Study on the Effect of Feed Conditions towards Temperature Drop in the Joule Thomson Valve for Natural Gas Dehydration

by

Teh Jason

15438

Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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Approved by,

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September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

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TEH JASON

ABSTRACT

In the oil and gas industry, the presence of water vapor and carbon dioxide has brought over much inconvenience to natural gas processing and transportation. Many technologies have been invented and applied to tackle this problem. The most common technologies that are being used for the dehydration of natural gas are absorption and adsorption. Common absorption material used are triethylene glycol (TEG) while common adsorption material used are silica gel and molecular sieve. By using the absorption and adsorption technique, large amount of moisture from the natural gas could be removed. This technology has been used in the industry for decades due to its promising efficiency. However, the packing column requires a large column space for maximizing the absorption amount. Next, high energy is needed for the regeneration of solid and liquid desiccants. Furthermore, the desiccant is exposed to the risk of poisoning when it is being exposed to heavy hydrocarbon and other gasses in the natural gas. Hence, a new method is being studied and the Joule Thomson Expansion throttling technique is proposed to remove the water vapor from natural gas and carbon dioxide mixture. The benefits of the proposed technique includes self- induced refrigeration, low operating cost, and simple mechanical design. In this project, the effect of feed conditions towards the temperature change in the Joule Thomson valve is investigated. The temperature change of the natural gas is important as condensation of water would happen providing that the temperature change is large enough. By achieving the dew point of the gas mixture, condensation process would occur. The investigation will be carried out using different feed pressure and different composition of gas mixtures. In addition, the simulation of the project is developed in HYSYS software built by AspenTech. The calculated value from the simulation is compared with the experimental data to study on the contributing factors towards the temperature change of the gas mixture. With the known temperature change, a further study could be carried out on the percent of water removal attainable.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the new era of globalization, the demand of the natural gas is increasing. Natural gas could be defined as a gaseous fossil fuel found in oil fields, natural gas fields and coal beds [1]. Over millions of years, decay of animal remains and the remains of the plant will form the natural gas. It is found in reservoirs beneath the surface of earth and is mixed up with petroleum [1]. The Southeast Asia's energy demand has been increasing tremendously. By today and 2035, it is expected that the demand will rise over 80% [2]. The natural gas has been widely used as fuel for cooking. Next, it is also used to heat up (water heating and space heating) and cool (air conditioning) household in the countries. Furthermore, natural gas provides cleaner fuel for transportation compared to gasoline and diesel[3].

The electricity supplied to the residential area are generated by natural gas too. Besides, natural gas could be used for the industrial and manufacturing purposes. It could be seen that natural gas plays an extremely important role in the world.

FIGURE 1 shows the production and consumption of natural gas in the United States while TABLE 1 shows the world natural gas consumption from year 1994-2010. From FIGURE 1, the production and consumption of the natural gas was reducing in the 1970-1984. However, it could be seen that the production and consumption started to rise rapidly starting from 1985. This proves that the natural gas consumption and demand is increasing every year

TABLE 1: World Natural Gas Consumption [4]

2000 and 2010 forecasts in 10^6 toe (NHV)

Country	Year		
	1994	2000	2010
North America	582.1	582-604	629-659
-Canada	67	72-77	77-81
-United States	515	510-527	553-578
Latin America	81.2	98-102	136-153
Western Europe	281.3	323-340	374-400
Eastern Europe	575.1	706-731	837-880
-CIS	521.3	638-655	740-774
Africa	38	51-55	77-94
Middle East	113.9	128-136	170-187
Asia/Ocenia	175.3	208-230	276-298
-Japan	50.1	55-60	68-77
-Australia/New Zealand	18.6	26-30	30-34
-Other countries	106.6	136-140	179-187
World	1846.8	2095-2197	2499-2669

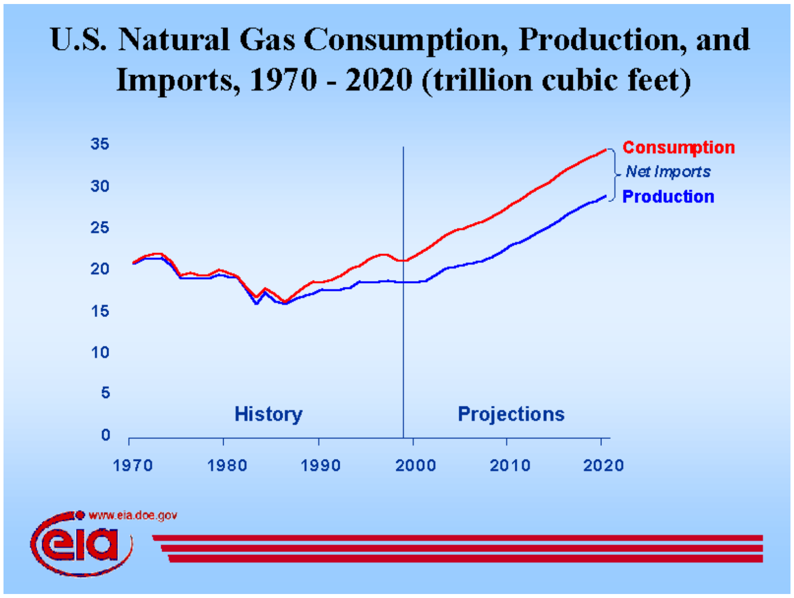

FIGURE 1: Production and Consumption of Natural Gas in the United States [5]

The natural gas, as one of the primary energy source, contains a lot of different hydrocarbons and impurities. Normally, the natural gas are saturated with water vapor and carbon dioxide. This is due to the presence of connate water in the reservoir rock. The undesirable components like water, hydrogen sulphide and carbon dioxide has to be removed to prepare the natural gas for sales [6].

The emission of carbon dioxide has significantly increased by more than 200% from 1990 to 2006 [7]. In Malaysia, most of the natural gas contains high carbon dioxide content ranging from 28% to 87% [7]. Hence, the gas sweetening process is essential and important. With presence of moisture (water) and carbon dioxide, the gas mixture rapidly destroys the pipelines and equipment. It also reduces the heating value of a natural gas stream and wastes pipeline capacity [7]. [8] also shows that carbon dioxide provides no heating value and have to be removed before distribution.

The current carbon dioxide removal technology includes, absorption, adsorption, membranes and cryogenic distillation [7]. The absorption, adsorption and membrane processes are used to remove the carbon dioxide from the flue gas. They are also being used extensively in the purification of natural gas. Cryogenic distillation is being used for the carbon dioxide liquefaction from the gas wells [7].

Prior to removing the carbon dioxide in the natural gas fields, the water vapor has to be removed. As an example, substances that could cause freezing in the cryogenic plant (water) has to be removed up to a level of 0.1ppmv before the carbon dioxide could be removed [8]. The dehydration of natural gas is essential before it could be sent to the cryogenic plant. Next, the absorption of water by ionic liquid (IL) could decrease the solvent capacity to absorb the carbon dioxide [8]. Furthermore, swelling and fouling of membrane could occur if water vapor is not removed from the natural gas during the removal of carbon dioxide [8].

The water vapor content in the natural gas could also result in hydrate formation, reduce the line capacity and corrode the pipelines [9]. The freezing of pipeline could occur if the water vapor are not removed. Furthermore, during the transportation of natural gas, large pressure drop and decrease of heating value could cause major problem to the oil and gas industry [10]. Therefore, the water vapor content in the natural gas has to be reduced to a certain limit for the sales contracts before the carbon dioxide removal process could be carried out. As an example, the pipeline specifications of the US government is 104mg of water per standard m^3 or 7lb of water per million standard cubic feet [11].

Dehydration of natural gas is therefore a really important and essential process. Dehydration of natural gas could be defined as the removal of water vapor content from the gas to lower the stream’s dew point [6]. The dehydration of the natural gas has a large correlation towards the temperature change in the gas stream as condensation of water would occur when the gas achieve the dew point temperature. There are a few different technologies that have been used. Absorption by liquid desiccants (i.e. Glycol solutions), adsorption by solid desiccants (silica gel, molecular sieve, alumina, etc.), gas permeation via membrane and refrigeration are the current technologies used for the dehydration process [10]. The absorption by liquid desiccants normally employs the use of ethylene glycol (EG), diethylene glycol (DEG), triethylene glycol (TEG) and tetraethylene glycol (TREG) for the dehydration purposes [12]. FIGURE 2 shows the TEG dehydration unit used to remove the water vapor before the removal of carbon dioxide. Adsorption technique is widely used in the industries to remove the water vapor. Desorption process is followed after the adsorption process when the desiccants are saturated with water vapor. Refrigeration is a chilling process where the gas is cooled. The cold gas would hold less water than the warm gas [12].

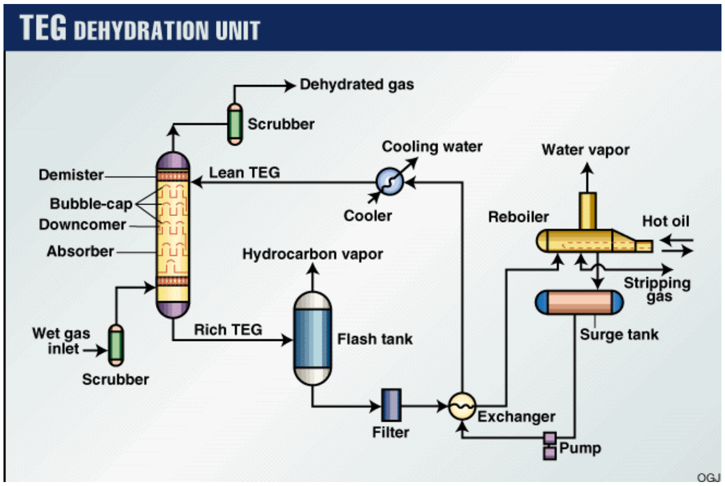

FIGURE 2: Dehydration of natural gas using Triethylene glycol (TEG) [13]

1.2 Problem Statement

The high carbon dioxide content in the gas fields in Malaysia demonstrated high carbon dioxide capture and storage (CCS) and dehydration opportunity. As mentioned in the introduction, absorption, adsorption, refrigeration and membrane technologies are used for the removal of water in the natural gas and carbon dioxide mixture. Nevertheless, there are some major drawbacks that could affect the dehydration process. Liquid absorption using glycol dehydrators is an excellent process for the water removal. TEG is the most cost effective glycol due to superior dew point depression and operating reliability [14]. However, they produce Volatile Organic Compounds (VOC) emissions [15]. Besides, the glycol could be contaminated easily and this could reduce the effectiveness of the dehydration process.

The adsorption process using solid desiccants have the disadvantage of high regeneration temperature, which increase the energy cost [14]. As an example, the use of molecular sieve as the adsorbent contribute to high expense as it is very expensive. The silica gel, when being used as adsorbent, has the tendency of being destroyed when it is contacted with water.

Furthermore, the refrigeration process requires high amount of cooling energy, contributing to higher cost of production. The water removing process using membrane has the advantage of low energy usage. Nonetheless, membrane has low chemical stability. Other techniques need to be explored and investigated to remove the water vapor cost-effectively and efficiently.

The Joule Thomson throttling effect is an interesting field to be investigated as the research and study on this topic is limited. Next, the experiment of J-T effect towards the temperature change and water removal of the natural gas is rarely reported and not thoroughly studied. The temperature change of the gas mixture is crucial as the condensation process will happen if the dew point of the gas mixture is attained. Once the condensation of water is enabled, the removal and dehydration of the gas mixture could be carried out. Hence, the expansion and cooling of the gas and water mixture based on the Joule Thomson effect should be conducted.

1.3 Objectives

The main objectives of the project are as follows:-

a) To simulate and conduct parametric analysis on natural gas, carbon dioxide and water mixture using Aspen Tech HYSYS
b) To investigate the effect of feed pressure on the temperature change in the natural gas, carbon dioxide and water mixture using Joule Thomson Expansion Valve
c) To investigate the temperature change with different composition of gas mixture under different feed pressure using Joule Thomson Expansion Valve.

1.4 Scope of study

The scope of study with regards to this project would compromise:-

1. The simulation on the effect of various feed conditions towards the change in temperature inside carbon dioxide, natural gas and water mixture using AspenTech HYSYS.
2. The experimenting on the effect of various feed pressure towards the change in temperature of gas mixture using Joule Thomson throttling valve.
3. The experimenting on the effect of different gas compositions towards the change in temperature using Joule Thomson throttling valve.

CHAPTER 2

LITERATURE REVIEW

2.1 Carbon Dioxide removal technologies

Natural gas contains a lot of different impurities. The major impurities that have to be removed include carbon dioxide and water. Absorption, adsorption, cryogenic distillation and membrane processes are employed for the carbon dioxide capture process.

