Dehydration of Gas Mixture Using Throttling Valve:

Effect of Pressure & Effect on Moisture Content

by

Annie Arvina Simon

16697

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

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(AP Dr Lau Kok Keong)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
May 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 persons.

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ANNIE ARVINA SIMON

ABSTRACT

Natural gas hydrate has always bring major problem to pipelines corrosion and plugging. Many technologies have been invented and applied to tackle this problem. The widely used and most feasible technologies used is absorption by using triethylene glycol (TEG). This technology has been used in industry for decades due to its promising efficiency. However, its packing column requires a large column space for maximizing the absorption amount. Besides, there are other drawbacks of using this method such as desiccant effectiveness which decreases promptly at temperatures greater than 80°F (26.67°C) and high energy consumption. Hence, the throttling technique is proposed to remove moisture content in natural gas mixture in achieving the essentials for critical offshore application, which removes water vapor in large production, small size and less weight. The advantage of the proposed system include self-induced refrigeration, small in size, low operating cost, simple mechanical design and unlikely to form hydrates. In this project, relationship between feed pressure and temperature drop in a throttling valve is studied. On top of that, the effect on different moisture content in hydrocarbon mixture with various throttling pressure is studied. Mathematical study is also developed to model and validate the temperature drop for different gas mixture under different feed pressure in a throttling valve. Calculated value is compared with experimental data to study the contributing factor of efficient water removal. Dehydration via throttling valve can be achieved by controlling the parameters: eg., increasing the feed pressure with constant temperature and increasing the feed temperature with inlet pressure kept constant. The dehydration of gas mixture by using throttling valve deemed a valuable result noting that the effectiveness of the throttling valve can go up to 87% if a proper insulation is installed.

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Firstly I would like to express my highest gratitude to God, The Almighty, for the guidance and blessing throughout my study year.

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I would like to dedicate this thesis to my family and friends. I have been extremely fortunate in my life to be surrounded with people who have shown me unconditional love and support.

Last but not least, a profound gratitude to all parties that have helped me directly and indirectly throughout this project. The support and encouragement from the party above will always be pleasant memory throughout my life. I hope that all the knowledge and experiences that I gain here will be very beneficial for me in the real working bracket in the future.

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LIST OF ABBREVIATION AND NOMENCLATURES

CO_2	Carbon Dioxide
lbm/MMscf	Pounds Per Million Standard Cubic Foot
NG	Natural Gas
ppmv	Parts Per Million By Volume.
P_{sat}	Saturation Pressure
P_{gauge}	Gauge Pressure
SLPM	Standard Liter per Minute
SRK	Soave-Redlich-Kwong Equation of State
TEG	Triethylene Glycol
T_{sat}	Saturation Temperature
vol%	Percentage by Volume

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Natural gas is formed when decayed plant and animals buried underground, are exposed to extreme pressure and heat. This hydrocarbon consists of carbon and hydrogen compounds and formed primarily of methane and other hydrocarbons include ethane, propane, and butane. Natural gas is well known for its cleanest, harmless and most useful gas in our daily life. Often used for cooking, heating, electricity generation, fuel for vehicles, there is a need to explore natural gas reserves in order to sustain the energy consumption.

Natural gas is saturated with water vapour and other impurities once brought from underground. The existence of water vapour in natural gas might lead to disastrous consequences such as corrosion of pipelines and blockage. If the water vapour is not removed, it will amplifies its corrosivity (when acid gas is present) and clog the pipelines with hydrate and ice formation. Consequently, the presence of the water vapour in the gas had contributed to first major incident in the Gulf Coast. Wet gas from gas well were produced into gas-lift systems and heater were installed to prevent freezing. However, endless trouble was experienced in a year and this led to substantial labor was needed to eliminate hydrates from the gas-lift systems. Wet-type gas dehydrator were then installed to avoid such event from happening [1].

According to Guo et al (2011), water vapour concentration in an untreated natural gas must be below 6-8 pounds of water per million standard cubic foot of gas (lbm/MMscf) before transmission through pipelines in order to avoid any major problem. Initially, the water content is in a magnitude of 100 lbm/MMscf [30]. In order to reduce the water content of natural gas, it must undergo dehydration process. Conventionally, several technologies are used for natural gas dehydration, including absorption and adsorption (commonly activated alumina, silica gel and silica-alumina gel and molecular sieves) [2]. Absorption using triethylene glycol (TEG) are most commonly employed for water vapor removal technology at offshore.

Many researchers focused on absorption and adsorption of water vapour and developing new technology for water vapour removal. Yet, the operating cost for these technologies are high and the column used is consuming large space at offshore which make its feasibility questionable.

In this project, the study of the mixed gas dehydration by using throttling valve is proposed, with its promising gains over the conventional dehydration technology. Throttling process is a process where a fluid flows through a restriction and kinetic energy and potential energy which are assumed negligible. It produces no shaft work, and occurs at constant enthalpy in the absence of heat transfer. Such throttling process will result in a pressure drop of the fluid.

1.2 Problem Statement

Current technology used for dehydration of natural gas is by using triethylene glycol (TEG) absorption. Based on the literature review on natural gas dehydration technologies, it was concluded that natural gas dehydration by using TEG absorption is the only immediately feasible option for water vapour removal [3]. Other systems are still in the development stage, and demonstration projects need to be commissioned before they can be implemented on a large production scale.

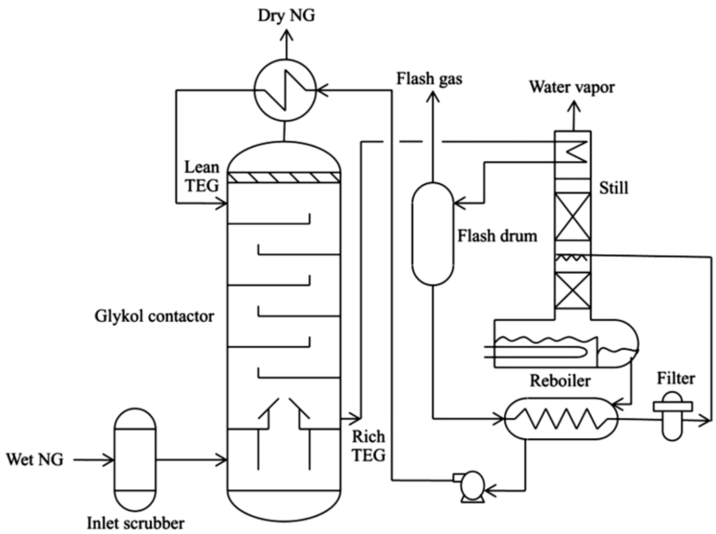

FIGURE 1 Scheme of TEG Absorption Dehydration [3]

The absorption and adsorption packing column using the gravity force required to be installed vertically with a certain height to optimize the separation efficiency. However, its high packing column increases the center of gravity for the platform and thus increases the burden of the jacket support steel. Other than installation size, the adsorption is generally not economically feasible in high gas pressure. Desiccant effectiveness decreases promptly at temperatures greater than 80°F (26.67°C) [4]. In Malaysia, the temperature of mixed gas, once brought from underground, is approximately 120°C and hence, a pressure reduction step is needed before feeding the natural gas into desiccant vessels. The installation of heating system, ventilation and cooling system would require a lot of space and also, high energy is consumed when operated. Therefore, this is not an economical approach for the wet natural gas dehydration.

Despite of its effectiveness, these two dehydration methods, both absorption and adsorption, give drawback summarized as following:

- Adsorbent and glycol used is expensive
- It requires more energy to regenerate adsorbent and glycol.
- Both column are heavy and require a lot of space for its plant.

