compression unit, moisture in the air which this moisture is concentrated since air is compressed. Due to high temperature of air after compression process, moisture remains in vapor state (above the dew point temperature). If systems is cooled, water in vapor phase will become to liquid. To avoid the condensation of water in piping and air-compressing systems, moisture must be removed. Nowadays, technologies to remove moisture from compressed air are after-coolers, refrigerant dryers, over-compression systems, and absorption and adsorption dryers. In air separation unit, inter cooler and after cooler are used in a multistage compressor.[8]

2.3.1.2 Preliminary air cooling and purification[9] [10]

After air is compressed to required pressure, the outlet temperature is about 100°C. Hot air from the compressor is cooled down to about 283K by chilled process water. Wash water tower is used to cool hot air by contact directly between cooling water and hot air in counter-current flow. Cooling water will be dispersed into small droplets by multiple spray nozzles which are installed on the top of wash water tower. The water droplets fall and contact with the counter current air. Air flows by using a drafted fan. Heat will be transferred from to cooling water. As a result, the temperature of hot air is decreased. Moreover, remaining moisture and possible traces such as SO_2, NO_2, NH_3, and Cl_2 in air could be removed in this step. In some cases, hot air after passing primary wash water tower will be cooled down again with mechanical refrigeration system to much lower temperature minimize power consumption.[9]

For air purification unit, the two cycle molecular sieve further remove impurities is used to remove the remaining of moisture, carbon dioxide (CO_2) and potentially hazardous hydrocarbons from the air. Those components must remove before the air enters the distillation since water and carbon dioxide (CO_2) could be frozen and change to solid damage form at low temperature and cryogenic equipment. This form of ice crystal could lead to explosions due to deposited on the surfaces of the process equipment. Two cycle operating consist of one adsorber that capture these impurities from purifying the air and the other adsorber is for regeneration of adsorber when molecular sieve become saturated with these impurities. Processes of regeneration cycle consist of heating, cooling, pressurizing and depressurizing. Waste gas from the rectification unit is used as the regeneration gas. It is heated up by electrical heater to desorbs water and CO_2 from the molecular sieve. At the cooling period, the heater is turned off and the adsorbent is cooled down with cold dry waste nitrogen gas. The peak temperature during cooling cycle is important indicator to indicate sufficient regeneration. After the completion of regeneration cycle, the adsorber is pressurized before being switched over to adsorption cycle. The cycles are automatically controlled. The dangerous acetylenes, dienes and C4+ hydrocarbons are completely eliminated during this process. However, rare gases are chemically fairly non-reactive (inert gases), so they do not affect with air separation process. In addition, from their low boiling point, they always in a gaseous state form during air separation.[10]

2.3.1.3 Air cooling[11] [12]

In order to obtain the required conditions for air distillation, the purified air is cooled down to near dew point of air which about -180°C by main heat exchanger (a plate fin heat exchanger)[10]. Inside a plate fin heat exchanger, air is cooled down to about liquefaction temperature while the cold oxygen and nitrogen gases streams from the distillation column are heated up[11]. Part of the liquefied air is rich in oxygen. The remaining gas is rich in nitrogen and is distilled to almost pure nitrogen.[12]

2.3.1.4 Air separation[11]

Cryogenic separation is used in air separation unit since the liquefaction of air occurs at a temperature from approximately -170°C to -190°C. The separation process must operate in a thermally-insulated cryogenic system. Most air-separation units currently adopt a double-column rectification process, involving two rectification columns which are pressure column and low pressure column as shown in Figure 2.6.

In pressure column, air are separated into 2 parts, the more volatile nitrogen at the top of column and an oxygen-enriched liquid in the sump. High-purity nitrogen vapor at the top column is condensed and heat that removed from nitrogen vapor is used to evaporate the liquid oxygen in the sump of the low-pressure column. About 60% of total gas flow to the condenser is required as reflux in the pressure column. Pressurized gaseous nitrogen can be taken out as a product at the top. The remaining of liquefied nitrogen is withdrawn, subcooled, and fed into the top of low- pressure column, where it is needed as reflux. The oxygen-enriched liquid from the pressure column sump is subcooled, and fed into the middle of the low-pressure column. At the low-pressure column, the sensible heat of the stream is used to heat the sump of pure argon column and a part of the liquid stream is evaporated on the top column of crude argon and pure argon column in main condenser, so providing the necessary reflux for these columns.

In the low-pressure column (LPC), components in air are separated into 3 main components which are high-purity oxygen and nitrogen, while a side cut stream with oxygen-argon gas mixtures is feed into the crude argon column. This column is operated at atmospheric pressure.

The least volatile component oxygen is enriched up to more than 99.5% in the sump. Gaseous of oxygen (GOX) product is withdrawn shortly above the reboiler. About half of the total 70-80 theoretical trays in the LPC are necessary to separate the argon from oxygen. In crude argon column, the oxygen-rich gas with about 7-12% argon and less than 100 ppm nitrogen is withdrawn which nitrogen content in this stream should be low because this component behaves as a noncondensable in the crude argon condenser. The most volatile component, nitrogen, it is enriched at the top. The gaseous nitrogen (GAN) is taken from the top of the low-pressure column. In the upper part of the LP column about 8-20 theoretical trays below the top, a waste gas with 0.5% of O_2 is withdrawn. The gaseous products and the waste gas are used to cool the liquid streams from the HP to the LP column and then warmed to environmental temperature in the main heat exchanger, so incoming feed air is cooled down. A part of waste gas is used to regenerate the second of two molecular sieve adsorbers in purification unit. After the depressurization phase to ambient pressure, the regeneration period includes a heating period with waste gas heated up to about 473 K and cooling period with waste gas.

In the crude argon column, the more volatile argon is separated completely almost from oxygen. Oxygen content in the crude argon at the top of the column which lower than 1 ppm and the small amount of nitrogen with less than 100 ppm in this feed is enriched to 0.3% N2 in crude argon at the top of the column because the equilibrium between oxygen and argon product is tight. Thus, only 3-4% of the gas to crude argon condenser can be taken out as crude argon product. Then, it is feed to the pure argon column. The remaining about 96% is condensed are forms the reflux. A pump is used to pump the liquid from the sump of this column back to the top of oxygen section of the LP column. In the pure argon column, the nitrogen is removed in the stripping section and released to the atmosphere, while pure liquid argon is taken out from the sump of the pure argon column as product.[11]

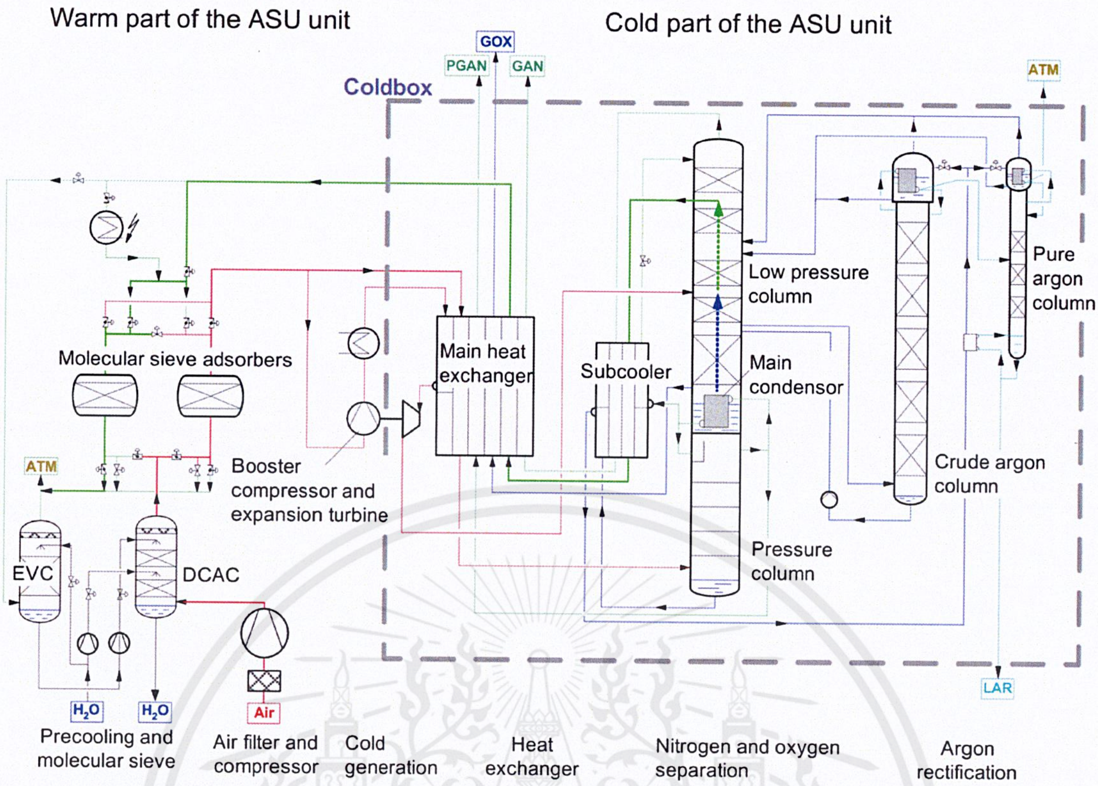


Figure 2.6. Flow diagram of an air separation unit for production of gaseous nitrogen, oxygen, and liquid argon.

2.3.1.5 Gaseous and liquid storage[9]

Gaseous oxygen and nitrogen are fed into pipelines to transport to uses. For liquid nitrogen, oxygen, and argon. They are stored in tanks and transported to customers.[9]

2.4 Compressed air systems[13]

2.4.1 Introduction compressed air systems

A compressor is a machine that is used to increase the pressure of a gas. Compressed air is used widely since small to large industry and is often considered the “fourth utility” at many facilities. In many cases, the compressed air system is so vital that the facility cannot operate without it. Plant air compressor systems can vary in size from a small unit of 5 horsepower (hp) to huge systems with more than 50,000 hp.

