EXPERIMENTAL STUDY ON ACID GAS REMOVAL USING ABSORPTION-ADSORPTION UNIT

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EXPERIMENTAL STUDY ON ACID GAS REMOVAL USING ABSORPTION-ADSORPTION UNIT

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Submitted to the Faculty of Chemical & Natural Resources Engineering in partial fulfillment of the requirements for the degree of Bachelor of Chemical Engineering (Gas Technology)

Faculty of Chemical & Natural Resources Engineering
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APRIL 2009

I declare that this thesis entitled “Experimental study on acid gas removal using Absorption and Adsorption unit” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 20 April 2009

Dedicated, in thankful appreciation for support,
encouragement and understanding
to my beloved family and friends.

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ABSTRACT

Acid gas removal is an important gas treatment in natural gas process. It is because carbon dioxide (CO_2) can cause global warming beside, if more than 3% of CO_2 composition in natural gas, it is unmarketable. CO_2 also cause corrosion to the pipeline because it can react with water vapor to form a carbonic acid. Nowadays, among the most effective and economic acid gas removal is by using package blended amine, for example MEA and MDEA in aqueous solution. This research focused on the percentage removal efficiency of CO_2 based on parameters such as MEA/MDEA mixture composition and amine concentration in an absorption-adsorption unit. The experiments began by combining methane and CO_2 flowrate to represent actual sour gas. The sour gas will flow through the absorption-adsorption column and at the same time, amine solvent flow through that column countercurrently with the gas. Amine solvent flows using the circulation pump at the flowrate 120 L/hr. For parameter MEA/MDEA mixture composition, five different ratios of amine solvents were used in every 10 minutes of experiment. The second parameter used is MDEA various concentrations by using the best amine mixture of the first parameter. As a result, increasing the composition of MDEA in MEA/MDEA mixture and increasing the MDEA concentration tend to increase the removal of acid gas. Thus, in analyzing the acid gas removal process efficiency in absorption-adsorption unit, parameters such as MEA/MDEA blending composition and MDEA concentration are among to be considered for reliability and economic benefits.

ABSTRAK

Process pengasingan bendasing didalam gas asli adalah satu proses yang sangat penting didalam industri. Ia adalah kerana carbon dioxide (CO_2) boleh menyebabkn pemanasan global dan pada masa yang sama jika kandungan CO_2 dalam gas asli melebihi 3% ia tidak dapat dijual. Gas CO_2 juga bole menyebabkn pengaratan kepada saluran paip gas kerana CO_2 bole bertindakbalas dengan wap air untuk menghasilkan asid karbonik. Dalam satu kajian menyeluruh pada proses ini, kaedah yang paling tepat dan menjimatkan ialah dengan mencampurkan MEA dengan MDEA mengunakan teknik penyerapan dan penjeraban. Penyelidikan ini tertumpu pada peratusan bagi penyingkiran gas CO_2 menggunakan parameter seperti nisbah kandungan MEA/MDEA dan juga kepekatan cecair MDEA yang digunakan. Experimen ini bermula dengan menggabungkan gas metana dengan gas CO_2 untuk menghasilkan kandungan gas asli yang sebenar sebelum proses pengasingan bendasing dibuat. Gas asli akan di alirkan melalui lajur yang padat dengan pengaktifan karbon dan pada masa yang sama, cecair amina dengan aliran penukar arus balikan. Cecair amina akan dialirkan menggunakan pam pemutaran dengan kadar aliran sebanyak 120 liter per jam. Parameter pertama ialan nisbah kandungan MEA/MDEA, dimana ada lima bacaan dibuat dan setiap satu selama 10 minit. Experimen kedua menggunakan kepekatan cecair amina sebagai parameter dengan menggunakan nilai optimum nisbah kandungan MEA/MDEA. Di dalam keputusan itu, didapati bahawa kenaikan jumlah MDEA dalam campuran MEA/MDEA dan kepekatan MDEA boleh meningkatkan proses pengasingan CO_2. Oleh itu, untuk menganalisis proses pengasingan CO_2 dengan lebih tepat dalam teknik penyerapan dan penjeraban, parameter seperti nisbah kandungan MEA/MDEA dan juga kepekatan cecair MDEA mestilah diambil kira untuk kepentingan ekonomi dan sebagainya.

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LIST OF ABBREVIATION

CH_4	-	Methane
C_2H_6	-	Ethane
C_3H_8	-	Propane
C_4H_{10}	-	Butane
C_5H_{12}	-	Pentane
CO_2	-	Carbon Dioxide
MDEA	-	Methyldiethanolamine
MEA	-	Monoethanolamine
DEA	-	Diethanolamine
AMP	-	2-amino-2-methyl-1-propanol
Toe	-	Table of Organization and Equipment
H_2S	-	Hydrogen sulfide
HCO_3^-	-	Bicarbonate ion
PTFE	-	Polytetrafluoroethylene
PFA	-	Perfluoroalkoxy or plastic or polymer resin

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CHAPTER 1

INTRODUCTION

1.1 Natural Gas

Natural gas is a gaseous fossil fuel consisting primarily of methane and also has significant quantities of ethane, propane, butane, pentane, carbon dioxide, nitrogen, helium and hydrogen sulfide. In 1950s, the story about natural gas has begun to arouse worldwide interest but it cannot compete with oil because it was difficult to exploit due to the size of investment and transport costs to the end user. Later in 1960s, the discoveries of gas and the proliferation of gas projects caused a steep climb in world production. After ten years of growth, in both production and proved reserves, natural gas was no longer a second-rate energy resource. In 1970s, its production approached the milestone figure of one billion tons oil equivalent (1.10^9 toe) and its serves rose to about half of proved reserves [1].

The oil crises from 1973 till 1979 caused world demand for crude oil to shrink drastically, while natural gas demand continued to grow, but at a slower pace. Gas has steadily gained on oil, as in term of energy equivalence, world gas production grew from 37% to 58% compared to oil production between 1970 and 1994 [2]. Consequently, the costs of the gas production and transport systems from producing well to the end user has increased and making it more difficult for natural gas to compete with other primary energy such as crude oil. In this condition, research and development on more efficient process and technologies has been

designed to reduce the costs of production, processing, and transport for natural gas. Table 1.1 below shows the properties of natural gas at the room temperature.

Table 1.1 Physical properties of natural gas [Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)]

Natural Gas	
Molecular formula	CH_4, C_2H_6
Molar mass	16 g/mol, 30 g/mol
Appearance	Colourless gas
Density	0.747 kg/Sm^3
Boiling point	-162^oC
Flash point	-187°C
Autoignition temperature	573°C
Flammable Limit	UEL = 15.4% vol LEL = 4.5% vol

1.2 Acid Gas in Natural Gas flow

Natural gas processing plants are used to purify the raw natural gas extracted from underground gas fields and brought up to the surface by gas wells. The processed natural gas, used as fuel by residential, commercial and industrial consumers, is almost pure methane and is very much different from the raw natural gas. The raw natural gas must be purified to meet the quality standards specified by the major pipeline transmission and distribution companies. Those quality standards vary from pipeline to pipeline and are usually a function of a pipeline system's design and the markets that it serves.

One of the contaminants in natural gas flow is carbon dioxide (CO_2). Known as acid gas, CO_2 has to be removed from natural gas to avoid problems such as corrosion, equipment plugging due to the formation of CO_2 solid in the low temperature system and also to maintain the heating value of natural gas. In this context, acid gas removal also can be known as gas treating or gas sweetening. The group of process uses the aqueous solution of various amines to remove CO_2 from natural gas. Removal of acid gas is a common unit process used in refineries, petrochemical plants, and other industries to remove the contaminant in natural gas.

1.3 Method in Removing Acid Gas

CO_2 is widely recognized as a major greenhouse gas contributing to global warming. This greenhouse gas is produced in large quantity worldwide by many important industries, including fossil-fuel electric power generation, steel production, chemical and petrochemical manufacturing, and cement production. In the past several decades, continuous and rapid development of these industries has caused considerable concern in this regard.

