Removal of Equilibrium Water in Natural Gas Using Joule-Thomson Expansion Valve

by

Mohd Haniff B Nazeer Ahamad (15066)

Dissertation submitted in partial fulfillment of the

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(Chemical Engineering)

Supervisor: Assoc. Prof Dr. Lau Kok Keong

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Universiti Teknologi PETRONAS
32610 Bandar Seri Iskandar
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by.

(ASSOC. PROF. DR. LAU KOK KEONG)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 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 excepts 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.

MOHD HANIFF B. NAZEER AHAMAD

ABSTRACT

Removal of water in natural gas is required at the preliminary stage of gas processing. There are several methods that can be applied for the dehydration of water such as absorption, adsorption, physical membrane and condensation process. For this project, condensation method will be used to remove excess water from the natural gas by introducing the Joule-Thomson effect. The Joule-Thomson effect can be observed through a valve where the water will start to condense by throttling the pressure from high level to low level. Two types of data gathering technique being done for this project which are by experimental feasibility and numerical analysis using process simulation. For the experimental feasibility, the temperature for the Joule-Thomson effect was recorded and compared using simulation. For numerical analysis using process simulation, a range of pressure is being test to find out what are the percentage of water recovery by using a Joule-Thomson valve and an expander with two different compositions which are 80% methane 20% carbon dioxide and 50% methane 50% carbon dioxide.. The implementation of this data for future is a suitable and economical way can be used to remove water from the natural just by having a Joule-Thomson effect and its valve rather than using other methods such as absorption, a compressor or membrane technologies.

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1 PROJECT BACKGROUND

Natural gas contains water vapour in its composition when it is being extracted whether the amount of water is high or low depends on the gas pressure itself. Usually high pressure gas contains a large amount of water vapour and required several processes to be removed. In addition, natural gas also contains other types of components such as carbon dioxide, sulphur and other chemicals. Usually the removals of water in high pressure gas are crucial in order to produce a much cleaner gas. The removal of water is done in the preliminary stage of gas processing where the water in removed before unwanted gas such as carbon dioxide is being separated from methane gas. This is because certain equipment or process such as the membrane technology could not work properly when there is water presence in it. Other than that, water can react with carbon dioxide to produce an acidic solution which can damage the internal of the pipe.

The theme of natural gas dehydration is closely connected with the storage of natural gas. There are two basic reasons why we need to store the natural gas after dehydration process has occurred. Firstly it can decrease the dependency on supply and secondly it can exploit the maximum capacity of the distribution lines. In order to remove the water from the gas during preliminary stage, there are several dehydration methods currently being used such as absorption, adsorption, membrane and condensation.

1.2 PROBLEM STATEMENT

For this project, a new method of removing water from natural gas would be studied primarily condensation process in addition with the usage of Joule-Thomson expansion valve. This research would be conduct to determine whether the possibility of using Joule-Thomson expansion valve as a new method to remove water from natural gas. This study includes what are the challenges being faced on removing water with the presence of Joule-Thomson effect, how does the JT effect relates with the vaporisation of water and what are the minimum requirements for the JT effect to occur such as temperature, pressure and flow rate.

1.3 OBJECTIVE

The objectives of this research study are as follows:

1. To study the effect of Joule-Thomson (JT effect) in dehydration of natural gas using condensation method
2. To study what are the difference using Joule-Thomson valve and a turbo expander on dehydration of natural gas

1.4 SCOPE OF STUDY

The scope of study for this research revolves around the method of removing water from natural gas by using condensation method. Condensation method is normally being done at low pressure and temperature system for the optimum condition. There are other ways that can be used to remove water vapour in natural gas such as using an expander. A case study will be performed to differentiate the effectiveness by using a Joule-Thomson valve and an expander on removing the water vapour. Both studies will be done in simulation and experimental analysis. This is to study the effectiveness and suitability of Joule-Thomson method on removing water vapour. The scope of the study includes the following:

1. Theoretically study of the condensation process
   a. Develop a dynamic model that represents Joule-Thomson effect
   b. Simulate the dynamic properties under wide range of operation parameters by using HYSYS simulation.
2. To determine the suitable pressure, temperature and flow rate
   a. Design a mathematical modelling for simulation
   b. Implement the condensation method on the existing test rig
   c. Validate the experimental result with the theoretical model

CHAPTER 2: LITERATURE REVIEW

2.0 DEHYDRATION METHOD

2.1 CONDENSATION

The removal of water from natural gas using condensation is a method of cooling the water molecules into liquid phase and then removes them from the stream. Natural gas can be cooled advantageously using the Joule-Thomson effect which is the purpose of the study being conducted [6]. The Joule-Thomson effect describes how the temperature of gas changes with pressure adjustment. For natural gas, owing to expansion, the average distance between the molecule increases thus leading to increase in their potential energy. During expansion, there is no heat exchange with the environment or work thus according to conservation law, the increase in potential energy leads to decrease in kinetic energy thus resulting a temperature decrease in natural gas [6].
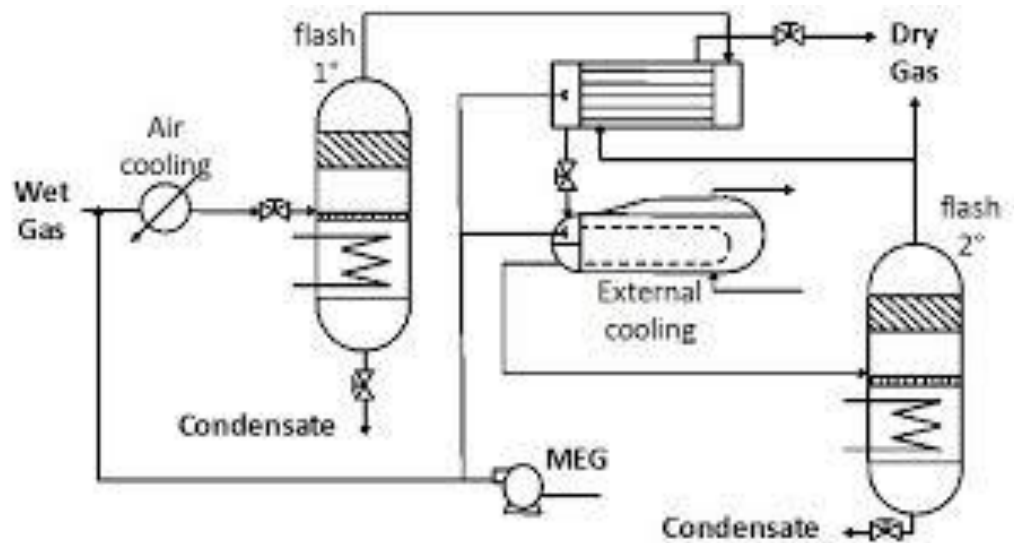
Figure 1: Scheme of dehydration method utilizing the JT effect and hydrate inhibition [6]

The wet natural gas is throttled in two steps inside the flash tanks. The lower temperature (due to JT effect) of the gas stream in the flash tanks leads to partial condensation of water vapours [6]. The droplets created are removed from the gas stream by a demister inside the flashes.
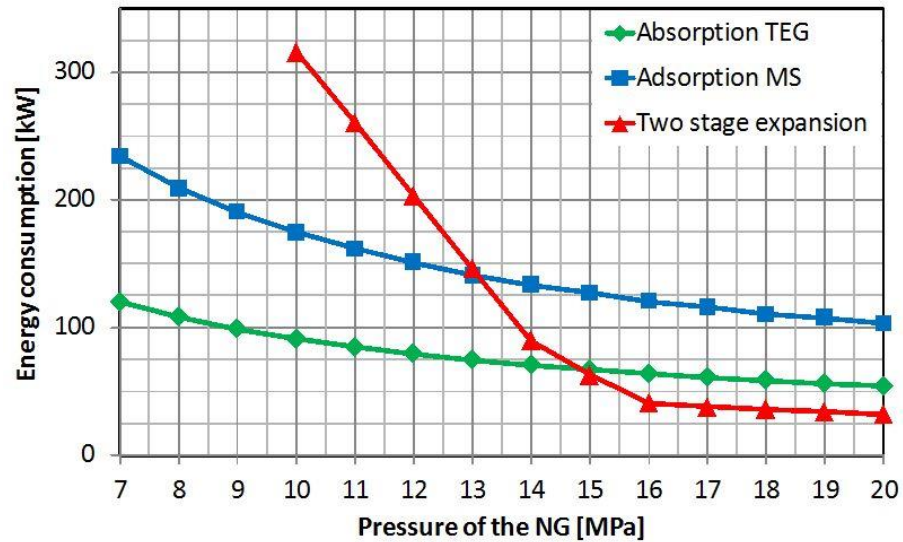
4

Under low pressure the condensation method was the most demanding one. Its demand decreased linearly with pressure [6]. As the natural gas pressure was further decreased the energy demand for the condensation method is still decreasing but with a lowering tendency. Under high pressure, the energy demand of the condensation method was at its lowest, and it remained nearly constant. The courses of the energy demand for the adsorption and absorption methods were almost similar. With increasing pressure of the dehydrated natural gas, the energy demand slowly decreased. The difference between these two methods is the amount of energy demand at lower pressure.

To summarize, condensation has the highest demand of energy at low pressure of natural gas due to the pressure being close to the distribution pressure, so that pressure cannot be used for the HT effect in flashes. Cooling is then being compensated by the air-pre cooler and the external cooling device which are not suitable for large volume of natural gas [6]. However, as the pressure between underground gas storage and distribution site increase, the space for expansion increase resulting the JT effect to proceed with an increasing impact. In addition, more research need to be done to ensure the condensation method is the most optimum method on dehydration of natural gas.

2.1 THE JOULE-THOMSON EFFECT

The Joule-Thomson effect describes the increase or decrease in the temperature of a real gas or a liquid when it is allowed to expand freely through a valve or other throttling device in an insulated area. The device was kept insulated so that no mechanical work is extracted from the liquid [3]. This Joule-Thomson effect is an example of an isenthalpic process where the enthalpy of the fluid is kept constant.

This effect was named after James Prescott Joule and William Thomson during 1852. These effects sometimes referred as the Joule-Kelvin effect in engineering field. For this effect to occur there should be temperature change when gas is allowed through an insulated device but the behaviour of an ideal gas oppose the Joule-Thomson effect [3]. That is why the Joule-Thomson effect does not applicable for ideal gas situation.

When it comes to Joule-Thomson effect the term inversion temperature has a role in it [4]. As we know Joule-Thomson is an isenthalpic expansion process in which a gas does positive work in the process of expansion, although the temperature might increase or decrease, depending on its initial temperature and pressure. For a real gas case at any given temperature, the gas has a Joule-Thomson inversion temperature [4]. If the Joule-Thomson inversion temperature is above the J-T expansion curve then it will cause the temperature of the gas to rise but if the inversion temperature is below the J-T expansion curve then gas will experience cooling process [4]. At normal cases, which the gas is at atmospheric pressure, the inversion temperature is very high and almost all the gases at those temperature and pressure conditions are cooled by the J-T expansion.

For this project, Soave-Redlich-Kwong equation of state is being used as a basis because is the most widely used cubic equations of state in refineries and gas-processing industries for the prediction of vapour-liquid equilibria for systems containing nonpolar components. The estimation of pure component properties can be determined using the following equation based on the thermodynamic principle.

$$P = \frac{RT}{V - b} - \frac{a}{V(V + b)}$$

Where,

$$b = 0.08664 \, \frac{RT_c}{P_c}$$

$$a = 0.42748 \, \frac{(RT_c)^2}{P_c} [1 + m(1 - \sqrt{T_\gamma})]^2$$

$$T_\gamma = \frac{T}{T_c}$$

And

$$m = 0.480 + 1.574\omega - 0.176\omega^2$$

From this equation we can generate two types of graphs, Pressure against Volume and Pressure against Temperature.

