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 specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Nurul Fadhilah Binti Salleh

CERTIFICATION OF APPROVAL

To Determine the Efficiency of Polyacrylamide and PVP as Drag Reducing Agent in Water Flow System

by

Nurul Fadhilah Binti Salleh

A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(PETROLEUM ENGINEERING)

Approved by,

Pn. Mazuin Binti Jasamai

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2012

Abstract

Waterflooding is classified as secondary recovery yields a second batch of oil after a field was depleted by primary production. Working on a water-oil immiscibility concept, the water from injection wells will physically sweep the displaced oil to adjacent production wells. However, due to unforeseen factors, the injection performance may differ from the initially designed injectivity. This research introduces polyacrylamide (PAM) and polyvinylpyrrolidone (PVP) as the drag reducing agent in water flow system. Considering fluid mechanics and polymer studies as the scopes of study that are interrelating, this study aims to perform an experimental analysis to determine the efficiency of polyacrylamide (PAM) and polyvinylpyrrolidone (PVP) as drag reducing agent by manipulating the Reynolds number, polymer concentration, and polymer degradation as the variable parameters. The experimental works start by pumping water from a storage tank and the injection point outlet is opened to introduce the polymer into the flow. The mixture was then allowed to flow through a 4-m galvanized pipe to the outlet and the pressure was observed using an analogue pressure gauge installed at the end of the test flow section. The results show that polyvinylpyrrolidone (PVP) gives the most significant drag reduction percentage. An increased drag reduction percentage was also observed at an increased Reynolds number and polymer concentrations but however, polymer degradation results in a decreased efficiency of drag reduction especially for polyacrylamide (PAM). This study may contribute to an improved water flow system especially for injection wells using polymer-type of drag reducing agent by increasing the injection capacity thus enhancing the efficiency of the designed waterflood system.

Table of Contents

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

List of Figures

List of Tables

Nomenclatures and Abbreviations

ρ	Fluid density
μ	Viscosity
A	Cross-sectional area
D	Pipe diameter.
e/D	Relative roughness
DRA	Drag reducing agent
f	Friction factor
g	Gravity acceleration constant
h	Total head
$NaCl$	Sodium Chloride
N_{Re}	Reynolds number
N_{ReS}	Solvent Reynolds number
P	Pressure
ppm	Parts per million
PVC	Poly-vinyl chloride
PAM	Polyacrylamide
PVP	Polyvinylpyrrolidone
Q	Volumetric flow rate
V	Average fluid velocity
z	Pipe elevation above some datum
%Dr	Drag reduction percentage
ΔP_b	Pressure drop before DRA addition
ΔP_a	Pressure drop after DRA addition

Chapter 1

1.1. Background of Study

In offshore operations, the injection of seawater for pressure maintenance or waterflooding is a common topic nowadays. By taking reservoir properties and expected injection water quality into considerations, a corresponding injection rate can be determined to sustain radial flow for pressure maintenance. The obtained injection rate must be kept maintained to meet the desired pressure maintenance scheme thus any unwanted factors that may contribute to the inefficiency of the system must be avoided.

Among of the factors that may contribute to the system inefficiency is fracturing of which will result in early water breakthrough; out of zone losses and failure in meeting the desired injection rate[1]. The occurrence of the latter may be a result of failure in identifying the possible causes that lead to the decrease of injection performance planned during design phase.

A decline in injectivity in water injection wells can have a large impact on the economic feasibility of offshore water disposal operations thus altering the flow behavior seems to be the most dominant factor in reducing the drag effect in the system. This research introduces polyacrylamide (PAM) and polyvinylpyrrolidone (PVP) as the tested drag reducing agent of polymer types.

It was reported that one successful application of drag reduction polymer was that in the Trans-Alaska Pipeline, where the target discharge of one million barrels per day was obtained without having to construct additional pumping stations[2]. This later brought to a clearer objective of the project; of which to manipulate certain variables in order to vary the flow type in the system and to find the optimum criteria for an efficient drag reduction system using polyacrylamide and polyvinylpyrrolidone (PVP). The identified criteria to be manipulated in this research are Reynolds number, polymer concentration, and polymer degradation.

1.2. Problem Statement

Frictional losses present in injection well supplying water for waterflooding results in a decreased amount of water injected into the reservoir thus influencing the economic feasibility of water injection. This study is aimed to come with an efficient polymer-type of drag reducing agent (DRA) to be applied in water flow system to allow a better derivability of the from system.

1.3. Objectives and Scopes of Study

The objectives of this study are :

- To experimentally study the efficiency of PAM and PVP as drag reducing agent.
- To perform experimental study on the effects Reynolds number and polymer concentration on drag reduction efficiency.
- To study the effect of polymer degradation on drag reduction efficiency.

This study will be involving fluid mechanics mainly in turbulent flow and polymer properties especially for polyacrylamide (PAM) and polyvinylpyrrolidone (PVP).

1.4. Feasibility of the Project within the Scope and Time Frame

The study is feasible to be conducted after considering the followings:

i) Sufficient budget allocation

ii) PVP and PAM are readily available in the market

iii) Numerous related researches and articles available for reference

iv) A well-planned milestones have been set

Chapter 2

2.1. Flow Equation Theory

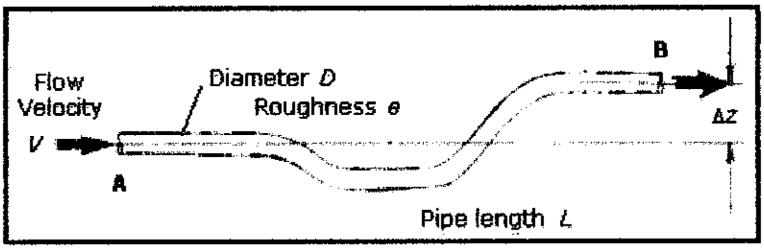


Figure 1: Incompressible flow along a pipe

Changes to inviscid, incompressible flow moving from Point A to Point B along a pipe are described by Bernoulli's equation,

$$h = z(x) + \frac{p(x)}{\rho g} + \frac{V(x)^2}{2g}$$

where p is the pressure, V is the average fluid velocity, ρ is the fluid density, z is the pipe elevation above some datum, and g is the gravity acceleration constant. Bernoulli's equation states that the total head h along a streamline remains constant. This means that velocity head can be converted into gravity head and/or pressure head, such that the total head h stays constant. In this flow, there will be energy lost.

For real viscous fluids, mechanical energy is converted into heat in the viscous boundary layer along the pipe walls and is lost from the flow. Therefore Bernoulli's principle of conserved energy cannot be used to calculate flow parameters. Still, the lost head can be tracked by introducing another term called viscous head into Bernoulli's equation to get,

$$h = z + \frac{p}{\rho g} + \frac{V^2}{2g} + \int_{x_0}^{x} \frac{f}{D} \frac{V(\tilde{x})^2}{2g} d\tilde{x}$$

where D is the pipe diameter. As the flow moves down the pipe, viscous head slowly accumulates taking available head away from the pressure, gravity, and velocity heads. Still, the total head h remains constant.

For pipe flow, we assume that the pipe diameter *D* stays constant. By continuity, we then know that the fluid velocity *V* stays constant along the pipe. With *D* and *V* constant we can integrate the viscous head equation and solve for the pressure at Point B,

$$p_B = p_A - \rho g\left(\Delta z + f\frac{L}{D}\frac{V^2}{2g}\right)$$

where *L* is the pipe length between points A and B, and Dz is the change in pipe elevation ($z_B - z_A$). Note that Dz will be negative if the pipe at B is lower than at A.

The viscous head term is scaled by the pipe friction factor *f*. In general, *f* depends on the Reynolds Number *R* of the pipe flow, and the relative roughness *e*/*D* of the pipe wall,

$$f = f\left(R, \frac{e}{D}\right)$$

The roughness measure *e* is the average size of the bumps on the pipe wall. The relative roughness *e*/*D* is therefore the size of the bumps compared to the diameter of the pipe.