In many industrial facilities, air compressors use more electricity than any other type of equipment. Inefficiencies in compressed air systems will be significant. Thus, Energy savings in air compressor need to consider due to improvement system can saving energy from 20 to 50 percent or more of electricity consumption. A properly managed compressed air system can save energy, reduce maintenance, decrease downtime, increase production throughput, and improve product quality.

Air compression systems consist of a supply and demand side. Supply side consist of compressors and air treatment. Parts of demand side are composed distribution and storage systems and end-use equipment. A properly managed supply side will result in clean, dry, stable air being delivered at the appropriate pressure in a dependable, cost-effective manner. A properly managed demand side minimizes wasted air and uses compressed air for appropriate applications. Improving and maintaining peak compressed air system performance requires addressing both the supply and demand sides of the system and how the two interact.

Compressed air system in modern industrial is composed of several major sub-systems and many sub-components. Major sub-systems include the compressor, prime mover, controls, treatment equipment and accessories, and the distribution system. The compressor is the mechanical device that takes in ambient air and increases its pressure. The prime mover powers the compressor. Controls serve to regulate the amount of compressed air being produced. The treatment equipment is used to remove contaminants from the compressed air, and accessories keep the system operating properly. Distribution systems are analogous to wiring in the electrical world which they transport compressed air to where it is needed. Compressed air storage can also serve to improve system performance and efficiency. Industrial compressed air system and its components represent in Figure 2.7.[13]

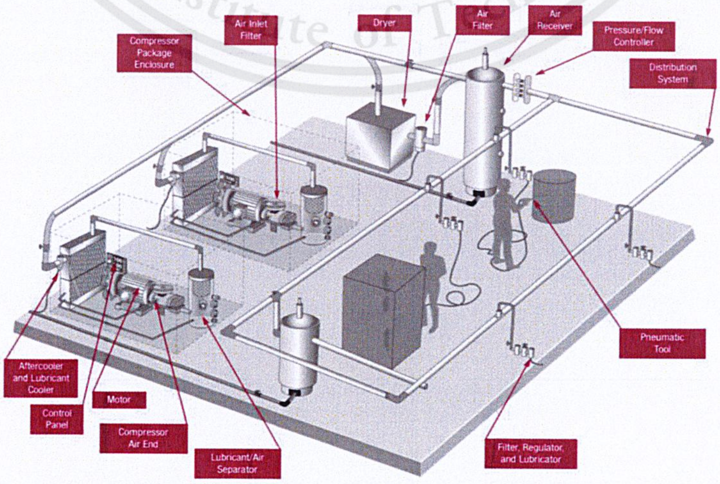


Figure 2.7. Components of a Typical Industrial Compressed Air System.

2.4.2 Types of compressors[13]

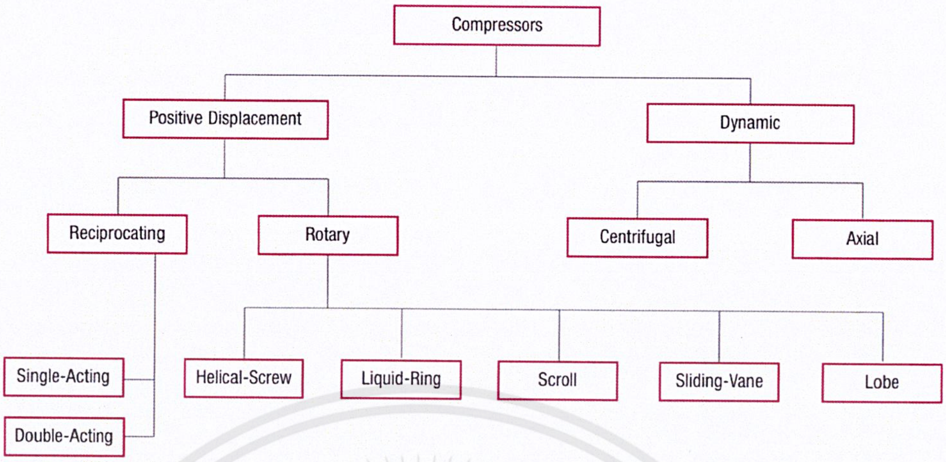


Figure 2.8. Types of compressor.

From Figure 2.8, it shows type of compressors which divided 2 basic compressor types that are positive-displacement and dynamic. For the positive-displacement type, compression chamber trap a given quantity of air or gas which volume is reduced mechanically to corresponding rise in pressure prior to discharge. Dynamic compressors sent velocity energy to continuously flowing air or gas by rotate impellers at very high speeds. The velocity energy is changed into pressure energy both by the impellers and the discharge volutes or diffusers. In the centrifugal-type dynamic compressors, the shape of the impeller blades determines the relationship between air flow and the pressure (or head) generated.[13]

2.4.2.1 Centifugal compressor[14]

In this project, centrifugal compressors are studied since centifugal compressors are used in air separation unit to compress air, nitrogen, and oxygen gas, the principle of these compressors are deeply studied. A centrifugal compressor is operated by its radial discharge flow. Air is drawn into the center of a rotating impeller with radial blades and then is pushed out towards the perimeter of the impeller by centrifugal forces. Result of pressure rising and a generation of kinetic energy is occurred by the radial movement of the air simultaneously. The air passes through a diffuser and a volute where the kinetic energy is converted into pressure before the air is led to the center of the impeller of the next compressor stage.

In industrial machinery, the maximum pressure ratio of a centrifugal compressor stage is often not more than 3. If system operate at higher pressure ratios, the stage efficiency is reduced. Operating with single-stage are used at low pressure such as wastewater treatment plants. For multistage applications allow the possibility of inter-cooling to reduce the power requirement. Multiple stages can be arranged in series on a single, low-speed shaft. They are often used in the oil and gas or process industry. The pressure ratio per stage is low, but a large number of stages and/or multiple compressor sets in series are used to achieve the desired outlet pressure. The impeller is normally made of special stainless steel alloy or aluminum. Shaft speed of impeller is very high when compare with other types of compressor. Speeds of this type compressor is operated commonly at 15,000-100,000 rpm.

In a modern configuration of the centrifugal air compressor, ultra high speed electric motors are used to drive the impellers directly. This technology creates a compact compressor without a gearbox and associated oil-lubrication system, thereby making it a completely oil-free compressor design. Each centrifugal compressor must be sealed in a suitable manner to reduce leakage along the shaft where it passes through the compressor housing. Many types of seals are used and the most advanced can be found on high-speed compressors intended for high pressures. The most common types are labyrinth seals, ring seals or controlled gap seals, (usually graphite seals) and mechanical seals.[14]

2.4.3 Adiabatic expansion[15]

An adiabatic process is a thermodynamic process, which is no heat transfer into or out of the system ($Q = 0$). The system can be considered to be perfectly insulated or processes occurred rapidly. In an adiabatic process, energy is transferred only as work. In these rapid processes, there is not enough time for the transfer of energy as heat to take place to or from the system. In practically, heat loss is losses from system but these losses are considered that low when compare with overall energy flow. Thus, some thermodynamic processes can approximate which is adiabatic process. The adiabatic (isentropic) expansion of an ideal gas may be stated by the following equation 2.1.

$$W_{AD}/m = kRT/(k-1)[(p_1/p_2)^{(k-1)/k}-1] \qquad (2.1)$$

This equation applies to both reciprocating and centrifugal expansion machines. The above expression can also be stated more simply as as shown in equation 2.2.

$$T_2 = T_1(p_1/p_2)^{(k-1)/k} \quad (2.2)$$

Where ; p = absolute pressure (Pa)

T = absolute temperature (K)

K = Cp/ Cv= isentropic exponent

2.5 Heat exchanger

Heat exchangers are widely used in a wide range of applications such as heating and air conditioning systems in household, chemical processing and power production in large plants. Heat exchangers are device which facilitate the exchange of heat between two fluids that have different temperatures while keeping them from mixing with each other. They differ from mixing chambers which are not allow the two fluids involved to mix. Shell and tube heat exchanger is used mostly in industrial applications. The advantages of this type are the configuration gives a large surface area in a small volume, good mechanical layout which are a good shape for pressure operation, uses well-established fabrication techniques, can be constructed from a wide range of materials, easily cleaned, well-established design procedures.

2.5.1 Shell and tube heat exchanger

From Figure 2.9, it shows schematic of shell and tube heat exchanger. Within shell and tube heat exchanger, a large number of tubes (sometimes several hundred) is packed in a shell with their axes parallel to that of the shell. Heat transfer of two fluids occurs between one fluid flows inside the tubes while the other fluid flows outside the tube through the shell. Baffles are commonly placed in the shell to enhance heat transfer and maintain uniform spacing between the tubes by forcing the shell side fluid to flow across the shell. The tube in shell and tube heat exchanger open to some large flow areas called headers at both ends of the shell, where the tube side fluid accumulates before entering the tubes and after leaving them.

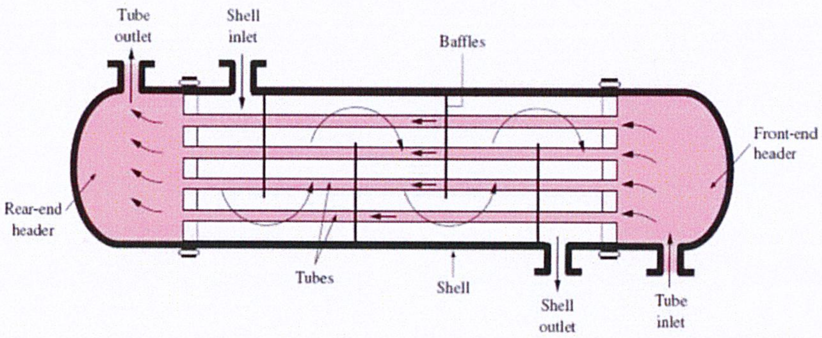


Figure 2.9. Schematic of shell and tube heat exchanger.

2.5.2 Calculate heat transfer area[16]

To calculate the heat transfer area, primary details of shell and tube heat exchangers. Follow the steps.