To mitigate the global warming problem, removal of CO_2 from the industrial flue gas is necessary. Various technologies had been developed for CO_2 removal by

various investigators in the past. These include absorption by chemical solvents, physical absorption, cryogenic separation, and membrane separation [3, 4]. Among those methods, CO_2 absorption by chemical solvents appears to offer an interesting and practical alternative. In fact, CO_2 absorption by alkanolamines has been the most effective one and extensive research has been performed by many investigators in the past several decades [5, 6].

The removal of acid gas impurities such as CO_2 from industrial gas stream is a significant operation in natural gas processing. The industrial gas streams containing acid gases impurities that must be purified in order to meet the requirement of acid gas mixtures sequential processing or environmental regulation. Since in the middle of 1980s, in order to further improve absorption performance of methyldiethanolamine (MDEA) solvent, blended alkanolamine solvents have been developed by adding another alkanolamine into MDEA. These blended solvents include MDEA blended with monoethanolamine (MEA), diethanolamine (DEA), and 2-amino-2-methyl-1-propanol (AMP) [7, 8]. The blended solvents have the compatibility of advantages of singles solvent in blended solvent [9].

1.3.1 Chemical Absorption Technique

Chemical absorption by a solvent is the technique most commonly used to remove acid gas in natural gas flow. The basic principle of this process is illustrated in Figure 1.1.

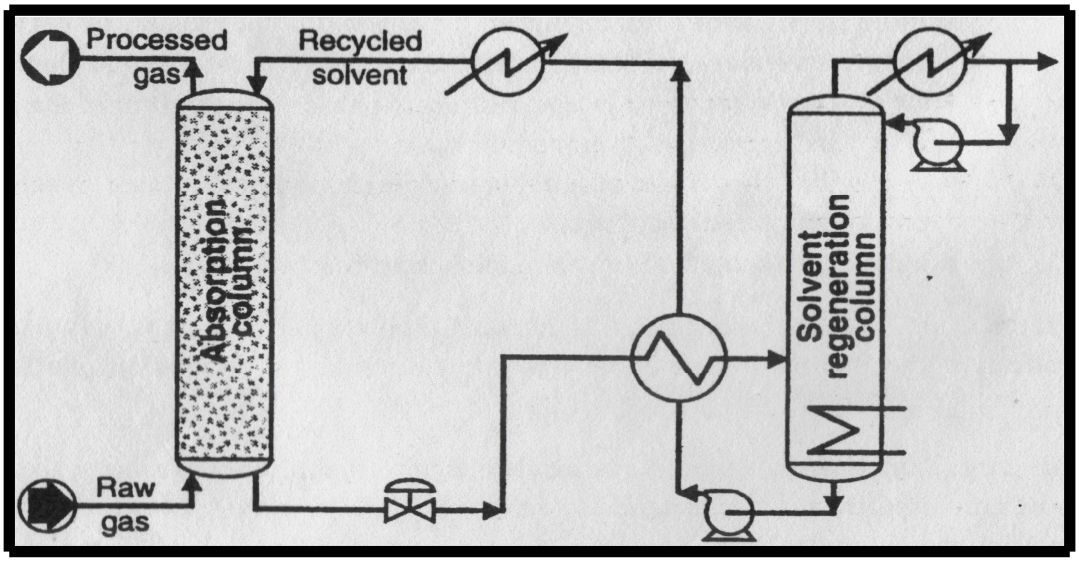

Figure 1.1 Schematic Diagram of Acid Gas Removal Using Chemical Absorption [10]

The gas to be processed is contacted in countercurrent flow with solvent in a plate or packed column. If the solvent introduced at the top of the column is pure, the solvent circulation rate and the number of plate can be set to obtain gas purity at the exit that corresponds to the specification. The solvent leaving the absorption column is sent to a distillation column for regeneration at lower pressure operating.

Various types of trays and packing are used. Information on these items and the design methods applicable in different specific cases can be found by referring to the general works already mentioned [11, 12]. There are three types of packing elements that are widely used such as Raschig ring, Pall ring and Beri saddle. The use of so-called “structure” packing made of modular elements occupying the entire

cross-section of the column and helps to reconcile good efficiency with low pressure drop [13].

1.3.2 Adsorption Technique

Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid (adsorbent), forming a film of molecules or atoms [14]. This separation process use a solid phase with large surface area, which selectively retains the components to be separated. The adsorbents are generally characterized by a microporous structure which affords a very large specific surface. There are four types of adsorbents that commonly used likes activated carbon, silica gel, molecular sieves (zeolite), and activated carbon.

The widely used adsorbent in industry nowadays is an activated carbon. There are many advantages offered by this adsorbent. Firstly, it is a highly porous and amorphous solid that consisting of microcrystallites with graphite lattices and usually prepared in small pellets or a powder. It is non-polar and cheap material that is suitable in reduces costs of processing natural gas. The carbonization process is completed by heating the material at 400 °C to 600 °C in an oxygen-deficient atmosphere that cannot support combustion. It is also used for adsorption of organic substances and non-polar adsorbates for waste gas treatment. Lastly, this material usefulness derives mainly from its micropore and mesopore volumes and the resulting high surface area.

1.3.3 A Combination of Absorption-Adsorption Technique

The gas absorption-adsorption unit is designed to demonstrate the basic principles of absorption and adsorption processes. Gas absorption is a process in which soluble components of gas mixture are dissolved in a liquid phase. The gas and liquid normally flow counter currently among some packing which serve to provide the contacting of interfacial surface through which mass transfer takes place. Meanwhile, adsorptions involve the binding of molecules from their liquid or gaseous environment onto the surface of solids. It is a separation process for the selective removal small quantities of components from a fluid mixture or solution.

Two packed columns filled with ceramic berl saddles mixed with activated carbon granules are provided for absorption-adsorption experiments. Each column is to be run individually. Methane and CO_2 are fed into the bottom of a packed column. Solvent is transferred to the top of the column either from feed vessel using centrifugal pumps, or entered directly from the laboratory supplies. Counter current flow among the carbon bed will cause the transfer of CO_2 from the gas mixture into the solvent and subsequently onto the activated carbon. The lean air mixture will exit at the top whereas the spent water will accumulate at the bottom of the column and overflow out into either the feed vessel or receiving vessel as shown in Figure 1.2.

Some CO_2 will present in the solvent can be stripped or desorbed in the feed vessel. Circulation of the hot liquid around the feed vessel through pump will release the dissolved CO_2 into vent. To remove adsorbed CO_2 from the activated carbon, hot air can be passed through the column while the vacuum pump is in switched on. The advantage using this combination unit is the efficiency in removing impurities is very high and it also can reduce the capital cost. The disadvantage using this combination unit is if one unit shutdown the other one also shutdown and it also very difficult for maintenance.