Therefore, in interest of producing a dry natural gas, it is crucial to develop a new technology in achieving the essentials for critical offshore application, which removes water vapour in large production, facility that is small in size and less weight. In this project, the study of the mixed gas dehydration by using throttling valve is proposed, with its promising gains over the conventional dehydration technology. Nonetheless, limited study has been done experimenting its effects on removal of water vapour in mixed gas.

1.3 Objectives & Scope Of Study

The objectives for this research work are:

1. To study the relationship between feed pressure and temperature drop in a throttling valve.
2. To calculate and compare the temperature drop for different gas mixtures under different feed pressures in a throttling valve.
3. To study the effect of throttling process on moisture content in hydrocarbon mixture with different feed pressures.

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

1. Experimenting on the temperature drop of mixed gas through throttling valve using various feed pressure.

2. Experimenting on the moisture content of mixed gas through throttling valve using various feed pressure.

3. Calculating the temperature drop of gas mixture by using MATLAB and its moisture content by using Raoult's law.

4. The factors contributing to efficient water vapour removal by throttling valve.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Natural Gas Hydrates

Many have aware of natural gas hydrates and it has been the under the spotlight of considerable research in recent years, because of the trouble they have caused in the natural gas and natural gasoline industries. Natural gas hydrates are white crystalline compounds of water and gas, which, under pressure, exist at temperatures considerably above the freezing point of water. Because of the relatively high temperatures at which the hydrates exist, they become a nuisance in high pressure gas operations where water is present, since their formation causes partial or complete plugging of valves and pipes. From a practical standpoint, the trouble incident to hydrate formation has been solved by dehydration of the gas before it enters the plant or pipe line, or by other remedial measures [5].

Gas dehydration is the most efficient way to remove water content in the natural gas and hence prevent hydrate formations. However, there is a practical limitation in using dehydration unit, offshore and onshore, as dehydration unit consume a lot of space and heavy [5,6].

2.2 Dehydration Methods

Natural gas is valuable as chemical feedstock and as a clean source of energy. This natural gas, once brought from underground, is saturated with water vapour. It has to undergo several processing steps before being transferred through pipelines to prevent pipelines from corrosion and hydrates formation. Conventional methods used for gas dehydration are absorption and adsorption. The methods may be used alone or combined to reach the desired water contents.

2.2.1 Dehydration of natural gas by absorption

In dehydration by absorption, water is removed by a liquid with strong affinity for water, glycols being the most common. The lean (dry) glycol removes the water from the gas in an absorption column known as a contactor. After the contactor the rich (wet) glycol must be regenerated before it can be reused in the contactor. The regeneration is done by distilling the glycol thus removing the water. With glycol absorption it is possible to lower the water contents down to approximately 10 ppmvol, depending on the purity of the lean glycol [5-11].

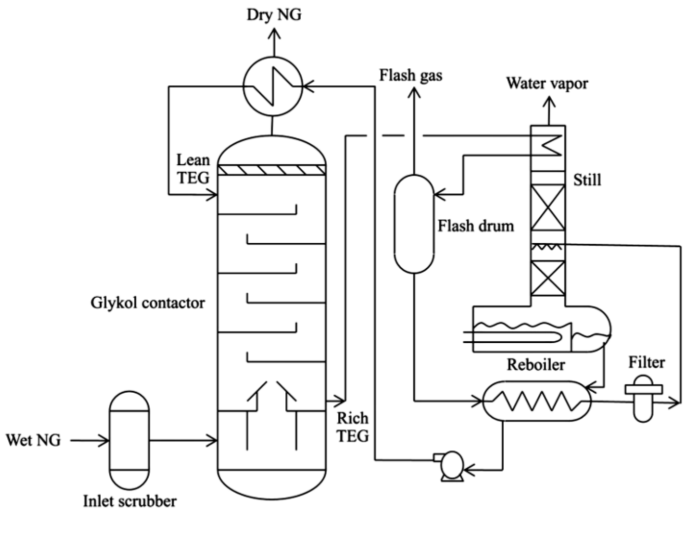

FIGURE 2 Absorption Dehydration Scheme

2.2.2 Dehydration of natural gas by adsorption

The second dehydration method is adsorption by solid desiccant. There are three types of solid desiccant which are used in industry as molecular sieve, alumina and silica gel. A comparison of physical properties of each solid desiccant is presented in Table 1.

TABLE 1 Comparison of Physical Properties of Solid Desiccants Used For Dehydration by Adsorption

Properties	Silica gel	Alumina	Molecular sieve
Specific area (m^2/g)	750-830	210	650-800
Pore volume (cm^3/g)	0.4-0.45	0.21	0.27
Pore diameter (Å)	22	26	4-5
Design capacity (kg_{H2O}/100 $kg_{desiccant}$)	7-9	4-7	9-12
Density (kg/m^3)	721	800-880	690-720
Heat capacity ($J \cdot kg^{-1} \cdot K^{-1}$)	920	240	200
Regeneration temperature (°C)	230	240	290
Heat of desorption (J)	3256	4183	3718

Adsorption dehydration use two bed system, where one bed is used for gas drying, while the other bed is for desiccant regeneration. Adsorbent regeneration is a process where hot dry gas passes through desiccants. This gas is then cooled, and the water condenses. The water is then separated off, and the gas is lead back to the wet gas.

2.3 Joule Thompson & Throttling Valve

The Joule-Thomson Effect (JTE) is the change in temperature of a fluid upon expansion in a steady flow process involving no heat transfer nor shaft work (at constant enthalpy). In the original experiment by Joule and Thomson, the throttling process was carried out by flowing gas through a cotton plug [12].

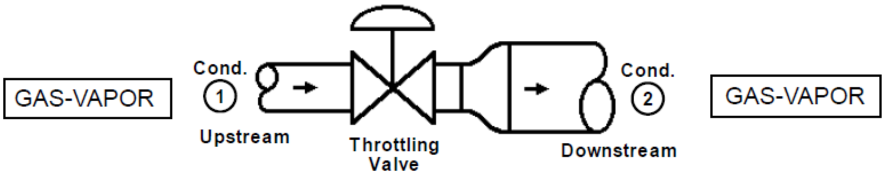

FIGURE 3 Throttling Valve Illustration [13]

Conditions:

For gas or or highly superheated vapor,

$$\dot{m}_1 = \dot{m}_2, \qquad A_1 < A_2, \qquad T_1 \approx T_2 \tag{1}$$

When a fluid flows through a restriction, such as partly closed valve, where the change in kinetic or potential energy is negligible, the main result of the process is a pressure drop in the fluid. This process produces no shaft work, without the presence of heat transfer and occurs at zero change in enthalpy. For most real gases at moderate conditions of temperature and pressure, a reduction in pressure at constant enthalpy results in a decrease in temperature but with small effect. Throttling of wet gas to sufficiently low pressure may cause the liquid to evaporate to become saturated liquid water (condensate) and the vapor to become saturated at the same P_{sat} and T_{sat}. Therefore, T_{sat} can be calculated for a given P_{sat} [13].

