INVESTIGATING THE EFFECT OF POLYMER-SURFACTANT COMPLEXES ON THE FLOW BEHAVIOUR IN PIPELINES

ANG MING KEY

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ABSTRACT

Transporting liquids in strategic pipelines is usually occur in turbulent flow mode and that is considered as one of the most power consuming sectors in the industry when most of the pumping power is dissipated in the turbulent flow structures formed during transportation. Frictional drag formed within fluid in pipelines can be reduced spectacularly by adding minute amount of additives which is known as the drag reducing agent. These drag reducing agents can enhance flow performance by restricting the formation of drags and eddies at high shear forces along pipeline system.

In the present work, drag reduction efficiency were studied by examining two similarly charged polymer (algin) and surfactant (Sodium Stearate) and its complexes in a rotating disk apparatus (RDA). The drag reduction performance will be evaluated by analysing the effect of solution viscosity and its corresponding torque exerted on RDA device for laminar and turbulent state. For this research, experiments were conducted using water as the testing fluid. From the experimental work, the highest drag reductions achieved from individual additives was 15.12 % and 23.63% for 600 ppm polymer, and 600 ppm surfactant respectively. Further testing was performed by evaluating the complexes. Whereas the highest drag reduction obtained for the complexes are found to be 25.54% from a 600 ppm 600 ppm polymer-surfactant complexes. Similarly charged polymer- surfactant can enhance flow performance by reducing the drag at adequate viscosity.

ABSTRAK

Mengangkut cecair dalam saluran paip strategik biasanya berlaku dalam mod aliran gelora yang dianggap sebagai salah satu sektor yang paling membazir dalam segi tenaga and melibatkan operasi kos yang paling tinggi dalam industri apabila kebanyakan kuasa mengepam dilesapkan dalam struktur aliran gelora semasa pengangkutan cecair melalui paip. Seret geseran cecair dalam paip boleh dikurangkan secara spektakuler dengan menambah sedikit bahan tambahan yang dikenali sebagai ejen mengurangkan seretan. Ejen menguranLkan seretan ini boleh mengurangkan formasi seret geseran dan ia boleh meningkatkan prestasi aliran cecair dengan menghadkan pembentukan seretan dan pusaran pada daya ricih yang tinggi sepanjang sistem saluran paip. Dalam kajian ini, sifat-sifat pengurangan seretan cecair telah dikaji dengan memeriksa dua jenis ejen tabahan ai itu, polimer (algin) dan surfactant (Sodium Stearate) serta polimer-surfactant kompleks, analisasi untuk kajian ini dijalankan dalam alat cakera berputar (RDA). Prestasi pengurangan seretan akan dinilai oleh menganalisis kesan kelikatan cercair dan tork bersamaan dikenakan pada peranti RDA untuk lamina dan gelora. Untuk kajian ini, eksperimen telah dijalankan dengan menggunakan air sebagai bendalir ujian. Dari kerja-kerja eksperimen, pengurangan seretan tertinggi yang dicapai daripada bahan tambahan individu masing-masing adalah 15.12 % dan 23.63 % untuk 600 ppm polimer, dan 600 ppm surfactant. Ujian lanjut telah dilakukan dengan menilai kompleks kedua-dua bahan tabahan ini. Manakala pengurangan seretan tertinggi yang diperolehi bagi kompleks didapati 25.54 % dari 600 ppm 600 kompleks polimer-surfaktan ppm. Begitu juga dikenakan polimer surfaktan boleh meningkatkan prestasi aliran dengan mengurangkan seretan pada kelikatan yang sesuai.

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LIST OF ABBREVIATIONS

Greek

v	Velocity of flowing medium
D	Diameter or length of pipe
μ	Dynamic viscosity of fluid
ρ	Density of fluid
ω	Angular velocity
r	Radius of rotating disk
τ	Torque

LIST OF ABBREVIATIONS

CAC	Critical Aggregation Concentration
CMC	Critical Micelle Concentration
DI water	Deionised water
DRA	Drag reducing agent
DR	Drag reduction
NRe	Reynolds's Number
PAC	Poly(Aluminium Chloride)
ppm	Part per million
PSP	Polymer saturation point
RDA	Rotating disc apparatus
RPM	Rotation per minute

1 INTRODUCTION

1.1 Motivation and Problem Statement

Transporting liquids in strategic pipelines is usually occur in turbulent flow mode and that is considered as one of the most power consuming sectors in the industry when most of the pumping power is dissipated in the turbulent flow structures formed during transportation.

