TO DETERMINE THE EFFICIENCY OF POLYVINYLPYRROLIDONE (PVP) AND POLYACRYLAMIDE (PAM) AS DRAG REDUCING AGENT FOR WATER INJECTION

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DISSERTATION

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CERTIFICATION OF ORIGINALITY

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

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Nadia’Izzati bte Mohemed Khirol Amin

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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Approved by,

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ABSTRACT

Water injection can be applied as secondary recovery method to repressurize the reservoir to maintain oil production and thus, can maintain the production rate. One of the main aims during water injection process is to increase the volume of water injected into the reservoir. However, the injection of water is often limited by pumping capacity on the platform or well site and the capacity of injection tubing or pipelines due to friction pressure loss. Moreover, it is commonly found in the pipeline system, water transported may exerted over long distance which allow to more pressures loss. Thus, this limitation affects the flow assurance of the well production. The main aim in this project is to study the effectiveness of using Polyvinylpyrrolidone (PVP) and Polyacrylamide (PAM) as Drag Reducing Agent for Water Injection by manipulating the polymer concentration from 100ppm to 800ppm and see the effect of Reynolds number and flow rate obtained. Drag reducing Agent (DRA) have been used in the oil industry for several years, both in oil and water based systems to enhance the flow assurance in the production line which caused by drag. Drag may contribute to pumping loses, decreasing in production capacity and potential of corrosion effect. Due to that, a lot of researches have been done to investigate the most effectiveness drag reducing agent that can be used to overcome this matter. In this project, an open flow experiment setup is fabricated which is mainly consist of 12.25m long of 1” diameter galvanized pipe and 0.5m long of 2” diameter of injection point. Two pressure gauge is used to monitor the pressure drop obtained along the 4m test section for each concentrations tested. Besides, a commercial DRA is used to compare the performance of tested polymer (PVP and PAM). The results show that PAM gives most significant drag reduction percentage with 21.9% compare to PVP, 18.8%. However, this commercial DRA shows greater drag reduction up to 30% with comparison with the optimum concentration of both polymers. Besides, it also observed that an increase of Reynolds number will increase the drag reduction percentage before the polymer start to degrade at too high flow rate. Thus, it is concluded that the ability of PVP and approve the PAM as a potential drag reducing agent which can be used effectively in water injection system. Besides, both tested polymers performance is not far behind with the DR% obtain by the commercial DRA.

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Secondly, gratitude goes to the lab technician of Block 15, Mr Juhairi from Petroleum Engineering Department for the support and kindness by insisting me in conducting the rheological test in the lab.

Apart from that, not forgetting too my friends and family who had helped me during the whole project period by giving me moral and mental support. Hope through this project, I have learned more on drag reduction as it currently a major problem in the pipeline system in oil and gas industry and do hope I gained a valuable experience which will help me in my future career development.

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CHAPTER 1

1. Introduction

1.1 Background of the Research

Water is injected into a reservoir via water injection wells to maintain reservoir pressure and hence maintain or boost oil production levels. In general, the more water is injected into formation the more oil that can be subsequently produced until water breakthrough occurs. Water injection is frequently encountered in long distance liquid transportation and limitation of pumping capacity on the platform or well site and the capacity of injection tubing or pipelines. The occurrence of these limits may result of friction loses in a tubing which is varies with other factor such as pipe roughness and Reynolds number that in reality depicts the turbulence level of the flow. This condition may affect the flow assurance of the flow line as it is a crucial factor for effectively producing and transporting of oil and gas besides may contribute to pumping losses and decreasing in production capacity.

In particular, turbulent flow (Reynolds number > 2,100) through the pipes presents even greater limitations on the pumping capacity. Turbulent flow can occur in the boundary layer near solids surfaces and the associated friction increased as the flow velocity increases (water injection rate increase). Loss of flow efficiency due to turbulent in oil pipeline has been driving force of numerous studies of the chemical additives that is used to minimize the dissipated energy hence increases the transportation efficiency. A reduction in energy loss in turbulent pipe flow in water/ solid transportation was reported more than 65 years ago and since the first reports of drag reduction was by Tom (1948)[4.] Tom stated that the addition of small concentration of high molecular weight polymer to water or other solvent can produce large reduction in frictional pressure drop for turbulent flow hence leading to the possibility to maintain the flow energy resulting increment in pipeline capacities. Thus, drag reducing agent (DRA) can be used to reduce frictional losses in pipeline which lead to decrease in the pressure gradient for a given flow rate. Lester (1985)[26,27] and Virk and Baher (1970)[38] have shown that drag reducing agents can be beneficial to reduce pressure drop in turbulent flow, but not in laminar flow. The phenomenon of drag reduction has been defined by Lumney (1969) as "the reduction of skin friction in turbulent flow below that of the solvent alone" [21].

The main purpose of drag reduction (DR) is to delay the onset of turbulent flows, In other words, a drag reducer will shift the transition from laminar flow to a turbulent flow to higher flow velocity. The turbulent core is reduced in size as the intermediate sub-layer expands. When injected continuously into a pipeline at concentration of typical 40-100ppm of formulated product, turbulent and resulting frictional pressure drop can be reduced by as much as 60%. Drag reducer or known as flow improver acts on the formation to increase fluid injectivity by increasing capacity of the system. The application of drag reducers has been widely used in oil and gas industry. The application of drag reducers has been applied in the Trans Alaska Pipeline, a major U.S oil pipeline[2]. From the field results, 20 ppm of DRA injection gave optimum injection increase of 13%. Thus, by additional of polymer may save the cost of constructing additional pump station. Besides that, used of DRA has increased the capacity of the Oseberg Transportation System (OTS) by 25% from 620, 000bopd to 770, 000bopd[5]. From the test, DRA have shown a reduced pressure loss in the line of about 50% corresponding to about 10% capacity increases. Drag reducers have been applied can give a lot of benefits in the pipeline system. It can save the pumping power, reducing energy consumption, increasing flow rate, decreasing the size of pumps and resolve problem due to turbulent pipe flow system. Due to its importance, the phenomenon has been subject of much revise in the past, in both theoretical and experimental field.

In this project, Polyvinylpyrrolidone (PVP) and Polyacrylamide (PAM) is used as polymeric additives solution to reduce the drag of liquid flow in a pipeline. There are several factors affecting the performance of polymer as DRA such as polymer concentration, polymer molecular weight, Reynolds numbers, degradation, length of the flow line and injection location. The effectiveness of DRA can be assessed by determining the magnitude of drag reduction at a given concentration and flow rate. By manipulating those factors as variable, the reducing efficiency and pressure drop can be obtained.

1.2 Problem Statement

The frictional pressure loss in the pipeline is due to the resistance encountered by flowing fluid coming into contact with solid surface such as pipe wall. Resulting from that, fluid molecule turns to eddies. Flowing fluid in turbulent regime where the Reynolds number > 2100 lead to huge pumping power loses along the pipeline. Besides, when fluid is transported in the pipelines, the force of drag is used to overcome the flow of the fluid in the flow line. This drag is the result of stresses at the wall due to fluid shearing and causing a pressure drop. Thus, sufficient pressure is needed to maintain the flow in the pipeline and obtain desired throughput.

Drag reduction increased with increased of molecular weight, concentration and flow rate. By using the long chain polymer that having average molecular weight of many orders of magnitude over 10^6 may enhance the flow assurance of the pipeline. However, polymer degradation occurs drastically in high flow rate and degradation is dependent on the molecular weight. The higher the molecular weight the more susceptible the polymer to shear degradation. This makes them susceptible to shear degradation in oil pipeline systems and hence performance decrease. Thus, in this situation more pressure must be applied to maintain the flow at the same average velocity especially when transported over long distances.

Corrosion due to used of water injection (used produce water/seawater injection) is the biggest threat in flow assurance in production. Corrosion effect may decrease the wall thickness and damage the surface of the pipeline/tubing. Thus, this will increase the friction and cause drag along the flow line and higher pressure drop occurs. Maximum allowable operating pressure needs to be reduced in order to prevent pipe fracture and thus this will decrease the production capacity in the pipeline. Hence, by using drag reducer chemical can reduce the liquid turbulence near the wall region and decrease the mass transfer rate of the oxygen to carbon steel.

1.3 Objectives of the study

The proposed project was studies to achieve the following objectives:-

1. To investigate the effectiveness of PVP and PAM water soluble polymer which are used as DRA during water injection system
2. To determine the pressure drop along the flow line and drag reduction percentage by using DRA
3. To investigate the effect several factors towards the drag reducing efficiency and pressure drop outcome after DRA injection. Those factors are:-
    a. Different polymer concentration
    b. Reynolds number
    c. Flow rate
4. To observe the difference in result by comparing the performance of PVP and PAM with commercial DRA

1.4 Scope of study

The scope of study is mainly focusing on the effects of PVP and PAM as the DRA in water injection system. The effectiveness of DRA can be assessed by determining the magnitude of drag reduction and pressure drop changes at a given concentration, flow rate and length of pipe. This project is divided into two phases which are research and experimental. The first phase will involves on research and study thoroughly about both polymers, the effect of several factors that affect the performance of DRA, the mechanism of fluid with or without DRA injection and the equations involved to calculated the pressure drop and reducing efficiency. During this phase, some modification on the experiment setup will be determined and it is suggested to add another pressure gauge and use the longer pipe length. Meanwhile, on the second phase will be involved in experimental work in the lab to test the factors that affect the polymer towards the reducing efficiency and pressure drop. The results obtained from the experiment will be analyzed and discussed. Experiment setup fabrication and polymer rheological test will be done during this phase in order to run the experiment.

1.5 Rational and Significance

This project is to study the effect of the different values of polymer concentrations and liquid flow rate in order to get the pressure difference along the test section point. From the pressure difference obtained, the drag reduction percentage (DR%) in the fluid can be determined. The value of %DR can be concluded that how effective the PVP and PAM in order to reduce the turbulent friction factor of the fluid.

If this project is successful, it will give the great impact to the industrial application especially for water injection system as PVP research on DRA in this industry is still under observation compare to PAM which is already commonly applied in industry. When the turbulent friction factor of the fluid decrease, the energy consumption will be saved and the flow rate of fluid also increases. Other rationale is cost can be saved in pipeline system due to drag reduction phenomenon as less construction of additional pumping stations which used for flow rate boost.

1.6 Feasibility of the project

This project needs to be carried out with experiment in order to meet the objective and it is feasible to be conducted after considering the followings:

a) Available equipments in the lab ease the process of making the solutions and get the rheological properties.
b) Slight modification need to be done on the existing experiment setup
c) PVP and PAM are widely available in the market
d) Numerous related researches and article available for reference
e) Sufficient budget allocation
f) A well-planned milestone have been set

CHAPTER 2

2. Literature Review

2.1 Drag Reducing Agent

Drag reduction is defined as the increase in pump ability of a fluid caused by the addition of small amount of an additive to the fluid[33]. This additive is known as a drag reducing agent (DRA) which is a long chained polymer with a very high molecular weight[18]. Polymer drag reduction was discovered about forty years ago by Toms (1947) who observed drag reduction of 30%-40% upon adding only 10ppm by weight of polymer to turbulent monocholo benzene flowing down in a pipe[4]. Toms' discovered a decrease in pressure gradient, for a given liquid velocity, with addition of DRA until minimum pressure gradient was reached. Further addition of DRA increased the pressure gradient gradually, until it exceeds that of the original solvent.

DRA is also called as a flow improver or friction reducer[3]. Dissolving a small amount of polymers (usually a few weight per million) in water can drastically reduce the pressure drop (frictional drag) of turbulent pipe or channel flow. The additives causing drag reduction can be divided in three groups: polymers, surfactant and fibers which act as the helper to prevent eddies in turbulent flow. These additives are helping to save the energy by reducing the circulation effects (prevent liquids molecule to rotate) that existed in turbulent flow. One of the first field reports of using a DRA in oil industry was in 1965 with the use of guar gum to reduce the cost of pumping aqueous fracturing fluids[14]. Virk (1975) reported the DRA's used in quantities in excess of 600ppm by weight may reached to 80% reduction in drag in single phase flow[40]. Since that time, the effectiveness of DRA's has been tested at lower concentration, mainly due to reduce downstream problem. Besides that, DRA's have been tested in single phase pipelines at concentration between 5 and 60 ppm by several researchers (Chang, 1983[8] ; Virk, 1975[40]). Result of two typical DRA's used to reduced pressure gradient in larger diameter crude oil pipeline are shown in figure below. A 40% reduction in drag is achieved with 10 ppm DRA. Increasing the DRA concentration to 60 ppm results in a 5% reduction in drag (Denys, 1995)[12]

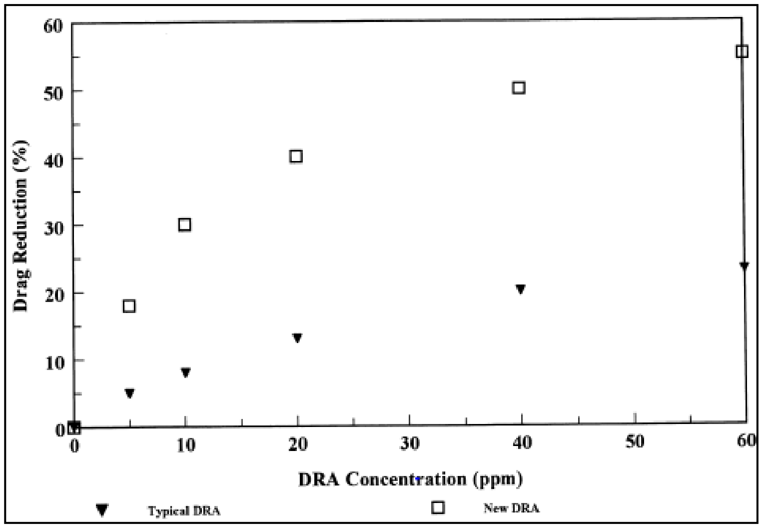

Figure 1: Drag Reduction Performance Single Phase Oil Flow

Drag reduction has a wide potential within the oil industry because large pressure drop reduction can be achieved with small concentration of DRA. Since then, there have been a number of uses for DRA in oil and gas industry including fracturing, acid stimulation, drilling fluids, water injection, coiled tubing operations, and oil transportation. Theoretically, drag reduction is only effective in turbulent flow and improves with decreasing viscosity and pipe diameter, or increasing Reynolds number. From the experimental study, higher turbulent flow and increased with DRA concentration resulted in more drag reduction[18]. However, the efficiency of DRA will reached a maximum point at a certain Reynolds number and this may result in reducing efficiency[17]. This due to the polymers degradation occurred drastically in high flow rate. Polymer degradation is dependent on the molecular weight. The higher the molecular weight the more it susceptible to polymer shear degradation (A.A. Hamouda, 2003)[1]

DRA molecular structure does not really survive the high shear forces generated by positive displacement pump. DRA show sensitivity to shear that degrades the polymer and decreases its performance compared to unsheared DRA. The structure of the polymer easily degraded due to shear forces and free radicals that reduce the effectiveness of polymeric DRA. David and Darby (1983) examined that shear degradation effects in 0.46 cm diameter tubes and point out that DRA degrade by age, losing effectiveness after a few days, and shear[7]. They computed friction factors for various DRA concentrations. The friction factors for a Reynolds number of 10^4 decreases from 0.004 to 0.0035 as a concentration of 100ppm DRA degrades. Choi et al (2000) who explaining degradation factors of turbulent also mentioned the influence of concentration towards degradation which is higher concentration of polymer additive will lowering degradation[50]. (Gullapalli, 1969) tested the drag performance of polyethylene oxides with salt solvent and data shown in the table below suggest that degradation is higher in dilute solutions as at 1lb/1000gal, in contrast to 8lb/1000gal. However, drag reduction at low shear rates is higher at lower concentration[51].