For turbulent flow ($R > 3000$ in pipes), *f* is determined from experimental curve fits. One such fit is provided by Colebrook,

$$\frac{1}{\sqrt{f}} = -2\cdot\log\left(\frac{e/D}{3.7} + \frac{2.51}{R\sqrt{f}}\right)$$

2.2. Literature Review

2.2.1. Polyvinylpyrrolidone (PVP)

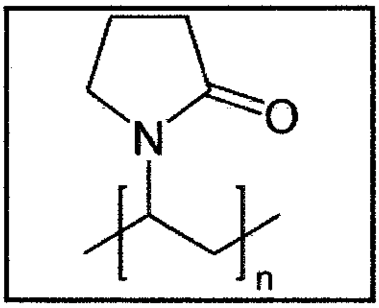


Figure 2: Chemical structure of PVP

PVP, of which is also known as polyvidone, is a water-soluble polymer[3] made from the monomer *N*-vinylpyrrolidone[4] with molecular formula of $(C_6H_9NO)_n$. It is a unique polymer that offers a good initial tack, chemical and biological inertness and is very low in toxicity. The polymer powder is white to light yellow in colour and has a density of 1.2g/cm^3 at standard condition[5] and is widely used in pharmaceutical industry as binder and adhesive[6].

In 1995, an experiment was done and it was found out that inclusion of salts into aqueous PVP solution leads to decreasing of the theta temperature and intrinsic viscosity[7] but this experiment was however conducted using inorganic salt thus the said effects might be differ from tests using tap water.

2.2.2. Polyacrylamide

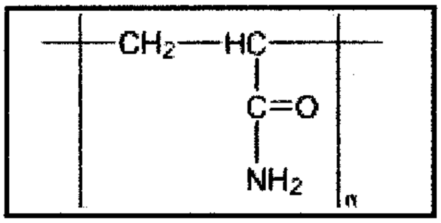


Figure 3: Chemical structure of polyacrylamide

Polyacrylamide is an example of water-soluble polymer[8] with an acrylic group. It is a very hydrophilic polymer which is insensitive to the addition of salts[9]; unlike PVP as mentioned previously, which is really affected with salt addition. This polymer is widely used as flocculent since it has a high affinity to surfaces due to its cationic nature at lower pH values. In a research conducted by P.J. Molloy et al., they used hydrolyzed polyacrylamide for the experiment and found out that the gel shrinking effect will increase with increasing salinity and a decreased volume was observed with increasing temperature[25].

There was another finding claiming that the yield stress of polyacrylamide solution decreases with increasing temperature and descreases with increasing concentration[10]. Another research concluded that mechanical degradation effect increases with decreasing concentration of polyacrylamide in the solution[11] and these findings give a significant hypothesis for this research which will be discussed in Chapter 3.

2.2.3. Experiment parameters

Drag reduction is a near-wall phenomenon and drag reducing agent works only in turbulent flow[12] and this is supported from Gadd's finding where he suggested that the damping of turbulence by polymer additives is due to their high resistance to elongational strain which acts to suppress streak formation and bursting in the near-wall region[13]. T. Al-Wahaibi et al. conducted an experiment in order to study the physical behavior of fluid flow and observed that high polymer concentration appears to damp more the interfacial waves present in the flow. They also observed that the presence of polymer reduces the two-phase pressure gradient and this effect becomes more significant as the water velocity increase[14]. H.A. Al-Anazi et. Al. concluded that DRA is only effective in turbulent flow instead of laminar flow but however, H.A. Abdul Bari et. Al. discovered significant findings where the efficiency of DRA will reach a maximum point at a certain Reynolds number and any further increase in the Reynolds number will result in reduced efficiency[15].

Another research pointed out that there are several factors affecting the performance of DRA, such as molecular weight of polymer, solubility, concentration, cloud point, degradation and flow turbulence[2]. In 2008, H.A. Al-Anazi et. Al. concluded from their experiment that polymer degradation reduces the drag-reducing effect[16] of a flowing system and it is also mentioned in another research paper that polymer solutions are strongly affected by mechanical degradation, which may result in shorter lifetime of drag reduction effectiveness[18] thus it is crucial to study the effect of degradation on the drag reduction efficiency.

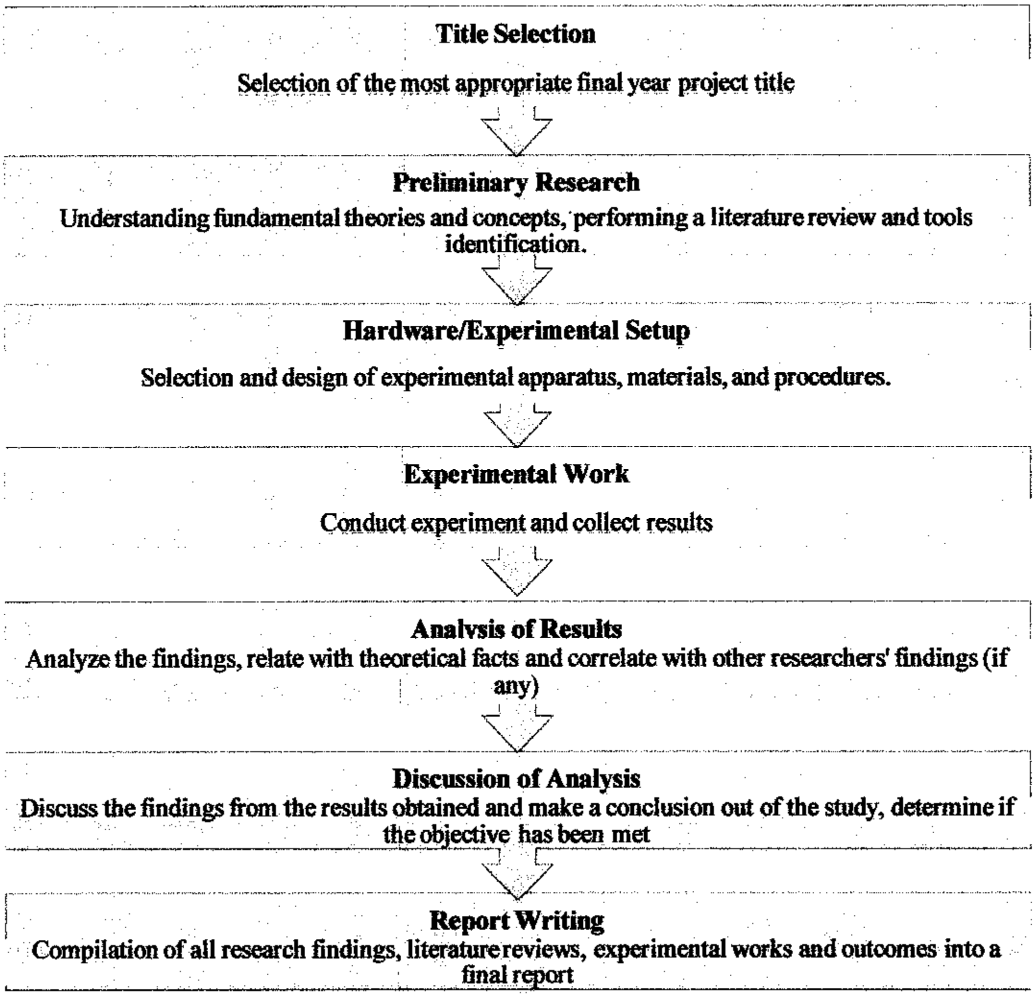
Later in 2009, Ahmed Kamel et. Al. studied the effect of salinity and temperature on drag reduction efficiency and concluded two important findings which are; an increase in temperature and salinity reduces drag reduction efficiency, and the effects of these two variables are only severe at low Reynolds number[18].

Ahmed Kamel's finding on the impact of increasing temperature on DRA efficiency may be explained by a discovery by Rahmat Sadeghi et. Al where they found out that the hydrophobicity of PVP increases with increasing temperature[19]. It may be concluded from these findings that an increase in temperature causes the polymer to mix improperly in the solution thus reduces the drag reducing efficiency of the polymer. In other words, increasing the temperature will cause a decrease in the solvent power of water, which later reduces the interaction between polymers in solution and turbulent flow. This statement is further explained with J. Nelson in a technical paper where it is mentioned that one of the key factors governing the amount of drag reduction achievable in a given system is; the solubility of the polymer in the continuous phase[20]. The effect of temperature on drag reducing agent is also experimented in another research where it is said that an increase in temperature will result in elongational viscosity, which increases small eddies and turbulent fluctuations[21]. These findings were the motivation of conducting the experiment using water at ambient temperature.