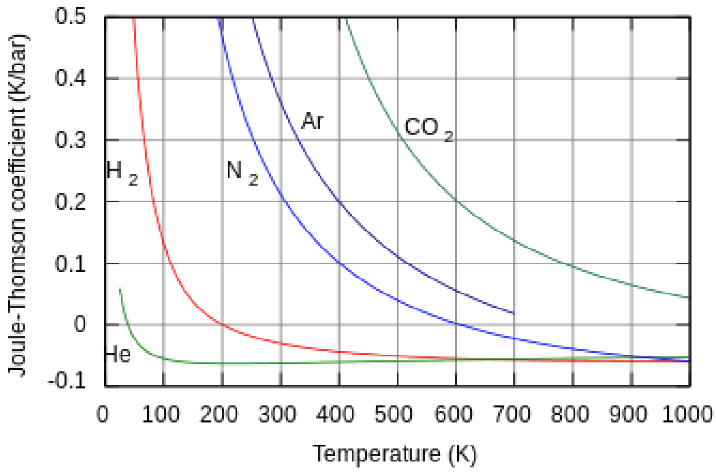

FIGURE 4 Joule-Thomson Coefficients for Different Gases at Atmospheric Pressure [24]

Joule-Thomson (Kelvin) coefficient, μ_{JT} is the rate of change of temperature, T with respect to pressure, P in a Joule-Thomson process (at constant enthalpy H). This coefficient can be expressed as:

$$\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H = \frac{V}{C_p}(\alpha T - 1) \tag{2}$$

Where V = volume of gas

C_p = heat capacity at constant pressure

α = coefficient of thermal expansion

Value of μ_{JT} for all real gases have an inversion point at which the μ_{JT} changes sign. The inversion temperature for Joule Thomson and the temperature of this point, are depending on the gas pressure before expansion.

Pressure decreases in the gas expansion, thus by definition, the sign of ∂P is negative. If the gas temperature is below the inversion temperature, μ_{JT} is positive since ∂P is always negative. Hence, ∂T must be negative, so the gas cools.

2.4 Equation Of State

Equations of state provide the foundation for quantitative description of real-fluid behavior. However generalized correlations allow prediction of the PVT behavior of fluids for which experimental data are lacking. Equations of state are useful in correlating densities of gases and liquids to temperatures and pressures.

Gas behavior is described by the compressibility factor, Z. Compressibility factor refers to the relationship between temperature, pressure and molar volume of a gas. In ideal gas cases, Z =1. Ideal gas law is a simple form of equation of state which is useful for gases at low pressure and molar volume approaches infinity.

$$P = \frac{RT}{V} \quad \text{(Ideal Gas Law)} \tag{3}$$

When dealing with real gas, ideal gas law is not applicable and must be replaced with more accurate equation of state. The first equation to predict vapour-liquid coexistence was van der Waals equation of state (1873). Later, the accuracy of the van der Waals equation is improved by Redlich-Kwong equation of state (Redlich and Kwong, 1949) by recommending a temperature dependence for the attractive term. Soave (1972) and Peng and Robinson (1976) suggested additional amendments of the Redlich-Kwong equation to precisely predict the vapour pressure, liquid density, and equilibria ratios. However, it is difficult to use Soave- Redlich-Kwong equation of state and Peng Robinson equation of state in calculation, thus these equation have been rearranged to a cubic form.

Cubic equations of state are equations that have volume terms raised to first, second, and third power when expanded. The simplest cubic equation of state is van der Waals equation of state which is used for phase equilibria. However, Van Konynenburg and Scott (1980) found out that though most of the critical equilibria demonstrated by binary mixtures could be qualitatively predicted by the van der Waals equation of state, it is rarely sufficiently accurate for critical properties and phase equilibria calculations. Henceforth, there are few alterations have been suggested to address this deficiency. These improved cubic equations of state are listed in Table 2.

TABLE 2 Improved Cubic Equations of State

Reference	Equations Of State	Eq.
Redlich-Kwong (1949)	$p = \frac{RT}{V-b} - \frac{a}{V(V+b)T^{0.5}}$	(4)
Soave-Redlich-Kwong (1972)	$p = \frac{RT}{V-b} - \frac{a(T)}{V(V+b)}$	(5)
Peng-Robinson (1976)	$p = \frac{RT}{V-b} - \frac{a(T)}{V(V+b)+b(V-b)}$	(6)

2.4.1 Soave/Redlich/Kwong (SRK) equation

In this project, Soave/Redlich/Kwong (SRK) equation of state is used in modeling the throttling process. Soave-Redlich-Kwong equations are widely used in industry [16]. The benefits of this equation is it is easy to use and that the relationship between temperature, pressure and phase composition is often accurately represented. Only critical properties and acentric factor is required for generalized parameters in order to use this equation. Nonetheless, the accuracy of this equation is limited to the estimation of phase equilibrium correlation. This affects the saturated liquid volume where the calculated value is higher than the measured data.

Spear et al. (1969) validated that the Redlich-Kwong equation of state could be used for vapor-liquid critical properties of binary mixtures calculation. Chueh and Prausnitz (1967a, b) also revealed that the Redlich-Kwong equation can be modified to predict both vapor and liquid properties. Furthermore, Deiters and Schneider (1976) and Baker and Luks (1980) have successfully utilized the Redlich-Kwong equation to the high pressure phase equilibria of binary mixtures. Deiters and Pegg (1989) used the Redlich-Kwong equation with quadratic mixing rules for phase diagrams for binary fluid mixtures calculation and to categorize them according to the global phase diagram.

Soave (1972) proposed to replace the term $\frac{a}{T^{0.5}}$ with a temperature-dependent term *a(T),* where;

$$a(T) = 0.474 \left(\frac{R^2 T_C^2}{p_C}\right)\{1 + m\left[1 - \left(\frac{T}{T_C}\right)^{0.5}\right]\}^2 \qquad (7)$$

$$m = 0.480 + 1.57\omega - 0.176\omega^2 \qquad (8)$$

$$b = 0.08664\ \frac{RT_C}{p_c} \qquad (9)$$

Where ω is the acentric factor.

2.5 Henry's Law and Raoult's Law

Solubility of gas always follows Henry's law. According to Smith and Abbott (2005), Henry's law stated that "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid" [13].

$$Henry's\ law: y_i = x_i H_i \tag{10}$$

Where H_i = Henry's constant

x_i = mole fraction of component i in liquid

y_i = mole fraction of component i in vapour

According to Larryn and Nikolay (2003), Henry's law is then modified as follow for the solubility of gas in water correlation. This equation is then named Raoult's law.

$$x_{CO_2} = \frac{f^0_{CO_2}\, y\gamma_y}{H_i\gamma_{CO_2}} \tag{11}$$

Where H_i = Henry's constant

x_{CO_2} = mole fraction of gas in aqueous phase

y = mole fraction of gas in non-aqueous phase

$f^0_{CO_2}$ = fugacity coefficient

γ_{CO_2} = activity coefficient of aqueous gas

γ_y = activity coefficient in non-aqueous phase

2.6 Research Gap

Table 3 summarized research done on dehydration unit.

TABLE 3 Research Gap on Dehydration Unit

Year	Author	Research Area / Finding
2005	Twu et al	Developed an advanced equation of state to determine the water dew point and calculate water content for triethylene glycol (TEG)–water system for glycol gas dehydration process.
2009	Karimi et al	Dehydration of high-pressure natural gas using supersonic (converging–diverging) nozzle.
2011	Netusil et al	Comparison is made between absorption by triethylene glycol, adsorption on solid desiccants and condensation according to their energy demand and suitability for use.
2011	Farag et al	The effect of various operating conditions (concentration of water vapor and gas flow rate) on dehydration of natural gas via 3A molecular sieve as solid desiccant materials.
2013	Zou et al	Studied on failure factors, such as pH analysis, thermogravimetry, differential thermogravimetry, scanning electron microscope, X-ray diffraction, and Fourier transform infrared spectrum characterizations of molecular sieve in natural gas dehydration.
2014	Ghiasi et al	Water content estimation of natural gas desiccated by solid calcium chloride dehydrator units.
2014	Ghiasi et al	Triethylene glycol (TEG) purity estimation in natural gas dehydration units by using fuzzy neural network.

