Dehydration of Natural Gas Via High Centrifugal Forces: Effect of Water Loading on Separation Efficiency

by

Amzar bin Abdul Aziz

Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Lau Kok Keong)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

CERTIFICATION OF ORIGINALITY

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

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AMZAR BIN ABDUL AZIZ

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Abstract

Moisture content in natural gases has an effect on separation process where it will depend on the separator efficiency to do the separation in order to remove moisture from the natural gas. Current methods that already been used for dehydration of natural gas are Joule Thomson Expansion, Solid desiccant dehydration and Liquid desiccant dehydration. Therefore, this project initiated to test on centrifugal force for dehydration of natural gas.

The objective of this project is to study the effect of moisture content in natural gas for separation process. A series of experiments will be carried out to study the effect of moisture on the separation process where the amount of moisture will be varied for each experiment. The prototype of the equipment is already been built. Therefore, the efficiency of the equipment will be tested and the results will be recorded. Then, the collected results will be analyzed to see what is the effect of the moisture content towards the efficiency of the equipment. Based on the results collected, the efficiency of the separation are determined which are based on the water collected from the water collection tank and it will be compared with the amount of water being supplied. The results shown as the water loading increases the separation efficiency of separation also increases.

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CHAPTER 1

INTRODUCTION

1.1 Summary

In this paper, a study is being done on centrifugal force to be used in separation of liquid (water) from natural gas or also known as dehydration of natural gas. Therefore, a prototype has been developed where the centrifugal separator is being attached to a system which is functioning to do dehydration of natural gas. Since the experiment need to simulate the real process which is natural gas mixed with water vapor, therefore the system were added with spray system where the water will be injected and the high pressure gas storage tank where the natural gas is stored. In **chapter 1**, a briefly explanation regarding the current methods that been used in industry will be done and what are the pros and cons of the current methods and what are the reason for the new method being proposed in this project. Here, the case study will be described the objectives of this project which is to study the effect of few parameters towards separation efficiency. The scope of study is narrowed down to study the effect of water loading on separation. In **chapter 2**, literature review on the journals and experiment reports that are related to separation process. The literature review are found based on journals and experiment reports that are related to the project which are using centrifugal force and study on water loading effect. The water loading effect can cover a large scope which is like effect of particle size of the water since it will affect the efficiency of the separator. Besides that there are also journals that did research on other types of centrifugal separator since this type of force can be used depend on the usage of the equipment whether in food industries or in oil and gas industries. In this chapter, it will be more focused on research that related to oil and gas application such as reinjection of gas into gas well. In **chapter 3**, there will be explanation on methodology of the experiment where it will briefly describe on how exactly the experiment is conducted. In this project, the experiment is done on a prototype system where the same system will be applied on the platform to do dehydration of natural gas. The operating condition for the experiment will be varied by referring to the current operating condition at the oil and gas platform. There also will be some description on the process and operation condition such as the temperature of supplied gas and water loading. In this chapter also will be described about the operating condition for certain equipments that involved during the process and what are the parameters that need to be observed and controlled during the experiment.

1.2 Background

Natural gas, as it is obtained from underground sources, contains water in varying amounts. This water can lead to corrosion and obstruction of valves and fittings in transmission lines due to condensation [1] . Natural gas in transit to market should be dehydrated to a controlled water content to avoid hydrate as well as to minimize the corrosion problems. Often hydrogen sulfide is present in field gases and has to be removed to a specific level (0.1 to 0.25 grain per 100 scf) because of its toxicity. Carbon dioxide is corrosive diluents, but it has a value for some enhanced oil recovery processes and is included in acid gas removal processes [2]. A variety of processes have been developed to reduce the water content. Currently there are three methods that already been applied to reduce the amount of water content in natural gas which are:

1. Joule-Thomson Expansion
2. Solid Desiccant Dehydration
3. Liquid Desiccant Dehydration

Joule-Thomson Expansion utilizes temperature drop to remove condensed water to yield dehydrated natural gas. The principal is the same as the removal of humidity from outside air as a result of air conditioning in your house. In some cases glycol may be injected into the gas stream ahead of the heat exchanger to achieve lower temperatures before expansion into a low temperature separator [3].

Solid desiccant dehydration, also known as solid bed, employs the principal of adsorption to remove water vapor. Adsorbents used include silica gel (most commonly used), molecular sieve (common in NGV dryers), activated alumina and activated carbon. The wet gas enters into an inlet separator to insure removal of contaminants and free water. The gas stream is then directed into an adsorption tower where the water is adsorbed by the desiccant. When the adsorption tower approaches maximum loading, the gas stream is automatically switched to another tower allowing the first tower to be regenerated [4].

The third method of dehydration is via liquid desiccant and is most common in the Northeast United States. This method removes water from the gas stream by counter current contact in a tray type contactor tower with tri-ethylene glycol (TEG). Natural gas enters the unit at the bottom of the adsorber tower and rises through the tower were it intimately contacted with the TEG solution flowing downward across bubble trays. Through this contact, the gas gives up its water vapor to the TEG. The water laden TEG is circulated in a closed system, where the water is boiled from the TEG. The regenerated TEG then is recirculated to the contacting tower [5].

Currently, the separation process using high centrifugal forces is used for reinjection process. It is also been used in food industries and biotechnology industries. Since there were claims made on the capability of certain centrifugal equipment in removing moisture from natural gas. A research on separation process using centrifugal forces is carried out. The reasons of this research is carried out is that to minimize the space usage on platform and to study the efficiency of this process to be used.

1.3 Problem Statement

In oil and gas industry, they are dealing with lots of separation processes and one of the process is using High centrifugal force for reinjection of natural gas into an underground reservoir. Gas reinjection is the reinjection of natural gas into an underground reservoir, typically one already containing both natural gas and crude oil, in order to increase the pressure within the reservoir and thus induce the flow of crude oil or else sequester gas that cannot be exported. This is not to be confused with gas lift, where gas is injected into the annulus of the well rather than the reservoir. After the crude has been pumped out, the natural gas is once again recovered. Since many of the wells found around the world contain heavy crude, this process increases their production. Most of the oil and gas company are using this method and there are ExxonMobil, Royal Dutch Shell, Talisman and PETRONAS.