Energy Balance

Calculate the unknown value such as heat duty, mass flow rate and temperature by using Eq. (2.3).

$$q = m_c c_{pc}\left(T_{c,out} - T_{c,in}\right) = m_h c_{ph}\left(T_{h,in} - T_{h,out}\right) \tag{2.3}$$

Where: q = Heat duty (kW)

m_c = Cold fluid mass flow rate (kg/s)

m_h = Hot fluid mass flow rate (kg/s)

c_{pc} = Cold fluid specific heat capacity (kJ/kg·˚C)

c_{ph} = Hot fluid specific heat capacity (kJ/kg·˚C)

$T_{c,out}$ = Cold fluid temperature, outlet (˚C)

$T_{c,in}$ = Cold fluid temperature, inlet (˚C)

$T_{h,out}$ = Hot fluid temperature, outlet (˚C)

$T_{h,in}$ = Hot fluid temperature, inlet (˚C)

Overall heat transfer coefficient

Overall heat transfer coefficient is used to calculate primary heat transfer area. Table1 is used to estimate primary overall heat transfer coefficient according to the type of fluid through a heat exchanger.

Table 2.3. Overall heat transfer coefficient.[16]

Hot fluids	**Cold fluids**	**Overall heat transfer coefficient** ($\mathbf{W/m^2\cdot{}^\circ C}$)
Heat exchangers		
Water	Water	800-1500
Organic Solvents	Organic Solvents	100-300
Light oils	Light oils	100-400
Heavy oils	Heavy oils	50-300
Gases	Gases	10-50
Coolers		
Organic Solvents	Water	250-750
Light Oils	Water	350-700
Heavy Oils	Water	60-300
Gases	Water	20-300
Organic Solvents	Brine	150-500
Water	Brine	600-1200
Gases	Brine	15 – 250
Heaters		
Steam	Water	1500-4000
Steam	Organic Solvents	500-1000
Steam	Light oils	300-900
Steam	Heavy oils	60-450
Steam	Gases	30-300
Dowtherm	Heavy oils	50-300
Dowtherm	Gases	20-200
Flue Gases	Steam	30-100

Flue	Hydrocarbon Vapours	30-100
Condensers		
Aqueous vapours	Water	1,000-1,500
Hot fluids	**Cold fluids**	**Overall heat transfer coefficient (W/m^2·°C)**
Condensers		
Organic vapours	Water	700-1000
Refinery Hydrocarbon	Water	400-550
Organic (some non-condensables)	Water	500-700
Vacuum condensers	Water	200-500
Vaporizers		
Steam	Aqueous solutions	1000-1500
Steam	Light organics	900-1200
Steam	Heavy organics	600-900

Logarithmic mean temperature difference (LMTD)

Calculate LMTD for counter-current flow by using Eq. (2.4).

$$\Delta T_{lm} = \frac{\left(T_{h,in} - T_{c,out}\right) - \left(T_{h,out} - T_{c,in}\right)}{\ln \dfrac{\left(T_{h,in} - T_{c,out}\right)}{\left(T_{h,out} - T_{c,in}\right)}} \tag{2.4}$$

Calculate LMTD for co-current flow by using Eq. (2.5).

$$\Delta T_{lm} = \frac{\left(T_{h,in} - T_{c,in}\right) - \left(T_{h,out} - T_{c,out}\right)}{\ln \dfrac{\left(T_{h,in} - T_{c,in}\right)}{\left(T_{h,out} - T_{c,out}\right)}} \tag{2.5}$$

Heat transfer area

$$A = \frac{q}{U\Delta T_m} \tag{2.6}$$

Where: A = Heat transfer area (m^2)

q = Heat duty (W)

ΔT_m = Mean temperature difference (°C)

U = Overall heat transfer coefficient ($W/m^2 \cdot °C$)

2.5.3 Calculation performance of heat exchanger

2.5.3.1 The log mean temperature difference (LMTD) method

The log mean temperature difference (LMTD) method is derived as follows:

Calculate LMTD for counter-current flow by using Eq. (2.7).

$$\Delta T_{lm} = \frac{\left(T_{h,in} - T_{c,out}\right) - \left(T_{h,out} - T_{c,in}\right)}{\ln \frac{\left(T_{h,in} - T_{c,out}\right)}{\left(T_{h,out} - T_{c,in}\right)}} \tag{2.7}$$

Calculate LMTD for co-current flow by using Eq. (2.8).

$$\Delta T_{lm} = \frac{\left(T_{h,in} - T_{c,in}\right) - \left(T_{h,out} - T_{c,out}\right)}{\ln \frac{\left(T_{h,in} - T_{c,in}\right)}{\left(T_{h,out} - T_{c,out}\right)}} \tag{2.8}$$

Assumption of LMTD expression is the overall heat transfer coefficient constant along with the entire flow length of the heat exchanger. If it is not following by assumption, an incremental analysis is required. The LMTD method is also applicable to crossflow arrangements which may be written as Eq. (2.9):

$$\Delta T_m = F_T \times \Delta T_{lm} \tag{2.9}$$

$$q = UA\,\Delta T_m$$

Where: ΔT_m = Mean temperature difference (°C)

ΔT_{lm} = Log mean temperature difference (°C)

F_T = Temperature correction factor

The efficiency of heat exchanger can be estimated by take the overall heat transfer coefficient from calculation based on energy balance divided by the overall heat transfer coefficient from design value.

2.5.3.2 The effectiveness – NTU method [17]

The effectiveness number of transfer units (NTU) method was developed to simplify a number of heat exchanger design problems. The heat exchanger effectiveness is defined as the ratio of the actual heat transfer rate to the maximum possible heat transfer rate. The heat exchanger effectiveness depend on the hot or cold fluid is a minimum stream. The efficiency is defined as follows Figure 2.10.

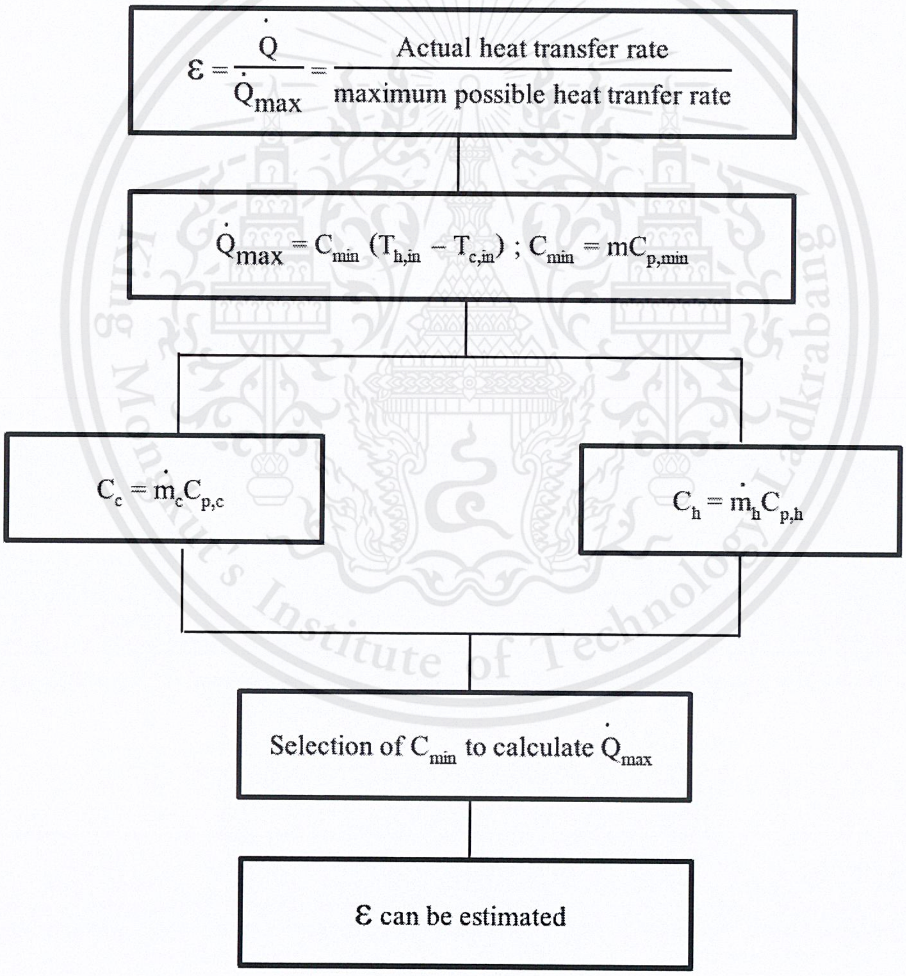


Figure 2.10. Chart for calculation the effectiveness – NTU method.

Chapter III

METHODOLOGY

In this project, the objective is to increase energy efficiency and reduce power consumption of compressor in air separation unit of Air Liquide company at Laem Chabang site. There are three main steps to conduct these studies 1) study on process flow diagram of ASUs process and air coolers 2) estimation efficiency of air cooler 3) study on effect of adjustment %open valve of air cooler power consumption of compressors.

3.1 Study on process flow diagram of ASUs process and air coolers

The process flow diagram of air separation unit is shown in Figure 3.1. Air coolers of 10 compressors are chosen for this study. There are main compressor (C10), Nitrogen compressor (C50,51,52), Recycle compressor (C30/60), Warm booster (C20), Cold booster (C21), and Oxygen compressor (C41,42). The red dash line boxes are presented locations of main compressors.

