Effect Of System Pressure Towards Natural Gas Dehydration Efficiency Using Centrifugal Force

by

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CERTIFICATION OF APPROVAL

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Approved by,

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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.

MOHD AZUARY BIN ABDUL AZIZ

ABSTRACT

The increasing market demand for natural gas has pushed the energy industries to explore new natural gas resources in remote location. Consequently, new dehydration technologies suitable for remote location operation must be in placed in order to exploit and transport these resources economically. Three main challenges in developing these new technologies are the compactness of the equipment, performance reliability and minimum human intervention in terms of maintenance and monitoring. This paper reviews the current dehydration technology, as well as the new and emerging technologies for natural gas dehydration, as well as the experimental set-up, the methodology and the initial analysis of the high-g separation for dehydration purposes. In this project, some of the factors that may have influence the cyclone performance such as the temperature, inlet gas velocity, water loading and the system pressure is identified. This study focused on the system pressure effect toward the separation efficiency. The prototype separator will be operated in the lab to verify scale-up parameters and separation efficiencies, as well as to provide information necessary to design a full-scale system. The full-scale system will be fabricated, installed in the field, and operated to demonstrate the technology.

ACKNOWLEDGEMENT

First of all, I would like to take this opportunity to praise to God, the Most Merciful and Most Grateful for His Permission so that I am able to finish my dissertation. Millions of thanks to my kind supervisor, AP Dr Azmi Mohd Shariff for his helps and advises upon accomplishment of my final year project.

I also would like to thank to Mrs Norhayati Mellon for her setting guidance and teaching me throughput the entire project. Finally, I would like to thank to those who help me in contributing the idea and useful feedbacks either directly or indirectly to improve my thesis.

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CHAPTER 1

INTRODUCTION

1.1 Background

Produced water is the largest generated waste stream by volume in the natural gas exploration. Natural gas must be dehydrated before transmission over a long distance through a pipeline to prevent the condensation of liquid water in order to ensure trouble-free operation. The major problem caused by the natural gas and water combination is the formation of hydrate in the pipeline thus blocking the transmission. The issue of the best method to dehydrate the natural gas has been a great concern among the scientist and engineers all over the world recently.

The current method of using the solid and liquid desiccant which is vastly used still has a lot of weaknesses such as high cost, high energy input and many others. For the purpose of clean, low input and high output, and simple, idea of cyclonic gas separation is developed. The use of rotational separation which generate high centrifugal force with magnitude amounting to several hundreds times to hundred thousands times of earth's gravity, centrifuges have been used for fluid and particle separation. It has gained acceptance in the industrial application.

There is limitation on size of particle removed by cyclone usually less than 10 microns only. Most of the time, cyclone is used to separate solids while cyclone used to separated water is called as hydrocyclone. Small cyclones are routinely used for particulate as small as 0.5 microns with 90% removal efficiency [1]. Conversely though, cyclones are now able to satisfy environmental and process requirements on particulate that is much finer that is commonly believed.

1.2 Problem Statement

Natural gas contains different amounts of contaminants among which are water vapour, which is considered as the most common impurity in natural gas mixtures. This vapour causes operational problems such as hydrate formation, corrosion, high pressure drop, and consequently slugging flow and reduction in gas transmission efficiency [8]. Water vapour also reduces the heating value of the gas and increases its specific value. The possibility of the obstruction of gas flow due to formation of hydrates within the flow lines is one of the most serious problems in the gas industry [2]. Therefore, it is important to remove the water from the natural gas before it is being transported to the natural gas processing plant.

Apart of these current technologies, there is still other technology that has great potential to be developed. Among them is the separation using centrifugal force. This is a new technology that is still under study believed to surpass the existing technologies.

1.3 Objectives

Claims were made on the capability of certain centrifugal equipment in removing moisture from natural gas. However, most reported data on moisture removal from natural gas is based on hypothetical outcome from experiments done using solid particles of less than 10 microns using SF6 as the carrier gas with operating pressure of 10 bar or less [14]. There are basically four main objectives of this research. They are to study the separation efficiency based on the following factors:

1. System pressure
2. Liquid loading
3. Temperature
4. Compressor speed

However, as for my final year project, this research is carried out to study only the effect of system pressure that influence the separation efficiency of moisture removal from natural gas using centrifugal forces.

1.4 Scope Of Study

Since studying all the factors affecting separation efficiency require a lot of time. Therefore, this study only focused on the

1. To study the effect of pressure variant from 40 bar to 60 bar on the mass flow through the system under dry condition.
2. To study the effect of pressure variation from 40 bar to 60 bar on the separation efficiency of water natural gas solution using centrifugal forces via IRIS.

CHAPTER 2

LITERATURE REVIEW

The world has move into exploring new methods for offshore gas processing, particularly in the area of gas dehydration to replace the older method with less monitoring requirement, smaller equipment size and weight higher efficiency. One of these initiatives is to move towards compact separation method as means of gas dehydration and sweetening. Early efforts in reducing the facility cost concentrate more on reducing the size of key equipment since footprint allocation on offshore facilities are very costly. One of the approaches is the application of enhanced physical forces to achieve the desired separation performance. This enhanced physical force can be as high as 500,000 gravitational forces resulting in small and compact separator [22].

To date, there are generally three concept of compact separator – centrifugation without expansion, centrifugation with expansion and acceleration to supersonic velocity and centrifugation with filter element acting as coalescer [4]. Although the technology is still new, the field application of these types of devices is already in operation.

For example, TWISTER technology by Shell in Norway, Netherland, Nigeria and Malaysia for acid gas removal[4], the application of degasser or deliquidiser equipment by Statoil at North Sea to solve slugging problem, gas-liquid cyclone separator, GLCC by Chevron with more than thousand field installation worldwide [12].

Today, there are basically three methods employed to reduce this water content. These are:

1. Joule-Thomson Expansion.

   Joule-Thomson Expansion utilizes temperature drop to remove condensed water to yield dehydrated natural gas. It requires high pressure difference to achieve the required temperature drop.

2. Solid Desiccant Dehydration.

   Also known as solid bed, employs the principal of adsorption to remove water vapor. Adsorbents used include silica gel, molecular sieve, activated alumina and activated carbon. Despite of its low cost and widely acceptable, it needs constant monitoring, foaming problem, liquid carryover and also drop in performance over time.

3. Liquid Desiccant Dehydration

   In this process, a liquid desiccant dehydrator serves to absorb water vapor from the gas stream. Glycol, the principal agent in this process, has a chemical affinity for water

Table 1: Technical Capability, Advantages and Disadvantages of Conventional Natural Gas Dehydration Techniques

Separation method	**Technical capabilities and advantages**	**Disadvantages**
Glycol absorption	1. Established and widely accepted method 2. Able to achieve final water content of 60 ppmv	1. Requires constant monitoring to minimise operational problems (glycol losses, foaming, glycol degradation etc) 2. Environmental problem associated with BTEX emission 3. High capital cost due to requirement of associated

		equipment
Adsorption (solid desiccant)	1. Able to reduce final water content to 0.1 ppmv. 2. Reduce capital cost (less associated equipment) 3. Minimal BTEX emission	1. Hydrothermal damaging of adsorbent 2. Impurities in feed gas causes bed contamination leading to poor performance 3. Incomplete regeneration leads to premature breakthrough
Adsorption (deliquescing desiccant)	1. Closed system, no BTEX emission 2. No heating requirement for regeneration, thus an added safety factor 3. Operation at higher pressure means less desiccant required due to lower water content	1. Waste product in the form of brine and considered as oilfield brine.
Expansion refrigeration	1. Able to remove water from natural gas stream to very low value	1. Needs glycol injection to prevent hydrate formation

CHAPTER 3

THEORY

In this research, the separation is done by mean of centrifugal force using cyclonic separation. Cyclonic separation is a method of removing particulates from an air or gas stream without the use of filters. A high speed rotating air-flow is established within a cylindrical or conical container called a cyclone. Air flows in a spiral pattern, beginning at the left end of the cyclone and ending at the right end before exiting the cyclone in a straight stream through the center of the cyclone and exit through the right.

Due to the difference in density and weight of the feed mixture, larger particles in the rotating air stream have too much inertia to follow the tight curve of the air stream and strike the outside wall, falling then to the bottom of the cyclone where they can be removed. In a conical system, as the rotating air-flow moves towards the narrow end of the cyclone the rotational radius of the air stream is reduced, separating smaller and smaller particles from the air stream. Hence, cyclones accomplish much more effective separation than gravity settling chambers. **Figure 1** illustrates the basic principle of cyclonic separation.

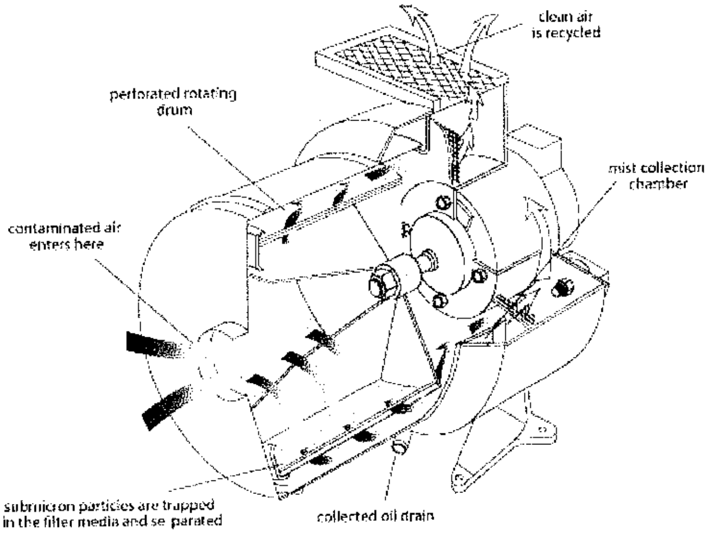

Figure 1: Basic principle of cyclonic separation.