2014	Jokar et al	Simulation and feasibility study of structured packing replacement in absorption column of natural gas dehydration process.
2014	Ahmadi et al	Artificial neural networks (ANNs) trained with particle swarm optimization (PSO) and back-propagation algorithm (BP) were utilized for equilibrium water dew point estimation of natural gas in TEG dehydration systems.
2015	Shirazian et al	Synthesis and characterization of LTA-type zeolite membranes on a-Al2O3 substrate through secondary growth method which were then evaluated on its efficiency to separate CH_4 and water vapour.
2015	Runhong Du et al	An electric potential gradient was used as supplementary driving force for polar molecules (e.g., water) to pass through the membrane. Enhancement in water permeation was evaluated and the improvement in water/gas separation was confirmed. The effects of operating parameters (including voltage gradient, pressure gradient, and operating temperature) on permeation were investigated.

From Table 3, it can be seen that many researchers try to improve conventional dehydration method and minimize the energy consumed. However, most of the research results in higher capital cost as well as increasing mechanical complexity and the process complexity. Also, almost all methods mentioned in Table 3 consumes high energy. None of the research aims to change the whole dehydration method by using throttling valve.

CHAPTER 3

METHODOLOGY/PROJECT WORK

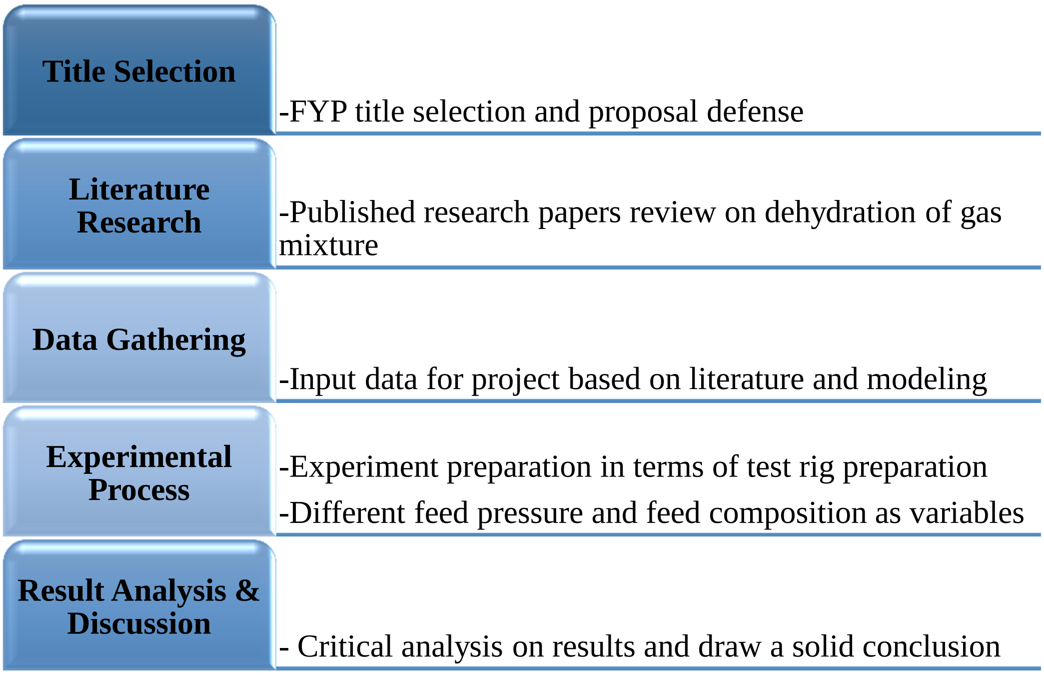

FIGURE 5 Methodology Overview

The first part of the project will be literature review. This part focusses on previous papers published by the ACS Publication, Science Direct and other qualified journals as the basis of study. The aim of this stage is to increase understanding on the idea of dehydration of natural gas in industry and subsequently structuring solid fundamental information to support the future study. The following stage is to gather the parameters and information for the inputs for the studies, basically from written survey of the distributed papers reviewed.

The data assembled will be placed into the degree of study for further analysis towards the change of this endeavor. The inputs gained from the various sources, for example, University of Technology PETRONAS (UTP) researches, lecturers and experts additionally have contributed a significant point towards accomplishing this stage.

Following the readiness of the test rig and chemicals, the experimental stage will be going as according to plan. Gas mixture composition and test rig preparation will be the key elements in performing this juncture. All the data will be analyzed through several techniques available including the use of equipment in the laboratory. Successively, the cultivated analysis of the outcomes will be drawn, and the conclusion would be forwarded upon.

3.1 Experimental Setup

Arrangement of steps and methodology are distinguished beforehand with a specific end goal to effectively finish the project. The following are the derived techniques with depiction of each of the stages in the undertaking.

A test rig will be modified in the present research work. Test rig consists of five sections as shown in Figure 6 will be utilized in this project.

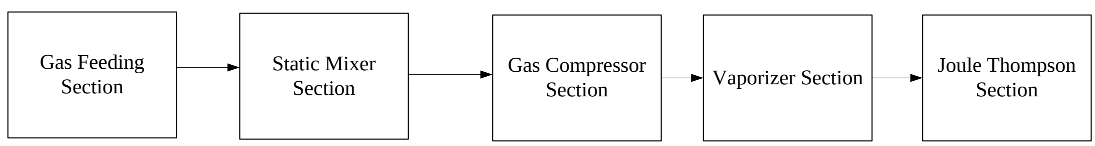

FIGURE 6 Block Diagram of Test Rig

The gas mixture is prepared by flowing the natural gas and CO_2 in the static mixer. Mass controller is used to control the composition of the binary gas mixture. The one-direction check valve is installed on each of the mass controller to inhibit the back flow from the static mixer. The maximum pressure of the static mixer is up to 12 bar. Hence, a check valve is also required to be installed at the end of the static mixer to prevent the back pressure from the compressor. The schematic diagram of the feeding section is shown in Figure 7. The mixture is then flowing to the compressor section.

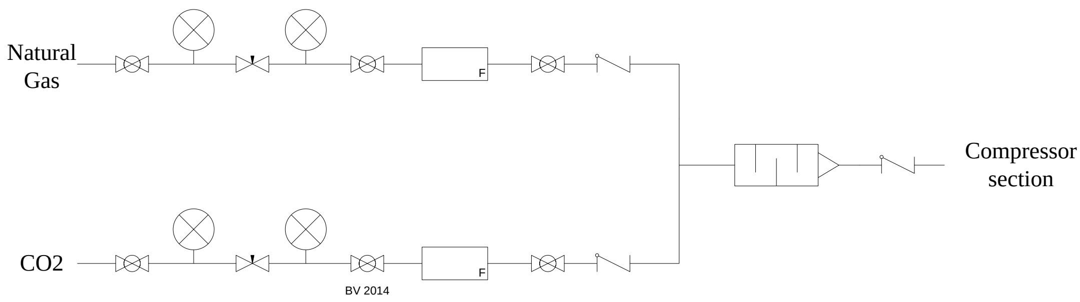

FIGURE 7 The Schematic of the Feeding Section.

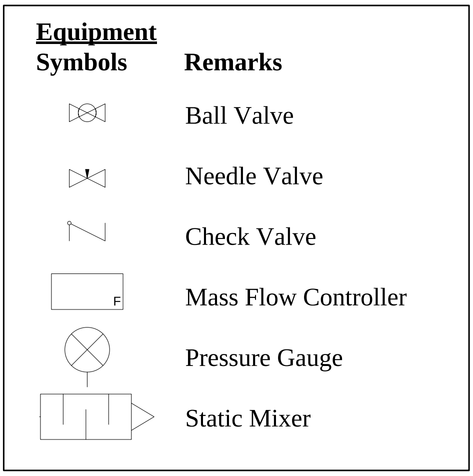

FIGURE 8 Equipment Symbols and Remarks

Figure 9 shows the schematic diagram of the gas compressor section, vaporizer section, and Joule Thomson section. The designed gas compressor possesses maximum flow rate up to 50 SLPM. The feedback system is required for lower flow rate experiment. 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 required input pressure. The mixed gas and water vapour are mixed in the vaporizer section. A sample point is taken right after the vaporizer and before the back pressure regulator. The pressure should drop to atmospheric pressure after the back pressure regulator. The wet mixed gas will then flowing to Joule-Thomson (JT) section. There will be another sample point after Joule Thomson section for moisture content evaluation. These samples were then collected and analyzed using moisture analyzer.