In fluid dynamic, turbulent flow is classified as an unsteady flow with no specific direction or flow pattern causes by drag forces between flowing fluid and pipe wall surfaces. Turbulent flow causes large pressure drop and energy loss in transportation system due to the formation of drags and eddies which is somehow unavoidable and difficult to control. Losses of energy are unavoidable since no pipes are perfectly smooth to have fluid flow without any friction. (Vasava, 2007)

Generally, there are three types of flow behaviour, which are the laminar flow, turbulent flow and transient flow; which is the intermediate stage between laminar and turbulent flow. (Cengel & Cimbala, 2004)

The main problem occurred in every transportation is the inevitable unsteady turbulent flow. These turbulent flow could cause drag and also the formation of eddies, which is also known as the swirling of fluid flowing inside pipelines. These eddies formation occurs due to frictional force between the fluid and the surface of the inner pipe. Thus, flowing energy continuously contributed and divert to the formation of drag. This phenomena also lead to loss of energy occurs and causes a large pressure drop of fluid flowing along in the pipelines.

In order to reduce the effect of large amount of energy lost and pressure drop, pumping systems were installed to increase back the pressure of fluids in the pipe. However, this leads to increase the cost of expenses in utility costs, not only the purchase cost but also installation and maintenance. According to the World Pumps 2013, pumping system made up for nearly 20% of the world's electrical energy demand and 25-50% of the energy usage in most of the industrial plant operations. Despite of this, cost and energy consumption could be reduced by applying appropriate method. (World Pumps March, 2013)

To reduce the utility cost and energy consumption, an alternative method can also be applied to maintain the energy and pressure of fluid in the pipeline. Many researchers have already been focusing in analysing drag reduction polymer additives and surfactant additives. Drag reduction research has been studied widely after the very first successful research done by Brian Toms in year 1948. According to Tom (1948), he found out that the addition of a relatively small amount of polymer can reduce the frictional force in a pipe under a constant pressure (Rheology: An Historical Perspective, 2005).

From the past few decades, polymer was used as an additive to reduce drag formation in turbulent flow system. The elastic properties of polymers enable polymers to elongate in a turbulent state. Elongation of polymeric chains help to restrict and minimize the formation of eddies and drags in piping system. However, the structure of polymeric chains has the potential to lose their drag reduction due to mechanical degradation when it experienced high shear forces. As a result, polymer losses it drag reduction properties in turbulent flow system. (Zhang,Y., et al, 2005)

To improve the mechanical properties and also to improve the effectiveness of drag reduction properties, another additive, which is the surfactant is added to form a complexes which have the high shear force resistance is added to the polymer to form a complexes which have high resistance to shear forces and also high drag reduction properties. (Hayder et al, 2013).

As a result, it is believe that the polymer-surfactant complexes could form new complexes which have high effective drag reduction properties that can withstand both high mechanical degradation and also thermal degradation. (Kim, et al. 2000), (Suksamranchit, et al. 2006), (Gasljevic, et al. 2007)& (Sirivat, et al, 2007)

To find a better solution to overcome turbulent flow problems in piping system, this work aims to prepare effective polymer-surfactant complexes which can withstand mechanical and thermal stress.

Anionic surfactant, Sodium Stearate, and anionic polymer, Alginic acid sodium salt (Algin) were chosen for this experimental work. These chemical were chosen based on its availability of chemicals, economic in price and environmental concern, which does not bring any side effect to environmental, human health and society. Besides that, the interaction between two similarly charged polymer and surfactant complexes are believed to have good drag reducing effect to prevent neutralization and precipitation in transporting fluid.

1.2 Objectives

The following are the objectives of this research:

- To investigate the drag reduction performance using anionic polymer.
- To investigate the drag reduction performance using anionic surfactant
- To investigate the drag reduction performance of similarly charged polymer-surfactant complexes.

1.3 Scope of this research

Suitable surfactant and polymer which are the anionic surfactant, Sodium Stearate and anionic polymer, Algin are chosen based on their ionic properties and solubility properties in water. Apart from that, the hazardous properties of the chemicals were also taken into consideration. Both the polymer and surfactant chosen for this research are safe to use and also does not create any environmental issue.