The centrifugal force in a cyclone ranges from about 5 times gravity in large, low velocity units to 2500 times gravity in small, high resistance units. These devices are used often in many applications, such as in spray-drying of foods, where the dried particles are removed by cyclones, in cleaning dust laden air, and in removing mist droplet from gases. Cyclones offer one of the least expensive means of gas particle separation. They are generally applicable in removing particles over 5µm in diameter from gases. For particles over 200µm in diameter, gravity settling chambers are often used. Wet scrubbers cyclones are sometimes used, where water is sprayed inside, helping to remove the solids.

Cyclonic devices are widely used for separation because of their:

1. Low capital investment, and maintenance costs in most applications
2. Lack of moving parts.
3. Can be used under extreme processing conditions, in particular at high temperatures and pressures and chemically aggressive feeds.
4. Very robust
5. Can be constructed from most any material suitable for the intended service including plate steel, casting metals, alloys, aluminuim, etc..
6. Can be fabricated from plate metal, or in the case of smaller units, cast in molds.
7. Can, in some processes, handle sticky or tacky solids with proper liquid irrigation.
8. Can separate either solids or liquid particulates, sometimes both in combination with proper design.

However, there are also disadvantages of cyclonic separation such as:

1. The flow rate is limited, requiring many cyclones that require extensive piping and valving.
2. High maintenance is required to keep underflow openings unplugged
3. Usually higher pressure loss than other separator types, including bag filters,

low pressure scrubbers and ESPs.

4. Subject to erosive wear and fouling if solids being processed are abrasive or sticky.
5. Can operate below expectation if not designed and operated properly.

In this method, wet natural gas is pumped into a horizontally mounted vessel. The liquid is directed into the cyclone so it spins at high velocity around the cone wall. The water is thrown outward by centrifugal force and downward by back pressure. The water is discharged through an underflow opening back into the water drum, while the clean dry natural gas follows a vortex column in the center and is discharged through an overflow opening into the absorption column and gas pipe line. **Figure 2** shows the exterior of the IRIS used and **Table 2** shows it's specification respectively.

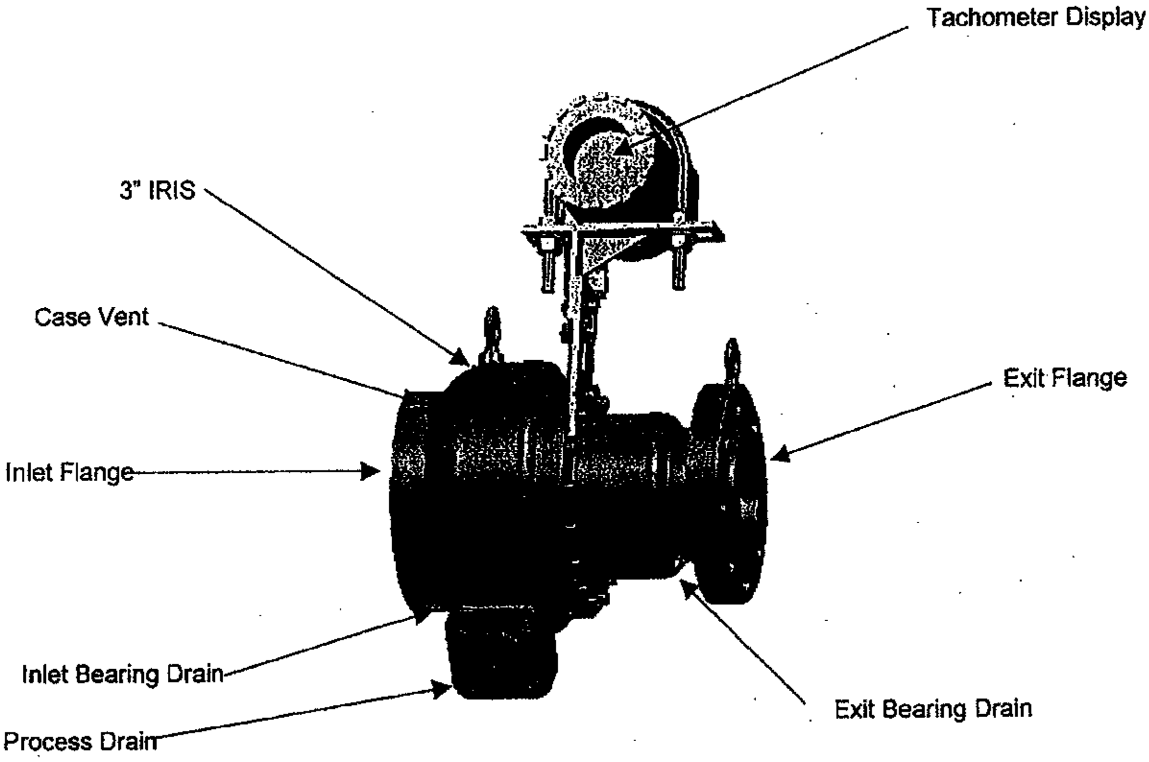

Figure 2: The exterior view of IRIS used to separate water from wet natural gas.

Table 2: Specification for IRIS

Pressure range	40 -1,350 psig (207-9,302 kPa)
Pressure drop across unit	.1 - 5% of Inlet Pressure
Operating temperatures	40° - 200° F (4° - 93° C)
Inlet Pipe Velocity	
- wide open	18 - 60 ft/s (3 -18.3 m/s)
- restricted / w trim plates	5 - 50 ft/s (1.5 -15.3 m/s)
Rotor Speeds	
-minimum	2400 RPM (recommended for good performance)
-maximum	12,000 RPM *
Turndown ratio	70% from maximum condition
Liquid removal capacity	
-by mass (LMF)	up to 30% of inlet gas flow by mass
-by volume (LVF)	up to 4% of inlet gas flow by volume

3.1 Terminal Radial Velocity in Cyclone Separator

It is assumed that particles on entering a cyclone quickly reach their terminal settling velocities. Particles sizes are usually so small that Stokes law is considered valid. For centrifugal motion, the terminal radial velocity, v_{tR} is given by equation (1.1), with v_{tR} being used for v_t:

$$v_{tR} = \frac{\omega^2 r D_p^2(\rho_p - \rho)}{18\mu} \qquad (1.1)$$

Since $\omega = v^2_{tan}/r$, where v_{tan} is tangential velocity of the particle at radius r, Equation (1.1) become

$$v_{tR} = \frac{\omega^2 r D_p^2(\rho_p - \rho)}{18\mu}\ \frac{v^2_{tan}}{gr} = v_t\,\frac{v^2_{tan}}{gr} \qquad (1.2)$$

Where v_t is the gravitational terminal settling velocity. The higher the terminal velocity vt the greater the radial velocity v_{tR} and the easier it should be to settle the particle at the walls. However, the evaluation of the radial velocity is difficult, since it is a function of gravitational terminal velocity, tangential velocity and the position radially and axially in the cyclone. Hence, the following empirical equation is often used:

$$v_{tR} = \frac{b_1 D_p^{\,2}(\rho_p - \rho)}{18\mu r^n} \qquad (1.3)$$

Where b_1 and n are empirical constants.

3.2 Separation Efficiency

The three particle fraction we are concerned with in cyclone separation are mainly the feed, denoted as M_f, the collected particle, M_c and the emitted fraction, M_e [1] . The mass balance for solids over the cyclone is:

$$M_f = M_c + M_e$$

Thus, the efficiency is simply expressed as:

$$\text{Efficiency, } \eta = \frac{\text{Amount of water collected in water tank, } M_c}{\text{Amount of water injected into the system, } M_f}$$

$$\eta = \frac{M_c}{M_f} = \frac{M_c}{M_c + M_e}$$

The efficiency is measured by collecting samples and weighing two of the fractions.

3.3 Properties of Natural Gas

3.3.1 Water Content of Natural Gas

The water content of a natural depends essentially on the temperature and pressure. Correction can be made to account for the composition of the gas and the salinity of the water. Dissolved salts reduce the partial pressure of water in the vapor phase, and the water content of the gas is accordingly decreased [2]. Amount of water at different pressure is shown in **Figure 3**.

