To Evaluate Effectiveness of Polyacrylamide (PAM), Polyvinylpyrrolidone (PVP), and Polyethyleneoxide (PEO) as Drag Reducing Agent for Water System

By

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CERTIFICATION OF APPROVAL

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Petroleum Engineering Programme
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(PETROLEUM ENGINEERING)

Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2012

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 continued herein have not been undertaken or done by unspecified source or persons.

(NURUL NADIA EZZATTY BT ABU BAKAR)

ABSTRACT

Drag Reducing Agent (DRA) are widely used in the oil and gas industry for improving the oil transportation and water injection system. The unique characteristic of the long-chain polymer that can dampens the turbulent and modify the flow regime of fluid hence reduce the frictional pressure loss along the pipelines. This research project aimed to evaluate the effectiveness of using polyacrylamide (PAM), polyvinylpyrrolidone (PVP), and polyethelyneoxide (PEO) as drag reducing agents in water pipelines system by studying the effect of volume and concentration towards drag reduction in pipelines. Besides, the effectiveness of PAM, PVP and PEO as drag reducers is compared.

This research project is experiment-based in which the experiment is conducted to achieve the objectives stated above. Experiment is carried out by pumping water from storage tank and injecting polymer into the flow system through injection point. The mixture is then allowed to flow through the 4-m galvanized pipe to the outlet and the pressure is observed. The steps are then repeated by using different concentration and type of polymer. The drag reduction and flow increase is calculated.

The effectiveness of DRA increased at higher concentration as compared to lower concentration of DRA. This is proven by the decrease in pressure drop and increase in drag reduction and flow throughput. From this experiment, it is known that different type of polymer will gives different result in terms of their flow rate.

In general, PAM is the most effective DRA as compared to PVP and PEO, with drag reduction up to 42.5% and flow throughput increased to 36%. This is because PAM has been commercially used in the industry and the field result is proven. By increasing the volume and concentration of drag reducing agents, the drag reduction is increased in which the pressure loss across the pipeline system will be minimized.

This research project will contribute to the study of flow assurance by reducing the drag factors in a pipeline system. Hence, the frictional loss is reduced, injection capacity increased and a designed pipeline could be more efficient in transporting fluids.

ACKNOWLEDGEMENT

All praised to Allah S.W.T, The Almighty, The Most Gracious and The Most Merciful. I wish to extend my deepest appreciation to everyone who contributed to the accomplishment of this Final Year Project.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

As the oil production from an oil well deteriorates, it is preferable to install a water injection system to improve the reservoir performance. Water injection, or also known as waterflooding, is a secondary oil recovery technique, aimed for pressure maintenance of reservoir. Secondary recovery employs water and gas injection, displacing oil and driving it to the surface; with no modification of fluid properties. Water injection involves drilling of injection well and introducing water into that reservoir to stimulate oil production. While the injected water helps to increase depleted pressure in the reservoir (also known as voidage replacement), it also helps to sweep or displace remaining oil from reservoir, push it towards production well, where it can be recovered. Even though the effectiveness of waterflooding differs according to formation characteristics, this technique can recover anywhere from 5% to 50% of the unswept oil, greatly enhancing the productivity and economics of the development.

The first commercial use of a polymeric drag-reducing additive to increase the flow rate in a crude oil pipeline began in 1979 in the Trans-Alaskan Pipeline System (TAPS). Injections of DRA made the higher throughput available without additional construction, extra pumps and pump stations, maximize pipeline capacity, economical and cost savings alternatives, and the DRA injection does not affect the quality of the products being transported.

In many cases, it is desirable to increase the flow of injection water instead of drilling another injection wells to maintain the reservoir pressure as the latter is very costly. Therefore, flow improvers for the injection water will be the most cost-effective way to increase the flow rate. Over 20 years, high molecular weight have been applied for this purpose. This project will study on the effectiveness of polyacrylamide (PAM), polyvinylpyrrolidone (PVP) and polyethyleneoxide (PEO) as drag-reducing agent for water injection.

1.2 Problem Statement

Drag in pipelines has always be a major concern as it could lead to frictional energy loss, decreasing the pressure and flow rate eventually reducing the production. It is important to reduce or eliminate this drag factor in our pipelines so that smooth transportation of products through pipelines or maximum injection fluids into reservoir can be achieved. Therefore, drag reducing agents (also known as drag reducers or flow improvers) is injected into the pipeline to reduce the frictional energy loss, reduce the pressure drop and increases the flow rate. Increasing the flow rate thus means increasing the flow capacity, where more injection water can be pumped at a certain time, swept more remaining oil in reservoir, thus increasing the production.

Water containing DRA in oilfield applications are used for water injection to increase flow capacity and water injection rate. It is widely known that long-chained polymers dominate in this system, such as water-soluble high molecular weight polyacrylamides of anioinic types. This project will test the effectiveness of polyacrylamide (PAM), polyvinylpyrrolidone (PVP) and polyethelyneoxide (PEO) as drag reducing agent for water injection by evaluating the pressure drop and flow rate across the pipes.

1.3 Objectives

1. To evaluate the effectiveness of polyacrylamide, polyvinylpyrrolidone and polyethelyneoxide as drag-reducing agent for water injection.
2. To study the effect of volume and concentration of drag-reducing agents towards drag reduction in water pipelines.
3. To compare the effectiveness of polyacrylamide, polyvinylpyrrolidone and polyethelyneoxide as drag reducers in water pipelines.
4. To investigate the effect of drag reducing agent towards pressure loss and flow rate in water pipelines.

1.4 Scope of Study

As outlined in the objectives, this project aimed to evaluate the effectiveness of PAM, PVP and PEO as drag-reducing agents in water injection. This study is divided into three parts. The first part will emphasize on the related studies done for drag reducing agents (DRA) as well as understanding the concept, properties and characteristics of DRA. The second part is about the experimental work. Different concentration of the polymer will be used in the experiment to study the effect of concentration towards the effectiveness of drag reducing agents in horizontal pipelines. The third part is the data analysis and discussion part where the effectiveness of the polymer in reducing drag inside pipes is evaluated in terms of pressure loss and flow rate. In addition, the comparison between the effectiveness of the three types of polymer as drag reducers is performed for further review.

This research project will involve the application of fluid mechanics in turbulent flow, characteristics of polymer (e.g PAM, PVP and PEO) and flow assurance.

1.5 Relevancy and Feasibility of Project

The research on drag reducing agents has gained much attention in oil and gas industry recently as it evaluate the effectiveness of the polymer injected into the water injection lines to improve the oil recovery. The water-soluble drag reducers' performance is assessed for their abilities in reducing pressure drop and increasing in the flow rate for horizontal water flow pipelines. It is projected that the outcome of this study will helps further studies on drag reduction in a pipeline as well as maximizing the volume of injected water into the reservoir by reducing the drag inside the pipes. This will helps in optimizing waterflooding techniques so that more oil production can be achieved to accommodate the current global demands.

Within the specific range of time given, this project is expected to give an understanding of effectiveness of drag-reducing agents used in industry as well as their performance in reducing drag in pipelines. The project is feasible as it can be carried out within the time frame and the experimental equipments are readily available in UTP.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

At the beginning of an oil field's production life, the reservoir utilizes its natural energy to allow hydrocarbon flow into the wellbore. This is called primary recovery of the oil. Over time, the natural energy utilized in the primary recovery depleted, and secondary recovery is necessary to continue the production. This secondary recovery of oil is also known as improved oil recovery which aimed at only pressure maintenance, without altering the reservoir fluid properties. Water or gas is injected into the reservoir from injection well to maintain the reservoir pressure and to sweep the remaining oil into the adjacent production well, hence maintain or boost oil production levels. The use of drag reducing agent to reduce the frictional loss in pipes has become the most cost effective option to improve the crude oil transportation and optimize water injection into reservoir. (Nelson, 2004) state that the maximum amount of water injected is limited by the injection pump capacity, tubing capacity and reservoir characteristics. By injecting DRA downstream the injection pumps, the differential pressure drop in the water injection may be reduced. As a result, the water injection rate may be increased until the maximum allowable operating pressure in the injection system is again reached.