The Joule-Thomson coefficient is the change of temperature with a decrease of pressure at constant enthalpy. In Joule-Thomson process the J-T coefficient is denoted as $\mu_{JT} = \left(\frac{\delta T}{\delta P}\right)_H$

The first law for a closed system on a unit mass basis is:

$$\delta q = du + pdv$$

If the process is reversible, from the second law,

$$\delta q = Tds$$

Hence,

$$du = Tds - pdv$$
$$dh = du + pdv + vdp$$
$$dh = Tds + vdp$$

Let us analyse the Joule-Thomson coefficient to gain insight why the coefficient changes sign:

$$s = f(T, p)$$

$$ds = \left(\frac{\partial s}{\partial T}\right)_p dT + \left(\frac{\partial s}{\partial p}\right)_T dp$$

For constant T, dT = 0

$$dh = \left(T \left(\frac{\partial s}{\partial p}\right)_T + v \right) dp$$

or,

$$\left(\frac{\partial h}{\partial p}\right)_T = T \left(\frac{\partial s}{\partial p}\right)_T + v$$

For h = f (T,p)

$$\left(\frac{\partial T}{\partial p}\right)_h \left(\frac{\partial p}{\partial h}\right)_T \left(\frac{\partial h}{\partial T}\right)_p = -1$$

Re-arranging,

$$\left(\frac{\partial T}{\partial p}\right)_h = -\frac{1}{(\frac{\partial h}{\partial t})_p} \left(\frac{\partial h}{\partial T}\right)_T = -1$$

And,

$$\left(\frac{\partial h}{\partial T}\right)_p = C_p$$

$$\mu = -\frac{1}{C_p} \left(\frac{\partial h}{\partial p}\right)_T$$

We can write,

$$h = f(T, p)$$

Differential of equation is,

$$dh = \left(\frac{\partial h}{\partial T}\right)_P dT + \left(\frac{\partial h}{\partial p}\right)_T dp$$

Re-arranging the equation,

$$Tds = dh - vdp$$

Combining the two equations above,

$$(\frac{\partial h}{\partial p})_T = T(\frac{\partial s}{\partial p})_T + v$$

Using Maxwell relation

$$(\frac{\partial h}{\partial p})_T = -T(\frac{\partial v}{\partial T})_p + v$$

Substituting into the previous equation,

$$\mu = -\frac{1}{C_p}[-T(\frac{\partial v}{\partial T})_p + v]$$

For a case of an ideal gas, pv = RT

$$(\frac{\partial v}{\partial T})_p = \frac{R}{p} = \frac{v}{T}$$

Substituting into Equation

$$\mu = 0$$

Zero value of μ is obtained in the ideal gas condition. This derived equation result shows that the Joule-Thomson effect is not applicable for ideal gas condition.

Substituting h = u + pv

$$\mu = +\frac{1}{C_p}[-\left(\frac{\partial u}{\partial p}\right)_T - \left(\frac{\partial (pv)}{\partial p}\right)_T]$$

$$\mu = +\frac{1}{C_p}[-\left(\frac{\partial (zRT)}{\partial p}\right)_T]$$

$$\mu = +\frac{1}{C_p}[-RT\left(\frac{\partial (z)}{\partial p}\right)_T]$$

For the case of real gas, the compressibility factor, z is not equal to one and functioned by the pressure. The first term in the brackets denotes the deviation from Joule's law, which states that the internal energy is a function only of temperature.

• On expansion, there is an increase in the molecular potential energy, and hence is negative. This results in a positive μ and a temperature decrease.

• The second term in the brackets indicates the derivation from Boyle's law (that v varies inversely with p) for a real gas. For most gases at low temperatures and pressures, is negative; however, it changes sign at higher temperatures and pressures.

In order to explain the formula of Joule-Thomson coefficient two scenarios were used as an example. Firstly if the gas temperature is below the inversion temperature, the J-T coefficient is positive, the difference pressure is always negative and the temperature difference is negative, thus the gas is undergoes cooling [13]. Secondly if the gas temperature is above the inversion temperature, J-T coefficient is negative, the difference in pressure is always negative and the temperature difference is positive then the gas is heating up [13].

2.2 LOW TEMPERATURE SEPARATION USING CONDENSATION
2.2.1 JOULE-THOMSON EXPANSION VALVE

Cooling of natural gas can also be achieved by expanding high pressure gas to a low pressure across an expansion valve [9]. Joule Thomson is a constant enthalpy process and the amount of temperature reduction is depends on the difference in pressure which is the inlet and outlet pressure as well as the gas composition.

Figure 3 shows that Joule –Thomson expansion process. The main process equipment is the expansion valve or chokes. The high-pressure gas enters through an inlet separator, which removes the condensed water and any liquid hydrocarbons. The gas streams out of the separator, then flows through a heat exchanger, exchanging heat with the cooled, low-pressure gas [9]. Some water and perhaps some hydrocarbon will condense in the heat exchanger from the high-pressure gas stream. The high-pressure gas then flows through the expansion valve, which drops the pressure of the gas to the design pressure. Simultaneously, a reduction in temperature occurs. Depending on the gas composition and the pressure and temperature of the gas mixture, a certain amount of the mixture will condense and form a liquid hydrocarbon stream. Water will also condense to the equilibrium water content of the gas at the final pressure and temperature [9].
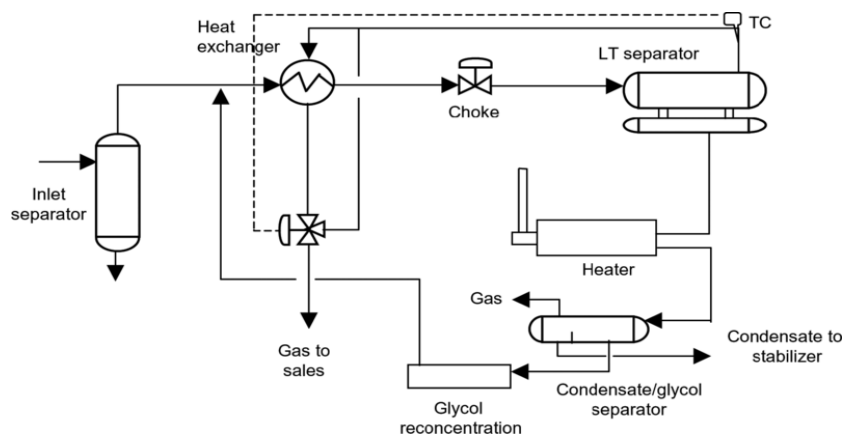
Figure 3: Joule-Thomson expansion process [9]

It stated that a gas will expands through restriction from high pressure to low pressure causing the gas to change its temperature [3]. This process occurs under conditions of constant enthalpy and it known as Joule-Thomson expansion. This process is an adiabatic process because the pressure change is too fast for the

significant heat transfer to take place. The Joule-Thomson coefficient is proportional with the increase in temperature drop and pressure drop [3]. For every gas there exists an inversion point that depends on the temperature and pressure, below which is cooled and above it is heated.

The Joule-Thomson inversion curve passes through a maximum in pressure at intermediate temperature and goes to zero at the end of the maximum inversion temperature. There is a single intersection point at zero pressure for the joule-Thomson inversion curve [3]. This feature has been reported in the literature at least by; this seems not clarified since many papers the Joule-Thomson inversion curve appears to have two inversion temperatures at zero pressure.

As an example, Figure 4 plots the joule- Thomson inversion curve (using the PR EoS) and the vapour pressure curve for methane. Inside the spinodal the cubic EoS has three real roots. Between the upper spinodal branch (limit of sub cooled vapour) and the vapour pressure curve (at $T_r \approx 0.76$ and $p_r \approx 0.17$ for methane, calculated with the PR EoS, b) the "liquid" root is the stable one and it is correctly used to calculate the JT coefficient [3]. Below the vapour pressure curve, the stable root is the vapour one. Using this root, no inversion point is found for the entire vapour region, where the JT coefficient is always positive. There is a threshold in the JT coefficient from negative to positive values when the vapour pressure curve is crossed, and there is no physical zero-pressure intersection at low temperatures; the JTIC ends at the vapour pressure curve.
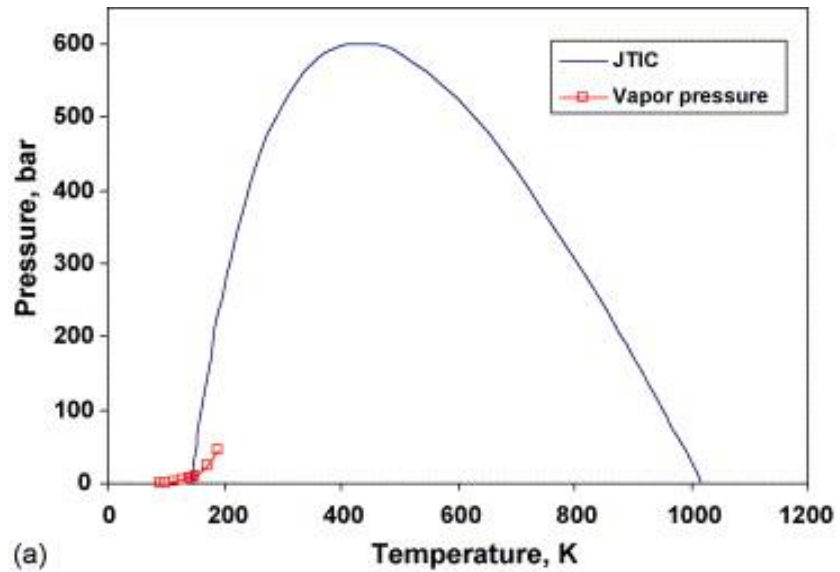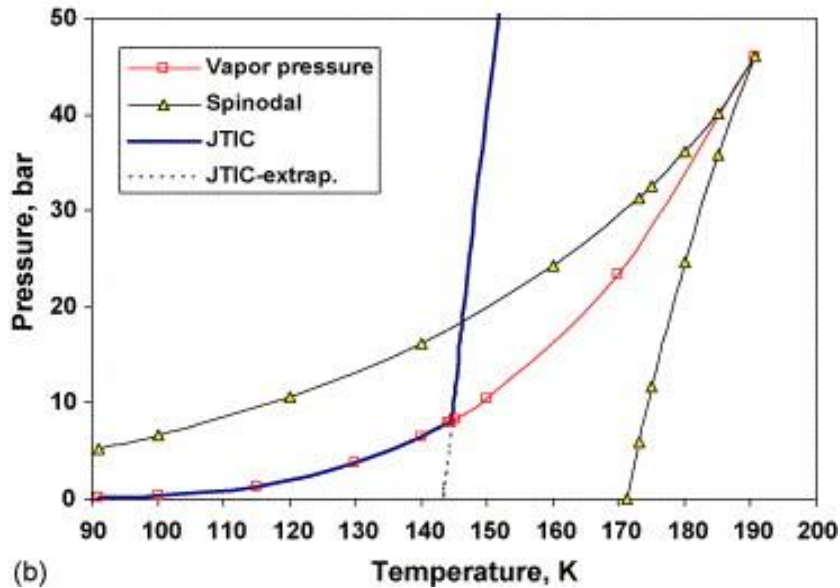
Figure 4: a) Joule-Thomson inversion curve for methane PR EoS b) Joule-Thomson inversion curve for methane-detail, PR EoS [9]

During an isenthalpic expansion if the difference in pressure is lower than zero than the gas is cooling but if the difference of pressure is above zero then the gas is heated instead [12]. Joule-Thomson effect is important because it can link directly to the nature of intermolecular forces between gas molecules [12]. Beyond the ideal gas level, molecules in a gas are subjected to attract and repulse intermolecular interactions. Thus, a real gas will show both positive and negative Joule-Thomson effect depending on the thermodynamic conditions.