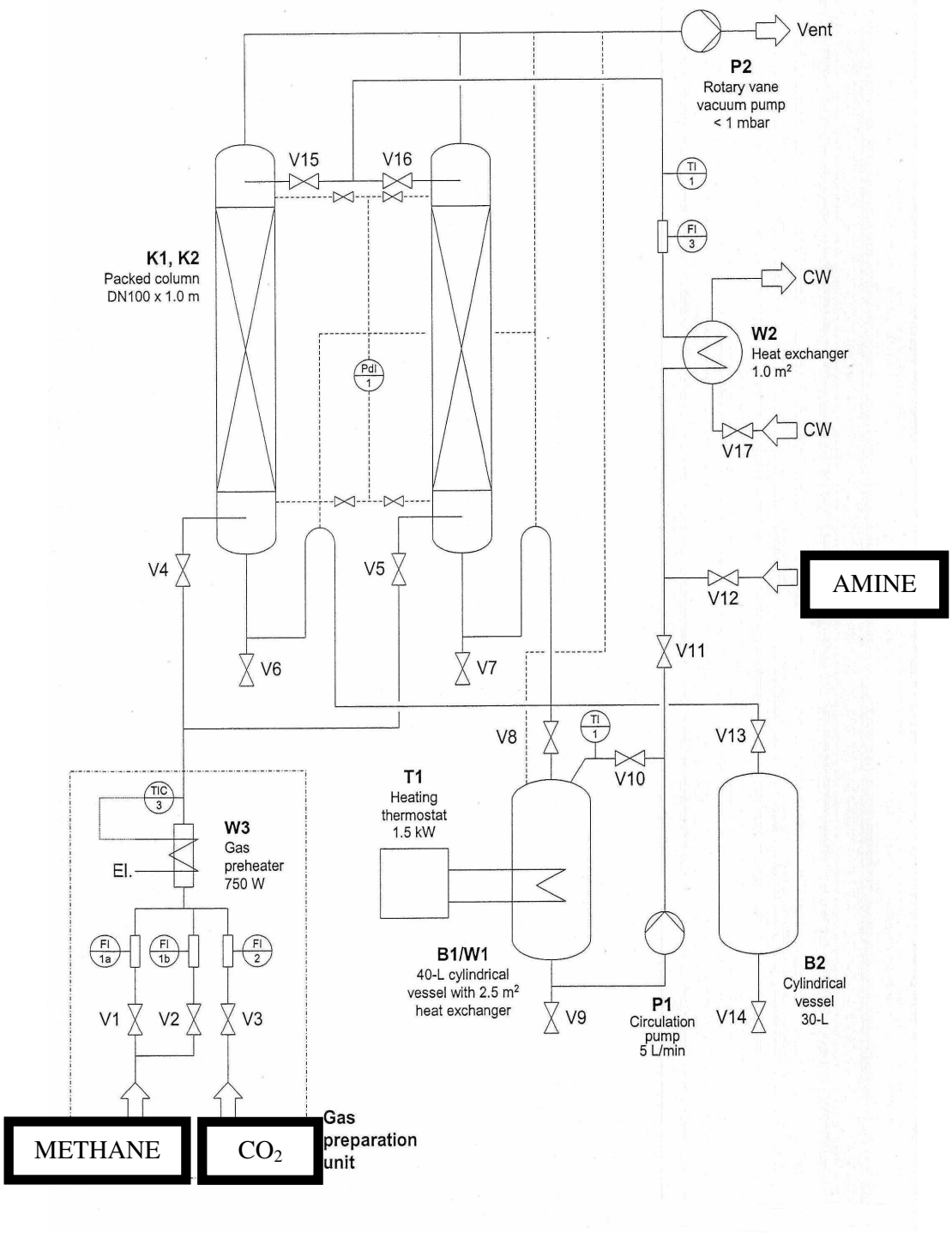

Figure 1.2 Combinations of Absorption and Adsorption (Absorption-Adsorption unit MODEL: BP 201)

The table 1.2 shows the advantages and disadvantages of combination adsorption and absorption. The advantages of this combination are it can remove impurities, which containing in the natural gas with the efficient. Besides of that, combination also can reduce capital cost. Nowadays, the adsorption should be used their adsorbent while the absorption process have their own absorbent. So, absorbent and adsorbent should be expensive and difficult to get. Compare with the combination, the unit also cheap compare with the absorption unit and adsorption unit. So, it reduces the time to do investigation.

The disadvantages of the combination are if the one of the combination is shutdown, the rest must be shut down. So it maybe difficult to manage when was doing the different experiment in one time. Subsequently, the adsorption and absorption have a different to perform the maintenance. Basically, the adsorption unit is difficult to perform because of this unit can use for the solid medium.

Table 1.2 Advantages and Disadvantages of combination Adsorption and Absorption

Advantages	**Disadvantages**
Remove impurities with efficient	If the one of the combination is shutdown, the rest must be shutdown
Reduce capital cost	Different to perform the maintenance

1.4 Problem Statement

In this research, its intention is to perform acid gas removal process in absorption-adsorption unit. To obtain optimum acid gas removal capability, several parameters need to be analyzed. Knowing the parameters which can mainly affect the acid gas removal capability is a key for reliability and economics benefits. Once the related parameters known, they must be varied in order to obtain optimum conditions.

1.5 Objective

In performing acid gas removal process on the absorption-adsorption unit, this research has highlighted two objectives which are to study significant parameters involved. The parameters are MDEA and MEA blending mixture composition and the solvent concentration.

1.6 Scope of Research Work

This research focus on two main scopes that are to experimentally investigate the absorption-adsorption unit in removing CO_2 and to investigate the advantage of MDEA blended with MEA as a chemical solvent.

1.7 Significance and Rationale of Research Work

It is very efficient to remove acid gas using absorption-adsorption unit by emphasizing the significant parameters.

CHAPTER 2

LITERATURE REVIEW

2.1 Methyldiethanolamine (MDEA)

MDEA which stands for methyldiethanolamine is a psychedelic hallucinogenic drug and empathogen-entactogen of the phenethylamine family [15]. It is a tertiary amine and act as a solvent. It has a greater capacity to react with acid gases because it can be used in higher concentrations. This advantage is enhanced by the fact that it is reacting with all of the hydrogen sulfide (H_2S) and only part of carbon dioxide (CO_2).

MDEA also delivers energy savings by reducing reboiler duties and lowering overhead condenser duties. It has proved to be highly selective for absorption of hydrogen sulfide (H_2S) when compared to carbon dioxide (CO_2) resulting in even lower circulation rates and higher quality acid gases for recycle to sulfur recovery unit. Among MEA, DEA, and MDEA, MEA has worst reputation for corrosion related problem. It is well documented in literature that MEA and DEA form degradation products when reacted with CO_2 whereas MDEA does not.

Operating MEA, DEA, and MDEA plants have demonstrated that corrosion can be minimized under proper operating conditions. However based on plant experiences and laboratory data, MEA has caused higher corrosion rate compared to DEA and MDEA [16].

MDEA as an absorption solvent of removing acid gases is widely used today in natural gas processing because it possesses the characteristics such as higher hydrogen sulfide (H_2S) selectivity, bigger absorption capacity, lower regeneration energy, smaller hot degradation and lesser corrosive. The basic properties of MDEA are showed in Table 2.1.

Table 2.1 Physical properties of MDEA [Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)]

Methyldiethanolamine	
Molecular formula	$CH_3N\ (C_2H_4OH)_2$
Molar mass	119.2 g/mol
Appearance	Clear, colorless, 150 APHA max.
Density	1.040
Melting point	-21°C
Boiling point	247°C @ 760mmHg
Solubility in water	complete
Solubility	Benzene, alcohol
Refractive index (n_D)	1.4694
Viscosity	101cP @ 20C
Flash point	135°C pmcc
Autoignition temperature	265°C
Explosive limits	0.9-8.4 vol% in air

2.2 Monoethanolamine (MEA)

Ethanolamine also called 2-aminoethanol or monoethanolamine (often abbreviated as ETA or MEA), is an organic chemical compound that is both a primary amine and a primary alcohol. Like other amines, MEA acts as a weak base and it is toxic, flammable, corrosive, colorless, and viscous liquid with an odor similar to that of ammonia. MEA is one of the most studied chemicals for post-combustion capture in power plants. MEA is very reactive with a possibility of high CO_2 removal efficiency. The downside of MEA is a high energy requirement per tonne CO_2 captured, and considerable waste generation caused by amine degradation [17]. The basic properties of MEA are showed in Table 2.2.

Aqueous solutions of MEA (solutions of MEA in water) are used as a gas stream scrubbing liquid in amine treaters. For example, aqueous MEA is used to remove CO_2 from flue gas. Aqueous solutions can weakly dissolve certain kinds of gases from a mixed gas stream. The MEA in such solutions acting as a weak base, then neutralizes acidic compounds dissolved in the solution to turn the molecules into an ionic form and making them polar and considerably more soluble in a cold MEA solution, and thus keeping such acidic gases dissolved in this gas-scrubbing solution. Therefore, large surface area contact with such a cold scrubbing solution in a scrubber unit can selectively remove such acidic component as CO_2 from some mixed gas streams. Basic solutions such as aqueous MEA can neutralize CO_2 into bicarbonate ion (HCO_3^-).