2.2 Drag reduction

The flow of liquid in a conduit, such as pipelines, results in frictional energy loss. As the result of this energy loss, the pressure of the liquid in the conduit decreases along the conduit in the direction of flow (Kelland, 2009). This could reduce the flow capacity of the liquid. Drag reduction is also called Toms phenomenon as was the first to discover that the frictional force in turbulent flow can be drastically reduced by adding certain long chain polymer into the solvent such as water. Campbell (2001) defined that drag reduction is a term frequently used to characterize the reduction in friction in turbulent flow through pipes, resulting in an increase in fluid flow and/or decrease in pressure loss. Savins (1964) defined drag reduction as the increase in the pumpability of a fluid caused by the addition of a small amount of an additive into the fluids. This additive is known as Drag-Reducing Agents (DRA) which is a long-chained polymer with a very high molecular weight. Nelson (2004) states that drag reduction is a reduction of pressure drop over some length of pipeline when traces of high molecular weight polymers are dissolved in the pipeline fluid. DRA are sometimes known as friction reducers or flow improvers. Drag reduction in turbulent flow is an important phenomenon both for practical applications in fluid transport and for basic studies in fluid mechanics (Hoyt, 1972 and Virk, 1975).

2.3 Drag Reducing Agents (DRA)

Drag Reducing Agents (DRA) or Drag Reducers are high molecular weight polymer, used to reduce or minimize the frictional pressure loss caused by turbulence in pipelines. DRAs interact with turbulent flow processes and reduce frictional losses such that the pressure drop for a given flow rate is less, or the flow rate for a given pressure drop is greater (Kelland, 2009).

The main oilfield applications of chemical capable of promoting the drag reducing are in crude oil transportation and water re-injection lines. Prasetyo (2003) classify that DRAs are solution of poly alpha olefins, high molecular weight copolymers, viscous or non-Newtonian fluids that are based on either hydrocarbon (isopentane or kerosene) or water solvent. Burger (1982) state that the use of drag reducers in crude pipelines presents three special requirements; the drag-reducing additive must be effective at low concentrations, the treated crude must be shear-stable during line flow and the treated crude must not cause downstream refining problems. DRAs used in crude oil are usually characterized as high molecular weight polymers, while hydrolyzed polyacrylamide and polyacrylate have been used as DRA in aqueous system (Campbell, 2001). DRAs used presently in oil and products pipelines are themselves hydrocarbon, and thus have no effect on refining process or refined products.

Prasetyo (2003) describe that DRA can help to optimize the pipeline capacity by reducing drag and lowering pressure drop across the pipeline. By reducing pressure loss, the pipeline operation can be optimized in several ways, such as increasing flow rate in the existing pipeline system whilst maintaining the operating pressure, reducing pipeline operating pressure whilst maintaining total throughput or flow rate and reducing energy and operating cost by eliminating pump booster station along the pipeline system. Recently, it has been found by Kang (1999) that DRA has other benefits such as changing flow pattern from slug to stratified flow, reducing corrosion rate and increase of production. Besides water injection and oil transportation, there are several uses of DRAs in oil and gas industry including fracturing, acid stimulation, drilling fluids, coiled tubing operations and many other applications (Kelland, 2009).

The performance of DRA depends on many factors such as oil viscosity, oil composition, pipe diameter, pipe roughness, fluid velocity, water cut, DRA concentrations, pipeline inclination, and type of DRA and shear degradation of DRA (Kang, 1999). Al-Wahaibi, et al (2007) and Derrule (1974) state that the higher drag reduction was encountered in n the rough pipes, where turbulence is increase, than in smooth one. It is also found that the effect of polymer is greater at high velocities where turbulence is stronger. In agreement with Al-Sarkhi and Hanratty (2001 a,b) where drag reduction was found to be higher in the smaller than the large pipe. Thus, it can be concluded that the pipe roughness, fluid velocities and diameter of the pipe are some factors that contributes to the turbulence environment in pipes and addition of high molecular weight polymer into the system result in high drag reduction. Besides, it is also very important to select proper DRA because effectiveness of DRA is different for different types of DRA. Shear degradation of DRA is also a main concern in the field due to the technical and economic aspects. Lester (1985) and

Pollert (1989) have indicated that DRA is easily degraded by shear stress raised by centrifugal pumps and most positive displacement pump. As DRA is shear-sensitive, therefore, it should be injected downstream after each pump station to prevent DRA from degrades which could reduce its performance.

According to Nelson (2004), 4 key factors for significant amount of drag reduction in pipelines are solubility of polymer in continuous phase, effective polymer dispersion, molecular weight of the polymers and the polymer concentration. Good dispersion of DRA will give optimum pipeline fluid dissolution hence high drag reduction is achieved. Meanwhile, high molecular weight, long-chained polymer is used to increase the shear viscosity which will dampens the turbulent more and give good drag reduction performance. The Reynolds number also is an important factor for drag reduction. High Reynolds number indicate turbulent regime which favors DRA performance. Generally, the higher the Reynolds number, the higher the drag reduction is expected. Reynolds number is given by equation below:

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

Equation 1: Reynolds Number

Where D is the pipeline diameter, ρ is the density, v is the velocity and μ is the viscosity of the system fluid.

The entrance length where the turbulent flow in a pipe is fully developed is another factor to be considered before proceeding with the experiment as the drag reducer work at its best performance in turbulent flow. The entrance length for turbulent flow is given by;

$$El_{turbulent} = 4.4Re^{1/6}$$

Equation 2: Entrance Length

The effectiveness of DRA can be assessed by determining the magnitude of drag reduction at a given concentration and flow rate. Percent drag reduction (%DR) Is defined, at a given flow rate, as the difference between the pressure drop of the untreated fluids (ΔP, as base line) and the pressure drop of the fluid containing DRA (ΔP_{DRA}) divided by the pressure drop of the base line. This can be presented by the following equation:

$$\%DR = \frac{\Delta P - \Delta P_{DRA}}{\Delta P} x 100$$

Equation 3: Drag Reduction (%DR)

The relationship between the percent drag reduction and percent flow (or throughput) increase (% FI) can be estimated using the following equation:

$$\%FI = \left\{ \left[\frac{100}{100 - \%DR} \right]^{0.556} - 1 \right\} x 100$$

Equation 4: Flow Throughput Increase (%FI)

The DRA concentration is calculated on a total liquid volume basis as follows:

$$V_{DRA} = \frac{C_{DRA}\ X\ V_{total}}{1\ X\ 10^6}$$

Equation 5: DRA concentration

V_{DRA} = Volume of the DRA t o be added

C_{DRA} = Desired DRA concentration (ppm)

V_{total} = Total liquid volume of the system

2.4 Mechanism of DRA

For over 20 years, high molecular weight polymers and surfactant has been successful in reducing pressure drop and enhancing flow in oil and aqueous system from production pipelines to water injection systems. The mode of action has been attributed to a reduction in frictional energy loss by dampening the turbulent fluctuations. As DRA dissolves and interact with pipeline fluid flow, its molecules start to uncoil and spread out. The long chain polymers will dampens the turbulent bursts near pipeline wall and reduce the frictional energy loss which result in smaller energy consumption. In fact, the effect of a drag reducer polymer is known significant in turbulent flow (Reynold's Number greater than 4000) as compared to the effect in laminar flow. This is because drag reduction occurs by an interaction of the polymer molecules of the drag reducers with the turbulence formation of the flowing fluid or hydrocarbon. (Prasetyo, 2003)

Table 1: Reynolds's Number and Flow Pattern

Reynolds's Number, Re	Flow Pattern
< 2300	Laminar
2300 – 4000	Transient
> 4000	Turbulent

In most petroleum pipelines, the liquid flows through the pipelines in a turbulent regime. Therefore, DRA can perform effectively in most pipelines. According to Prasetyo (2003) and Jubran (2005) in turbulent regimes, there are three zones or layers. Nearest to the pipe wall is a zone called laminar sub layer. In this zone, the fluid follows the pipeline flow in a typical laminar flow regime. The increase in point velocity as the point moves away from the wall, is linear function of the distance from the wall, and directly parallel to the wall in the direction of pipe flow. There are no cross flows in this zone. In the very center of the pipe is the turbulent core zone. This zone is the largest region and includes most of the fluid in the pipe. This is the zone where eddy currents and random motion of turbulent flow. The turbulent core carries all of the flow where variations in point velocity are random and dependent of this distance. Between the laminar sub layer and turbulent core zones lies the buffer zone. In the buffer zone, variation of point velocity with point position is not established. This zone is important because it is here that the turbulence first forms.