Next, the polymers-surfactant complexes will be studied and prepared by varying the concentration ranging from 100ppm to 800ppm at room temperature. Once the chemical composition is prepared, the flow behaviour in a piping system will be carried out in a rotating disc apparatus (RDA) and Brookfield DV-III Ultra Programmable Rheometer. The Reynolds number, viscosity and drag reducing effect of the drag reducing agent will also be studies in this experiment. An effective drag reducing agent is expected to increase the viscosity of fluid to prevent the formation of drags.

1.4 Main contribution of this work

Two new drag reducing agents, anionic surfactant, Sodium Stearate and anionic polymer, Alginic Acid Sodium Salt were introduced. These two drag reducers are abundant and are economic resources that can be easily obtained in the market. Sodium Stearate is a fatty acid that originates from vegetable and animal oils, whereas Alginic acid sodium salt is an anionic natural polymer that originates from the cell walls of brown algae. Similarly charged DRA were used to prevent any formation of precipitate and neutralization of additives in the transported fluid.

Therefore, using these DRAs as flow enhancer in transporting liquid will be economic and environmental friendly as an alternative to the pumping stations. Not only that, this research enable us to find a better solution to maintain flow energy, pressure and velocity that can be employed in both domestic and industrial piping system. Hence, the operating cost and utility cost associated with the allocation of pumping stations along pipelines can be reduced.

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides literature review and description on the origins, applications and general information of fluid flow and various drag reducing agents related to the field of this research. A general description on the flow characteristics of fluid system, as well as the parameters and factors that is associated with the flow phenomena. This chapter also provides a brief discussion of the application of drag reducing agent in the current industry and its advantages. Besides that, experiments done by other researcher were also compared and review in this chapter.

Chapter 3 gives a review of the materials and methods used in this research study. Review of the characteristics and properties of DRA are outlined in this chapter. Besides that, methods used to conduct the experimental work are also stated clearly in this chapter. Formula and techniques use to analyse results is also presented here.

Chapter 4 summarized and discuss the results and data collected throughout the experimental work. The effect of additives in fluid is also compared with the literature review and work done by other similar past research.

Chapter 5 summarized the results and findings of DRA used in this research and outline the recommendations and potential used for future work which might be useful from this work.

1.6 Summary

This paper presents an experimental study of drag reducing agent in a RDA to simulate actual fluid flow in piping system.

2 LITERATURE REVIEW

2.1 Overview

This chapter consist of reviews done by previous researcher. Reviews included the types of fluid flow behaviour and its characteristics. Besides, reviews on various additives as drag reducing agent that can enhance the flow behaviour are also included in this text.

2.2 Introduction

Turbulent flow occurs in piping system causes large pressure drop and lost of energy in transportation system. By overcome the problem, pumping stations were installed to increase back the pressure to normal operation pressure. However, installation of pumping station along pipeline system in the transportation is involved high energy, power and cost consumption. One of the alternatives is to introduce drag reducing agent, DRA to reduce the loss of energy and pressure by enhancing the flow behaviour.

2.3 Types of Flow

In General, there are three types of flow behaviours, which are the laminar, turbulent and transient flow. These flow behaviours are strongly dependent on several factors such as the fluid’s density and viscosity, velocity, temperature and surface roughness of the contacting solid, which is the surface of the inner pipe. By accounting these data, Reynolds number can be calculated and it can help us to identify the fluid flow profile. Fluid engineers have to firstly estimate the Reynolds number range of the flow under study. (Cengel & Cimbala, 2004)