2.2.2 EXPANDER

The turbine expansion low temperature dehydration system differs from choke expansion is that turbine turns a shaft from work which is extracted. A typical expander process is shown below:
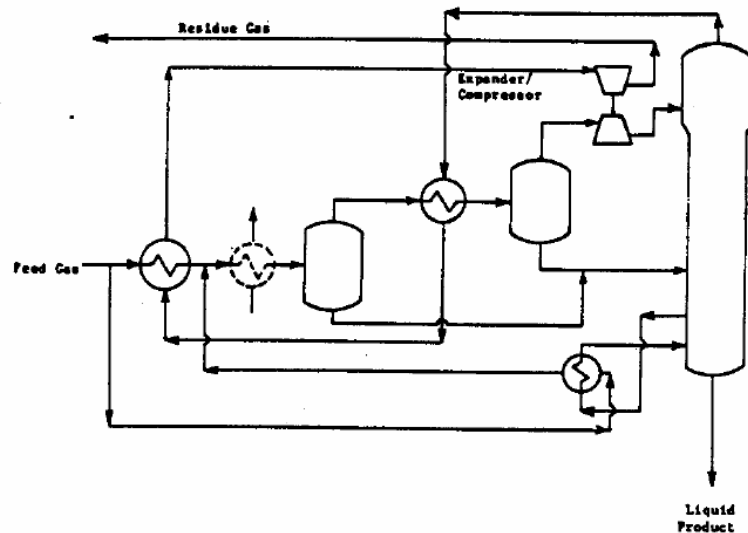
Figure 5: Typical Expander Process

The gas enters through an inlet separator with any liquid separated at this point being introduced to a low point in the stabilizer tower. The gas then goes through heat exchanger with the cold gas leaving the stabilizer. Another separator is installed if sufficient liquid is formed in the gas-gas heat exchanger with the liquid being introduced at an immediate point in the stabilizer, the cold gas then flows to the expander where the pressure is reduced and low temperature is achieved. The gas and liquid mixture leaves the expander and flows to the separator that normally is on the top of the stabilizer column. Sales gas flows back through the exchangers and may be compressed in the direct connected centrifugal compressor before being put into the sales gas line. Since extremely low temperature are achieved in a typical turbo expander plant, dehydration is normally the first step through some plants do use chemical injection. The gas frequently is expanded below sales gas pressure and the recompressed to make use of the work that must be extracted from the shaft of the turbine.

A fairly recent development in gas processing, the turbo expander is one of the possible ways in gas processing. The favourable operating characteristic allows the plant to run unattended through long periods and its durability to withstand very high and low pressure makes it one of the better choices for water removal.

2.3 RESEARCH GAP

- Limited research has been done in this are to overcome the problem of removing water from natural gas
- The suitable conditions for the Joule-Thomson effect to occur was not being studied before
- The feasibility of using Joule-Thomson effect as a method on removing water compared to other types of separation process

CHAPTER 3: RESEARCH METHODOLOGY

The data being obtain for the studies is being carried out using experiment feasibility by using Joule-Thomson expansion valve and process simulation using Aspen HYSYS.

3.1 EXPERIMENT FEASIBILITY

3.1.1 MATERIALS

Methane and carbon dioxide gas will be used for the removal of water by using separation process and expansion valve. The purity of the carbon dioxide/methane gas is unknown as it contains other components such as water. The experiment of water removal in carbon dioxide/methane gas is conducted using apparatus at the pilot plant RCCO2C.

3.1.2 SAMPLE PREPARATION

Carbon dioxide and methane gas was used for the experiment. The gases are obtained at the RCCO2C lab. The apparatus is set up at the lab using a simple separation process.

3.1.3 EQUIPMENT/ APPARATUS

These are the equipment being used for the project:

1)   Micro Inline Separation Contactor
2)   Pressure Relief Valve
3)   Ball Valve
4)   Pressure Transmitter
5)   Pressure Indicator
6)   Pressure Transmitter
7)   Pipes, tubes

3.1.4 PROCEDURE
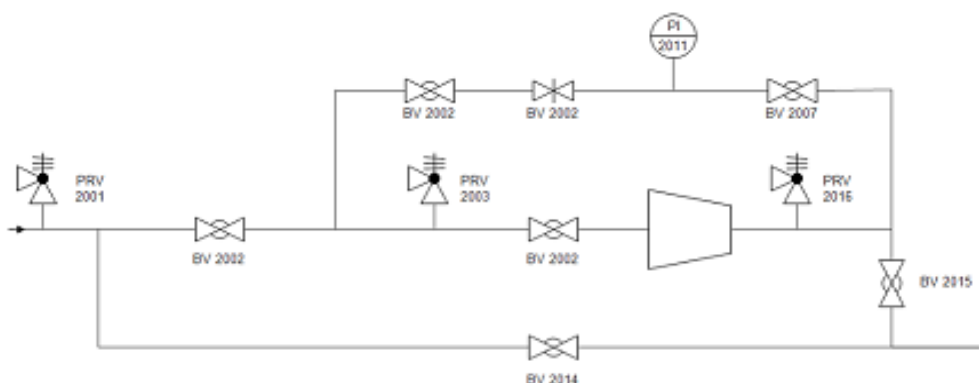
Figure 6: Compression Section

1. Start the system (set the diagnostic pressure maximum point to 160 bar, flow rate at 2000 ml/min)
2. Open valve P11001B
3. Closed valve BV4015
4. Control the pressure needed using the knob on PRV 4012
5. Closed valve MV4014 before setting the pressure
6. Open valve BV1005B, set 25 sl/min for mass flow controller for carbon dioxide
7. Closed PRV 2003 and let the pressure increase to 2.5 bar
8. Closed PRV4012 to let the pressure builds up inside the pipe
9. Start the compressor
10. Open PRV 2003, ensure the pressure is 0 bar
11. Set the pressure until 20 bar (1st run) using PRV4013
12. Run the experiment until steady-state temperature (the steady state temperature will be compared with the temperature obtain from modelling)
13. Observe the formation of water droplets on the pipe due to condensation (Joule-Thomson effect)
14. Repeat the experiment using 30 bar, 40 bar, 50 bar, 60 bar and 70 bar.
15. All data will be recorded for plotting the graph

The pressure is built up until 50 psi then we will control the outlet by using a valve. Gradually increase the percent opening of the valve so that we can determine how fast the water vapour in the gas condensed to form water droplets. This method is being supported by using a pressure transmitter, pressure regulator and a choke valve with manual throttling. Although the removal of water in methane gas is near impossible at low pressure which is the allowable pressure that can withstand by the equipment, we can still run some few test to obtain the data for the plotting of calibration curve.

3.1.5 DATA GATHERING/ANALYSE

Based on the data being obtained from the experiment, a graph will be done to find out the normal behaviour of the condensation process using carbon dioxide gas. The data that is being obtain from the experiment are being compared with the theoretical data obtain from the MATLAB simulation modelling using SRK model for our basis and from HYSYS simulation. A comparison will be made to produce a graph which actually represents an ideal case and a real case situation. The graph will be used for further analysis as reference for different set of gas which has different concentration of carbon dioxide at different type of pressure. This data can be used to determine the percentages of water recovery for every pressure at same temperature.

3.2 PROCESS SIMULATION (ASPEN HYSYS)
3.2.1 THE JOULE-THOMSON METHOD

33 kg/h of gas and 33 kg/h of water were mixed together in a mixer in order to make the gas saturated. Then saturated gas was allowed to pass through the Joule-Thomson valve. The pressure used for the simulation varies from 10 bar to 70 bar which is the maximum pump pressure that can be provided. As the temperature is kept constant throughout the experiment which is at 30℃ consequently the gas became cold due to Joule-Thomson effect. A separator was installed immediately after the downstream of the valve. Water was removed from the gas at the separator. The top product form the separator is the dry gas ready to be delivering into the pipeline.

HYSYS analysed the entire process at varied conditions of inlet temperatures and pressure to get the desired outputs such as outlet temperature, molar enthalpy, and molar entropy. All the inputs and outputs were given in the following tables and figures were plotted using those data.

3.2.2   EXPANDER METHOD

In this section, the saturated gas is passed through an expander, which allowed the pressure drop down to optimum pressure. The temperature drop achieved was more than that in Joule-Thomson method. Similar to the Joule-Thomson method, HYSYS was used to analyse the entire process at varied conditions of inlet temperature and pressure to get the desired outputs such as outlet temperature, molar enthalpy, and molar entropy and apart from Joule-Thomson method certain amount of energy was recovered. This energy recovery was calculated in terms of heat. All the inputs and outputs are given in following tables and some figures were plotted by using those data.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 EXPERIMENTATION

Based on the experiment conducted at the lab, the Joule-Thomson effects were being observed with several test results. The experiment was done by using pure carbon dioxide gas (100% CO_2) with almost zero impurities. The experiment was being handled at the test rig which is a part of the Micro Inline Separator Contactor. The temperature required for the system to achieve a steady state condition was being recorded for 30 minutes at 5 minutes interval. The experiment was carried out with a set of pressure range between 20 bar to 50 bar. The experiment was run at the initial pressure as being mention before until it reaches 1 bar with duration of 30 minutes. The flow rate was kept constant throughout the experiment for all the pressure which is 33.012 kg/hour (30 standard liquid per minute). The results are the temperature at different pressure for the Joule-Thomson effect to occur.
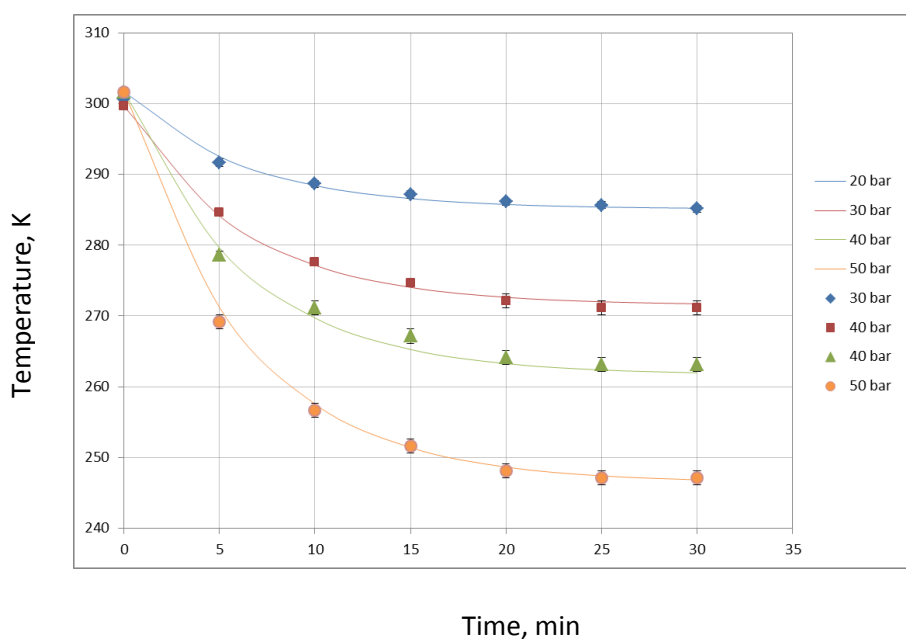

Figure 7: Temperature (K) at the outlet valve to become steady-state against the time (min) for pure carbon dioxide gas

The data obtain from the experiment is then being compared with the data obtain from the simulation using the same parameters and operating conditions.