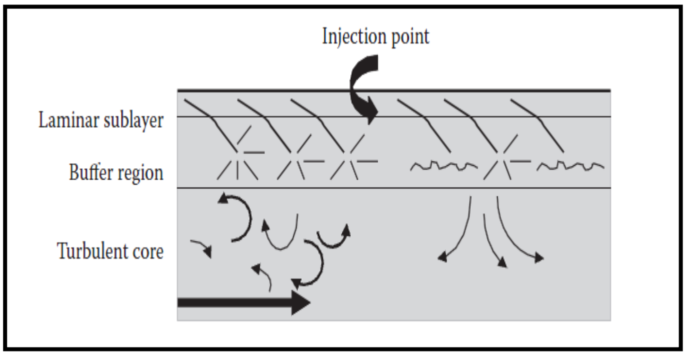

Figure 1: Injection of DRA polymer into turbulent flow suppressing energy bursts.

A portion of the laminar sublayer, called “streak”, occasionally will move up to the buffer zone. Once the streak enters the buffer zone, it will begin to vortex and oscillate, moving faster as it gets closer to the turbulence core. Finally, the streak becomes unstable and breaks up as it throws fluid into the core of the flow. This ejection of fluid is called “turbulent burst”. The burst creates the turbulence in the core. Energy is wasted in different directions causing drag and pressure loss.

Drag-reducing polymers interfere with the bursting process or inhibit the formation of turbulent burst and turbulence, or at least reduce the degree of turbulence, and in turn, reduce the drag or pressure loss. The drag reducer polymers somehow stretch in the flow, absorb the energy in the streak and thereby prevent the turbulent burst. As such, drag reducer polymers are most active in buffer zone.

2.5 Water-Soluble DRA

DRA are usually designed to be either oil-soluble (for application to oil lines) or water-soluble (for application to water lines). Oil soluble DRAs become less effective as the water cut increases. Therefore, it is crucial to determine the most appropriate type of DRA to be used for optimum performances. Nelson (2004) described that typical water-soluble DRA are water-in-oil emulsions with ultra-high molecular weight polymers dissolved in the water droplets. When the drag reducers come into contact with water, the polymer breaks out of the emulsion and is activated in the water phase. The polymer molecules than interact with the water phase in the near wall region of the pipeline to reduce the hydraulic pressure drop.

Three water-soluble DRA that will be studied in this research is polyacrylamide (PAM), polyvinylpyrrolidone (PVP) and polyethelyneoxide (PEO).

2.5.1 Polyacrylamide (PAM)

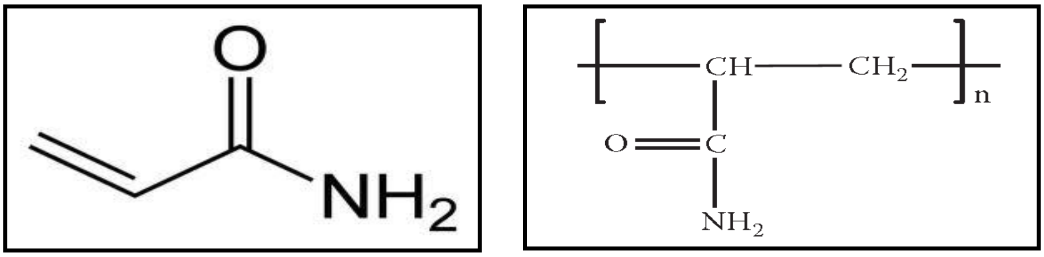

Figure 2: Chemical Structure for Polyacrylamide (PAM)

It is widely known that polyacrylamide (PAM) and related derivatives are the most preferred polymetric water-soluble DRA in the oil industry for water injection. They are more practical use as DRAs than polyethyleneoxide (PEO), as they have more side chain and are less susceptible to shear degradation. Molecular weight for acrylamide copolymers can be as high as 20 000 000 Da. Polyacrylamide DRAs are highly efficient in water injection systems because only 10-30 ppm polymer is needed to achieve significant pressure drop (Kelland, 2003). Below are the properties for PAM:

Table 2: Properties of Polyacrylamide (PAM)

Chemicals Name	Poly(acrylamide-co-acrylic acid)
Molecular formula	$(C_3H_5NO)_n$
Appearance form	Powder
Mol wt	M_w 5,000,000
Transition temp	T_g 165°C
Viscosity	2-3 cP, 0.1 % in H_2O
Density	0.75 g/mL at 25 °C (lit.)
Solubility	Water and some protic solvents: soluble

Source: Sigma Aldrich

2.5.2 Polyvinylpyrrolidone (PVP)

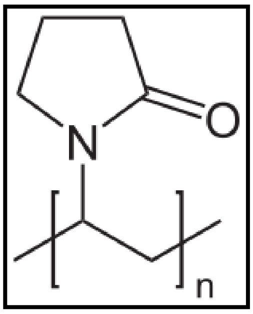

Figure 3: Chemical Structure for Polyvinylpyrrolidone (PVP)

Polyvinylpyrrolidone or PVP is a water-soluble polymer made from the monomer N-vinylpyrrolidone. PVP polymer purpose as a film former, protective colloid and suspending agent, dry-receptive resin, binder and stabilizer, adhesive, complexing agent and physiologically alert. PVP has potential to be a drag reducing agent. Below is the properties for PVP:

Table 3: Properties of Polyvinylpyrrolidone (PVP)

Chemical Name	Poly(vinylpyrrolidone)
Molecular formula	$(C_6H_9NO)_n$
Mol wt	average mol wt 10,000
Viscosity number	12-18 (lit.)
Appearance	white to light yellow, hygroscopic, amorphous powder
Density	1.2 g/cm³
Melting point	150 - 180 °C (glass temperature)

Source: Sigma Aldrich

2.5.3 Polyethyleneoxide (PEO)

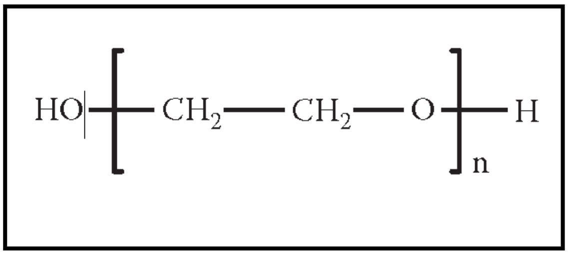

Figure 4: Chemical Structure for Polyethyleneoxide (PEO)

PEO is made by metal-catalyzed polymerization of ethylene oxide to give a very high molecular weight, up to 8 000 000 Da. PEO is commercially available. PEO is characterized by high viscosity, good water solubility. Excellent dispersing effect can be achieved by only a small amount of PEO. Besides, it will not influence the functions of the other additives. However, as it is prone to shear degradation when injected under turbulent flow, it uses in oil industry is small. However, PEO is one of the polymers that have been subject for intensive research in the phenomenon of drag reduction.

Table 4: Properties of Polyethyleneoxide (PEO)

Related Categories	Poly(Ethylene Oxide)
Appearance	White Powder
Property	Straight Chain/Non-Ionic Type
Mol Wt	Average M_v 100,000
Contains	200-500 Ppm BHT As Inhibitor
Refractive Index	*N*20/D 1.4539
Viscosity	12-50 Cp, 5 % In H_2O(25 °C, Brookfield)(Lit.)
Transition Temp	T_g −67 °C
	T_m 65 °C
Density	1.13 G/Ml At 25 °C
Melting Point	66-70°C
Solution Ph	6.5-7.5

Source: Sigma Aldrich

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Problem Statement:
Problem identification based on current issues with the significance of the project proposed.