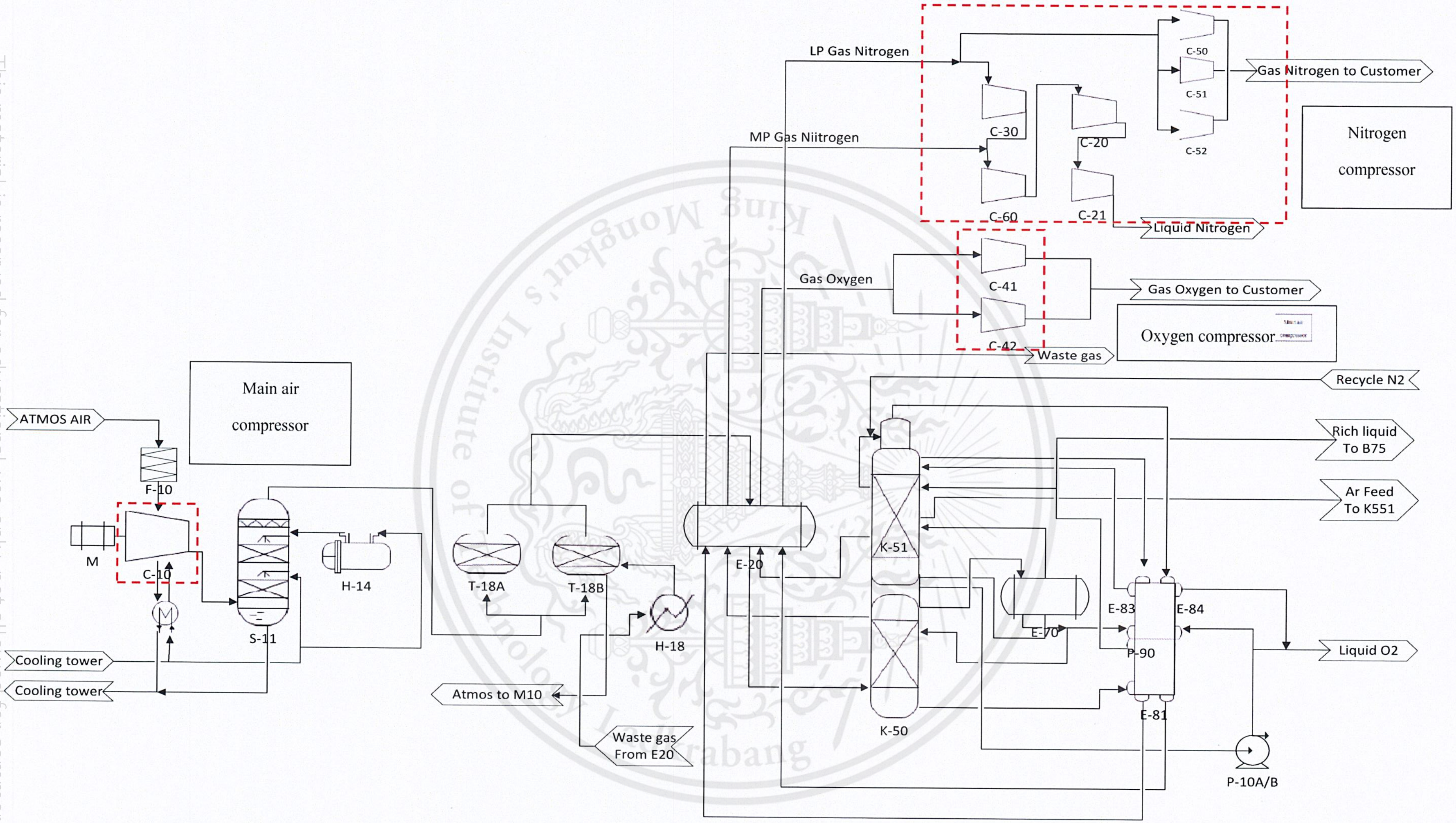


Figure 3.1. Process flow diagram of air separation unit which focus on compression unit.

3.1.1 Air coolers in main air compressor

The flow diagram of air coolers in main air compressor (C10) is presented in Figure 3.2. The main air compressor (C10) has 3 stages with 2 intercoolers ; HE101 and HE102, for cooling compressed gases. Type of heat exchangers is shell and tube which compressed air flow in shell side and cooling water flow in tube side.

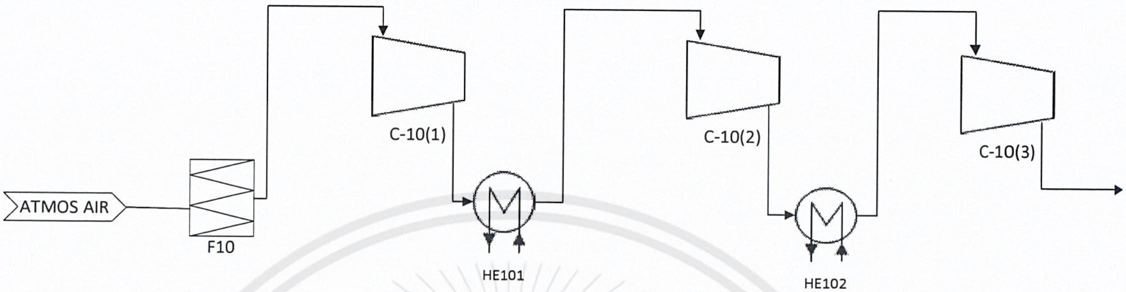


Figure 3.2. Process flow diagram of inter cooler in C10.

3.1.2 Air cooler in Nitrogen compressor

As mentioned in section 3.1.1, There are 2 groups of nitrogen compressor, i.e., nitrogen recycle compressor (C30, C60) and nitrogen compressor (C50, 51, 52). C30 has 2 stages with 1 intercooler (HE301) and 1 aftercooler (HE302). C60 has 4 stages which has 3 intercoolers and 1 aftercooler that are HE601, HE602, HE603, and HE604, respectively. Process flow diagram of C30 and 60 is shown in Figure 3.3. Types of heat exchanger in both of compressors are shell and tube that compressed nitrogen flow in shell and cooling water flow in tube. Compressed nitrogen after C60 is sent to warm booster (C20) and cold booster (C21) for producing liquid nitrogen. C20 and C21 have 1 intercooler, air coolers of there booster are HE20 and HE21, respectively as shown in Figure 3.4. Type of heat exchangers in both of air boosters are shell and tube that compressed nitrogen flow in tube and cooling water flow in shell. While group 2 are nitrogen compressor (C50, C51 and C52) have 2 stages. In stage 1 of C50 and C51, there are parallel compressors. C50 and C51 have 2 intercoolers in stage 1 each including HE501A, HE501B, HE511A, and HE511B and 1 aftercooler each including HE502, and HE512 as shown in Figure 3.5. C52 have 1 intercooler (HE521) and 1 aftercooler (HE522). Type of heat exchangers in both compressors are shell and tube that compressed nitrogen flow in tube and cooling water flow in shell.

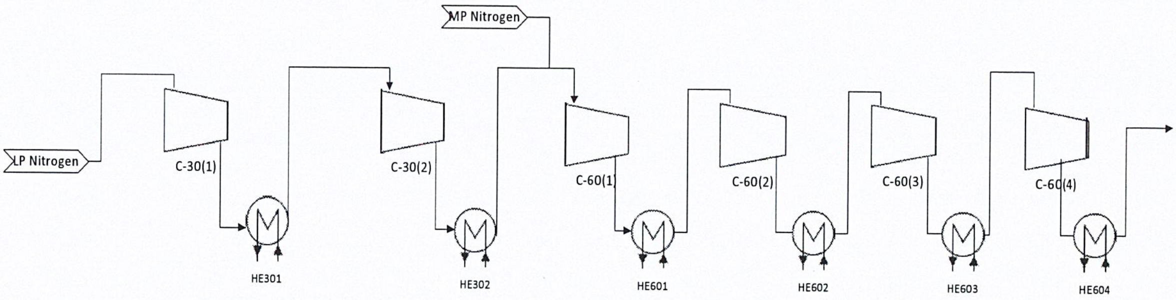


Figure 3.3. Process flow diagram of inter cooler and after cooler in C30,60 (recycle compressor).

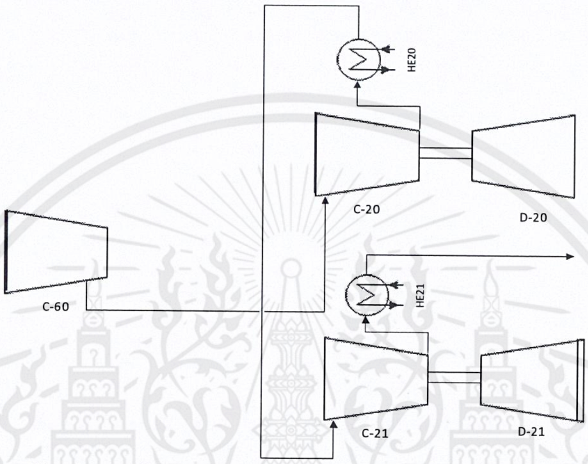


Figure 3.4. Process flow diagram of after cooler in C20,21 (Warm and cold booster).

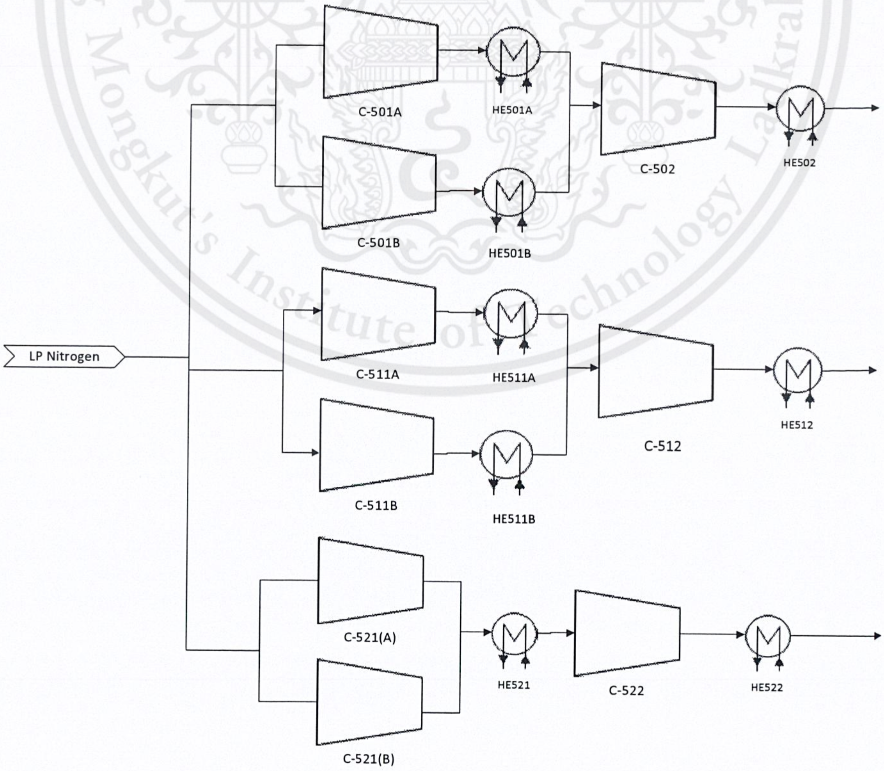


Figure 3.5 Process flow diagram of inter cooler and after cooler in C50,51,52

(Nitrogen compressor).