Method	Final Temperature °C			
	20 bar	30 bar	40 bar	50 bar
Simulation	7.3	-9.54	-22.7	-42.2
Experimentation	12	-2	-10	-26

Table 1: Final temperature for the system to reaches 1 bar with different initial pressure

The data being recorded from the experiment is by using pure carbon dioxide gas as the material for the study of Joule-Thomson effect. The temperature obtain from the simulation is much lower compared to experimentation results. This is due to certain limitations that can be done during the experimentation. The result shows that the Joule-Thomson effect occurs during the temperature during the system at its steady-state. As the temperature becomes constant during the experiment, the gas will expand causing its temperature to reduce. The Joule-Thomson effects are related to the pressure drop across the valve. The higher the pressure drop the across the valve the higher the amount of water droplets that will be formed.

Based on the experiment analysis of using pure carbon dioxide gas to test the Joule-Thomson effect in the duration of 30 minutes, the temperature recorded was higher compared to the results obtain from the simulation by using HYSYS. The reason is because there are heat loss to the surrounding during the experiment was conduct while for the simulation a basis of no heat loss to the surrounding was used. These temperatures are the actual temperature recorded in an interval of 5 minutes using a set of pressure from 20 bar to 50 bar. The allowable operating pressure for the experiment set up were 10 bar up to 50 bar. The experiment was run until it reaches 1 bar as its final pressure.

The Joule-Thomson effect can occur at lower temperature due to the free expansion of the gas causing the water vapour inside the gas to condense. At an operating higher pressure will results in lower temperature for the Joule-Thomson effect to occur. As the gas expand at a high speed inside the Joule-Thomson valve, the water start to changes its physical properties due to high driving force. This situation

is similar to our well condition during extraction of pure natural gas. The well has a high pressure build up which contains many components such as carbon dioxide, sulphur and water. In order to fully utilize the condition of the gas which comes out from the well, the Joule-Thomson effect was studied using Joule-Thomson expansion valve to ensure its reliability on removing water. According to the results obtain from the experiment, its shows that the Joule-Thomson effect can occur at higher pressure.

4.2 PROCESS SIMULATION (ASPEN HYSYS)

The numerical studies was conducted using the process simulation (Aspen HYSYS) and these are the data that is being obtained from the Joule-Thomson valve method and Expander method. There are two types of composition being used throughout the process simulation which are 80% methane 20% carbon dioxide and 50% methane 50% carbon dioxide.
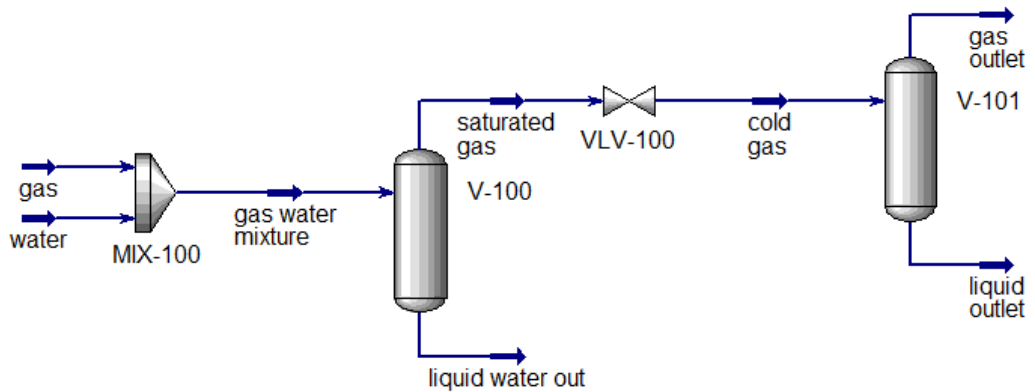

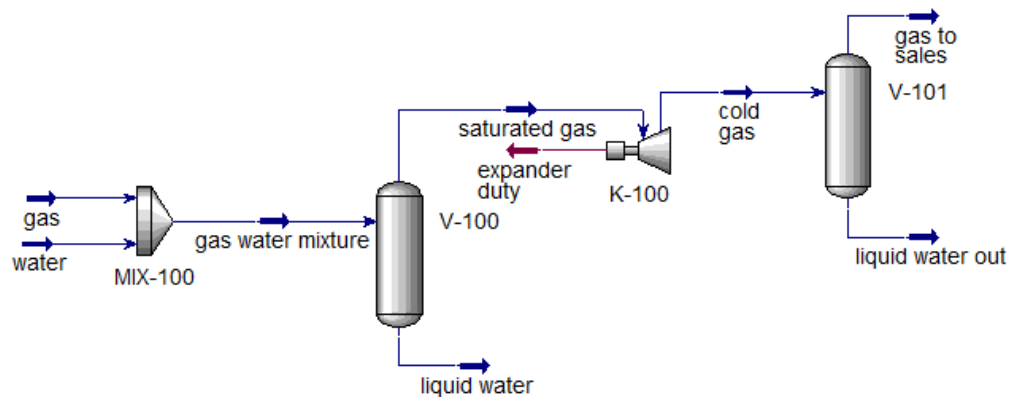*Figure 8: Process flow diagram of Joule-Thomson Method*

Figure 9: Process flow diagram of an Expander method

24

Assumption

1) SRK model was used for the simulation
2) No heat loss to the surrounding

Variables:

Pressure 10 bar -70 bar

Composition 1: 80% Carbon dioxide 20% methane

Composition 2: 50% Carbon dioxide 50% methane

Separator pressure: The most suitable pressure to reach optimum point

4.2.1 JOULE-THOMSON VALVE METHOD FOR 80% METHANE 20% CARBON DIOXIDE

Temperature °C	Initial Pressure Bar	Pressure Drop Bar	Water composition at outlet gas for separator 1 (x1)	Water composition at outlet gas for separator 2 (x2)	Water Recovery (x1-x2)/x1 *100%
30	10	5	0.0043	0.0042	2.33
30	20	10	0.0025	0.0024	4.00
30	30	20	0.0019	0.0018	5.26
30	40	25	0.0016	0.0015	6.25
30	50	30	0.0014	0.0011	21.43
30	60	35	0.0013	0.0009	30.77
30	70	40	0.0013	0.0007	46.15

Table 2: Composition 80% Methane, 20% Carbon dioxide

Initial Temp. °C	Inlet into the valve				Outlet into the valve			
	Inlet Pressure Bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^5)	Molar Entropy KJ/Kgmole °C	Pressure Drop bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^5)	Molar Entropy KJ/Kgmole °C
30	10	28.45	-1.021	166.1	5	25.99	-1.021	171.8
30	20	29.17	-1.019	159.9	10	24.33	-1.019	165.5
30	30	29.43	-1.019	156.1	20	19.71	-1.091	164.9
30	40	29.57	-1.020	153.3	25	17.54	-1.020	161.0
30	50	29.64	-1.021	150.9	30	15.71	-1.021	158.1
30	60	29.69	-1.022	149.0	35	13.80	-1.022	155.6
30	70	29.72	-1.023	147.2	40	11.93	-1.023	153.6

Table 3: Thermodynamic properties for the Joule-Thomson Valve Method

4.2.2 EXPANDER METHOD FOR 80% METHANE 20% CARBON DIOXIDE

Temperature °C	Initial Pressure Bar	Pressure Drop Bar	Water composition at outlet gas for separator 1 (x1)	Water composition at outlet gas for separator 2 (x2)	Water Recovery (x1-x2)/x1 *100%	Polytrophic Efficiency
30	10	5	0.0044	0.00405	7.89	73.537
30	20	10	0.0025	0.00218	12.42	73.471
30	30	20	0.0019	0.00155	18.09	73.210
30	40	25	0.0018	0.00139	22.34	73.110
30	50	30	0.0016	0.00092	42.34	72.980
30	60	35	0.0015	0.00072	51.54	72.876
30	70	40	0.0014	0.00046	66.78	72.774

Table 4: Composition 80% Methane, 20% Carbon dioxide

Initial Temp. °C	Inlet into the expander				Outlet from the expander			
	Inlet Pressure Bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^5)	Molar Entropy KJ/Kgmole °C	Pressure Drop Bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^4)	Molar Entropy KJ/Kgmole °C
30	10	28.64	-1.389	166.6	5	-1.459	-1.401	168.5
30	20	29.33	-1.387	160.3	10	-4.063	-1.398	161.8
30	30	29.59	-1.386	156.4	20	-24.75	-1.403	158.8
30	40	29.72	-1.386	153.5	25	-21.43	-1.401	155.6
30	50	29.80	-1.387	151.1	30	-20.07	-1.401	153.0
30	60	29.84	-1.388	149.1	35	-19.54	-1.401	150.8
30	70	29.86	-1.390	147.2	40	-19.38	-1.402	148.9

Table 5: Thermodynamic properties for the Expander Method

Figure 10: Pressure inlet against water composition at seperator 1 using Joule-Thomson Method for 80% methane 20% carbon dioxide composition
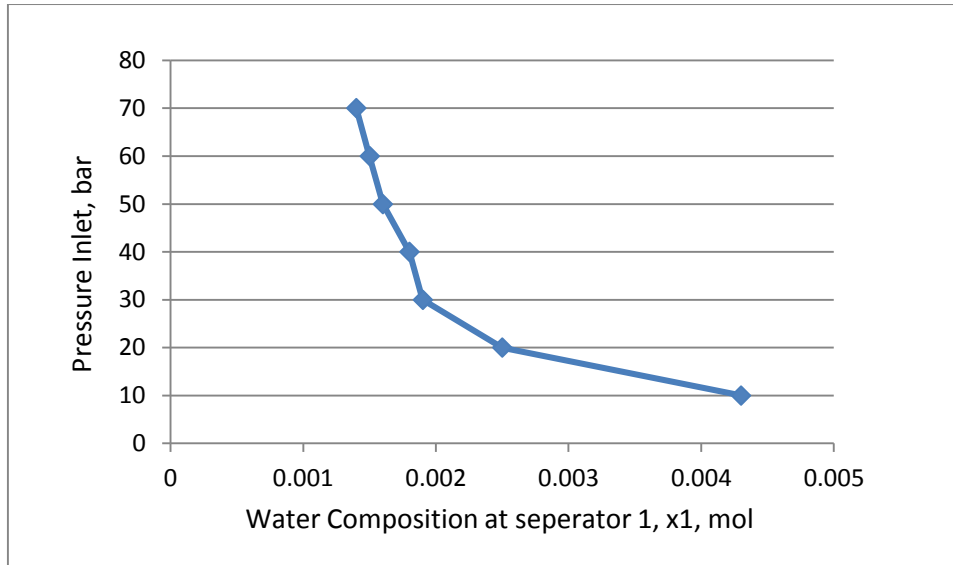

Figure 11: Pressure inlet against water composition at seperator 2 using Joule-Thomson Method for 80% methane 20% carbon dioxide composition

Figure 12: Pressure Inlet against water recovery using Joule-Thomson Method for 80% methane 20% carbon dioxide gas composition

Figure 13: Pressure drop against water Recovery using Joule-Thomson Method for 80% methane 20% carbon dioxide

Figure 14: Pressure inlet against water composition at separator 1 using Expander Method for 80% methane 20% carbon dioxide gas composition
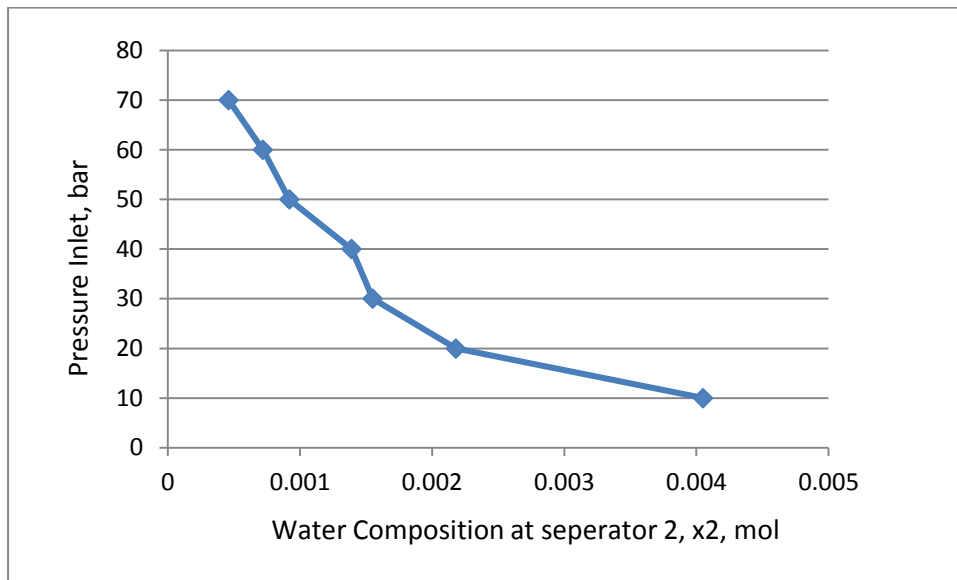