↓

Literature Review:
Study and review journals, articles and books related to the project proposed for deeper understanding of the concept involved and for experimental purposes

↓

Experiment Design:
Clear view on procedures of the experimental works and preparation on the equipments and chemicals

↓

Data Analysis and Interpretation:
Analysis of the result obtained and comparing the outcomes with the conceptual understanding and practicality

↓

Report Writing:
Report the findings with conclusion and recommendation for improvement

3.2 Experimental Details

3.2.1 Experimental Setup

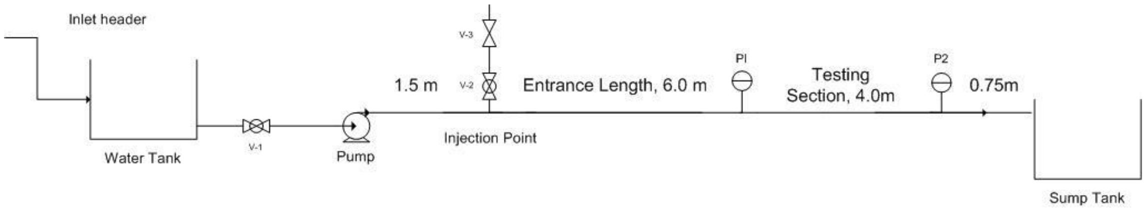

Figure 5: Schematic Diagram of experiment setup

The experimental setup consists of an open flow loop pipeline. The main part consists of a 4m galvanized pipe with inner diameter 0.0254m (ID). DRA injection point located in the middle of the pipeline, after the centrifugal pump section. Two pressure gauges are located after the injection point to observe the pressure and calculate the pressure drop. The sump tank will act as the last point where the fluid sample is taken for further properties analysis.

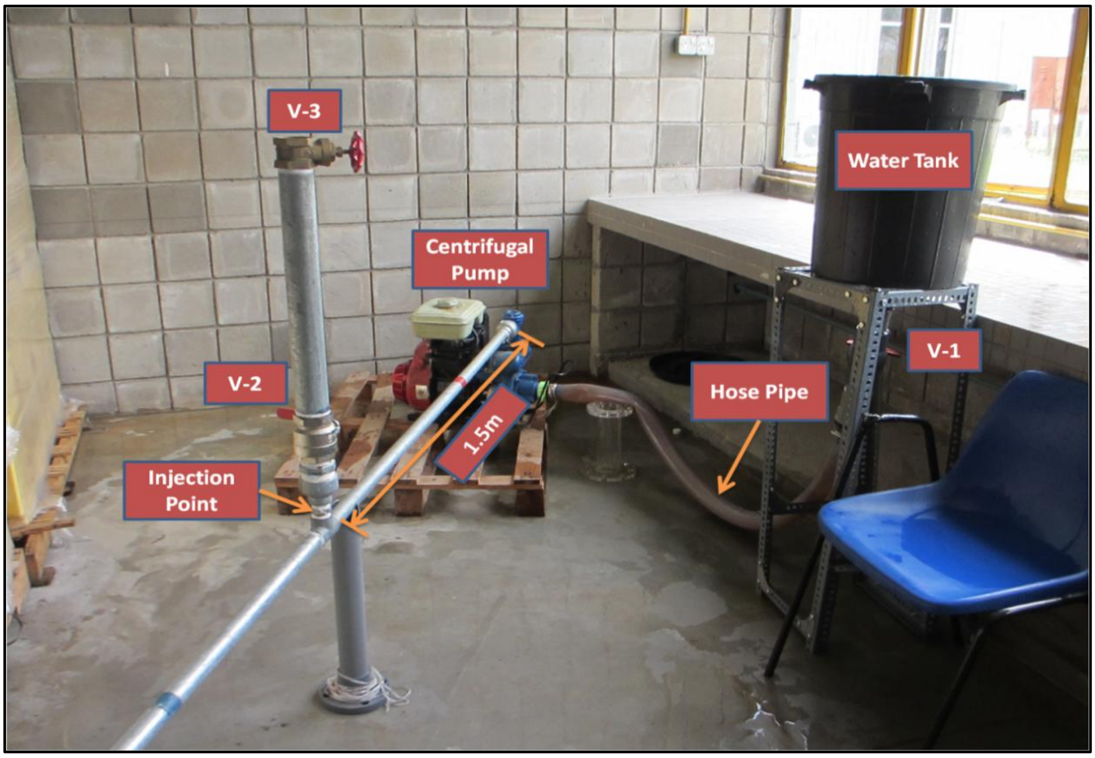

Figure 6: Equipment setup for water tank, pump and DRA injection point

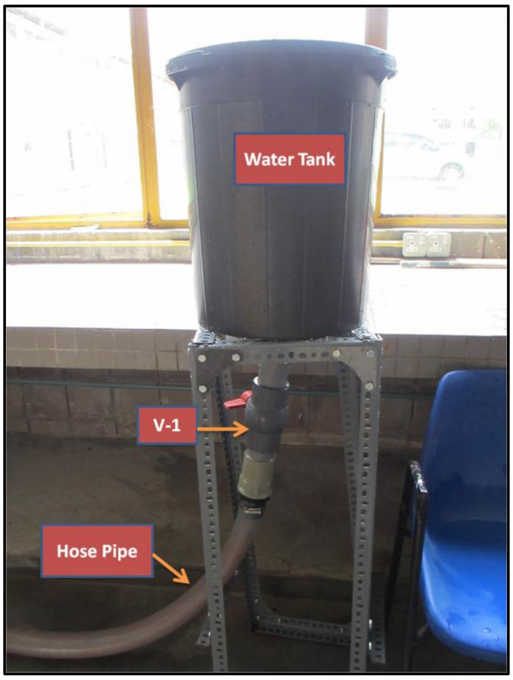

Figure 7: Water tank setup

Water tank that can accommodate 36L tap water is used in this experiment. A steel supporter is placed below the water tank to support the tank as well as set it up about 2m from the ground to easier the water flow based on gravitational and potential energy. A ball valve is placed between the water tank and the hose pipe to control the flow of the water to the pump; either in open or closed position.

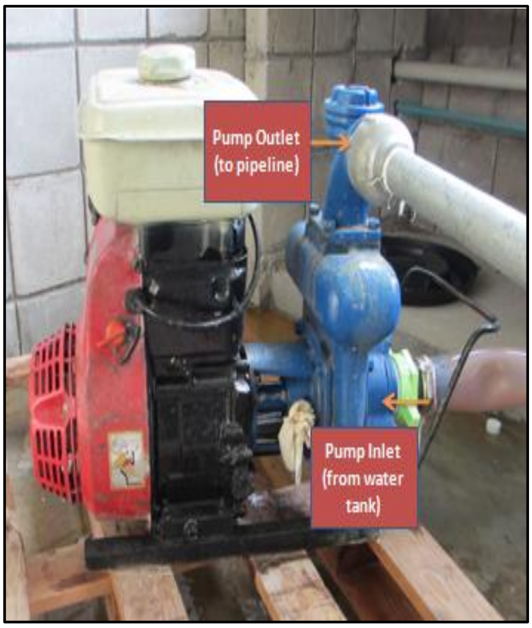

Figure 8: Centrifugal pump

Centrifugal pump is utilized in this research. The pump will provide additional energy to the water to flow through the pipeline system. The pump can be adjusted to low RPM and high RPM. This pump is used to represents the real phenomenon where the fluid will be transported under high energy environment and thus exposed to many shear forces and friction.

Figure 9: DRA Injection point

DRA injection point includes one ball valve (V-2) and one gate valve (V-3). One liter DRA solution is poured into the injection skid and the valves will function as controller to ensure that the DRA will flow into the pipelines and well mixed with the tap water before the pressure drawdown is measure. As DRA can easily degrade under high shear forces, the injection point is located 1.5m after the pump to ensure DRA maintains its structure and can perform effectively.