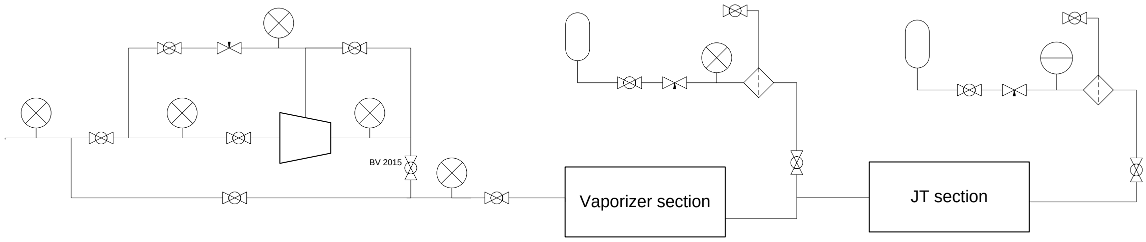

FIGURE 9 Schematic Diagram of Gas Compressor Section, Vaporizer Section, and Joule Thomson Section.

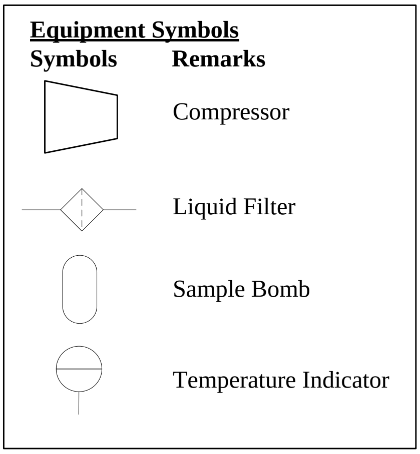

FIGURE 10 Equipment Symbols and Remarks

In order to achieve project's objective, feed composition (natural gas, CO_2, and moisture content) will be varied to study on its effect on dehydration. Furthermore, pressure inlet also will be set starting from 10 bar up to 50 bar. However, before running the experiment, the outlet temperature of the gas stream (post throttle) will be calculated with SRK Equation, while value for moisture content in the test stream will be calculated using Raoult's law.

3.1.1 Detailed Procedure

1. The temperature drop for different gas mixtures at different feed pressure is predicted using MATLAB (SRK equation) before start the experiment.
2. The moisture content for different gas mixtures at different feed pressure is predicted using Raoult's law before start the experiment.
3. For experiment, start the system (set all pressure point to 160 bar, flow rate at 40 SLPM).
4. Open valve PI 1001B, BV 1004B, BV 1005B.
5. Set the pressure to 10 bar (1^{st} run) using the knob PRV 4012. Closed valve NV4014 before setting the pressure. Release the PRV 4012 after setting the pressure.
6. Release the pressure by controlling NV 4014.
7. Set 40 SLPM for mass flow controller for carbon dioxide.
8. Closed PRV 2003 and let the pressure increase to 2.5 bar.
9. Open valve BV2013, BV2007, BV2005, and BV2002.
10. Start the pump.
11. Regulate NV2012 and PRV2009 to ensure pressure at PRV2003 is kept at 2.5 bar.
12. Start the stopwatch once PI 2016 reading exceeds PI 4013 reading.
13. Run the experiment until steady-state temperature (the steady state temperature will be compared with the temperature obtain from modelling).
14. Record the temperature after throttling valve every minute.
15. Repeat the experiment using 20 bar, 30 bar, 40 bar and 50 bar by regulating PRV 4012. Wait for the system to be stable (temperature of the system is in equilibrium with surrounding) before start any experiment.

16. To feed natural gas (only) into the system, open valve PI 1001A, BV 1004A, BV 1005A and close valve PI 1001B, BV 1004B, BV 1005B. Set flowrate to 40 SLPM.
17. 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. Set flowrate to 20 SLPM for both natural gas and carbon dioxide.
18. All data will be recorded prior plotting the graph.
19. To study moisture content, repeat step 1 to 10. Switch on the power supply for vaporiser and set to 30V.
20. Switch on moisture analyser to check on moisture content before throttling valve. Take reading after it has reach equilibrium (5 minutes). Repeat experiment with various throttling pressure (20 bar, 30 bar and 40 bar).

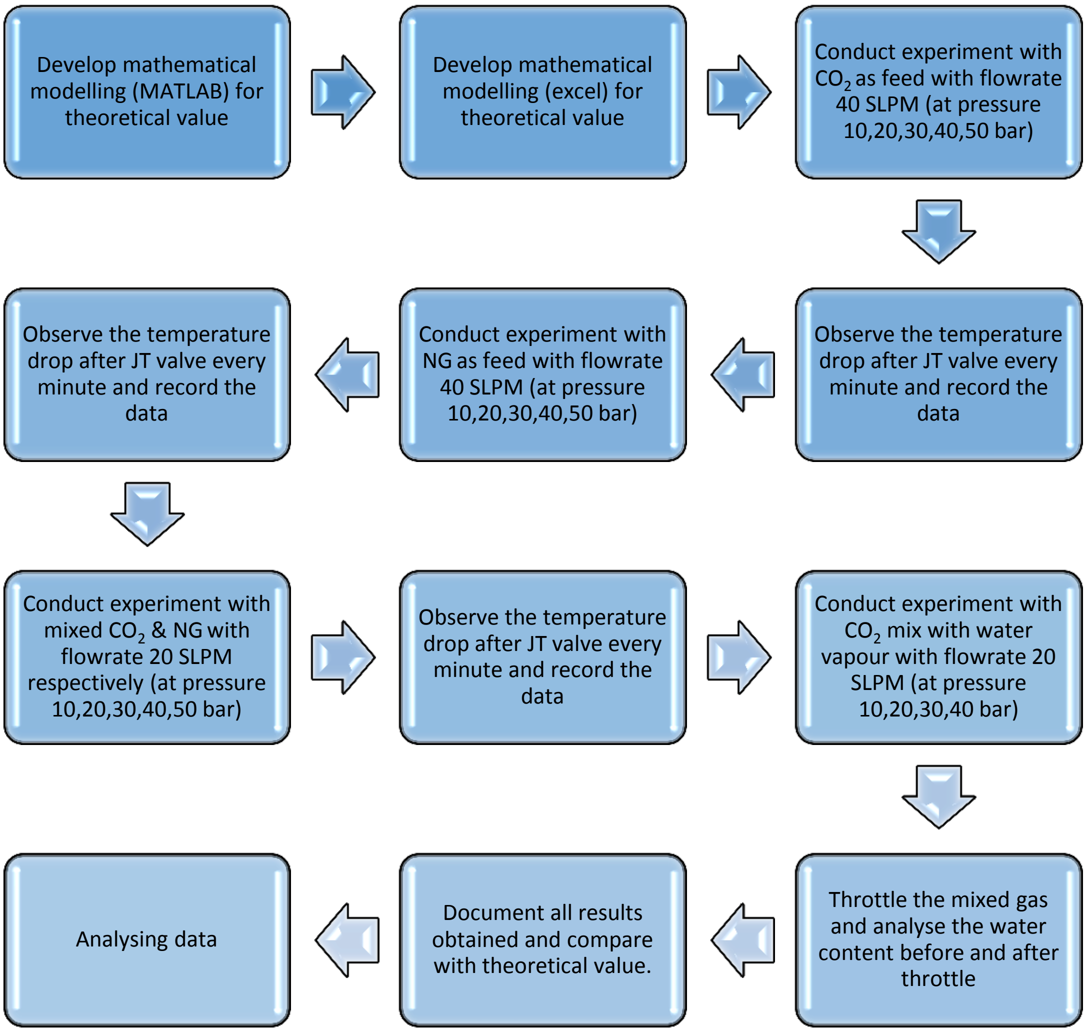

FIGURE 11 Work Flowchart

3.2 Activity Gantt Chart

Table 4 and 5 shows the activity gantt chart of the research work:

TABLE 4 Gantt Chart for Final Year Project 1

Milestone	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP 1 briefing														
Selection of project														
Literature research														
Submission of extended proposal														
Proposal defence														
Interim report submission														
Key Milestone														
Gathering data on gas hydrate, dehydrations methods, and Joule Thomson effect														
Prepare the methodology for the research.														
Preliminary result based on theoretical value.														
Preparation of gas samples to be run for pressure drop effect.														