3.1.3 Air cooler in Oxygen compressor

For oxygen from main heat exchanger, it sent to oxygen compressor (C41 and C42) to build pressure to required pressure before sent to customer via pipeline. Oxygen compressors (C41 and C42) have 3 stages with 2 intercoolers and 1 aftercooler that are HE 411 HE412, HE413, HE421, HE422 and HE423 as shown in Figure 3.6. Type of heat exchangers in both of compressor are shell and tube that compressed oxygen flow in tube and cooling water flow in shell.

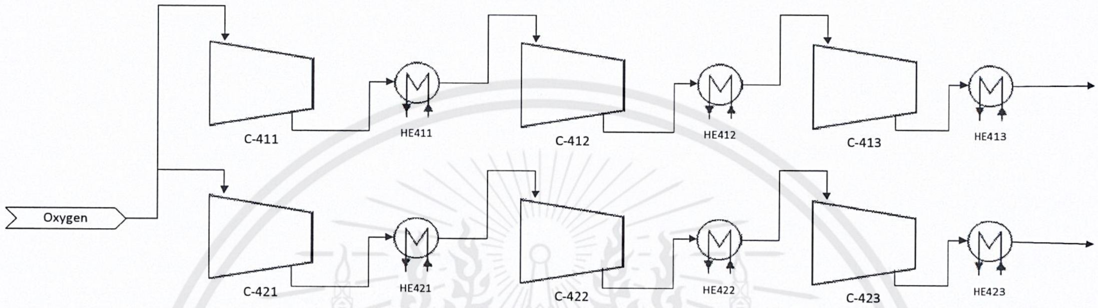


Figure 3.6. Process flow diagram of inter cooler and after cooler in C41,42 (Oxygen compressor).

3.2 Estimation efficiency of heat exchanger

Efficiency of heat exchanger can be estimated by log mean temperature difference (LMTD) and the effectiveness-NTU method. LMTD method are divided 4 steps for estimation efficiency heat exchanger. Firstly, heat transfer rate is estimated by using energy balance equation of hot and cold streams. Then, log mean temperature difference (ΔT_{lm}) is determined by using inlet and outlet temperature of both stream. After that, overall heat transfer coefficient (U) in $W/m^2 \cdot °C$ is calculated. Finally, efficiency of heat exchanger can be estimated from overall heat transfer coefficient in actual divided by overall heat transfer coefficient in design. For the effectiveness-NTU method, it divided 2 steps. Maximum possible heat transfer rate ($\dot{Q}_{max}$) is calculated in step 1. Efficiency of heat exchanger can be estimated by divided actual heat transfer rate with maximum possible heat transfer rate as follows Figure 3.7.

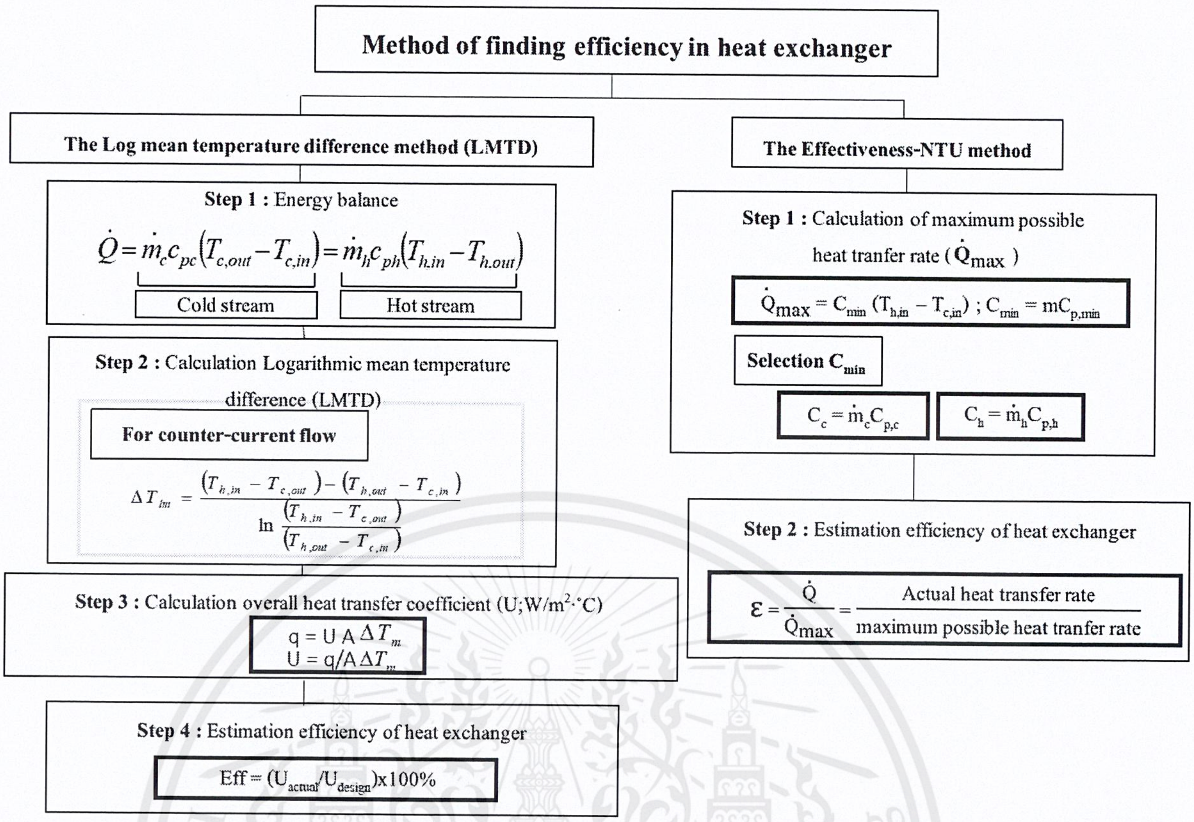


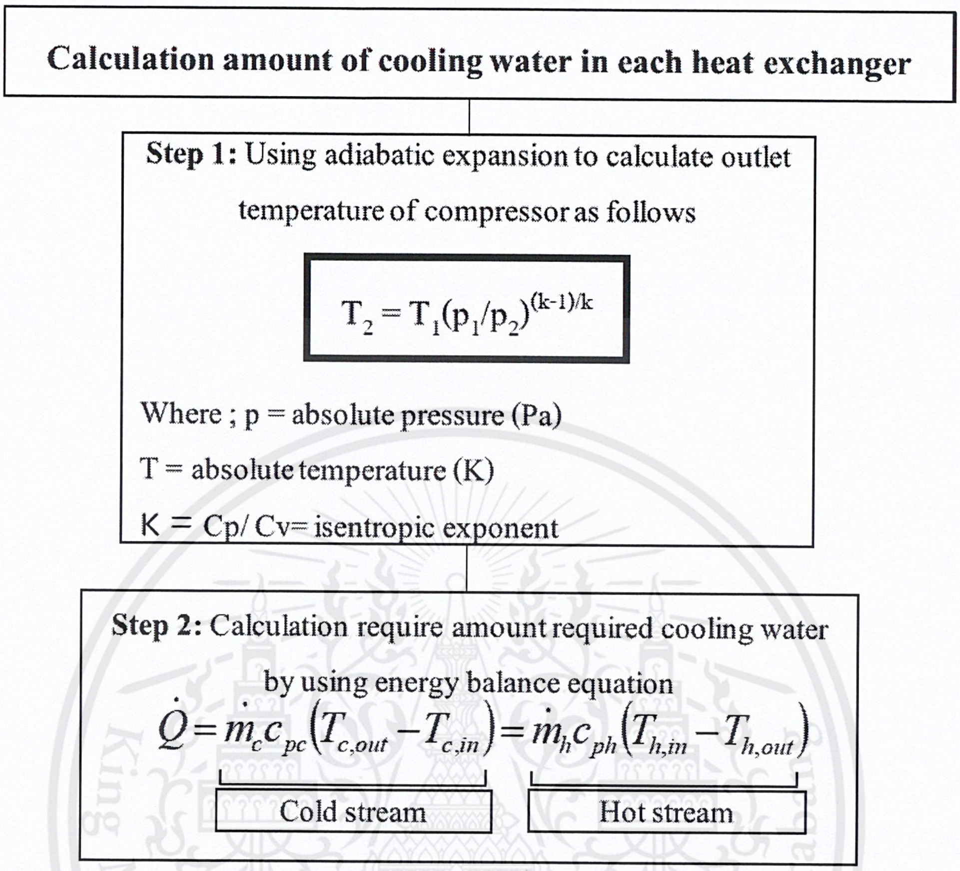
Figure 3.7. Estimation efficiency of heat exchanger.

3.3 Study on effect of %open valve of air cooler on power consumption of compressor

The objective in this part is to study changing of power consumption of compressor in plant after adjust %open valve of air cooler. Methodology in this part was divided into 4 steps including calculation required volumetric of cooling water, selection of cooling water valve to adjust flow rate, design study cases of %open valve of cooling water, investigate the changing of power consumption of compressor.

3.3.1 Calculation required volumetric flow rate of cooling water

The required volumetric flow rate of cooling water in each heat exchanger is calculated by adiabatic expansion and energy balance equation as shown in Figure 3.8.