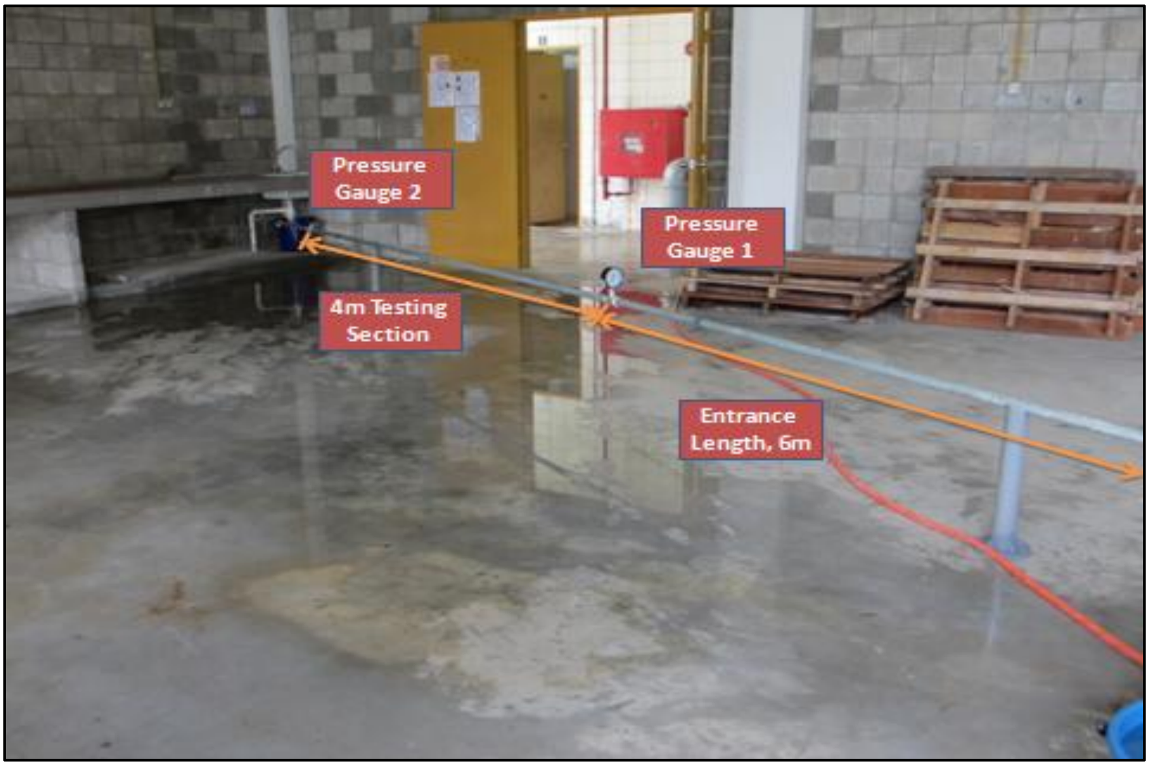

Figure 10: Open flow system

The open flow system consists of:

1. Entrance Length of 6.0m. This entrance length is important to ensure that turbulent flow is fully developed and the DRA has reacted with the tap water before pressure drawdown is measured.

2. Pressure gauges. Pressure Gauge 1 and Pressure Gauge 2 is installed to measure the pressure drawdown across 4m testing section.

3. 4m testing section. Along this section, it is assumed that the fully turbulent flow regime is achieved and the DRA polymer reacted with the tap water and pipeline wall.

Figure 11: Sump Tank

Sump tank is used to collect the volume of 36L tap water that go through the pipeline. 0.75m pipe length is installed after the pressure gauge 2 to prevent any unstable flow out of fluid that could affect the pressure reading.

3.2.2 Preparation of polymer solution

Different concentration of PVP, PAM and PEO is used for this experiment, ranging from 400 to 1000ppm. The preparation procedures are as follows:

1. 1000ml of distilled water is poured into the beaker to prepare 400 ppm of DRA solution.

2. 0.4g of polymer powder is weighed up and added into the beaker containing 1000ml distilled water.

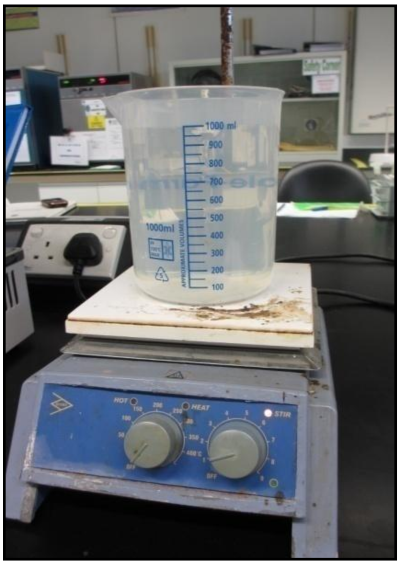

Figure 12: Solution preparation

3. The mixture is stirred at low mixing speed using magnetic stirrer for 30 minutes. It is important to maintain the slow speed as the polymer mixture could degrade at a high speed.

4. Steps 1-3 is repeated by changing the mass to 0.6, 0.8, and 1.0 grams of polymer powder to create 600, 800 and 1000 ppm of DRA solutions.

5. Two samples of each DRA concentration are prepared for averaging purposes.

6. Table 2 shows the concentration values of the polymer solutions:

Table 5: Concentration value for different mass of polymer

Mass(g)	0.4	0.6	0.8	1.0
Concentration (ppm)	400	600	800	1000

7. The density for each solution is recorded by using digital densitometer.

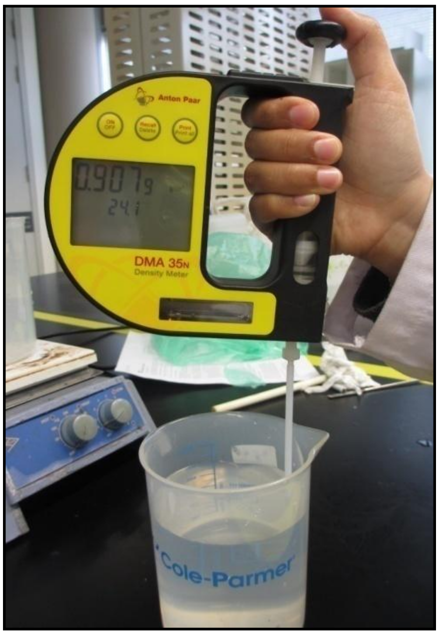

Figure 13: Densitometer

3.2.3 Experimental Procedure

1. Before starting the pump, make sure that valve 1 are opened while valve 2 and valve 3 are closed.

2. The operation begins when the pump is started. The base case (water flow without DRA added) is run. The flow rate and pressure drop at the end of the water pipeline are recorded.

3. Then valve 1 are closed and the pump will be switch off.

4. Valve 3 is open to add DRA into the injection column. Valve 3 is then closed.

5. Next, start the pump again and opened valve 1 to allow the fluid to flow inside the pipeline. Valve 2 is then opened simultaneously to let the DRA solution from injection point to mix with the flowing fluid inside the pipeline.

6. The time taken for 36L of water pass through the pipeline and pressure of the system is recorded by using stopwatch and camera.