Concentrated Number/ 1,000 gal	Gal/Min	8V/D (sec^{-1})	$\frac{D\Delta L}{4L}$ (psi)	Drag Reduction (percent)
1	1.65	3,330	.0010	56.2
1	2.96	5.960	.0025	65.4
1	5.13	10,340	.0063	70.5
1	6.59	13,280	.0103	71.3
1	7.86	15,840	.0118	76.6
1	10.17	20,490	.0229	73.6
1	12.00	24,180	.0356	70.5
1	12.68	25,500	.0454	65.7
3	1.46	2,940	.0010	44.9
3	2.86	5,760	.0027	60.7
3	5.13	10,340	.0062	71.3
3	6.67	13,440	.0098	73.5
3	8.78	17,690	.0118	82.0
3	12.00	24,180	.0235	80.5
3	14.52	29,260	.0336	80.9
3	16.36	32,970	.0451	79.4
8	.91	1,840	.0012	32.1
8	2.10	4,230	.0026	57.2
8	4.14	8,340	.0061	65.4
8	5.83	11,750	.0101	70.5
8	6.84	13,780	.0115	75.7
8	10.53	21,220	.0234	76.2
8	13.14	26,480	.0330	77.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 1: Pipe Test Data for Polyhall 654 in fresh water at 85F

In water injection system, water may be transported over a long distance. As liquid flow through, the pressure drop is increasing by increasing distance. Hayder (2011) mentioned for a long distance, the addition of DRA has proved to maintain efficiency towards energy conservation. This is why the %DR increases with increase of pipe length. It is believed that the degree of turbulence increases by increasing the length due to the increase in eddy collision inside the pipe. However, DR% start to decrease when the shear degradation of the polymer start to appear. Indeed, polymer molecule was subjected to shear forces for a longer period of time and resulting in losses of efficiency[20]. Shetty and Solmon (2009) mentioned that the relaxation time which related to %DR as decreased by increasing the pipe length due to diffusity polymer inside pipe length that decreased as it flow[34].

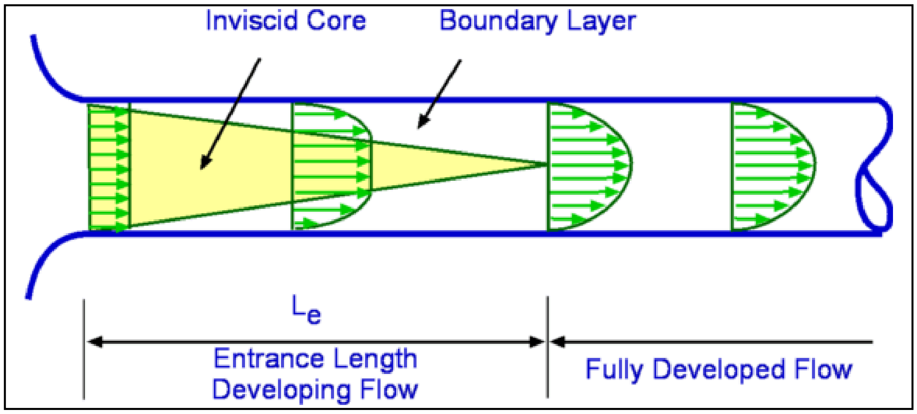

Figure 2: Flow at the entrance length

In order to obtain the established friction factors, it is essential to measure the pressure drop between two pressure taps in a fully developed flow region. The length of the pipe between the start and the point where the fully developed flow begins is called the entrance length (Figure 2). Suggested by Dessisler (1950)[13], Kays and Crawford (1993)[41], Tung et al (1978)[36] the minimum entrance length required for a fully developed velocity profile in turbulent flow was calculated from the relationship of diameter of the pipe. Yoo (1974)[32] showed that above x/d=40, there was no change in the pressure drop measurements for Newtonian and purely viscous non-Newtonian fluids. Besides, there is other equation used in function of Reynolds number of the flow to measured the entrance length for fully develop turbulent or laminar flow[43].

$$\text{Equation 1}: \frac{Le}{d} \approx 0.06\ Re\ for\ a\ Laminar\ flow$$

$$\text{Equation 2}\ \frac{Le}{d} \approx 4.4\ Re^{\ 1/6}\ for\ a\ Turbulent\ flow$$

Below is the table that shows all the assumption of theory for entrance length equations.

Reference	Theory	Measured Le
Dessisler (1950)	Le fo TURBULENT of Newtonian fluids = 50 D	Le= 1.27m
Kays and Crawford (1993)	Le for LAMINAR of Newtonian fluids= 100 D	Le= 2.54 m
	Le for TURBULENT of Newtonian fluids= 20 D	Le= 0.51 m
Yunus A. Cengel et al	Le for LAMINAR = 0.06 RE* D	Le= 3.2 m
	Le for TURBULENT = 4.4 RE^(1/4) *D	Le= 0.67 m
	Le for TURBULENT = 10 D	Le= 0.25 m
Yoo (1974)	L/D= 40 no change in ΔP	Le= 1.02 m
Tung et al (1978)	Le < 100 D for Newtonian fluids	Le < 2.54m
Cho and Harnett (1982)	*L/D > 110 for Non-Newtonian fluids*	*L/D = 236 m, more than 110 Thus, critical Le = 3m which gives ratio of 118*

According to Cho and Hartnett (1982)[42], the pressure drop for non-Newtonian fluids was measured at x/d >110 for all concentrations of aqueous polyox and Separan solutions, and there was no difference after changing the tap intervals and locations beyond x/d=110. For this reason, the pressure drop was measured at x/d=236 for all solutions in this study.

As shown in Figure 3 the pressure distribution behaves non-linearly and the pressure slopes is not constant at entrance region which is due to the different boundary layer thickness in the inviscid core. However, after the flow is fully developed, the slope becomes constant and the pressure drop is directly drop caused by the viscous effect.

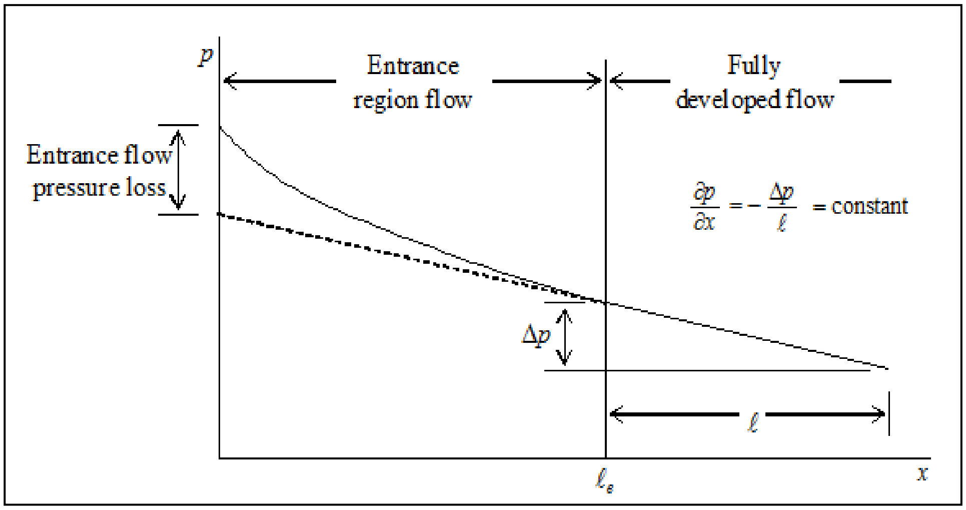

Figure 3: Pressure distribution in horizontal pipe

2.2 Drag Reduction Mechanism

Turbulence flow is defined by Hoerner (1995) as a state of "…a more or less irregular "eddying" motion, a state of commotion and agitation, consisting of velocity fluctuation superimposed to the main flow within the boundary layers."[30]. Friction factor of the pipe wall represent important factor to the degree of turbulent. Besides that, DRA is only works in turbulent flow. In turbulent flow, there are three different zones or layers. Nearest the pipeline wall is a zone called laminar sub layer. In this zone, the fluid follows the pipeline flow in 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 flow in this zone. In very centre of the pipe is turbulent core zone. This zone is the largest region and includes most of the fluid in the pipe. This is the zone of the eddy currents and random motion of turbulent flow. The turbulent core carries all of the flow where the variation in point velocity is random and dependent of this distance. Between the laminar sub layer and turbulent zone 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 the turbulent first forms.

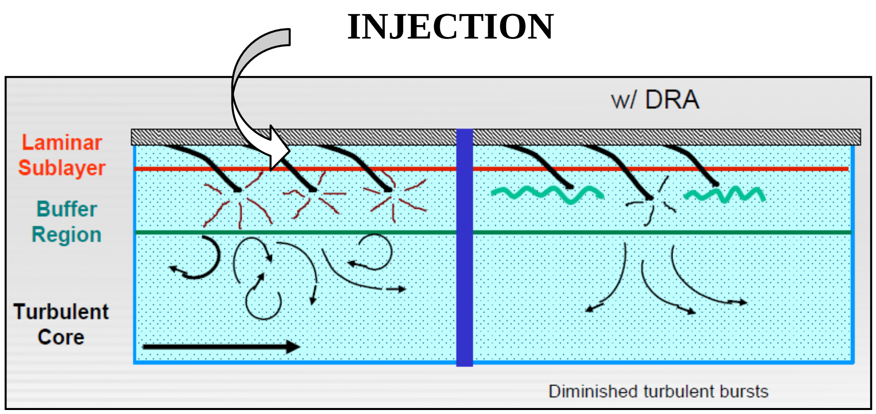

Figure 4 : Drag Reduction Mechanism

At first section, laminar sub layer called 'streak' will occasionally move to the buffer region which is the first formation of turbulence. This streak will begin to vortex, oscillate and hence start to move faster as it gets closer to the turbulent core. Thus, the streak becomes unstable and breaks up as it throws fluid into the core of the flow. Water injection into the turbulence core (turbulent burst) will cause of wasted energy.

Thus, DRA interfere with bursting process or inhibit the formation of turbulent burst and prevent the turbulence from being formed, or at least reduce the degree of turbulence and yet reduce the drag or pressure loss. DRA somehow stretch in the flow, absorb the energy in the streak and thereby prevent the turbulent burst. Below is the figure of dampened turbulent after DRA injection.

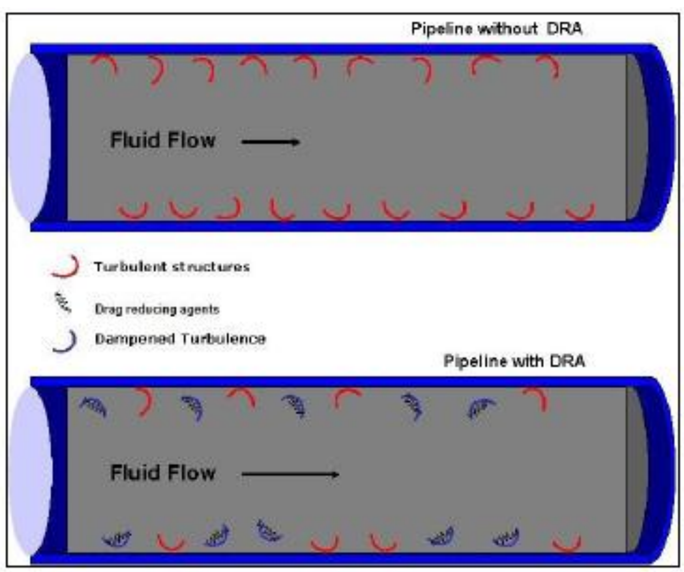

Figure 5: Illustration of dampened turbulence after DRA injection

2.3 Principles and Theory

Friction drag behavior is typically correlated as friction factor with Reynolds number. The amount of pressure loss due to friction or also known as head losses due to friction are depends on the flow rate, properties of the water (water specific gravity and viscosity), pipe diameter, pipe length and internal friction factor or roughness effect of the wall. In general, friction factor depends on Reynolds number, R of the pipe flow, and the relative roughness e/D of the pipe wall.

$$\text{Equation 3 : } f = f\left(R, \frac{e}{D}\right)$$

Equation below shows the relationship between pressure drop in a pipe and the fanning factor friction:-

$$\text{Equation 4 : } \Delta P = \frac{2f\rho U^2 L}{d}$$

Where:

ρ= fluid density

ΔP= pressure drop across the pipe

f= fanning friction factor

d= diameter of the pipe

U= mean velocity in the flow direction averaged across the pipe's cross section

L= length of the pipe

The general Reynolds number equation is:-

$$\text{Equation 5: } NRe = \frac{\rho UD}{\mu}$$

Where:

μ= kinematic viscosity of the fluid

The fanning factor can be calculated by using equation of Yunus and Cimbala (2006)[43]:-

$$\text{Equation 6: } f = \frac{\Delta PD/4L}{\rho U^2/2}$$

Virk and Baher (1970) examined the effect of Reynolds number on polyacrylamide and polyethylene oxide drag reduction[38]. They defined four different flow regimes: laminar, transition, turbulent without drag reduction, and turbulent with drag reduction. The DRA was effective only in the most turbulent flow (RE>40,000). They also conclude that the drag reduction was proportional constant is currently unknown, but is characteristic of the polymer, solvent and possibly the pipe. Finally, they attribute the maximum drag reduction to maximum boundary layer thickness. This is best observed when plotted on Prandtl-von Karmen (PK) coordinates as a correlation for the maximum drag reduction asymptote. Below is shown the envelope between two universal asymptotes, PK law for Newtonian turbulent flow and the maximum drag reduction asymptote (Virks asymptote).