Table 2.2 Physical properties of MEA [Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)]

Ethanolamine	
Molecular formula	C_2H_7NO
Molar mass	61.08 g/mol
Appearance	Viscous colourless liquid with ammonia odour
Density	1.012 g/cm^3
Melting point	10.3 °C
Boiling point	170 °C
Solubility in water	Miscible
Vapor pressure	25 Pa (20 °C)
Flash point	85 °C c.c.
Autoignition temperature	410 °C
Explosive limits	5.5 - 17 %
U.S. Permissible exposure limit (PEL)	3 ppm

2.3 Blending MDEA with MEA

A recent advancement in gas treating technology is the application of sterically hindered amines, which offer absorption capacity, absorption rate, selectivity, and degradation resistance advantages over conventional amines for CO_2 removal from gases [18]. An understanding of the kinetic phenomena of the acid gases reactions with the mixed amine systems is essential for the effective design for the absorption units using blended-amine systems as absorbents.

Utilizing the advantages of each amine, the blended amines have been suggested to be useful in the absorption of acid gas [19]. By varying the relative concentrations of the amines, an optimum absorption system can be designed for a specific application. The addition of a small amount of primary amine to conventional tertiary amines can enhance the rate of absorption of CO_2 to a large extent without appreciably changing the stripping characteristics. Blends of primary and tertiary amines such as MEA and MDEA have been suggested for CO_2 removal [20].

The latest trends on gas treating are based on mixed amine systems where the properties of one of the amines help to compensate for the undesirable effects of the second amine. For example, the addition of a small amount of a primary amine, MEA to a tertiary amine, MDEA will enhances the rate of absorption of CO_2 largely without changing the stripping characteristics [21].

2.4 Methane

Methane is a chemical compound with the molecular formula CH_4. It is the simplest alkane, and the principal component of natural gas. It is the major component of natural gas, about 87% by volume. At room temperature and standard pressure, methane is a colorless, odorless gas; the smell characteristic of natural gas as used in homes is an artificial safety measure caused by the addition of an odorant, often methanethiol or ethanethiol.

Methane has a boiling point of −161 °C at a pressure of one atmosphere. As a gas it is flammable only over a narrow range of concentrations (5–15%) in air. Liquid methane does not burn unless subjected to high pressure (normally 4–5 atmospheres). The concentration of methane is shipped as non-liquified compressed gas in cylinders. It is also used in the manufacture of acetylene, ammonia, ethanol and methanol. Table 2.3 below show the properties of methane in room temperature.

Methane in the Earth's atmosphere is an important greenhouse gas with a global warming potential over a 100-year period. This means that a methane emission will have 21 times the impact on temperature of a carbon dioxide emission of the same mass over the following 100 years. Methane has a large effect for a brief period (a net lifetime of 8.4 years in the atmosphere), whereas carbon dioxide has a small effect for a long period (over 100 years). Because of this difference in effect and time period, the global warming potential of methane over a 20 year time period is 72. The Earth's methane concentration has increased by about 150% since 1750, and it accounts for 20% of the total radiative forcing from all of the long-lived and globally mixed greenhouse gases. Usually, excess methane from landfills and other natural producers of methane are burned so CO_2 is released into the atmosphere instead of methane because methane is such a more effective greenhouse gas. Recently methane emitted from coal mines has been successfully converted to electricity.

Table 2.3 Physical properties of methane [Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)]

Methane	
Molecular formula	CH_4
Molar mass	16.042 g/mol
Appearance	Colorless gas
Density	0.717 kg/m^3gas 415 kg/m^3 liquid
Melting point	-182.5 °C, 91 K, -297 °F
Boiling point	-161.6 °C, 112 K, -259 °F
Solubility in water	3.5 mg/100 mL (17 °C)
Flash point	-188 °C

2.5 Carbon Dioxide

Carbon dioxide (chemical formula: CO_2) is a chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in Earth's atmosphere in this state. It is a colorless, odorless gas. When inhaled at concentrations much higher than usual atmospheric levels, it can produce a sour taste in the mouth and a stinging sensation in the nose and throat. These effects result from the gas dissolving in the mucous membranes and saliva, forming a weak solution of carbonic acid. This sensation can also occur during an attempt to stifle a burp after drinking a carbonated beverage. Amounts above 5,000 ppm are considered very unhealthy, and those above about 50,000 ppm (equal to 5% by volume) are considered dangerous to human life.

CO_2 is used by the food industry, the oil industry, and the chemical industry. It is used in many consumer products that require pressurized gas because it is inexpensive and nonflammable, and because it undergoes a phase transition from gas to liquid at room temperature at an attainable pressure of approximately 60 bar (870 psi, 59 atm), allowing far more CO_2 to fit in a given container than otherwise would. Life jackets often contain canisters of pressured CO_2 for quick inflation. Aluminum capsules are also sold as supplies of compressed gas for airguns, paintball markers, for inflating bicycle tires, and for making seltzer. Rapid vaporization of liquid CO_2 is used for blasting in coal mines. High concentrations of CO_2 can also be used to kill pests, such as the Common Clothes Moth. Table 2.4 show the physical properties of CO_2 in room temperature.

Table 2.4 Physical properties of methane [Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)]

Carbon Dioxide	
Molecular formula	CO_2
Molar mass	44.0095(14) g/mol
Appearance	Colorless gas
Density	1,560 g/L (solid) 1,101 g/L (liquid) 1.98 g/L (gas)
Melting point	−78.5°C (194.7 K) −109.3°F
Boiling point	−56.6°C (216.6 K) −69.9°F (at 5.185 bar)
Solubility in water	1.45 g/L at 25°C, 100kPa
Viscosity	0.07 cP at −78 °C

2.6 Gas Analyzer

Figure 2.1 below shows the portable gas analyzer. Gas analyzer is used in the process industry and it is used to directly measure flow of various gases. If the flow drops below a set point the controls will adjust and sound an alarm. It has the capability of auditing nitrogen, argon, helium, hydrogen, CO_2 and air. The use of this analytical technique is widely recognized for its capacity to provide the most accurate means of gas measurement. In this work, it is use to analyze the gas composition of natural gas before and after the absorption and adsorption process.

There are many advantages in using gas analyzer. Gas analyzers offer the following benefits such as it can protects the environment against emission of toxic gases from various types of equipment or vehicles, and thereby controlling global warming beside it can generate visible quantifiable results. This device also light weight and can be easily transportable rather than by using other types of gas measurement. It is also can improve combustion efficiency of the equipment after analyze the composition of combustion gas.

Gas analyzers serve industries such as medical, food and beverage, aerospace, automobile, semiconductor and many more. This portable device can be used to identify vehicle emission, environmental, industrial and also to monitor gas emissions from power plants, chemical plants, refineries, cement factories and incinerators. Lastly it can be used to monitor the atmosphere during heat treatment process.

Figure 2.1 Gas analyzer

2.5 Previous Work

The table 2.5 illustrates that the previous work based on the research of acid gas removal using amine solvent. The research on absorption using amine was started by Sheng H. Lin, and Ching T. Shyu. They do this research at 1999 and the research is contact about the performance characteristics and modeling of carbon dioxide absorption by amines in a packed column. The information that can be taking as a guide is the advantage of using amine solvent rather than other types of removal acid gas.

In 2004, the research on acid gas removal using MEA and methanol was done by Alain Valtz, Christophe Coquelet and Dominique Richon. The information that can be taking as guide in this research is the advantage of MEA as a solvent. The investigation about the advantage of MDEA was done in 2007 by José M. Navaza, Diego Gómez-Díaz and M Dolores La Rubia. Both of the researches explain the characteristic and the advantage of MEA and MDEA in a single solvent.

Subham Paul, Aloke K. Ghoshal, and Bishnupada Mandal involved in the investigation of the theoretical studies on separation of CO_2 by single and blended aqueous alkanolamine solvents in flat sheet membrane contactor in year 2007. They found that MDEA blending with MEA as a solvent can increase the absorption of CO_2.