In this project, the method that been used is dehydration using high centrifugal force. Since there were claims made on the capability of certain centrifugal equipment in removing moisture from natural gas. Therefore the project is carried out to test the efficiency of centrifugal equipment in separation of moisture in natural gas and it also purposely to study the factors that influence the separation efficiency of moisture removal from gas using centrifugal forces.

For this project, test rig already been installed and ready to be tested. Therefore, with the test rig that already been provided, there are a few testing need to be run to study the factors that affect the efficiency of separation process using high centrifugal forces.

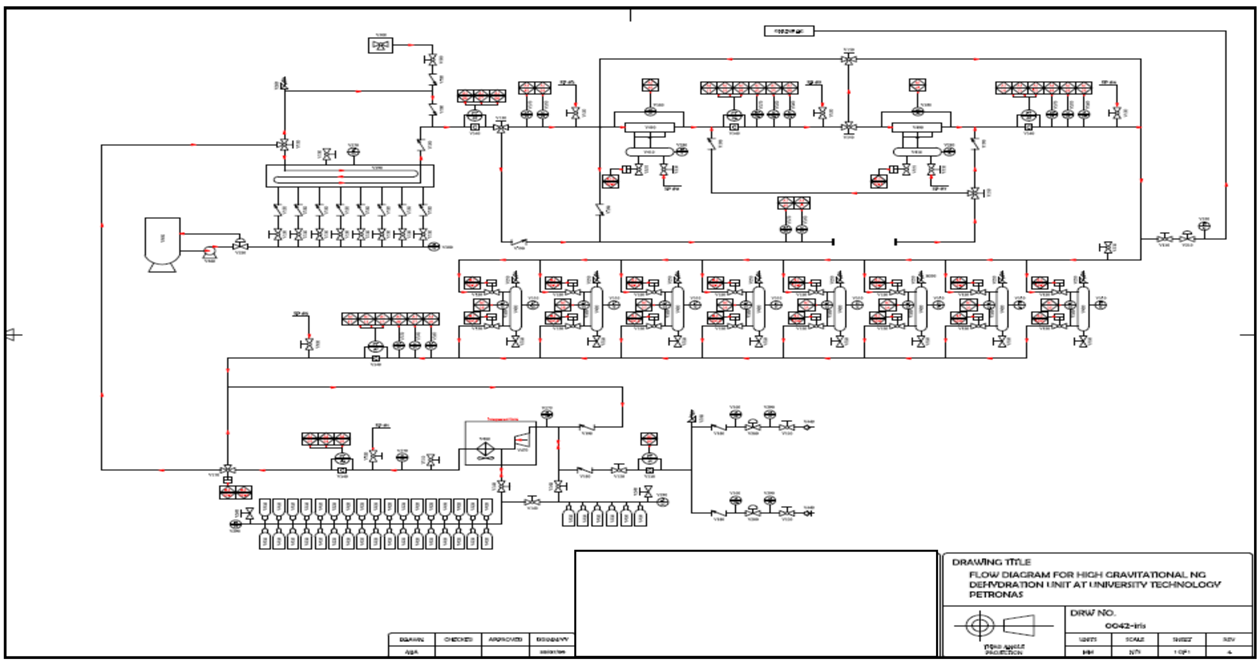

Figure 1: **P&ID**

1.4 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 [7]. Therefore the research project on centrifugal force as separation process for natural gas is conducted. In this project, there are four factors that are been studied which is :

1. To study the effect of inlet gas velocity (i.e. compressor speed) on separation efficiency at fixed liquid loading, operating pressure and temperature
2. To study the effect of liquid loading on separation efficiency at fixed compressor speed, system pressure and temperature
3. To study the effect of temperature on separation efficiency at fixed system pressure, inlet gas velocity and liquid loading
4. To study the effect of system pressure on separation efficiency at fixed liquid loading, compressor speed and temperature

Lastly, statistical analysis will be done of operating condition for optimum separation efficiency using Minitab.

1.5 Scope of study

In this project, it will be focusing on second factor listed above which is to study the effect of liquid loading on separation process. To study the effect, the other parameters need to be remained constant throughout the experiment. In this study, the amount of liquid loading will vary from 10% to 30% amount of water based on the flow rate of the natural gas which means:

e.g. : average flow rate of natural gas : 2351.38 kg/hr

Let say the experiment is going to be run at 20% liquid loading. Therefore the amount of water that is going to be injected into the natural gas stream is:

2351.38 kg/hr x 20% = **470.276 kg/hr of water vapor**

Since the unit had been used for flow meter is in L/min. Therefore, the unit needs to be converted.

470.276 kg/hr x L/kg x 1 hr/60min = **7.837 L/min**

This experiment will determine the efficiency of the separator at different amount of water loading. From the results collected, the data also will be analyzed to find other relation on water loading that can affect separation efficiency such as size particle of the liquid or water since the size of the liquid particle is not constant as we increase the percentage of the liquid loading. This is also affected by how many valves that been opened during the experiment.

CHAPTER 2

LITERATURE REVIEW

The technology is especially costly for offshore operations: the required size and weight are a major burden for naval structures. The need to exploit offshore oil reserves, as well as to cut down equipment costs, have been motivating the research on new, compact, gas–liquid separation techniques[8]. In various applications two phase gas-liquid flows have to be separated. For that purpose, static gravity separators are often used. For this reason intensive effort has been undertaken to develop separation techniques that use centrifugal forces in order to reduce their dimensions. A new concept for transient gas-liquid separation is based on a rotary pump with gas-separation inside the impeller. It consists of a stationary casing and a rotating shaft with an impeller. In contrast to the impeller of a centrifugal pump, this impeller is open on both sides. The liquid is forced through the impeller into a ring chamber by means of centrifugal forces and the pressure is increased. The gas penetrates the impeller in the axial direction and leaves the separator. If the flow that enters the separator is intermittent, the liquid flow rate has to be damped in order to obtain a steady liquid outflow with low pressure fluctuations behind the impeller. The liquid flow fluctuations are moderated using a variable positioning of the interface between gas and liquid inside the impeller. A further separation of solid particles from the liquid is additionally obtained through a centrifuge mounted below the impeller [9].