Chapter 3

3. <u>Methodology</u>

3.1. Project activities



Title Selection

Selection of the most appropriate final year project title

Preliminary Research

Understanding fundamental theories and concepts, performing a literature review and tools identification.

Hardware/Experimental Setup

Selection and design of experimental apparatus, materials, and procedures.

Experimental Work

Conduct experiment and collect results

Analysis of Results

Analyze the findings, relate with theoretical facts and correlate with other researchers' findings (if any)

Discussion of Analysis

Discuss the findings from the results obtained and make a conclusion out of the study, determine if the objective has been met

Report Writing

Compilation of all research findings, literature reviews, experimental works and outcomes into a final report

Figure 4 : Project work flow

*Gantt Chart for this project is attached in Appendix 1.

3.2. Polymer solution preparation

This experiment will be using PAM and PVP solutions at different concentration ranging from 10ppm to 300ppm. The aqueous solutions were prepared by first weighing the corresponding amount of the polymer needed and later mix polymer powder with distilled water in the beaker using magnetic stirrer at low mixing speed for 30 minutes. For instance, 10ppm polymer solution was prepared by mixing 0.01g of polymer to 1l of distilled water and stir the solution at low speed. In order to simulate polymer degradation in this experiment, the aqueous solutions were prepared in two sets; fresh and degraded polymer, where the fresh polymer solution was prepared by mixing the polymer solution at low speed whilst high speed for the degraded polymer solution. Table 1 gives the concentration values of the solution used in the experiment.

Polymer	Concentration					
	Fresh					
PAM	10ppm	30ppm	50ppm	100ppm	200ppm	300ppm
	Degraded					
	10ppm	30ppm	50ppm	100ppm	200ppm	300ppm
	Fresh					
PVP	10ppm	30ppm	50ppm	100ppm	200ppm	300ppm
	Degraded					
	10ppm	30ppm	50ppm	100ppm	200ppm	300ppm

Table 1 : Solution concentrations of PAM and PVP

3.3. Experimental setup

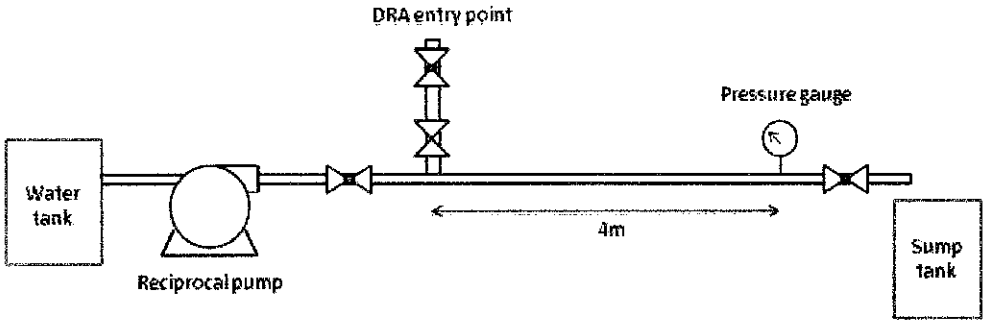


Figure 5: Schematic of experimental setup

The experimental setup used in this study will consist of the following components:

i) A 50 gallon and 200 gallon for fluid mixing and storage
ii) 4-m galvanized pipe at the test section
iii) A reciprocal pump to feed the fluid to the test section
iv) Pressure gauge

The support structure for the test facility consists of a trussed boom and a four-post tower structure to allow sufficient potential energy to feed the reciprocal pump. The test section consists of a 4m long galvanized pipe and the pressure gauge is located at the end of test section where the flow patterns are considered to be fully developed at this location. The test fluid will flow into sump tank where a fluid sample will be taken for further analysis.

The experimental setup is as attached in Appendix 3. The experimental procedure for running the experiment is as following:

i) Before the pump starts, Valve 1 and Valve 4 are ensured opened while Valve 2 and Valve 3 are closed.
ii) The operation begins when the pump is started. Open the DRA point outlet to allow the solution to enter the water flow.
iii) Pressure reading is recorded.
iv) Then, Valve 1 and Valve 4 are closed. Repeat procedure i) to iii) with different polymer solutions.

3.4. Data acquisition and experimental calculations

With the data obtained from the experiment, the following parameters will be required to allow further analysis for the experiment:

i) <u>Solution Reynolds number</u>

This can be calculated using the following equation as follows:

$$\mathrm{Re} = \frac{\rho . \mathrm{V} . \mathrm{D}}{\mu} \quad where\ V = \frac{Q}{A}$$

The fluid volumetric flow rate, Q, was recorded by measuring the time required for the water to fill the water tank at a predetermined volume, v, of $0.025825\mathrm{m}^3$. The predetermined volume, v, is then divided by the time recorded at each run to obtain volumetric flow rate, Q. Numerically,

$$\mathrm{Re} = \frac{\rho . \mathrm{v} . \mathrm{D}}{\mathrm{t} . \mathrm{A} . \mu}$$

where;

$\mathrm{Q} = \ Volumetric\ flow\ rate\ (m^3/s)$

$\rho = \ Fluid\ sample\ density\ (kg/m^3)$

$\mu = Fluid\ sample\ vicosity\ (kg/m.s)$

$t = Time\ (s)$

$v = Predetermined\ volume = 0.025825m^3$

$D = Pipe\ diameter = 0.0254m$

$A = Pipe\ cross\ sectional\ area = 0.00050671m^2$

The density and the viscosity of the fluid is measured by taking a sample after each run and have the samples tested using corresponding measurement equipment. This experiment focus on the effect of drag reduction percentage only in turbulent flow (Re > 4000) thus the volumetric flow rate, Q will be manipulated to achieve a range of Reynolds number to be more than 4000. Providentially, the reciprocal pump used in this experiment is capable of providing turbulent flow in the designed system so there was no further modification needed for the other Reynolds number parameters.

ii) %Dr calculation

Pressure drop reading through the test section prior to and after the addition of polymer solution will be required to calculate the drag reduction percentage (%Dr) as follows:

$$\%Dr = \frac{\Delta P_b - \Delta P_a}{\Delta P_b}$$

iii) Solution rheological parameters

The rheological parameters of the polymer solution and test fluid will be measured to allow further analysis on the effect of the physical properties of the solution on drag reduction performance. The parameters needed to be measured are density and viscosity.

Chapter 4

4. Results an Discussions

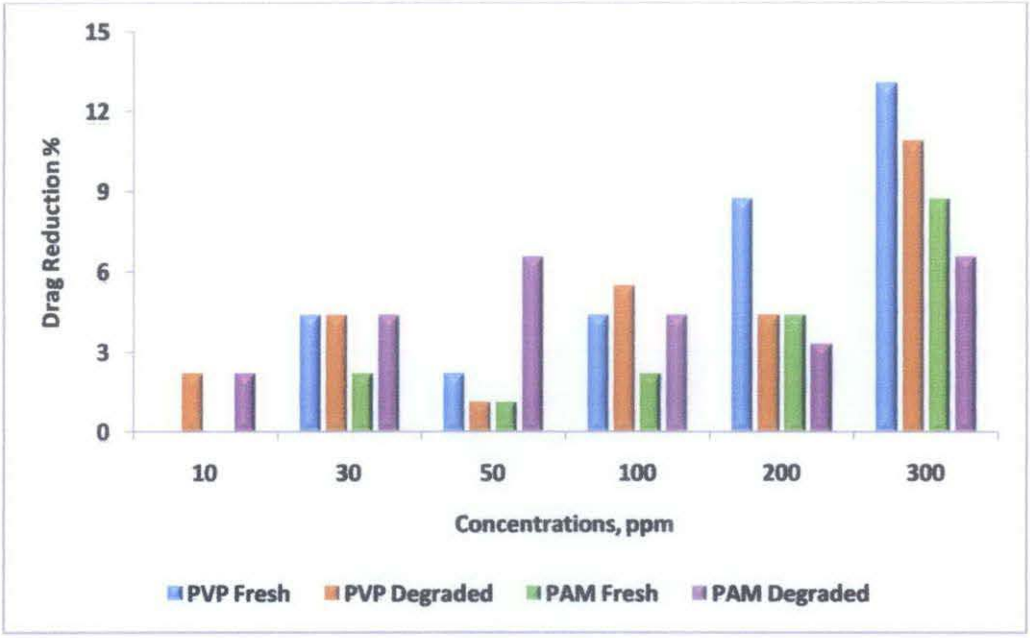


Figure 6 : Comparison of drag reduction efficiency of fresh and degraded polymers with different concentrations at high pump speed