7. Switch off the pump once all of the reading had been taken.

8. Before proceed with other concentration and type of polymer, the pipeline system is flushed with tap water twice.

9. Repeat step 1 till 8 for each DRA concentration and DRA type. All data is recorded and tabulated in Table 3.

Table 6: Data Tabulation

Concentration (ppm)	P1 (psi)	P2 (psi)	Time,t (s)
0			
400			
600			
800			
1000			

10. The Drag Reduction (DR) and Flow Increase (FI%) for the system is calculated using formula:

$$\%DR = \frac{\Delta P - \Delta P_{DRA}}{\Delta P} x100$$

$$\%FI = \left\{ \left[\frac{100}{100 - \%DR} \right]^{0,556} - 1 \right\} x100$$

11. The graph of %DR versus Concentration and %FI versus Concentration for PAM, PVP and PEO is plotted.

3.3 Tool for Experiment

The experimental setup for this experiment consists of the following:

1. Water and Sump Tank
2. 12.5 m galvanized pipe
3. Centrifugal Pump
4. Valves
5. Pressure Gauge
6. Magnetic Sitrrer

3.4 Material for Experiment

1. Distilled water
2. Tap water

3.5 Chemicals for Experiment

1. Polyacrylamide (PAM)
2. Polyvinylpyrrolidone (PVP)
3. Polyethyleneoxide (PEO)

3.6 Gantt Chart

No	Semester	FYP 1																FYP 2															
	Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14		1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Selection of project topic	■	■						mid-sem break								sem break								mid-sem break								
2	Preliminary research work		■	■	■	■																											
3	Project Understanding		■	■	■	■																											
4	Literature review				■	■	■	■																									
5	Submission of extended proposal						■																										
6	Proposal defence									■	■																						
7	Experimental work											■	■	■	■	■		■	■	■	■	■	■	■		■	■	■	■	■			
8	Submission of interim draft report														■																		
9	Submission of interim report															■																	
10	Submission of progress report																									■							
11	Interpretation data and parametric analysis																									■	■	■	■	■			
12	Pre-SEDEX																												■				
13	Report writing											■	■	■	■	■		■	■	■	■	■	■	■		■	■	■	■	■			
14	Submission of draft report																													■			
15	Submission of dissertation (soft bound)																														■		
16	Submission of technical paper																														■		
17	Oral presentation																															■	
18	Submission of dissertation (hard bound)																																■

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Variables

The variables for this experiment are stated as follows:

1. Constant variables

1. Volume of distilled water mixed with polymer power (1000mL)
2. Time taken to mix polymer (30 minutes)
3. Speed of magnetic stirrer
4. Volume of water (36L)
5. Amount of DRA injected into pipeline (1000mL)

2. Manipulated variables

1. Concentration of DRA (400,600,800,1000ppm)
2. Type of DRA (PAM, PVP, PEO)

3. Responding variables

1. Time taken for 36L water pass through pipelines, t.
2. Pressure drop (P1-P2)

4.2.1 Assumptions

i) Fully turbulent flow is developed

As drag reducing agents performed at its best in turbulent regime, it is assumed that all a full-turbulent regime has been developed in the pipelines before the pressure drawdown is measured at the pressure gauges.

ii) Full-pipe flow

The fluid in the pipe is assumed to be delivered in full diameter of the pipe. This is important to ensure that the fluid has contact with the pipe wall and a buffer zone is developed where drag reducing agent act effectively to dampen the turbulence burst.

iii) DRA dissolved completely in the distilled water

While preparing the DRA solution, the water-soluble polymers are assumed to dissolve completely in the distilled water. The 30 minutes stirring time is enough to disperse and dissolve the polymer molecules in the water.

iv) DRA is well mixed with the transported water

After the injection point, DRA is assumed to be well mixed with the tap water pumped and thus react with the pipe wall and gives the desired result. The injection point is designed to be 90^o to the pipeline system so that once the valve is opened, the DRA will flows directly in the direction of the fluid flows and react accordingly to reduce the frictional energy losses.

4.3 Experiment Calculation

i) Average Pressure Drop

Pressure drop between the pressure gauges is recorded and calculated by the following equation:

$$\Delta P = P_1 - P_2$$

ii) Percentage of drag reduction

Pressure drop reading which is recorded throughout the experiment, before and after addition of the drag reducing agent is to calculate the percentage of the drag reduction, $\%DR$ as shown in the equation below:

$$\%DR = \frac{\Delta P - \Delta P_{DRA}}{\Delta P} \, x \, 100$$

iii) Percentage of the flow increase

The percentage drag reduction is needed to calculate the percentage of the flow (or throughput), as shown in the equation below:

$$\%FI = \left\{ \left[\frac{100}{100 - \%DR} \right]^{0.556} - 1 \right\} x \, 100$$

iv) Flow Rate

Flow rate result can be obtained by divided the constant volume of water with the different time taken for the water to reached at constant point in the drainage tank.

$$Flow\ rate = \frac{Volume}{time}$$

From the experiment conducted, below are the data that shows the results of the experiment.

Table 7: Raw Data of experiment

	concentration (ppm)	P1 (psi)	P2 (psi)	P1-P2 (psi)	avg pressure dop, psi	avg time,s	avg time (min)
Dry Run	0	16	2.5	13.5	13.5	20	0.33333
PAM	400	14	5	9	8.5	12.79432	0.21324
		14	6	8			
	600	16	5	11	10	12.92954	0.21549
		14	5	9			
	800	16	5	11	9.25	11.72947	0.19549
		14	6.5	7.5			
	1000	14	7.5	6.5	7.75	12.30578	0.2051
		14	5	9			
PVP	400	15	4	11	11.75	14.55	0.2425
		15	2.5	12.5			
	600	15	5	10	9.5	14.45	0.24083
		14	5	9			
	800	14	5	9	9	14.05	0.23417
		14	5	9			
	1000	12	4	8	8.5	14.2	0.23667
		14	5	9			
PEO	400	15	7.5	7.5	8.75	16.66	0.27767
		15	5	10			
	600	16	7.5	8.5	9.25	17.17264	0.28621
		16	6	10			
	800	14	6.5	7.5	9.25	17.68388	0.29473
		16	5	11			
	1000	14	5	9	9.625	19.53007	0.3255
		14	3.75	10.25			

4.4 Discussions

4.4.1 Average Pressure Drop

Table 8: Average Pressure Drop vs Concentration

Concentration (ppm)	Average Pressure Drop (psi)		
	PAM	PVP	PEO
0	13.5	13.5	13.5
400	8.50	11.75	8.75
600	10.00	9.50	9.25
800	9.25	9.00	9.25
1000	7.75	8.50	9.63

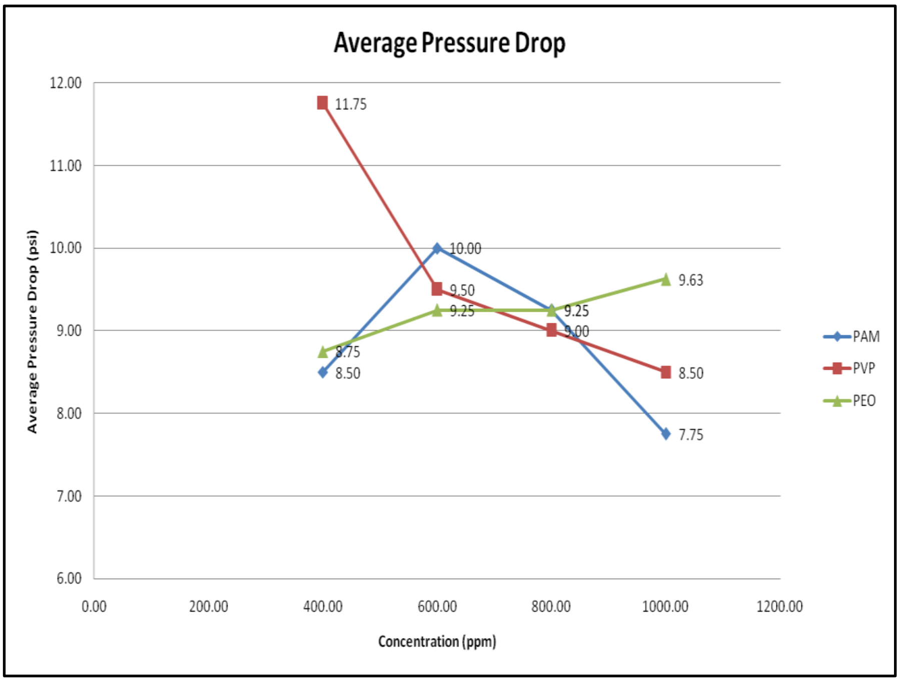

Figure 14: Average Pressure Drop vs Concentration

Figure 13 shows a plot of average pressure drop versus concentration for PAM, PVP and PEO. Addition of DRA into the water system gives positive impact towards the pressure drop as smaller pressure drop is achieved. From the plot, it can be seen that the pressure drop is reduced as the concentration of DRA is increased for PAM and PVP but opposite for PEO. For PVP, the highest pressure drop is at 400ppm (11.75psi) and the pressure drop becomes smaller as the concentration is increased from 400ppm to 1000ppm which is only 8.5psi. The reduction in pressure drop may due to the availability of the abundant polymer molecules to interact and dampens the turbulent eddies; causing smaller pressure drop across the pipelines.