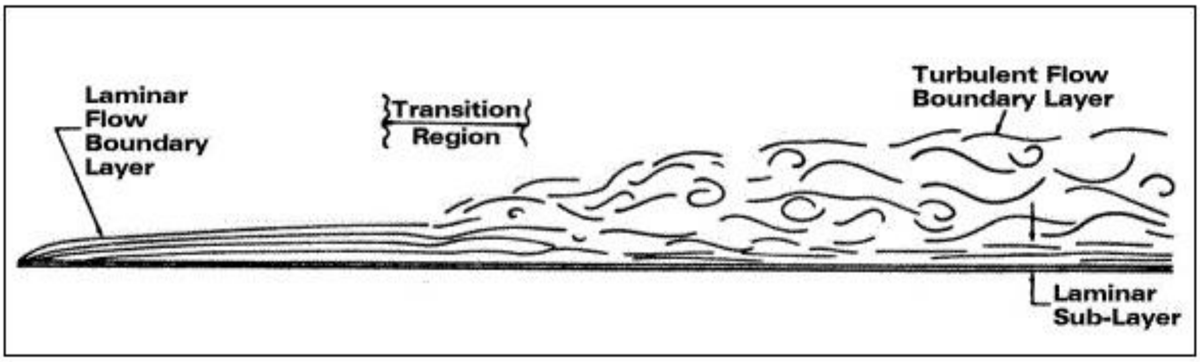

Figure 2-1: Illustration of the types of flow behavior

Table 2-1: Characteristics of different flow behaviour

Types of Flow	Characteristics	Reynold's No
Laminar	· Low flow velocity · Smooth sliding of adjacent layers · Under controlled conditions, i.e., moving speed of fluid · Field of velocity vectors constant in time	Re<2000
Transient	· Combination of Laminar and Turbulent flow, with turbulence in the centre of the pipe, and laminar flow near the edges	2000<Re<4000
Turbulent	· High flow velocity · Mixing between adjacent layers · Unpredictable field of velocity vectors · Continuously forming eddies and drags · Loss of energy due to formation of eddies and vortices	Re< 4000

2.3.1 Laminar Flow

Laminar flow is also known as streamline flow where fluid travels smoothly and in an orderly manner with a constant axial velocity. This type of laminar flow generally occurs when dealing with small pipes and low flow velocities, ant it is often defined as a steady state flow in which the fluid flows at constant fluid motion without occurrence of friction between fluid layers and contacting layers. Apart from that, it is an ideal type of flow behaviour in piping system that only exists under controlled conditions. (Cengel& Cimbala, 2004)

2.3.2 Turbulent Flow

In fluid dynamics, turbulent is classified as fluid flow with violent disorder with no specific direction or flow pattern. It is also quoted as a random secondary motion caused by eddies within the fluid. (Vasava,P.R., 2007). When velocity of moving fluid increases, the flow pattern would be unstable and loss of energy accompanied by pressure drop may occur due to the formation of drag which creates vortices and eddies. Turbulence often occurs at high flow rates and in a larger diameter pipe. Apart from that, the flow rate of the fluid may also be affected by the loss of energy and pressure. (Usui,H. & Saeki,T., 1998), (Cengel & Cimbala, 2004)

In 1997, Warhaft conducted a research and studied on the transition and turbulent flow, he found out that eddies formed in the fluid at turbulent state tends to vibrate and collide with adjacent water molecules, and this phenomena leads to sudden exchange of momentum as eddies often changes its shapes and orientation when they travels along the flow. Besides, the formation and disappearance of eddies is continuous in the fluid, as a result, it degrade the performance of flow and eventually slow down the fluid motion and causes a huge pressure drop and energy loss in the flow system. (Warhaft, 1997)

2.3.3 Transitional flow

Transitional flow is combination flow behaviour of laminar and turbulent flow. In a transient flow, laminar flow will occurs near the surface of the contacting object, whereas turbulent flow will happens in the middle of the pipe. The Reynold's number is between 2000 to 4000. (Cengel & Cimbala, 2004)

2.4 Drag reducing agents

Drag reducing agent (DRA), which is also known as a pipeline flow improver have been applied in various industry for many years , especially in the oil drilling application and other fluid transportation flow in pipelines or any enclosed system. These drag reducing agents can be classified as additives, polymers, surfactants, fibers and suspended solids. Researchers have proved that low viscosity and high concentrated drag. (Fink, 2012).

Drag reduction was first discovered by Toms Phenomenon in 1949. He accidentally found out that an addition of minute amount of polymer additive, i.e. part per million (ppm) can reduce the turbulent frictional drag of a fluid in a turbulent flow. Since then, this field attracted many researchers and industries due to its economic benefits compared to pumps installation to reduce the loss of energy and pressure drop in flowing fluids. Many attempt on drag reducing polymers for possible applications in industry. (Toms, 1949), (Whitea,A, 1967), (Savins,J.G, 1977).