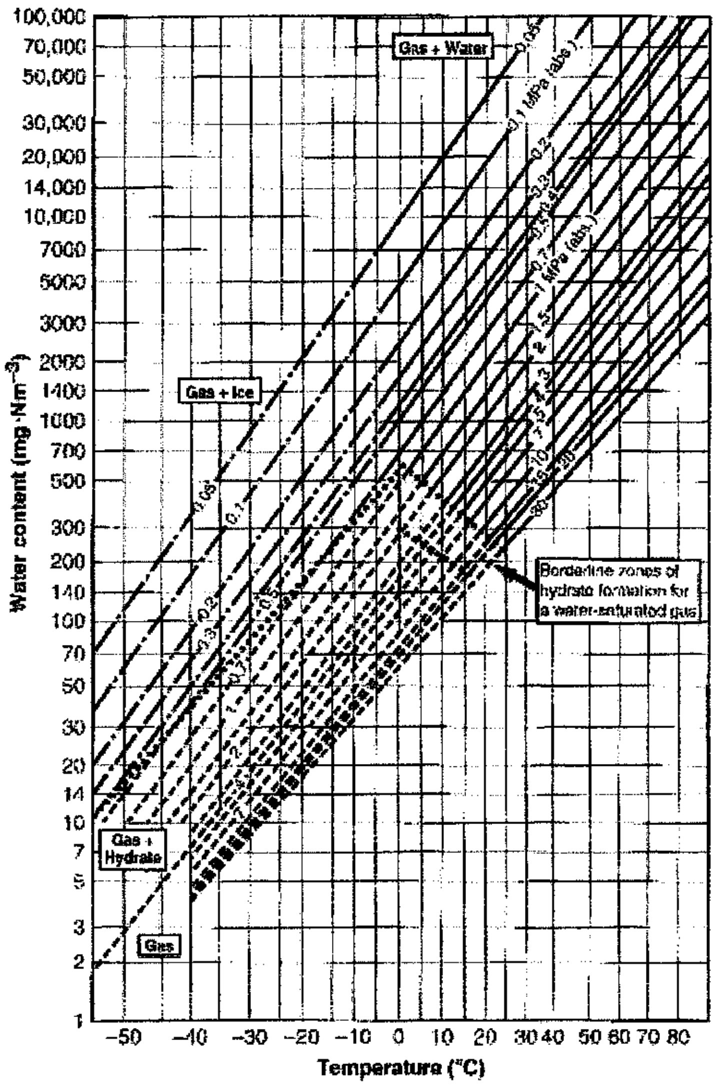

Figure 3: Water content of natural gas.

3.3.2 Viscosity of Natural Gas

At low pressure, the viscosity of a gas mixture can be estimated from the viscosity of the pure substances by the equation (Herning and Zipperer, 1936):

$$\mu_1 = \frac{\sum \mu_j y_j M_j^{1/2}}{y_j M_j^{1/2}}$$

$$\mu = \mu_1 \text{ x viscosity ratio}$$

Where ,

y_j = mole fraction of component

M_j = molecular weight of component

μ_j = viscosity of component

The variation in viscosity of different natural gas components as a function of temperature is shown in **Figure 4** for a pressure equal to atmospheric pressure (Carr et al., 1954). Since the study being carried out uses natural gas at high pressure, a corrective term must be used.

A diagram developed by Carr et al. (1954) also helps to estimate the viscosity of a natural gas at atmospheric pressure for different temperatures as a function of the specific gravity or the the molecular weight.

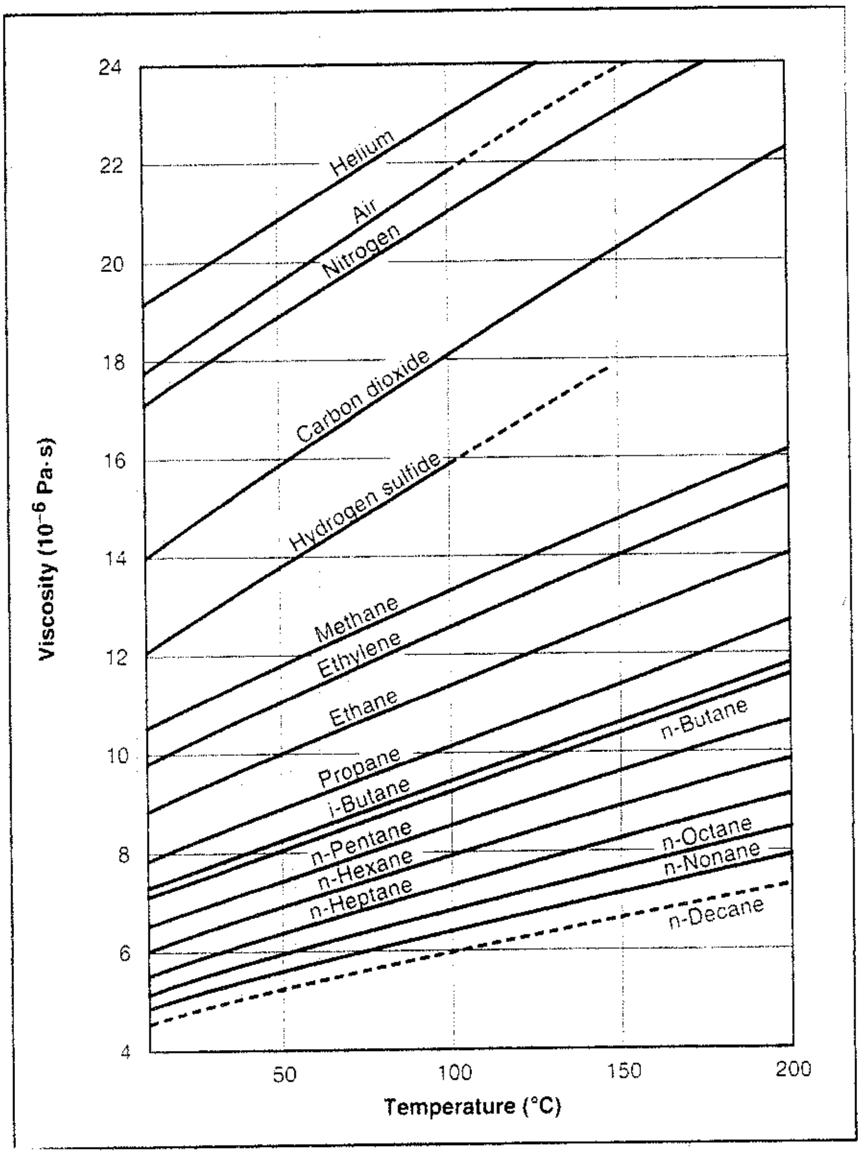

Figure 4: Viscosity of natural gas component as atmospheric pressure

The chart shown in **figure 5** gives the ratio of the viscosity of the gas under pressure to the viscosity of gas at atmospheric pressure, as a function of reduced coordinates P_R and T_R. If the composition is known, the pseudocritical temperature and pressure are calculated by equation,

$$P_{pc} = \Sigma y_i P_{ci} \text{ and } Tpc = \Sigma\, y_i T_{ci}$$

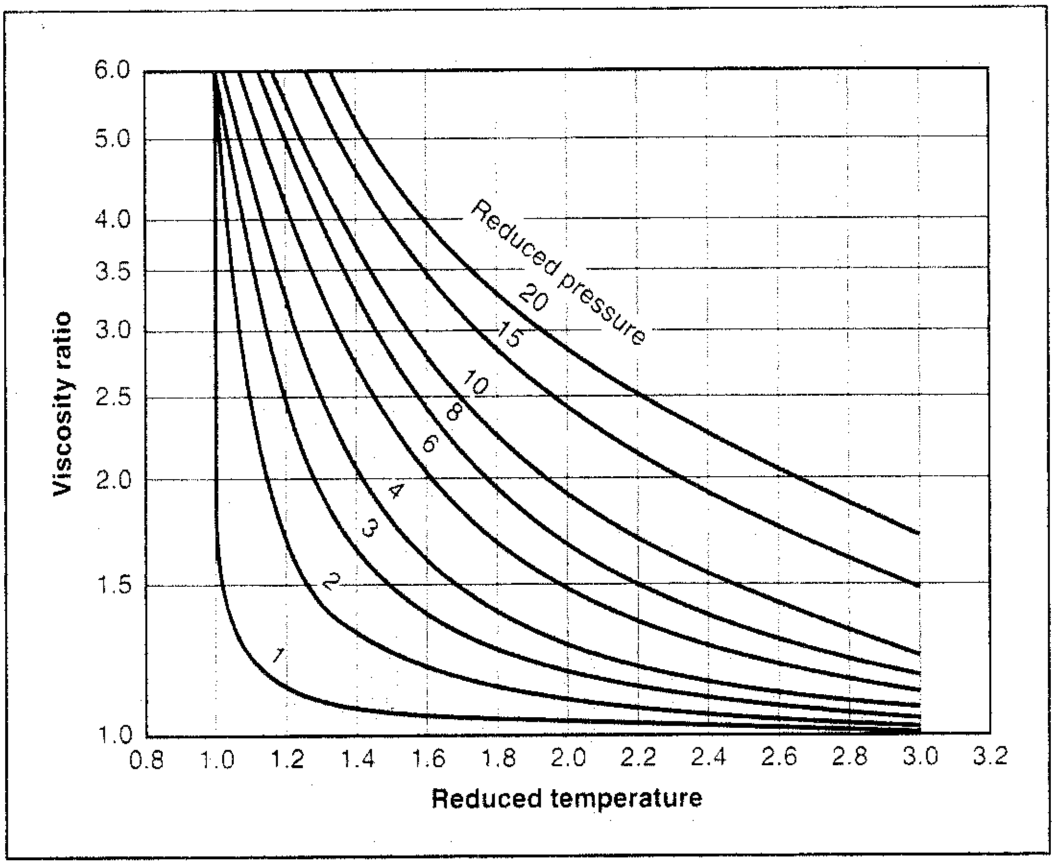

Figure 5: Viscosity ratio as a function of reduced temperature and reduced pressure

CHAPTER 4

METHODOLOGY

4.1 Procedure Identification

This research is carried out in the lab by experimental approach. There were several factors that affecting the separation efficiency that have to be studied upon completing the research such as the pressure, water loading, temperature and also the . The following is the parameter we can vary while doing the experiment to obtain the desired outcome:

1) Operating pressure can vary from 10 bar to 80 bar.
2) Gas flow rate range from 0.5 MMSCFD to 5.0 MMSCFD.
3) Water loading up to 30% by mass of gas flow.
4) Water temperature variation up to 50°C.