For PAM, the pressure drop increased as the concentration is increased from 400ppm to 600ppm which is 8.5psi to 10psi. Possible explanation on this result may due to the technical error by which failure of equipment occur during experiment. After 600ppm, the pressure drop steadily reduced as the concentration is further increased to 800ppm and 1000ppm. The smallest total pressure drop achieved is 7.75psi by adding 1000ppm of PAM into the system as more polymer molecules are available to suppress the turbulent eddies.

For PEO, there is only slight change in the pressure drop for all concentration, and the pressure drop increased as the concentration is increased. Addition of 600ppm and 800ppm of PEO shows the pressure drop maintained at 9.25psi. Then the pressure drop increased as the concentration increased to 1000ppm which up to 9.625psi. This may due to the fact that the system has reached the optimum concentration of DRA and further increase in concentration does not affect the drag reduction. Instead, the overdose polymer molecules only act as obstruction which increases the pressure drop.

4.4.2 Drag Reduction (%DR)

Table 9: Drag Reduction vs Concentration

Concentration (ppm)	%DR		
	PAM	PVP	PEO
400	37.04	12.96	35.19
600	25.93	29.63	31.48
800	31.48	33.33	31.48
1000	42.59	37.04	28.70

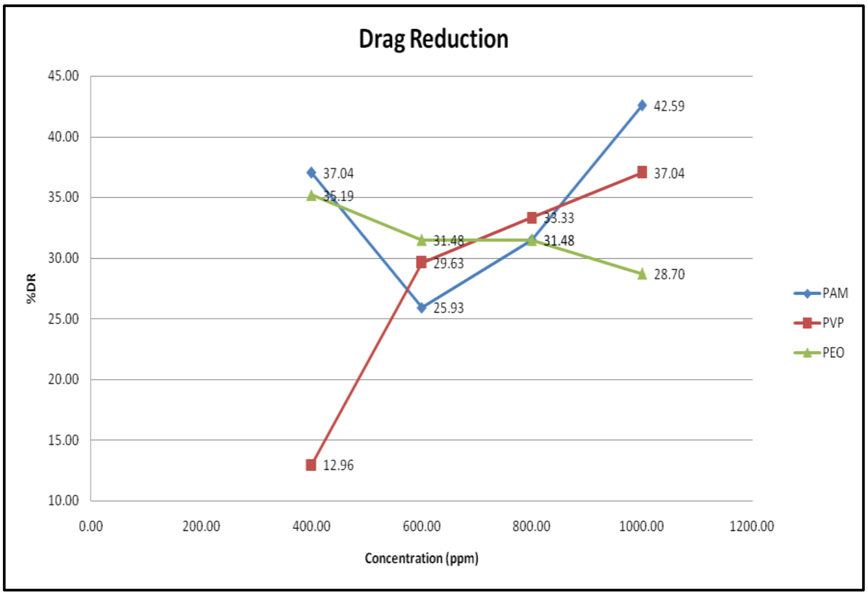

Figure 15: %DR vs Concentration

Figure 14 shows the drag reduction for all the three polymers against the concentration. The percentage of drag reduction (%DR) is calculated using equation (3). The equation shows the relationship between the pressure drop measured by adding DRA and without DRA (base case). Therefore, by having smaller pressure drop after addition of DRA into the system, higher the drag reduction is expected to be achieved. In PAM and PVP cases, drag reduction increases as the concentration is increased. This is because the pressure drop is decreased across the pipelines; indicating that the drag is reduced. The highest drag reduction recorded is 42.5% with addition of 1000ppm PAM. PEO shows a decrease in the drag reduction as the concentration is increased. The highest drag reduction for PEO is at 400ppm which is 35% and further increased in concentration caused drop in drag reduction to 28%. Highest drag reduction for PVP is achieved at 1000ppm concentration which is 37%.

4.4.3 Flow Throughput Increase (%FI)

Table 10: Flow Increase vs Concentration

Concentration (ppm)	%FI		
	PAM	PVP	PEO
400	29.33	8.03	27.27
600	18.16	21.58	23.39
800	23.39	25.29	23.39
1000	36.15	29.33	20.70

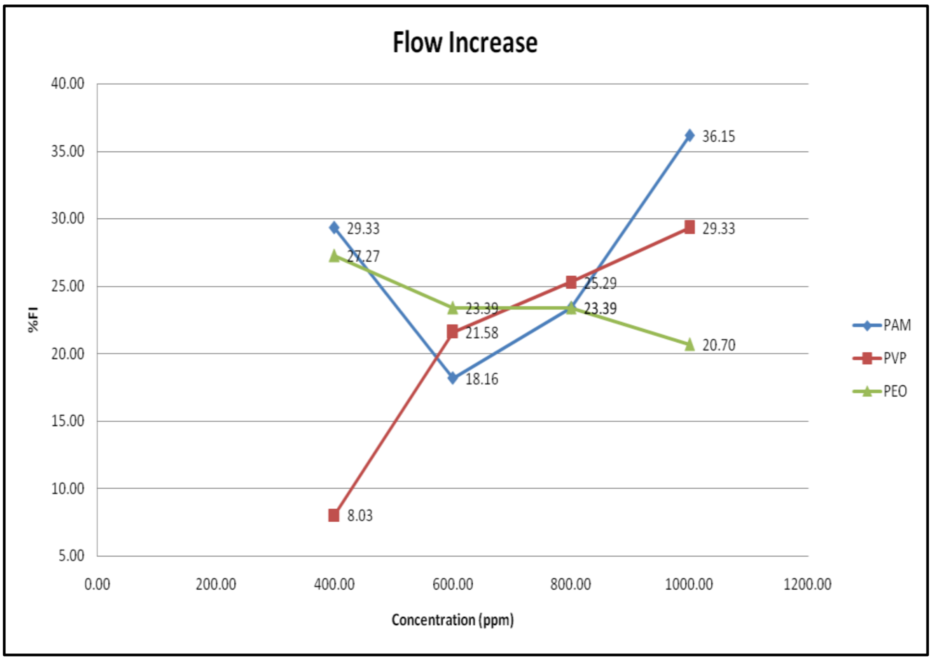

Figure 16: %FI vs Concentration

Figure 5 shows the percentage flow throughput increase (%FI) versus the concentration. %FI is calculated using equation (4) which includes the drag reduction factor. The graph trends for all the three polymers are similar to the drag reduction plots. The highest %FI is when 1000ppm of PAM is injected into the system; about 36.1%. Meanwhile, addition of 1000ppm of PVP gives %FI up to 29.3% and for PEO, highest %FI is at 400ppm concentration which is 27.3%. The flow throughput will increase as the drag reduction is increased. The study flow increase shows that the capacity of the pipelines to transfer a volume of fluid increases as the drag is reduced.

4.4.2 Average Flow Rate

Table 11: Average Flow Rate vs Concentration

Concentration (ppm)	Average Flow Rate (gpm)		
	PAM	PVP	PEO
400	44.64	39.22	34.25
600	44.18	39.49	33.23
800	48.70	40.61	32.27
1000	46.42	40.18	29.22