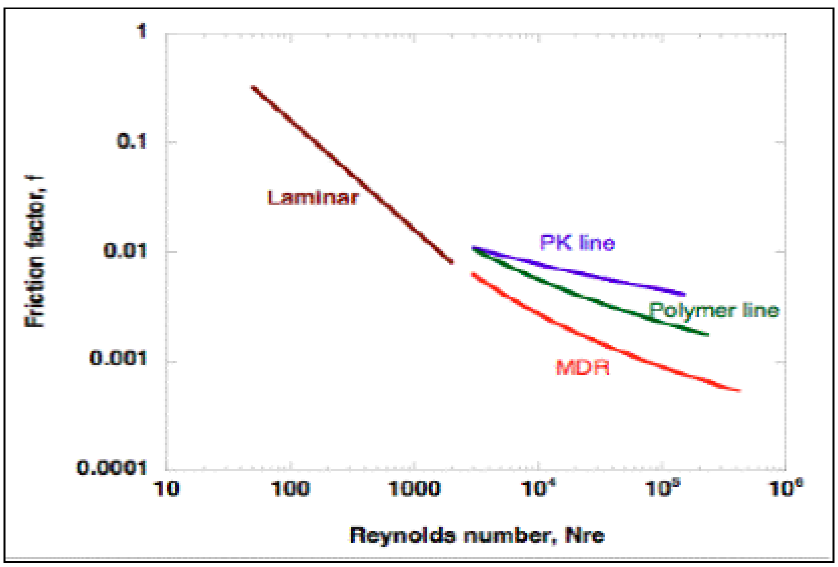

Figure 6: F vs Re plot depicting drag reduction

Between the two limits is a polymeric regime. The polymer line is for some particular polymer, molar mass and concentration. The PK line is for behaviour of a Newtonian fluid. Meanwhile, the red line is maximum achievable drag reduction asymptote line (MDR). Prandtl-von Karman plots are excellent way to analyze polymer turbulent drag reduction data. Virk (1975) collected all the data available in literature pertaining to drag reduction and explain them in simple phenomenological equations. These relationships then were used to create PK plots[40].

Newtonian and polymer solutions exhibit distinct flow regimes based on Reynolds number. In the laminar flow regime solutions (Re<2000 in pipe), it obeys the Poiseuille law which is:-

$$\text{Equation 7: } \frac{1}{\sqrt{f}} = \frac{Re\sqrt{f}}{16}$$

With further increase in flow rate, the fully turbulent flow is attained (Re>3000) and in this regime different equation is used. Below is shown the main physical features of polymer drag reduction on a friction factor Reynolds number plot for turbulence regime. The green line is MDR and blue line show data for a particular onset condition and slope increment. Meanwhile the orange line is the PK line for Newtonian fluid.

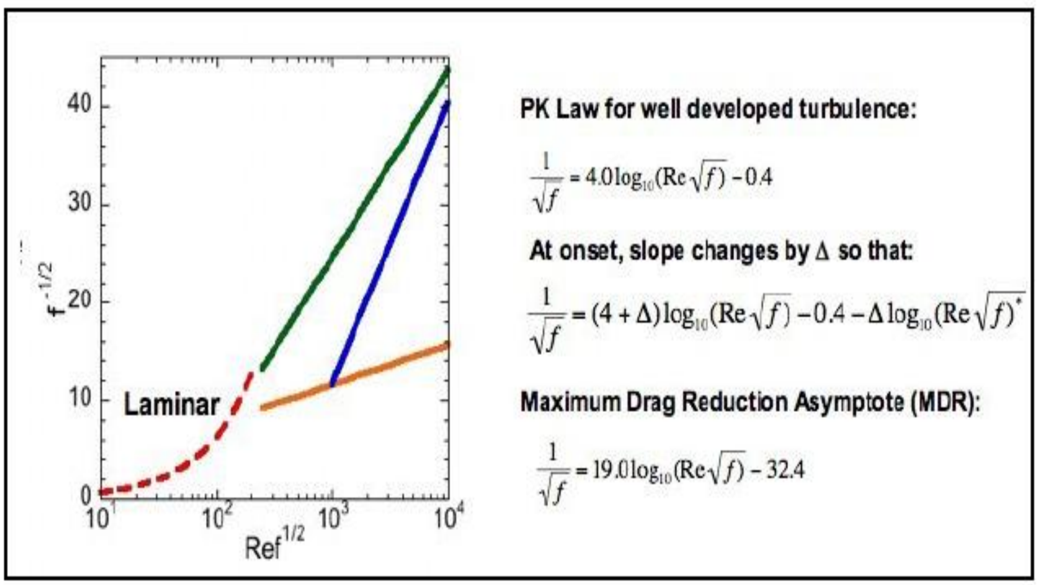

Figure 7: Prandtl-Karman plot for representing polymer drag reduction

2.4 Drag Reduction

The percent of drag reduction (%DR) or the effectiveness of the DRA can be defined as the ratio of the reduction in the frictional pressure difference of before (ΔPb) and after (ΔPa) drag reducer added, and multiply it by 100. Equation shown below (Virk, 1970)[38]:-

$$\text{Equation 8 : DR\%} = \frac{\Delta \text{Pb} - \Delta \text{Pa}}{\Delta \text{Pb}} \text{ x } 100\%$$

Then, the efficiency factor for the DRA can be defined as follow:-

$$\text{Equation 9: } E_{DRA} = \frac{\%\text{ Drag reduction}}{C_{DRA}}$$

When DRA is added to crudes or refined products in a pipeline, these polymers reduce transverse flow gradients, effectively creating a laminar flow in the pipe. This is especially true close to the pipe walls where the axial flow velocity profile has a very steep gradient in which significant pressure losses occur. Lowering these internal fluid losses increase the bulk throughput of the pipeline for a given pumping energy, hence operating costs are reduced. Based on the figure below, the pump pressure of the treated flow is lower over the flow rate in the turbulent regime (Stanford P.Seto, 2005)[35].

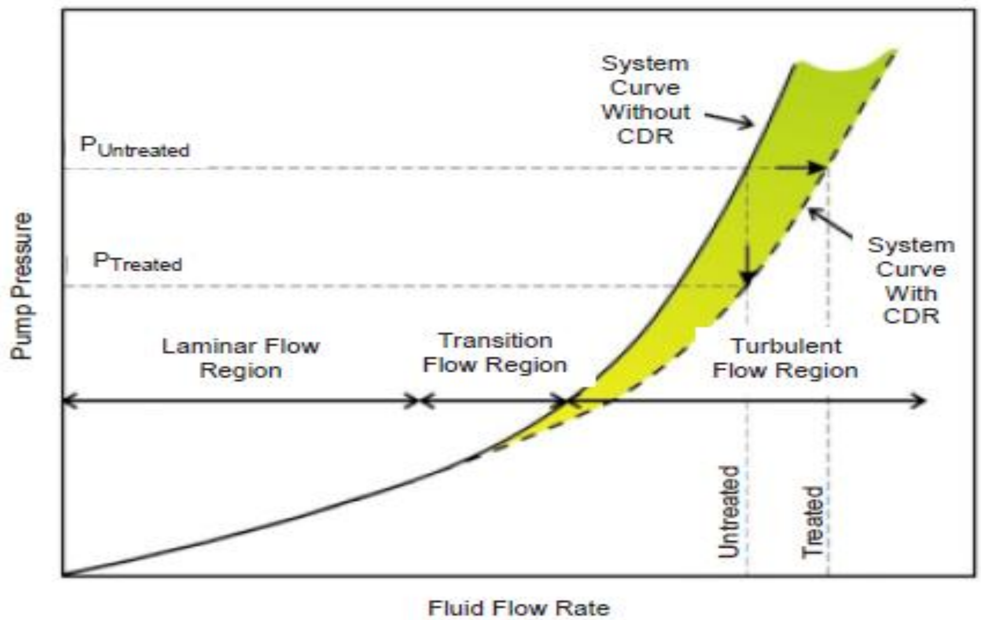

Figure 8: Effect of chemical drag reducer (CDR) on pipeline pump pressure of flow rate

Grabois et al, 1991 tested of different concentration water soluble friction reducer to obtain an effective reduction in pressure drop in three phase system of water, oil and gas[15]. It is noted that the friction reducer provided a 20-35% percent reduction in pressure drop over the base case when no friction reducer was present.

RUN NUMBER	FRICTION REDUCER PPM	PRESSURE DROP PSI	% REDUCTION IN PRESSURE DROP
1	NONE	146	—
2	33	116.8	20
3	66	109.5	25
4	33	125.3	21
5	66	109.5	25

Table 2: Different concentration of friction reducer over % reduction in pressure drop

2.5 Polymer Drag Reducing Agent

To date, polymers solution are the most studied and most often employed of the drag reducing systems. Several typical polymer drag reducing solutions are shown in below table.

Water soluble polymers	Solvent soluble polymers
Poly (ethylene oxide)	Polyisobutylene
Polyacrylamide	Polystyrene
Polyvinylpyrrolidone	Poly (methyl methacrylate)
Xanthan gum	Polydimenthylsiloxane
Carboxymethyl cellulose	Poly (cis-isoprene)
Hydroxyethyl cellulose	

Table 3: Drag Reducing Polymer Solutions

The higher the molecular weight (MW) of the polymer, the more effective it function as drag reducer (Hoyt, 1972)[23]. Polymer with a MW below 100, 000 seem to be ineffective. In the other words, the higher the MW will give greater drag reduction for a given concentration and Re number. The longer polymer chain the polymer chain provides more chance for entanglement and interaction with the flow. It has been confirmed that the extension of the polymer chain is critical for drag reduction. The most effective drag reducing polymers are essentially in linear structure, with maximum extensibility for a given molecular weight. Hoyt (1972) mention the Poly (ethylene oxide), polyisobutylene and polycryamide are the typical example of linear polymers and commonly used in the oil industry as a drag reducer. Polymer lacking linear structure such as gum Arabic and the dextrans are ineffective for drag reduction[23].

2.5.1 Polyvinylpyrrolidone (PVP)

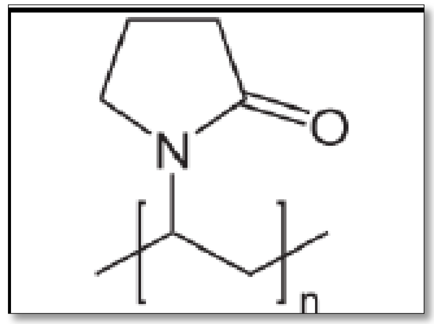

Figure 9: Chemical structure of PVP

Polyvinylpyrrolidone (PVP) is a linear polymer of 1-vinyl-2-pyrrolidone monomers (Bindu, 1998)[6] with molecular formula of (C6H9NO)n. PVP is commonly called Polyvidone or Povidone and it is a water soluble polymer and compatible with wide range of solvents and thus form hydrophobic interaction. In its linear form, the polymer PVP is highly soluble in water, as a crosslink network, it is capable of imbibing very large amounts of water and is therefore quite effective as a hydrogel (Daniel et al, 2009)[10]. However, a downside of the hydrophilicity of PVP is that the high absorbency of the material leads to fragile structure (Davis, 1988[11]: Haaf, 1985[19]). PVP offers a good initial attack, chemical and biological inertness and is very low toxicity. Besides, it gives a good reaction in organic salt. Ulviya et al (1995) found that inclusion into aqueous PVP solution leads to decreasing of θ temperature and intrinsic viscosity[37]. It shows that the presence of inorganic salt in aqueous PVP solutions changes the first physics structure solutions in the direction of untwining of the macromolecules in the globules. That is why movement of molecules of the polymer in solutions becomes eased, decreasing the viscosity of the PVP-salt system. Nevertheless, the outcome of this experiment might be different due to dissolve the PVP with seawater or pure water.

2.5.2 Polyacrylamide (PAM)

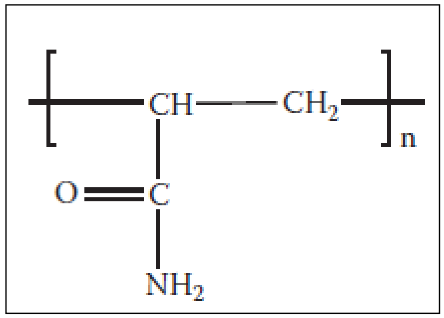

Figure 10: Chemical Structure of PAM

Polyacrylamide (PAM) is another preferred polymeric water soluble DRA in oil industry for water injection. PAM is susceptible to chemical, thermal, and mechanical degradation. It has more practical use as DRA than Polyethyleneoxide (PEO) as they have a side chain and are less susceptible to shear degradation which can be seen in Figure 10. Molecular weights of acrylamide copolymers can be as high as 20,000,000 DA. Partially Hydrolyzing PAM (PHPA) is a copolymer of acrylamide and acrylate monomers that has been extensively used in water-injection polymer flooding projects to increase the injected volumes. Based on Gullapalli (1968)[51], the drag reduction increased with molecular weight, concentration and flow rate and PAM shows better than 25% DR% in tap water than in API brine due to polyelectronic expansion of the chains in tap water. Other than that, some research used hydrolyzed polyacrylamide and found the shrinking gel effect will increase with increasing salinity and decreasing volume obtained with increasing temperature.

2.5.3 Commercial DRA

A commercial DRA is used to compare it performance with PVP and PAM. This DRA is a non-fermenting pre gelatinised high temperature starch used to control filtration in water-base mud. It is design to reduce fluid loss and increase viscosity in all water base mud. It is especially applicable and economical in saturated salt and brine system. Besides, it is less effective in high pH/high calcium or saturated brine and it common name is known as modified starch which is a substitute of Polysaccharide polymer.