TABLE 2 presents the latest technologies of carbon dioxide capture and their industrial applications. Absorption process uses liquid sorbent to absorb the carbon dioxide from the flue gas. This is the most mature technology used for the carbon dioxide capture [16]. The adsorption process is similar to the absorption process except that a solid adsorbent is used to bind the carbon dioxide molecule. Cryogenic distillation is a gas separation process using distillation at very low temperature and high pressure, which is similar to other conventional distillation processes. However, they are used to separate components of gaseous mixture (due to their different boiling points) instead of liquid [16]. To remove the carbon dioxide, the natural gas needs to be dried. As an example, the cryogenic process of removing carbon dioxide requires the removal of water beforehand to prevent freezing from occurring [8]. Next, moisture content in the gas has to be removed prior to the carbon dioxide removal using membrane as the water vapor in the gas could affect the performance and selectivity of the membrane [8]. The absorption of that water by the ionic liquid could decrease the solvent’s capacity if the natural gas contains water. This will also degrade the reduction in regeneration duty associated with amine IL solution. [8]

TABLE 2: Carbon dioxide capture technologies [7].

Technology	Industrial applications	Critical issues for large scale application	Future needs/emerging trends
Absorption	Removal of CO2 from flue gas.	Energy requirement for regeneration.	Improved process design.
	Purification of natural gas.	Pretreatment of other acid gases.	Solvents with high CO2 capacity and low regeneration energy
			Rotating absorber.
			Novel and improved contacting equipment.
Membranes	CO2 separation in H2 production.	CO2selectivity. Degradation/fouling issue.	Ceramic facilitated transport.
	Purification of natural gas.		Cross-linking the mixed matrix membranes to attain enhanced Permeability and selectivity.
Cryogenic distillation	CO2 liquefaction from gas wells.	Refrigeration <0 8C.	Hybrid process.
		Pretreatment for impurities that freeze above operating temperature (e.g. H2S).	Integration with sequestration processes.
			Efficient refrigeration cycles.
Adsorption	CO2 separation in H2 production.	Adsorbents tend to have low capacity/selectivity.	New adsorbents that adsorb CO2 in presence of water vapor
	Purification of natural gas.	Energy penalty for regeneration.	
		Long cycle times.	Carbon-based adsorbents.

2.2 Effects of water vapor and carbon dioxide in natural gas transportation

The existence of water vapor in natural gas during transportation has caused major problems over the past few years. This is particularly true where the sub seas pipelines are exposed to extreme conditions such as low temperature and high pressure where hydrate could form easily [17]. The formation of the hydrate could cause pipe blockage and corrode the pipeline. The water vapor would increase the corrosivity of the natural gas, particularly when the acid gases such as carbon dioxide is present [14].

The presence of moisture can cause excessive pressure drop, hydrate, the decrease of heating value, the reduction in gas transmission efficiency, and corrosion in transmission pipelines in the process of producing and transporting natural gas [10]. The natural gas hydrates are crystalline and solid compound that could be formed from water and hydrocarbon molecules. The water molecule acts like a three dimensional cage while the other hydrocarbon molecule will be trapped within the water molecule. The formation of hydrates require high pressure, low temperature and presence of natural gas and water. The condensed liquid would increase the operating pressure and destroy the equipment over time [9]. The presence of carbon dioxide also reduce the heating value of the natural gas stream and affect the pipeline capacity for transportation [7].

To ensure a trouble free and safe operation, water vapor in the natural gas has to be removed from the carbon dioxide for natural gas processing and transportation.

2.3 Absorption

The existing technologies available now for the dehydration process are absorption, adsorption, membrane process and refrigeration. The absorption process uses liquid desiccants such as glycol to remove the water content of the natural gas. A suitable solvent such as glycol should have the following properties [4]:

a) Strong affinity for water
b) Low cost
c) Non corrosive
d) Thermal stability
e) Easy regeneration
f) Low affinity towards acid gases and other hydrocarbons
g) Low tendency to foam and emulsify
h) Low solubility in hydrocarbons
i) Low viscosity

Triethylene glycol is normally used for the removal of water [18]. The whole process happen in an absorption tower where the wet natural gas is contacted with the TEG solution counter currently [18]. The wet natural gas will enter the bottom of the tower while the Lean concentrated TEG will be fed to the top of the tower. The TEG solution will then absorb the water from the natural gas and will be regenerated. The glycol will undergo the distilling process to remove the water before they are reused. However, TEG glycol dehydrators produce volatile organic compounds and hazardous air pollutants from the reboiler vents [15]. Next, foreign matter such as dirt could contaminate the glycol solution easily. Furthermore, the glycol solution tend to become viscous at low temperature. They are hard to pump and might solidify when the plant is not operating [14]. The other downside is that the glycol solution has to be regenerated after usage, which is an energy intensive process (high cost) and they generate only low quality of water[19]. The use of TEG also produce BTEX emission. The BTEX is classified by the United States Regulations as a carcinogenic substances and is a toxin[20]

2.4 Adsorption

The next technology available is the use of solid desiccant. It is an adsorption process where solid adsorbent is used to capture the water vapor. The adsorption process could be defined as a physical phenomenon that happens when molecules of gas are brought to contact with a solid surface and some of them condense on the surface [6]. The common adsorbent are molecular sieves, activated alumina and silica gel. The wet natural gas is passed through a bed of adsorbent material. The water and moisture in the gas will adsorb onto the adsorbent and a dry gas would be produced. When the adsorbent is saturated with water vapor, the bed will have to be regenerated [12]. The adsorbent should have the following properties [4]:

a) Low pressure drop
b) Chemical inertness
c) Fast adsorption kinetics
d) Reversible adsorption allowing regeneration of the adsorbent
e) High adsorption capacity at equilibrium

FIGURE 3 shows the dehydration process using adsorption procedure. The adsorption process happens in Dryer A while the regenerative process happens in Dryer B.

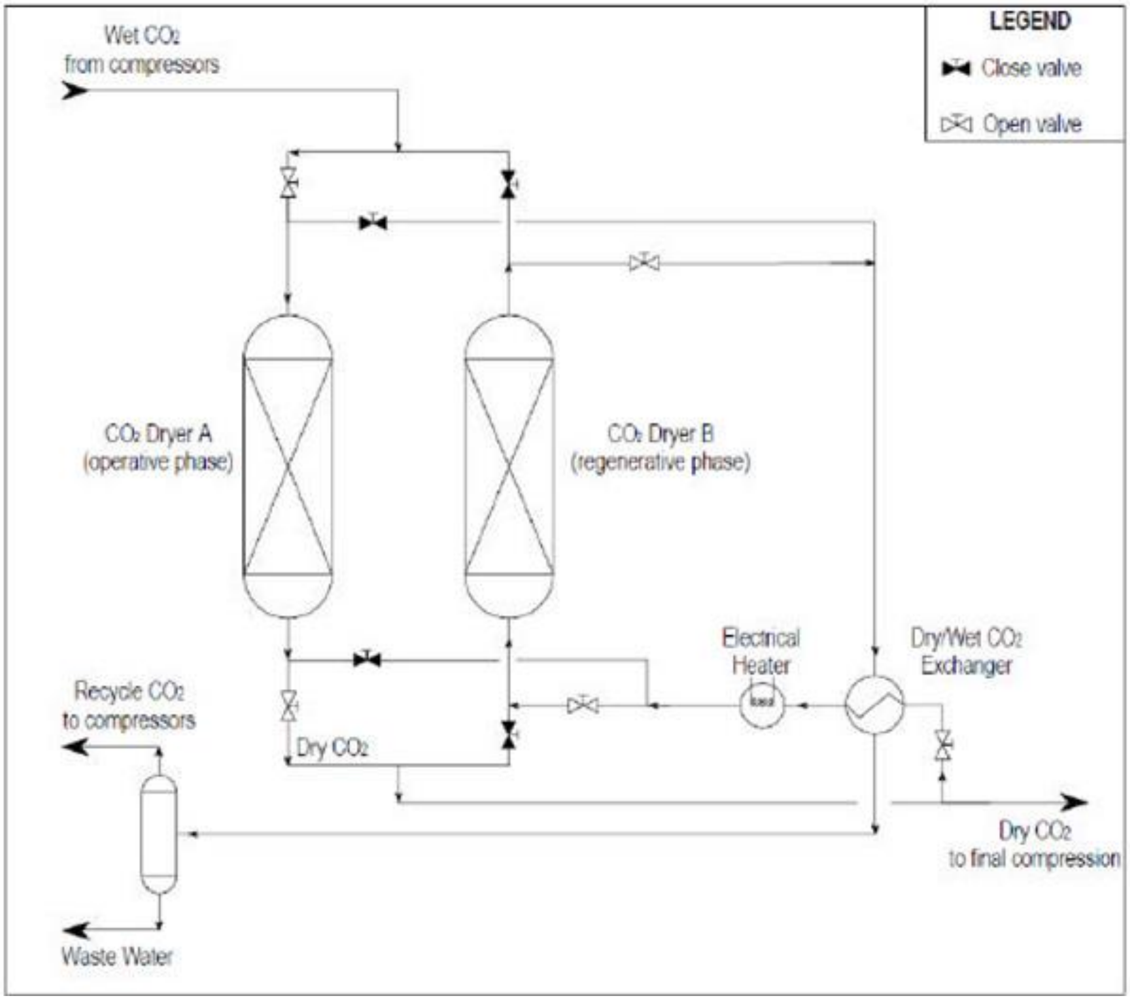

FIGURE 3: Dehydration of natural gas using adsorption process [21]

Activated alumina could be used as one of the adsorbent for the adsorption process. By using this, low water content of about 1ppm volume could be achieved. The disadvantages of using activated alumina is that the heavy hydrocarbons that are adsorbed could not be desorbed during regeneration [4].

Molecular sieve has high capacity for water removal, high removal of impurities and greater resistance to coking and fouling [14]. The molecular sieves used are normally silicoaluminates. The crystal structure forms cavities making up a micro porous network on a molecular scale [4]. The molecular sieve adsorbent could reduce the water content to about 0.03ppm vol. However, they have to be regenerated at high temperature and contributed to the expensive utility cost.

Silica gel has high water removal capacity and could be regenerated at low temperature. They could remove water up to 10ppm vol. Besides, silica could be used for the dehydration of sour gas due to its high tolerance to hydrogen sulfide [1]. The major downside of silica gel is due to the tendency of being shattered in contact with water [14]. Free water will destroy the silica gel which causes the granules to burst and reacts with bases [4].

The other downsides of the adsorption process are the high consumption of energy, high capital and maintenance cost [22]. The desiccants could be sensitive to the poisoning with the other gas and liquids in the natural gas [6].

2.5 Refrigeration

The dehydration of natural gas also could be carried out using refrigeration process. By using refrigeration to cool the gas, partial liquefaction will occur and the water in the gas could be removed. A typical refrigeration process can easily reduce the water content of a gas stream down to the1 lb/MMCF level [16]. The cold temperatures in a refrigeration process result in water removal. This is due to the fact that the cold gas can carry less water than warm [12]. Ethylene glycol are normally added to prevent hydrate formation. However, the condensed water removed is dirty and corrosive [19]. FIGURE 4 demonstrates the refrigeration process where the gas mixture are being cooled by using refrigerant, causing the temperature to drop to the dew point of the water. The temperature change of the gas will result in the condensation of water and the removal process could be performed by using glycol. The chilled gas will be sent to the gas-gas heat exchanger to pre-cool the inlet gas while the rich glycol will be regenerated.