2.4.1 Fibers

Paper pulps such as Kraft hardwood pulp (Luettgen et al, 1991) and wood pulp (Kazi, 1999) have been studied in the drag reduction field. They measured the drag reduction based of velocity profile of laminar and turbulent flow and they found out that fiber has the potential to enhance the flow behaviour of fluid compared to the pure fluid. Addition of fiber suspension in fluid leads to an increase of its effective viscosity in the turbulent core. Besides, the fibers were studied due to its low cost and environmental friendly behaviour.

2.4.2 Surfactant

Surfactants derived from the words "Surface Active Agents". Surfactant is a compound that can lower the surface tension of liquid and interfacial tension between fluids and wall surface. Surfactants usually made up of organic compounds and are amphipathic molecules that both have hydrophilic part and hydrophobic part in a single molecule. (Nobel, A., et al, 2005). The types of surfactant are classified according to the head group, where it can be classified as anionic, cationic, non- ionic or zwitterionic. Surfactants are widely used in the industry where it involved in various applications, and can be found in detergents, wetting agents, emulsifiers, foaming agents, and dispersants.

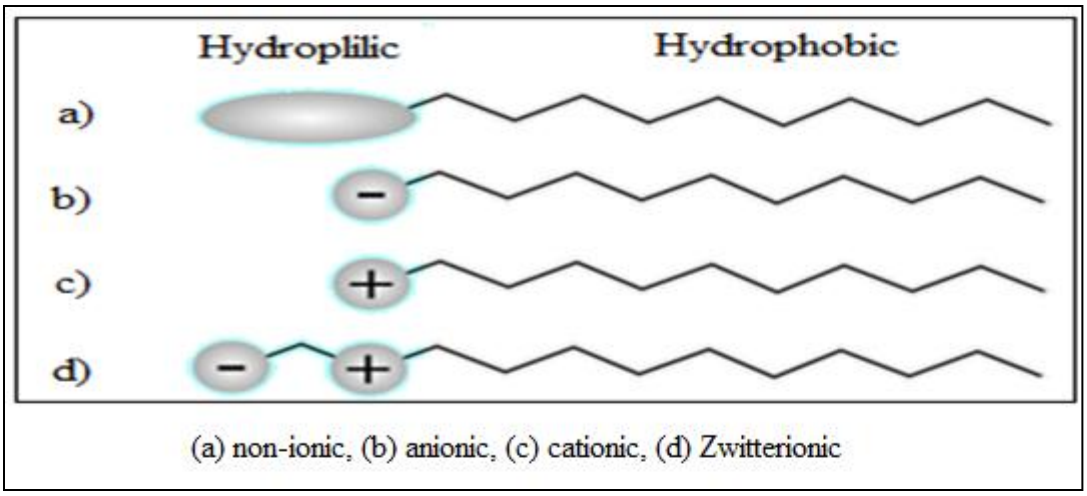

Figure 2-2: Illustration of typical surfactant molecule structure according to the composition of their hydrophilic head group

Surfactant tends to clump together in a solvent to form a spherical shaped globule known as the micelle. Micelles will be formed when it reaches a certain concentration known as the critical micellar concentration, CMC. (Jiang., et al. 2011) & (Panmai., S et al, 1999)

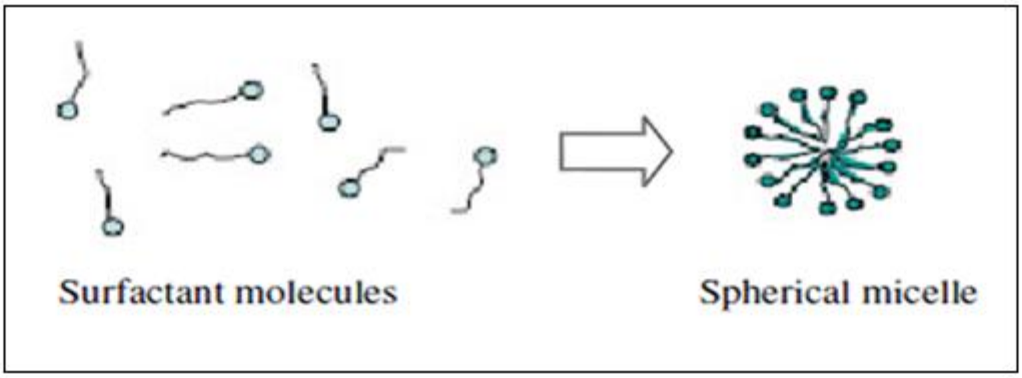

Figure 2-3: Illustration of formation of micelle from surfactant molecules in water