Figure 15: Pressure inlet against water composition at separator 2 using Expander Method for 80% methane 20% carbon dioxide gas composition
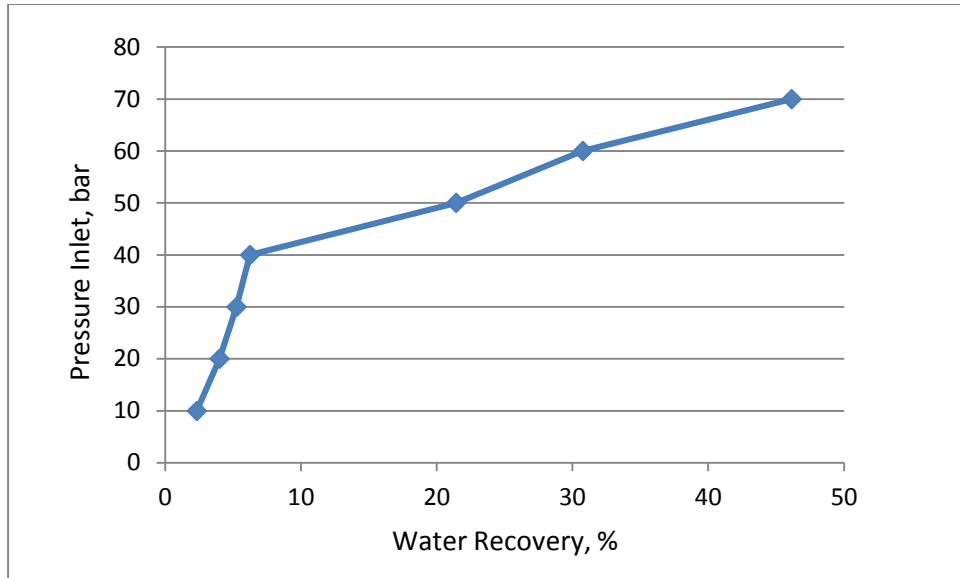
Figure 16: Pressure inlet against water recovery using Expander Method for 80% methane 20% carbon dioxide gas composition
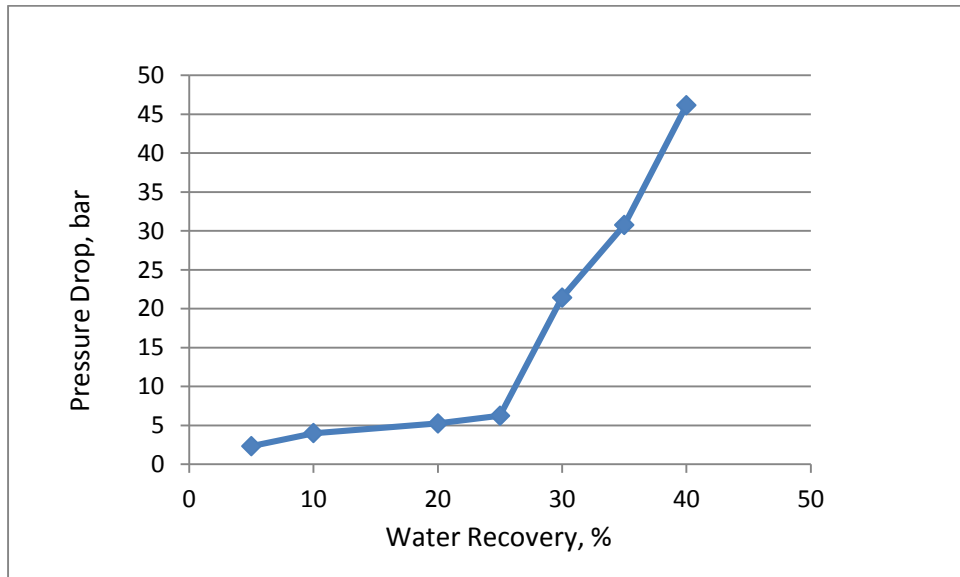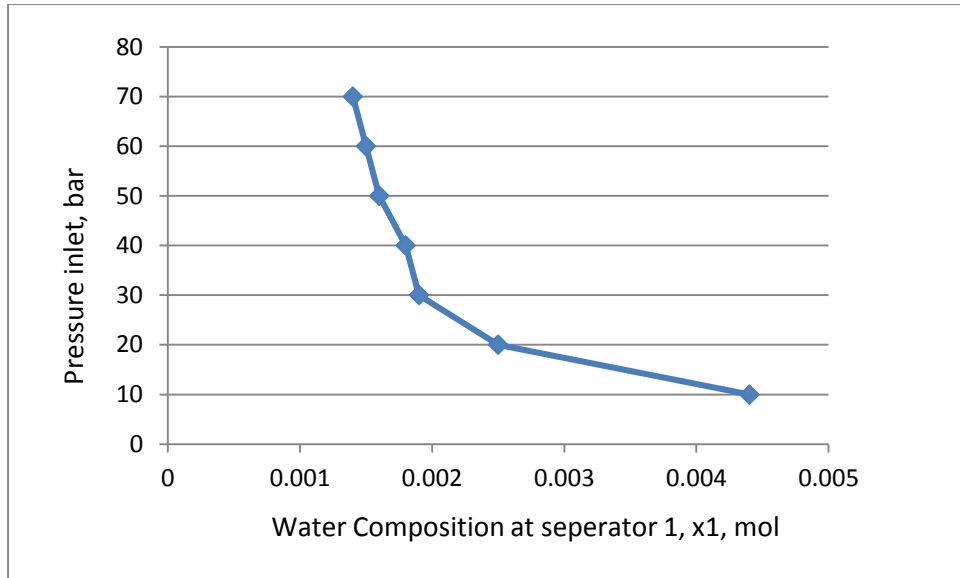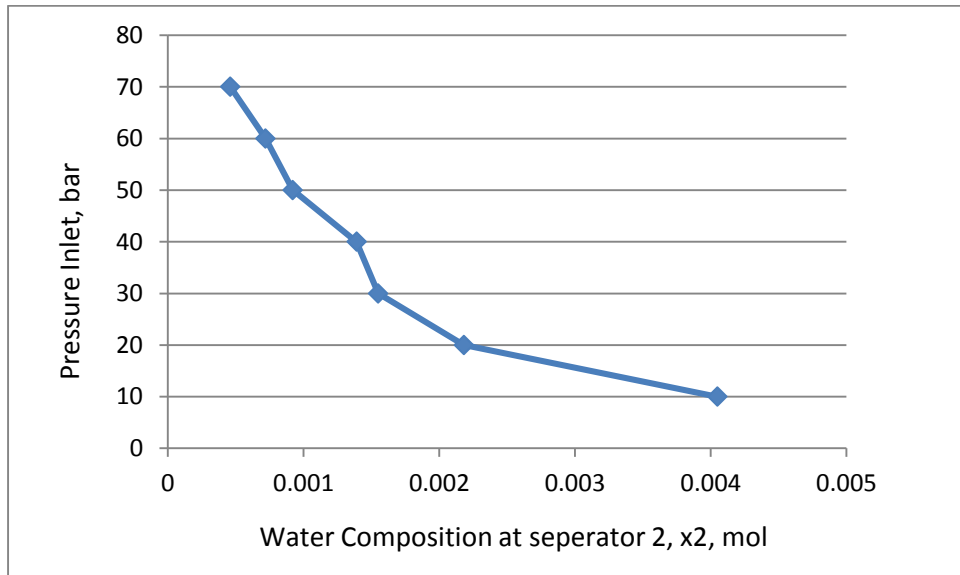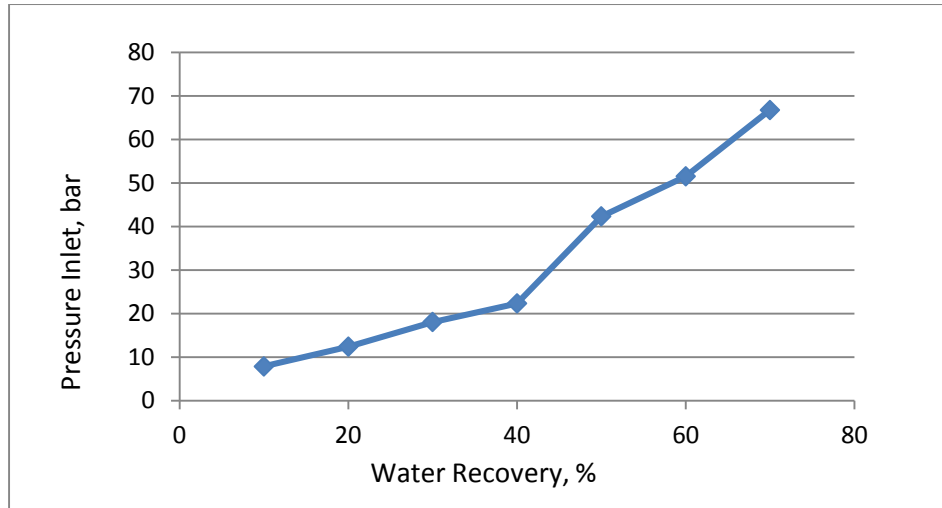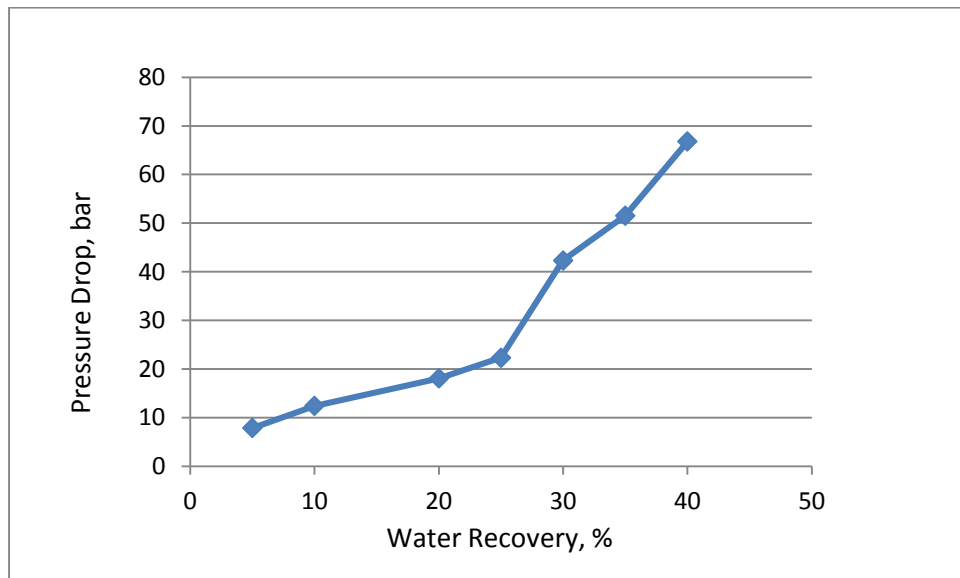