Lastly, Chih-Yuan Lin, Allan N. Soriano and Meng-Hui Li from R&D Center for Membrane Technology and Department of Chemical Engineering in Chung Yuan Christian University start the research with the finding of kinetics study of CO_2 absorption into aqueous solutions containing MDEA and DEA solubility of CO_2. Their researches give the information about the various parameters that were used in order to increase the efficiency of removing acid gas.

Table 2.5: Previous Work of the research

Author	Year	Finding	Remarks
Sheng H. Lin, and Ching T. Shyu	1999	Performance characteristics and modeling of carbon dioxide absorption by amines in a packed column	Advantages of using amine in removing acid gas
Alain Valtz, Christophe Coquelet and Dominique Richon	2004	Volumetric properties of the monoethanolamine–methanol mixture	Advantage in using MEA
José M. Navaza, Diego Gómez-Díaz and M Dolores La Rubia	2007	Removal process of CO_2 using MDEA aqueous solutions	Advantage of MDEA in removing acid gas
Subham Paul, Aloke K. Ghoshal, and Bishnupada Mandal	2007	Theoretical studies on separation of CO_2 by single and blended aqueous alkanolamine solvents in flat sheet membrane contactor	MDEA blending with MEA
Chih-Yuan Lin, Allan N. Soriano and Meng-Hui Li	2008	Kinetics study of carbon dioxide absorption into aqueous solutions containing MDEA and DEA	Effect of parameters in absorption of blended amine

CHAPTER 3

METHODOLOGY

3.1 Introduction

In order to remove acid gas from natural gas, the technique used in this research was absorption-adsorption unit where MDEA and MEA act as solvent. The unit is used in this research is SOLVEQ QVF Gas Absorption-Adsorption Unit (Model: BP 201).

The Absorption and Adsorption Unit have a certain component should be know. All glass components of the SOLVEQ-QVF Gas Absorption Adsorption Unit are made of borosilicate 3.3 glass with PTFE gaskets. This unit has packed column, vessel and heat exchanger, liquid cooler, gas preheater, circulation pump, vacuum pump and heating thermostat.

Table 3.1 below is the general description and assembly for the component of the absorption and adsorption unit.

Table 3.1 General description absorption and adsorption unit

Packed columns (K1 & K2)	Feed vessel & Heat Exchanger (B1/W1)
1. Diameter: DN 100 2. Height: 1.0m 3. Filled with a mixture of 10mm ceramic berl saddles and granular activated carbon (size 4 x 8) in 5:1 proportion.	1. Glass cylindrical vessel with coil heat exchanger. 2. Nominal capacity: 40 L 3. Heat exchange area: 2.5 m2
Receiving vessel (B2)	Liquid cooler (W2)
1. Glass cylindrical vessel 2. Nominal capacity: 30 L	1. Glass coil heat exchanger 2. Heat exchange area: 1.0 m2
Gas preheater (W3)	Circulation pump (P1)
1. Process air heater with temperature Control 2. Power: 750 W	1. Magnetic sealless centrifugal pump 2. Capacity: 5 L/min 3. Head: 8 m
Vacuum pump (P2)	Heating thermostat (T1)
1. Rotary vane vacuum pump 2. Capacity: 1.75 m3/hr 3. Vacuum: 0.1 mbar max	1. External circulation heating thermostat 2. Temperature range: ambient to 200^{o}C 3. Temperature control: ± 0.1^{o}C 4. Heater power: 1.5 kW

3.2 Analysis Method

Figure 3.2 shows the natural gas was analyzed by gas analyzer to determine the composition of natural gas before and after the experiment. The analyzing of the CO_2 was started by flowing the methane gas and CO_2 at the certain flow rate. As a result, it can determine the CO_2 content of the natural gas before the process. So, data from gas analyzer before the experiment will determine the inlet composition of CO_2 in natural gas. After the process of acid gas removal, the natural gas will analyze again to determine the outlet CO_2 composition. The differences between inlet and outlet natural gas will determine the CO_2 that have been removed in the process.

Figure 3.1 Analyze Acid Gas Content Using Gas Analyzer

3.3 Operating Procedure

3.3.1 General Start-up Procedures

Ensure all valves are closed except vent valve V21 and bypass valve V11. The main power was turn on for the control panel. To fill feed vessel B1 with amines solvent, unscrew the vent cap and pour in the liquid with the help of a hand pump. Select which packed column to run by opening the following valves:

Column K1: open valves V4 and V14

The valves were switched on the differential pressure transmitter (Pdl-1) connection so that the pressure drop of the selected column can be measured; column K1: open valves V17 and V19. Ensure that the activated carbon in the selected column has been regenerated. The valve was opened on the Natural Gas supply line and ensures that the supply pressure is set between 2 to 3 bars. The unit is now ready for experiment.

3.3.2 Safety Consideration

The unit must be operated under the supervision of an authorized staff that has been properly trained to handle the unit. All operating instructions supplied with the unit must be carefully read and understood before attempting to operate the unit. Feed stock which severely affects PTPE, PFA and borosilicate glass are not to be used. The system should not be subjected to shock, sudden impact, vibration, additional load, or permanent external action of aggressive vapours. Any leak always was checked and rectified. Then, be extremely careful when handling hazardous,

flammable or polluting materials. The system was restored to operating conditions after any repair job. Make sure the system is sufficiently ventilated when working at atmospheric pressure. Only properly trained staff shall be allowed to carry out any servicing. Manufacturer's manual must always be observed. Before any servicing, shut down the whole operation and let the system to cool down and be properly ventilated. Any coarse or abrasive cleaners on glass components were not used. Leaking couplings should be careful retightened. Any gaskets or a seal was replaced if necessary.

3.3.3 General Shut Down Procedures

Make sure that vacuum pump P2 is switched off. Valve V4 was closed. The circulation pump P1 was switched off. The liquid from the bottom of columns K1 was drained by opening valves V6. All valves in the unit except vent valve V21 was closed and bypass valve V11. The valves on the natural gas supply line were closed and release the supply pressure. If necessary, all liquid from the feed vessel B1 was drained by opening valve V10. The main power for the control panel was switched off.

3.4 Experiment Procedures (Batch Absorption-Adsorption process)

Perform the general start up procedures as describes in section 3.3.1. Feed vessel B1 was filled with 10L amine solvent and start with packed column K1. The valve V8 was closed. A circulation pump P1 was switched on, then open and adjust valve V12 & V11 to give the solvent flow rate 120 L/hr. The solvent was allowed to enter the top of column K1, flow down the column and accumulate at the bottom until it overflows back into feed vessel B1.

Valve V2 was opened and adjusted to give CO_2 flow rate of 0.2m3/hr and Valve V3 also opened and adjusted to give methane flow rate of 1.7m3/hr into column K1. Then, the gas mixture was flown through the packed column for five minutes. The outlet gas was analyzed by gas analyzer to determine the composition of CO_2 that has been removed. The outlet gas was analyzed at every five minutes. Throughout the experiment, monitor and maintain the gas and amine solvent flow rates by adjusting the appropriate valves. The experiment was repeated by four other reading at the different MDEA and MEA mixture composition and different solvent concentration.

At the end of the experiment, valves V4 and V5 was closed, following by valves V2 and V3 and the circulation pump P1 was switched off. The liquid from the bottom of columns K1 and K2 was drained by opening valves V6 and V7. All liquid from the feed vessel B1 was drained by opening valve V10. Figure 3.2 show the summary of methodology that has been conducted in this research.