Calculation amount of cooling water in each heat exchanger

Step 1: Using adiabatic expansion to calculate outlet temperature of compressor as follows

$$T_2 = T_1(p_1/p_2)^{(k-1)/k}$$

Where ; p = absolute pressure (Pa)

T = absolute temperature (K)

K = Cp/ Cv= isentropic exponent

Step 2: Calculation require amount required cooling water by using energy balance equation

$$\dot{Q} = \underbrace{\dot{m}_c c_{pc}\left(T_{c,out} - T_{c,in}\right)}_{\text{Cold stream}} = \underbrace{\dot{m}_h c_{ph}\left(T_{h,in} - T_{h,out}\right)}_{\text{Hot stream}}$$

Figure 3.8. Step to calculate required volumetric flow rate of cooling water.

3.3.2 Selection of cooling water valve to adjust flow rate

Selection valve of cooling water is considered by comparison of required volumetric flow rate that calculated from 3.2.1 and measure volumetric flow rate from ultrasonic flow meter. The results are shown in Table 3.1.

Table 3.1. Comparison of required and measured cooling water flow rate in each heat exchanger.

Number of heat exchanger	Required volumetric flowrate (m^3/h)	Measured volumetric flowrate (m^3/h)
Total flow of HE101,102	94.85	162.23
Total flow of HE301,302,601,602,603,604	475.52	531.10

Table 3.1. Comparison of required and measured cooling water flow rate in each heat exchanger (cont.).

Number of heat exchanger	**Required volumetric flowrate (m^3/h)**	**Measured volumetric flowrate (m^3/h)**
Total flow of HE421,422,423	22.95	30.61
Total flow of HE20,21	175.20	163.98
Total flow of HE501A,501B,502	14.89	10.19
Total flow of HE511A,511B,512	14.89	8.97
Total flow of HE521,522	46.61	32.44
Total flow of HE411,412,413	22.95	13.89
S11	50.01	50.08
H14	10.00	10.01

From Table 3.1, it was found that measured volumetric flow rate of cooling water in heat exchanger of compressor group 10 (HE101,102), 30 (HE301,302), 60 (HE601,602,603,604), 42 (HE421,422,423) are more than required volumetric flow rate of cooling water. These data indicated the overuse of cooling water. However, heat exchangers of group 30, 60, 42 are critical equipment for the process that should not interfere. The case studies are focus only on group 10 (HE101,102). In addition, there are two heat exchangers, i.e., S11 and H14, that required and measured volumetric flow rate are almost equivalent. These heat exchangers are operated in appropriate flow rate. There are 5 groups of heat exchanger that measured volumetric flow rate lower than required valve. However, heat exchanger of group 20, 21, 51 (HE511A,511B,512), 41(HE411,412,413) are critical equipment that should not touch. Heat exchanger of group 50 and 52 are chosen for case studies. Location of heat exchangers group 10 (HE101,102), 50 (HE501A,501B,502), and 52 (HE521,522) are shown in Figure 3.9.

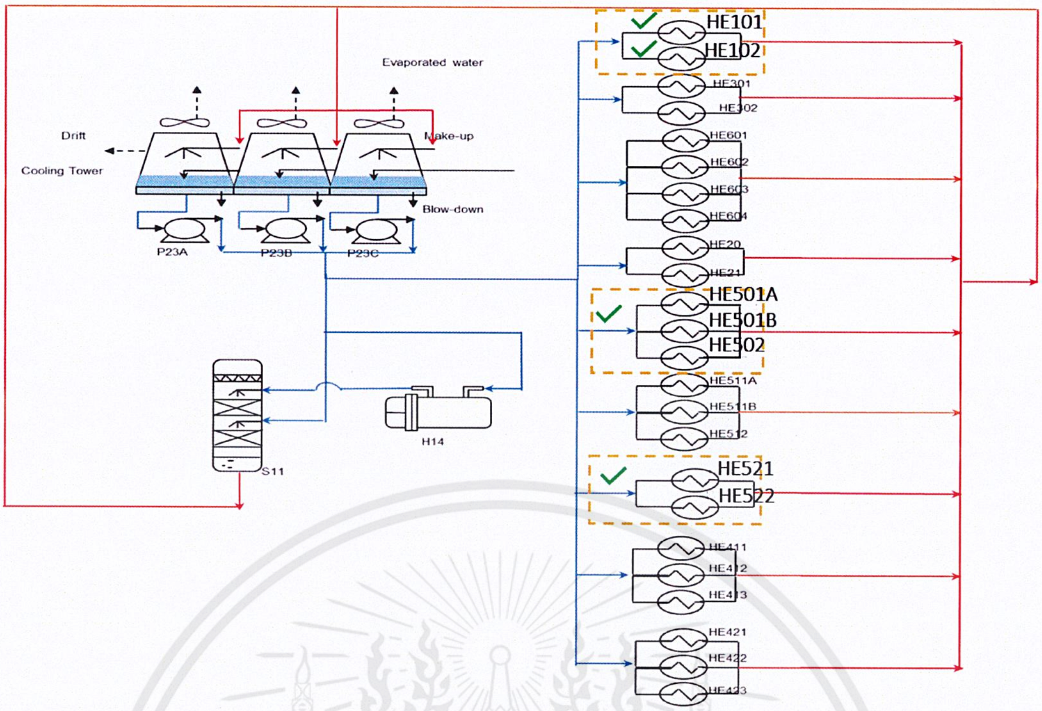


Figure 3.9. Network of cooling water system.

3.3.3 Investigate the change of power consumption of compressor

After checking specification and limitation of valves that use for heat exchanger group 10, 50 and 52, the valve for HE101 and 102 could be opened in 4 levels, i.e., 30, 50, 75, and 100% open. However, valves of heat exchanger group 50, 52 are rather small so valve could be adjusted only 10 and 100% open. There are 32 case studies for adjustment of %open valve as shown in Table 3.2. There 32 study cases were performed in plant by using SCADA to change %open valve. The results was retrieved by using SCADA software as well.

Table 3.2. 32 case studies for adjustment of %open valve.

%Open valve				
Group 10		Group 50	Group 52	
HE101	HE102		HE521	HE522
100	100	100	100	100
75	100	100	100	100
50	100	100	100	100
30	100	100	100	100
100	75	100	100	100
75	75	100	100	100
50	75	100	100	100
30	75	100	100	100
100	50	100	100	100
75	50	100	100	100
50	50	100	100	100
30	50	100	100	100
100	30	100	100	100
75	30	100	100	100
50	30	100	100	100
30	30	100	100	100
100	100	10	10	10
75	100	10	10	10
50	100	10	10	10
30	100	10	10	10
100	75	10	10	10
75	75	10	10	10
50	75	10	10	10

Table 3.2. 32 case studies for adjustment of %open valve (cont.).

%Open valve				
Group 10		Group 50	Group 52	
HE101	HE102		HE521	HE522
30	75	10	10	10
100	50	10	10	10
75	50	10	10	10
50	50	10	10	10
30	50	10	10	10
100	30	10	10	10
75	30	10	10	10
50	30	10	10	10
30	30	10	10	10

Chapter IV

Results & Discussion

In this chapter, results will be discussed into 2 parts, i.e., efficiency of heat exchanger and effect of %open valve on power consumption of compressor.

4.1 Estimation efficiency of heat exchanger

From availability of data, only efficiency of HE 20, 21, 521 and 522 were estimated by LMTD and NTU methods. Monthly plot of efficiency of 4 heat exchanger that calculated from both methods are presented in Figure 4.1 - 4.4, respectively.

Figure 4.1 shows monthly plot of efficiency heat exchanger HE20 along with flow rate of nitrogen from 30 October 2016 to 15 October 2019. From graph, it was found that efficiency of heat exchanger from LMTD method are greater than value from NTU method. The average of efficiency from LMTD and NTU method are 0.86 and 0.64, respectively at average flowrate of nitrogen 20.49 kNm^3/h. Efficiency of heat exchanger did not change significantly during three year period except month that with higher flow rate of nitrogen.

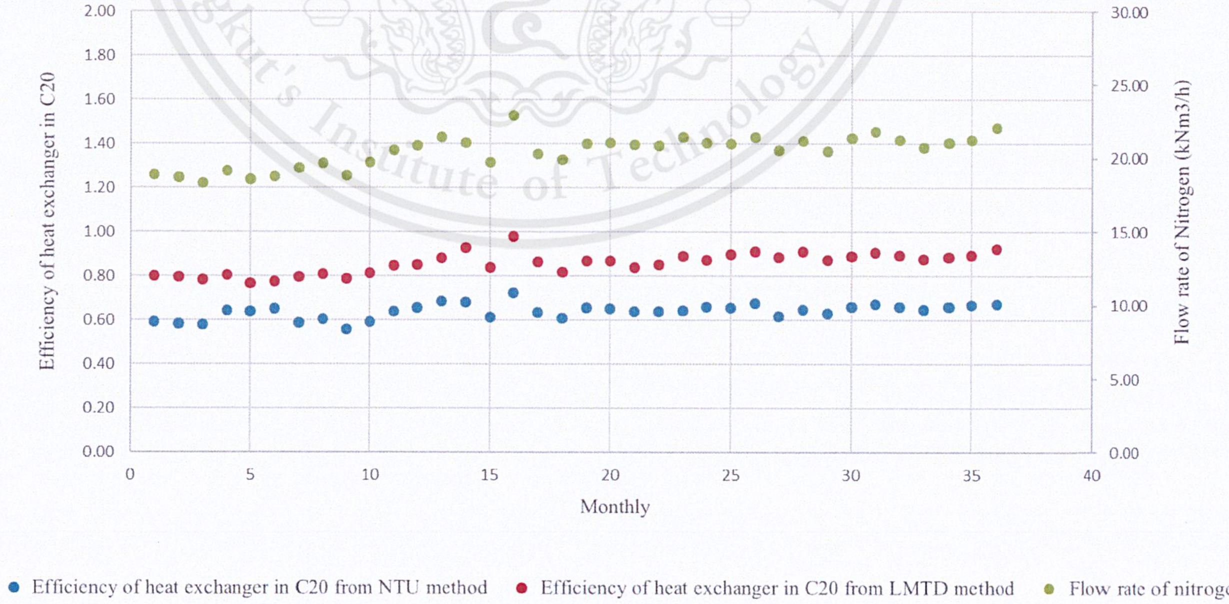


Figure 4.1. Monthly plot of heat exchanger of HE20 efficiency and flow rate from 30 October 2016 to 15 October 2019.