Figure 17: Pressure drop against water recovery using Expander Method for 80% methane 20% carbon dioxide gas composition

4.2.3 JOULE-THOMSON VALVE METHOD FOR 50% METHANE 50% CARBON DIOXIDE

Temperature °C	Initial Pressure Bar	Pressure Drop Bar	Water composition at outlet gas for separator 1 (x1)	Water composition at outlet gas for separator 2 (x2)	Water Recovery (x1-x2)/x1 *100%
30	10	5	0.0044	0.0043	2.27
30	20	10	0.0026	0.0025	3.47
30	30	20	0.0020	0.0019	5.00
30	40	25	0.0017	0.0014	17.65
30	50	30	0.0015	0.0010	33.33
30	60	35	0.0014	0.0007	50.00
30	70	40	0.0014	0.0005	64.29

Table 6: Composition 50% Methane, 50% Carbon dioxide

Initial Temp. °C	Inlet into the valve				Outlet into the valve			
	Inlet Pressure Bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^4)	Molar Entropy KJ/Kgmole °C	Pressure Drop Bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^4)	Molar Entropy KJ/Kgmole °C
30	10	28.75	-1.602	166.5	5	25.81	-1.602	172.1
30	20	28.93	-1.601	158.2	10	23.28	-1.601	167.8
30	30	29.68	-1.598	156.3	20	17.87	-1.598	165.0
30	40	29.82	-1.598	153.3	25	15.39	-1.598	160.9
30	50	29.89	-1.598	150.9	30	12.92	-1.598	157.8
30	60	29.93	-1.599	148.8	35	10.37	-1.599	155.3
30	70	29.94	-1.601	146.9	40	7.856	-1.601	153.0

Table 7: Thermodynamic properties for the Joule-Thomson Valve Method

4.2.4 EXPANDER METHOD FOR 50% METHANE 50% CARBON DIOXIDE

Temperature °C	Inlet Pressure Bar	Pressure Drop Bar	Water composition at outlet gas for separator 1 (x1)	Water composition at outlet gas for separator 2 (x2)	Water Recovery (x1-x2)/x1 *100%	Polytrophic Efficiency
30	10	5	0.0044	0.004199	4.56	69.541
30	20	10	0.0025	0.002331	6.75	70.330
30	30	20	0.0019	0.001737	8.54	70.638
30	40	25	0.0017	0.001337	21.34	70.246
30	50	30	0.0016	0.000945	40.89	70.488
30	60	35	0.0015	0.000616	58.90	70.616
30	70	40	0.0015	0.000414	72.37	70.770

Table 8: Composition 50% Carbon dioxide, 50% Methane

Initial Temp. °C	Inlet into the expander				Outlet from the expander			
	Inlet Pressure Bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^4)	Molar Entropy KJ/Kgmole °C	Pressure Drop Bar	Temp. °C	Molar Enthalpy Kcal/Kgmol (10^4)	Molar Entropy KJ/Kgmole °C
30	10	28.66	-1.602	166.5	5	-1.410	-1.613	167.9
30	20	29.37	-1.599	160.2	10	-4.082	-1.611	161.6
30	30	29.64	-1.599	156.3	20	-24.64	-1.616	158.6
30	40	29.78	-1.599	153.3	25	-21.70	-1.614	155.4
30	50	29.85	-1.600	150.9	30	-20.46	-1.613	152.7
30	60	29.90	-1.601	148.8	35	-20.03	-1.613	150.5
30	70	29.91	-1.602	146.9	40	-19,96	-1.614	148.5

Table 9: Thermodynamic properties for the Expander Method

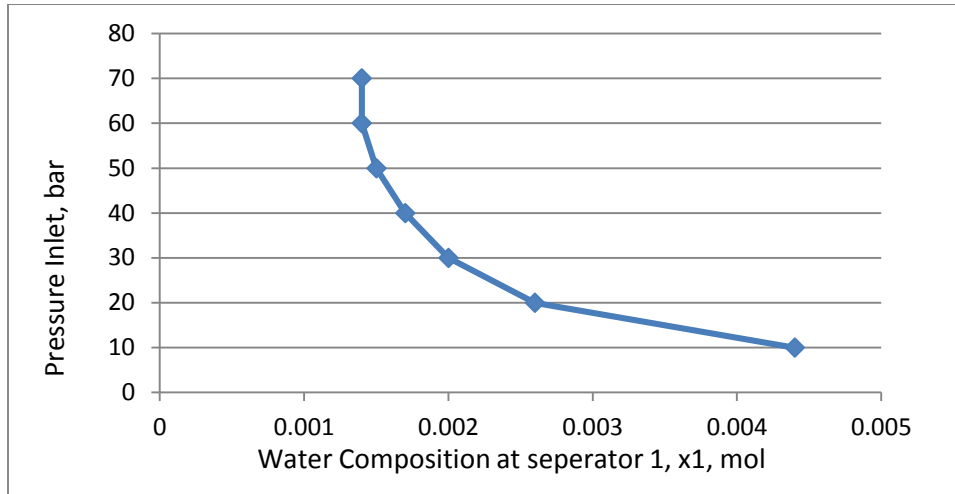Figure 18: Pressure inlet against water composition at seperator 1 for Joule-Thomson Method for 50% methane 50% carbon dioxide composition
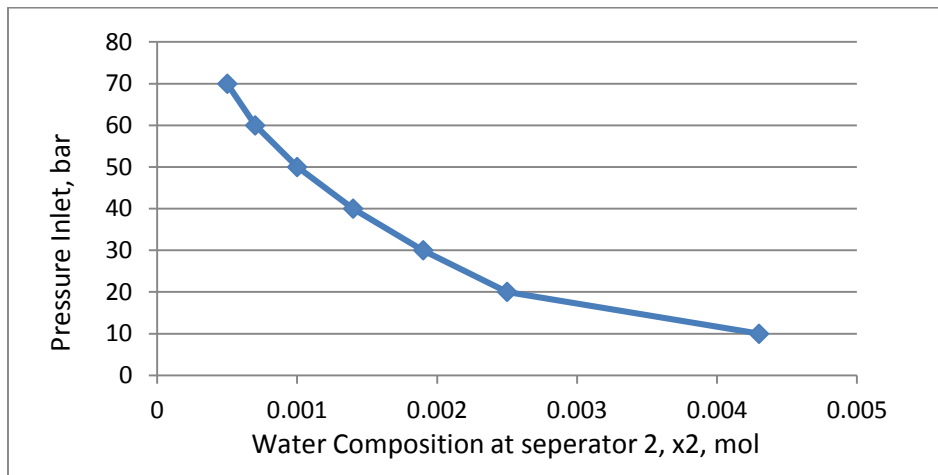

Figure 19: Pressure inlets against water composition at seperator 2 using Joule-Thomson Method for 50% methane 50% carbon dioxide composition

Figure 20: Pressure Inlet against water recovery using Joule-Thomson Method for 50% methane 50% carbon dioxide gas composition