Figure 5 below is the P&ID of the rest rig used in this experiment.

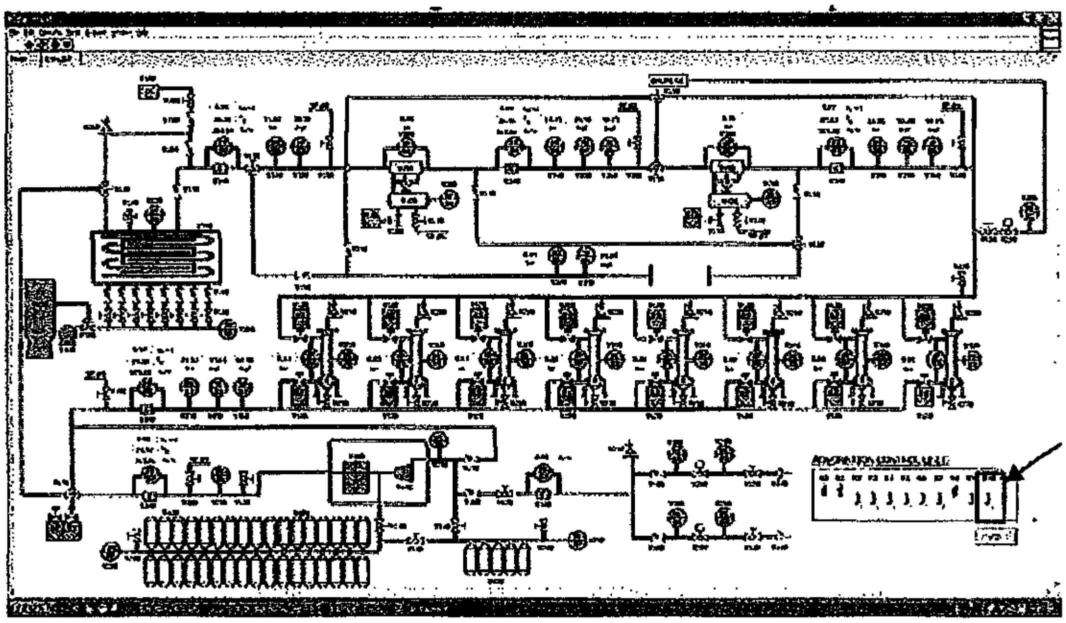

Figure 6:P&ID of the test rig

In order to study the effect of pressure towards separation efficiency, the pressure must be varied while maintaining the other parameters such as the liquid loading, temperature, and compressor speed. In the test rig, the compressor is capable of producing pressure up to 80 bars. Thus, pressure can be varied from 10 to 80 bars. However, based on the operating condition in the real natural gas well, the value of the variable parameters is then set at:

Pressure: 40 bars to 60 bars

Temperature: 50 °C and 65 °C

Compressor speed: 100%

Liquid loading: 20%

4.1.1 Pre Start Procedures

1. Any gas leak within the gas leak area is visually checked.
2. Valve V140/1 and V140/3 at the natural gas storage tank are opened.

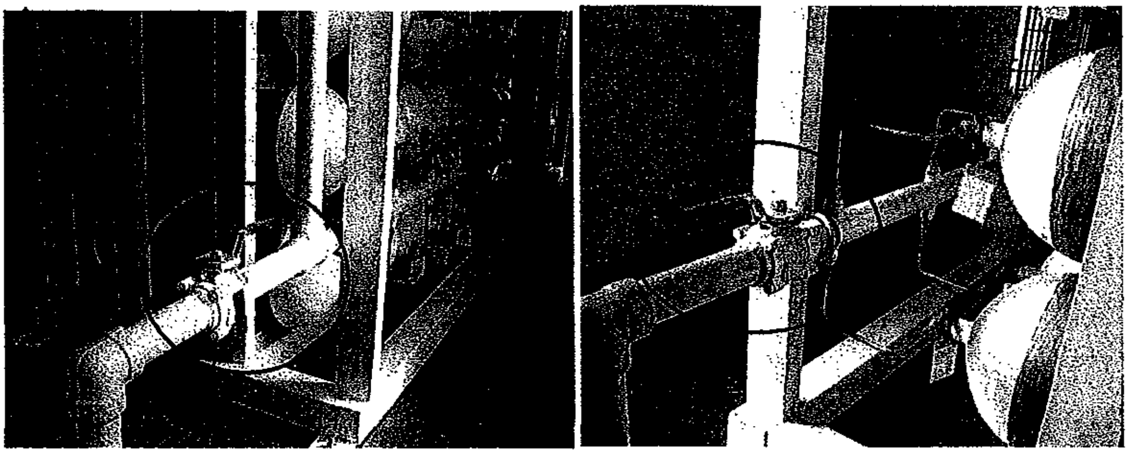

Figure 7:Valve at storage tank, V140/1 and V140/3.

3. Valves V120 and V131 on both knock-out drums are opened.

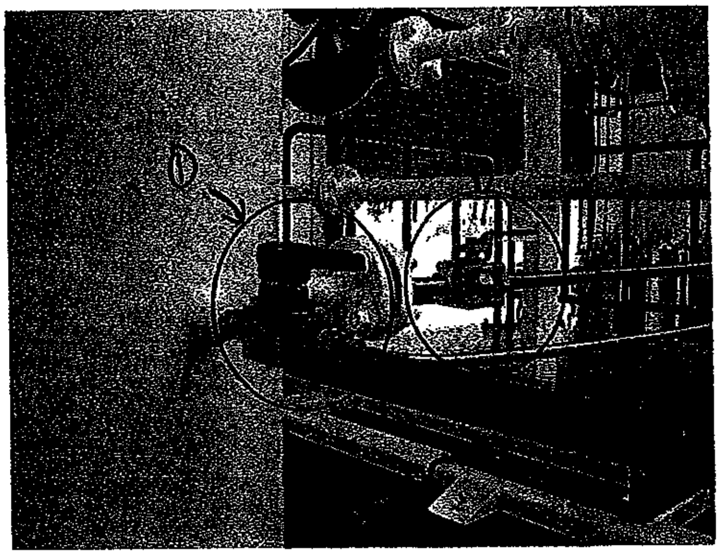

Figure 8: Valves V120 and V131

4. At the labview front panel , R8 and R9 is switched "ON" depending on desired flow direction. R8 will flow the natural gas to test module while R9 will circulate the natural gas between the buffer and storage cylinders.
5. At least 2 of the 8 absorption columns is switched 'ON'. The absorption columns are labeled R1 to R8 on the Labview front panel.

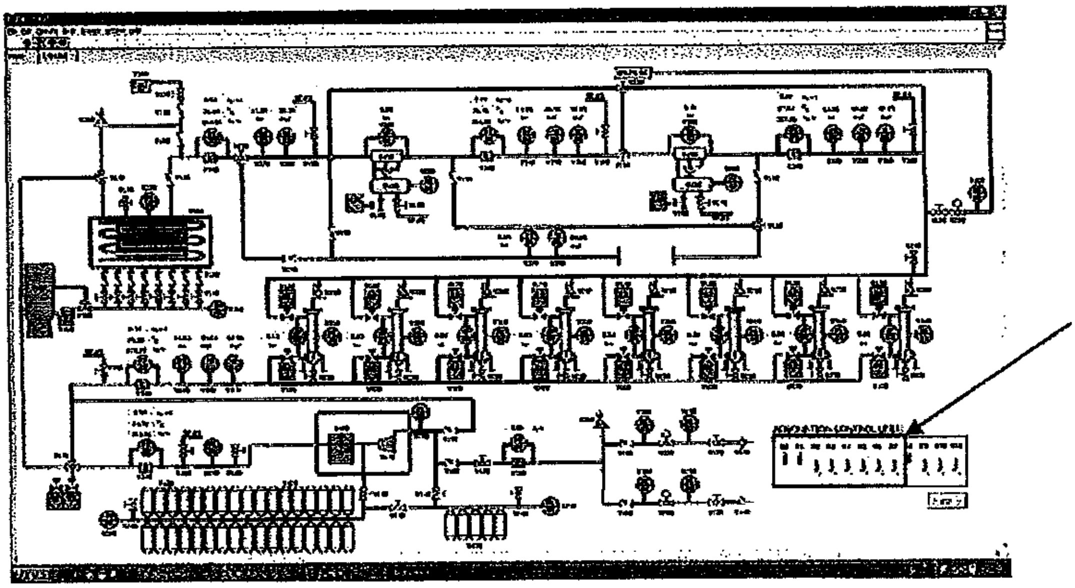

Figure 9: Labview Front Panel

4.1.2 Starting Procedure: Dry Run

1. At the compressor control panel door, the button at the isolator switch labeled 'online/offline' is turned 'ON'.

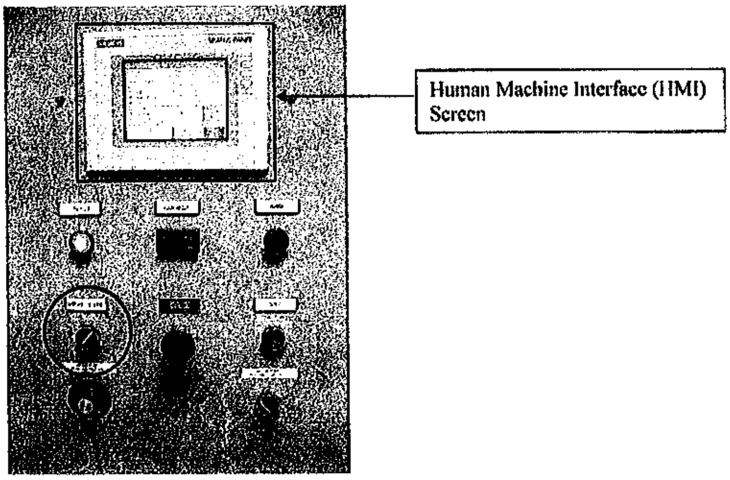

Figure 10: Human Machine Interface (HMI)

2. Compressor is started and the natural gas will flow in the selected direction.
3. The compressor parameters could be viewed on Human Machine Interface (HMI) screen.
4. In the Human Machine Interface, the pressure and compressor speed is adjusted according to desired value.
5. The test section is now in dry run system. The reading is recorded as required.