Figure 6 and Figure 7 show the effect of drag reduction efficiency of fresh and degraded polymer in different polymer concentrations at high pump speed. It can be inferred from both graphs that the drag reduction is more significant at high pump speed compared to that of low pump speed. This observation is due to the turbulence level presents in the system of which is crucial in providing a suitable medium for the polymers to be effective. High pump speed results in an increased turbulence level of the flow which consequently causes large eddies to collide thus forming smaller eddies in the flow. The molecules of polymer introduced to the flow will later be part of these eddies, suppressing the eddies thus eventually impede any further formation of eddies.

Figure 7 shows an odd trend of the performance for the two polymers at low pump speed, but however it is obvious that the performance is much lowered than that of the high pump speed. It may be deduced that the eddies formed in the flow by low pump speed do not collide intense enough to form smaller eddies in the flow thus causing the polymer to be less effective.

It can be observed from Figure 6 that at concentrations of 200ppm and 300ppm, fresh PVP gives the highest drag reduction which is at nearly 9% and 13% respectively. On top of that, there is another remarkable finding comparing the two polymers; the drag reduction efficiency of degraded PVP is observed to be at least on par with, or higher than that of fresh PAM for all concentrations tested.

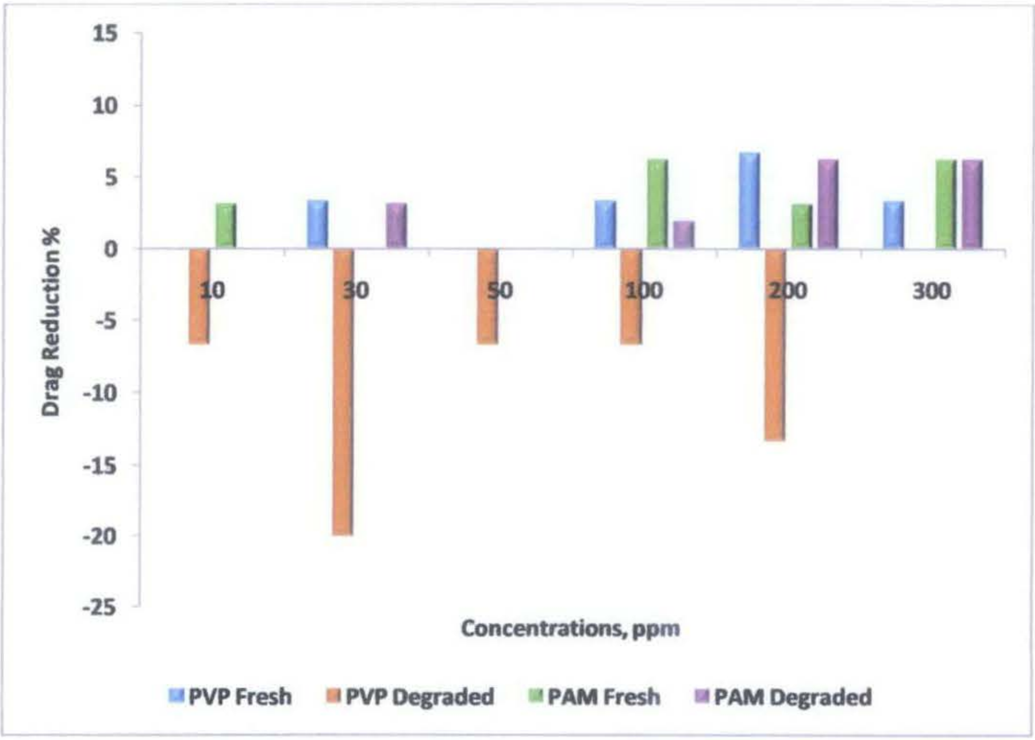


Figure 7 : Comparison of drag reduction efficiency of fresh and degraded polymers with different concentrations at low pump speed

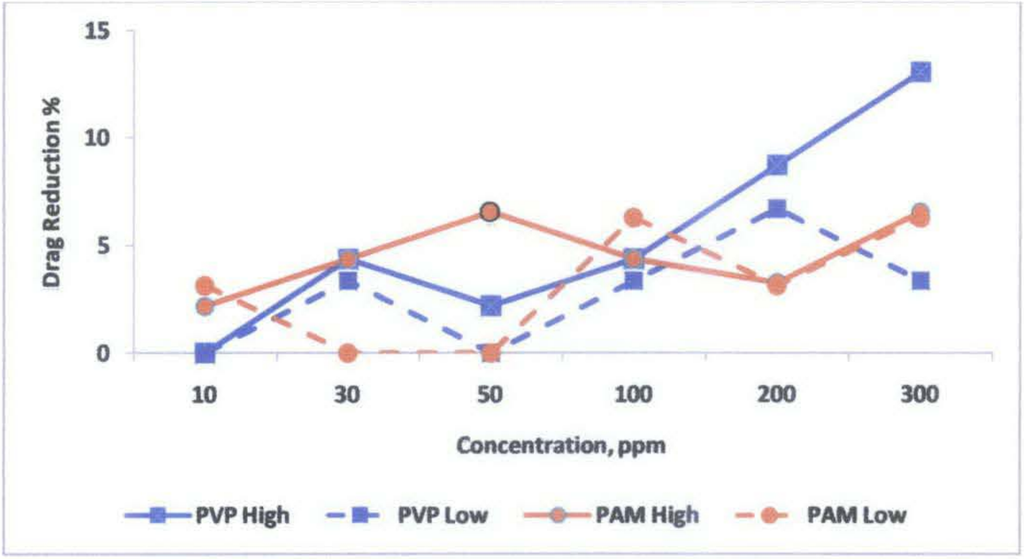


Figure 8 : Effects of polymer concentrations to drag reduction efficiency for fresh polymer at both low and high pump speed

Figure 8 and Figure 9 compare the performance of the fresh and degraded polymers respectively, at different concentrations in function of pump speed. As can be clearly seen in these two figures, the drag reduction percentage increases with increasing polymer concentration and this is especially true for PVP. This can be explained by understanding the fact that increasing the polymer concentration subsequently increases the number of molecules present in the flow; thus leads to a more efficient drag reduction system as more molecules are involved in suppressing the eddies.

Figure 9 generally reflects that degraded polymer gives an almost identical drag reduction pattern as the concentration increases but however, it can be clearly observed that degraded PVP at high pump speed gives the highest drag reduction percentage and this is especially true for four out of six concentrations tested. It may be inferred from this finding that PVP is more resistant to mechanical degradation compared to PAM due to its capability of giving higher drag reduction percentage compared to that of PAM.