Figure 21: Pressure Drop against water Recovery using Joule-Thomson Method for 50% methane 50% carbon dioxide gas composition
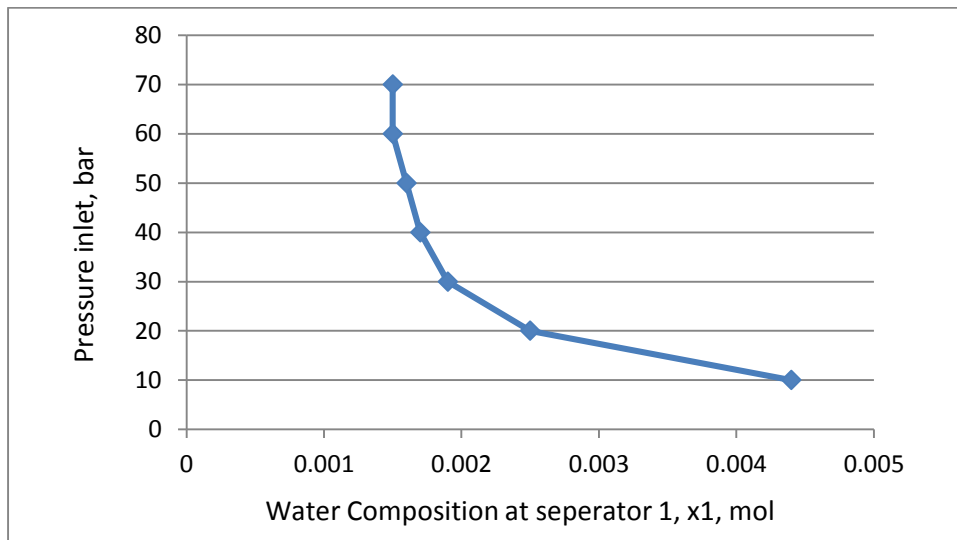
Figure 22: Pressure inlet against water composition at seperator 1 using Expander Method for 50% methane 50% carbon dioxide gas composition
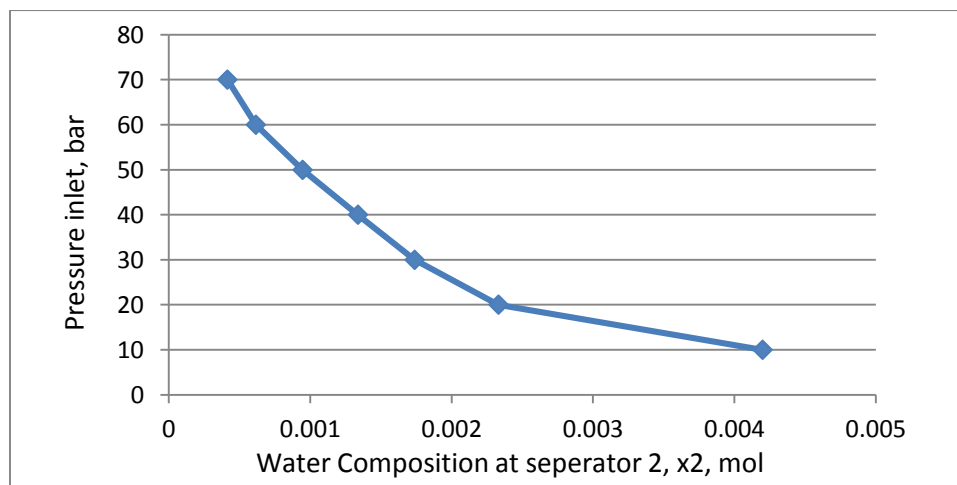
Figure 23: Pressure inlet against water composition at seperator 2 using Expander Method for 50 % carbon dioxide gas composition
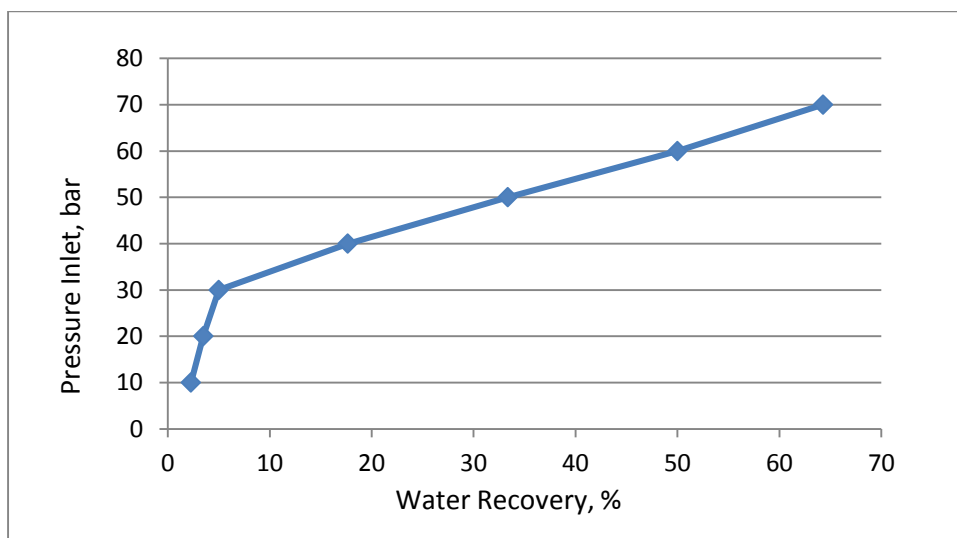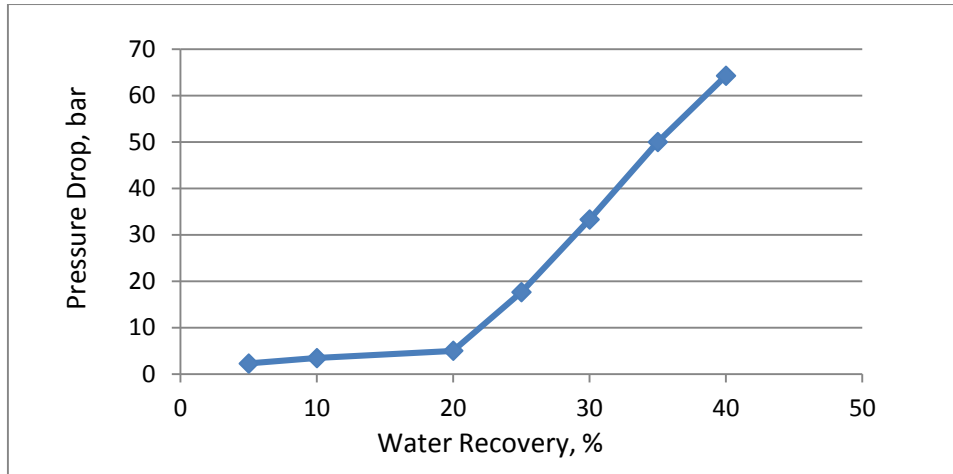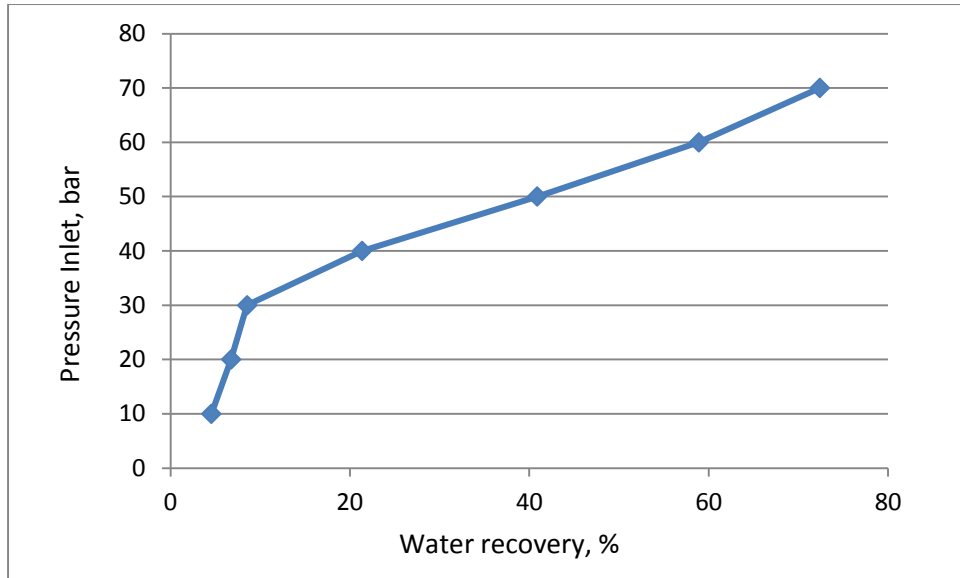
Figure 24: Pressure inlet against water recovery using Expander Method for 50% methane 50% carbon dioxide gas composition
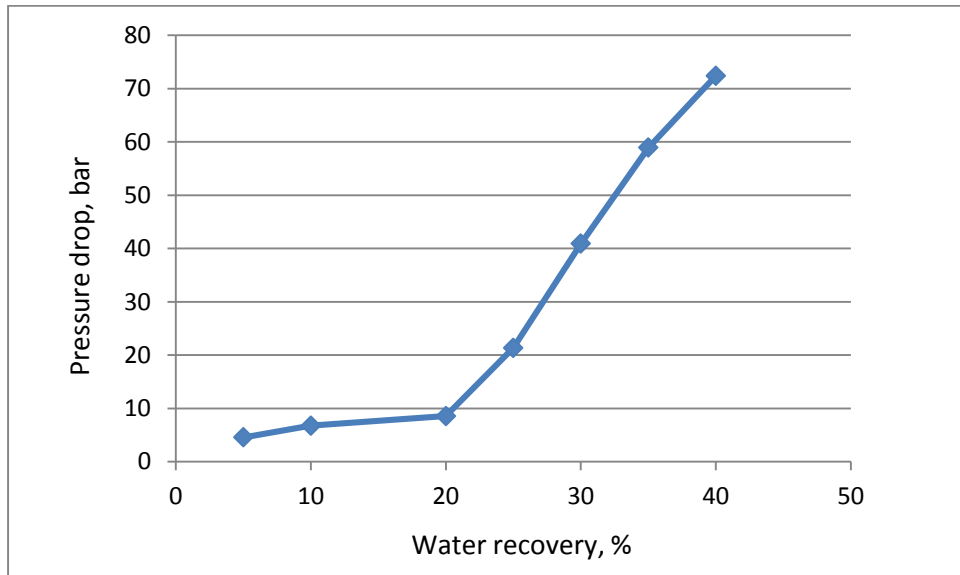
Figure 25: Pressure drop against water recovery using Expander Method for 50% methane 50% carbon dioxide gas composition

Joule-Thomson and Expander methods were analysed to compare their dehydration performance, operating efficiency and thermodynamic properties. These could finally give a conclusion on selecting a proper method for gas dehydration system using condensation process. The discussion was made based on the two results which are from 80% methane 20% carbon dioxide and 50% methane 50% carbon dioxide composition.
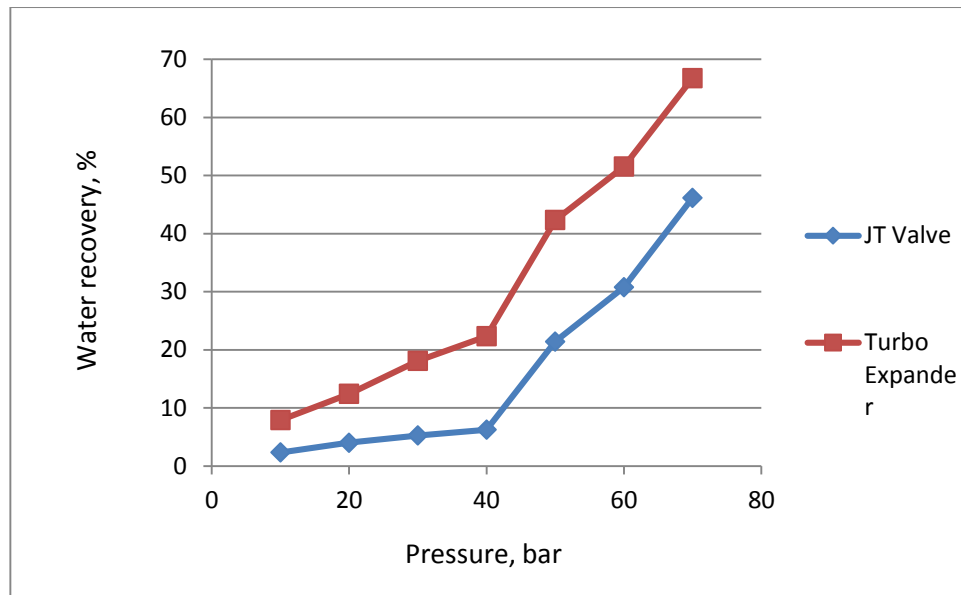
Figure 26: Comparison between Joule-Thomson expansion valve and turbo expander in removing water using mixture gas (80% Methane 20% Carbon dioxide)
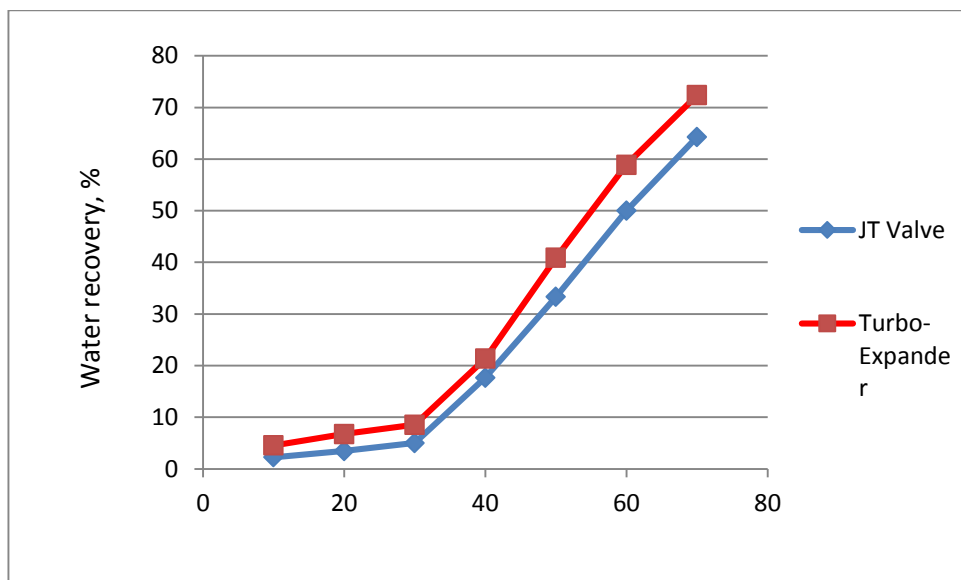
Figure 27: Comparison between Joule-Thomson expansion valve and turbo expander in removing water using mixture gas (50% Methane 50% Carbon dioxide)

Based on the graph of the for 80% methane 20% carbon dioxide and 50% methane and 50% carbon dioxide, the turbo expander has a higher water recovery compared to the Joule-Thomson expansion valve. However, the difference for water recovery is small for Joule-Thomson valve in both cases. For the first experiment, which uses 80% methane and 20% carbon dioxide the maximum amount of water recovered for both equipment at pressure drop of 40 bar are 46.15 % for JT valve and 66.78 % for turbo expander. For the second experiment, which uses 50% methane and

50% carbon dioxide the maximum amount of water recovered for both equipment at pressure drop of 40 bar are 64.27 % for JT valve and 72.37 % for turbo expander.

According to the data that is being obtained, for both equipment as the pressure drop increases the percentage of water recovery also increases. In order to have a higher amount of water recovery, we need to use energy thus leading to increment in cost. However, the Joule-Thomson expansion valve does not required any input of energy because it is based on free expansion. The gas will expand freely inside the valve causing the gas to be cooled down thus condensation is favoured. Without adding more cost to the operation, we can easily remove the water from the gas by using its natural state form. From the data itself, it shows that the difference of water recovery for JT valve and turbo expander is small and practical. In addition, the JT valve is easily to be operated compared to the turbo expander.

4.2.5 JOULE-THOMSON METHOD

All the calculations were based upon the same flow rate of 33 kg/h of gas and water initially. At first the whole process was analysed with range of initial pressure of 10 bar to 70 bar. The pressure drop for each case was recorded. Initial temperatures were set to be 30 ℃ for every case. In each case, outlet properties such as temperature, enthalpy, entropy, gas composition and water recovery is being observed.