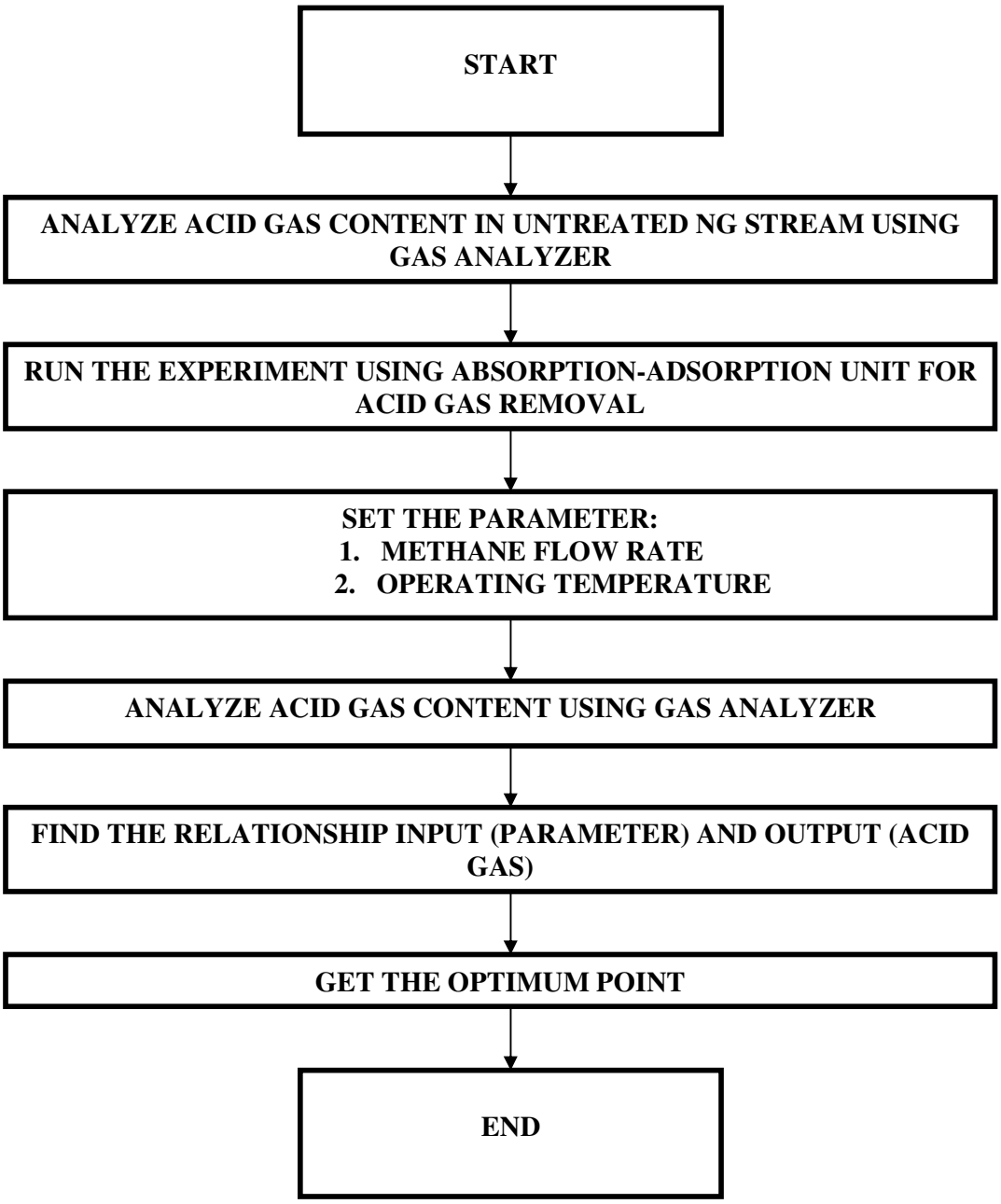

Figure 3.2 Summary of Methodology

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this study, there are 2 elements that cover including the preparation of raw natural gas and acid gas removal by using absorbent. The result of percentage ratio of methane and CO_2 are presented in this chapter. The result of various ratio MEA/MDEA mixture compositions are presented in this study. There are five different mixtures that are used to remove the percentage of CO_2 in natural gas. The results also show the various concentration of solvent by using the optimum value of MEA/MDEA ratio. There are five different concentration are used in this experiment.

4.2 Representing Sour Natural Gas by Mixing Methane and Carbon Dioxide

Table 4.1 show the percentage of methane and CO_2 based on the flowrate that is calculated in appendix C. Flowrate for methane is 1.7m^3/hr will give 88.2% v/v in natural gas flow. The balance percentage is 11.8% v/v that has been achieved by adjusting the flowrate at 0.2m^3/hr of CO_2 flowrate.

Table 4.1 Result of percentage natural gas by adjusting the flowrate

Gas	Flowrate (m^3/hr)	Percentage (%)
Methane	1.7	88.2
CO_2	0.2	11.8

The purpose of combining the flowrate of methane and CO_2 is to achieve the similar content of actual sour natural gas. Higher content of CO_2 is used so that it is easier to detect the absorption of CO_2 because the more CO_2 in natural gas was flown, the possibility of CO_2 contact with amine solvent will be higher.

4.3 Ratio of MEA and MDEA mixture composition

Table 4.2 illustrates the result of percentage acid gas that has been removed from natural gas by using five different ratio of volume MEA and MDEA. Five ratio of MEA/MDEA is 9:1, 8:2, 7:3, 6:4, and 5:5. Result show that there are no CO_2 been remove at ratio 9:1 and 8:2. For the second result, the composition of CO_2 starts to change at ratio 7:3 and the value of CO_2 removal efficiency is 0.73%. When the ratio of MEA and MDEA turn to more stable, the removal of CO_2 will be increased. At the last reading for ratio 6:4 and 5:5, the CO_2 removal efficiency is 1.46% and 2.44% respectively.

Based on the observation of the graph, when the composition of MDEA increased, the absorption of CO_2 also increased. At ratio 9:1 and 8:2 there are no changed occur because of small amounts of MDEA is added. Too large MEA rather than MDEA will effect on absorption process because two moles of MEA can only absorb up to one mole of CO_2. The absorption of CO_2 starts to increase at ratio 7:3, 6:4, 5:5 because of the good combination of MEA and MDEA. The latest trend on acid gas treating is based on mixed amine system where the properties of one the amine help to compensate for the undesirable effects of second amine [21]. For example, the addition of small amount of primary amine (MEA) to a tertiary amine

(MDEA) will enhance the rate or absorption of CO_2 largely. MDEA has the maximum loading capacity that can absorb more CO_2 rather than MEA but MDEA alone does not react with CO_2 directly because it lacks the N-H bond required to form the carbamate ion with CO_2, so blended with a little MEA will affect the bigger absorption of CO_2.

Table 4.2 Result of MEA and MDEA ratio mixture in removing acid gas

No Research	Time (min)	Ratio composition of solvent (0.3M)	Solvent flowrate (L/hr)	Gas composition (vol%)		Mass flowrate (kg/hr) of CO_2		Removal Efficiency (%)
				Sour gas	Sweet gas	Sour gas	Sweet gas	
1	10	9 liter of aqueous MDEA : 1 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.8%	0.41 of CO_2	0.41 of CO_2	0
2	10	8 liter of aqueous MDEA : 2 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.8%	0.41 of CO_2	0.41 of CO_2	0
3	10	7 liter of aqueous MDEA : 3 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.3% CO_2=11.7%	0.41 of CO_2	0.407 of CO_2	0.73
4	10	6 liter of aqueous MDEA : 4 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.4% CO_2=11.6%	0.41 of CO_2	0.404 of CO_2	1.46
5	10	5 liter of aqueous MDEA : 5 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.5% CO_2=11.5%	0.41 of CO_2	0.4 of CO_2	2.44

