INVESTIGATING THE EFFECT OF POLYMER MOLECULAR WEIGHT ON DRAG REDUCTION PERFORMANCE USING ROTATING DISK APPARATUS (RDA)

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ABSTRACT

The investigation of turbulent drag reduction, which is caused by the addition of a small amount of polymer or some other substances to the liquids flowing systems has been the focus of attention of many scientists for the last decades. Due to the reduction of the drag, pumping power for the pipeline will significantly reduced and thus will decrease the cost of electricity in total production cost. In this study, the effect of the presence of a drag reducing agent (DRA) and its variety of molecular weight on the torque produced in rotating disk apparatus containing water is investigated. The experimental procedure was divided into three parts; obtaining several different polymer molecular weights using ultrasonication method, testing the water using different polymer molecular weight at different polymer concentration and lastly is adding the different concentration of surfactant in the fixed concentration of water- polymer solution. Three polymer molecular weights are obtained by using ultrasonificator method with value of 11.7967 x10^6 g/mol, 4.830 x10^6 g/mol and 1.7179 x10^6 g/mol. A drastic reduction of drag in the turbulent flow of solutions as evaluated with torque differences in comparison to the pure solvent can be observed, even when only minute amounts of the additives are added. The percentage of drag reduction is relatively increases as we increase the polymer molecular weight and polymer concentration. A maximum drag reduction of 47.62% has been observed at polymer molecular weight of 11. 7697 x10^6 with polymer concentration of 200 ppm. In polymer- surfactant complex solution, 29% of drag reduction were reported with surfactant concentration of 2000ppm.

MENGKAJI KESAN JISIM MOLEKUL POLIMER KE ATAS PENGURANGAN GESERAN MENGGUNAKAN RADAS CAKERA BERPUTAR

ABSTRAK

Kajian tentang pengurangan geseran dalam pengolakan cecair, yang mana dengan penambahan sedikit campuran polimer asli atau beberapa bahan cecair yang lain ke dalam sistem pengaliran cecair telah menjadi tumpuan ramai ahli sains dalam dekad ini. Dengan pengurangan geseran ini, kuasa pam yang diperlukan untuk mengangkut cecair telah berjaya dikurangkan dan juga turut mengurangkan kos janakuasa elektrik yang diperlukan. Dalam kajian ini, kesan kehadiran agen pengurangan geseran dan kepelbagaian jisim molekul ke atas tork yang dihasilkan di dalam radas cakera berputar (RDA) yang mengandungi air telah disiasat. Prosedur eksperimen telah dibahagikan kepada tiga bahagian; mendapatkan beberapa jisim molekul polimer menggunakan kaedah ultrasonifikator, menguji air menggunakan jisim molekul polimer yang berbeza pada kepekatan polimer yang berbeza dan yang terakhir menambah kepekatan ‘surfactant‘ yang berbeza ke dalam larutan air- polimer yang berkepekatan tetap. Tiga jisim molekul polimer telah diperolehi menerusi kaedah ultrasonifikator dengan nilai 11.7967 x10^6 g/mol, 4.830 x10^6 g/mol dan 1.7179 x10^6 g/mol. Satu pengurangan geseran yang drastik dalam aliran yang bergelora boleh dilihat apabila terdapat perbezaan tork dengan pelarut yang tulen walaupun hanya sedikit bahan terlarut ditambah. Peratusan pengurangan geseran bertambah apabila jisim molekul dan kepekatan polimer bertambah. Pengurangan geseran yang maksimum iaitu sebanyak 47.62% telah diperhatikan pada jisim molekul 11.7697 x10^6 g/mol dengan kepekatan polimer sebanyak 200 ppm. Dalam larutan kompleks polimer- ‘surfactant‘, pengurangan seretan sebanyak 29% telah dilaporkan dengan kepekatan ‘surfactant‘ sebanyak 2000ppm.