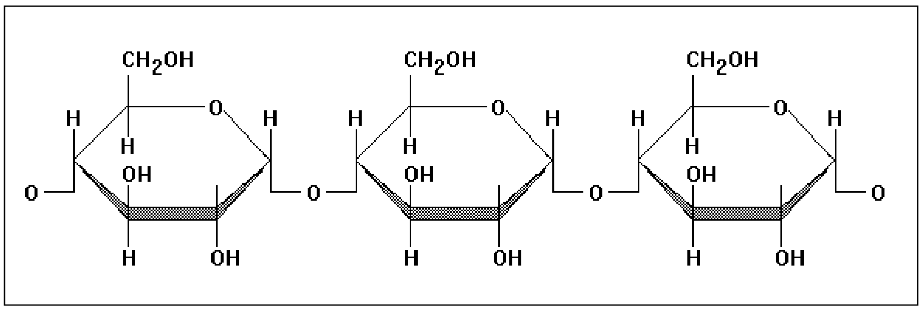

Figure 11: Structure of starch Polysaccharide

Polysaccharide is a long carbohydrate molecules of repeated monomer units joined together by glycosidic bonds. They range in structure from linear to highly branch. Examples include Polysaccharides such as starch and glucogen and structural polysaccharides such as cellulose and chitin. Starches are glucose-containing polysaccharides which consist, essentially, of amylose with branches. These branches come off of glucose carbon number six and are themselves highly similar to amylose. As mention by J.W. Hoyt (1985)[51], dilute solutions in many polysaccharides have lower frictional resistance in pipe flow than pure water. Certain industrial polysaccharides Chakrabarti et al (1991)[51] and Deshmukh and Singh (1987)[52], such as hydroxypropylguar, guar gum, and xanthan gum, have been found to be reasonably shear-stable drag-reducing agents. The advantage of polysaccharide polymers is their high mechanical stability against degradation when compared to flexible synthetic polymers with similar molecular weights; however, they are highly susceptible to biological degradation.

CHAPTER 3

3. Methodology

3.1 Research Methodology

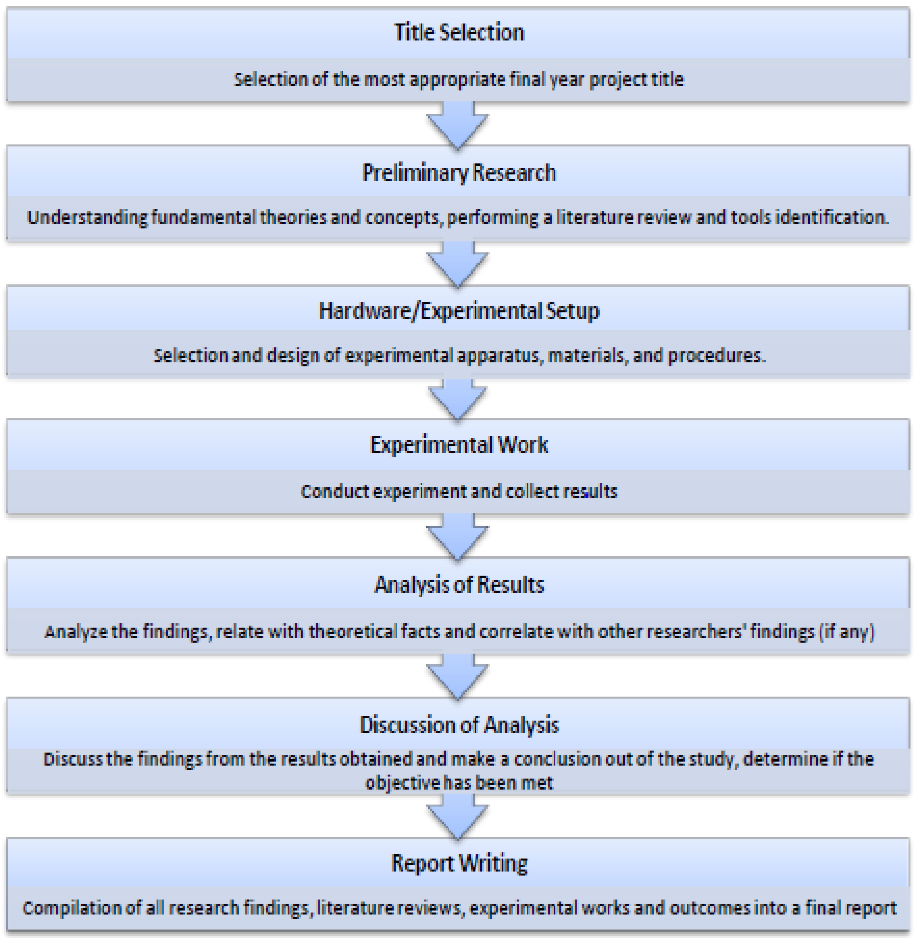

Figure 12: Flow Chart of Research

3.2 Title Selection

In completing this final year project, students are required to demonstrate the ability to integrate fundamental knowledge in developing techniques, methods and analyses. A project topic can be selected from the listed topics given or proposed a new project topics. Thus, the final title that had been chosen is “Determine the Efficiency of Polyvinylpyrrolidone (PVP) and Polyacrylamide (PAM) as Drag Reducing Agent for Water Injection”

3.3 Preliminary research/ Literature review

Basic understanding about this topic can be found such as the polymer properties, flow mechanism, factors affect drag reducing percentage and pressure drop due to friction from the technical papers, journals and others literature review. From those information obtained, it can assist to meet the objective of this project in order to determine the magnitude of drag reduction efficiency and pressure drop at given concentrations and flow rate. Based from the existed experiment setup from the previous project, some modification on the pipe length and additional pressure gauge will be setup for this project. Thus, some research need to be made in order to examine the entrance length needed to create fully turbulent flow at the test section point.

3.4 Experimental Setup

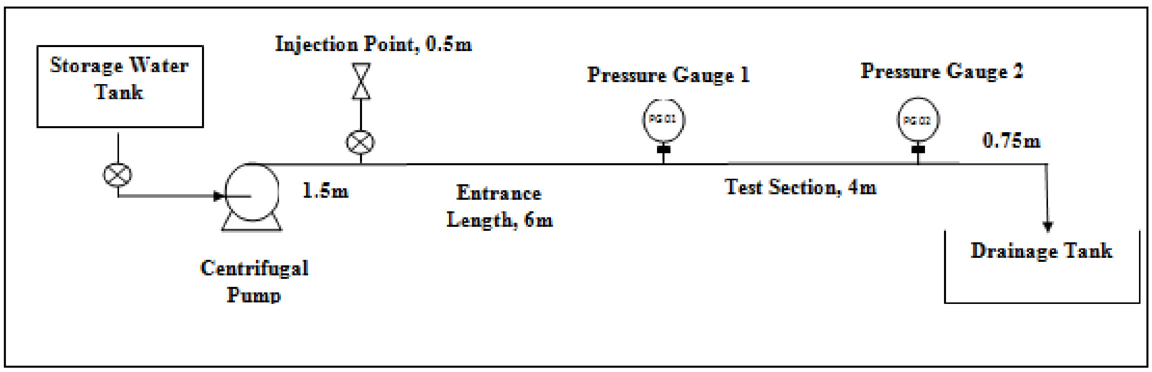

Figure 13: Schematic Diagram of Experiment Setup

The layout of the experimental setup is shown in Figure 13. The main objective of this project is to define the effectiveness of PVP and PAM as the drag reducing agent (DRA) for water injection system. This DRA effectiveness will be determined using the open flow pipe setup to see the polymer flow effect with water. The main parts of the experiment are consists of tanks, galvanized pipe, centrifugal pump, and pressure gauges.

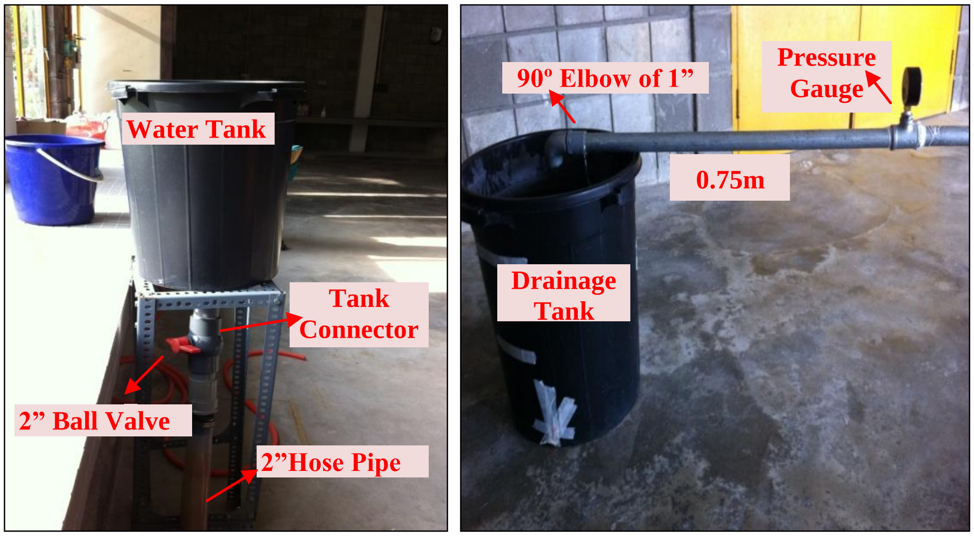

Figure 14: Water tank and drainage tank

In Figure 14, two piles are used for the water tank and drainage tank which are functions for water storage and to drain the water at the end of flow pipe. The water tank is placed higher on fabricated steel stand which is approximately 2m from ground to ease the flow of the water based on gravitational and potential energy effects. 2 inch ball valve is attached in between the tank connector and 2 inch hosepipe in order to control the flow either open or closed. The hosepipe is then attached to the pump inlet of diameter 2 inch.

Figure 15: Centrifugal pump to injection point

In Figure 15 shows the centrifugal pump is selected instead of positive displacement pump due to DRA molecule structure is easily to degrade by the high shear forces generated by that pump. This pump has a control mechanism lever either to adjust to high or low revolution per minute (RPM).

The experiment will be carried out with constant diameter of one inch (1”) galvanized iron (G.I) steel pipe with total length of 12.25m from water tank to drainage tank. From the pump outlet, a reducer of 2x1” is used to attach the galvanized pipe of 1” diameter and 1.5 m length.

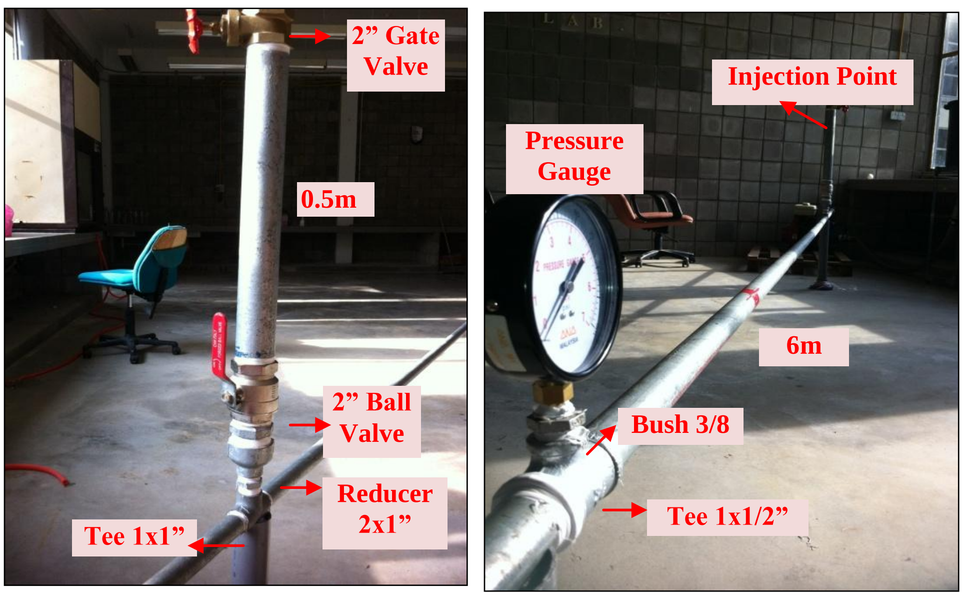

Figure 16: Injection point to first pressure gauge

As shows in Figure 16, a tee of 1x1” is used to attach the 1” G.I pipe with injection point. The injection point is placed few distances from the pump to avoid the shear degradation effect on DRA molecular structure as it does not survive in highly shear forces generated by the pump. From tee, a reducer of 2x1” is used and attached with 2” ball valve which is function to control the flow of additives to be directly flow with water in main pipe. Right after ball valve, a 0.5m of 2” G.I pipe is installed and gate valve is placed at the top of injection point.

The length of the entrance length and test section has been increased up to 6 m and 4 m respectively in order to generate complete turbulent flow for the DRA to react with water and thus the pressure drop result obtained will be more accurate. As from the observable fact, the drag reduction is related to the pressure drop by reducing the turbulent flow. The degree of turbulence is increase by increasing the length of the pipe due to increase in eddy collision inside the pipe. Thus, the present of polymer additives will suppress the smaller eddies and yet reduce the energy loses in the pipe. Thus, the minimum length required in order to fully develop velocity profile in turbulent flow is 6 meter and first pressure gauge is installed to monitor the pressure drop.

Figure 17: First pressure gauge to second pressure gauge

Figure 17 shows the pressure drop across the tube will be measured by the two pressure gauges which will be installed after the injection point and before the drainage tank. Along the 4 meter test section length, it is assume the flow of fluid is in stable turbulent flow for the polymer to react with water. Right after the second pressure gauge, 0.75m of 1” G.I pipe is installed to avoid the fluctuations of fluid to flow out which may affect the pressure reading. The flow of water is then return to the drainage tank which is placed with attachment of 90º of 1” elbow. This tank is used as control volume which has the capacity to drain 43 litter of water and measure the volumetric rate of fluid in pipe based on the time taken to fill in the pile.

3.5 Experimental Work

3.5.1 Rheological Test

Rheological test is conducted for different concentration of polymer tested in lab at Block 15 to obtained viscosity and density of the dissolved polymer. Eight concentrations of PVP and PAM need to be prepared by dissolving few grams of the polymers in 1000ml of distilled water. Below is the table of concentration with weight of polymer:-

Weight of polymer (gram)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Concentration (ppm)	100	200	300	400	500	600	700	800

Table 4: Polymer concentrations

The concentrations need to be stirred constantly for about one hour using the magnetic stirrer (Figure 18) to ensure the polymer mix completely with the distilled water.