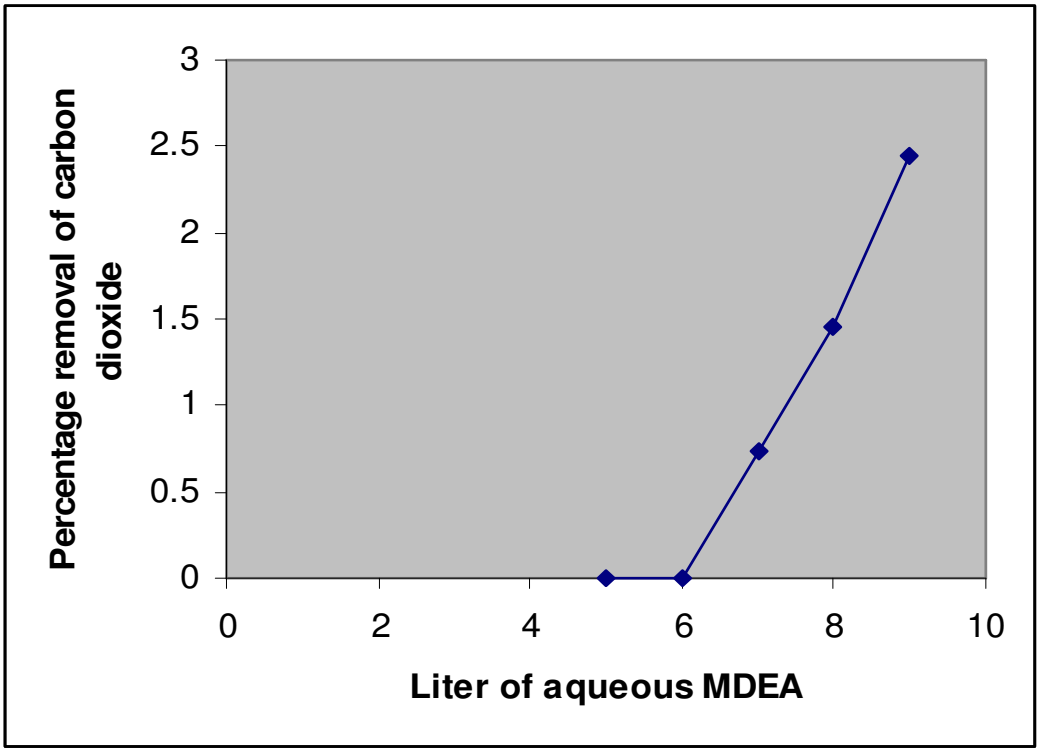

Figure 4.1 Graph percentage removals of CO_2 vs Liter of aqueous MDEA

4.4 Concentration of Amine Solvent

The result for different concentration of MDEA solvent for 0.3M, 0.35M, 0.4M, 0.45M and 0.5 M using the ratio of 5:5 is presented in table 4.3. It showed that the removal of CO_2 is increasing when the concentration of amine solvents is increased. The removal efficiency of CO_2 that has been removed using 0.3M of MDEA is about 2.44%. At the MDEA concentration 0.35M and 0.4M, the removal efficiency of CO_2 increases for 1.0% each. There was 6.59% of removal efficiency of CO_2 when using the 0.45M concentration of MDEA. Finally, at 0.5M concentration of MDEA about 9.02% of CO_2 has been removed. Based on the graph, the rate of absorption is increase due to increasing of the amine concentration.Generally speaking, increasing of amine concentration increases the driving force for absorption of CO_2. Since the rate of CO_2 absorption is controlled by a chemical

reaction in the liquid phase where amine is one of the reactant, so increasing of amine concentration has positive effect on absorption efficiency.

Table 4.3 Result of amine concentration in removing acid gas

No Research	Time (min)	Concentration (Molar)	Solvent flowrate (L/hr)	Gas composition (vol%)		Mass flowrate (kg/hr) of CO_2		Removal Efficiency (%)
				Sour gas	Sweet gas	Sour gas	Sweet gas	
1	10	5 liter of aqueous MDEA (0.3M) : 5 liter of aqueous MEA (0.3M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.5%	0.41 of CO_2	0.400 of CO_2	2.44
2	10	5 liter of aqueous MDEA (0.35M) : 5 liter of aqueous MEA (0.35M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.4%	0.41 of CO_2	0.397 of CO_2	3.17
3	10	5 liter of aqueous MDEA (0.4M) : 5 liter of aqueous MEA (0.4M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.3% CO_2=11.3%	0.41 of CO_2	0.393 of CO_2	4.15
4	10	5 liter of aqueous MDEA (0.45M) : 5 liter of aqueous MEA (0.45M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.4% CO_2=11.1%	0.41 of CO_2	0.383 of CO_2	6.59
5	10	5 liter of aqueous MDEA (0.5M) : 5 liter of aqueous MEA (0.5M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.5% CO_2=10.7%	0.41 of CO_2	0.373 of CO_2	9.02

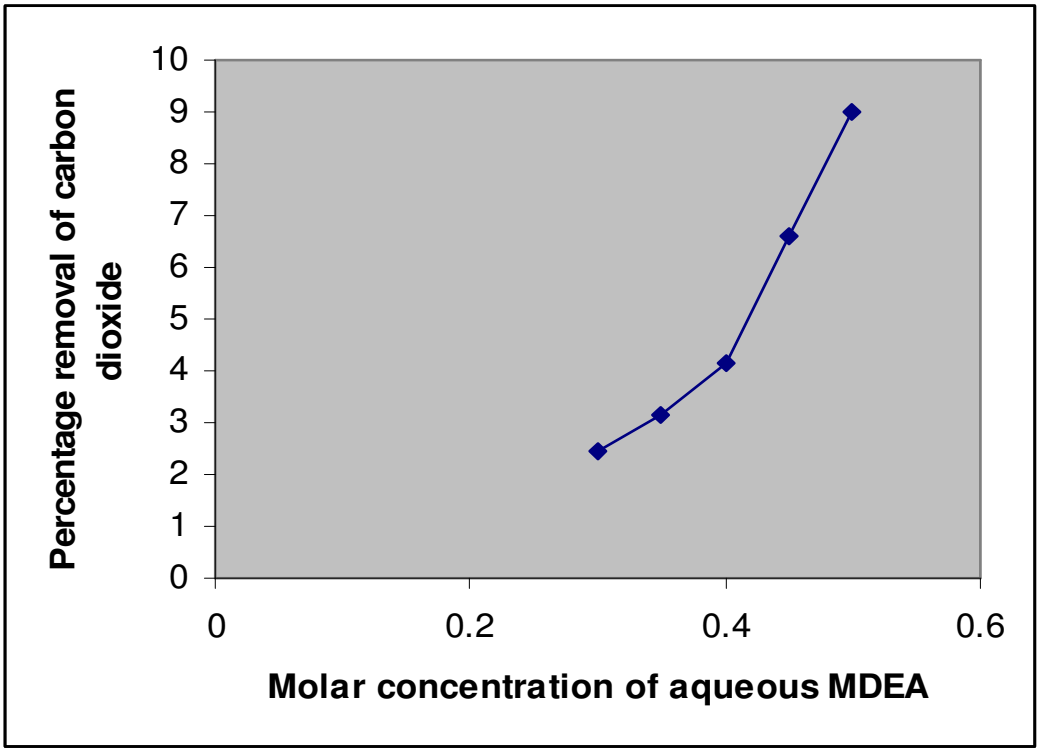

Figure 4.2 Graph percentage removals of CO_2 vs Molar concentration of aqueous MDEA

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The objective of this research is to analyze the performance of adsorption-absorption unit in removing acid gas by emphasizing significant parameter such as ratio MEA/MDEA mixture composition and the concentration of MDEA in acid gas removal process. The mixture composition and the concentration play important role in acid gas removal process. The higher percentage of removal efficiency was obtained at ratio 5:5 and concentration 0.5M. Beside that, absorption-adsorption unit also reduces the energy used and obtained higher removal of acid gas.

In this research, absorption using selected amine can remove acid gas with higher rate of removal. The amine that is use in this research is MEA and MDEA that is widely use beside it have higher absorption of CO_2, bigger loading capacity, easy and economic regeneration and non-corrosive. The effectiveness parameters such as mixture composition and amine concentration should be investigated for a reliable, available and maintainable plant with economical consideration.

5.2 Recommendations

From the experimental results, there are some recommendations that were suggested to improve or to enhance the maximum efficiency of the results. The following recommendations are proposed like a series of investigation on the purity of the amine solvent should be considered and conducted. Further study on this research parameters by changing the ratio of amine mixture and using pure amine as a solvent. Besides that, further study on other parameters like pressure, temperature and many other parameters to get the higher rate of removal acid gas. In addition, further study of the adsorption by using zeolite as an adsorbent.