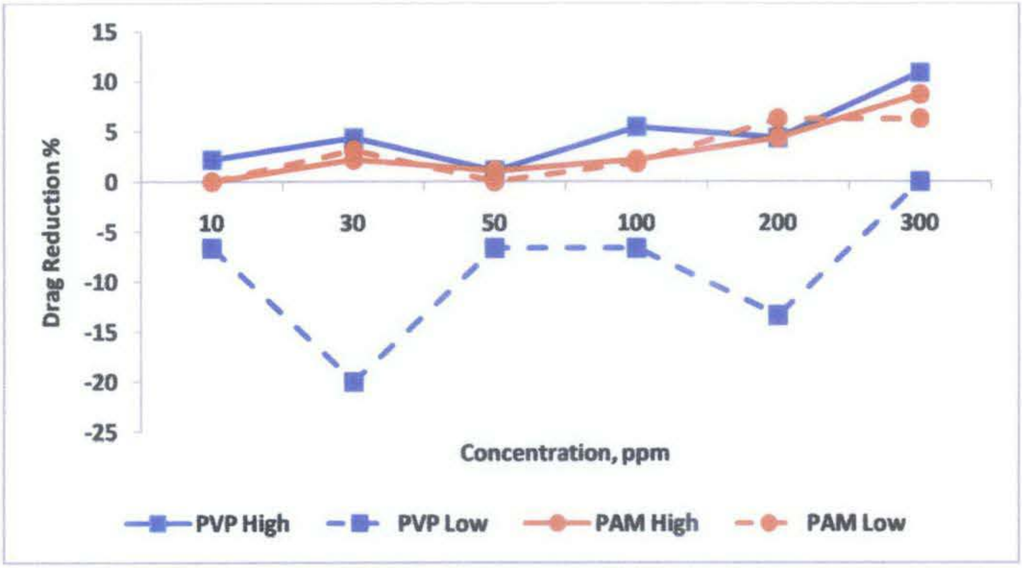


Figure 9 : Effects of polymer concentrations to drag reduction efficiency for degraded polymer at both low and high pump speed

In order to analyze the previous inference made relating to the effects of polymer degradation, charts as displayed in Figure 10 and Figure 11 are constructed. Figure 10 shows that the drag reduction percentage of PVP is not as significant as PAM (Figure 11). For instance, taking 50ppm for both polymers, it is obvious that the drag reduction percentage caused by polymer degradation for PVP (Figure 10) decreases from about 2% to about 1%; whilst for PAM the drag reduction percentage depletes from 6.5% to 1%.

A decrease in drag reduction efficiency due to mechanical degradation may be explained by the fact that degradation irreversibly alters the polymer structure caused by chemical reactions initiated by mechanical energy[22]. J.M Maerker et al. discovered from their research[24] that there will be a slight reduction in the molecular weight of the polymer when it is degraded mechanically. This finding may be explained more by Abdel-Alim and Hamielec where they found out that a reduction in the molecular weight of the degraded polymer is more pronounced with the higher molecular weight fraction[23]. These literature reviews explain why mechanical degradation gives a significant decrement in the drag reduction percentage for PAM; as the PAM that is used for this research has a molecular weight of over than 5,000,000 (Appendix 8). Side-to-side comparison of these two figures is attached in Appendix 7.

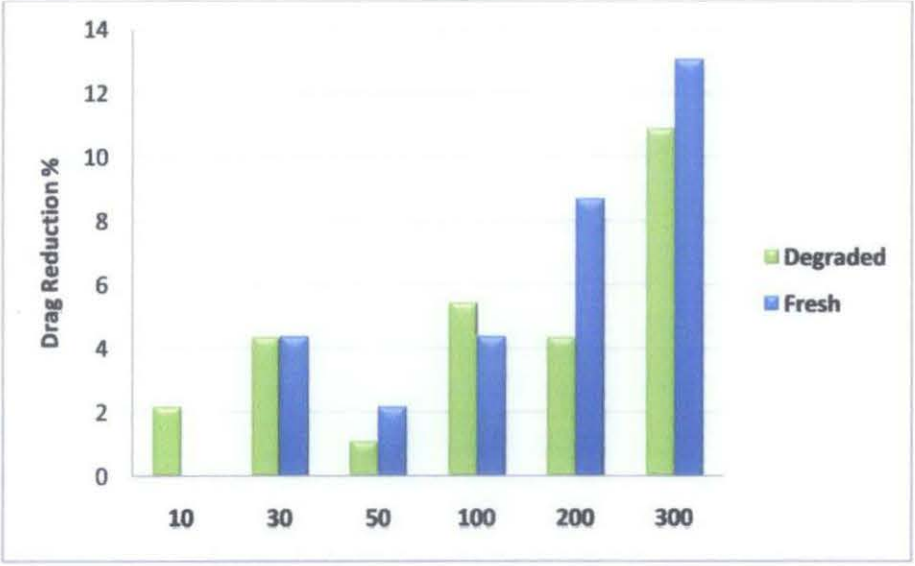


Figure 10 : Comparison of drag reduction efficiency of fresh and broken PVP at high pump speed

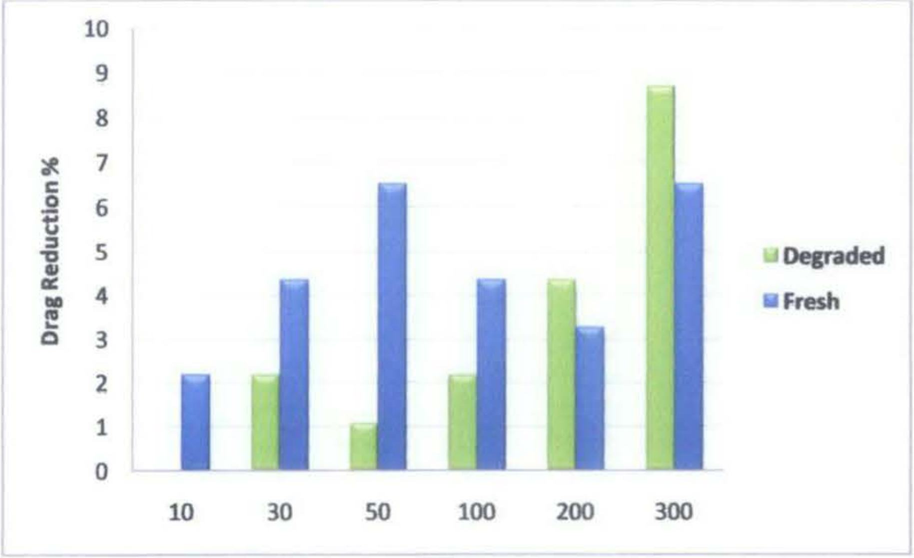


Figure 11 : Comparison of drag reduction efficiency of fresh and broken PAM at high pump speed

Figure 12 and Figure 13 below analyze the drag reduction percentage of fresh polymers at 200ppm and 300ppm and confirm that PVP gives the highest drag reduction percentage at both concentrations despite of the pump speed except for 300ppm PVP (Figure 13). It can be observed that the drag reduction of PVP for low pump speed decreases from 7% to about 3% as the concentration is increased from 200ppm to 300ppm and we can deduce that the optimum concentration for PVP at low pump speed is between 200ppm and 300ppm.

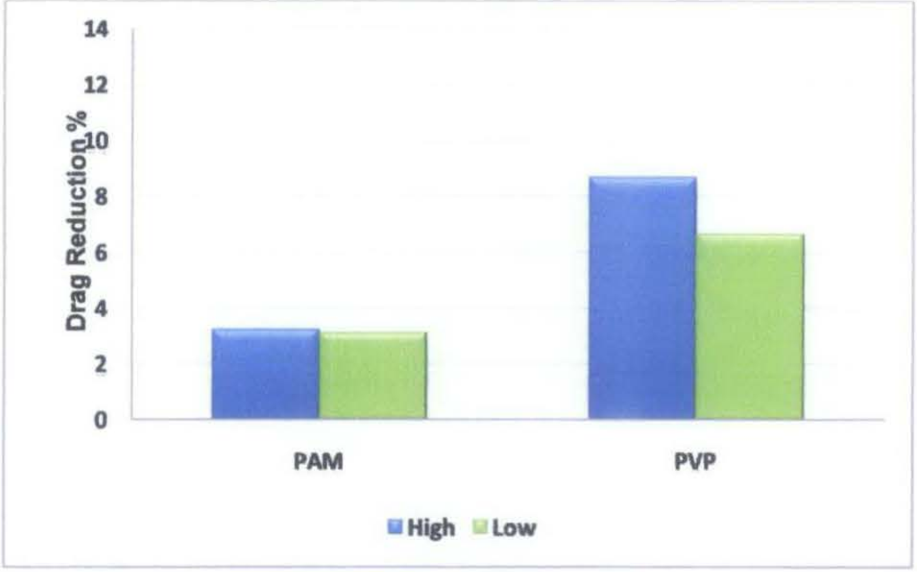


Figure 12 : Drag reduction efficiency of fresh polymers at 200ppm for both low and high pump speed