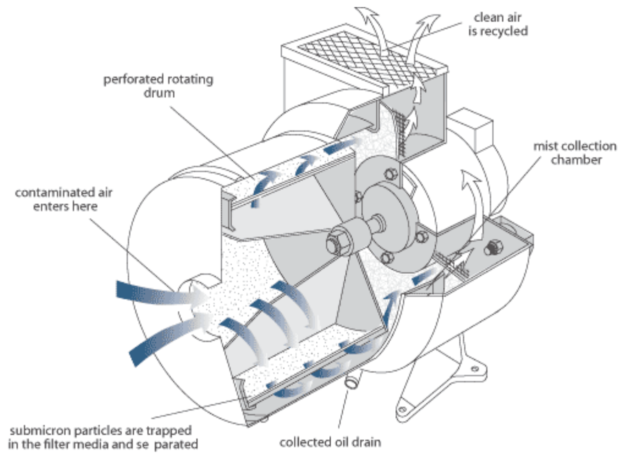

Figure 2: Centrifugal separator mist eliminator

(taken from: BPA (Industry expert reviews and comparison)

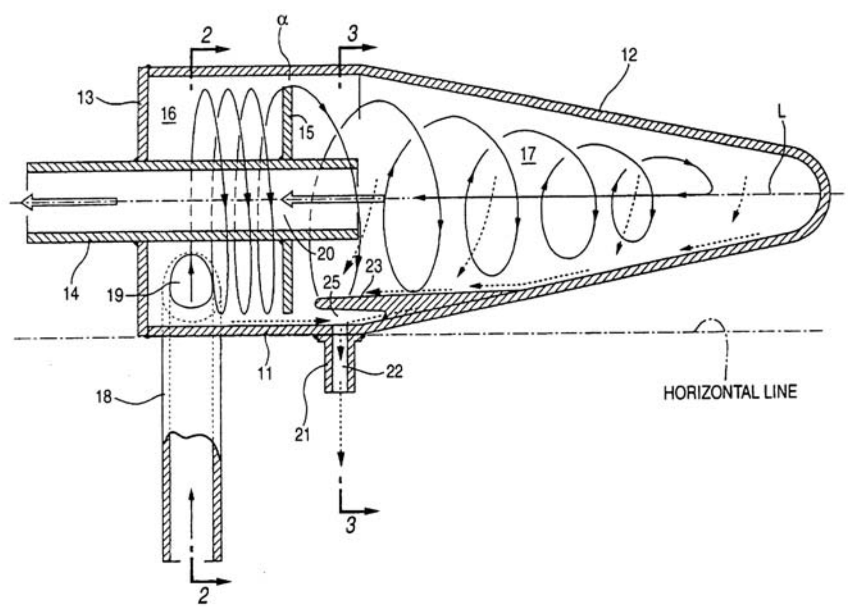

Figure 3: Centrifugal air-oil separator [10]

The same concept of centrifugal force is being used in this research to study the performance of separation done by using this process.

The use of centrifugal forces to separate fluids is a prove since it been used by many industries. The process can be described as an object (in this case the object is the water or vapor) of known weight that held in a circular path by a string of known length, and the weight is moving at constant speed. The inward force that is developed is known as the centripetal force. The equal and opposite reaction that is in outward direction is known as centrifugal force. This is the force that we use to separate gas well fluids in centrifugal separator [6].

The flowing pressure at the wellhead furnishes the energy for the process. Upon expansion to lower pressure at the wellhead choke, the natural gas, condensate and water flow to the centrifugal separator for rotation and subsequent separation. The fluids tend to separate layers of uniform density. Water collects on the internal surface of the separator, condensate flows on the water and the gas flows in a circular pattern in the center.

The separation also depend on the size of the particle where in this case is the size of water vapor will affect the efficiency of the separator. In the experiment, the size of water particle is maintained within 0.5 microns which is based on the current operation condition at platform.

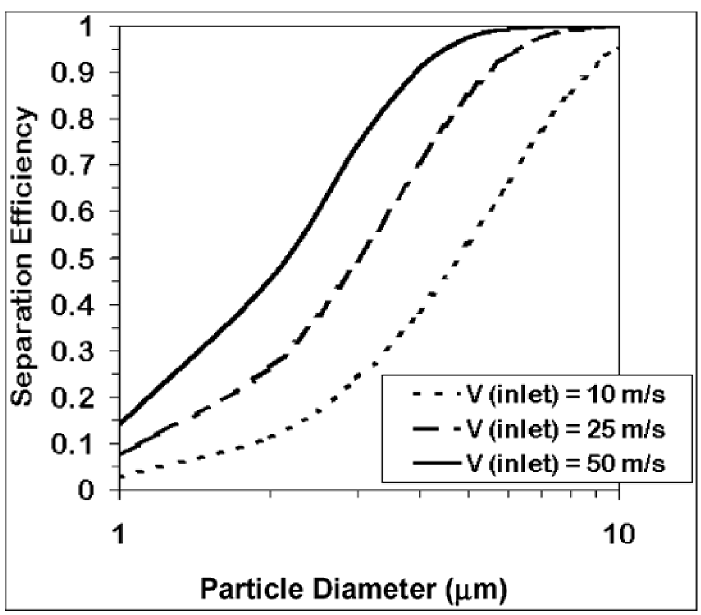

Figure 4: Separation efficiency vs particle diameter

The rotational particle separator was introduced as a new technique for separating solid and or liquid particles of 1 μm and larger from gases. The technique can be used as an alternative to the current methods that been used in many industries which are based on application of filter media, electrostatic precipitation, or wet scrubbing. Practical designs of the rotational particle separator available on the market include equipment for purifying gases of industrial processes and portable air cleaners for appliances [13].

The core component of the rotational particle separator is the rotating filter element (fig.5). It consist of a large number of axially oriented channels which rotate as a whole around a common axis. Solid and or liquid particle material present in the gas flowing through the channels is centrifuged towards the outer collecting walls (fig. 6). The purified gas leaves the channels while separated particles material adheres to the collecting walls as a result of centrifugal forces, Van der Waals forces and or forces due to surface tension.