TABLE 5 Gantt Chart for Final Year Project 2

Milestone	**Week**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Conduct experiment of different pressure drop on test rig	■	■	■	■	■	■	■							
Progress Report submission								■						
Pre-SEDEX										■				
Submission of Dissertation (soft bound)													■	
Submission of Technical Paper													■	
Submission of Project Dissertation (Hard Bound)														■
Key Milestone														
Conduct experiment of different pressure drop on mixed gas	■	■	■	■	■	■								
Conduct experiment of moisture content on mixed gas							■	■	■	■	■			
Analyzing results										■	■	■		
Submission of dissertation and technical paper													■	■

TABLE 6 Key Milestones

Milestones	**Target Date**
1. Preliminary Experiment test	31st March 2015
2. Submission of Progress Report	9th July 2015
3. Pre-EDX	29th July 2015
4. Submission of Dissertation (Soft bound)	10th August 2015
5. Submission of Technical Paper	14th August 2015
6. Oral Presentation	24th-25th August 2015
7. Submission of Project Dissertation (Hard Bound)	15th September 2015

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the outcomes from the experimental works. All the outcomes are critically analyzed and being discussed in detail throughout this chapter. Towards the end of this chapter, effect of pressure drop towards the dehydration of mixed hydrocarbon using throttling valve (Joule Thomson Valve) is clearly conveyed.

4.1 Effect Of Inlet Pressure Towards Dehydration Of Hydrocarbon

One of the objectives of this research is to investigate the effect of pressure towards the dehydration of gas mixture using throttling valve. The value of temperature drop is calculated using MATLAB. These values are shown in Table 7, 8 and 9.

TABLE 7 Data Obtained From MATLAB (Calculated Data) For 100 vol% CO_2

Initial pressure [bar]	Final pressure [bar]	Initial temperature (°C)	Outlet Temperature (°C)	Temperature Drop (°C)
11	1.013	30	16.59	13.41
21	1.013	27	4.36	22.64
31	1.013	27	-9.54	36.54
41	1.013	30	-25.88	57.88
51	1.013	27	-46.26	73.26

TABLE 8 Data Obtained From MATLAB (Calculated Data) For 100 vol% Natural Gas

Initial pressure [bar]	Final pressure [bar]	Initial temperature (°C)	Outlet Temperature (°C)	Temperature Drop (°C)
11	1.013	26	22.41	3.59
21	1.013	26.5	17.76	8.74
31	1.013	26.5	13.07	13.43
41	1.013	28.5	8.34	20.16
51	1.013	28	3.6	24.4

TABLE 9 Data Obtained From MATLAB (Calculated Data) For 50vol% CO_2 & 50vol% Natural Gas

Initial pressure [bar]	Final pressure [bar]	Initial temperature (°C)	Outlet Temperature (°C)	Temperature Drop (°C)
11	1.013	28.5	20.21	8.29
21	1.013	26.5	12.87	13.13
31	1.013	26.5	5.17	22.33
41	1.013	28.5	-2.915	34.915
51	1.013	28	-11.41	40.41

From Table 7, 8, and 9, it can be concluded that the temperature decreases over time. Outlet temperature however, shown significant drop as inlet pressure increased. The temperature drop is higher when 100 vol% carbon dioxide is used to as test stream. This indicates that the Joule-Thomson effect is higher in carbon dioxide as compared to natural gas.

These gas mixtures are then tested experimentally using commercial throttling valve. Several studies were run using test rig to study the temperature drop for gas at three feed composition, 100 vol% carbon dioxide (CO_2), 100 vol% natural gas (NG) and 50 vol% carbon dioxide (CO_2) 50 vol% natural gas (NG). The test stream was introduced to the throttling valve at different pressure 10 bar, 20 bar, 30 bar, 40 bar, and 50 bar without water content.

TABLE 10 Inlet Stream Conditions

Gas Mixture	Volumetric flow rate (SLPM)	Feed Pressure (bar)
100 vol% CO_2	40	10
		20
		30
		40
		50
100 vol% Natural Gas		10
		20
		30
		40
		50
50 vol% CO_2 & 50 vol% Natural Gas		10
		20
		30
		40
		50

The Joule-Thomson Effect (JTE) is the change in temperature of a fluid upon expansion in a steady flow process involving no heat transfer nor shaft work (at constant enthalpy) [12].

When a fluid flows through a restriction, such as partly closed valve, where the change in kinetic or potential energy is negligible, the main result of the process is a pressure drop in the fluid. This process produces no shaft work, without the presence of heat transfer and occurs at zero change in enthalpy. For most real gases at moderate conditions of temperature and pressure, a reduction in pressure at constant enthalpy results in a decrease in temperature. Throttling of wet gas to sufficiently low pressure may cause the liquid to evaporate to become saturated liquid water (condensate) and the vapor to become saturated at the same P_{sat} and T_{sat} [13]. Therefore, T_{sat} can be calculated for a given P_{sat}.

Figure 12, 13 and 14 shows that temperature of the test stream decreases across time which follows the trend of calculated values. This trend follows Joule-Thomson theory as the gas cools down to certain temperature after throttling process. This is due to the Joule-Thomson coefficient of the carbon dioxide is higher compared to the natural gas as stated by Smith (2005). Temperature drop is higher when 100 vol% of CO_2 is used as test stream. These results are illustrated in Figure 15. It goes to show that the throttling effect in CO_2 gas is higher as Joule Thomson coefficient for CO_2 is higher as stated by Karimi (2009).

A significant value for temperature drop is observed as the inlet pressure increases. Pressure reductions involved the conservation of energy theory so as Bernoulli's principle. As pressure drop is high, the velocity of fluid increases (as the mass of test stream is constant). This causes the temperature drop if the test stream becomes higher at high pressure drop [13].