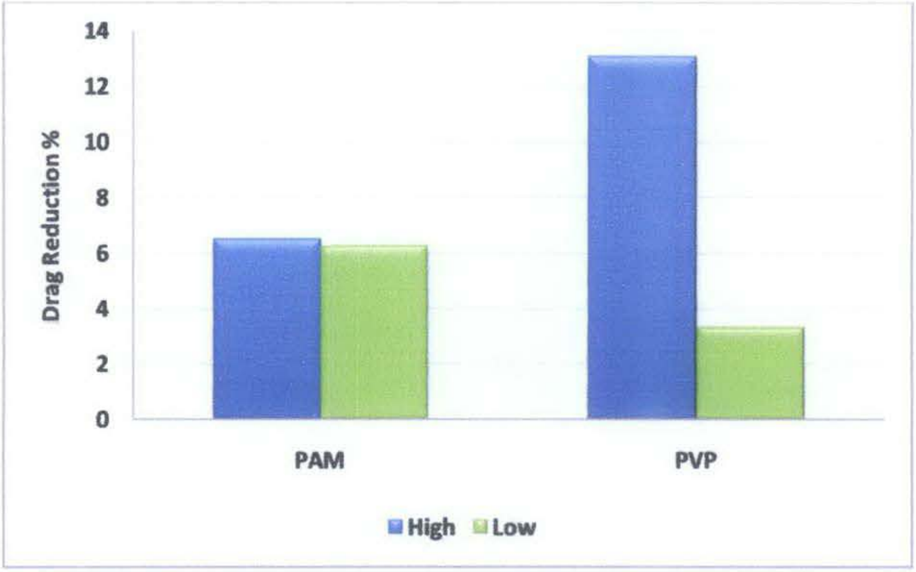


Figure 13 : Drag reduction efficiency of fresh polymers at 300ppm for both low and high pump speed

Chapter 5

5. Conclusions and Recommendations

A complete study of flow test has been performed using two types of polymer; polyacrylamide (PAM) and polyvinylpyrrolidone (PVP) and pressure after the addition of polymer solution was experimentally studied. The drag reduction percentage was investigated in function of Reynolds number, polymer concentrations and polymer degradation. Based on the experimental observations, the conclusions are as following:

- Polyvinylpyrrolidone (PVP) gives the most significant drag reduction percentage.
- As pump speed directly proportional to Reynolds number, observations depict that an increase in Reynolds number results in an increased drag reduction percentage due to large eddies collision forms smaller eddies in the flow. The molecules of polymer introduced to the flow will later be part of these eddies, suppressing the large eddies thus eventually impede any further formation of eddies.
- An increased drag reduction percentage was also observed at an increased polymer concentrations as higher concentrations results in an increased number of molecules suppressing the eddies present in the flow.
- DRA efficiency decreases if the polymer is applied to mechanical degradation as the physical properties of the polymers are deteriorated.

To allow further improvements and better interpretations in this study, the following recommendations are suggested:

- It is substantially crucial to replace the existing pressure gauge with pressure drop gauge OR to add another pressure gauge in the system right before the first valve of the existing test equipment.
- To change the reciprocal pump to centrifugal pump to avoid the pulses that resulted from changing discharge pressure or head of the pump.
- Since utilizing reciprocal pump causes the gauge indicator to be constantly moving, it is best recommended to use camera to capture the pressure reading at desired instant.
- To investigate the effect of vertical flow system on the drag reduction percentage.
- To investigate the effect of different DRA points on drag reduction.
- To study the effects of pipe diameter on drag reduction efficiency.
- To experimentally study the rheology properties of the polymer solutions.
- To relocate the pump right below the water tank to allow the pump to be quickly filled with the fluid.
- To use higher polymer concentrations.

REFERENCES

[1] M. M. Sharma, S. Pang, K. E. Wennberg and L.N. Morgenthaler, 2000. "Injectivity Decline in Water-injection Well: An Offshore Gulf of Mexico Case Study". SPE 60901. SPE Prod. & Facilities 15 (1)

[2] B.K. Berge and O. Solsvik: "Increased Pipeline Throughput using Drag Reducing Agent Additives: Field Experiences". SPE 36835 presented at the 1996 SPE European Petroleum Conference held in Milan, Italy, October 22-24

[3] W. Bae, S. Kwon, H.S. Byun and H. Kim (2004). "Phase Behavior of the poly(vinyl pyrrolidone) + N-vinyl-2-pyrrolidone + carbon dioxide System". J. of Supercritical Fluids 30, 127-137.

[4] F. Haaf, A. Sanner and F. Straub (1985). "Polymers of N-Vinylpyrrolidone: Synthesis, Characterization and Uses". Polymer Journal 17 (1): 143–152

[5] Polyvinylpyrrolidone (n.d.). In Wikipedia the Free Encyclopedia. Retrieved from http://en.wikipedia.org/wiki/Polyvinylpyrrolidone on 19th April 2011.

[6] T.W. Wong, P.W.S. Heng, T.N. Yeo and L.W. Chan (2001). "Influence of PVP on Aggregation Propensity of Coated Spheroids". International Journal of Pharmaceutics 242, 357-360.

[7] U.U. Salamova, Z.M.O. Rzaev, S. Altindal and A.A. Masimov (1995). "Effect of Inorganic Salts on the Main Parameters of the Dilute Aqueous PVP Solutions". Polymer 37 (12), 2415-2421.

[8] B.L. Rivas, E.D. Pereira and I. Moreno-Villoslada (2003). "Water-soluble Polymer-metal Ion Interactions". Prog. Polymer Science 28, 173-208

[9] K. Holmberg, B. Jönsson , B. Kronberg and B. Lindman (2003). Surfactants and Polymers in Aqueous Solution. England: John Wiley & Sons Ltd.

[10] M.H. Yang (2000). "The Rheological Behaviour of Polyacrylamide Solution – Yield Stress". Polymer Testing 20, 635-642.

[11] C.W. Morris and K.M. Jackson (1978). "Mechanical Degradation of Polyacrylamide in Porous Media". SPE 7064 presented at the 5th Symposium on Improved Methods for Oil Recovery of the SPE of AIME held in Tulsa, Oklahoma, April 16-19

[12] E.D. Burger, W.R. Munk and H.A. Wahl, 1982. "Flow Increases in the Trans-Alaska Pipeline through use of a Polymeric Drag-reduction Additive". Journal of Petroleum Technology, 377-386

[13] G.E. Gadd (1965). "Turbulence Damping and Drag Reduction Produced by certain Additives in Water". Nature 206, 463.

[14] T. Al-Wahaibi, M. Smith and P. Angeli, 2006. "Effect of Drag-reducing Polymers on Horizontal Oil-water Flows". Journal of Petroleum Science and Engineering 57 (2007) 334-346

[15] H.A. Abdul Bari and R.B.M Yunus, 2010. "Formulization of Okra-natural Mucilage as Drag Reducing Agent in Different Size of Galvanized Iron Pipes in Turbulent Water Flowing System". Journal of Applied Sciences 10 (23): 3105-3110

[16] H.A. Al-Anazi, M.G. Al-Faifi, and J. Gillespie: "Evaluation of Drag Reducing Agent (DRA) for Seawater Injection System: Lab and Field Cases". SPE 100844 presented at the 2006 SPE Asia Pacific Oil & Gas Conference and Exhibition in Adelaide, September 11-13

[17] Y. Kawaguchi, T. Segawa and Z. Feng (2002). "Experimental Study on Drag-reducing Channel Flow with Surfactant Additives-Spatial Structure of Turbulence Investigated by PIV System". Journal of Heat and Fluid Flow 23, 700-709.

[18] Ahmed Kamel and Subhash N. Shah, 2009. "Effects of Salinity Temperature on Drag Reduction Characterizations of Polymers in Straight Circular Pipes". Journal of Petroleum Science and Engineering 67: 23-33

[19] R. Sadeghi and M.T. Zafarani-Moattar, 2004. "Thermodynamics of Aqueous Solutions of Polyvinylpyrrolidone." Journal Chemical Thermodynamics 36: 665-670

[20] J. Nelson, 2003. "Optimizing Production using Drag Reducing Agents in Water Injection Wells". Offshore Engineer.