4.1.3 Starting procedure : Wet Run.

1. Before starting wet run, the test section shall be ran on dry run for at least 15 minutes.
2. The water flowrate is calculated. It should be not more that 30% of natural gas flow rate by mass.
3. The valve V110/3-V110/10 is opened depending on water flow rate. It should be as follows:

Table 3:Number of valve to be opened based on water flowrate.

Water Flowrare (L/min)	Number of valve to be opened

Less the 6	2
6-15	4
15-20	6
More than 20	8

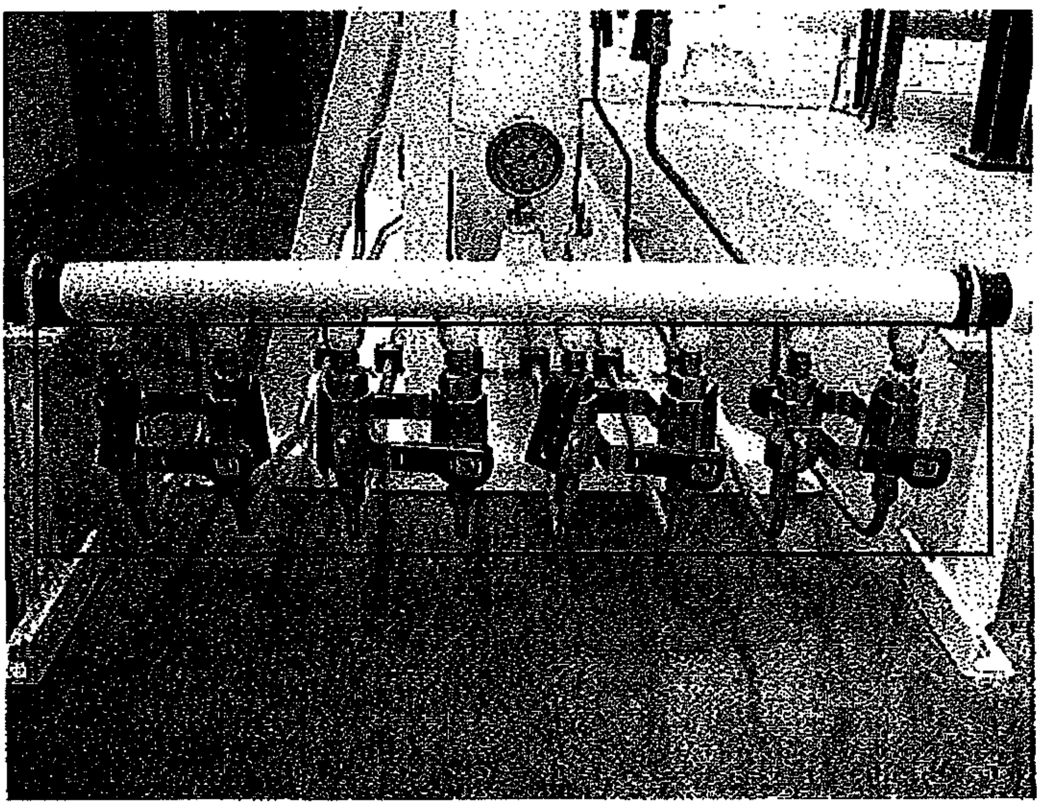

Figure 11: Water injection valve

4. To start water pump, the isolator switch labeled 'water pump online/offline' is switched 'ON'.
5. The water pump speed controller knob is turned in accordance to flow rate chart.
6. The water flow ware meter V345/1 will display water flow rate and accumulated total sprayed into the test section. The water pump speed controller is slightly adjusted to obtain desired water flowrate.

4.1.4 Stopping Procedures

1. The water pump speed controller knob is turned to 0% and the isolator switch is turned to 'offline' position.
2. Valves V110/3-V110/10 is closed.
3. Run dry is continued for 15 minutes.
4. Test section pressure at Human Machine Interface is reduced to 10barg.
5. Valve V120 and V131 on both knock out drum are closed.

4.2 Data Recording

Table 4 below is the example of test run at pressure 40 bar while maintaining the compressor speed at 100% , temperature at 35°C and liquid loading at 20%. The data has to be taken three times to get more accurate data.

Table 4: data sheet for test run at 40 bar.

				FT3			FT4		
Pressure	Compressor speed	Liquid Loading	Actual pressure	mass flow	gas density	T	mass flow	gas density	T
(bar)	%	%	(bar)	(kg/hr)	(kg/m3)	°C	(kg/hr)	(kg/m3)	°C
40	100	10							
	100	10							
	100	10							

	FT5								
mass flow	gas density	T	IRIS 1	IRIS 2	dP IRIS 1	dP IRIS 2	MO3	MO4	M05
(kg/hr)	(kg/m3)	°C	rpm	rpm	(bar)	(bar)	°C	°C	°C

The experiment is then repeated for pressure of 50 bars and 60 bars. The liquid loading as well as the compressor speed can be gradually increased for the next experiment.

Table 5 below show the data that has to be collected in the experiment while **Table 6** summarizes the schedule of the experiment has to be carried out to ensure the data can be collected in the limited time frame.

Table 5: Number of experiments need to be carried out

For 40 bar

<table>
<tr><td>Pressure (bar)</td><td colspan="18">40</td></tr>
<tr><td>Compressor Speed (%)</td><td colspan="6">60</td><td colspan="6">80</td><td colspan="6">100</td></tr>
<tr><td>Liquid Loading (%)</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td></tr>
<tr><td>Temperature (°C)</td><td colspan="3">35</td><td colspan="3">45</td><td colspan="3">35</td><td colspan="3">45</td><td colspan="3">35</td><td colspan="3">45</td></tr>
</table>

For 50 bar

<table>
<tr><td>Pressure (bar)</td><td colspan="18">50</td></tr>
<tr><td>Compressor Speed (%)</td><td colspan="6">60</td><td colspan="6">80</td><td colspan="6">100</td></tr>
<tr><td>Liquid Loading (%)</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td></tr>
<tr><td>Temperature (°C)</td><td colspan="3">35</td><td colspan="3">45</td><td colspan="3">35</td><td colspan="3">45</td><td colspan="3">35</td><td colspan="3">45</td></tr>
</table>

For 60 bar

<table>
<tr><td>Pressure (bar)</td><td colspan="18">60</td></tr>
<tr><td>Compressor Speed (%)</td><td colspan="6">60</td><td colspan="6">80</td><td colspan="6">100</td></tr>
<tr><td>Liquid Loading (%)</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td><td colspan="2">10</td><td colspan="2">20</td><td colspan="2">30</td></tr>
<tr><td>Temperature (°C)</td><td colspan="3">35</td><td colspan="3">45</td><td colspan="3">35</td><td colspan="3">45</td><td colspan="3">35</td><td colspan="3">45</td></tr>
</table>

Since this project will take about one year time to complete, a proper and systematic time management as shown in **Table 7** has to be done to ensure the project is finished in time. However it is common in laboratory approach to repeat the experiments which the data having large deviations or errors. On top of that, there will be a modification be done on the existing laboratory around June and July 2010 for a research on supersonic separation. Therefore, the experiments have to be planned accordingly to ensure all the experiments can be finished with good result.

Table 6:Gantt chart of scheduled activities

		Jan				Feb				March				April				May				June			
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Semester 1	Identification of Problem	■	■	■	■																				
	Literature Review	■	■	■	■	■	■	■	■																
	Equipment Setup					■	■	■	■																
	Equipment Testing									■	■	■													
	Collecting Data									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Progress Report												■	■											
	Analysing Data																	■	■	■	■	■	■	■	■
	Final Report																								
	Presentation																								

		July				August				Sept				Oct				Nov				Dec			
	Week	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Semester 2	Identification of Problem																								
	Literature Review																								
	Equipment Setup																								
	Equipment Testing																								
	Collecting Data																								
	Progress Report																								
	Analysing Data	■	■	■	■	■	■	■	■	■	■														
	Final Report											■	■	■	■										
	Presentation															■	■								

CHAPTER 5

RESULT

The table below summarized the final data collected from 27 experiments that had been done so far. All of the experiments were conducted at temperature of 35°C.