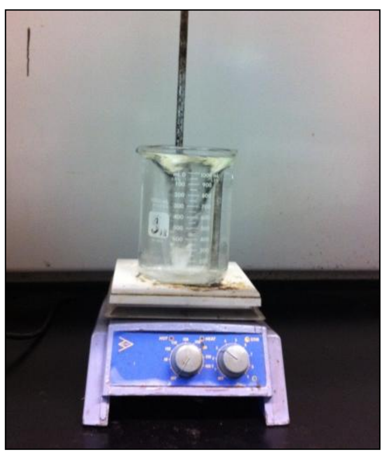

Figure 18: Magnetic Stirrer

Once all the samples have been prepared, the rheological of each concentration will be determined using the digital density and Fann viscometer. The results are important to obtain in order to calculate the Reynolds number value. Below are the pictures of the devices used.

Figure 19: Digital density and Fann Viscometer

3.5.2 Experimental tools, procedure and equations

Experiment tools

1. 2 pile of 43 litter capacity
2. 2” hosepipe
3. 1 tank connector
4. 2 ball valve of 2”
5. 1 centrifugal pump
6. 2 reducer of 2x1”
7. 12.25m of 1” galvanized pipe
8. 0.5m of 2” galvanized pipe
9. 1 tee of 1x1”
10. 2 tee of 1x1/2”
11. 2 bush of 3/8
12. 1 gate valve of 2”
13. 2 pressure gauge with scale of 0-100 psi
14. 1 90º degree elbow of 1”
15. 100 gram of PVP
16. 100 gram of PAM
17. 100 gram of commercial DRA

Experiment Procedure

1. Ball valve (1) at the water tank and ball valve (2) at injection point need to be closed while storage the water in the tank
2. The DRA solution is inserted in the injection point and closed the gate valve (3). The volume of solution in injection section is approximately 1 litter.
3. The operation begins as the pump is started.
4. Valve 1 is opened and the water will be delivered through the testing section without injecting any DRA.
5. Time and pressure reading is taken for both pressure gauges to get the pressure drop for the base case.
6. Then, valve 1 is closed to storage the water and the pump will be turned off.
7. Once water is full in the tank, pump will be turned on and valve 1 and valve 2 is opened slowly to flow the mix solution (DRA and water)
8. Time and pressure reading is taken and compared it with the results obtained for base case. The pressure gauge readings are recorded using camera.
9. Time taken is based on the control volume of the drainage tank which is until it reached to the limit of 43 litters in order to estimate the volumetric flow rate of the fluid.
10. The experiment will be repeated for different concentrations and different speed of pump (high and low RPM) to observed the drag reduction impact.
11. Pump will be turned off once all the water is full in the drainage tank and all the readings are taken.
12. Each run are repeated 3 times, and results with best repeatability was used in the analysis.
13. All the data obtained will be tabulated in table and plotted on the graph to see the effect and differences.

Summary of equations used

Initially, experiment is carried out with no drag reducing agent present. The result obtained is used for baseline values for the pressure drop. Then the experiment is continued with the different concentrations of polymer and later observed the pressure drop shown by the both pressure gauges and time taken for the fluids to flow to the drainage pump for each run. The experiment will be run for two speeds of pump which is high and low RPM for each concentration.

Below are the summary of equations involved in order to determine the reducing efficiency and pressure drop outcome obtained from the tested variable parameters.

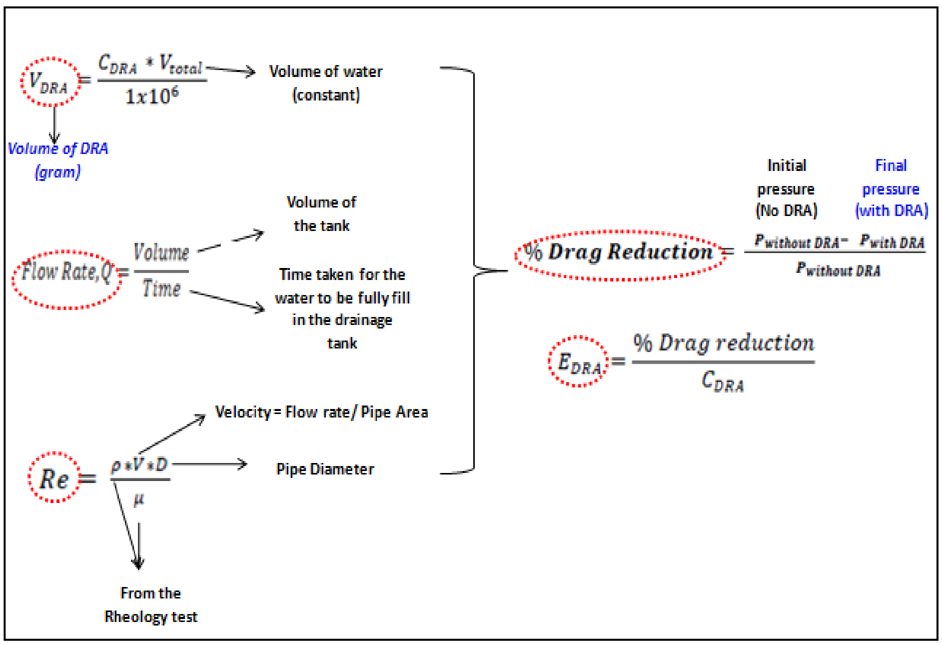

Figure 20: Summary of Equation Involve

i) Initially, the experiment will be tested with no DRA present. Then the result will be compared with present of DRA concentration. The DRA concentration can calculated on a total volume basis as follows:-

$$\text{Equation 10} : V_{DRA} = \frac{C_{DRA} \times V_{total}}{1 \times 10^{6}}$$

ii) 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.

$$\text{Equation 11: Flow rate, Q} = \frac{\text{Volume of Water,m}^3}{\text{Time taken,s}}$$

iii) Reynolds number can be calculated by the using below equation. The density and viscosity value will be obtained from the polymer rheological test. Meanwhile the velocity value is taken from the flow rate result. DRA effect can be seen in turbulent flow which is the Re> 2100. Thus, the volumetric flow rate need to be manipulated in order to achieved high Reynolds number.

$$\text{Equation 12: Re} = \frac{\rho\times V\times D}{\mu}$$

$$\text{Equation 13: Velocity,} \frac{\text{m}}{\text{s}} = \frac{\text{Flow rate,} \frac{\text{m}^3}{\text{s}}}{\text{Area of pipe,m2}}$$

iv) Percent of drag reduction, DRA efficiency and flow increment percentage can be defined at a given concentration as the conclusion of overall DRA performance.

$$\text{Equation 14: \% Drag reduction} = \frac{P_{base}-P_{DRA}}{P_{base}}$$

$$\text{Equation 15: } E_{DRA} = \frac{\text{\% Drag reduction}}{C_{DRA}}$$

$$\text{Equation 16: FI\%} = \left[\left(\frac{1}{1-\frac{DR\%}{100}}\right)^{0.55} - 1\right] \times 100$$

3.6 Data Analysis

Based on the result obtained from the experiment, all the value will be tabulated in table and graph to see the relation between the variable factors and the reducing efficiency percentage.

3.7 Gantt Chart

Below are the Gantt chart shown which depicts the overall methodology for this research.

No	Activity/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection/Confirmation	/	/												
2	Preliminary Research Study Related to Topic Selected		/	/											
3	Preliminary Report Draft & Submission (Progress Report 1)			/	/										
4	Studies on Project Work (Theories, Objective & Methodology)				/	/	/								
5	Studies on DRA calculations and Develop the spreadsheet					/	/								
6	Prepare the Experiment and Fabrication						/	/	/						
7	Test the rheology of the material							/	/						
8	Prepare the Proposal Defend							/	/						
9	Submission of Progress Report								/	/					
10	Project work continue								/	/	/	/			
12	Interim Report Preparation & Submission											/	/		
13	Oral Presentation													■	■
14	Submission of Project Dissertation														■

Figure 21: Gantt Chart

CHAPTER 4

4. Results and Discussion

4.1 Variables

For this project, the parameters used are divided into three categories which are:-

1) Constant

It is a controlled variable which is the value cannot be change along the experiment as to ensure the validity and uniformity of the result obtained. The variables are volume of the tank, amount of DRA injected, time to dilute the polymer with distilled water, and amount of distilled water used to dissolve polymer.

2) Manipulated

It is an independent variable that is manipulated or change along the experiment to see the effect of it in different conditions. The variables are the concentration of DRA and the speed of pump which is high or low RPM.

3) Responding

It is the outcome of the experiment which is based on the manipulated variables. The variables are the pressure drop and time taken.

4.2 Assumptions

1) Fully turbulent flow developed

The length of the pipe between the start and the point where the fully developed flow begins is called the entrance length. Once the flow is fully developed the velocity profile does not vary in flow direction as the pressure reading will be stable. The entrance length of 6m has been set up and it is assumed the turbulent flow is fully developed along that length.

2) Polymer is dissolved 100% with distilled water

Every concentration is stirred on magnetic stirrer constantly for about one hour with assumption it is dissolved completely with distilled water within that period.

3) Well mixed with the fluid once the DRA is injected

As the pipe is not transparent, it is assumed that the fluid is well mixed with the injected DRA when the valve at the injection point is opened.

4) All the DRA solutions are injected right into the pipe

Since that it is important to place the DRA injection after the discharge fluid from the pump in order to avoid polymer degradation. Thus, a tee is used and the injection point is 90º in upward position to the pipe. It is assume that the DRA are flow downward rightly into the pipe and mixed with the water flow once the ball valve is opened.

4.3 Graphs and Discussions

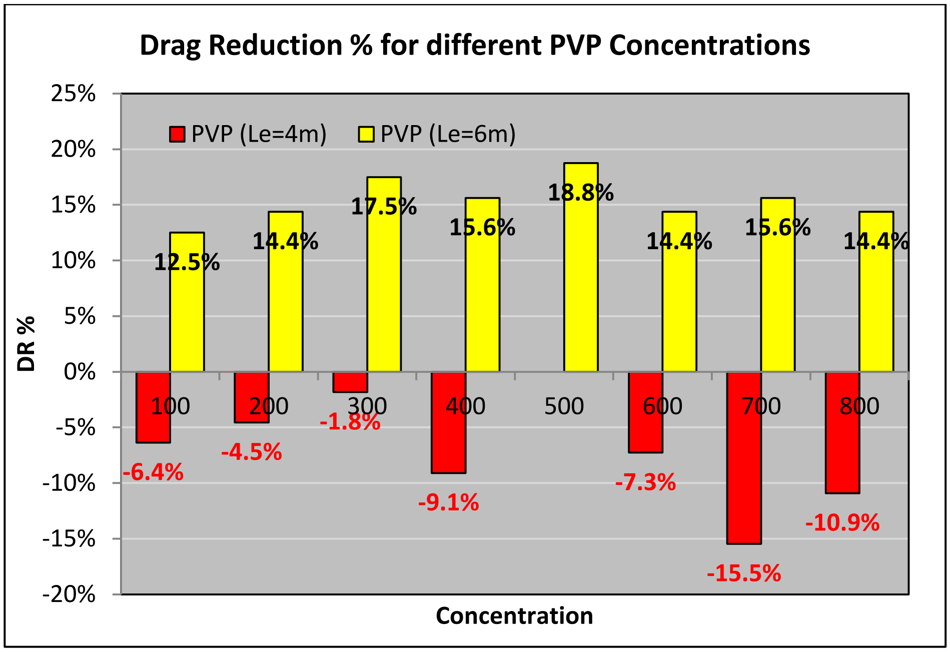

Figure 22: Effect of PVP concentrations versus DR % at different entrance length

The experiment was run for eight concentrations of PVP and PAM at high RPM only as the low RPM speed is too slow to ensure the pumped water is fully full in the pipe of 12.25m long. Thus, the performance of both polymers as the drag reducing agent with different concentrations which flow through along 1" diameter pipe is tabulated in graph shown in Figure 22: Effect of PVP concentrations versus DR % at different entrance length for high RPM. At first run, an entrance length of 4m is used in between injection point to the first pressure gauge is selected. However, high pressure drop obtained for injected DRA compare to pressure drop of base case which will give negative drag reduction %. From Figure 22, the negative results obtained for entrance length of 4m for all PVP concentrations except 500ppm. From here, it shows the entrance length of 4m is not long enough for the flow to fully develop as turbulent flow for the DRA to works and adsorbs the turbulent eddies and thus reduce the pressure along the flow. Thus, a 6m entrance length is used to replace the previous length to ensure the DRA works in turbulent flow. It is clearly seen the positive results obtained by using entrance length of 6m, the optimum DR% shows 18.8% at 500ppm.

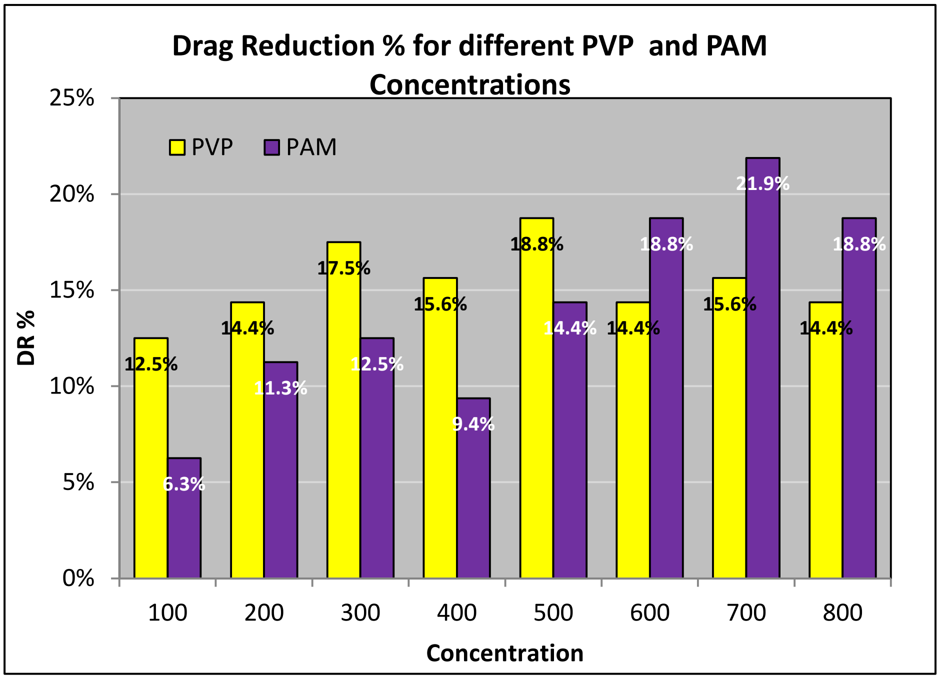

Figure 23: Effect of PVP and PAM concentrations versus DR %

From Figure 23, it can be noticed that the DR% is generally increases with increases polymer concentration. As the polymer molecule dissolve, they interact with the burst eddies at the boundary layer reducing the small eddies hence dissipated energy. By increasing the number of polymer molecules it can cause the damping of more turbulent eddies. However, at certain optimum concentration (PVP=500ppm and PAM=700ppm) the DR% starts to decline and this is probably due to over dosage of the buffer zone that formed in the turbulent flow in pipe. It is expected that the DR% would be increase if the flow rate is high (pump speed higher). Besides that, it might be due to human error during reading the pressure drop or the solution is not completely dissolved each other.