[21] F. Gallego and S. N. Shah, 2009. "Friction Pressure Correlations for Turbulent Flow of Drag Reducing Polymer Solutions in Straight and Coiled Tubing". Journal of Petroleum Science and Engineering 65 : 147-161

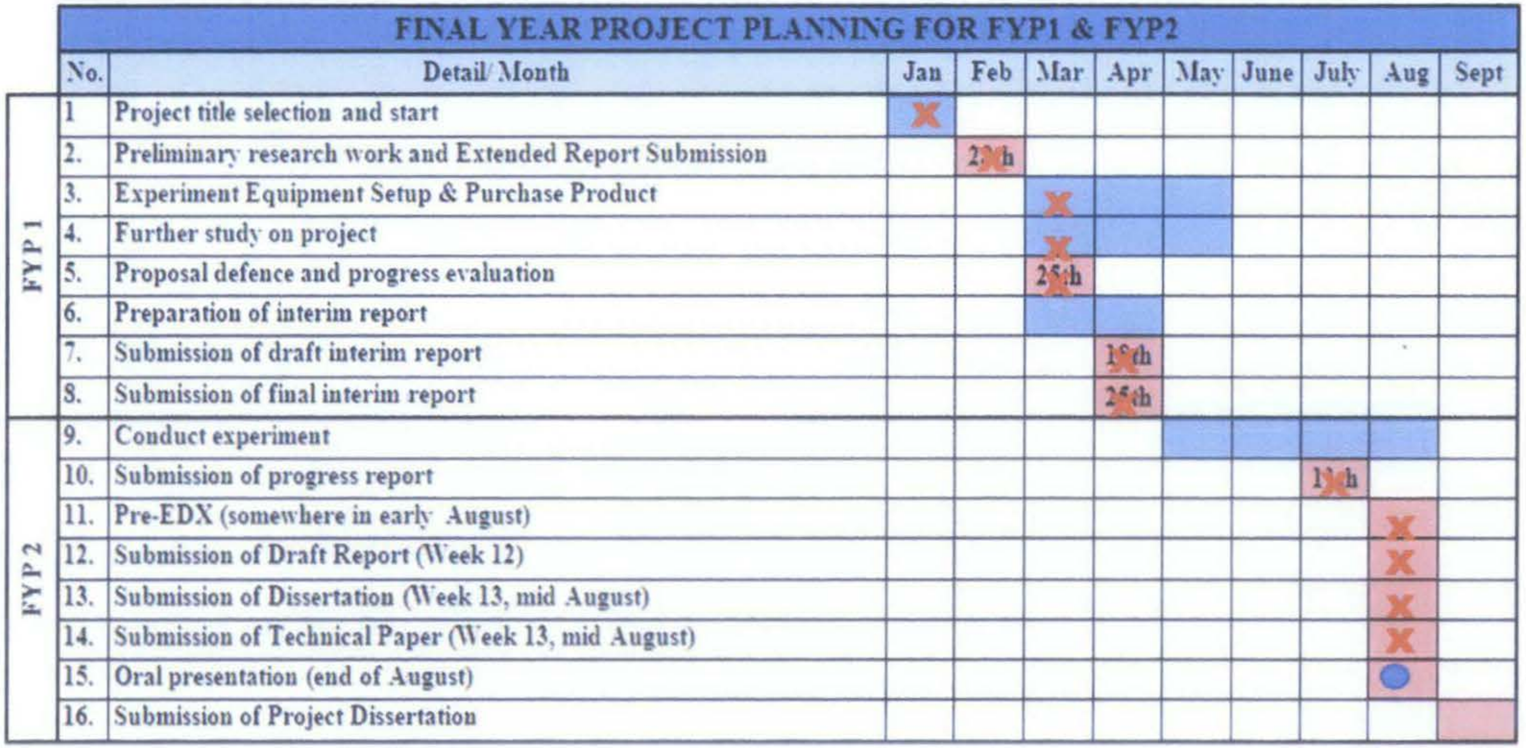
[22] M.J. Caulfield, G.G. Qiao and D.H. Solomon. (2002). "Some Aspects of the Properties and Degradation of Polyacrylamides". Chem. Rev. 102, 3067-3083.

[23] A.H. Abdel-Alim and A.E. Hamielec, 1973. "Shear Degradation of Water-soluble Polymers : Degradation of Polyacrylamide in a High-shear Couette Viscometer". Journal of Applied Polymer Science 17 (12). 3769-3778

[24] Maerker, J.M (1974). "Shear Degradation of Partially Hydrolyzed PAM Solutions". SPE 5101 presented at the SPE-AIME 49th Annual Fall Meeting, held in Houston, October 6-9

[25] P.J. Molloy, M.J. Smith and M.J. Cowling (1999). "The Effects of Salinity and Temperature on the Behaviour of Polyacrylamide Gels". Materials and Design 21, 169-174.

APPENDICES



	FINAL YEAR PROJECT PLANNING FOR FYP1 & FYP2										
	No.	Detail/ Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
FYP 1	1	Project title selection and start	✗								
	2.	Preliminary research work and Extended Report Submission		2[illegible]h ✗							
	3.	Experiment Equipment Setup & Purchase Product			✗	🟦	🟦				
	4.	Further study on project			✗	🟦	🟦				
	5.	Proposal defence and progress evaluation			25th ✗						
	6.	Preparation of interim report			🟦	🟦					
	7.	Submission of draft interim report				1[illegible]th ✗					
	8.	Submission of final interim report				25th ✗					
FYP 2	9.	Conduct experiment					🟦	🟦	🟦	🟦	
	10.	Submission of progress report							1[illegible]h ✗		
	11.	Pre-EDX (somewhere in early August)								✗	
	12.	Submission of Draft Report (Week 12)								✗	
	13.	Submission of Dissertation (Week 13, mid August)								✗	
	14.	Submission of Technical Paper (Week 13, mid August)								✗	
	15.	Oral presentation (end of August)								●	
	16.	Submission of Project Dissertation									🟥