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ρ	-	Density of fluid
μ	-	Absolute viscosity
v	-	Kinematic viscosity
ή	-	Intrinsic Viscosity

LIST OF ABBREVIATIONS

DR(%)	-	Percentage of drag reduction
DRA	-	Drag reduction agent
ΔP	-	Pressure drop
ΔP_L	-	Pressure loss
Re	-	Reynolds number
DRmax	-	Maximum drag reduction
V_{avg}	-	Average flow velocity
V	-	Volumetric flow rate
D	-	Diameter of pipe
ppmw	-	Part per million (weight)
K	-	Polymer- solvent characteristic parameter
[C]	-	Intrinsic concentration
PSP	-	Polymer Saturation Point
PDRA	-	Drag reducing polymer
ALS	-	Ammonium Lauryl Sulfate
GAELE	-	Glycolic Acid Ethoxylate Lauryl Ether

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Since 60 years ago, drag has been identified as the main reason for the loss of energy in pipelines and other similar transportation channels due to the turbulence flow and the friction between flowing fluid and pipe wall surfaces. These energy losses can be identified through pressure drop, which will results in more pumping power consumption.

In the turbulent pipeline flow consists of three regions across the pipe diameter such as the laminar sublayer, the buffer region, and the turbulent core. Fluid near the pipe wall (the laminar sublayer) tries to stay stationary while fluid in the center region of the pipe (the turbulent core) is moving quickly. This large difference in fluid velocity between the laminar sublayer and the turbulent core causes turbulent bursts to occur in the buffer region. Turbulent bursts propagate and form turbulent eddies, which cause inefficiencies in the hydraulic energy that drives the fluid down the pipeline.

Drag Reducing Agents (DRA) can be classified into three major categories such as polymers, surfactants and suspended solids. The most effective drag reducing agent that commonly used in industry is polymers. Toms (1948) first discovered the idea of drag reduction when he studied the effect of polymer added into a turbulent Newtonian fluid. He proved that the addition of small amount of polymers which is in ppm in turbulent flow can produce a significant result in reducing frictional drag. There are two types of polymer, which are synthetic polymer and natural polymers. Synthetic polymers are obtained from petroleum oil and mean while natural polymers can be extracted from resources in nature.

Nowadays, drag reduction is frequently served as a typical approach to save pumping power in pipelines or other transportation channels and equipments, particularly those deal with crude oil and refinery products. A pumping power saving corresponds to the reduction of pressure drop in these medium. Studies on various drag reduction agent have proven its ability in reducing pressure drop (Li *et al*., 2006; Cho *et al*., 2007; Abdul Bari *et al*., 2008).

To analyze turbulent drag reduction, most research groups used closed loop pipe flows, which is using produced pressure difference as drag reduction measurement. In contrast, this study will use a high-precision rotating disk apparatus (RDA) to measure drag reduction. RDA systems have been used for measuring both the mechanical shear degradation of polymeric materials and frictional reduction (Choi *et al*, 1987; Gyr *et al*, 1995; Choi and Jhon, 1996, Cadot *et al*, 1998). The flow in the neighborhood of a rotating disk is a great practical importance, particularly in connection with rotary machines. In addition, because the rotating disk flow is drag flow with no imposed pressure gradients, the origin of the turbulent boundary layer is different compared to the pressure driven flow case in pipelines (Kim *et al*, 1999). The RDA system, interfaced with the computer control unit and combines high speed data sampling with controlled disk rotational speed will accurately measure fluid friction from laminar to turbulent flow.

According to Kim *et al*, (1999) flow in rotating disk is used to describe external flow, the simplest turbulent boundary layer, which occurs on a flat plate at zero incidences. Many researchers typically studies frictional drag for an internal flow occurs within pipeline, whereas for an external flow, one studies the total drag (frictional plus form drag). External flow includes flow over flat plates as well as flow around sub-merged objects. The drag reduction phenomenon is only related to the frictional part. A maximum of 80% of the drag reduction can be achieved in tube flow, while the rotating disk flow generally produces about 50% of the maximum drag reduction because of the difference in the ratio between the frictional drag and the total drag for tube flow (inner flow) and rotating disk flow (outer flow).