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APPENDIX A

Gantt Chart for Undergraduate Research Project I

Subject/Week	4	5	6	7	8	9	10	11	12	13	14	15	16
Getting topic from coordinator													
Meeting and discussion with supervisor													
Finding journal and other information													
Writing proposal (draft)													
Prepare slide presentation													
Presentation							→						
Finalize proposal report							→						
Seminar Methodology													
Preparation for URP II													

= Actual progress

APPENDIX B

Gantt Chart for Undergraduate Research Project II

Subject/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Literature Research																	
Experiment Familiarization																	
Equipment Setup																	
Experiment Work																	
a) Sample Collection																	
b) Absorptio-adsorption unit																	
c) Absorption Methods																	
d) Adsorption Methods																	
e) Analysis Methods																	
Discussion With Supervisor																	
Preparation Of Full Thesis																	
a) Abstract																	
b) Introduction																	
c) Literature Review																	
d) Methodology																	
e) Result And Discussion																	
f) Conclusion																	
g) Reference																	
h) Appendix																	
Preparation Of Technical Paper																	
Submission 1st Draft Thesis																	
Correction Of 1st Draft Thesis																	
Submission Of Final Draft Thesis																	
Submission Of Full Thesis																	

APPENDICES C

Calculation of Dilution Process.

$$M_1 = \frac{S.G \times Purity \times 1000 mg/L}{MW}$$

Where:

S.G = specific gravity of the component.

MW = molecular weight.

Given the specific gravity of MDEA is 1.0418 with the purity of 98.0%.

$$M_1 = \frac{1.0418 \times 0.98 \times 1000 mg/L}{119.16}$$

M_1 = 8.568 M

For 0.3 M of MDEA,

$$M_1 V_1 = M_2 V_2$$
$$8.865 (V_1) = 0.3 (35)$$
$$V_1 = 1.184L$$

So, to get 36.148 L of 0.3M MDEA solvent, 1.148 L MDEA with purity 98% must be diluted with 35 L of water.

For 0.35 M of MDEA,

$$M_1 V_1 = M_2 V_2$$
$$8.865 (V_1) = 0.35(5)$$
$$V_1 = 0.197 L$$

So, to get 5.197 L of 0.35 M MDEA solutions, 0.197 L MDEA with purity 98% must be diluted with 5 of water.

For 0.4 M of MDEA,

$$M_1 V_1 = M_2 V_2$$
$$8.865 (V_1) = 0.4 (5)$$
$$V_1 = 0.23 L$$

So, to get 5.23 L of 0.35 M MDEA solutions, 0.23 L MDEA with purity 98% must be diluted with 5 of water.

For 0.45 M of MDEA,

$$M_1 V_1 = M_2 V_2$$
$$8.865 (V_1) = 0.45 (5)$$
$$V_1 = 0.25 \text{ L}$$

So, to get 5.25 L of 0.45 M MDEA solutions, 0.25 L MDEA with purity 98% must be diluted with 5 of water.

For 0.5 M of MDEA,

$$M_1 V_1 = M_2 V_2$$
$$8.865 (V_1) = 0.5 (5)$$
$$V_1 = 0.29 \text{ L}$$

So, to get 5.29 L of 0.5 M MDEA solutions, 0.29 L MDEA with purity 98% must be diluted with 5 of water.

Given the specific gravity of MEA is 1.0179 with the purity of 99.50%.

$$M_1 = \frac{1.0179 \times 0.995 \times 1000 mg/L}{61.08}$$

M_1 = 16.58 M

For 0.3 M of MEA,

$$M_1 V_1 = M_2 V_2$$
$$16.58 (V_1) = 0.3 (15)$$
$$V_1 = 0.27L$$

So, to get 35.27 L of 0.3M MEA solvent, 0.27 L MDEA with purity 99.5% must be diluted with 15 L of water.

For 0.35 M of MEA,

$$M_1 V_1 = M_2 V_2$$
$$16.58 (V_1) = 0.35(5)$$
$$V_1 = 0.11 L$$

So, to get 5.11 L of 0.35 M MEA solutions, 0.11 L MEA with purity 99.5% must be diluted with 5 of water.

For 0.4 M of MEA,

$$M_1 V_1 = M_2 V_2$$
$$16.58 (V_1) = 0.4 (5)$$
$$V_1 = 0.12 \text{ L}$$

So, to get 5.12 L of 0.4 M MEA solutions, 0.12 L MEA with purity 99.5% must be diluted with 5 of water.

For 0.45 M of MEA,

$$M_1 V_1 = M_2 V_2$$
$$16.58 (V_1) = 0.45 (5)$$
$$V_1 = 0.14 \text{ L}$$

So, to get 5.14 L of 0.45 M MEA solutions, 0.14 L MEA with purity 99.5% must be diluted with 5 of water.

For 0.5 M of MEA,

$$M_1 V_1 = M_2 V_2$$
$$16.58 (V_1) = 0.5 (5)$$
$$V_1 = 0.15 \text{ L}$$

So, to get 5.15 L of 0.5 M MEA solutions, 0.15 L MEA with purity 99.5% must be diluted with 5 of water.

APPENDICES D

Table 4.2 Result of MEA and MDEA ratio mixture in removing acid gas

No Research	Time (min)	Ratio composition of solvent (0.3M)	Solvent flowrate (L/hr)	Gas composition (vol%)		Mass flowrate (kg/hr) of CO_2		Removal Efficiency (%)
				Sour gas	Sweet gas	Sour gas	Sweet gas	
1	10	9 liter of aqueous MDEA : 1 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.8%	0.41 of CO_2	0.41 of CO_2	0
2	10	8 liter of aqueous MDEA : 2 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.8%	0.41 of CO_2	0.41 of CO_2	0
3	10	7 liter of aqueous MDEA : 3 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.3% CO_2=11.7%	0.41 of CO_2	0.407 of CO_2	0.73
4	10	6 liter of aqueous MDEA : 4 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.4% CO_2=11.6%	0.41 of CO_2	0.404 of CO_2	1.46
5	10	5 liter of aqueous MDEA : 5 liter of aqueous MEA	120	CH_4=88.2% CO_2=11.8%	CH_4=88.5% CO_2=11.5%	0.41 of CO_2	0.4 of CO_2	2.44

Set Pressure : 1 bar

Methane flow rate : 1.7m^3/hr

CO2 flow rate : 0.2m^3/hr

Methane flow rate fixed at the 4.0 m^3/hr because of the optimum point.

APPENDICES E

Table 4.3 Result of amine concentration in removing acid gas

No Research	Time (min)	Concentration (Molar)	Solvent flowrate (L/hr)	Gas composition (vol%)		Mass flowrate (kg/hr) of CO_2		Removal Efficiency (%)
				Sour gas	Sweet gas	Sour gas	Sweet gas	
1	10	5 liter of aqueous MDEA (0.3M) : 5 liter of aqueous MEA (0.3M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.5%	0.41 of CO_2	0.400 of CO_2	2.44
2	10	5 liter of aqueous MDEA (0.35M) : 5 liter of aqueous MEA (0.35M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.2% CO_2=11.4%	0.41 of CO_2	0.397 of CO_2	3.17
3	10	5 liter of aqueous MDEA (0.4M) : 5 liter of aqueous MEA (0.4M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.3% CO_2=11.3%	0.41 of CO_2	0.393 of CO_2	4.15
4	10	5 liter of aqueous MDEA (0.45M) : 5 liter of aqueous MEA (0.45M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.4% CO_2=11.1%	0.41 of CO_2	0.383 of CO_2	6.59
5	10	5 liter of aqueous MDEA (0.5M) : 5 liter of aqueous MEA (0.5M)	120	CH_4=88.2% CO_2=11.8%	CH_4=88.5% CO_2=10.7%	0.41 of CO_2	0.373 of CO_2	9.02

Set Pressure : 1 bar

Methane flow rate : 1.7m^3/hr

CO2 flow rate : 0.2m^3/hr