✗ Completed

● On-going

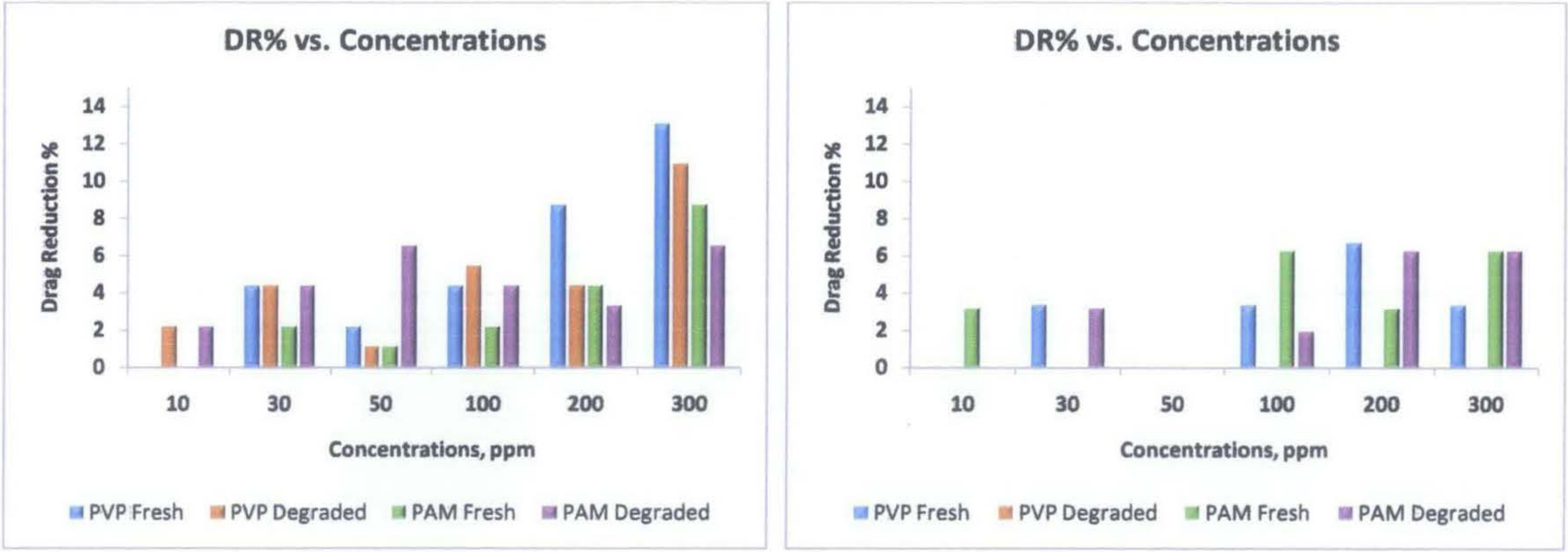
Appendix 1 : Gantt chart

Completed experiment setup

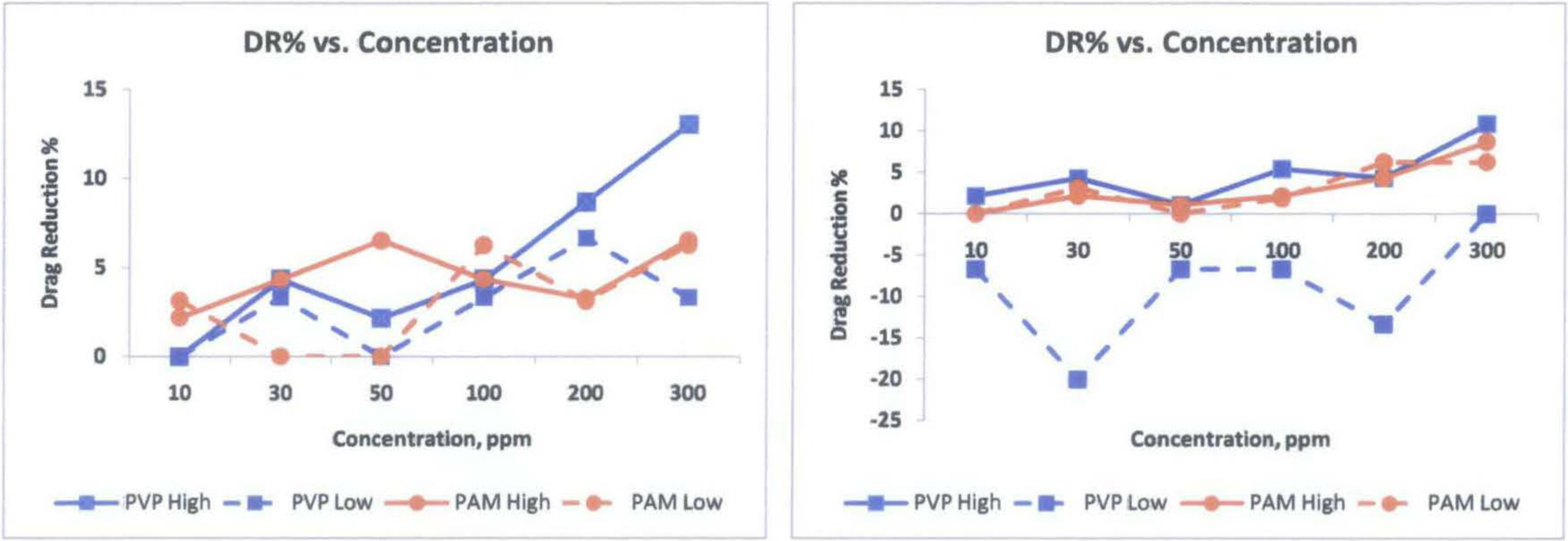
Reciprocal Pump (Model : Honda G200)

Pressure gauge configuration at the end of the test section

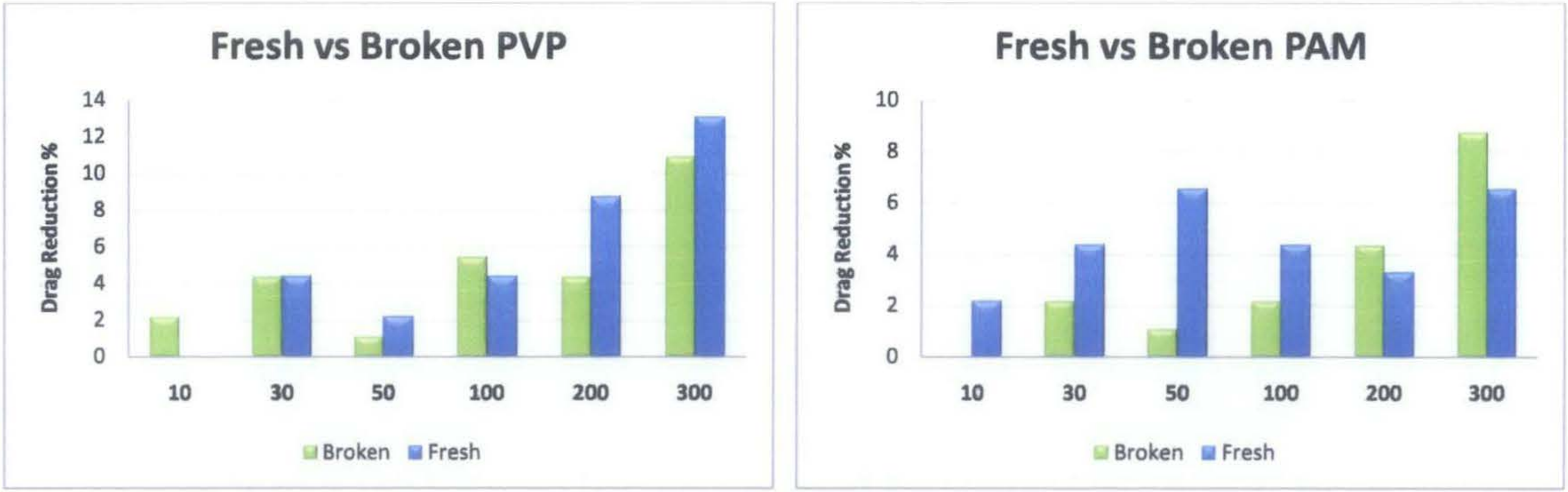
Appendix 2 : Experiment setup with the components



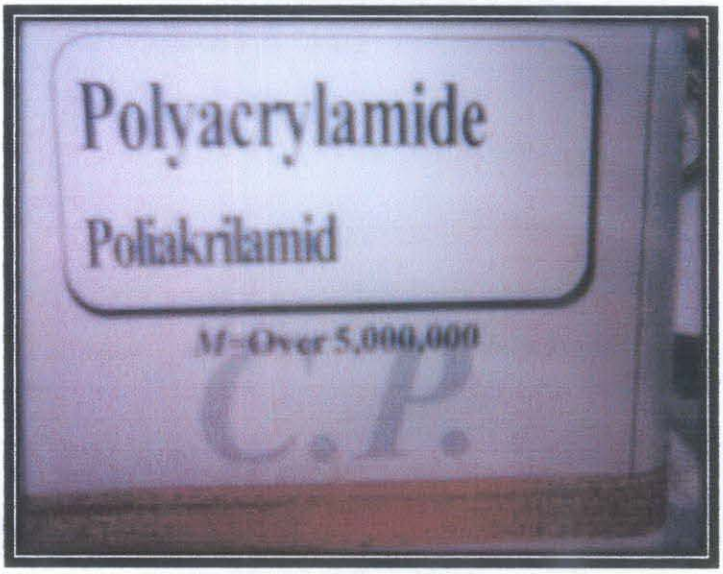
Appendix 3 : Side-to-side comparison of drag reduction efficiency of fresh and degraded polymers with different concentrations at high (left) and low (right) pump speed



Appendix 4 : Side-to-side comparison of the effects of polymer concentrations to drag reduction efficiency for fresh (left) and degraded (right) polymer at both low and high pump speed



Appendix 5 : Side-to-side comparison of drag reduction efficiency of fresh and broken PVP (left) and PAM (right) at high pump speed



Appendix 6 : Polyacrylamide used (M > 5,000,000)