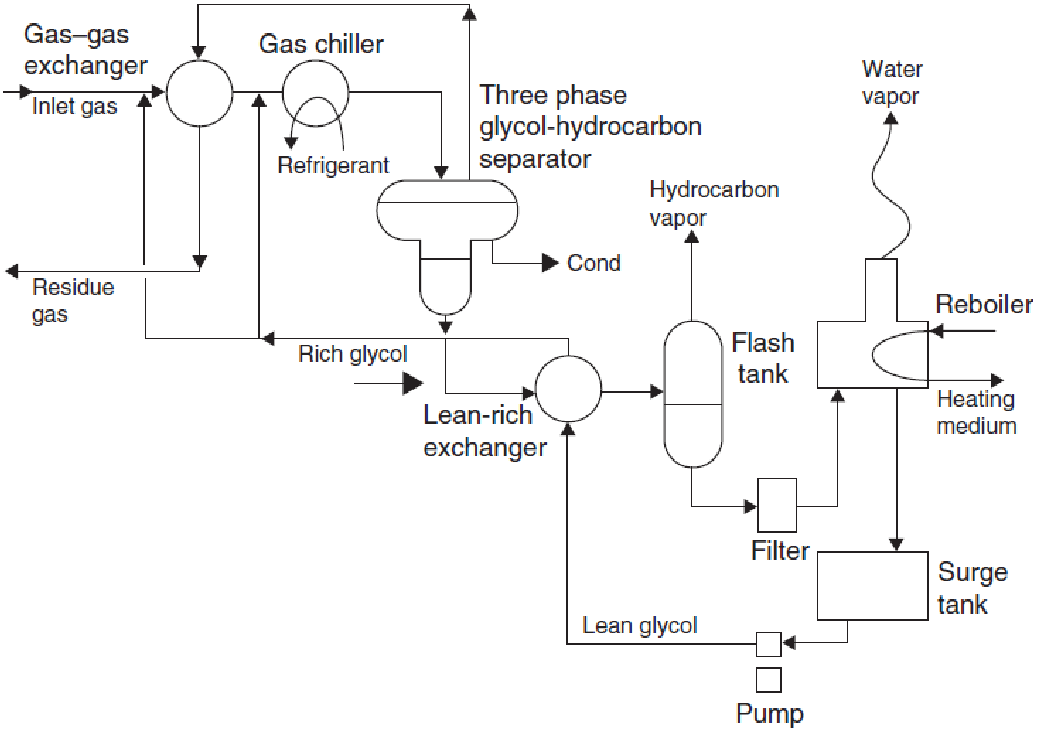

FIGURE 4: Dehydration using refrigeration [12]

2.6 Membrane

Membrane process could be used for dehydration of natural gas. Membrane process of removing water vapor is an effective process. It offers superior characteristics such as low cost, low energy consumption and easy operation [22]. Some of the disadvantages are low chemical stability, swelling phenomenon and poor mechanical and thermal strength [22]. Furthermore, large floor space, requires high maintenance and high CAPEX (capital expenditure) is needed for the membrane separation process. Membrane has to be changed periodically to maintain high efficiency of separation.

2.7 The Joule Thomson Effect

Joule Thomson effect is an adiabatic and isenthalpic process where the temperature of the gas is changed with expansion without any work being done. The gas undergoes a throttling process where the kinetic energy is reduced and the potential energy is being increased [23]. The gas is allowed to expand freely and the pressure of the gas is reduced. Simultaneously, the temperature of the gas is changed [23]. At room temperature, all gases except hydrogen, helium and neon cool upon expansion by Joule Thomson process. This project uses the concept of Joule Thomson Expansion. Water could be removed from the natural gas when the gas flows through the valve. The sudden drop of pressure and temperature causes the water vapor to condense out and hence, they could be separated.

The Joule Thomson effect is normally applied only on real gas. For the case of using ideal gas, the temperature remains constant. The temperature changed of the real gas when it is passed through the valves depends on the initial temperature and pressure. It also depends on the J-T expansion inversion temperature curve [3].

The Joule Thomson coefficient could be denoted as $\boldsymbol{\mu_{JT}}$ and the unit is K/Pa. it could also be expressed as the rate of change of temperature with regards to pressure at constant enthalpy. It could also be expressed in terms of volume, V, heat capacity Cp and thermal expansion α. Usually, if the gas temperature is below the inversion temperature, it will cool as it is expanded and vice versa [3, 23].

$$\mu_{\mathrm{JT}} \equiv \left(\frac{\partial T}{\partial P}\right)_H = \frac{V}{C_{\mathrm{p}}}(\alpha T - 1) \qquad (1)$$

TABLE 3 shows the relationship between the inversion temperature and the Joule-Thomson coefficient.

TABLE 3: summarize of J-T coefficient and the effect on the gas. [23]

Gas Temperature	μ_{JT}	∂P	∂T	gas
below inversion temperature	postive	negative	negative	cools
above inversion temperature	negative	negative	positive	heats

From the table, it could be observed that when the gas temperature is below the inversion temperature, Joule Thomson coefficient would be positive. During the expansion process, the change in pressure will always be negative. By going through equation 1, if the Joule Thomson coefficient is positive and the change in pressure is negative, the change in temperature must be negative. This indicates the gas mixture cooling down. However, if the gas temperature is above the inversion temperature and the Joule Thomson coefficient is negative, the vice versa will happen.

The μJT will change sign at the inversion point for real gas application. The temperature of this point is called the Joule–Thomson inversion temperature and it depends on the pressure of the gas before expansion. The cooling of the gas prior to Joule Thomson expansion is necessary and the isenthalpic expansion through a control valve could be used to refrigerate the gas [4]. The Joule Thomson effect is applied on petrochemical industry where gases are being liquefied. Furthermore, it is also being applied in the cryogenics application.

[24] proves that temperature drop will occur in natural gas mixture due to the Joule Thomson effect by varying the pressure drop. A pressure drop of 20 and 100kPa difference could result in temperature change of about 0.25K. Next, temperature drop of 15 K is possible with the pressure drop of around 68bar [25]. However, the experiment carried out in the past is based on high inlet temperature of the gas and the temperature drop of the gas mixture depends greatly on the feed conditions. The research on the effect of feed conditions towards the temperature change of the gas mixture using Joule Thomson Valve for natural gas dehydration is still very limited. Hence, this study is important and could fulfill the required objectives.

2.8 HYSYS Simulation

AspenTech HYSYS is produced by AspenTech to optimize process manufacturing. It is a comprehensive process modeling tool used by the world’s leading oil and gas producers, refineries, and engineering companies for process simulation and process optimization in design and operations [26]. The software could tackle the most challenging and complex manufacturing problem. Furthermore, HYSYS could be used in increasing capacity, improving margins, reducing costs, becoming more energy efficient and ensuring safety of a process and plant [26]. HYSYS could accurately compute the pressure and temperature of the natural gas and carbon dioxide mixture using equation of state (EOS) and rigorous model. Hence, it is really suitable for the oil and gas industry. It is also applicable for the project as natural gas and carbon dioxide are used for the experimental purposes.

2.9 Research Gap

TABLE 4 shows the research done over the years in multiple different journals, reports and books. The findings and comparisons are summarized as below in the research gap table.

TABLE 4: Research Gap Table

Author	Technology	Research Finding	Remarks
M. A. Satyro et al. [18]	Absorption	Triethylene glycol is normally used for the removal of water	
Anadarko Petroleum Corporation and the Domestic Petroleum Council [15]	Absorption	TEG glycol dehydrators produce volatile organic compounds and hazardous air pollutants from the reboiler vents	
H. Sijbesma et al. [19]	Absorption	The glycol solution has to be regenerated after usage, which is an energy intensive process and they generate only low quality of water	The dehydration process using absorption technique has many major downsides like contamination and release of harmful compounds

A. Rojey [4]	Adsorption	Heavy hydrocarbons that are adsorbed could not be desorbed during regeneration. Silica gel is destroyed by free water which causes the granules to burst and reacts with bases	
M. Stewart et al. [6]	Adsorption	The desiccants could be sensitive to the poisoning with the other gas and liquids in the natural gas	
S. Shirazian et al. [22]	Adsorption	High consumption of energy, high capital and maintenance cost	The different adsorbents used for the adsorption process have different weakness in the dehydration of natural gas.
H. Sijbesma et al. [19]	Refrigeration	The condensed water removed is dirty and corrosive.	Refrigeration method is an energy intensive process (high cost) and the water removed is not clean
S. Shirazian and S. N. Ashrafizadeh [22]	Membrane	Low chemical stability, swelling phenomenon and poor mechanical and thermal strength.	Membrane process is easy to be operated and has low energy consumption. The process still has some downsides as stated.
C. Day et al. [25]	Joule Thomson effect	Temperature change using different feed inlet temperature corresponding to pressure drop.	Limited studies on the effect of pressure drop towards the temperature change.

I.Maric [24]	Joule Thomson Effect	Estimation of Joule Thomson Coefficient. Temperature change due to Joule Thomson effect using pressure drop of 20 and 100kPa	Studies on the pressure drop effect towards temperature change is not extensive.
A. Rojey [4]	Joule Thomson Expansion	The isenthalpic expansion through a control valve could be used to refrigerate the gas, while bringing to a pressure compatible with transport requirements.	Limited study on the Joule Thomson effect towards the temperature change of gas mixture. Hence, more research on this topic should be conducted.

From the research gap table, we could observe that many researches have been conducted on the removal of water from natural gas using absorption and adsorption technology. Both technologies are effective in removing the water or moisture content from the natural gas. However, there are still some major drawbacks. As an example, adsorption and absorption processes require a regeneration process after the adsorbent or absorption liquid is saturated with water vapor. This requires high energy and maintenance, leading to high cost expenditure in the oil and gas industry.

Next, refrigeration process is also an energy intensive process. The water removed by this process is corrosive and dirty. Membrane process of removing water vapor is superior compared to the refrigeration, adsorption and absorption process. Nevertheless, the membrane used has low chemical stability and poor mechanical strength.

While there are studies on the Joule Thomson effect of natural gas, the studies and researches on the effect of feed conditions towards the temperature change of the gas mixture are limited. The parameters used in the past researches were inadequate and not extensive enough. Hence, the research on this field is proven to be feasible.

CHAPTER 3

METHODOLOGY

The project is begun with the understanding on the dehydration of natural gas and the implications of moisture in the gas processing industry. Next, various available methods of dehydration technologies are investigated. The study on the effect of feed conditions (pressure and gas composition) towards the temperature change using Joule Thomson valve is carried out due to the limitation of research conducted in this field.

FIGURE 5 shows the process flow chart for the project. The process consists of the first stage, which is the study and understanding of Joule Thomson effect on the real gas application. Next, the simulation of the Joule Thomson effect will be carried using Aspen Tech HYSYS to study the effect of feed conditions toward the temperature change in the gas mixture. After that, experiment is carried out using MICRO INLINE SEPARATOR CONTACTOR (MISEC). In the experiment, different sets of inlet pressure is observed and the change in temperature of the gas mixture is studied after the throttling through the Joule Thomson Expansion Valve. Different compositions of gas mixture under different feed pressure will also be tested to determine their effect towards the temperature change. The experimental results are compared with the simulation results in HYSYS. Re-design and change in parameters would be implemented if the experimental results deviate too much from the simulation results. The change in temperature of the gas is also being investigated. The relationship and connection between the pressure change and temperature change of the gas is studied. Hence, the objective of the experiment is fulfilled.

3.1 Project Flowchart

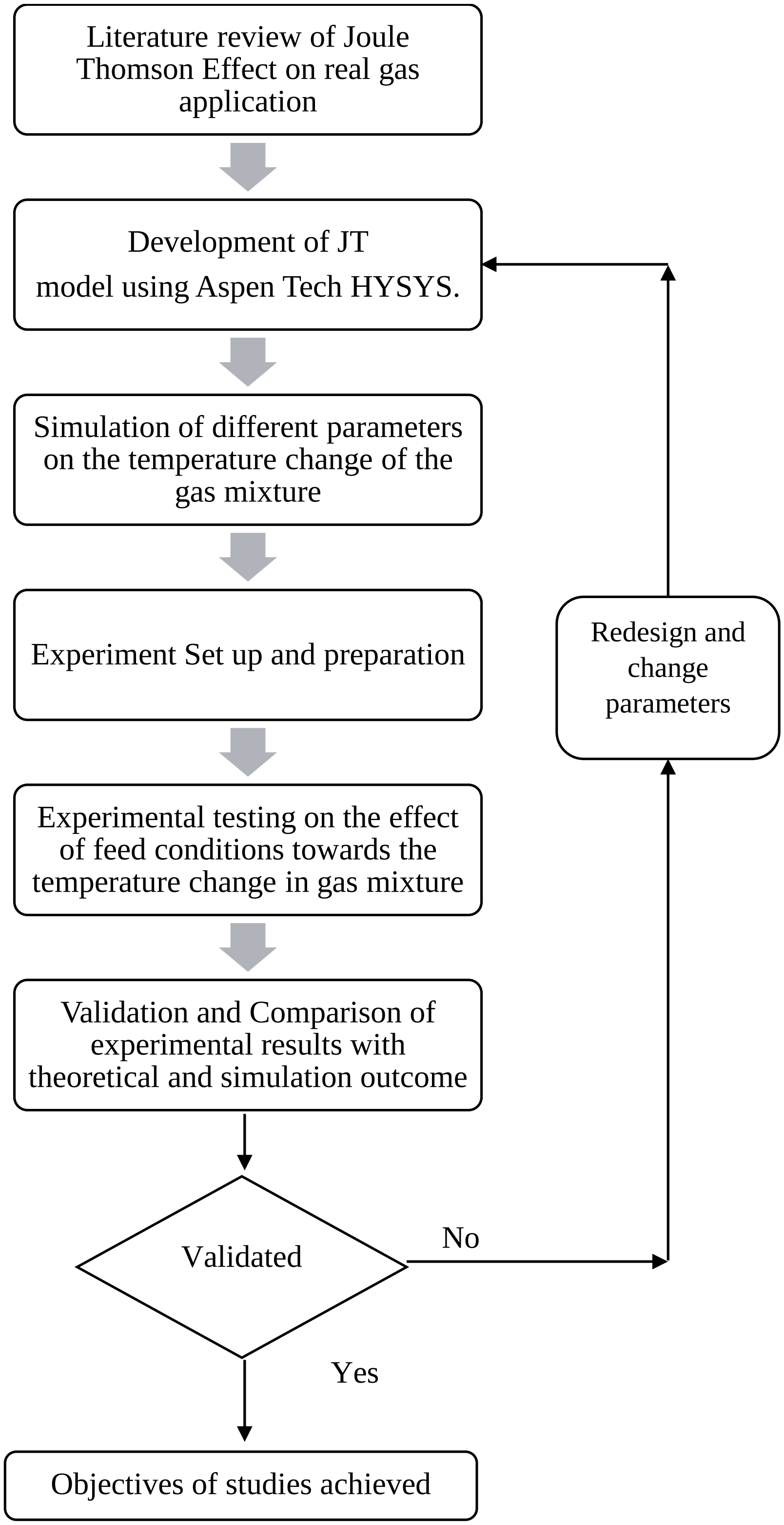

FIGURE 5: Project Flowchart

3.2 Procedure

A test rig would be used for this experiment. The equipment used is MICRO INLINE SEPARATOR CONTACTOR (MISEC). Temperature change of the gas mixture would be studied and investigated. The test rig consists of 6 sections as shown in FIGURE *6*