In this investigation, a polymer solution will be mixed in water solution in rotary disk apparatus. Drag reduction performance will be investigated with varied polymer molecular weight and concentration correlating with speed of the RDA due to the injection of polymer. The injection of this polymer can enhance rotating torque and as a result, the pattern flow will move more smoothly. The benefits when using drag reducing phenomenon is the allowing of a greater production flow rate at an economical cost and simultaneously reduction of operating costs such as pumping power.

1.2 Problem Statement

Note that drag reduction is a 60 year old problem associated with originally with the name Toms as the Toms phenomena, where the addition of even very small (i.e. 5 ppm) of polymeric material can cause the reduction of turbulent drag by 80% in fully developed boundary layer and channel flows. Drag reduction by polymers in turbulent flows is an extremely complicated problem. It combines the complexity of turbulent flow (difficult even for a Newtonian fluid) with the problems of polymer physics; their combination changes the character of the turbulence and leads to a yet more complex and difficult problem. Many flows in industrial applications such as oil pipelines are turbulent flow. The turbulent flow with high velocity in the pipe flow system causes the formation of eddies or wakes in many different length scales and characterized by larger pressure drops and larger pumping power requirements than those of laminar flows. The scale of turbulent eddies in a larger contribution of turbulent energy production to mean mechanical energy loss. The energy losses in the pipe flow system can affect the production efficiency and economical cost like pumping power. Pump is widely use for effective fluid transportation before drag reduction phenomenon. The installations of pump cause the plant more costly because of drag in the turbulent flow. By using pump into the plant, the higher energy consumption is needed.

1.3 Objectives

Based on the research background and problem statements described in the previous section, these are the following objectives of this research:

1) To investigate the effect of polymer molecular weights on the drag reduction in pipeline water system.
2) To study the effect of polymer concentration on percentage of drag reduction in water system.
3) To study the effect of polymer- surfactant complex solution on percentage of drag reduction in water system using RDA.

1.4 Scopes of Study

The following scopes have been identified in order to achieve the objectives:

1. Three different molecular weight of polymer ($11.7697 \times 10^6 g/mol$, $4.830 \times 10^6 g/mol$ and $1.7179 \times 10^6 g/mol$), were produce using ultrasonication method and were experimented with significance to their effect in the turbulent drag reduction in rotary disk apparatus.
2. Different polymer molecular weight and concentration will be utilized to investigate the effect of this polymer used in the drag reduction phenomenon.
3. Distilled water will be the test fluid in this study.
4. The torque readings for pure distilled water and additional of polymer in the rotary disk apparatus was collected to calculate the corresponding torque, followed by the percentage of drag reduction.
5. Density and viscosity of pure fluid was used to calculate the Reynolds Number (NRe) of the fluid.
6. Two different surfactants were used to investigate the effect of polymer-surfactant complex solution on drag reduction at fixed polymer molecular weight and concentrations.

1.5 Rationale and Significance of Study

Drag reduction is an alternative way to reduce pumping power losses during transportation through pipelines. By injecting the drag reduction agent into a pipeline, the friction pressure losses in a pipeline would be decreased. The significance of this study was to discover a new scheme to reduce the turbulent drag, which is the main step to the pumping power saving and ultimately lead to cost saving. Furthermore, power saving is very essential to the cost saving in the plants. Originally from the name Toms as the Toms phenomena, he said that the addition of even very small (i.e. 5 ppm) of polymeric material can cause the reduction of turbulent drag by 80% in fully developed boundary layer and channel flows. It was showed that the presence of turbulence can be reduced with the addition of small amount of polymer. Also, recently studies found that the addition of surfactant into a polymer solution could be an effective method in reducing the mechanical degradation of polymer especially in high temperature flow system. So, two different surfactants were used to enhance the polymer solution characteristics.