Bari and research team had investigated the effect of surfactant, Sodium Lauryl Ether Sulphate (SLES) and solid particles in kerosene fluid. Their research shows that the drag reduction property increases with solid particle concentration, suspended particle size, surfactant concentration and solution viscosity. (Bari, H et al, 2009)

2.4.3 Polymer

Polymer is a substance that has relatively high molar weight, they classified as long chain giant molecules assembled from repeating single unit, monomer by covalent bonding. The process of combining monomer to form long chain polymer is known as polymerization. Basically, polymers are divided into two main categories, which are the natural polymer and the synthetic polymer. (Ophardt, 2003).

Natural polymers are giant molecules that occur naturally that can be found in living organism such as plants and animals. The examples of natural polymers are cellulose, starch, and polysaccharides. While synthetic polymers they are man-made polymers produced by using various technology. Plastics, synthetic fibers and elastomers are examples of synthetic polymers. (Meyer& Chawla, 1999)

There are three types of polymeric chains linking structure, which are the linear chain, branched chain and crossed linked chain. The types of chains produced mainly depend on the polymerization reaction conditions and the carbon-carbon bonds. (Teach Engineering, 2013).

Polymers are found to be an effective drag reducing agent in aqueous and organic liquids even at a very low concentration as low as few part per million by weight. This is due to their high molecular weight, and long flexible chain molecule. (Patterson, et al, 1969).

The first successful research has done by Toms have proven the positive effect of polymer as a drag reducer. He obtained a 50% drag reduction (DR) in monochlorobenzene compared with the pure solvent using poly(methylmethacrylate) additive. (Toms, 1949)

In 1985, Lester conducted a research and he found out that the drag reduction properties of polymers are more effective in turbulent state compared to laminar state. Polymeric chains tend to stretch in the solution and restrict the formation of eddies and drags and hence results in a reduction in turbulence. (Lester, 1985), (Sher& Hetsroni, 2008)

Polymeric additives were considered by many authors due to its unique viscoelastic properties and its ability to reduce drag forces in pipeline system. Viscoelastic property causes the fluid to be more viscous and elastic and thus, it restricts the movement of fluid molecules to the formation of drags and eddies. Lim (2010) also stated that the common theory of polymer drag reduction is due to their high elastic properties that can restrict the motion of eddies and the transport of momentum from one large eddies to small eddies. (Lim, 2010) & (Hayder et al, 2013).

The addition of polymer enhanced the formation of micelles in fluid, by lowering the critical micelle concentration (cmc). In the chemical industry, polymer often used as additives to fluid lower the drag in the piping system. (Jiang, 2011)& (Sarkhi, 2013).

However, it was reported that there is a drawback of using polymer as a drag reducing agent in turbulent fluid. Polymeric chain can be degraded due to high mechanical shear forces. This is because in turbulent flow, polymeric additives are exposed to shear stress which causes elongation of polymeric chain and eventually break the polymeric bond in the solution and lead to the decrease of drag reduction properties. (Zhang, 2005)

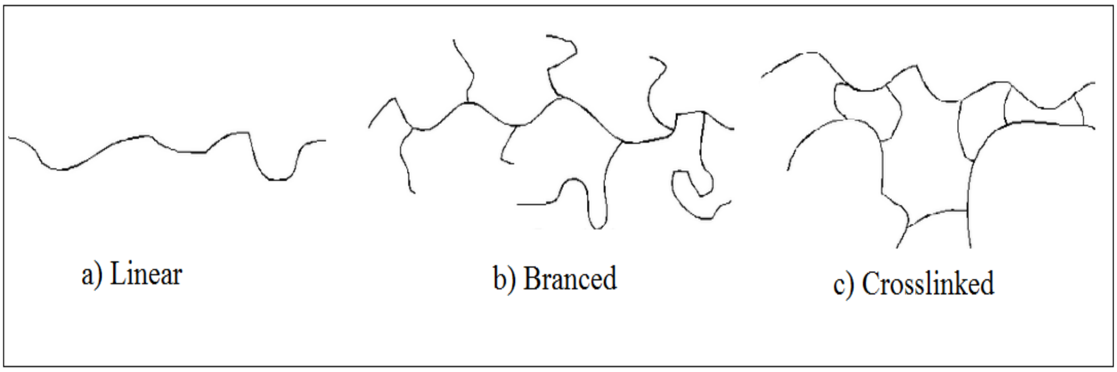

Figure 2-4: Illustration of polymeric structure.