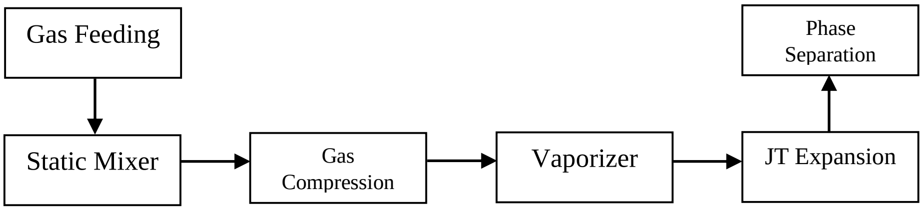

FIGURE 6: Flow chart of in-line ultrasonic reactor test rig.

For this experiment, carbon dioxide and natural gas will be introduced into the system through the gas feeding section. A static mixer is used to mix up both of the gases. Mass controller will be used to control the composition of the binary gas mixture. The flow rate of the carbon dioxide and natural gas will be measured in standard liter per minute (SLPM). One direction valve is used to inhibit the back flow of the gas. Next, a check valve is also being utilized to prevent the back pressure form the gas compressor section. After the static mixer, the gas will then flow towards the gas compression section.

FIGURE 7 demonstrates the gas compressor section, vaporizer section and the Joule Thomson throttling valve section.

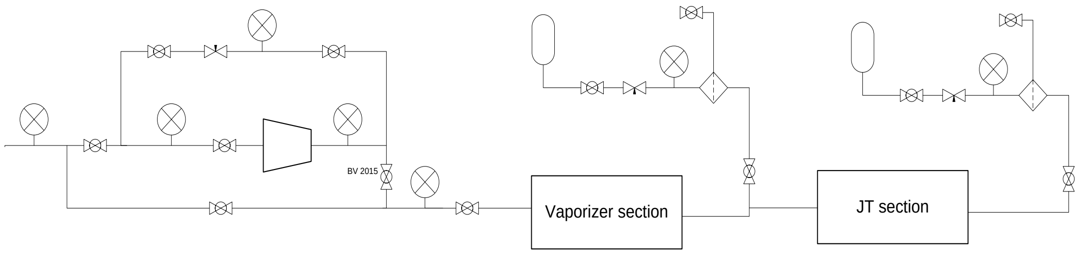

FIGURE 7: Schematic diagram of gas compressor section, vaporizer section and the Joule Thomson throttling valve section.

From FIGURE 7, we could understand the set-up of the experiment. The gas compressor could handle a maximum flow rate up to 50 SLPM. When operating below 50 SLPM, a feedback system is used to regulate the flow and pressure of the gas. The gas from the output of compressor is fed back to the input which controlled by a pressure regulator and needle valve. The feedback system is used to maintain the input pressure required.

After that, water is introduced into the gas mixture through the vaporizer. The introduction of water into the system will depend on the parameters set on the experiment. Sample point will be taken after the vaporizer section. The inlet temperature and pressure will be recorded by using a temperature probe. The outlet pressure is being regulated by the air pressure regulator. The gas mixture will then flow through the Joule Thomson section. It will flow through the Joule Thomson valve and being expanded to atmospheric pressure. Another sample point is used to evaluate the outlet temperature of the gas mixture after the Joule Thomson valve.

The pressure and gas mixture compositions will be varied in order to study the temperature change using Joule Thomson valve. Different sets of inlet pressure starting from 10 bar to 40 bar and different gas mixture composition will be introduced in the experiment. FIGURE 8 represents the equipment symbols used in the process flow diagram drawn for the experimental testing rig.

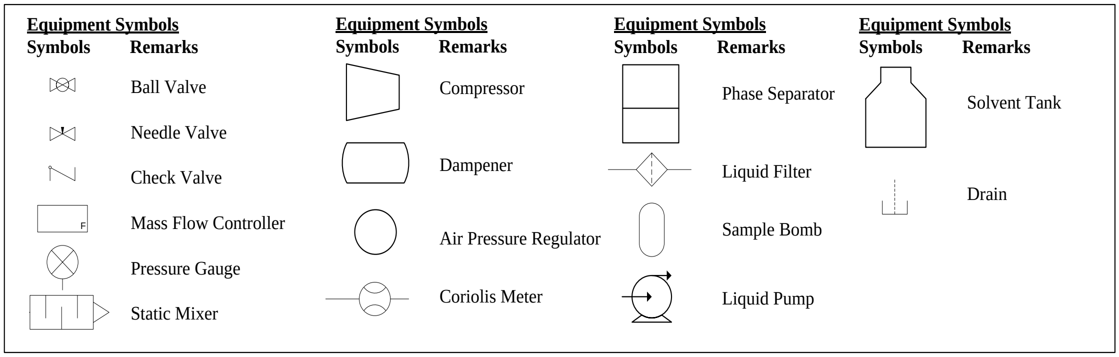

FIGURE 8: Equipment Symbols and Remarks

3.3 HYSYS Simulation

HYSYS Simulation is carried out to simulate the effect of feed conditions towards the temperature change using Joule Thomson expansion valve. The fluid package chosen for the HYSYS simulation is Peng Robinson. This will accurately simulate the relationship between temperature, pressure and phase composition. Besides, real gas case where Joule Thomson Expansion concept is applied are well represented by the Peng Robinson equation of state. It will predict the vapor properties and liquid and vapor liquid equilibrium precisely. Parameters like molar flow, temperature, pressure and composition are needed to complete the simulation. Different sets of pressure drop and gas mixture compositions are being simulated using Aspen Tech HYSYS. The temperature change would then be compared and validated with the experimental results. The Joule Thomson model could be demonstrated in the figure as shown below.

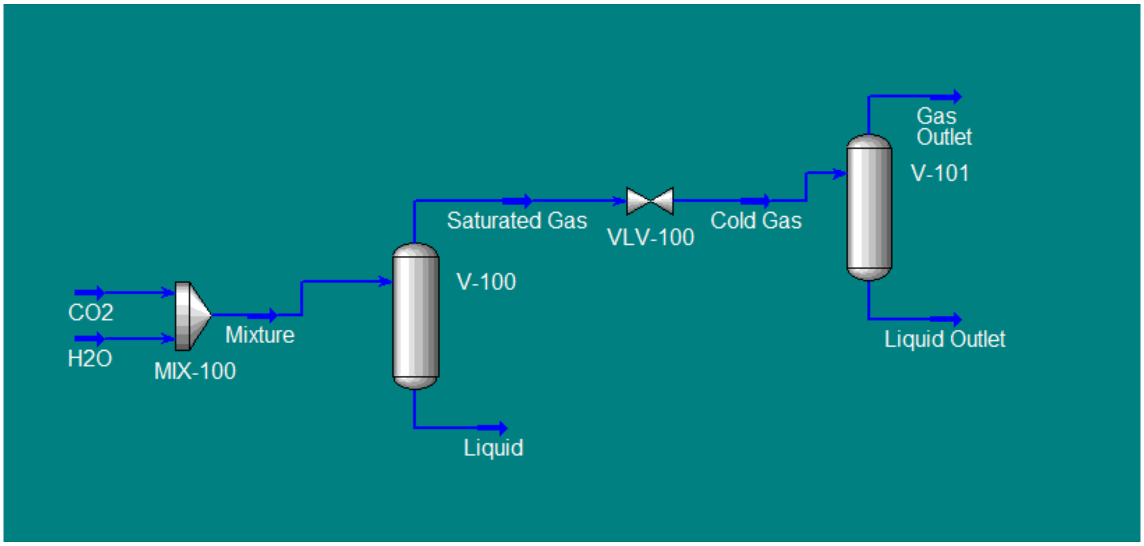

FIGURE 9: Simulation of expansion of carbon dioxide and water mixture.

The simulation shows the effect of gas composition towards the temperature drop using Joule Thomson valve. Different parameters set such as the introduction of methane (natural gas) into the system, the presence or absence of water in the system and the feed pressure will be considered in the simulation. For illustration purpose, carbon dioxide is mixed with water in a mixer (MIX-100). 30 standard liters per minute (slpm) of carbon dioxide will be feed into the simulation as how the experiment would be carried out. While the different inlet pressure would be varied, the feed gas and water are set to be at room temperature, which is around 29 ^{o} C. By mixing them together, this will simulate the experiment section where the vaporizer will vaporize water to saturate the gas stream. In the simulation, to ensure the saturation of dry gas, the water feed inlet is increased until the first drop of liquid is formed at the bottom of the first flash column. This will saturate the carbon dioxide with water vapor. The saturated gas stream and water will be separated using a flash column (V-100) into liquid and saturated gas. The saturated gas will then be expanded through the valve, VLV-100, which is the Joule Thomson valve. The pressure of the saturated gas will drop down to atmospheric pressure. Consequently, the gas will become cold and temperature change is expected. The second flash separator (V-101) is installed to separate the condensed water out if there is any. The top product from the flash would be the dry gas while the bottom will be the water recovered. The simulation of the process with various feed pressure and various feed composition of gas and water mixture would be performed as how the experiment would be conducted. As an example, 21 slpm of carbon dioxide and 9slpm of natural gas mixture (70% carbon dioxide and 30% natural gas) will be introduced to the system and feed pressure starting from 10 bar to 40 bar will be tested. Lastly, the temperature change is observed and recorded.

3.4 Detailed Procedure

1. The temperature drop for different composition of gas mixture under different feed pressure is predicted using HYSYS (Peng Robinson package) before the experiment is started.
2. The experiment is started where the electronic system is switched on.
3. The temperature probe is connected to the computer so that the inlet temperature could be measured.
4. The vaporizer is fitted into the system. It is then connected to the power supply.
5. The total flow rate is set at 30 SLPM while the gas composition is set according to the parameter simulated.
6. Valve PI 1001B, BV 1004B, BV 1005B is opened.

7. The pressure is set at 10 bar (1st run) using knob PRV 4012. Valve NV4014 is closed before setting the pressure. PRV 4012 is released after setting the pressure.
8. PRV 2003 is closed while the pressure is increased to 2.5 bar.
9. Valve BV2013, BV2007, BV2005, and BV2002 is opened
10. The pump is started.
11. NV2012 and PRV2009 are regulated to ensure the pressure at PRV2003 is kept at 2.5 bar.
12. The stop watch is started once PI 2016 readings exceeds PI 4013 reading.
13. The experiment is conducted until the outlet temperature acquires steady state (30 minutes).
14. Record the inlet and outlet temperature after throttling valve every 10 minutes until steady state is achieved.
15. The experiment is repeated using different feed pressure (20 bar, 30 bar, 40 bar) and different feed gas composition (90% CO_2, 10% CH_4 and 80% CO_2, 20% CH_4)
16. To feed carbon dioxide mixed with natural gas into the system, open valve PI 1001A, BV 1004A, BV 1005A, PI 1001B, BV 1004B, BV 1005B.
17. The data will be recorded and plotted in graph.
18. To study for wet gas mixture, the vaporizer is filled with water and the power supply is turned on. The voltage is then set to 30V.