CHAPTER 2

LITERATURE REVIEW

To flow liquid or gas in pipes, energy must be extended to overcome frictional losses. This energy is extracted from the fluid pressure, which is decrease along the pipe in the direction of flow. For a fixed pipe diameter, these pressure drops increase with increasing pipe length until a maximum is reached when the pressure drop along the pipe is equal to the supply pressure at the beginning of the flow. When flow in the pipe is turbulent, this maximum flow rate can be increase by the addition of small amounts of certain high molecular weight polymer to the fluid. These polymers intermingle with the turbulent flow processes and reduce the frictional pressure. This phenomenon commonly called drag reduction. Adding small amount of polymer been used in commercial oil pipelines, fire hoses and storm sewer to increase the flow capacities of the existing system. It also can be used to reduce supply pressures, pumping cost and pipe diameter for a given flow capacities.

2.1 Types of Fluid Flows

Fluid is a substance that existed in liquid or gaseous phase. The difference between a solid and fluid is illustrious based on the substance's ability to resist an applied shear or tangential stress that would change its shape. A solid can resist an applied shear stress and bowed temporarily or permanently depending on the force of the stress; whereas a fluid will continuously deforms under the influence of the stress (Cengel and Cimbala, 2006).

Essentially, there are three types of flow in pipeline which are Laminar, Transitional and Turbulent flow. When calculating heat or mass transfer or head loss, it is important to know the type of fluid flow whether it is laminar, transitional or turbulent. Laminar flow happens when dealing with small pipes and low flow velocities. Laminar flow can be regarded as a series of liquid cylinders in the pipe. Non – laminar flow is called turbulent flow. Turbulent flow happens at high flow rates and with larger pipes diameter. In turbulent flow, eddies, wakes or vortexes make the flow is unpredictable and unstable. The transitional flow actually is a mixture of laminar and turbulent flow. This happens when the turbulent in the center of pipe and the laminar flow near the edges. Each of these flows behaves in different equations that predict their behavior and have different manners in terms of their frictional energy loss while flowing in the pipelines (Witold, 2008).

In these cases, turbulent or laminar flow in circular pipeline could be determined by the dimensionless Reynolds Number. As discovered by Osborne Reynolds (1842 – 1912) the Reynolds number is important in analyzing at any type of flow when there is substantial velocity gradient such as shear. The Reynolds number is proportional to inertial force that divided by viscous force.

$$Re = \frac{Inertial\ forces}{Viscous\ forces} = \frac{V_{avg} D}{v} = \frac{\rho V_{avg} D}{\mu} \qquad (2.1)$$

Where D is diameter of the pipe in m, ρ is the density of the fluid in kg/m^3, V is the average velocity of the object relative to the fluid (m/s), μ is the dynamic viscosity of the fluid (Pa·s or $N·s/m^2$ or kg/(m·s)). (Geankoplis, 2003)

However, if calculation involved investigation of fluid flow using rotary disk apparatus (RDA), equipment that used to describe external flow, Reynold number for rotational flow is described by Kim *et al* (2001) as

$$NRe = \frac{\rho \omega r^2}{\mu} \qquad (2.2)$$

Where r is fluid density, ω is angular velocity [2 p× (revolutions per minute)/60 rad/s], r is radius of disk and μ is fluid viscosity [Pa·s]. Kim *et al* (2001) also state that the flow becomes turbulent in an RDA at a critical Reynold number of 3×10^5. Critical Reynolds number, Re_{cr} is the value where the flow becomes turbulent and this value varies for different geometries and flow conditions. The transition from laminar to turbulent flows is also dependent on other factors; such as pipe surface roughness, surface temperature, vibration and fluctuations in the flow

At high Reynolds numbers, the inertial forces, which are proportional to the fluid density and the square of the fluid velocity, are more significant compared to viscous forces, and therefore the viscous forces cannot inhibit the random and rapid fluctuation of the fluid. This condition of flow is known as turbulent flow and Reynold number can be defined as above than 4000 (NRe >4000). Whereas in low or moderate Reynolds number that is less than 2300 ($N_{Re} < 2300$), the viscous forces are significant enough to restrict the fluid fluctuation and keep the fluid under smooth ordered motion; and this is known as laminar flow. In most practical conditions, having Reynolds in-between 2000 until 4000($2000 < N_{Re} < 4000$), is called transitional flow (Cengel and Cimbala, 2006).