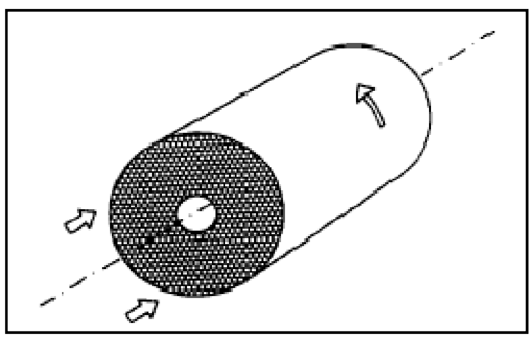

Figure 5 : Filter element of rotational separator

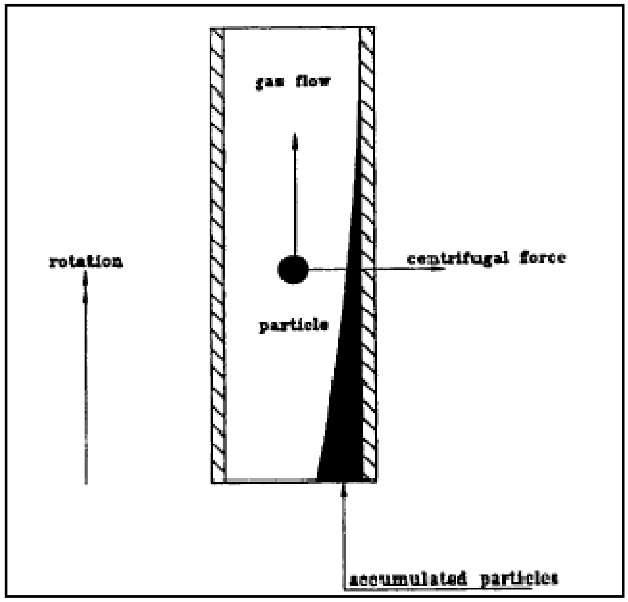

Figure 6 : Particle Separation in a channel of the rotational particle separator

In the paper, the process is further explained on how the separation occur. The channels of the rotational separator are designed such that laminar flow exists. Having a laminar flow in the process is important since the turbular flow can affect the separation efficiency where the liquid particle might be separated from the gas phase before it reaches the separator. At entry or soon after, the gas will co-rotate with the filter element and flow in axial direction parallel to the walls of the channels. In this process, we are also concerned about the size of the particle since the working principal of the separation process using high centrifugal force need an inertia for the separation to occur. With high centrifugal force, there are possibilities that separation can occur. Particles can be assumed to follow the streamlines of the gas with the exception of the radial direction where as a result of the centrifugal force, particles move radially relative to the gas. The velocity at which particles move radially can be calculated on the basis of equilibrium between the centrifugal force and the drag force according to Stokes' law. Stokes' law describes the resistance due to the relative motion between a particle and the gas. The expression of equilibrium of force is shown in the equation below :

$$\frac{\pi}{6}\rho_P d_P^3 \Omega^2 r = 3\pi\eta d_P u_P \qquad [1]$$

ρ_P - Specific mass of the particle

Ω - Angular velocity

d_P – Particle diameter

r - Distance between the channel and rotation axis

η - Dynamic viscosity

u_P – Radial velocity of the particle

Whether a particle reaches the outer collecting wall of the channel depends on the residence time in the channel and the radial distance to be travelled by the particle. The smallest particle which is just able to reach the outer collecting wall with 100% probability is the particle which in the available time moves over a radial distance corresponding to the maximum height of the channel.

Analysis on the application of high-gravitational forces for natural gas dehydration

Water exists in natural gas stream in two forms – as free water and as water vapour. Free water refers to water that exists in liquid form. Water vapour however, exists in equilibrium with natural gas due to the interactive forces between molecules – in particular the hydrogen and van der Waals forces.

Terms of separation based on high-gravitational concept, the separation efficiency depends largely on the density difference between the particles or phases. Equation 1 gives the expression to calculate the settling velocity of the particles of interest, which is directly proportional to the density difference. The value of settling velocity indicates the ease of separation of the particles, i.e. the higher the value of settling velocity, the easier the degree of separation. In this case study, the concern is more to the water in vapor state which is very important to be separated from the natural. The free water is less concern since it can be easily separated using gravitational force and design of the compact high centrifugal force separator allow the water to flow down into a pipeline that connected to knockout drum (water tank collector).

Two methods then exists in separating water vapour from natural gas – the first method involved forcing the water vapour to form liquid, where separation can then be achieved via centrifugal forces, or utilizing the physical and chemical properties of the gases by removing water vapour through absorption, adsorption or membrane processes. As mentioned earlier, water vapour exists in equilibrium with natural gas. A favourable environment is then required to evoke the equilibrium condition, thus forcing some of the water vapour to form liquid. This can be achieved via 2 means – reduction in temperature or reduction in pressure. Reducing the temperature or pressure to the right level will force condensation to take place [11].

$$v_t = \frac{\omega^2 r D_p^2 \left(\rho_p - \rho\right)}{18\mu} \qquad [2]$$

Liquid Entrainment in the Inlet Pipe.

The liquid droplet entrainment in the gas core at the inlet section is an important parameter for predicting the liquid phase split and separation efficiency. Meng et al.conducted experimental studies of low liquid loading gas-liquid flow in near-horizontal pipes. Based on their data, the liquid droplet entrainment fraction for slightly inclined pipe can be above 80% for high gas velocities. Correlation developed by Ishii and Mishiam matched the experimental data of Meng et al. only for entrainment fractions less than 40%. At present, no correlation is available for high entrainment rates [12].

Inlet Nozzle Analysis.

A mechanistic model to determine liquid film and gas core velocities through the inlet nozzle was developed by Gomez et al. The model is flow pattern dependent, which considers the annular and mist flow patterns. This model provides the liquid film analysis and gas core analysis, where the liquid entrainment, as suggested by Gomez et al., is determined by Wallis correlation [12].

Gas Swirling Flow Characterization.