3.5 Gantt chart

The tables below represent the gantt chart for FYP I and FYP II

TABLE 5: Gantt Chart for FYP I

No	Gantt Chart	Period of Planning (Weeks)													
	Description of Planning	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Data Gathering	■	■	■	■	■	■	■	■	■	■				
2	Proposal Drafting			■	■	■	■	■	■	■	■	■	■	■	
3	Submission of Extended Proposal						■								
4	HYSYS Simulation													■	■
5	Proposal Defence								■	■					
6	Submission of Draft Interim Report													■	
7	Submission of Interim Report														■

TABLE 6: Gantt Chart for FYP II

No	Gantt Chart	Period of Planning (Weeks)													
	Description of Planning	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Experiment Set up and Preparation	🟨	🟨	🟨	🟨	🟨	🟨	🟨							
2	Submission of Progress Report								🟨						
3	Pre- SEDEX										🟨				
4	Submission of Draft Final Report											🟨			
5	Submission of Dessertation (soft bound)												🟨		
6	Submission of Technical paper												🟨		
7	Viva													🟨	
8	HYSYS Simulation	🟨	🟨	🟨	🟨	🟨	🟨	🟨							
9	Training on Operating Equipment	🟨	🟨												
10	Experimental testing on the effect of pressure drop			🟨	🟨	🟨	🟨								
11	Experimental testing on the effect of gas mixture composition under different feed pressure							🟨	🟨	🟨	🟨	🟨			

3.6 Milestones

TABLE 7 and TABLE 8 shows the milestones of project for final year project I and final year project II respectively.

TABLE 7: Milestones of Project of FYP I

Milestones	Target
Submission of Extended Proposal to Supervisor	03-07-15
Proposal Defense	14-15 / 07/15
HYSYS Simulation	05-08-15
Submission of Interim Draft Report	04-08-15
Submission of Interim Final Report	14-08-15
Submission of Marks by Supervisor	26-08-15

TABLE 8: Milestones of Project of FYP II

Milestones	Target
Submission of Progress Report	11-09-15
Pre-SEDEX	09-11-15
Submission of Dissertation (soft bound)	08-12-15
Submission of Technical Paper	09-12-15
Viva Oral Presentation	16-12-15
Submission of Dissertation (hard bound)	12-01-15

CHAPTER 4

RESULTS AND DISCUSSION

The results part will be divided into two parts. The first part would be the simulation results while the latter would be the experimental results. All the outcomes are being discussed and analyzed in detail throughout this chapter. The effect of feed conditions towards the temperature drop of gas mixtures using Joule Thomson Valve is clearly conveyed.

4.1 Simulation Results

TABLE 9 and TABLE 10 demonstrated the Joule Thomson expansion under different feed pressure on the temperature drop using dry and wet carbon dioxide gas.

TABLE 9: Joule-Thomson Expansion on the temperature change using different inlet pressure of 30 slpm pure carbon dioxide and water mixture.

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	29.00	17.88	10.00	11.12
16.01	1.013	29.00	11.95	15.00	17.05
21.01	1.013	29.00	5.68	20.00	23.32
26.01	1.013	29.00	-0.95	25.00	29.95
31.01	1.013	29.00	-8.04	30.00	37.04
36.01	1.013	29.00	-15.34	35.00	44.34
41.01	1.013	29.00	-22.64	40.00	51.64

TABLE 10: Joule-Thomson Expansion on the temperature change using different inlet pressure of 30 slpm pure carbon dioxide only

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	29.00	17.96	10.00	11.04
16.01	1.013	29.00	12.04	15.00	16.96
21.01	1.013	29.00	5.79	20.00	23.21
26.01	1.013	29.00	-0.82	25.00	29.82
31.01	1.013	29.00	-7.88	30.00	36.88
36.01	1.013	29.00	-15.47	35.00	44.47
41.01	1.013	29.00	-23.73	40.00	52.73

The Joule Thomson Expansion model is developed in the Aspen Tech HYSYS simulation and it could be referred back to FIGURE 9. The results shown above are simulated in HYSYS using Peng Robinson package. Another ideal package that could be used for the simulation purposes would be the SRK (Soave-Redlich-Kwong) package. It provides a comparable results compared to the Peng Robinson package. The SRK model is also suitable for the application of simulation in sour water, air separation, hydrate inhibition and TEG Dehydration. Meanwhile, the Peng Robinson equation of state provides a more accurate representation of the Joule Thomson cooling effect. Over the operating range, the variation in heat capacity of carbon dioxide and methane is modeled using a quadratic function of temperature which makes it possible to account for the changes in thermal inertia of the fluid over the wide temperature range anticipated. The initial temperature for this simulation is set as 29 ^oC, which is at the room temperature while the dry and wet carbon dioxide under different sets of pressure inlet would be introduced into the system. The amount of carbon dioxide gas used in simulation is fixed as the same amount used in the experiment where the total gas mixture flow rate would be 30 standard liters per minute (SLPM). The parameters changed would be the feed pressure while temperature drop is observed and recorded in the table shown above.

Generally, it could be observed that as the pressure drop increases, the temperature drop increases [25]. This could be proven by looking at the Joule Thomson coefficient and equation. The Joule Thomson coefficient of carbon dioxide is 1.11 K/bar at 298 K and 1.013bar [27]. As an example, when the carbon dioxide gas flows through the throttling valve, the isenthalpic process occurs. The gas is being expanded without producing any shaft work and the heat transfer is zero. Provided that the gas is below the inversion temperature curve, reduction of pressure at constant enthalpy will result in the decrease of temperature. When the carbon dioxide gas temperature is below the inversion temperature, the larger the pressure changed, the larger the drop in temperature. The results simulated in HYSYS is the same as what is proven by Joule Thomson Equation (Equation 1).

The next simulation is carried out using 90% CO_2, 10% CH_4 where it is shown in TABLE 11 and TABLE 12.

TABLE 11 : Joule-Thomson Expansion on the temperature change using different inlet pressure of water and gas mixture [90% CO_2, 10% CH_4] (30slpm total)

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	29.00	18.76	10.00	10.24
16.01	1.013	29.00	13.35	15.00	15.65
21.01	1.013	29.00	7.69	20.00	21.31
26.01	1.013	29.00	1.75	25.00	27.25
31.01	1.013	29.00	-4.52	30.00	33.52
36.01	1.013	29.00	-11.15	35.00	40.15
41.01	1.013	29.00	-17.70	40.00	46.70

TABLE 12: Joule-Thomson Expansion on the temperature change using different inlet pressure of dry gas mixture [90% CO_2, 10% CH_4] (30slpm total)

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	29.00	18.83	10.00	10.17
16.01	1.013	29.00	13.43	15.00	15.57
21.01	1.013	29.00	7.79	20.00	21.21
26.01	1.013	29.00	1.86	25.00	27.14
31.01	1.013	29.00	-4.38	30.00	33.38
36.01	1.013	29.00	-10.99	35.00	39.99
41.01	1.013	29.00	-18.03	40.00	47.03

It could be observed that the trend follows the same as the simulation using only pure carbon dioxide gas. However, the at the specific pressure drop, the temperature drop is now lower.

After that, the simulation of temperature drop under different feed pressure using 80% CO_2, 20% CH_4 gas mixture is conducted and is shown in TABLE 13 and TABLE 14

TABLE 13: Joule-Thomson Expansion on the temperature change using different inlet pressure of water and gas mixture [80% CO_2, 20% CH_4] (30slpm total)

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	29.00	19.58	10.00	9.42
16.01	1.013	29.00	14.65	15.00	14.35
21.01	1.013	29.00	9.53	20.00	19.48
26.01	1.013	29.00	4.19	25.00	24.81
31.01	1.013	29.00	-1.37	30.00	30.37
36.01	1.013	29.00	-7.19	35.00	36.19
41.01	1.013	29.00	-13.30	40.00	42.30

TABLE 14: Joule-Thomson Expansion on the temperature change using different inlet pressure of dry gas mixture [80% CO_2, 20% CH_4] (30slpm total)

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	29.00	19.65	10.00	9.35
16.01	1.013	29.00	14.72	15.00	14.28
21.01	1.013	29.00	9.61	20.00	19.39
26.01	1.013	29.00	4.29	25.00	24.71
31.01	1.013	29.00	-1.25	30.00	30.25
36.01	1.013	29.00	-7.06	35.00	36.06
41.01	1.013	29.00	-13.14	40.00	42.14

For the mixture of 80% CO_2, 20% CH_4, the temperature drop is the lowest at the specific pressure drop compare to pure carbon dioxide gas and 90% CO_2, 10% CH_4 gas mixture. A better representation is shown in FIGURE 10 and FIGURE 11. FIGURE 10 shows the comparison of temperature drop under different pressure drop using dry gas mixture of different composition while FIGURE 11 shows the comparison of temperature drop under different pressure drop between the wet gas mixtures with different composition.

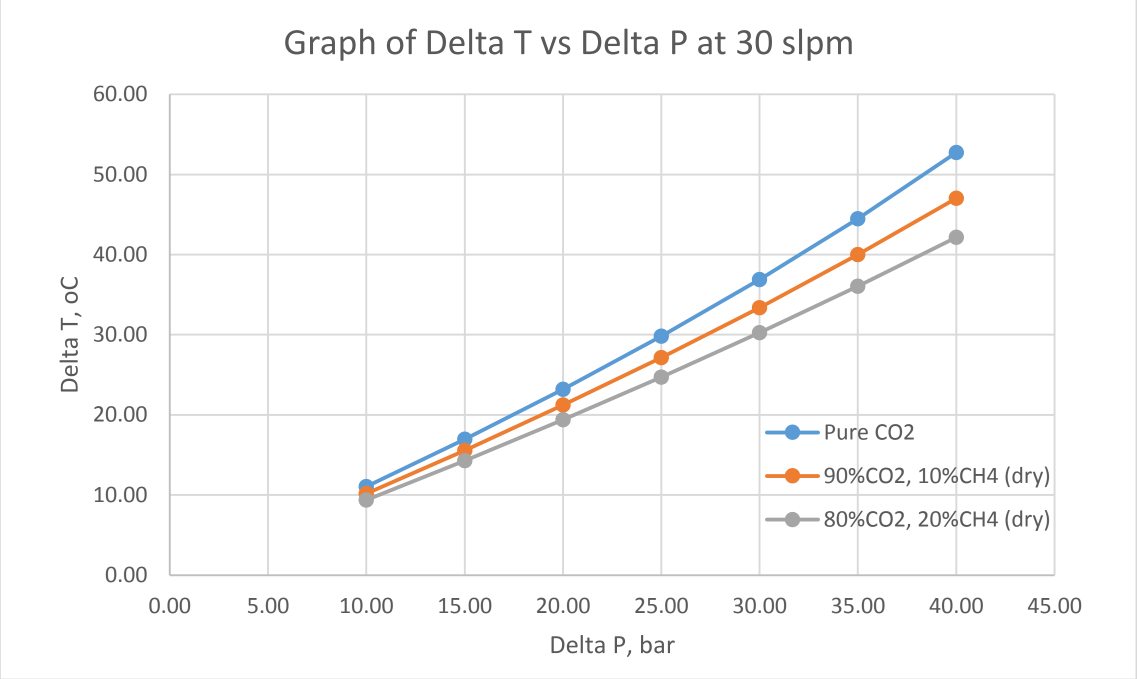

FIGURE 10: Graph of change in temperature versus change in pressure using different composition of dry gas mixture

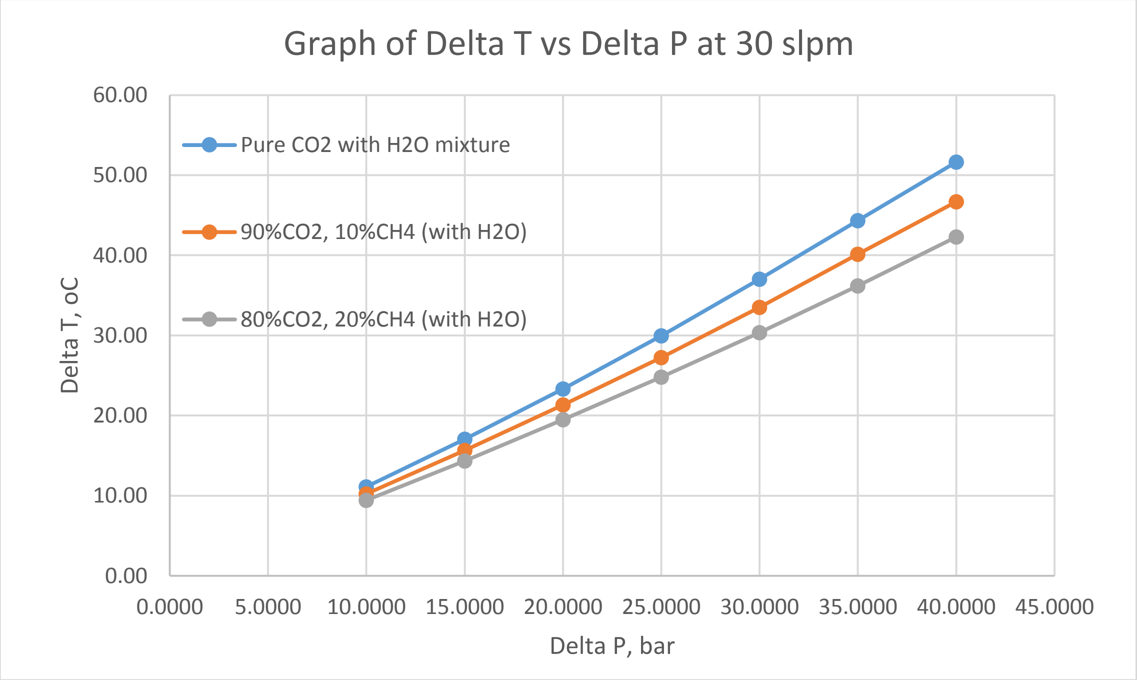

FIGURE 11: Graph of change in temperature versus change in pressure using different mixture of gas composition (wet)