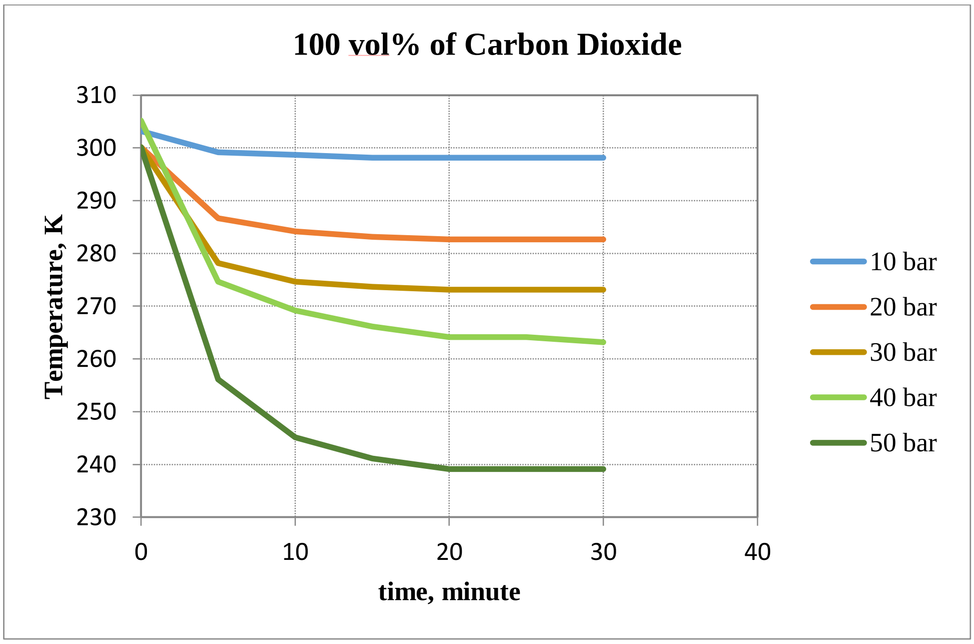

FIGURE 12 Temperature Recorded Per Minute at Different Throttling Pressure for 100vol% CO_2 Feed

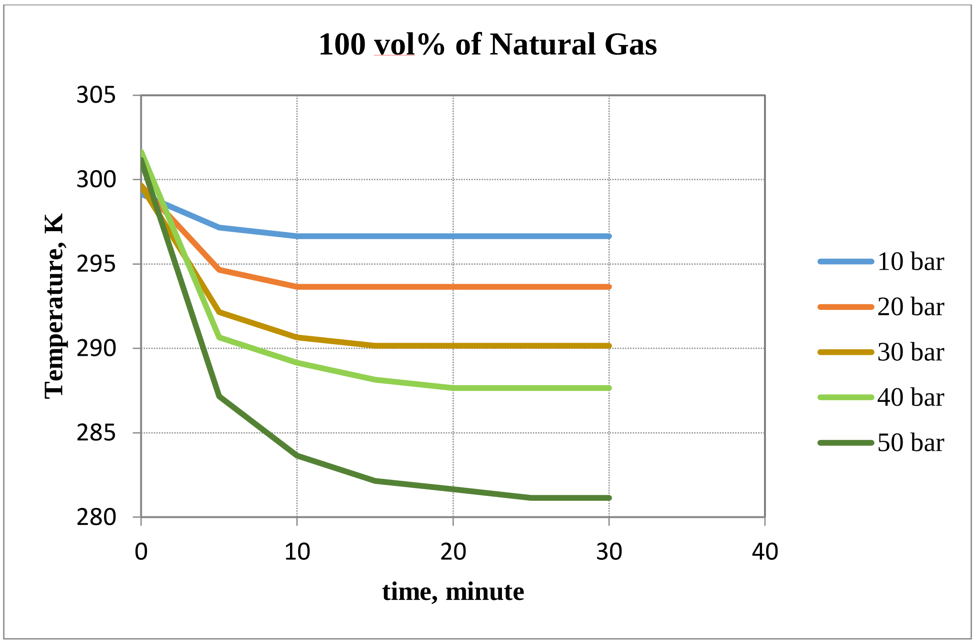

FIGURE 13 Temperature Recorded Per Minute at Different Throttling Pressure for 100vol% Natural Gas Feed

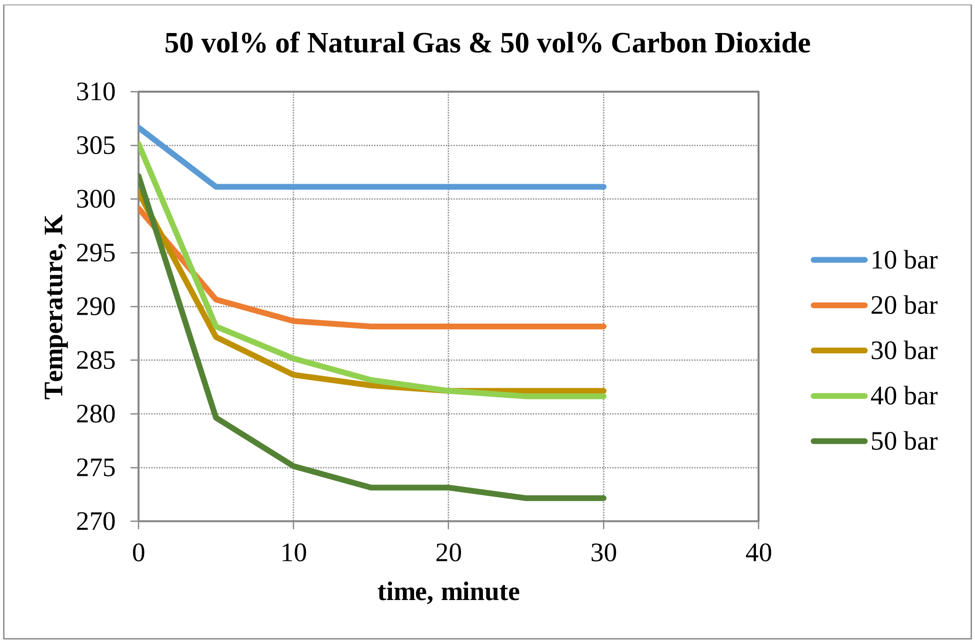

FIGURE 14 Temperature Recorded Per Minute at Different Throttling Pressure for 50vol% CO_2 50vol% Natural Gas Feed

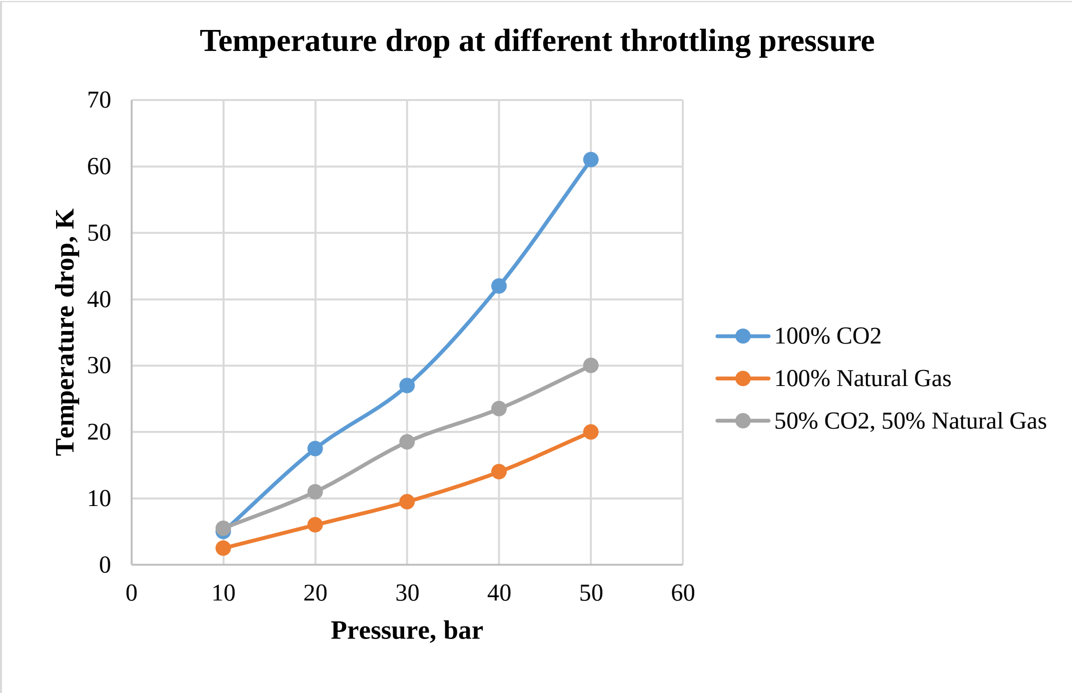

FIGURE 15 Temperature Drop at Different Pressure for Various Feed Composition

Table 11, 12 and 13 shows the comparison of outlet temperature obtained from calculated values and experimental values. Experimental data obtained did not reach the expected calculated values due to improper installation of insulator. During experiment at approximately minute 28, the outlet temperature was 0.5 ºC lower than minute 27. However, at minute 29, it increases back to its temperature at minute 27. This goes to show there are heat coming in from the surrounding, affecting the result of outlet temperature.