The inlet nozzle analysis will provide the gas and liquid tangential velocities and the liquid

droplet separation process. The gas upward swirling flow model can be used to predict the minimum droplet size being forced to the GLCC wall. A concept to quantify the swirling decay along the upper part of the GLCC was suggested by Chang and Dhir. They considered a local swirl intensity factor, V, which is defined as the ratio of tangential momentum flux to axial momentum flux at a given cross section [12].
The expression for drag coefficient, C_d, as suggested by Magnaudet is given as,

$$Cd = \frac{24}{\text{Re}}(1 + 0.15\,\text{Re}^{0.687}) \qquad [3]$$

where *Re* is the Reynolds number of the droplet, which is calculated based on diameter, d_d , density, r $_d$, and the resultant relative velocity, v_{dd} , of the droplet, and the viscosity of the continuous phase, m*g* . The applicable range of Reynolds number for the above correlation is from 1 to 1000 [12].

Chapter 3

Methodology

In this project, a few experiments are going to be conducted to study the efficiency of the equipment to do separation process. In this study, it will be more focused on the water loading where the amount of water loading will be varied while the other parameters will be remained constant throughout the experiments. These are purposely to observe the effect of water loading alone on the performance of the separator.

Experiment procedure :

Before the experiment is started, the required operating condition need to be decided.

e.g	Operating pressure	: 40 bar – 60 bar
	Compressor speed	: 80%
	Water loading	: 10% - 30%
	Amount of water added	: 50 Liter

At first stage, the test rig or prototype is tested with dry run where the process will run with dry gas only without having water addition. This is purposely to have reference point for the experiments with wet run so that it can assure that the system is back to its original state or condition after the process is finished. In this case study, the experiment is done on certain operating pressure. The only parameter that will be varied is that the liquid loading. Since this process is operating at high pressure which is range from 40 - 60 bar. The operating pressure need to be increased slowly in order to avoid a sudden shock of pressure to the system which can be catastrophic. When the system is co nfirm stable, a few readings need to be monitor throughout the experiment which are compact centrifugal separator speed, moisture analyzer, level of knockout drum (water collection tank) and operating pressure before and after the compact centrifugal separator. Since there is two compact centrifugal separator in the system, there will be three point of pressure readings need to be observed. Then, from the flowrate of gas, the amount of water loading can be determined based on percentage of water loading for the experiment.

e.g. : average flow rate of natural gas : 2351.38 kg/hr

Let say the experiment is going to be run at 20% liquid loading. Therefore the amount of water that is going to be injected into the natural gas stream is:

2351.38 kg/hr x 20% = **470.276 kg/hr of water vapor**

Since the unit had been used for flow meter is in L/min. Therefore, the unit needs to be converted.

470.276 kg/hr x L/kg x 1 hr/60min = **7.837 L/min**

During the water addition is done, the same readings need to be taken to see if there is any different in term of moisture analyzer reading and compact centrifugal separator speed.

After the experiment has finished, the data collected will be analyzed. From the data, the separation efficiency can be calculated based on total amount of water that been injected into the gas stream. The patern of compact centrifugal separator (centrifugal separator) also can be studied based on its speed before water addition, during water addition and after water addition. The size of the liquid particle also need to be consider because there will be different in term of size of the particle when the water is injected into the pipeline.

Gantt Chart

Experiment	July				August				September				October				November			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Continue on run experiments																				
Analyzing data																				
Progress report I																				
Progress report II																				
Poster presentation																				
Dessertation																				
Oral presentation																				

Table 1: FYP schedule

CHAPTER 4

RESULTS

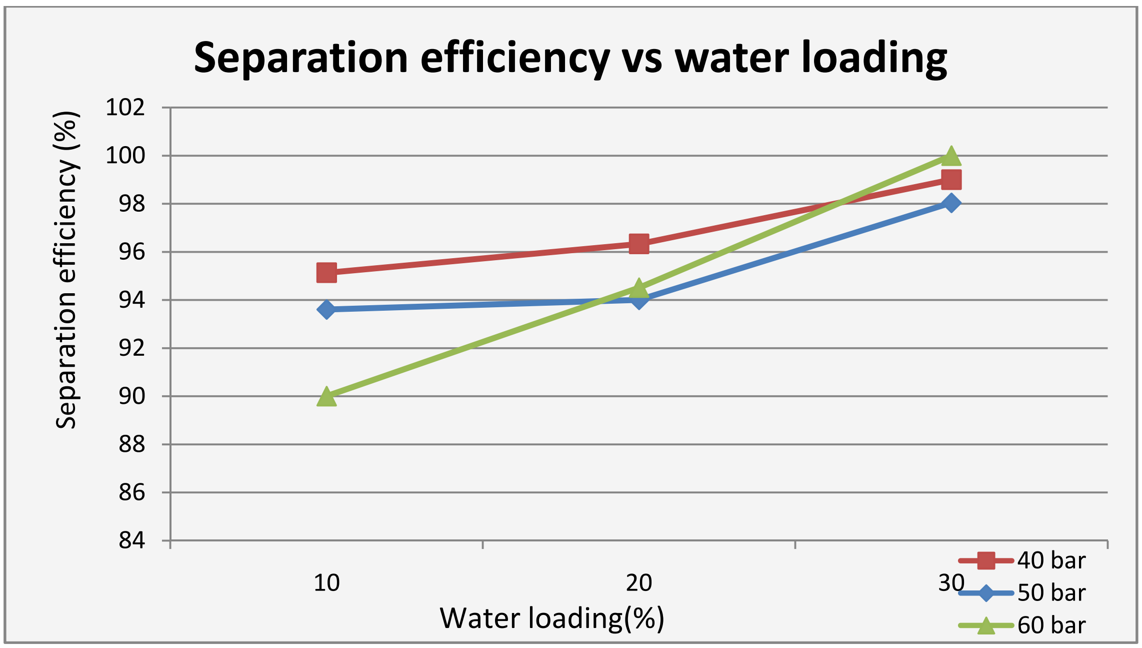

Figure 7 : Separation efficiency vs water loading

Based on the graph above, the results show that the separation efficiency is increasing as the percentage of water loading is increasing. The experiments are operated at three different pressures which are at 40 bar, 50 bar and 60 bar and at all of the set up pressure, the pattern of separation efficiency for the compact centrifugal separator shows an increment in separation efficiency.