FIGURE 10 shows that the change in pressure have a greater effect on the temperature drop using pure carbon dioxide rather than mixture of natural gas and carbon dioxide. When the percentage of carbon dioxide is reduced in the gas mixture composition, the temperature drop due to the change in pressure is reduced too. Hence, the Joule Thomson effect is greater in the carbon dioxide gas compared to natural gas as represented by methane. The temperature drop is the highest when pure carbon dioxide is used in the simulation, where at a pressure drop of 40 bar, a temperature drop of about 53 ^{o}C is expected. Following pure carbon dioxide is the 90% CO_2, 10% CH_4 gas mixture where a temperature drop of around 48 ^{o}C will occur at a pressure drop of 40 bar. The least temperature drop is expected in the gas mixture of 80% CO_2, 20% CH_4. This is due to the higher Joule Thomson coefficient in carbon dioxide compared to natural gas [28, 29]. As an example the Joule Thomson coefficient of carbon dioxide at 29 ^{o}C and 21 bar is 1.0641K/bar where as Joule Thomson coefficient of methane at 29 ^{o}C and 21 bar is 0.41328 K/bar [30]. Higher Joule Thomson coefficient implicates better response to change in pressure. At the same pressure drop, a gas with a higher Joule Thomson coefficient will have a greater temperature drop.

For the comparison of wet gas mixture, the Joule Thomson effect is still the same as before where wet carbon dioxide gas has the highest temperature drop at the given pressure drop followed by 90%CO_2, 10%CH_4 and 80%CO_2, 20%CH_4. The Joule Thomson effect is the same as the dry gas where it has the most significant effect on carbon dioxide due to the higher value of Joule Thomson coefficient.

Now, the comparison of temperature drop between the dry and wet gas mixture under different feed pressure is made. FIGURE 12 and TABLE 15 demonstrate the comparison of temperature drop between the dry pure carbon dioxide gas and wet carbon dioxide gas under different feed pressure.

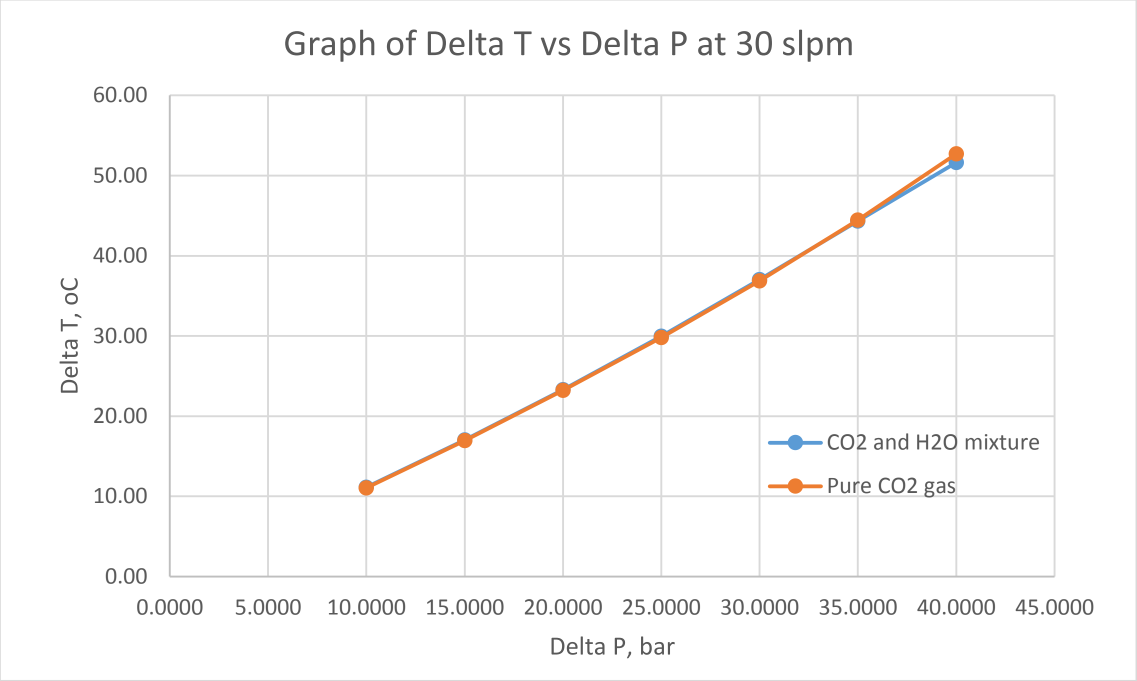

FIGURE 12: Graph of change in temperature versus change in pressure using wet and dry pure carbon dioxide gas

TABLE 15: Comparison of the temperature drop between wet and dry carbon dioxide gas under different feed pressure

Inlet Pressure bar	Outlet Pressure bar	Delta P bar	Delta T/ °C		Difference
			With H_2O	Without H_2O	
11.01	1.013	10.000	11.12	11.04	0.08
16.01	1.013	15.000	17.05	16.96	0.09
21.01	1.013	20.000	23.32	23.21	0.11
26.01	1.013	25.000	29.95	29.82	0.13
31.01	1.013	30.000	37.04	36.88	0.16
36.01	1.013	35.000	44.34	44.47	-0.13
41.01	1.013	40.000	51.64	52.73	-1.09

The temperature drop of the wet carbon dioxide gas is higher compared to the dry carbon dioxide gas at the specific pressure drop from 10 bar to 30 bar. This is clearly demonstrated in TABLE 15. The water vapor (including steam) will provide the cooling effect under the Joule Thomson expansion. At atmospheric pressure, the Joule Thomson coefficient of water vapor at 100 ^{o}C will be 6.669 K/bar [30]. However, starting from the pressure drop of around 35bar, the temperature drop between the 2 gases start to differ. The temperature drop of the carbon dioxide and water mixture is now lower compared to the pure dry carbon dioxide gas at the same pressure drop. The reason for the difference in temperature drop is due to the condensation of water in the wet gas mixture. Condensation of water will release latent heat which will heat up and increase the temperature at the outlet of the Joule Thomson valve. This results in the decrease in temperature drop of the wet gas mixture compares to the dry gas mixture at the same pressure drop and composition.

This trend is also demonstrated from FIGURE 13 and TABLE 16 where comparison between dry and wet gas mixture is made.

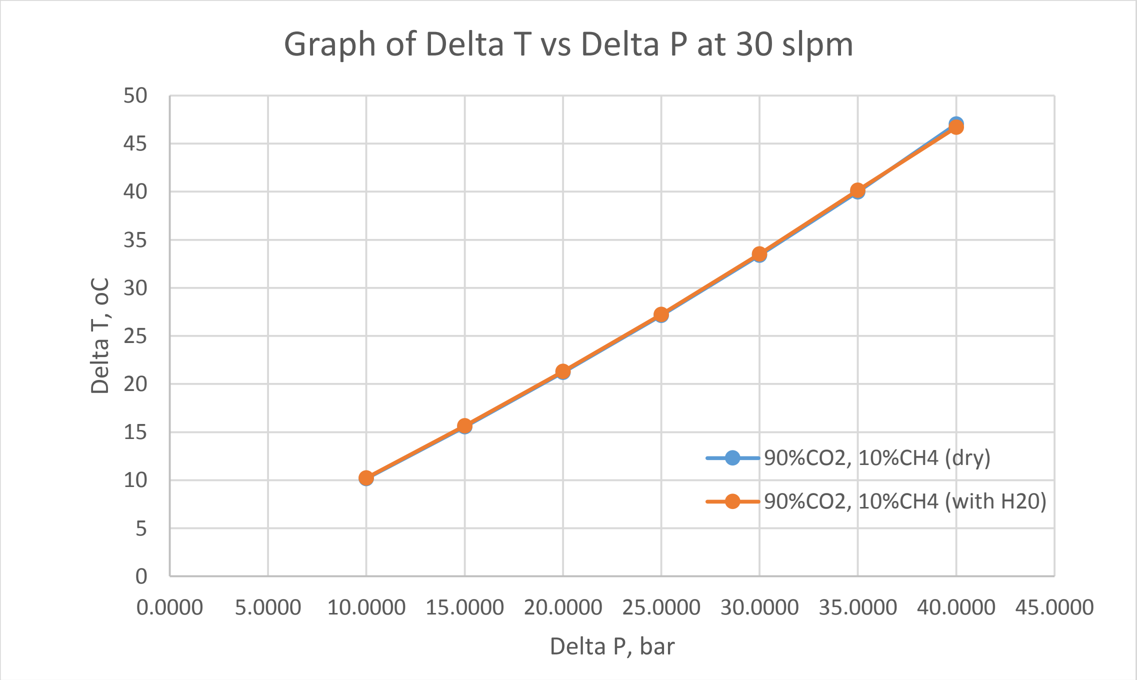

FIGURE 13: Graph of change in temperature versus change in pressure using wet and dry 90%CO_2, 10%CH_4 gas mixture

TABLE 16: Comparison of the temperature drop between wet and dry [90%CO_2, 10%CH_4] gas mixture under different feed pressure

Inlet Pressure bar	Outlet Pressure bar	Delta P bar	Delta T/ ^oC		Difference
			With H_2O	Without H_2O	
11.01	1.013	10.00	10.24	10.17	0.07
16.01	1.013	15.00	15.65	15.57	0.08
21.01	1.013	20.00	21.31	21.21	0.10
26.01	1.013	25.00	27.25	27.14	0.12
31.01	1.013	30.00	33.52	33.38	0.14
36.01	1.013	35.00	40.15	39.99	0.16
41.01	1.013	40.00	46.70	47.03	-0.33

In TABLE 16, the temperature drop between dry and wet gas mixture of 90% CO_2, 10% CH_4 under different feed pressure is shown. The trend of the temperature drop is the same as before where the temperature drop of the wet gas mixture is higher compared to the dry gas mixture at the same pressure drop. Nevertheless, the trend started to change at a pressure drop of 40 bar where the temperature drop of the dry gas mixture is now higher compared to the wet gas mixture. This indicates the process where condensation of water occur. Similarly, this is also proven as shown in FIGURE 14 and TABLE 17 where 80% CO_2, 20%CH_4 is used. FIGURE 14 and TABLE 17 represent the comparison of temperature drop under different pressure drop using wet and dry 80%CO_2, 20%CH_4 gas mixture