Table 7: Current data that had been collected from experiment

Pressure (bar)	Water Loading (%)	Compressor Speed (%)	Efficiency 1st Iris (%)	Efficiency 2nd Iris (%)
40	10	60	Can't be done	Can't be done
		80	97.14	Not observable
		100	95.13	Not observable
	20	60	82.00	Not observable
		80	92.00	30.00
		100	95.15	40.81
	30	60	78.00	Not observable
		80	87.00	15.38
		100	94.00	Not observable
50	10	60	88.00	Not observable
		80	93.60	Not observable
		100	93.00	Not observable
	20	60	86.44	Not observable
		80	94.00	16.67
		100	96.08	Not observable
	30	60	90.02	Not observable
		80	91.18	24.44
		100	92.83	Not observable
60	10	60	84.80	Not observable
		80	99.00	Not observable
		100	95.28	Not observable
	20	60	90.29	17.24
		80	100	Not observable
		100	95.25	26.13
	30	60	88.24	20.83
		80	95.74	34.78
		100	100.00	Not observable

The component of natural gas used in this study is analyzed by using Gas chromatography and the result is shown in table 8.

Table 8: Gas chromatography analysis of natural gas sample

Component	Fraction (mol %)
Nitrogen, N_2	0.26
Methane, CH_4	92.61
Carbon dioxide, CO_2	1.64
Ethane, C_2H_2	3.98
Hydrogen Sulfide, H_2S	0.8
Propene, C_3H_6	0.52
Butene, C_4H_8	0.08
Butane, C_4H_{10}	0.07
Pentane, C_5H_{12}	0.04

CHAPTER 6

DATA ANALYSIS

6.1 Data Analysis for Dry Run

Objective 1 : To study the effect of pressure variant from 40 bar to 60 bar on the mass flow through the system under dry condition

6.1.1 Experimental result

Dry run means the experiment is done without injecting water into the system. Data collected during dry run can be made as reference data and compared to the data taken during wet run. For example, the mass flow and IRIS 1 speed value during dry run should be close to wet run experiment. Table 8 shows data collected from 9 dry run done while varying pressure at pressure constant compressor speed, 60%. The experiment is repeated at compressor speed of 80% and 100%.

Table 9 : Data collected at dry run condition

Compressor speed(%)	Pressure (Bar)	Mass Flow (kg/hr)	IRIS 1 speed (RPM)
60	40	869.65	1275
	50	1251.67	1950
	60	1562.41	2210
80	40	1238.79	1826.67
	50	1736.77	2300
	60	2162.09	2766.67
100	40	1525.62	2213.33
	50	2129.15	3016.67
	60	2716.48	3686.67

From the plot obtained in Figure 10 and Figure 11, it can be observed that IRIS 1 speed and mass flow is increasing with pressure and compressor speed. Based on ideal gas law, (PV=nRT), number of moles of gas is increase as pressure is increased. Hence the mass flow is also increase.

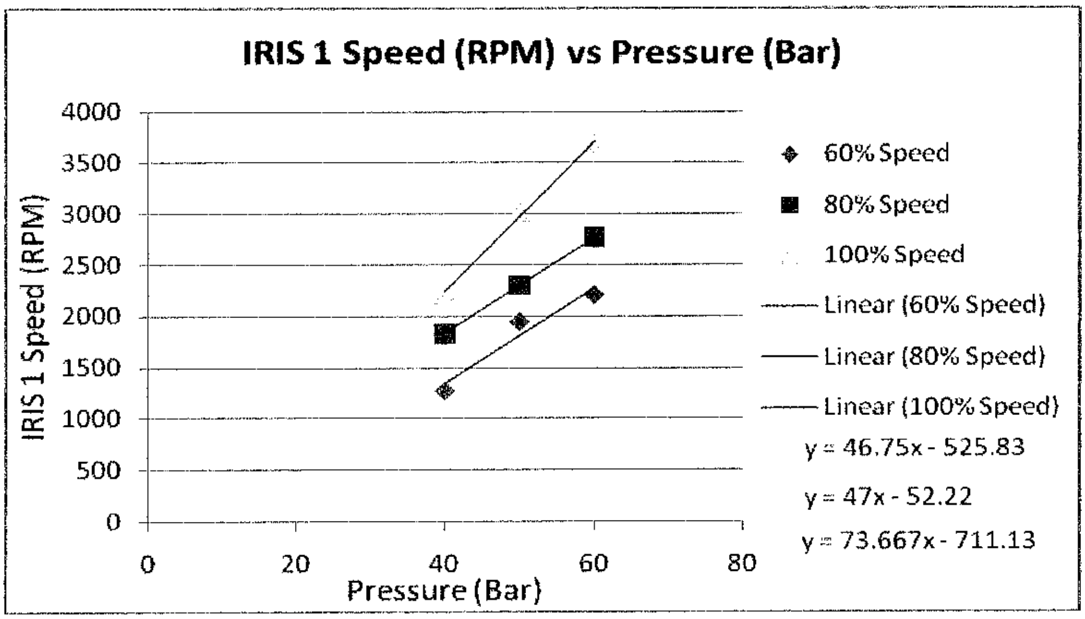

Figure 12 : IRIS 1 Speed VS Pressure

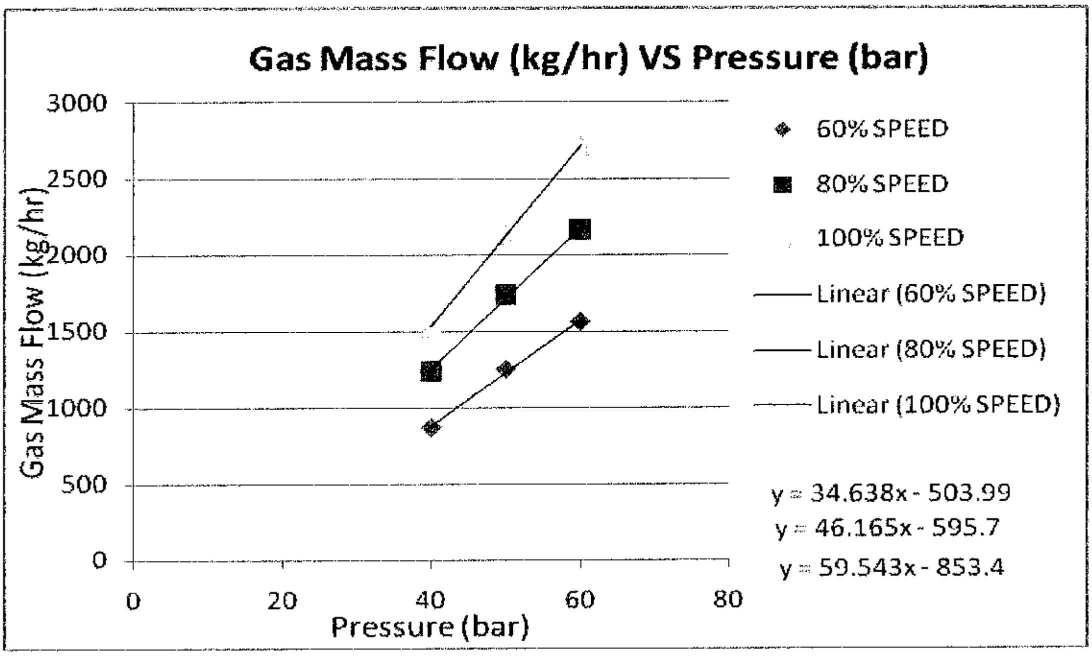

Figure 13 : Gas mass flow VS Pressure

6.2 Analysis for Wet Run

Objective 2 : To study the effect of pressure variation from 40 bar to 60 bar on the separation efficiency of water natural gas solution using centrifugal forces via IRIS.

6.2.1 Separation Efficiency VS Pressure

Theoretically, when the pressure of natural gas in the system is increased, separation efficiency will be much higher because at the when the pressure increases, the velocity of the gases will be higher. Higher velocity will increase kinetic energy in the system thus will result in higher energy. Therefore, the separation in the IRIS will be higher.

Table 10: data at 10% Liquid Loading

Compressor Speed (%)	Pressure (bar)	Gas Flowrate (LPM)	Separation Efficiency (%)	IRIS 1 (RPM)	IRIS 2 (RPM)
60	40	0	0	0	0
	50	1295.50	88.00	1836.67	2866.67
	60	1756.27	84.80	2423.33	2223.33
80	40	1469.62	97.14	2515	2460
	50	1842.92	93.60	2723.33	2556.67
	60	2269.14	99.00	2903.33	2730
100	40	1678.63	95.13	2897	2823
	50	2370.18	93	3796.67	3856.67
	60	2005	95.28	2390	2590

At 10% water loading, the gas flowrate and separation efficiency is much lower compared to higher water loading. This is due to the load exerted to the system is much lower at lower water loading.