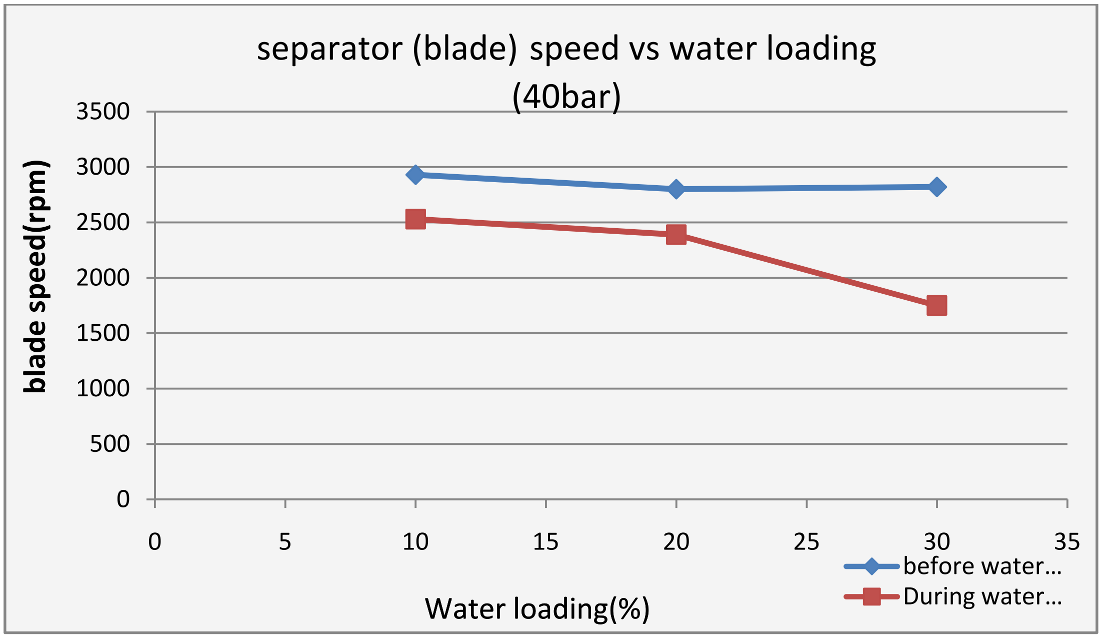

Figure 8: separator (blade) speed vs water loading

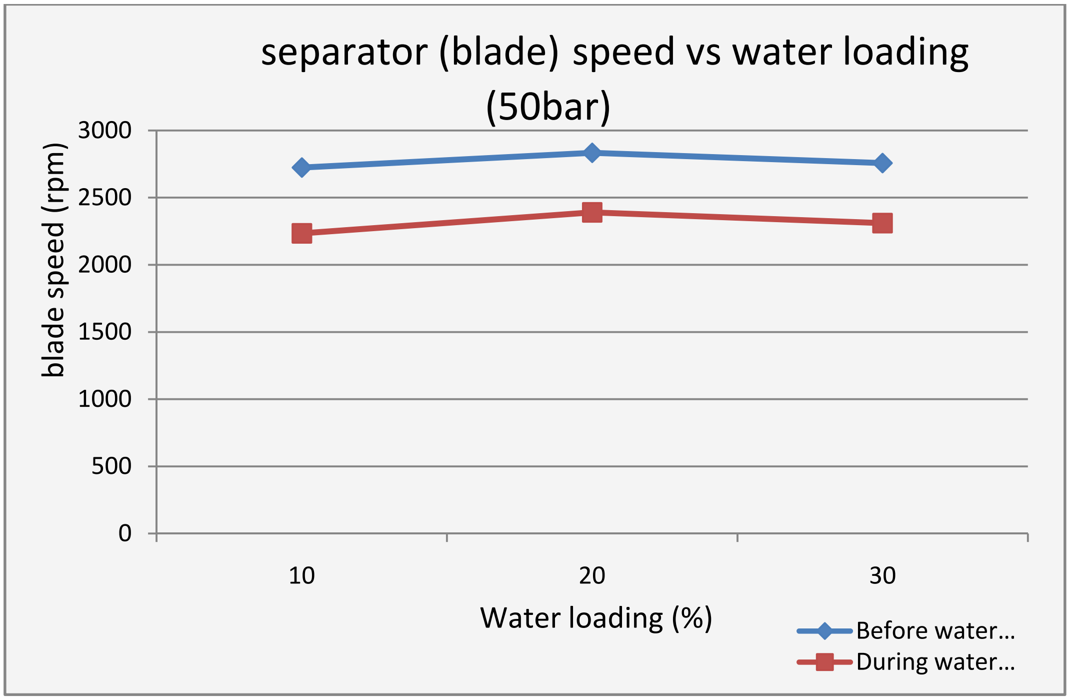

Figure 9 : separator (blade) speed vs water loading

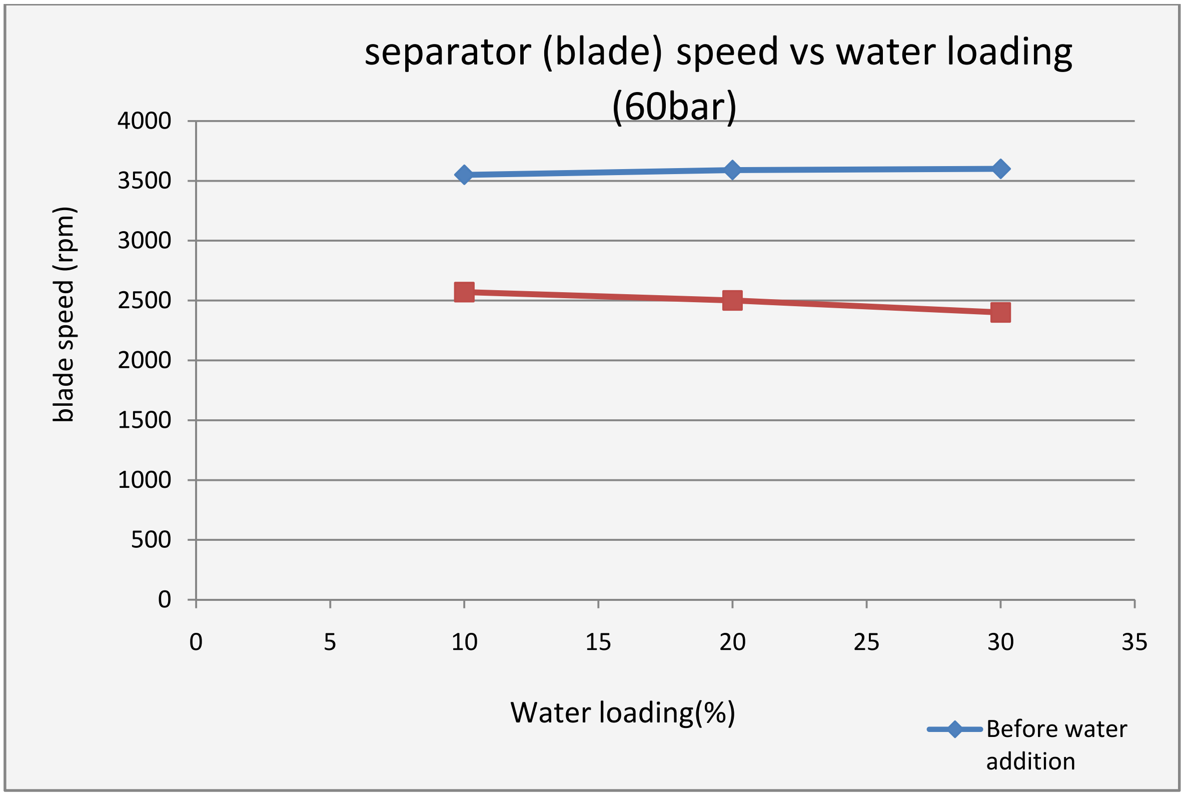

Figure 10 : separator (blade) speed vs water loading

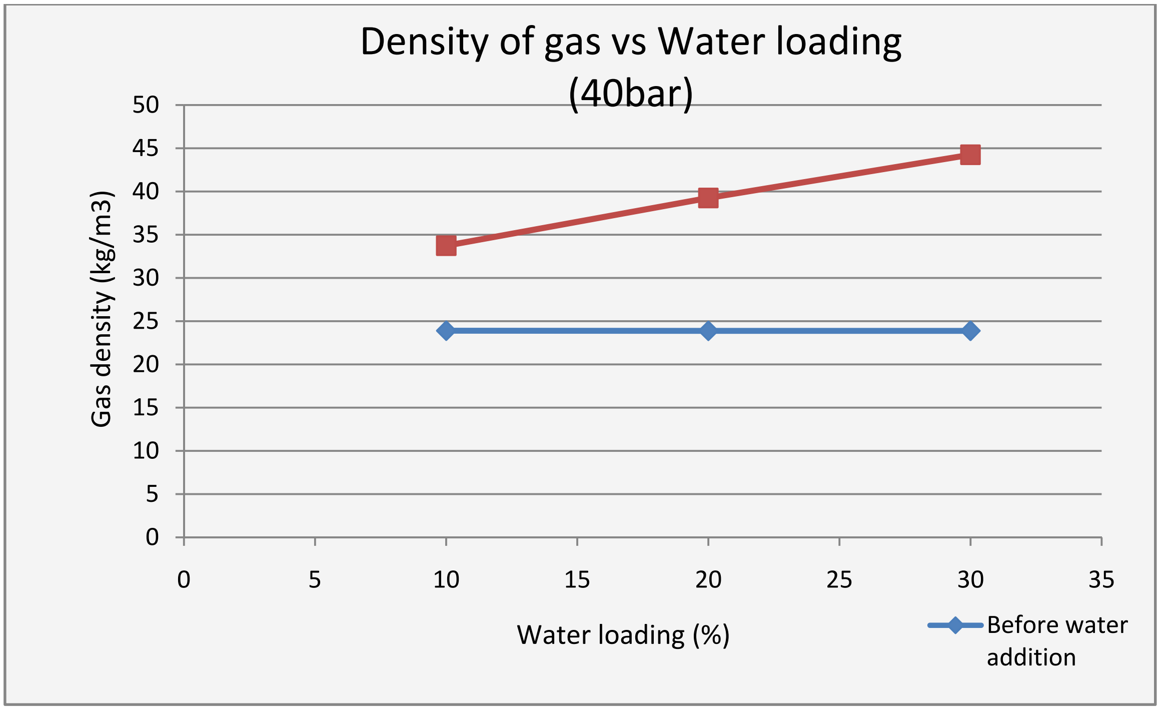

Figure 11 : Gas density vs water loading

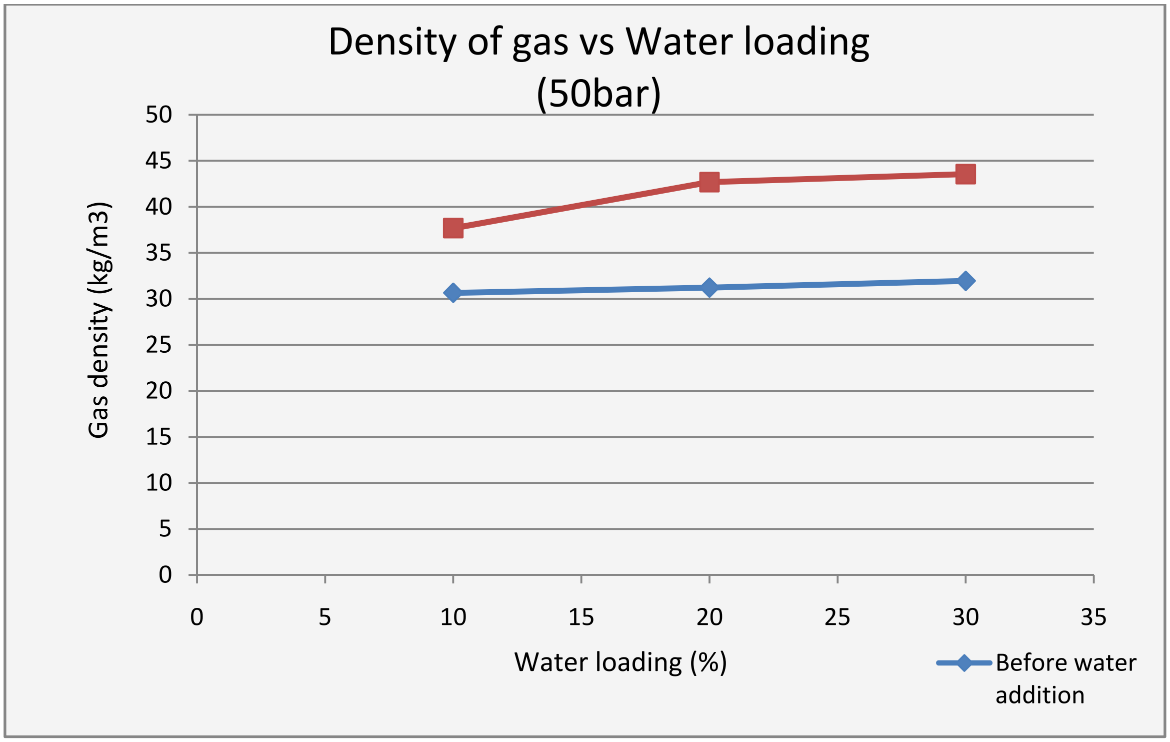

Figure 12 : Gas density vs water loading

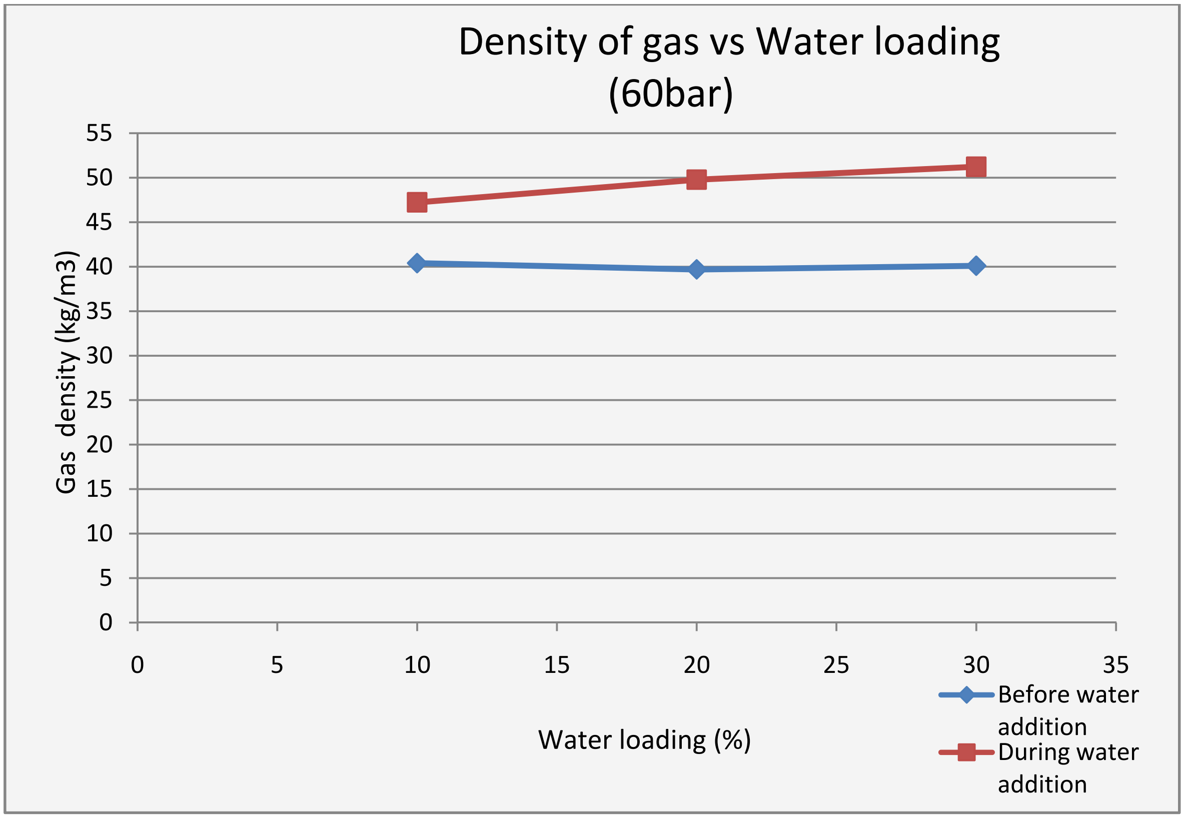

Figure 11 : Gas density vs water loading

CHAPTER 5

DISCUSSION

Based on the results that have been collected, the data are divided into three which are:

- Separation efficiency vs water loading
- blade speed vs water loading
- Gas density vs water loading

Based on figure 5 (Separation efficiency vs water loading), the graph shows that the efficiency of the separator is increasing as the water loading increase. The results show the same pattern at all tested pressures which are increasing in separation efficiency with the increasing of water loading. This results can be explained by referring to the Stoke's Law :