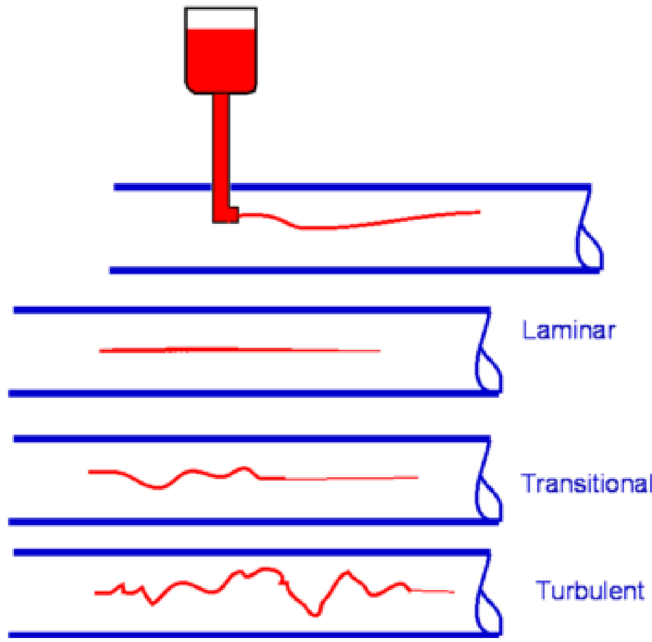

Figure 2.1 Types of flow inside circular pipelines as goes from laminar, transition and become turbulent flow.

(Source: http://www-mdp.eng.cam.ac.uk/web/library/enginfo/aerothermal_dvd_only/aero/fprops/pipeflow/node8.html)

2.1.1 Laminar Flow

At low velocities, where the layers of the fluids seem to slide by one another without eddies or swirls being present, the flow is called laminar and holds the Newton's law of viscosity (Geankoplis, 2003). Hoener (1965) has defined Laminar flow as 'state of flow where the various fluid sheets do not mix with each other'. It also is described as a uniform stable streamline flow without any mixing between layers. Other than that, laminar flow also defined as steady state flow in which the liquid flows through the pipe smoothly in laminations (E.Shashi Menon et.al, 2005). It can be consider as a smooth motion of the fluid as the objects goes through it. As the flow rate increases, more and more disturbance or eddies are formed due to friction between the adjacent layers of the liquid as well as friction between the pipe wall and the liquid (E.Shashi Menon et.al, 2005).

A simple summary about laminar flow are low velocity, dye does not mix with water, fluid particles move in straight lines, simple mathematical analysis possible and rare in practice in water systems (Andrew ,2008).

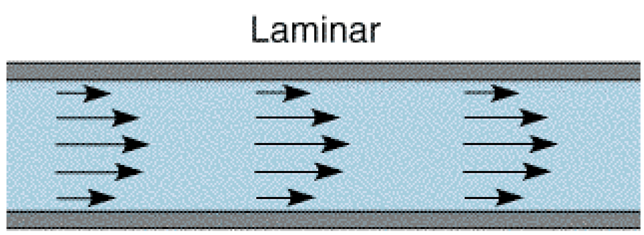

Figure 2.2 Laminar Flow in streamline.

(Source: http://www.ceb.cam.ac.uk/pages/hydrodynamic-voltammetry.html)

2.1.2 Turbulent Flows

When a flowing fluid is being obstructed by a bend, valve or even the roughness of the pipe wall, compression would take place. When this happens, local temperature and pressure of the fluid will increase. This will results in a turbulent flow as the