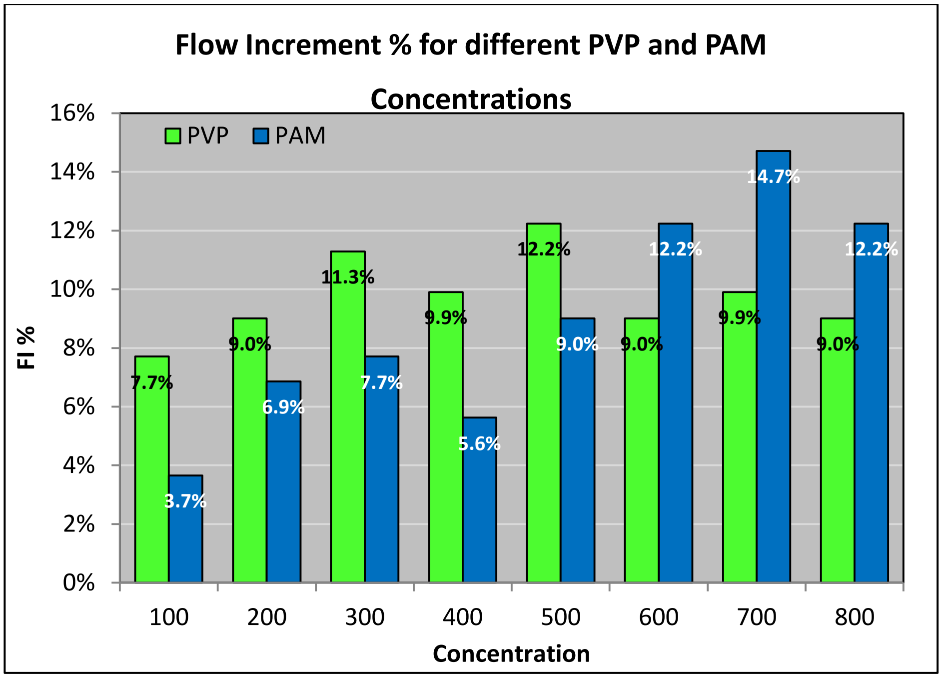

Figure 24: Effect of PVP and PAM concentrations versus flow increment percentage

In Figure 24, it shows the flow increase percentage for various DRA concentrations. This figure shows the expected increase in flow capacity by each DRA concentrations used in pipe. The highest increment obtained for PVP is about 12.2% at 500ppm and meanwhile PAM shows higher increment which is 14.7% at 700ppm. From here, it is observed the relationship between FI% and DR% is directly proportional with each others for various concentrations. The graph of both performances for both polymer were compiled together in one graph which shown in Figure 25 and Figure 26.

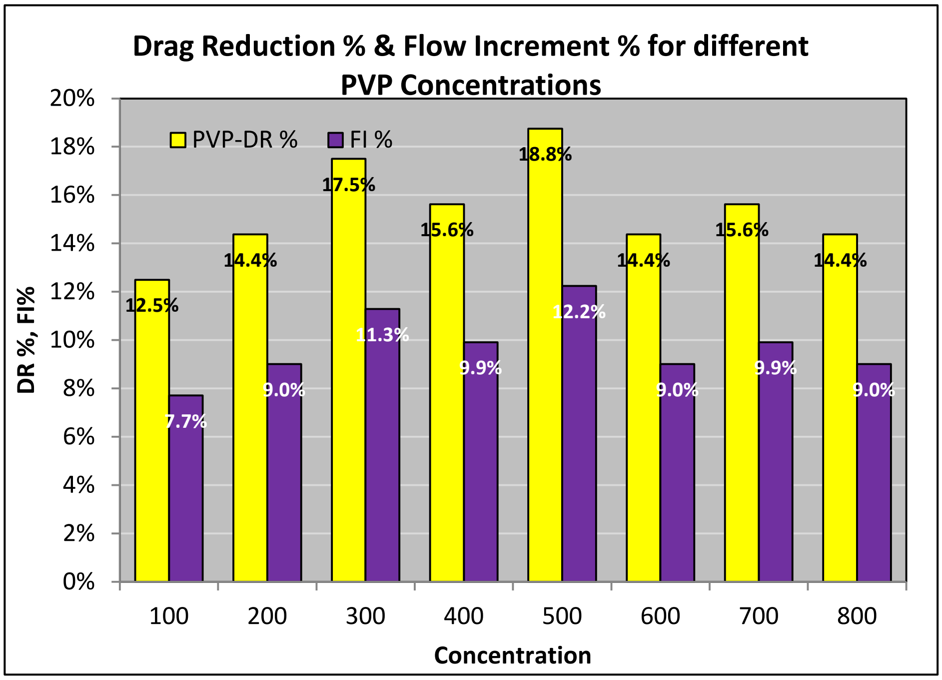

Figure 25: Effect of PVP concentrations versus FI% and DR%

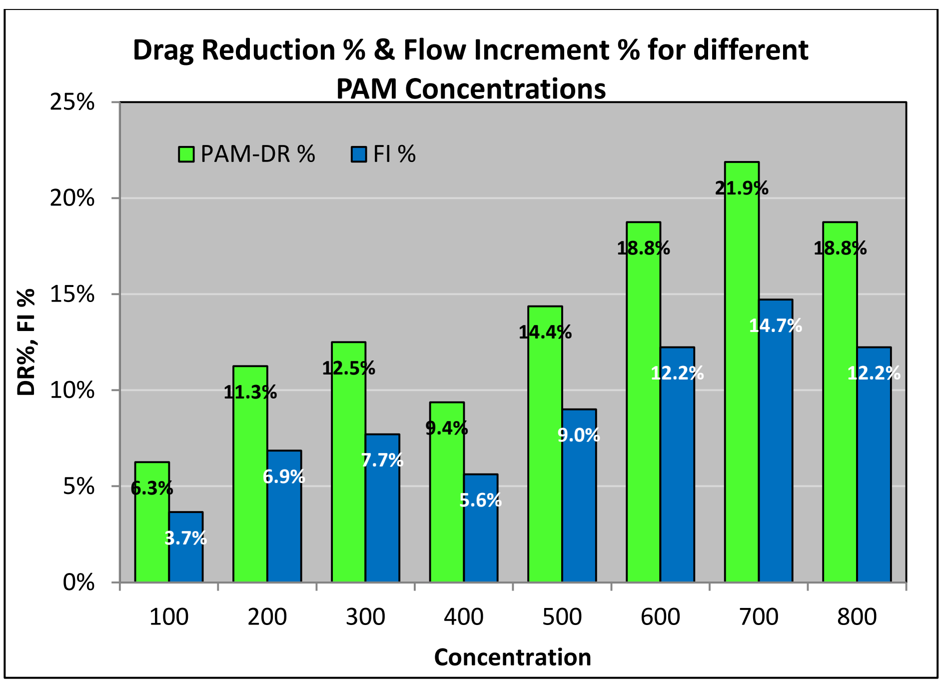

Figure 26: Effect of PAM concentrations versus FI% and DR%

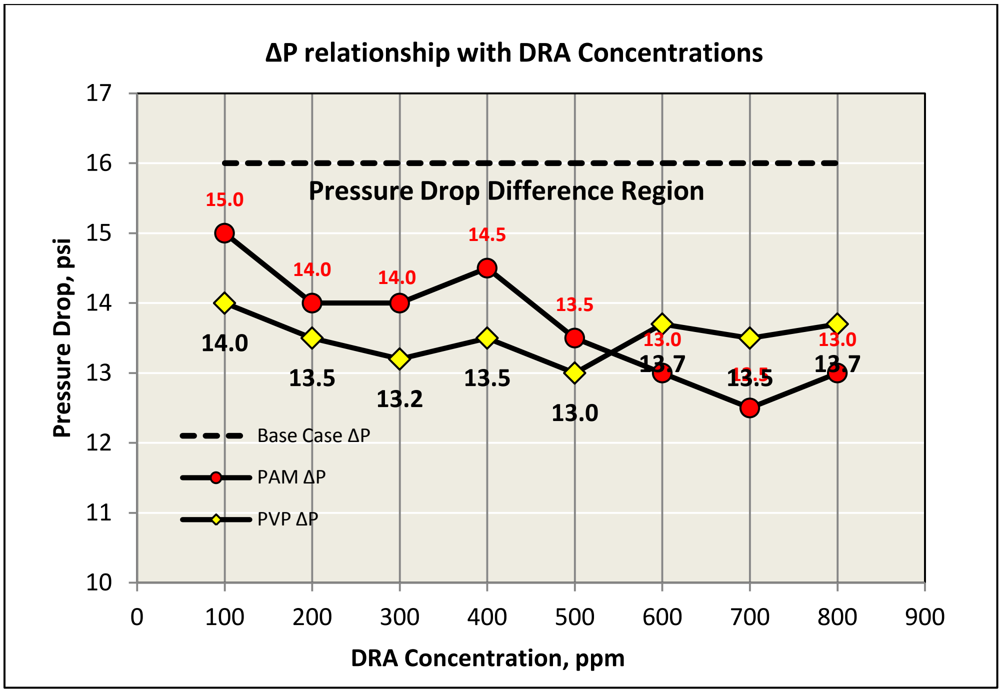

Figure 27: Effect of pressure drop of base case compared with pressure drop of PVP and PAM versus different concentrations

From Figure 27, it shows the pressure drop measured across the pipe for base case and tested polymer case. As from fact, DRA only works in turbulent flow and from that figure it indicates the differences of value obtained between base case and injected polymers. The optimum range of highest difference of pressure drop (biggest region) of PAM is in between 500 to 700ppm. Besides, slightly different of pressure drop is found in overall when compare PVP to the base case. The highest point of PVP pressure drop is at 500ppmwhich is 3 psi. The more of polymer molecule added, it is proved that the flow become smoother which can maintain the energy inside and reduce the pressure. Thus, the turbulent flow becomes laminarize and the objective of this project is achieved. This is aligned to the theory objective which is to reduce in frictional pressure drop that may ease the flow inside the pipe and eliminated the additional pump, reduce energy used and save the cost.

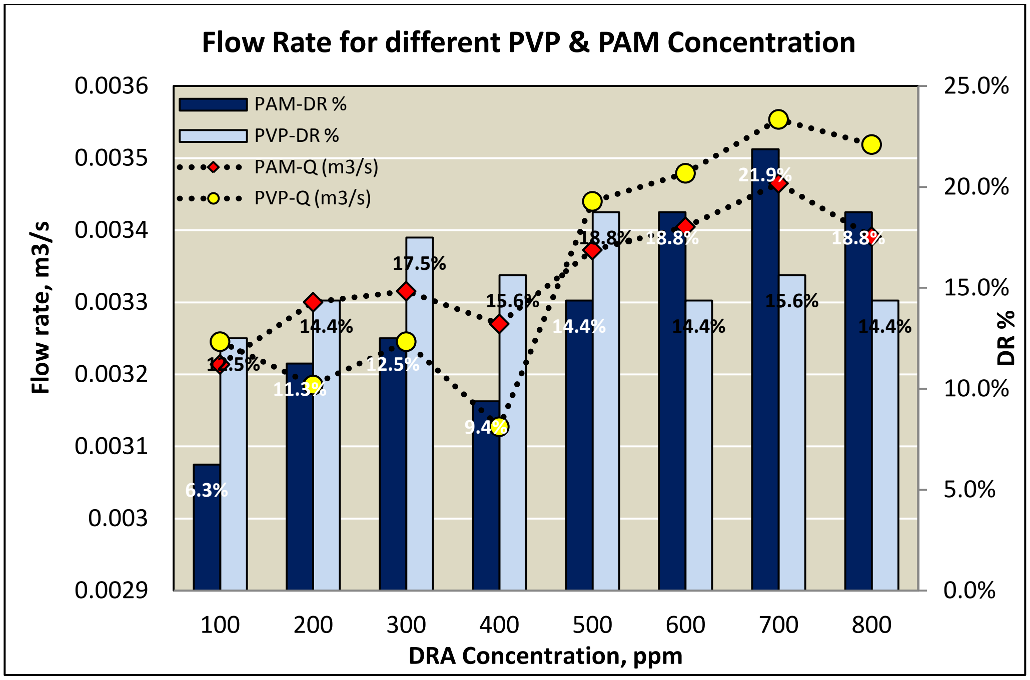

Figure 28: Effect of flow rate of fluid versus PVP and PAM concentrations

Normally, in industry the increased of pump ability is used to increase the flow rate without exceeding the safe pressure limits within the flow system. In this experiment, the flow rate is expected to increase as the concentration of polymer is increased. Higher concentration of polymer gives wide possibility of polymer chain to suppress the eddy. Thus, the present of DRA reduce the frictional drag and increase the flow capacity. The result of flow rate versus polymer concentration is shown below in Figure 28. The time taken for fluid to flow is shorter compared to the base case time. However at high flow rate which the additives reach the optimum point (PVP=600ppm, PAM=800ppm), it gives the decrease in DR% due to shear degradation factor towards polymer molecule at high velocity (PVP=0.0035m^3/s and PAM=0.0034m^3/s)