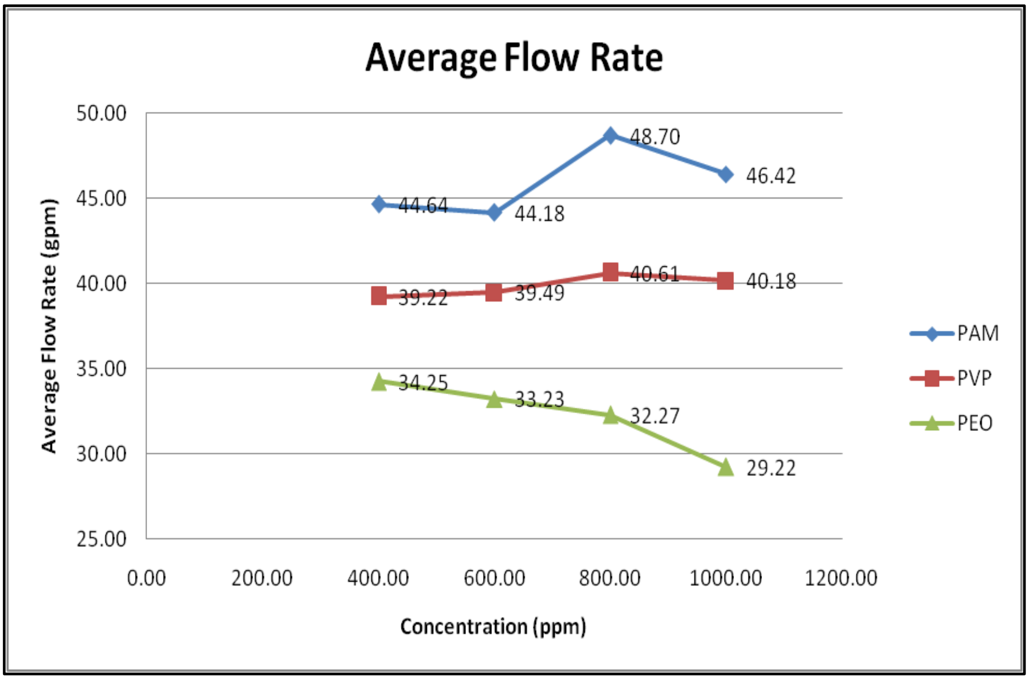

Figure 17: Average Flow Rate vs Concentration

Figure 16 shows the average flow rate measured versus the concentration of DRA. PAM gives the highest result in average flow rate and the trend is fluctuated; with the highest flow rate at 800ppm which is 48.6 gpm. Average flow rate decreased as concentration is increased for PEO polymer with highest flow rate at 400ppm (34.2 gpm) and smallest flow rate at 1000ppm (29.2 gpm). For PVP, the average flow rate increase steadily but in small proportion by increasing concentration of the polymer which is from 39.2 gpm to 40.2 gpm. As the drag force has been removed or suppressed by the addition of DRA, the flow rate is higher as the fluid can flow easily. The polymer acts as lubricants for the flow as they stick to the pipe wall and thus reduce the friction between the fluids and the wall.

This experiment also demonstrates the effect of different type of DRA polymer injected into the system. PAM gives the most positive effect to the system by having smallest pressure drop and highest drag reduction, flow increase and flow rate as compared to PVP and PEO. This result can be explained by discussing the properties of the polymer itself, especially the molecular weight and polymer structure.

The molecular weight of the polymer needs to be taken into consideration. In this research, PAM have the highest molecular weight of over 5,00,000, followed by PVP with molecular weight of 10,000 and PEO with molecular weight of 4000. The performance of high molecular weight polymer is demonstrated in this experiment. It is clearly shown that high molecular weight polymer will give smaller pressure drop, better drag reduction, high flow throughput increase and higher flow rate. This is because the longer polymers will be best suited to break up turbulence bursts or eddies in the flow [6]. These small eddies are easier to be suppressed as they have lower energy in them.

In regards of polymer structure, PAM and PVP a side chain as compared to PEO which is linear. This can be one of the factors which contribute of the decrease of effectiveness of PEO. By having more side chain, PAM and PVP are less susceptible to shear degradation [6]. Thus, less shear problems are encountered and the polymer can performed better.

4.5 Limitations

1. Equipment Failure

Centrifugal pump used for this experiment can be considered as “worn out” where it may not functional at its best performance like before. Sometimes it cannot be started and the efficiency of the pump is uncertain. We cannot actually measure whether it deliver constant capacity of the fluid for all the experiment. However, the pump was sent for services a few times to ensure it works well.

2. Budget Allocation

The budget allocated for Final Year project is only RM 500 for chemicals and materials needed to run the experiment. This limits our plan to purchase more accurate devices such as digital pressure gauge which costs minimum RM 1000. The intention to change the setup like the new pump and new injection skid for more reliability of result has to be stopped due to this constraint.

3. Time constraint

This project needs to be completed in 3 months; after extensive literature review during Final Year Project 1. Within these 3 months, the more than 40 solutions of drag reducing agent have been prepared which each of it took 30 minutes to stir. Besides, only one magnetic stirrer available in lab for the students to use it and we need to share it with other students as well. Making things worse, the pump need to be sent for services, thus the process to assemble and dissemble the pump needs time. The datelines for the project are shifted to front and thus we need to complete the project early than planned.

4.6 Errors

1. Systemic Error

This error is commonly due to the design of the experiment.

a) The injection point

Drag reducing agent should be injected parallel to the water flow to allow the polymer fully dissolved with water at the first point so that the first pressure reading will show the reading of the dissolved fluid. However, in this project the DRA is injected perpendicular to the water flow as the injection point is place vertically to the pipe.

b) Centrifugal pump

The centrifugal pump used is not adjustable pump which do not has range of values of revolution per minute (RPM). Thus, only high and low RPM options available to run the experiment. However, the low RPM is too low to pump the fluid through the long pipe. Thus, the results obtained for low RPM is not accurate as the water does not fully full the pipeline which contribute to low pressure than it supposedly to be. Due to that, the low RPM results are not considered valid for this project.

c) DRA solution

The DRA solution is prepared with the assumptions of they are fully soluble in the water. Next, some of the DRA solutions have been prepared some time before the experiment is carried out. It is recommended that DRA solution prepared should not be kept too long before injected into the pipeline.

2. Parallax error

Parallax error is error while taking the measurement. In this project, the pressure reading needs to be taken for every run at two point in between the test section point. Due to short time taken for the water to flow, it may contribute to error will reading the pressure. Besides, turbulent water is flow along the pipe and thus this leads to fluctuation reading at the pressure gauge.

3. Human error

Human error happened when the time taken for each run when the water is fully fill in the drainage tank. The reaction time of the person in charge to stop the stopwatch exactly at 36L water volume may contributes to the error.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

It is expected that this research project could give an understanding on the effect of concentration on drag reduction and the most effective drag reducing polymer. Experiments have been carried out to investigate the effectiveness of PAM, PVP and PEO as drag reducing agents in water system. Flow characteristics such as pressure drop, drag reduction (%DR), flow throughput increase (%FI) and flow rate with DRA concentration of 400ppm, 600ppm, 800ppm, and 1000ppm has been studied.

The turbulent regime of a pipeline can be determined by Reynolds number equation;

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

Al-Anazi et al (2006) studies on the evaluation of DRA for seawater injection have given a clearer picture on the effect of concentration towards the drag reduction (%DR) and flow increase (%FI). The effectiveness of DRA increased at higher concentration as compared to lower concentration of DRA. This is proven by the decrease in pressure drop and increase in drag reduction and flow throughput, as shown in Figure 14, 15, and 16. From this experiment, it is known that different type of polymer will gives different result in terms of their flow rate as the concentration is increased, according to the trend of drag reduction and flow increase. PAM gives the highest flow rate as compared to PVP and PEO. This can be explained by referring to their molecular weight and polymer structure. Polymer with high molecular weight and more branches would act more effectively as drag reducing agent.

In general, PAM is the most effective DRA as compared to PVP and PEO, with drag reduction up to 42.5% and flow throughput increased to 36%. However, both PVP and PEO have high potential to be developed as DRA as both gives about similar ranges of drag reduction and flow increase. In fact, the addition of small volume of DRA which can result in such drag reduction and flow increase can be very fascinating in economical aspect. With reduction in drag, the pipelines will have more capacities and more volume of fluids can be transported or injected.

To improve the integrity and the relevancy of this project, a few recommendations and improvisations are suggested as below:

1. To test on the rheological properties of the polymer; its shear degradation and elasticity so that better understanding of the effect of these properties towards drag reduction is known.

2. To investigate the effect of gravity towards drag reduction in vertical flow.

3. To study the effect of DRA towards the improvement of flow and formation damage in core (coreflooding)

4. To improvise on the experimental setup (the injection skid, pressure gauge) for more accurate readings.

5. To design a pipeline so that DRA effect on both oil and water can be identified.

6. To determine the best point in the pipeline where the turbulent force happen so that the performance of DRA is known.

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