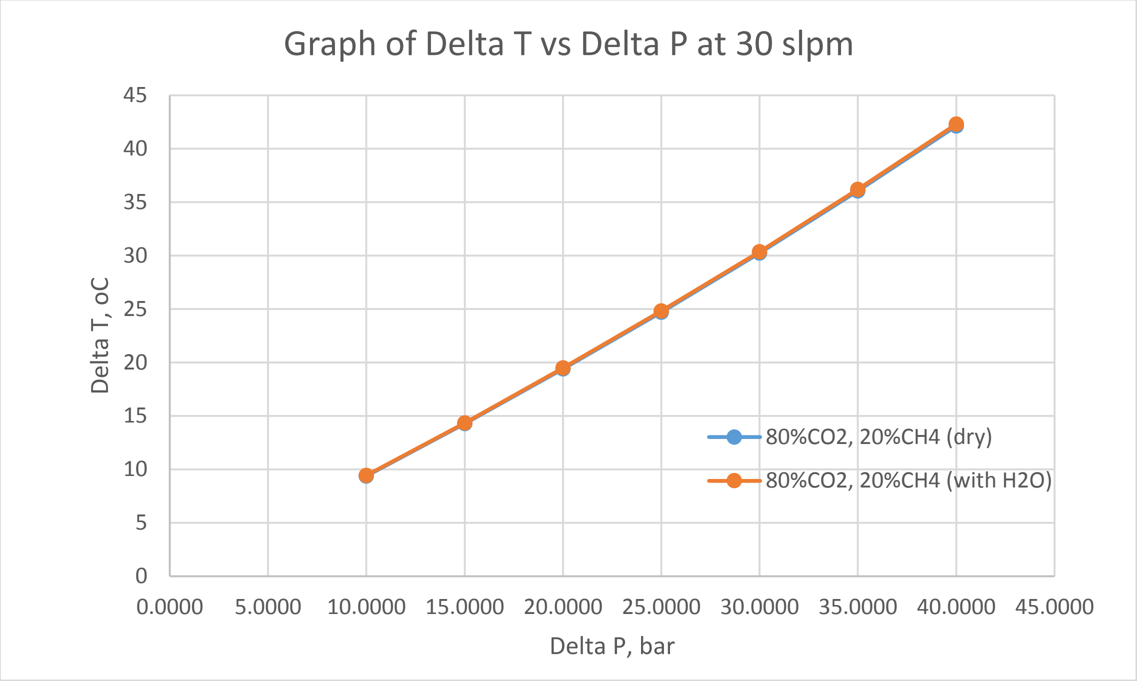

FIGURE 14: Graph of change in temperature versus change in pressure using wet and dry 80%CO_2, 20%CH_4 gas mixture

TABLE 17: Comparison of the temperature drop between wet and dry [80%CO_2, 20%CH_4] gas mixture under different feed pressure

Inlet Pressure bar	Outlet Pressure bar	Delta P bar	Delta T/ °C		Difference
			With H_2O	Without H_2O	
11.01	1.013	10.00	9.42	9.35	0.07
16.01	1.013	15.00	14.35	14.28	0.07
21.01	1.013	20.00	19.48	19.39	0.09
26.01	1.013	25.00	24.81	24.71	0.10
31.01	1.013	30.00	30.37	30.25	0.12
36.01	1.013	35.00	36.19	36.06	0.14
41.01	1.013	40.00	42.30	42.14	0.16

For this case, the temperature drop of the wet gas mixture is higher compared to the dry gas mixture throughout the pressure drop of 10 to 40 bar as the change in phase and the condensation of water does not occur. The Joule Thomson expansion effect is not as strong as before due to the lower concentration of carbon dioxide gas and lower Joule Thomson coefficient of the methane gas [30]. Pressure drop greater than 40 bar is needed for the condensation process to begin. Hence, from the simulation and comparison results shown above, it could be demonstrated that wet gas mixture has a higher temperature change due to the Joule Thomson expansion when compared to the dry gas mixture provided that the condensation process does not occur. Next, higher pressure drop is needed for a higher temperature change to occur in natural gas mixture [4]. A higher temperature drop will imply a higher chance for the condensation of water to happen as the dew point of the gas mixture is acquired. Therefore, the dehydration process is possible.

4.2 Experimental Results

TABLE 18 and TABLE 19 shows the results of experimental testing on the temperature change under different feed pressure using dry and wet carbon dioxide gas. . The experiment is conducted at room temperature and a total feed of 30 standard liters per minute (slpm) is introduced into the system. The temperature change is investigated while parameters like feed pressure and gas mixture compositions are being varied.

TABLE 18: Joule-Thomson Expansion on the temperature change using different inlet pressure of 30 slpm pure carbon dioxide and water mixture. [Experimental]

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	29.10	21.50	10.00	7.60
21.01	1.013	29.50	11.50	20.00	18.00
31.01	1.013	29.20	0.00	30.00	29.20
41.01	1.013	29.10	-13.00	40.00	42.10

TABLE 19: Joule-Thomson Expansion on the temperature change using different inlet pressure of 30 slpm pure carbon dioxide only. [Experimental]

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	30.90	25.00	10.00	5.90
21.01	1.013	30.40	14.50	20.00	15.90
31.01	1.013	29.60	2.00	30.00	27.60
41.01	1.013	29.40	-14.00	40.00	43.40

From the results shown above, a trend of increasing temperature change is observed along with the increasing pressure drop. The trend is the same as shown in the simulation. Next, the experimental testing on the temperature change under different feed pressure using 80% CO_2, 20% CH_4 is shown in TABLE 20 and TABLE 21.

TABLE 20: Joule-Thomson Expansion on the temperature change using different inlet pressure of wet gas mixture [80% CO_2, 20% CH_4] (30slpm total) [Experimental]

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	30.60	23.50	10.00	7.10
21.01	1.013	30.70	18.00	20.00	12.70
31.01	1.013	31.00	11.50	30.00	19.50
41.01	1.013	31.40	4.50	40.00	26.90

TABLE 21: Joule-Thomson Expansion on the temperature change using different inlet pressure of dry gas mixture [80% CO_2, 20% CH_4] (30slpm total) [Experimental]

Inlet Pressure bar	Outlet Pressure bar	Inlet Temperature ^oC	Outlet Temperature ^oC	Delta P bar	Delta T ^oC
11.01	1.013	28.60	22.00	10.00	6.60
21.01	1.013	28.90	16.50	20.00	12.40
31.01	1.013	31.10	12.50	30.00	18.60
41.01	1.013	31.20	4.50	40.00	26.70

For the experiment using 80% CO_2, 20% CH_4, as the pressure drop increases, the temperature drop increases. The trend is also the same as what is shown in the simulation. However, the temperature change of the 80% CO_2, 20% CH_4 gas mixture is lower compared to the pure carbon dioxide gas at the specific pressure drop. As an example, at a pressure drop of 40 bar, the temperature change of dry carbon dioxide is 43.4 ^oC whereas a temperature change of only 26.7 ^oC is expected from 80% CO_2, 20% CH_4. This is due to the same reason explained in the earlier section where the Joule Thomson coefficient of carbon dioxide is higher than the natural gas. The higher the Joule Thomson coefficient, the higher the temperature drop [24].

FIGURE 15 and TABLE 22 are the experimental results comparing the temperature change between wet and dry carbon dioxide gas under different feed pressure.

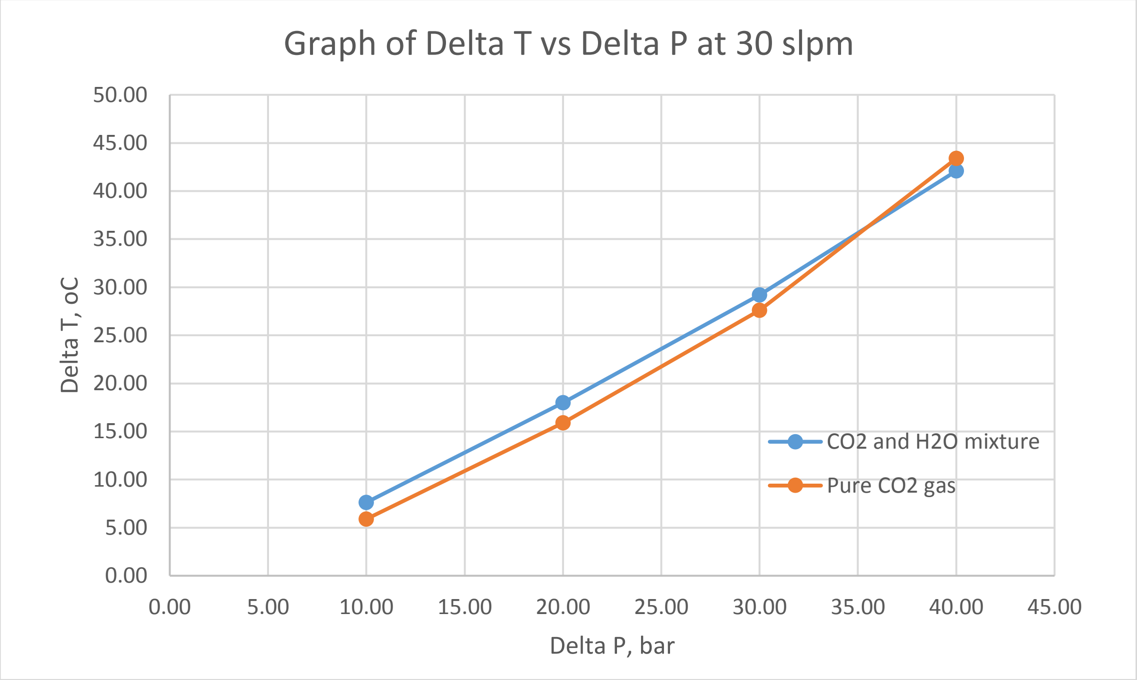

FIGURE 15: Graph of change in temperature versus change in pressure using wet and dry pure carbon dioxide gas [Experimental]

TABLE 22: Comparison of the temperature drop between wet and dry carbon dioxide gas under different feed pressure [Experimental]

Inlet Pressure bar	Outlet Pressure bar	Delta P bar	Delta T / °C		Difference
			With H_2O	Without H_2O	
11.01	1.013	10.00	7.60	5.90	1.70
21.01	1.013	20.00	18.00	15.90	2.10
31.01	1.013	30.00	29.20	27.60	1.60
41.01	1.013	40.00	42.10	43.40	-1.30

It could be observed that the trend follows the same as the simulation results. The temperature change increases as the pressure drop increases [25]. Next, temperature change of the wet gas is higher compared to the dry at the pressure drop from 10 to 35 bar. Starting from 35 bar, the temperature drop of the dry gas is greater compared to the wet gas mixture. This indicates the condensation of water which release heat into the system causing the temperature drop to be lesser.

Now, the comparison is made using the dry and wet 80%CO_2, 20%CH_4. The results are shown in TABLE 23 and FIGURE 16.

TABLE 23: Comparison of the temperature drop between wet and dry carbon dioxide and natural gas mixture [80%CO_2, 20%CH_4] under different feed pressure [Experimental]

Inlet Pressure bar	Outlet Pressure bar	Delta P bar	Delta T/ °C		Difference
			With H_2O	Without H_2O	
11.01	1.013	10.00	7.10	6.60	0.50
21.01	1.013	20.00	12.70	12.40	0.30
31.01	1.013	30.00	19.50	18.60	0.90
41.01	1.013	40.00	26.90	26.70	0.20

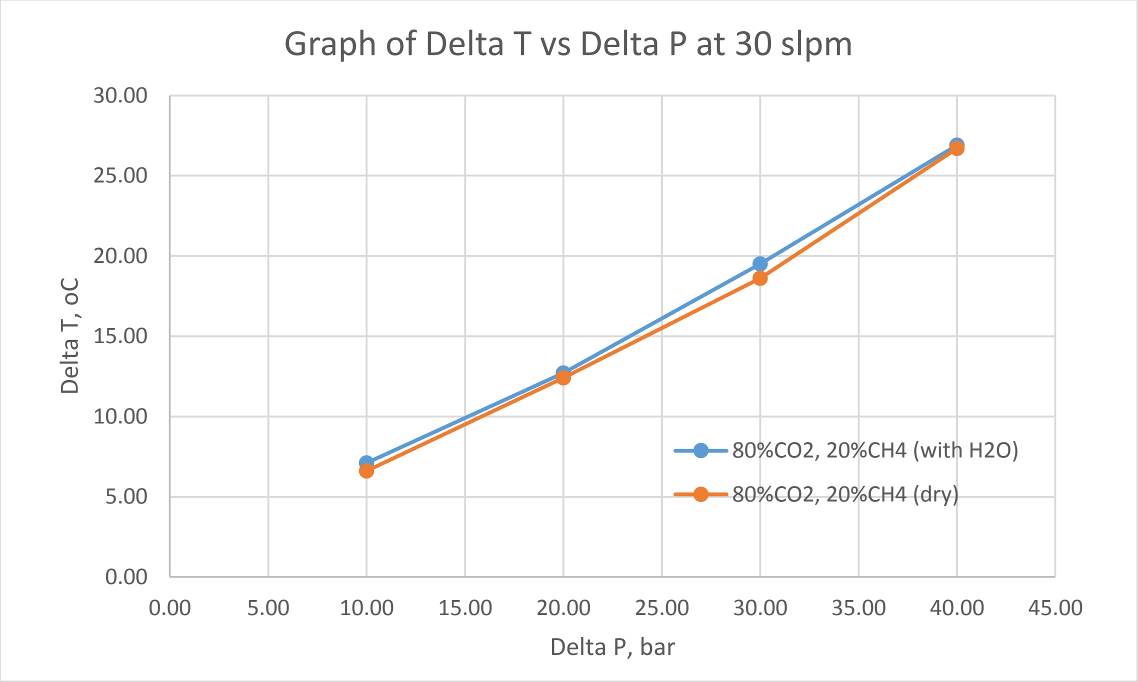

FIGURE 16: Graph of change in temperature versus change in pressure using wet and dry carbon dioxide and natural gas mixture [80%CO_2, 20%CH_4] [Experimental]

From TABLE 23 and FIGURE 16, the experimental trend is the same as shown in the simulation. The temperature drop of the wet 80%CO_2, 20%CH_4 gas mixture is slightly greater compared to the dry gas mixture. This is due to the Joule Thomson cooling effect of the water where water vapor has a positive Joule Thomson coefficient in the gas mixture. There are no overlapping of the graph, showing that the condensation process did not occur. A higher pressure drop is needed for the condensation to take place.