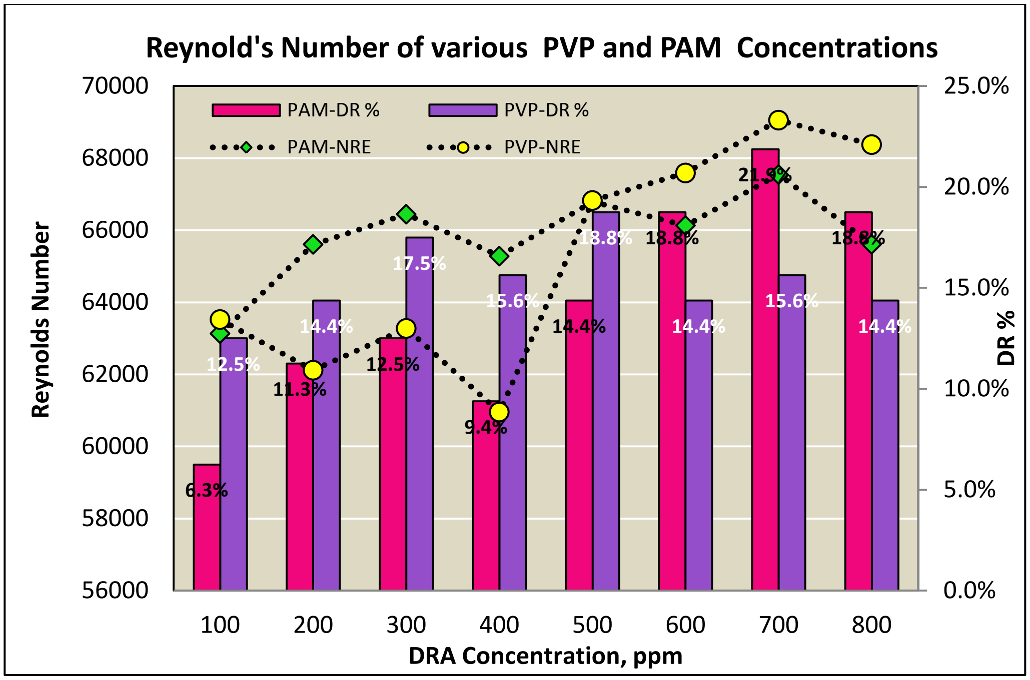

Figure 29: Effect of Reynolds number and DR% versus PVP concentrations

In Figure 29 it shows the behaviour of the DR% and Reynolds number in different concentrations. The Reynolds number measures id dependent on flow rate of liquids pumped. For PVP, it is found that the DR% increases by increasing the Reynolds until approximately 67000 and reaching the optimum DR% at 18.8%. However, above 68000 Reynolds number it gives decrease in DR% compared with maximum value which means to increment of fluid velocity. Increase the Reynolds will result more turbulent flow which lead to overcoming the effect of the PVP molecules in suppressing the turbulence concentration. The polymer molecule is no longer effective to very high degree of turbulent due to high shearing force that resists the performance of the polymer. Thus, the DR% decrease for 600ppm - 800ppm which is the increase of Reynolds is beyond the optimum value of DR%. Meanwhile, the increasing performance of PAM is found till it reach the optimum DR% of 21.9% with Reynolds number of 68000 and started to decline at 800ppm when the Reynolds number drop to 66000. This is probably due to higher viscosity of dissolves solution which leads to lower velocity to flow through in the pipe.

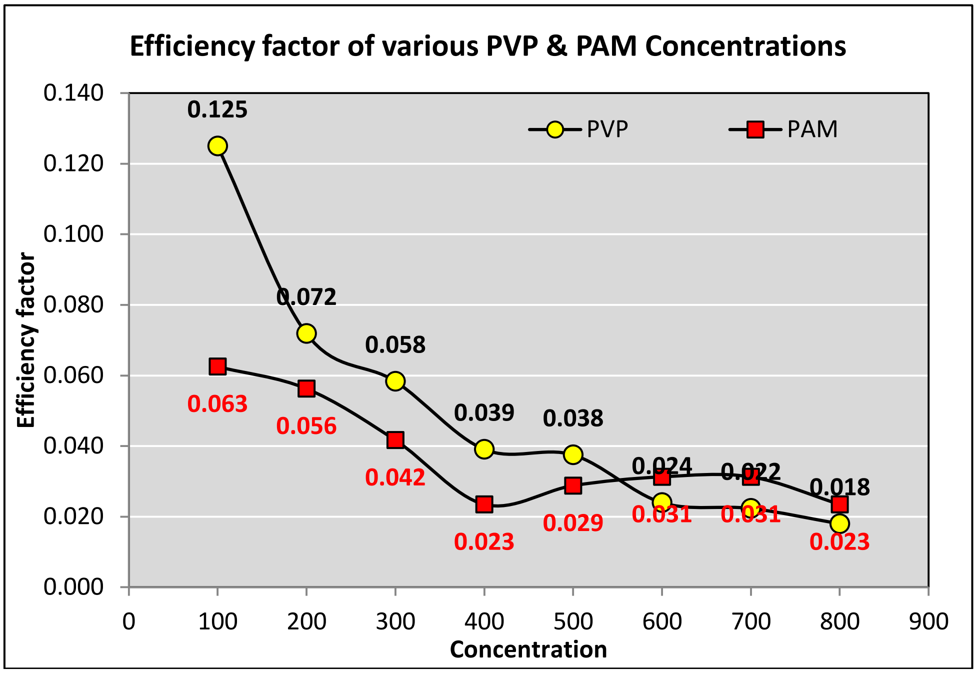

Figure 30: Effect of efficiency factor towards different PVP and PAM concentrations

As shown in Figure 30, it shows PAM efficiency factor is small which is in range of 0.023 to 0.031 for the increasing DR% at 500ppm to 700ppm (14.4%-21.9%). Meanwhile, in contrast with PVP, the low efficiency factor obtained is within the range of 0.018-0.024 for 600ppm-800ppm. However the DR% of PVP in that range is decreasing to 14.4% from 18.8%. This means, even though the efficiency factor needed is small, the polymer added has no function as the polymer molecules degraded at high velocity.

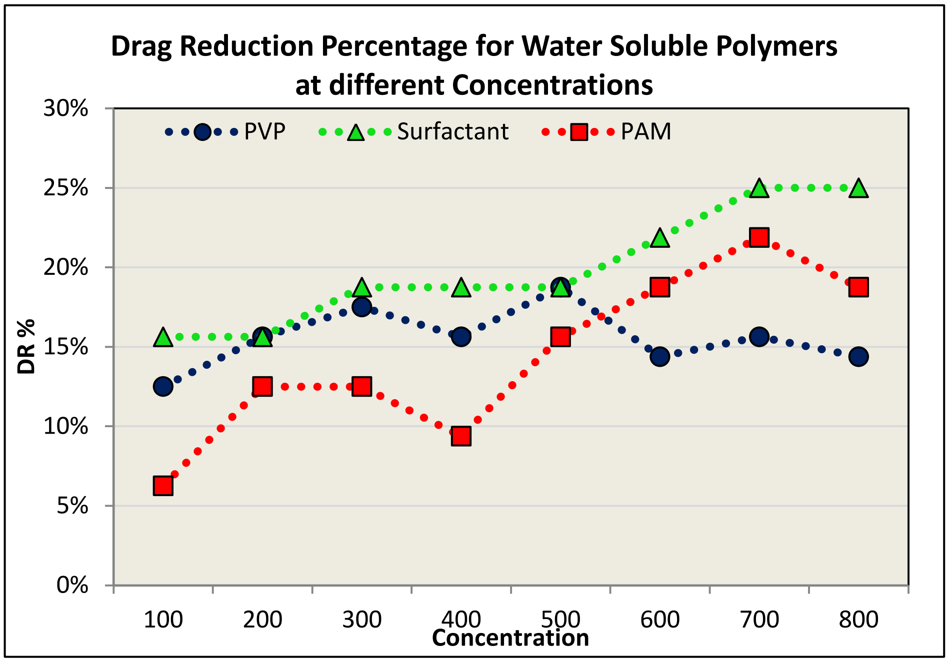

Figure 31: Effect of DR% versus water soluble polymers concentrations

Below is the graph of performance for the water soluble polymers that runs together in this experiment. As it indicates in Figure 31, it shows the DR% achieved is maintaining increased (15.6%-25%) at 500ppm to 700 ppm for PAM and Surfactant. In contrast with PVP, the DR% keeps increases from 100ppm to 500ppm with 18.8% and beyond that concentration limit it started to decline to 14.4%.

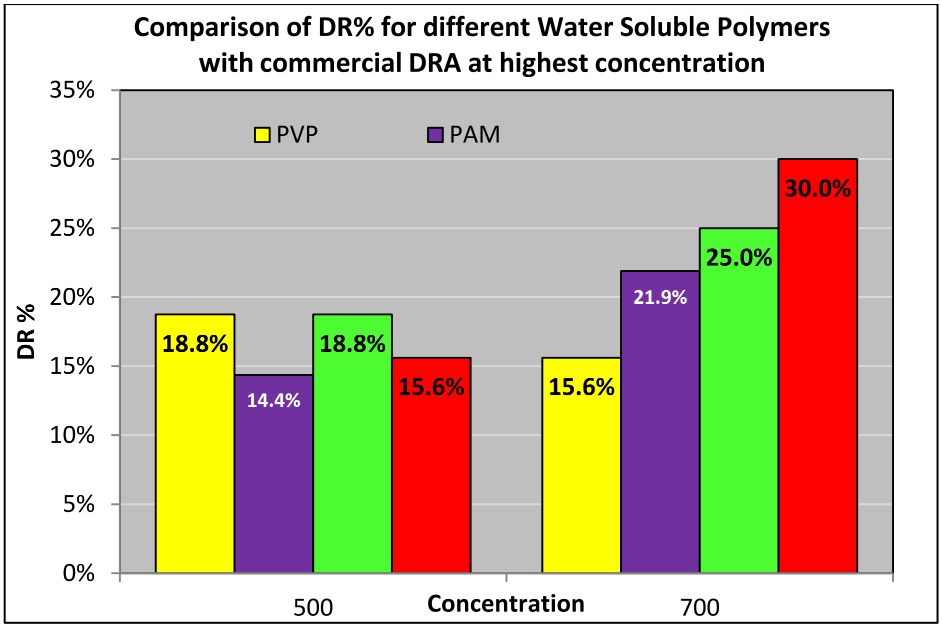

Figure 32: Effect of DR% versus water soluble polymers concentrations with comparison to commercial DRA

A commercial DRA was tested for optimum concentration of highest DR% obtained from PVP and PAM which are 500ppm and 700ppm. The result of comparison for water soluble performance and commercial DRA is shown in Figure 32. At 500ppm, the DR% shows an average result achieved by all polymers which is in range of 15.6%-18.8% reduction. Besides, the increasing trend of DR% is found at 700ppm with highest DR% obtained by the commercial DRA, 30%. From here, it shows that the PVP polymer chain is not strong which easily break at high flow rate or not long enough to provides more chance of entanglement and interaction with flow if compare to others polymers tested. However, all water soluble gives shows good performance by giving positive result of DR% especially PVP as it is more economical which less amount of polymer need (optimum concentration) for highest DR%

In term of relative cost consideration, it shows that commercial DRA is more expensive than the examined polymer. Below is the example of relative cost estimation:

Chemical	Optimum ppm	RM/kg	RM/gram	RM/100 ppm	RM/Opt. ppm
PVP	*500*	*400*	*0.40*	*0.04*	*0.20*
PAM	*700*	*300*	*0.30*	*0.03*	*0.21*
Commercial DRA	*700*	*700*	*0.70*	*0.07*	*0.49*

4.4 Limitation

There are few limitation that had probably influence the results obtained in this project

1. Budget allocate for Final Year Project

This project is based on experimental work which need to fabricate all the equipments and materials in order to run the experiment, With the budget allocate for this project which is approximately RM500, thus it limit the plan to buy more accurate measurements such as flow meter, hydrodynamic pressure reading and pump with adjustable RPM.

2. Workforce to run the experiment

This experiment took a few seconds in order collect all the data needed. As the pump is started, there need a person to be in charged at the water tank valve, injection valve, time keeper and pressure reading reader. Thus, it needs more than one person in order to take all the values obtained. Thus, the other alternative for this limit is by recording the value of pressure while opening those valves. This limit sometimes may affect the time taken as the experiment took not more than 30 seconds.

3. Time constraint

Only 4 month given in order to run the experiment after undergoes research progress during final year project one. Within this four month, more than 40 solutions of drag reducing agent had been prepared which each of it took approximately one hour to stir. Besides, only two magnetic stirred available in lab for the students to use it. Other than that, along this project a lot of trial and error have been undergoes to get the expected result especially change in experiment setup and experiment methodology. Due to those changes, all the process needs to be started from beginning in order to be in the right path and better result.

4.5 Errors

1. Systemic error

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

a) The injection point

The drag reducing agent supposedly to be injected at the same axis of water flow to allow the polymer fully dissolved with water at the first point. Thus the first pressure reading will show the reading if 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 exact value 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 for long pipe. Thus, the results obtained for low RPM is not accurate as the water flow along the pipe is not fully full 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) Volume of water and drainage tank, injection point

The time taken for the water to flow till the end of drainage tank is too fast for high RPM. Meanwhile, the water and drainage tank used in this project is capable to storage approximately 43 litter per tank which is design for 1 litter injected DRA. Thus the pressure reading is hardly to define. With bigger volume of tanks and injection length will contribute to continuously fully water flow in pipe with more chances of DRA react with water along the pipe. Thus, the results obtain more accurate for longer time.

2. Parallax error

Parallax error is error while reading 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 between the brain and the hand to stop the time is not exactly on time. This will give effects to the results obtained.

CHAPTER 5

5.1 Conclusion

As mention previously, the objective of this project is to study the effect of PVP used as a DRA in a water injection. The effect of the DRA concentration and flow rate will be investigate using the open flow system and pressure drop (ΔP) of every test and time will be taken to see the outcome of drag reducing efficiency (DR%). Based on the result obtained, the project's objectives have achieved successfully. As an increase of both polymers concentrations had shown an increment of drag reduction percentage. The flow increment percentage has reached up 12.2% for PVP and 14.7% for PAM which indicates positive impact for the flow capacity in pipe. The Reynolds number obtained shows the fluid was flow in turbulent regime while measuring the pressure drop. Besides, the DR% obtained is generally increase with increasing Reynolds number until the polymers meet certain point of optimum concentration. Addition of polymer into the pipe show high flow rate with increase DR% obtained as the additives react with fluid to reduce the friction inside the pipe and the flow become smoother. However, PVP start to degrade at 600ppm meanwhile PAM at 800ppm. In overall, PVP shows good performance with DR% increase up to 18.8% with slightly different with PAM which is commonly used in the industry for reducing drag problem. Besides, both tested polymers performance is not far behind with the DR% obtain by the commercial DRA which is 30% at 700ppm.