$$F_d = 6\pi \eta R V \qquad [4]$$

Stoke's law is only applied for laminar flow which has a very small Reynold's number. Therefore, in this experiment we assumed that the flow of the natural gas is in laminar flow which occurs in a straight pipeline. The other reason is that, the water vapor is dispersed into the natural gas with a very small size which is range around 10 microns. From the Stoke's law, the settling velocity can be derived where the equation can determine the time taken for the water to settle down.

$$v_t = \frac{\omega^2 r D_p^2 (\rho_p - \rho)}{18\mu} \qquad [5]$$

Based on the equation, with a significant different in density between the gas mixture and the initial gas density will lead to higher efficiency in separation and easier to separate the water vapor from the natural gas. The size of the particle also can affect the separation efficiency where in this case the particle is referring to the water vapor. The larger the size of the particle, the easier separation can be done. This is because of the larger particle will contain higher density compared to the smaller one. Therefore, by using centrifugal force method as separation, the separation will lead to a higher separation efficiency.

In deriving an expression for the radial migration velocity of particles in a centrifugal field (see Equation 1), Stokes' Law is used to describe the resistance force acting on the particle in the case of relative movement. Stokes' Law however, does not take into account the effects of molecular flow apparent when the particle diameter becomes of the same order of magnitude or smaller than the mean free path of the gas. In that case, Stokes' Law can be corrected using the Cunningham correction factor. The expression for the radial migration velocity given by Eq. 6 becomes, in corrected form,where λ is the mean free path. For example, air at room temperature and pressure, λ = 0.066 µm.

$$u_P = \frac{\rho_P d_P^2 \Omega^2 r}{18\eta} \qquad [6]$$

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