TABLE 24 and TABLE 25 show the percentage deviation of the temperature change between the simulation and the experimental results for dry and wet carbon dioxide gas while TABLE 26 and TABLE 27 illustrate the percentage deviation of the temperature change for the dry and wet carbon dioxide and natural gas mixture [80%CO_2, 20%CH_4].

TABLE 24: Comparison of simulation and experimental temperature change for pure dry carbon dioxide gas

Initial Pressure bar	Final Pressure bar	Delta T/ ^{o}C		Percentage Deviation%
		Theoretical	Experimental	
11.01	1.013	11.04	5.90	46.56
21.01	1.013	23.21	15.90	31.48
31.01	1.013	36.88	27.60	25.16
41.01	1.013	52.73	43.40	17.69

TABLE 25: Comparison of simulation and experimental temperature change for carbon dioxide and water mixture

Initial Pressure bar	Final Pressure bar	Delta T/ ^{o}C		Percentage Deviation %
		Theoretical	Experimental	
11.01	1.013	11.12	7.6	31.65468
21.01	1.013	23.316	18	22.79979
31.01	1.013	37.04	29.2	21.16631
41.01	1.013	51.64	42.1	18.47405

TABLE 26: Comparison of simulation and experimental temperature change for dry carbon dioxide and natural gas mixture [80%CO_2, 20%CH_4]

Initial Pressure bar	Final Pressure bar	Delta T/ ^{o}C		Percentage Deviation %
		Theoretical	Experimental	
11.01	1.013	9.35	6.6	29.41176
21.01	1.013	19.39	12.4	36.04951
31.01	1.013	30.254	18.6	38.52053
41.01	1.013	42.14	26.7	36.63977

TABLE 27: Comparison of simulation and experimental temperature change for wet carbon dioxide and natural gas mixture [80%CO_2, 20%CH_4]

Initial Pressure bar	Final Pressure bar	Delta T/ ^oC		Percentage Deviation %
		Theoretical	Experimental	
11.01	1.013	9.42	7.1	24.62845
21.01	1.013	19.475	12.7	34.78819
31.01	1.013	30.37	19.5	35.7919
41.01	1.013	42.3	26.9	36.40662

The percentage deviation ranges from 17 to 46%. This is due to the heat gained from the environment. In the simulation, an isenthalpic condition is assumed where there is no change of enthalpy throughout the expansion process. Next, an adiabatic condition is also assumed where there is no heat transfer between the system and the surroundings. Furthermore, the work done for the process zero. This fulfill the definition of the Joule Thomson expansion effect. However, for the experimental work, there will always be heat gained or loss even with proper insulation. Besides, the throttling process through the valve is not entirely isenthalpic. There is some changes of the enthalpy after the Joule Thomson valve. Moreover, in the simulation, the geometrical sizing and the parameter of the valve is not considered. From the experimental point of view, the percentage opening of the valve, the boundary conditions and the type of valve used will have a different effect on the Joule Thomson throttling process. This would contribute to the percentage deviation in the temperature change of the simulation and experimental results. Additionally, the uncontrollable inlet temperature of the feed gas mixture in the experiment would also affect the temperature drop under the different pressure drop. The Joule Thomson coefficient would depend greatly on the Joule Thomson inversion curve. For the case of methane and carbon dioxide, the lower the feed temperature, the higher the Joule Thomson coefficient. The higher the Joule Thomson coefficient, the greater the temperature change in response to the pressure drop [24]. The inlet feed temperature of the experiment will depend on the room temperature which varies from 27^oC to 32^oC depending on the weather conditions. This would also contribute to the percentage deviation in temperature change of the simulation and experimental results.

CHAPTER 5
CONCLUSION AND RECOMMEDATION

5.1 Conclusion

As a conclusion, the natural gas extracted from deep sub-seas comprises of impurities like water, carbon dioxide, sulphur and other components. The dehydration process of the natural gas mixture is mandatory to enhance the transportation and processing of the gas. The Joule Thomson expansion effect towards the temperature change at various feed conditions is clearly conveyed.

With the simulation results, it could be concluded that as the pressure drop increases, the change in temperature increases. The temperature change using higher feed pressure is superior to the temperature change using lower feed pressure. The greater the decrease in temperature, the higher the chances for the water condensation process to happen. Nevertheless, the water condensation would only occur when the dew point of the mixture is achieved. This could be achieved when the pressure drop of the gas mixture is great enough.

Besides, the temperature change of the wet gas is greater compared to the dry gas at the same composition and pressure drop. This is due to the fact that the Joule Thomson expansion could have a cooling effect on water vapor. The water vapor in the gas mixture will contribute to the higher temperature change compared to the dry gas at the same composition and pressure drop. However, as the dew point of the gas mixture is achieved, water condensation process will occur. The condensation of water will release latent heat into the system. At this particular case, the temperature drop of the wet gas mixture is now lesser compared to the dry gas mixture.

The pure carbon dioxide gas stream has a higher temperature drop response compared to natural gas and carbon dioxide mixture at the specific pressure drop. Carbon dioxide has a higher Joule Thomson coefficient compared to the natural gas. This implies that the Joule Thomson effect is greater in pure carbon dioxide compared to natural gas mixture. Thus, the Joule Thomson coefficient and equation is proven valid. The dehydration of gas mixture by using throttling valve deemed to be effective and further studies on this area should be conducted.

5.2 Recommendations

Some of the recommendations and future work for the betterment of the project are shown below:

a) Parameter such as the feed temperature should be investigated as it depends greatly on the Joule Thomson inversion curve. Since the Joule Thomson coefficient depend greatly on the feed inlet temperature and pressure, it will have a different effect on the temperature change and water recovery achievable.
b) A better insulation around the throttling valve is essential to ensure minimal heat loss during the experiment. This will reduce the percentage deviation of the experimental results and the simulation results.
c) Experiment on the change in moisture content of the natural gas mixture should be conducted by using dew point analyzer to investigate the Joule Thomson throttling effect towards the possible water recovery
d) CFD should be conducted to investigate on the flow pattern and the temperature distribution around the Joule Thomson Valve for further studies.

REFERENCES

[1] J. G. Speight, *Natural Gas A Basic Handbook*. Houston, Texas: Gulf Publishing Company, 2007.

[2] C. K. Soo-Il Kim, Jung Woo Lee and Shigeru Suehiro. (2013). *Southeast Asia Energy Outlook*. Available: https://www.iea.org/publications/freepublications/publication/SoutheastAsiaEnergyOutlook_WEO2013SpecialReport.pdf

[3] P. Robert and G. Don, *Perry's Chemical Engineers' Handbook*, 6th ed.: McGraw-Hill, 1984.

[4] A. Rojey, *NATURAL GAS PRODUCTION PROCESSING, TRANSPORT*. Paris: Editions Technip, 1997.

[5] (2015). *Natural Gas Consumption*. Available: http://www.eia.gov/naturalgas/

[6] S. Maurice and A. Ken, *Gas Dehydration Field Manual*. UK: Gulf Professional Publishing, 2011.

[7] L. S. Tan, A. M. Shariff, K. K. Lau, and M. A. Bustam, "Factors affecting CO2 absorption efficiency in packed column: A review," *Journal of Industrial and Engineering Chemistry,* vol. 18, pp. 1874-1883, 2012.

[8] T. E. Rufford, S. Smart, G. C. Y. Watson, B. F. Graham, J. Boxall, J. C. Diniz da Costa*, et al.*, "The removal of CO2 and N2 from natural gas: A review of conventional and emerging process technologies," *Journal of Petroleum Science and Engineering,* vol. 94-95, pp. 123-154, 2012.

[9] A. A. Hassan, M. M. Ezzat, H. Amer, and A. W. Nashed, "Natural gas dehydration by desiccant materials," *Alexandria Engineering Journal,* vol. 50, pp. 431-439, 2011.

[10] C. Zou, P. Zhao, M. Wang, D. Liu, H. Wang, and Z. Wen, "Failure analysis and faults diagnosis of molecular sieve in natural gas dehydration," *Engineering Failure Analysis,* vol. 34, pp. 115-120, 2013.

[11] H. Lin, S. M. Thompson, A. Serbanescu-Martin, J. G. Wijmans, K. D. Amo, K. A. Lokhandwala*, et al.*, "Dehydration of natural gas using membranes. Part I: Composite membranes," *Journal of Membrane Science,* vol. 413-414, pp. 70-81, 2012.

[12] J. Carroll, "Dehydration of Natural Gas," pp. 175-195, 2014.

[13] P. Gandhidasan, A. A. Al-Farayedhi, and A.-M. Ali A, "PC program estimates TEG circulation rate, number of trays," *Oil & Gas Journal,* 1999.

[14] P. Gandhidasan, A. A. Al-Farayedhi, and A. A. Al-Mubarak, "Dehydration of natural gas using solid desiccants," p. 14, 2000.

[15] Anadarko Petroleum Corporation and the Domestic Petroleum Council. (2007). *Natural Gas Dehydration*. Available: epa.gov/gasstar

[16] D. Y. C. Leung, G. Caramanna, and M. M. Maroto-Valer, "An overview of current status of carbon dioxide capture and storage technologies," *Renewable and Sustainable Energy Reviews,* vol. 39, pp. 426-443, 2014.

[17] D. Parks and D. Pack, "Design concept for implementation of a novel subsea gas dehydration process for a gas/condensate well," *Journal of Petroleum Science and Engineering,* vol. 109, pp. 18-25, 2013.

[18] M. A. Satyro, F. Schoeggl, and H. W. Yarranton, "Temperature change from isenthalpic expansion of aqueous triethylene glycol mixtures for natural gas dehydration," *Fluid Phase Equilibria,* vol. 305, pp. 62-67, 2011.

[19] H. Sijbesma, K. Nymeijer, R. van Marwijk, R. Heijboer, J. Potreck, and M. Wessling, "Flue gas dehydration using polymer membranes," *Journal of Membrane Science,* vol. 313, pp. 263-276, 2008.

[20] A. J. Kidnay and W. R. Parrish, *Fundamentals of Natural Gas Processing*: Taylor & Francis Group, 2006.

[21] M. Luca, T. Vincenzo, F. Carlo, and D. Rosa, "Rotating Equipment for Carbon Dioxide Capture and Storage," UK2010.

[22] S. Shirazian and S. N. Ashrafizadeh, "LTA and ion-exchanged LTA zeolite membranes for dehydration of natural gas," *Journal of Industrial and Engineering Chemistry,* vol. 22, pp. 132-137, 2015.

[23] ChemEngineering. *Joule- Thomson Effect*. Available: https://chemengineering.wikispaces.com/Joule%E2%80%93%C2%ADThomson+effect

[24] I. Marić, "A procedure for the calculation of the natural gas molar heat capacity, the isentropic exponent, and the Joule–Thomson coefficient," *Flow Measurement and Instrumentation,* vol. 18, pp. 18-26, 2007.

[25] C.Day, M.Stephan, and L.R.Oellrich, "Measurements of the isobaric enthalpy increment and the isenthalpic Joule–Thomson effect of (methane + water) and (methane + ethane + water)," *The Journal of Chemical Thermodynamics,* vol. 29, 1997.

[26] AspenTech. (2015). *About AspenTech*. Available: http://www.aspentech.com/Company/About-AspenTech/

[27] Peter Atkins and J. d. Paula. (2009). *Physical Chemistry (9th ed.)*.

[28] A. A. Simon, "Dehydration of Gas Mixture Using Throttling Valve: Effect of Pressure & Effect on Moisture Content," Chemical Enginnering Department, Universiti Teknologi Petronas, 2015.

[29] I. Marić, "The Joule–Thomson effect in natural gas flow-rate measurements," *Flow Measurement and Instrumentation,* vol. 16, pp. 387-395, 2005.

[30] NIST. Thermophysical Properties of Fluid Systems [Online].

APPENDICES

Appendix A: Picture of test rig

Gas mixture feed section

Throttling pressure setting

Vaporiser Section

Joule Thomson (throttling valve) section

Internal part of vaporizer