Efficiency of HE 21 are shown in Figure 4.2, show similar trend as of HE20. However, variation of data is a little bit greater than HE20. The average efficiency of heat exchanger from LMTD and NTU method are 0.54 and 0.61, respectively at average flowrate of nitrogen 20.49 kNm^3/h. For this heat exchanger, average data from LMTD method are lower than HE20.

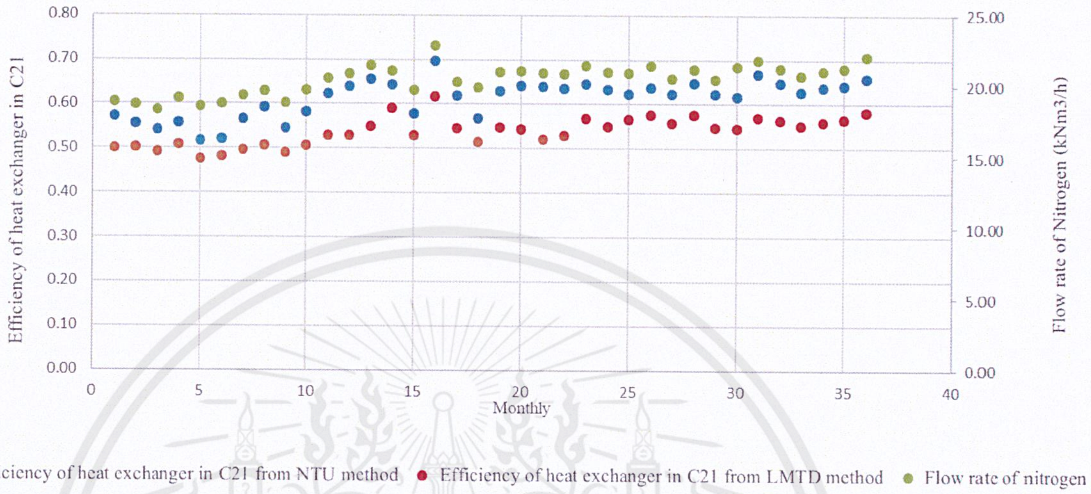


Figure 4.2. Monthly plot of heat exchanger of HE21 efficiency and flow rate from 30 October 2016 to 15 October 2019.

Data for HE521 and 522 are only available for 6 months from 30 November 2017 to 5 May 2018. Efficiency of both HE521 and HE522 are shown in Figure 4.3 – 4.4. The graph indicated that efficiency of heat exchanger are varied with flow rate of nitrogen. However, efficiency of HE521 from LMTD method are lower than NTU method as shown in Figure 4.3. The average value from LMTD and NTU method are 0.50 and 0.58, respectively at average flowrate of nitrogen 1.69 kNm^3/h.

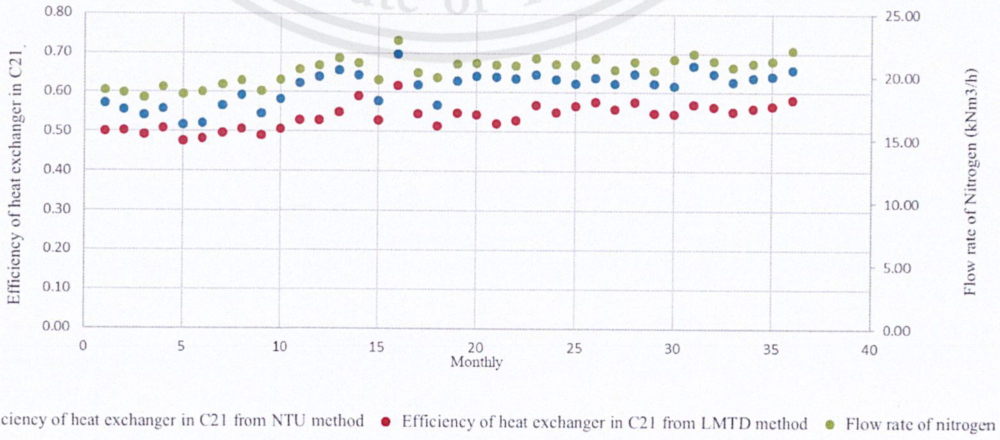


Figure 4.3. Monthly plot of heat exchanger efficiency in HE521 and flow rate from 30 November 2017 to 5 May 2018.

For HE522, efficiency show similar trend as HE522. However, efficiency of HE522 from LMTD are higher than that of NTU which opposite to HE521. The average value from LMTD and NTU method are 0.75 and 0.58, respectively at average flowrate of nitrogen 1.69 kNm^3/h.

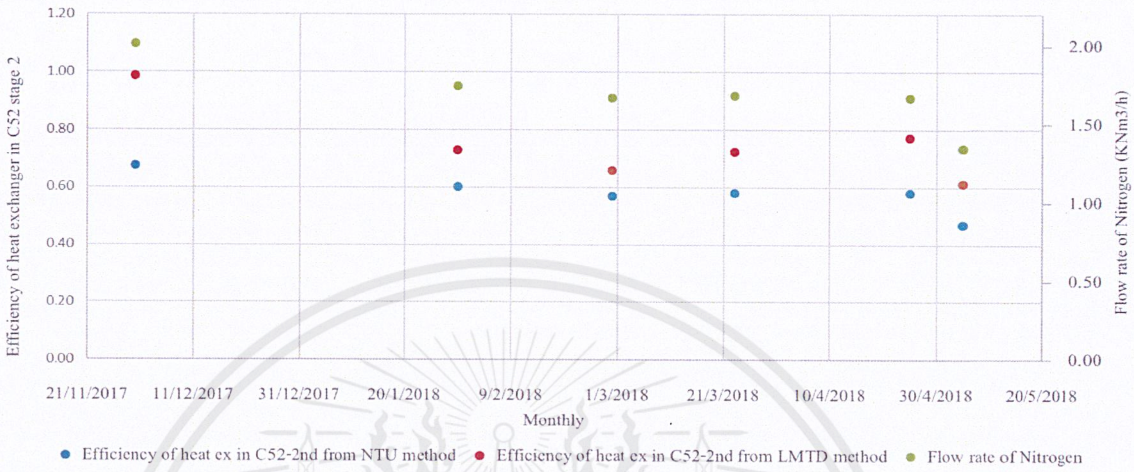


Figure 4.4. Monthly plot of heat exchanger efficiency in HE521 and flow rate from 30 November 2017 to 5 May 2018.

The comparison of efficiency of heat exchanger from LMTD and NTU methods in each heat exchanger are shown in Table 4.1.

Table 4.1. Efficiency of heat exchanger from LMTD and NTU method and inlet flowrate of Nitrogen.

Number of heat exchanger in compressor	Inlet flowrate of Nitrogen (kNm^3/hr)	Efficiency of heat exchanger	
		LMTD method	NTU method
HE20	20.49	0.86	0.64
HE21	20.49	0.54	0.61
HE521	1.69	0.50	0.58
HE522	1.69	0.75	0.58

It shows that the value of efficiency of heat exchanger from NTU method are very close. However, efficiency from LMTD are varied from 0.50 to 0.86. These heat exchangers were used for more than 20 year since the start up of the plant. The main cause of decreasing of efficiency in heat exchanger are fouling. Fouling is occurred from the deposition and accumulation of unwanted materials such as scale, algae, suspended solid and insoluble salts on the internal or external surface of processing equipment of heat exchangers. Fouling reduces the heat transfer rate and increases the pressure drop of heat exchanger. Fouling on the process equipment can have a significant, negative impact on the operational efficiency of the unit by lead to production losses and increased maintenance costs. The company should find solution to enhancement of heat exchanger by cleaning heat exchanger.

4.2 Study on effect of %open valve on power consumption of compressor

There are 32 case studies that have been carried out. The change of power consumption in C30 and C60 and presented in Table 4.2. There are 23 and 3 cases that power consumption did not change and increase when adjust %open valve, respectively. There are only 6 cases that power consumption reduce significantly.

Table 4.2. Change of power consumption in C30 and 60 for 32 case studies.

%Open valve					Changing of power consumption of C30 and 60 (kW)
C10		Heat exchanger in C50	C52		
HE101	HE102		HE521	HE522	
75	100	100	100	100	almost no change
30	100	100	100	100	almost no change
100	75	100	100	100	almost no change
100	50	100	100	100	almost no change
100	30	100	100	100	almost no change
75	75	100	100	100	almost no change
50	75	100	100	100	almost no change
30	75	100	100	100	almost no change
75	50	100	100	100	almost no change
50	50	100	100	100	almost no change
30	50	100	100	100	almost no change

Table 4.2. Change of power consumption in C30 and 60 for 32 case studies (cont.).

%Open valve					Changing of power consumption of C30 and 60 (kW)
C10		Heat exchanger in C50	C52		
HE101	HE102		HE521	HE522	
75	30	100	100	100	almost no change
50	30	100	100	100	almost no change
30	30	100	100	100	almost no change
75	75	10	10	10	almost no change
50	75	10	10	10	almost no change
30	75	10	10	10	almost no change
50	50	10	10	10	almost no change
30	50	10	10	10	almost no change
100	30	10	10	10	almost no change
30	30	10	10	10	almost no change
75	75	10	10	10	almost no change
50	30	10	10	10	almost no change
50	100	100	100	100	18.74
100	50	10	10	10	26.65
75	50	10	10	10	40.03
100	75	10	10	10	- 38.57
100	100	10	10	10	- 41.19
75	30	10	10	10	- 42.22
75	100	10	10	10	- 47.05
30	100	10	10	10	-75.71
50	100	10	10	10	-97.87

4.2.1 Study cases that reduce power consumption of compressor

From Table 4.1, it was found when %open valve of HE in C50, HE521, and HE522 at 10% with 6 combination of HE101 and HE102 of 100 and 75, 100 and 100, 75 and 30, 75 and 100, 30 and 100, and 50 and 100. However, the maximum reduction of power consumption occur when %open valve of HE102 is 100 and HE101 is 50%. The result from SCADA program of this case is presented in Figure 4.6.