Advantages of Joule-Thomson Method

This method is very simple and operation is very easy. It can operate efficiently. The Joule-Thomson is an entropic expansion. It can removes water at a faster rate compared using an expander. The time taken for the condensation to occur for Joule-Thomson Method is shorter compared to using an expander because it is easier for the gas to expand in Joule-Thomson valve rather than the expander.

Limitations of Joule-Thomson Method

The major limitation is that it cannot cool the gas as low as Turbo expander can do. Since it operates isentropic, it does not produce any energy. It is not a good choice when high level of dehydration is required. Controlling of the valve opening may be a problem; here the opening was fixed at 50%. A significant amount of energy may be required for the plant operation. In addition, the amount of water recovery for the Joule-Thomson method is lower for certain pressure compared using an expander.

4.2.6 EXPANDER METHOD

Similar to Joule-Thomson method, all the calculations were based upon 33 Kg/h of gas and 33 Kg/h of water initially. At first the whole process was analysed with range of initial pressure of 10 bar to 70 bar. The pressure drop for each case was recorded. Initial temperatures were set to be 30 ℃ for every case. In each case, outlet properties such as temperature, enthalpy, entropy, gas composition, water recovery and polytrophic efficiency of the expander were observed in each case.

Advantages of Turbo Expander Method

This is a modern method for gas dehydration. Its mechanical part can produce considerable amount of energy in the form of heat that can minimize energy cost for the plant operation. So it can offer higher temperature drop than Joule-Thomson method and eventually higher water recovery is possible. This method is a good choice when high water recovery is desired. At higher temperatures and pressures it creates higher temperature drop and consequently higher energy production and water recovery are achieved. It offers higher water recovery at high pressure up to 100 bar.

Limitation of Turbo-Expander Method

In ideal case, it is an isenthalpic process. But in reality, the expansion cannot completely approach the isentropic case but produce a high percentage of the ideally possible work and it requires a lot of time taken for it to produce high water recovery.

It showed that entropy was decreasing with the increase of inlet pressure while polytrophic efficiency increases with the increase of pressure. It can remove more water at low temperatures but then water composition at the gas stream of the separator outlet becomes low and it is a loss in production cost. Since this type of plant is expensive, it is not wise to choose when less water recovery is desired.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

As conclusion, the percentage of water recovery is higher for expander compared to Joule-Thomson expansion valve. The percentage of water recovery for Joule-Thomson valve is considered to be high for the process. One of the advantage of using Joule-Thomson expansion valve rather than an expander is that the JT valve does not required any input of energy because it is based on expansion of natural gas. Due to the expansion, the temperature of the gas will drop causing the gas to be cool thus condensation will occur. Another reason why JT valve is better than expander is it is easy to be operated and installed in offshore facilities. It does not require a large amount of space to be installed thus cutting the operation cost as well as maintenance cost. By studying the optimum temperature, pressure and flow rate for the JT effect to occur we can easily remove the water inside the natural gas without using other kind of separation process such as absorption and adsorption.

Recommendation that can be done to improve the quality of the study is according to experiment feasibility, the results obtain were from only pure carbon dioxide gas for our case study. Due to the limitation of chemical materials and mechanical failure, the data obtain from the mixture gas could not be obtained. For future studies, we can run the experiment using different composition of gases to show the rate of water recovery in real cases. As expected results, the turbo expander will have a higher water recovery compared to Joule-Thomson valve but the data obtain will be used to validate the results that are being obtained from simulation.

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APPENDICES

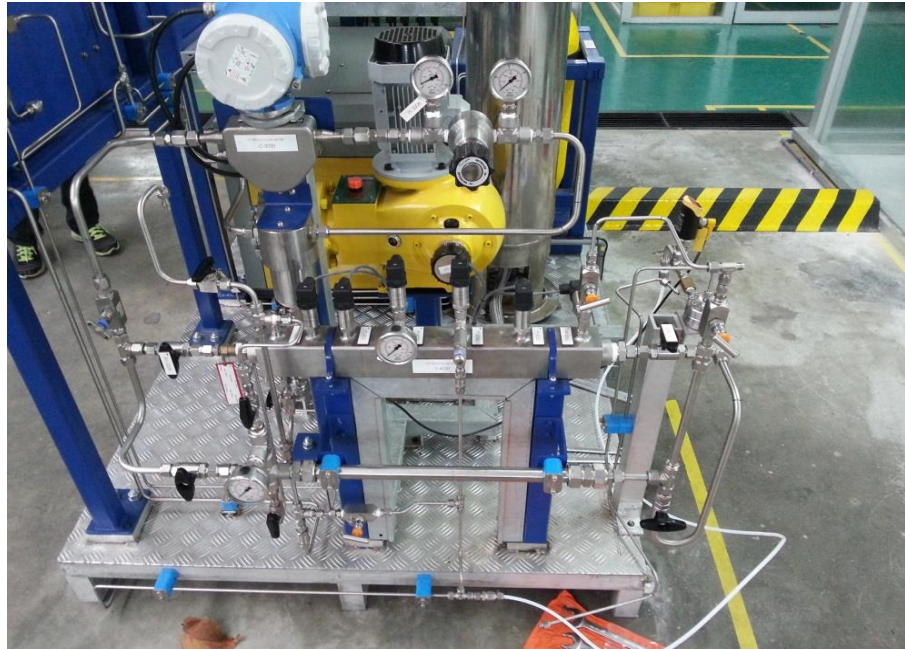## 10.2 List of Equipment Used

Figure 28: Micro Inline Separation Contactor (MISEC)

Figure 29: Flow Controller for gas feed

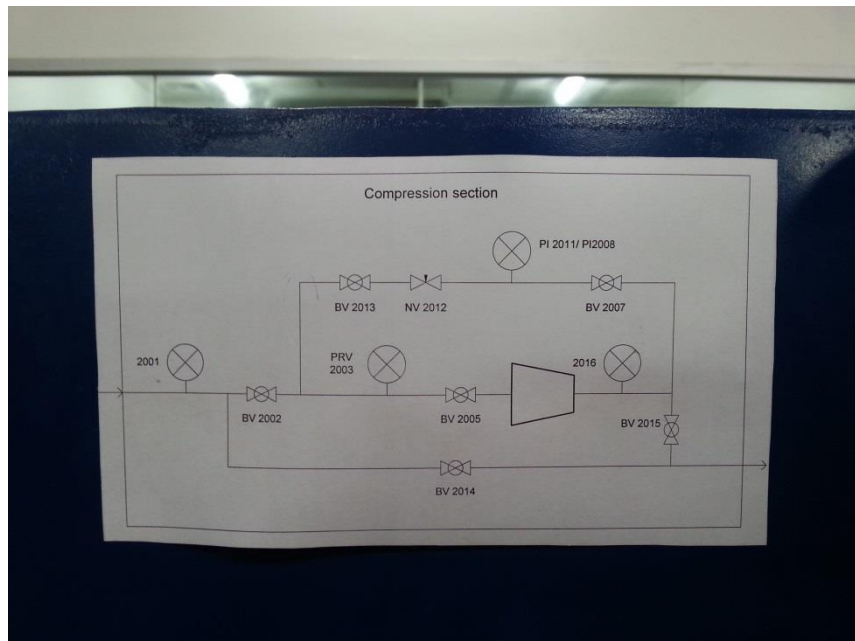*Figure 30: Pressure relive valve and Ball valve controller*

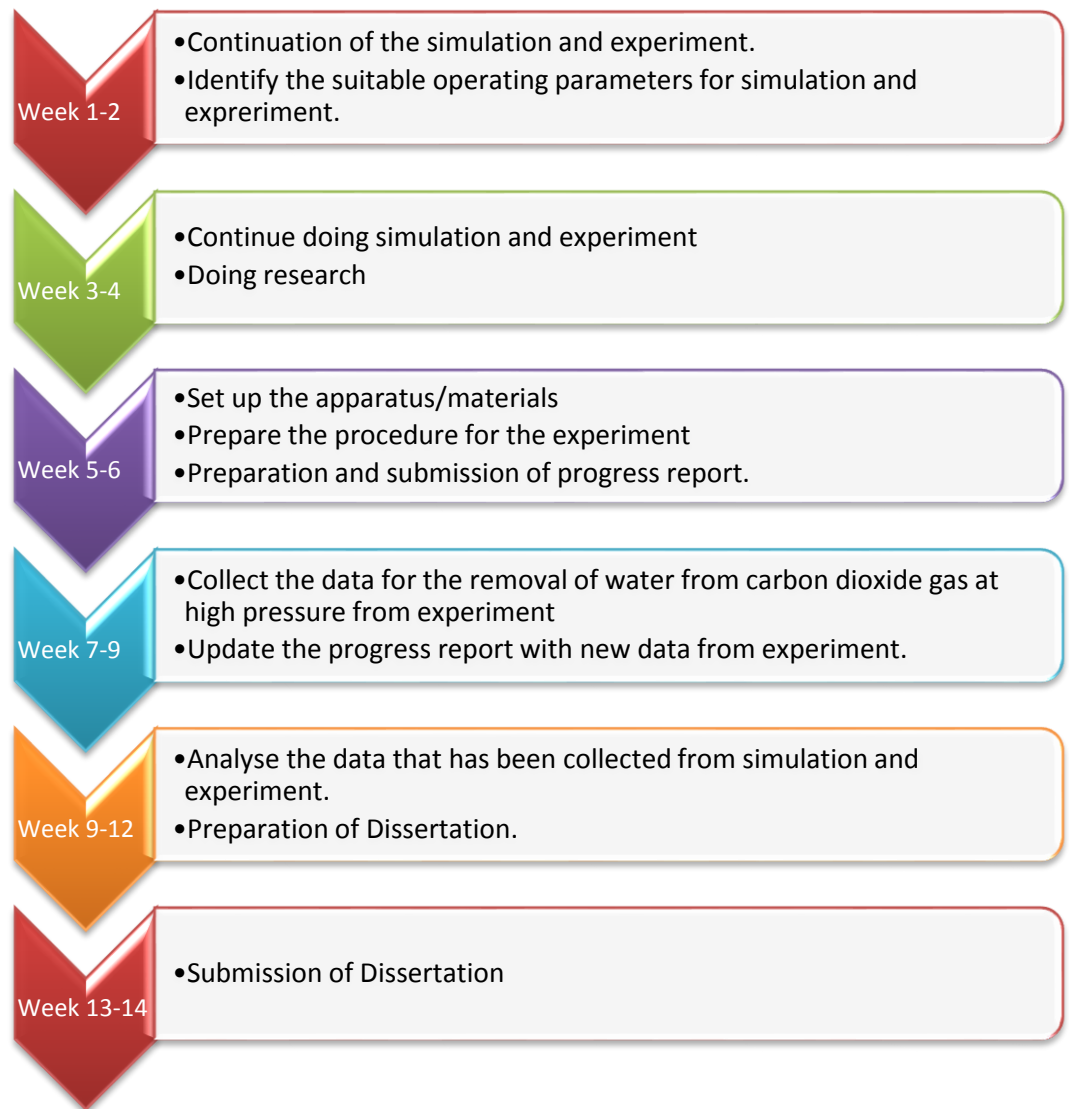*Figure 31: Joule-Thomson experiment setup*

10.2 Key Milestone

Week 1-2
- Continuation of the simulation and experiment.
- Identify the suitable operating parameters for simulation and expreriment.

Week 3-4
- Continue doing simulation and experiment
- Doing research

Week 5-6
- Set up the apparatus/materials
- Prepare the procedure for the experiment
- Preparation and submission of progress report.

Week 7-9
- Collect the data for the removal of water from carbon dioxide gas at high pressure from experiment
- Update the progress report with new data from experiment.

Week 9-12
- Analyse the data that has been collected from simulation and experiment.
- Preparation of Dissertation.

Week 13-14
- Submission of Dissertation

Figure 32: Key Milestones for FYPII

10.3 Gantt Chart

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