5.2 Recommendations

For future continuation in this project, there is a lot of improvement can be implemented to get more accurate data and better results.

a) It is recommended to used adjustable speed of centrifugal pump as the current pump is only applicable for low and high RPM speed only.
b) In order to clearly seen the mechanism of polymer with the water injected into the pipe, it is suggested to use transparent pipe.
c) Flow meter can be used to measure the flow rate accurately and the injected polymer should be injected at the axis of the flowing water.
d) Instead of using water, crude oil can be used to test the effectiveness of the DRA flow with oil.
e) Variety of pipe diameter and flow at the bend side can be tested to see the performance of DRA.
f) Various the pipe diameters as 1” is too small which easily to create turbulent flow in the pipe.
g) Use smaller scale pressure gauge / digital pressure to obtain more precise results.
h) Use the same amount of water (blank injection) into the pipeline when measured the pressure for base case.
i) Calculated C_{DRA} should be measured against total water flow
j) Density of the water in the outlet tank should be used in the Reynolds nmber calculation

CHAPTER 6

6. References

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APPENDIX A

CHEMICAL USED IN THE EXPERIMENT

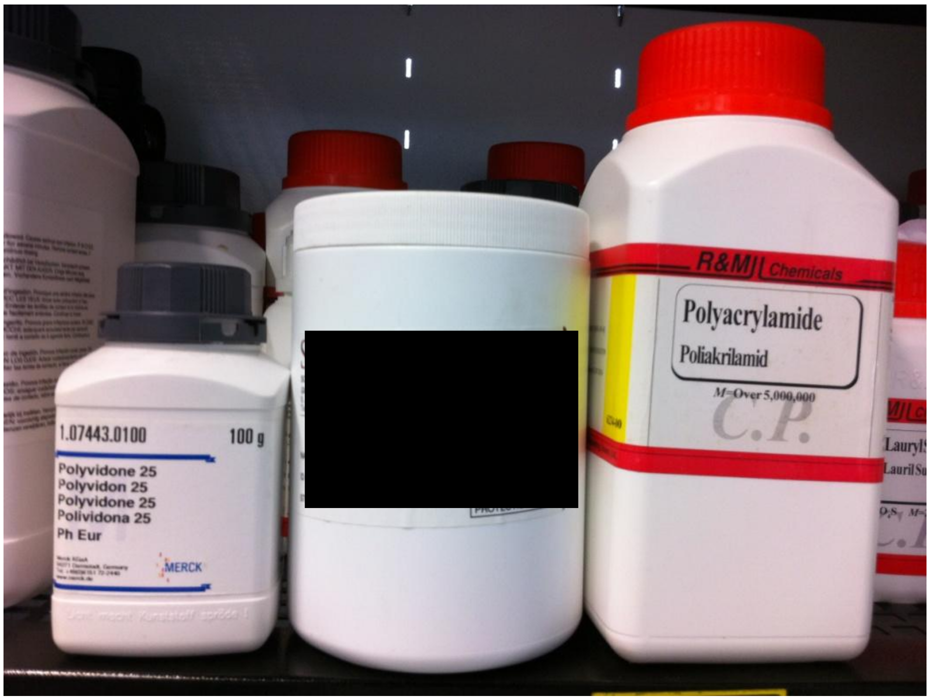

Figure 33: Chemicals used in the experiment (PVP, PAM and Commercial DRA)

APPENDIX B

EXPERIMENT DATA SHEET RESULT

a) **Polyvinylpyrrolidone (PVP) (Entrance Length = 6meter)**

POLYVINYLPYRROLIDONE (PVP)																
DRA Volume gram	Water Volume ml	DRA Concentration ppm	μ cp	μ kg/m.s	ρ g/cm^3	ρ kg/m^3	t s	PVP-Q m^3/s	V m/s	PVP-NRE	P (1) psi	P (2) psi	PVP ΔP psi	PVP-DR % %	EDRA factor	FI % %
0.1	1000	100	2.56	0.00256	0.9996	999.6	13.25	0.0032	6.40	63521	21.5	7.5	14.0	12.5%	0.125	7.7%
0.2	1000	200	2.57	0.00257	0.9998	999.8	13.50	0.0032	6.29	62114	21.0	7.3	13.7	14.4%	0.072	9.0%
0.3	1000	300	2.57	0.00257	0.9996	999.6	13.25	0.0032	6.40	63274	21.0	7.8	13.2	17.5%	0.058	11.3%
0.4	1000	400	2.57	0.00257	0.9993	999.3	13.75	0.0031	6.17	60954	21.5	8.0	13.5	15.6%	0.039	9.9%
0.5	1000	500	2.58	0.00258	0.9998	999.8	12.50	0.0034	6.79	66823	21.0	8.0	13.0	18.8%	0.038	12.2%
0.6	1000	600	2.58	0.00258	0.9999	999.9	12.36	0.0035	6.87	67587	22.0	8.3	13.7	14.4%	0.024	9.0%
0.7	1000	700	2.58	0.00258	1.0001	1000.1	12.10	0.0036	7.01	69053	21.5	8.0	13.5	15.6%	0.022	9.9%
0.8	1000	800	2.58	0.00258	1.0001	1000.1	12.22	0.0035	6.94	68375	22.0	8.3	13.7	14.4%	0.018	9.0%

Table 5: Data recorded and calculated for **PVP** for concentration of 100ppm -800ppm at entrance length of **6m**

b) Polyvinylpyrrolidone (PVP) (Entrance Length = 4meter)

POLYVINYLPYRROLIDONE (PVP)																
DRA Volume gram	Water Volume ml	DRA Concentration ppm	μ cp	μ kg/m.s	ρ g/cm^3	ρ kg/m^3	t s	PVP-Q m^3/s	V m/s	PVP-NRE	P (1) psi	P (2) psi	PVP ΔP psi	PVP-DR % %	EDRA factor	FI % %
0.1	1000	100	2.55	0.00255	0.9997	999.7	12.9	0.0033	6.58	65507	20.0	8.3	11.7	-6.4%	-0.064	-3.4%
0.2	1000	200	2.58	0.00258	0.9995	999.5	12.5	0.0034	6.79	66803	20.0	8.5	11.5	-4.5%	-0.023	-2.4%
0.3	1000	300	2.59	0.00259	0.9998	999.8	12.3	0.0035	6.90	67648	20.0	8.8	11.2	-1.8%	-0.006	-1.0%
0.4	1000	400	2.55	0.00255	0.9992	999.2	11.8	0.0036	7.19	71577	20.5	8.5	12.0	-9.1%	-0.023	-4.7%
0.5	1000	500	2.57	0.00257	0.9997	999.7	11.6	0.0037	7.32	72281	20.0	9.0	11.0	0.0%	0.000	0.0%
0.6	1000	600	2.56	0.00256	0.9999	999.9	11.4	0.0038	7.44	73851	20.3	8.5	11.8	-7.3%	-0.012	-3.8%
0.7	1000	700	2.59	0.00259	1.0001	1000.1	11.1	0.0039	7.65	74983	20.5	7.8	12.7	-15.5%	-0.022	-7.7%
0.8	1000	800	2.58	0.00258	1.0001	1000.1	10.8	0.0040	7.86	77365	20.0	7.8	12.2	-10.9%	-0.014	-5.6%

Table 6: Data recorded and calculated for **PVP** for concentration of 100ppm -800ppm at entrance length of **4m**

c) Poolyacrylamide (PAM)

POLYACRYLAMIDE (PAM)																	
DRA Volume gram	Water Volume ml	DRA Concentration ppm	μ cp	μ kg/m.s	ρ g/cm^3	ρ kg/m^3	t s	PAM-Q m^3/s	V m/s	PAM-NRE	P (1) psi	P (2) psi	PAM ΔP psi	PAM-DR % %	EDRA factor	FI % %
0.1	1000	100	2.55	0.00255	0.9993	999.3	13.38	0.0032	6.34	63131	23	8	15.0	6.3%	0.063	3.7%
0.2	1000	200	2.52	0.00252	0.9994	999.4	13.03	0.0033	6.51	65605	22	7.8	14.2	11.3%	0.056	6.9%
0.3	1000	300	2.5	0.00250	0.9995	999.5	12.97	0.0033	6.54	66443	22	8	14.0	12.5%	0.042	7.7%
0.4	1000	400	2.51	0.00251	0.9996	999.6	13.15	0.0033	6.45	65279	22.5	8	14.5	9.4%	0.023	5.6%
0.5	1000	500	2.53	0.00253	0.9995	999.5	12.75	0.0034	6.66	66788	21.5	7.8	13.7	14.4%	0.029	9.0%
0.6	1000	600	2.58	0.00258	0.9997	999.7	12.63	0.0034	6.72	66129	21	8	13.0	18.8%	0.031	12.2%
0.7	1000	700	2.57	0.00257	0.9994	999.4	12.41	0.0035	6.84	67543	20.5	8	12.5	21.9%	0.031	14.7%
0.8	1000	800	2.59	0.00259	0.9996	999.6	12.68	0.0034	6.69	65607	21	8	13.0	18.8%	0.023	12.2%

Table 7: Data recorded and calculated for **PAM** for concentration of 100ppm -800ppm at entrance length of **6m**

d) Commercial DRA

COMMERCIAL DRA																
DRA Volume gram	Water Volume ml	DRA Concentration ppm	μ cp	μ kg/m.s	ρ g/cm^3	ρ kg/m^3	t s	CD-Q m^3/s	V m/s	CD-NRE	P (1) psi	P (2) psi	CD ΔP psi	CD-DR % %	EDRA factor	FI % %
0.5	1000	500	2.59	0.00259	0.9998	999.8	13.81	0.0031	6.14	60251	20.5	7	13.5	15.6%	0.031	9.9%
0.7	1000	700	2.53	0.00253	1.0001	1000.1	12.56	0.0034	6.76	67839	17.5	6.3	11.2	30.0%	0.043	21.9%

Table 8: Data recorded and calculated for **Commercial DRA** for concentration of 500ppm and 700ppm at entrance length of **6m**

APPENDIX B

SAMPLE OF CALCULATION FOR RESULT

A) Calculation of solution preparation

Equation:

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

Where,

V_{DRA} = Volume of DRA (gram)

C_{DRA} = Desired DRA concentration (ppm)

V_{total} = Total volume of liquid (ml)

Example:

For 100ppm,

$$VDRA = \left(\frac{100ppm \times 1000ml}{1 \times 10^6}\right) = 0.1 \text{ gram}$$

Thus, 0.1 gram of PVP will be used to dissolve with 1000ml of distilled water to obtain 100ppm. The result of other concentration was shown in Table 4

B) Calculation of flow rate, velocity and Reynolds number

<u>Flow Rate</u>

Equation:

$$\text{Flow rate, Q} = \frac{\text{Volume of Water, m}^3}{\text{Time taken, s}}$$

Example:

At 100 ppm, the time taken during the flow is 13.25. The volume of water is taken from the pile volume which is as control volume of 43 litters.

$$Q = \left(\frac{0.043 \text{ m}^3}{13.25s}\right) = 0.0032 \text{ m}^3/s$$

Velocity

In order to obtain velocity of the fluid, the flow rate calculated will be divided by area of the pipe.

Equation:

$$Q = \text{Velocity}, \frac{m}{s} \times \text{Area } m^2$$

Thus the equation of pipe area is below:

$$\text{Area } m^2 = \pi r^2$$

Example:

$$\text{Area } m^2 = \pi \left(\frac{0.0254m}{2}\right)^2 = 0.00051$$

For 100 ppm,

$$\text{Velocity}, \frac{m}{s} = \frac{0.0028}{0.00051} = \frac{6.40m}{s}$$

Reynolds Number

From the velocity value calculated, thus the Reynolds number can be obtained from equation shown below:

$$Re = \frac{\rho \times V \times D}{\mu} \text{ where } \qquad \text{Velocity, m/s} = \frac{\text{Flow rate, } m^3/s}{\text{Area of pipe, } m^2}$$

Where,

ρ = density of the polymer solution (kg/m^3)

μ = viscosity of the polymer solution (kg/m.s)

D = diameter of the pipe (m)

V= velocity of the fluid (m/s)

Example:

$$\text{Re} = \left(\frac{999.6\,\frac{\text{kg}}{\text{m}^3} \times 6.40\,\frac{\text{m}}{\text{s}} \times 0.00254\text{m}}{0.00256\,\frac{\text{kg}}{\text{m}}.\text{s}} \right) = 63521$$

C) Calculation of the polymer performance
(Drag Reduction, Flow Increment, Efficiency Factor)

Drag Reduction

Equation:

$$\%\ \text{Drag reduction} = \frac{P_{\text{base}} - P_{\text{DRA}}}{P_{\text{base}}}$$

Example:

The pressure drop for base case is about 16 psi and for 100 ppm is about 14 psi, thus the DR% obtained is:

$$\text{DR\%} = \left(\frac{16 - 14}{16}\right) \times 100\% \quad = 13\%$$

Flow Increment

Equation:

$$\text{FI\%} = \left[\left(\frac{1}{1 - \frac{\text{DR\%}}{100}} \right)^{0.55} - 1 \right] \times 100$$

Example:

From the DR% measured, the value is inserted into FI% equation.

$$\text{FI\%} = \left[\left(\frac{1}{1 - \frac{13\%}{100}} \right)^{0.55} - 1 \right] \times 100\% \quad = 8\%$$

Efficiency Factor

Equation:

$$E_{DRA} = \frac{\%\ \text{Drag reduction}}{C_{DRA}}$$

Example:

The DR% obtained will be divided with the concentration of DRA

$$E_{DRA} = \frac{13\%}{100} = 0.125$$

D) Calculation of the volume of the water flow in pipe at one time

Equation:

$$\text{Volume} = \pi \times r^2 \times \text{Length}$$

Example:

Based on experiment setup, the total length of pipe used is about 12.25meter for 1" diameter of pipe.

$$\text{Volume} = \pi \times \left(\frac{0.0254}{2}\right)^2 \times 12.25\text{m} = 0.0062\ \text{m}^3 \sim 6.21\ \text{liter}$$

This means that at one time running the experiment, it is about 6.21litter water needed in the pipeline.

For volume of water at the injection point is shown below:

$$\text{Volume} = \pi \times \left(\frac{0.0254}{2}\right)^2 \times 0.5 = 0.00101\ \text{m}^3 \sim 1.01\ \text{liter}$$

Thus the total water transmitted to the drainage tank at one time is about 7.22litter for 12.25m pipe.