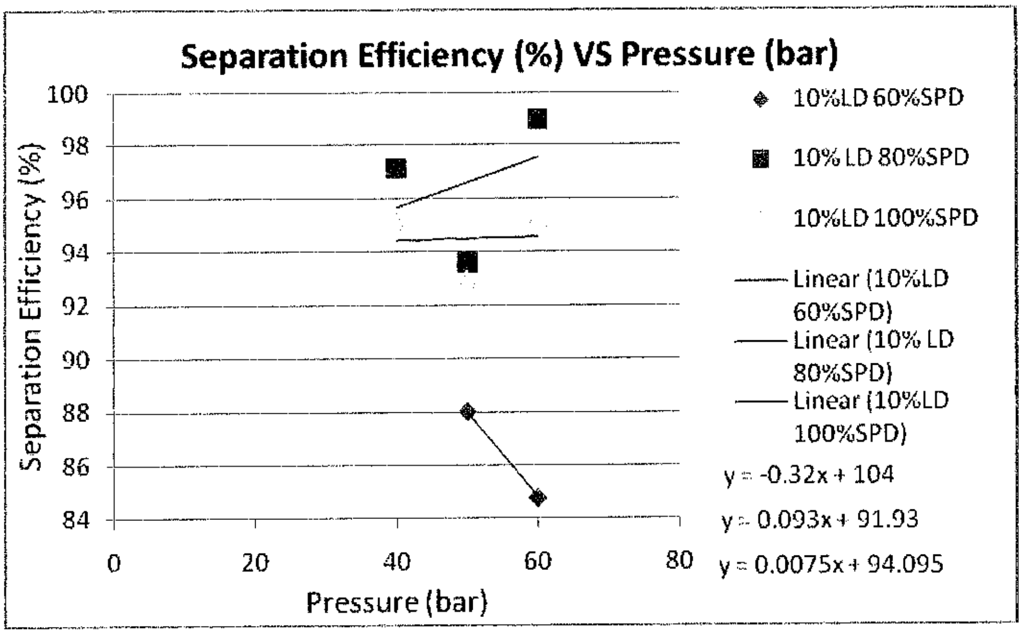

Figure 14: Separation Efficiency vs Mass Flow at 10% liquid loading

Table 11: Data at 20% Liquid Loading

Compressor Speed (%)	Pressure (bar)	Gas Flowrate (LPM)	Separation Efficiency (%)	IRIS 1 (RPM)	IRIS 2 (RPM)
60	40	1011.61	82	1850	2223.33
	50	1297.2	86.44	1856.67	2860
	60	1764.94	90.29	1893.33	2173.33
80	40	1232	92	1826.67	2056.67
	50	1955.91	94	2833.33	2846.67
	60	2231.35	100	2810	2486.67
100	40	1800	95.15	3150	3140
	50	2367.44	96.08	3643.33	3330
	60	2154	95.25	2690	2690

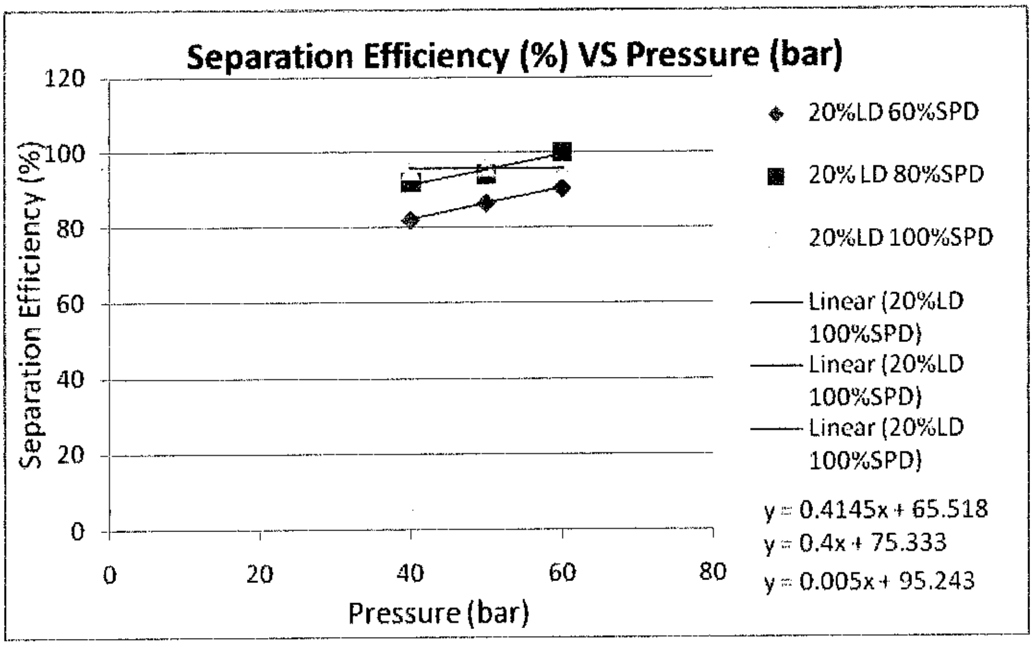

Figure 15 : Separation Efficiency vs Mass Flow at 20% liquid loading

Table 12: data at 30% Liquid Loading

Compressor Speed (%)	Pressure (bar)	Gas Flowrate (LPM)	Separation Efficiency (%)	IRIS 1 (RPM)	IRIS 2 (RPM)
60	40	1011.18	78.00	1890	2610
	50	1459.96	90.02	2326.67	2116.67
	60	1725.63	88.24	2310	2196.67
80	40	1206.81	87.00	1870	2570
	50	1940	91.18	2940	3053.33
	60	2363.3	95.74	2996.67	2746.67
100	40	1787.78	94	3243.33	3333.33
	50	2321.61	92.83	3683.33	3670
	60	2737.98	100	3783	3530

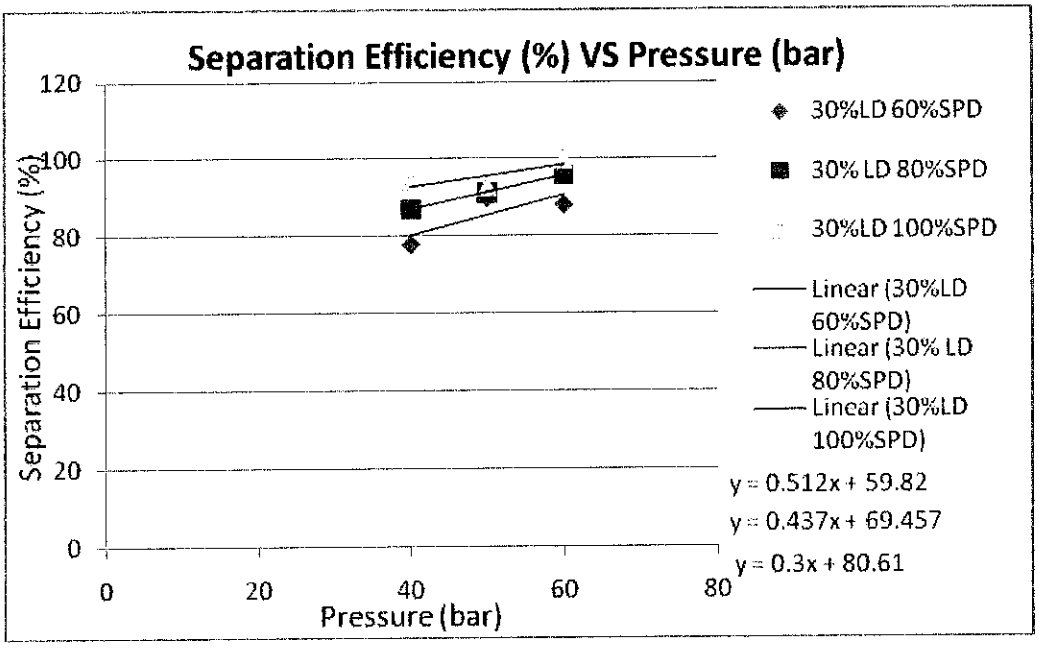

Figure 16: Separation Efficiency vs Mass Flow at 30% liquid loading

6.2.2 IRIS 1 Speed VS Pressure

IRIS is designed to remove water at high pressure. IRIS 1 speed is higher before the water is injected into the system compared to when the water is present. It is because the water load will exert some weight onto the IRIS blade thus making it slows down. However, after the water has been separated, the IRIS speed will increase back to the speed before the water is injected. IRIS 1 is designed to remove the water at 99% efficiency while IRIS 2 is installed to remove the remaining water that pass through IRIS 1.

The following graph shows the IRIS 1 Speed plotted against mass flow at different pressure which is 40 bar, 50 bar and 60 bar. The reading of IRIS 1 speed used in the graph is at before the water is injected into the system. In theory, IRIS 1 speed is much higher at higher pressure since higher kinetic energy is exerted onto the IRIS blade. For most of the cases, the trend shows that as the pressure is increasing, the IRIS speed will also increase.