Warholic and Hanratty conducted a drag reduction test on water, and they found out additional of dilute co-polymer of polyacrylamide and sodium-acrylate as low as 0.25ppm, can lead to a significant drag reduction in water. (Warholic et al, 1999)

However, synthetic polymer such as poly(acrylamide), poly(diallyldimethyl ammonium chloride), Poly(aluminium chloride) and Chitosan were reported to be used as a coagulant in the water treatment plant and wastewater treatment to settle out suspended colloids. These polymers are positively charged, which is also known as cationic polymer were widely used in the industry due to its coagulating effect. (Hu et al, 2013), (Jiang, 2004)

2.4.4 *Polymer surfactant complexes*

Polymer surfactant complexes have been studied extensively. In 1967, Jones studied on the interaction between polymers and surfactants and he identified two transition points, which are the critical aggregation concentration (CAC) and polymer saturation point (PSP) by conducting measurements and analysing surface tension and viscosity data. (Jones, 1967)

Apart from that, another research has been done and the statement has confirmed by Malcher and the research team. They found out that the effectiveness of drag reduction in pipe using polymer surfactant complexes is much better than just using surfactant alone as the drag reducer. The complexes enhanced the hydrophobic interactions between polymer and surfactant. It is manifested by lower friction factors. (Malcher et al, 2012).

Besides that, studies found that the combination of polymer and surfactant can form a better and effective drag reducing agent by improving the rheological properties. These complexes combine both the strengths, which are the high drag reducing properties from polymer and high mechanical resistance from surfactant. Besides that, it is believed that the bonding of polymer and surfactant complexes can be enhanced by mixing two oppositely charged molecules, such as ionic binding between ionic polymer and surfactant and hydrophobic bonding between nonionic polymer and surfactant. (Kim, et al. 2000), (Suksamranchit, et al. 2006), (Gasljevic, et al. 2007) , & (Sirivat, et al, 2007)

2.4.5 *Anionic polymer and cationic surfactant*

Hayakawa& Kwak (1982) studies the interaction of two oppositely charge anionic polymer, sodium polystryrenesulfonate (NaPS) and cationic surfactant, Dodecyltrimethylammonium Bromide (DTAB). They found out that the interaction of both the compounds involved both electrostatic and hydrophobic interactions. Oppositely charged compounds can bind easily and at a very low concentration compared to similar charged compounds. (Hayakawa et al, 1982)

Another experiment has been done by Liu,J., et. al (1997), they studied the binding isotherms of anionic polymer - Sodium polyaspartate(NaPAsp) of three different molecular weights with cationic surfactants-tetradecylpyridinium chloride (TeP) and dodecylpyridinium chloride (DoP). By reducing the molecular weight, the length of the polymer chain decreases, and this leads to the electrostatic potential around the ionic polymer decreases resulting in lower polymer-surfactant affinity.

3.0 MATERIALS AND METHODS

3.1 Overview

In this chapter, experimental material, apparatus, setups and procedure will be explained. The main purpose of this research project is to investigate and prepare an effective drag reducing complexes by using two types of additives. For material, basically there are three main materials used, which are the deionised water, the testing medium. While for the DRA are anionic surfactant, Sodium Stearate, and anionic polymer, Algin. Besides that, the apparatus involve in this research are rotating disc apparatus and Brookfield DV – III Ultra Programmable Rheometer, these apparatus enable us to find out the rhelogical properties of the sample solutions. In the current work, eight different concentrations will be tested range from 100ppm to 800ppm to find out the best concentration to enhance the flow performance.