TABLE 11 Error Percentage for 100 vol% CO_2

Initial pressure [bar]	Final pressure [bar]	Initial temperature [K]	Final temperature [K]		Error
			Experiment [K]	Theoretical [K]	
11	1.013	303.15	298.15	289.74	0.51
21	1.013	300.15	282.65	277.51	1.18
31	1.013	300.15	273.15	263.61	-1.00
41	1.013	305.15	263.15	247.27	-0.61
51	1.013	300.15	239.15	226.89	-0.27

Composition : 100 vol% CO_2
Flow rate : 40 SLPM
Steady State time : 30 minute

TABLE 12 Error Percentage for 100 vol% Natural Gas

Initial pressure [bar]	Final pressure [bar]	Initial temperature [K]	Final temperature [K]		Error
			Experiment [K]	Theoretical [K]	
11	1.013	299.15	296.65	295.56	0.05
21	1.013	299.65	293.65	290.91	0.15
31	1.013	299.65	290.15	286.22	0.30
41	1.013	301.65	287.65	281.49	0.74
51	1.013	301.15	281.15	276.75	1.22

Composition : 100 vol% Natural gas
Flow rate : 40 SLPM
Steady State time : 30 minute

TABLE 13 Error for 50vol% CO_2 + 50vol% Natural Gas

Initial pressure [bar]	**Final pressure [bar]**	**Initial temperature [K]**	**Final temperature [K]**		**Error**
			Experiment [K]	**Theoretical [K]**	
11	1.013	301.65	301.15	293.36	0.39
21	1.013	299.15	288.15	286.02	0.17
31	1.013	300.65	282.15	278.32	0.74
41	1.013	305.15	281.65	270.235	3.92
51	1.013	302.15	272.15	261.74	0.91

Composition : 50 vol% CO_2 + 50 vol% Natural gas

Flow rate : 40 SLPM

Steady State time : 30 minute

4.2 Effect on Moisture Content Towards Dehydration Of Hydrocarbon

Several studies were run using test rig to study the moisture content for 100vol% carbon dioxide (CO_2). Other gas mixture cannot be tested using current vaporizer due to it is not suited yet for a test stream with the presence of oxygen. The current vaporizer is using ultrasonic atomization principle (ultrasound) and is connected to its own power supply. Short circuit and worst case, explosion might occur due to the presence of natural gas (might contains oxygen). The test stream was introduced to the throttling valve at different pressure 10 bar, 20 bar, 30 bar, and 40 bar. Vaporizer power was kept constant at 30V. Water in the vaporizer was fed by batch. Maximum pressure that the vaporizer can hold is 40 bar.

TABLE 14 Inlet Stream Conditions

Gas Mixture	**Volumetric flow rate (SLPM)**	**Feed Pressure (bar)**
100 vol% CO_2	20	10
		20
		30
		40

Table 15 shows the experimental result gained for moisture content of inlet and outlet. Table 16 shows the calculated value of moisture content using Raoult's law. The inlet water content in the gas stream from experimental data has not reach equilibrium yet. This might be due to the flowrate of gas is too fast, which makes its retention time is low and consequently, the gas cannot absorb the water. Initial water content in gas stream decreases as the inlet pressure increase which follows the trend stated by Karimi (2009).

TABLE 15 Experimental Result of Moisture Content

P_{gauge} initial (bar)	**P_{gauge} final (bar)**	**Initial Dewpoint at atmospheric (°C)**	**Final Dewpoint at atmospheric (°C)**	**Initial water content (ppmv)**	**Final water content (ppmv)**	**Recovery, Experiment (%)**
10	1.013	-50.5	-55.0	37	21	43.24
20	1.013	-52.9	-57.0	27	16	40.74
30	1.013	-54.1	-57.9	23	14	39.13
40	1.013	-55.0	-58.5	21	13	38.10

TABLE 16 Theoretical Result Calculated Using Raoult's Law

P_{gauge} initial (bar)	P_{gauge} final (bar)	Initial water content (ppmv)	Final water content (ppmv)	Recovery, Simulation (%)
10	1.013	37	31.25	15.53
20	1.013	27	11.72	56.60
30	1.013	23	6.032	73.78
40	1.013	21	2.56	87.79

In experimental result, recovery decreases by the increase of inlet pressure though Joule-Thomson effect is greater at high pressure. These results contradicts with calculated values. The position of moisture analyzer and the method of measuring the moisture content are assumed to be contributing to this problem. There is one valve connecting the stream line with moisture analyzer. The gas flowrate to the moisture analyzer is controlled and hence, valve is not fully opened. There might be some throttling effect at the valve itself which makes the reading of moisture contents obtained are lower. The water bath was installed at the vaporizer when measuring the outlet water content. This water bath functioned as temperature controller for vaporizer. Water bath was not installed during the inlet moisture content measurement. This affects the absorption efficiency because the vaporizer temperature is getting higher across time. Consequently, the moisture content in the gas stream is increases as the temperature of vaporizer increases.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Natural gas extracted from underground sources is saturated with liquid water and heavier molecular weight hydrocarbon components. The dehydration of natural gas to a dew point lower than the operating temperature of the chiller plant is significant to prevent freeze up problems, causing flow restriction, with resulting consequences in terms of plant operating efficiency.

This research project clearly shows the effect of throttling process on various feed composition at different inlet pressure. The effectiveness of throttling valve is also conveyed. Temperature drop increases by the increase of inlet pressure of test stream. However, temperature drop in 100 vol% carbon dioxide is higher than in 100 vol% natural gas. Moisture content recovery should increases as the inlet pressure of gas stream increases.

The dehydration of gas mixture by using throttling valve deemed a valuable result noting the effectiveness of the throttling valve can go up to 87% if a proper insulation is installed. However, further experiments with longer steady state time is recommended for the effect of feed pressure towards the temperature drop of gas mixture.

5.2 Recommendations and Future Work

There are few recommendations that need to be taken into consideration for a betterment of this project.

Recommendations are as follows (for the improvement of method or equipment):

i. The insulator for throttling valve and the line after throttling valve (temperature indicator, water filter and sample point) needs to be improved. Heat loss are still detected and it is affecting the efficiency of test rig.
ii. Vaporizer should be built with explosion proof. Natural gas cannot be tested in vaporizer section as explosion might occur (natural gas contains small amount of oxygen).
iii. Valve used to control flow of gas to moisture analyser should be fully opened. Some Joule Thomson effect might occur if it is partially opened and it affects the result of moisture content in the gas.

Recommendations for future works are listed as below:

i. Test on dehydration by throttling valve can be done by varying other parameters such as composition of mixed gas as feed and feed flow rate.
ii. Experiment on the moisture content of natural gas and mixed gas (natural gas mix with carbon dioxide).
iii. Simulate the flow in throttling valve using HYSYS and COMSOL.

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APPENDICES

Appendix A: Picture of test rig

Throttling pressure setting

Gas mixture feed section

Joule Thomson (throttling valve) section

Vaporiser Section

Internal Part of Vaporiser

Water Bath Used to Control the Temperature of Vaporiser