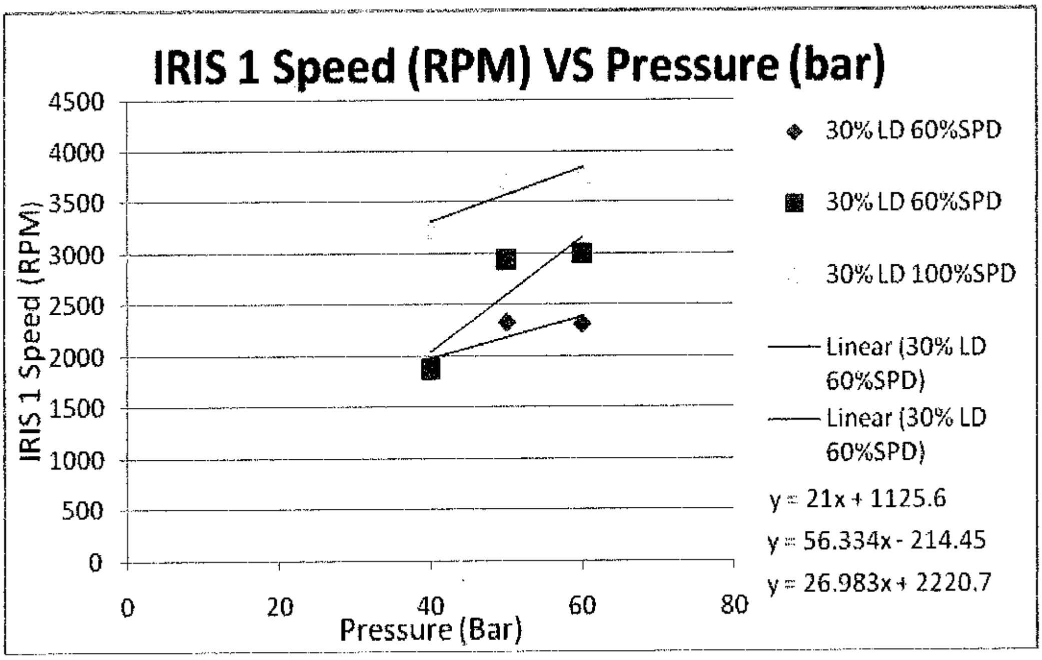

Figure 17: IRIS 1 Speed vs mass flow at 10 % liquid loading

6.2.3 Gas Velocity Vs Pressure

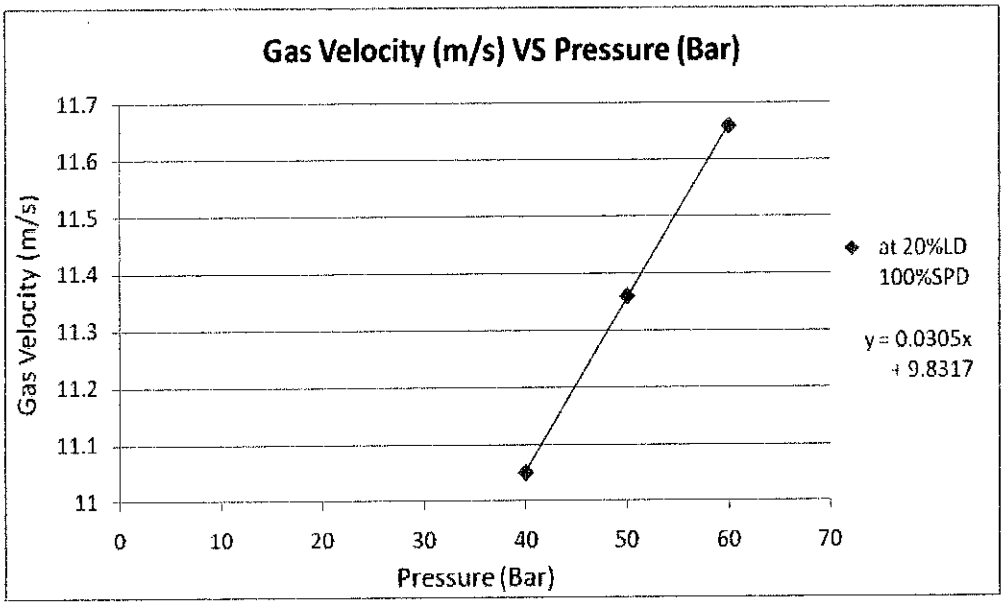

Figure 18: Gas velocity (m/s) vs pressure (bar)

Table 13: Gas velocity at different pressure at 20% liquid loading and 100% compressor speed.

Pressure (bar)	Gas velocity (m/s)
40	11.05
50	11.36
60	11.66

Gas velocity is obtained by converting the mass flow.

For example at 40bar, 20% liquid loading and 100% compressor speed

Mass flow = 1796.7 kg/hr

Gas density = 25.231 kg/m^3

Volume flow = mass flow / density

= 71.2 m^3 /hr

Area of 2 inch pipe = 0.00181 m^2

Velocity = (volume flow / area of pipe) / 3600

= 11.05 m/s

6.2.4 Terminal Radial Velocity of gas, Vtr

Mass flow also can be expressed as velocity. In this study, terminal radial velocity, v_{tr} inside the IRIS can be calculated by using the following equation;

$$v_{tR} = \frac{D^2{}_p\ g(\rho_p - \rho)v^2{}_{\tan}}{18\mu r}$$

Table 10 is developed in order to find the viscosity of natural gas. Since the natural gas used consist of gas mixtures, it is necessary to find the viscosity of each component and find the average viscosity using the equation:

$$\mu_1 = \frac{\sum \mu_j y_j M_j^{1/2}}{y_j M_j^{1/2}}$$

Table 14: Viscosity calculation for gas mixtures

	yi	Pc (Mpa)	Tc (K)	yiPc	yiTc
H_2	0.0026	3.3798	126.19	0.008787	0.328094
CH_4	0.9261	4.596	190.3	4.256356	176.2368
CO_2	0.0164	7.38	304.1	0.121032	4.98724
C_2H_4	0.0398	5.04	282.4	0.200592	11.23952
H_2S	0.008	8.94	373	0.07152	2.984
C_3H_6	0.0052	4.61	364	0.023972	1.8928
C_4H_8	0.0008	4.02	419.4	0.003216	0.33552
C_4H_{10}	0.0007	3.79	425	0.002653	0.2975
C_5H_{12}	0.0004	3.36	469	0.001344	0.1876
Sum				4.689472	198.4891

	μj	yj	M	M^1/2	μj*y*M^1/2	yj*M^1/2
H_2	0.0000175	0.0026	14	3.741657387	1.70245E-07	0.009728
CH_4	0.0000104	0.9261	16	4	3.85258E-05	3.7044
CO_2	0.0000142	0.0164	44	6.633249581	1.54475E-06	0.108785
C_2H_4	0.0000100	0.0398	28	5.291502622	2.10602E-06	0.210602
H_2S	0.0000122	0.008	34	5.830951895	5.69101E-07	0.046648
C_3H_6	0.0000080	0.0052	42	6.480740698	2.69599E-07	0.0337
C_4H_8	0.0000076	0.0008	56	7.483314774	4.54986E-08	0.005987
C_4H_{10}	0.0000077	0.0007	58	7.615773106	4.1049E-08	0.005331
C_5H_{12}	0.0000064	0.0004	72	8.485281374	2.17223E-08	0.003394

Sum	4.32937E-05	4.128575

$$\mu_1 = \frac{4.32937\text{E}-05}{4.128575} = 1.04864\text{E}-05$$

Lets take an example of dry run at 50 bar, 20% liquid loading and 80% compressor speed;

Gas temperature, T = 33.532 °C, = 306.5K

T_{pc} = 198.4891 K

Tr = 306.5/198.4891

= 1.544

Gas pressure, P = 49.395 bar = 4.94 Mpa

P_{pc} = 4.689472 Mpa

Pr = 4.94/4.689

= 1.054

From figure 5, at Tc = 1.544 and Pc = 1.054, viscosity ratio is about 1.2. Thus,

μ = 1.04864E-05 x 1.2

= 1.248×10^{-5} Pa.s

Viscosity, μ	1.248×10^{-5} Pa.s
IRIS radius, r	0.0381 m
Particle diameter, Dp	50μm
Particle density, ρ_p	1000 kg/m^3
Gas density, ρ	30.95 kg/m^3
Speed of rotation, N	2833 rpm
Angular velocity, ω	2πN/60 = 296 rad/s
v_{tan}	ωr = 296 x 0.0762 = 22.5

$$v_{tR} = \frac{D^2{}_p\ g(\rho_p - \rho)v^2{}_{\tan}}{18\mu r}$$

$$v_{tr} = \frac{(20\times10^{-6})^2 \times 9.81\times(1000-30.95)\times22.5^2}{18(1.248\times10^{-5})0.0381} = 56.31m/s$$

The table below summarizes the radial velocity for different pressure at constant liquid loading and compressor speed.

Table 15: Radial velocity at different pressure

Pressure,P	**Radial Velocity, V_{tr} (m/s)**
40	23.41
50	56.31
60	63.56

As pressure an increase, the radial velocity of gas is increasing, thus will result in faster IRIS rotation. Thus, more energy is exerted on the blade resulting in higher separation efficiency.

CHAPTER 7

CONCLUSION

Theoretically, mass flow of natural gas is increased whenever the system pressure is increased which is the higher the pressure in the reservoir, the faster the gas flow. Based on the experiment done under dry condition, it is proved that the mass flow is increased with system pressure. Thus, first objective that is to determine the effect of mass flow is then satisfied.

During wet run, the effect of pressure on mass flow of gas is still valid. The second objective of this experiment is to study the effect of pressure variant towards the separation efficiency. Ftom the grah plotted in section 5.2.1, the separation efficiency is increased with pressure. The velocity of gas also increase with pressure, thus the natural gas must be directed to the IRIS at high pressure to achieve good separation efficiency. The terminal redial velocity is also higher when pressure increases resulting in faster rotation of IRIS blade.

As a conclusion, the separation efficiency of natural gas is higher at higher system pressure and varies with the change of liquid loading and compressor speed.

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