From Figure 4.6, it shows effect to power consumption of C30 and 60 after adjustment %open valve in red area The power consumption in C30 and 60 (black line in Figure 4.6) decresed rapidly from 3850.63 kW to 3752.76. From this graph, the outlet temperature of hot and cold stream are also decreased. The adjustment of overuse of cooling water by changing %open valve HE101 to 50%, not change valve of HE102 and 10% of HE in C50, HE521 and 522 is the best combination to reduce power consumption.

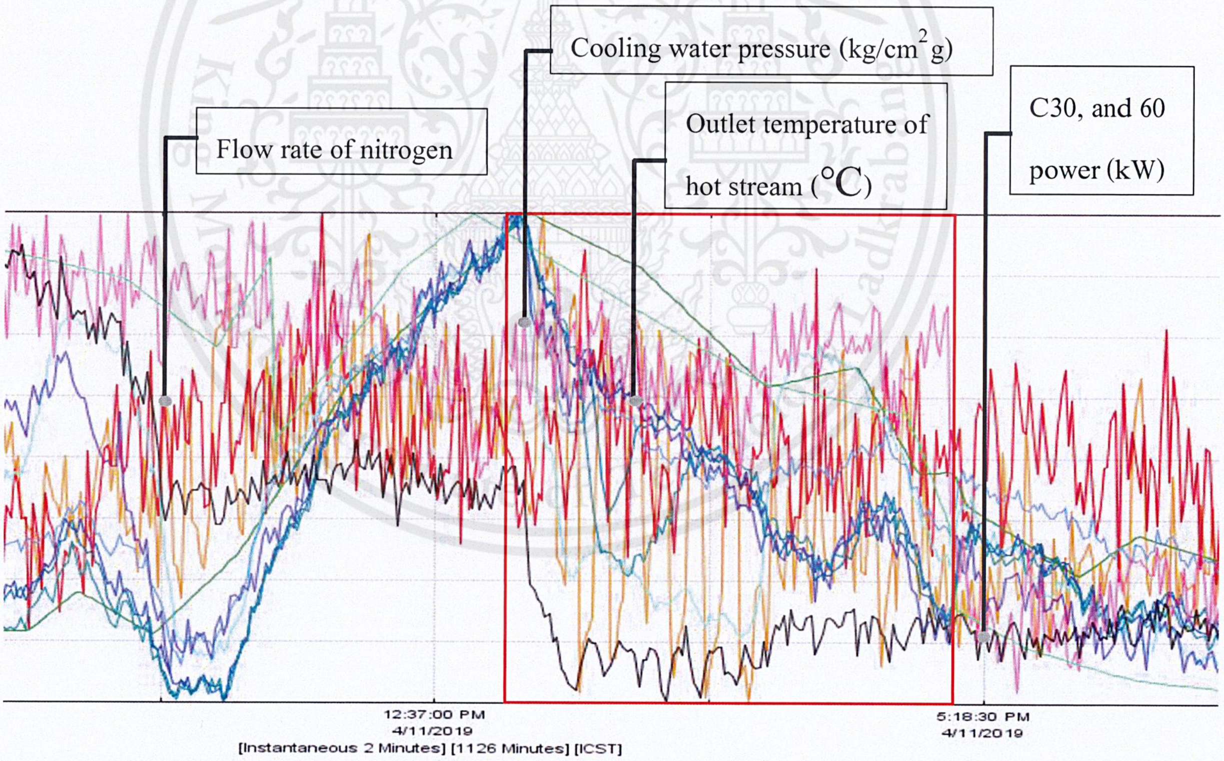


Figure 4.5. Show parameter which effect to power consumption of heat exchanger in C30 and C60 in case open valve HE101(50%), 102(100%), 50(10%), and 52(10%).

Chapter V

CONCLUSION

5.1 Conclusion

1) Efficiency of HE 20, 21, 521, 522 are estimated by LMTD and NTU methods. The monthly plot of efficiency from Oct 30, 2016 to Oct 15, 2017 show that efficiency of HE20 and 21 did not change significantly for three years. The average of efficiency from LMTD and NTU methods are 0.86 and 0.64, respectively at average flow rate of nitrogen 20.49 kNm^3/h for HE20 and 0.54 and 0.61, respectively at same flow rate of nitrogen for HE21. For HE521 and 522, data only available for 6 months from Nov 30, 2017 to May 5, 2018 their monthly trends are like HE20 and 21. The average efficiency from LMTD and NTU methods are 0.5 and 0.58, respectively for HE521 and 0.75, and 0.58 for HE522

2) HE21 and HE521 are least efficiency heat exchanger, company should arrange to clean deposit/scale to improve their efficiencies. Efficiency of heat exchanger depend on flow rate of nitrogen.

3) For study on effect of %open valve from power consumption, there are 32 cases were carried out in plant. However, there are only 6 cases that power consumption is decreased. The best scenario is %open valve of HE101, HE102, HE of C50, HE521, HE522 at 50, 100, 10, 10, and 10. It could reduce power consumption about 98 kW. There are only 6 cases that power consumption reduce significantly.

5.2 Suggestion

1) Install control valve for HE101, 102, 50, and 52 to manipulate easily follow condition %open valve which is studied to saving water and operating cost.

2) HE21 and HE521 should be cleaned.

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APPENDIX

Table A.1. Show efficiency of heat exchanger HE20 and HE21 by LMTD and NTU method with flowrate of nitrogen.

Date	**Volumetric flow (kNm3/h)**	**Efficiency of heat exchanger HE20 and HE21**			
		LMTD method		**NTU method**	
		HE20	**HE21**	**HE20**	**HE21**
30/10/2016 - 29/11/2016	18.93	0.80	0.50	0.59	0.57
29/11/2016 - 29/12/2016	18.73	0.80	0.50	0.58	0.56
04/01/2016 - 28/01/2017	18.31	0.78	0.49	0.58	0.54
28/01/2017 - 27/02/2017	19.17	0.81	0.51	0.64	0.56
27/02/2017 - 29/03/2017	18.57	0.77	0.48	0.64	0.52
29/03/2017 - 12/04/2017	18.76	0.78	0.48	0.65	0.52
28/04/2017 - 28/05/2017	19.36	0.80	0.50	0.59	0.57
28/05/2017 - 27/06/2017	19.67	0.81	0.51	0.61	0.59
27/06/2017 - 27/07/2017	18.86	0.79	0.49	0.56	0.55
27/07/2017 - 26/08/2017	19.73	0.81	0.51	0.59	0.58
26/08/2017 - 25/09/2017	20.58	0.85	0.53	0.64	0.62
25/09/2017 - 25/10/2017	20.92	0.85	0.53	0.66	0.64
25/10/2017 - 24/11/2017	21.48	0.88	0.55	0.68	0.66
24/11/2017 - 24/12/2017	21.07	0.93	0.59	0.68	0.64
24/12/2017 - 23/01/2018	19.74	0.84	0.53	0.61	0.58
23/01/2017 - 22/02/2018	22.91	0.98	0.62	0.73	0.70
22/02/2018 - 24/03/2018	20.34	0.87	0.54	0.64	0.62
24/03/2018 - 12/04/2018	19.94	0.82	0.52	0.61	0.57
23/04/2018 - 23/05/2018	21.02	0.87	0.55	0.66	0.63
23/05/2018 - 22/06/2018	21.09	0.87	0.54	0.65	0.64
22/06/2018 - 22/07/2018	20.93	0.84	0.52	0.64	0.64
22/07/2018 - 21/08/2018	20.88	0.85	0.53	0.64	0.64
21/08/2018 - 20/09/2018	21.44	0.89	0.57	0.64	0.65
20/09/2018 - 20/10/2018	21.05	0.88	0.55	0.66	0.63
20/10/2018 - 19/11/2018	20.99	0.90	0.57	0.66	0.62

19/11/2018 - 19/12/2018	21.44	0.91	0.58	0.68	0.64
05/01/2019 - 18/01/2019	20.60	0.88	0.56	0.62	0.62
18/01/2019 - 17/02/2019	21.19	0.91	0.58	0.65	0.65
17/02/2019 - 19/03/2019	20.48	0.87	0.55	0.63	0.62
19/03/2019 - 12/04/2019	21.38	0.89	0.55	0.66	0.62
18/04/2019 - 18/05/2019	21.83	0.91	0.57	0.68	0.67
18/05/2019 - 17/06/2019	21.27	0.89	0.56	0.66	0.65
17/06/2019 - 17/07/2019	20.74	0.88	0.55	0.65	0.63
17/07/2019 - 16/08/2019	21.10	0.89	0.56	0.66	0.64
16/08/2019 - 15/09/2019	21.30	0.90	0.57	0.67	0.64
17/09/2019 - 15/10/2019	22.09	0.92	0.58	0.67	0.66

Table A.2. Show efficiency of heat exchanger HE521 and HE522 by LMTD and NTU method with flowrate of nitrogen.

Date	Volumetric flow (kNm3/h)	Efficiency of heat exchanger HE521 and HE522			
		LMTD method		NTU method	
		HE521	HE522	HE521	HE522
30/11/2017	2.01	0.62	0.99	0.69	0.67
30/01/2018	1.75	0.50	0.73	0.60	0.60
28/02/2018	1.67	0.46	0.66	0.56	0.57
23/03/2018	1.69	0.49	0.72	0.58	0.58
21/04/2018	1.67	0.50	0.77	0.58	0.58
05/05/2018	1.35	0.41	0.61	0.47	0.47

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