3.2 Introduction

This undergraduate research project aims to prepare a drag reducing agent which has high mechanical resistance and high drag reducing properties. The complex is made up of combining two types of DRA, polymer and surfactant additives. The drag reducing agents used here are similarly charged polymer and surfactant. Before conducting the experiment and testing in RDA, sample solution of water with additional polymer and surfactant additives will be prepared in 8 different solution ranges from 100ppm to 800ppm respectively. All the samples will first be tested by using viscometer to obtain the new value of viscosity. After obtaining the new viscosity, data analysis will be carried out to see the effect of the additives used. Experiment and testing will be proceed if the additive shows good drag reduction interaction. For the second testing, samples solution will be run using a Rotating Disc Apparatus, RDA. RDA is used to find out the torque of each of the solution exerted at different flow behaviour. After recording all the data, two different solutions, polymer solution and surfactant solution will be mixed, and the viscosity and torque of polymer-surfactant complexes will be tested using viscometer and Rotating Disc Apparatus. The drag reduction efficiency will be evaluated by the torque experienced by the rotating disc at different rotating speed from laminar to turbulent flow.

3.3 Raw Materials

3.3.1 Transported Liquid

The purpose of this research is to enhance the transportation of liquid fluid in any enclosed system in pipelines. Deionised water (DI Water) is obtained from the Chemical Engineering Laboratory, and it is used in the experimental works. Besides, this work investigates the flow performance of water in the addition of new polymer surfactant complexes as the drag reducing agent. Properties of water are shown in Table 3.1. (Appendix A.2, Geankoplis, 2003)

Table 3-1: Physical properties of water in 25^{o}C.

Formula	H_2O
Density	997.08 kg/m^3
Viscosity	0.8937 mPa.s
Molecular Weight	18.016 g/mol
Heat Capacity	4.182 kJ/kg.^{o}C

3.3.2 Anionic Surfactant

In this research, anionic surfactant, Sodium Stearate is chosen to be the surfactant additive. Sodium Stearate is used because of its physical and chemical properties, economic in price and most importantly it is not hazardous to human, environment and society. The average molecular weight of Sodium Stearate is 306.46 g/mol and it is soluble in water. (Sigma Aldrich Malaysia, 2013) & (GuideChem, 2012)

Table 3-2: Physical Properties of Sodium Stearate

Formula	$C_{18}H_{35}NaO_2$
Density	1.103 g/cm3
Appearance	White powder
Molecular Weight	306,46 g/mol

3.3.3 Anionic Polymer

Alginic acid sodium salt also known as Algin or Alginate, is an anionic polymer that can be found in the cell wall of brown algae. This polymer is chosen because of its ability to increase viscosity of water and it is safe and do not bring any side effect or hazard to the human and environment. It has a density of 1.601 g/cm^3 and viscosity of 15-20 cP. (Raymond et al, 2009)& (Sigma Aldrich Malaysia, 2013)

Table 3-3: Physical properties of Algin

Density	1.601 g/cm^3
Appearance	White to beige powder
Viscosity	15-20 cP
Molecular Weight	14000

3.4 Equipment

3.4.1 Rotating Disk Apparatus (RDA)

Drag reduction measurements were performed using the same equipment, RDA as previously reported in (Choi et al, 2000), (kim et al, 2001), (Kim et al, 2011), & (Vatankhah et al, 2011). However, the model of DRA used in this experiment is DS2-20P7-AS. The graphical image of RDA is shown in **Figure 1** and it consists of a stainless steel solution container, with a dimension of 165 mm diameter, 88 mm high and it is covered with a 60 mm thick removable lid. The rotating disk has a diameter of 148 mm and a thickness of 3 mm. The servo motor model is XinJie Electronic Co. Ltd. with the servo driver DS2-20P7-AS, where the motor capacity is 0.75 kW.

The cylinder can store up to a maximum volume of 1200mL of sample solution. The rotational speed of disk is controlled by a computer control unit and the maximum rotational speed is up to 3000 rpm. Torque value exerted by the fluid can be obtained from the computer display system.

In the present work, a high precision RDA is used to study the drag reduction properties of drag reducing agent instead of pipeline system due to its accurate measurement. RDA simulates external flow of fluid in lab scale. Since the flow is an external flow, the flow regime becomes turbulent when the dimensionless Reynolds's number exceed 3×10^5 in RDA. (Kim et al, 1999), (Choi et al, 2000).