THE EFFECT OF PIPE LENGTH ON THE PERCENTAGE DRAG REDUCTION FOR WATER FLOWING INTO PIPES WITH DIFFERENT DIAMETERS

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I declared that this thesis entitled "*The effect of pipe length on the percentage of drag reduction for water flowing into pipes with different pipe diameters*" is the result of my own researched excepted as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ________________________

Name : LIM MEOW SUAN

Date : 30 APRIL 2009

Special thanks to my family because of their love,

Dear loving person of your moral support,

Lots of thanks to my friends, who guide and help me,

Last, but not least to my supervisor, thanks a lot.

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Thank you.

ABSTRACT

Fluids are very common and widely used in various industry processes. The only way to transfer fluids is to use pipe. During the transfer, the turbulent flow in pipe always causes a phenomenon called drag. However, this effect could be reduced by addition of Drag Reduction Agents (DRA's). This study is aimed to provide a clear understanding of the effects of various pipe lengths and pipe diameter on the percentage of drag reduction based on experimental work. In this work, an anionic surfactant, Sodium Dodecyl Sulfate (SDS) will be used as a DRA'S to investigate the purpose as stated above. An experimental apparatus consisting of two tanks, pump, pressure drop indicator, flow meter, test specimen pipe and piping network are set up. The parameters of investigation include concentration of the additive (100, 300 and 500 ppm), different pipe lengths (0.5, 1.0, 1.5, and 2.0 m) as well as different pipe diameters (0.5, 1.0, 1.5 in) at different water flow rates. Through the equivalent altered scale, some interesting results may be discovered.

ABSTRAK

Penggunaan bendalir adalah biasa dan digunakan secara meluas di industri. Satu-satunya cara untuk memindahkan bendalir adalah melalui penggunaan paip. Semasa pemindahan, aliran membuak di dalam paip kebiasaanya akan menyumbang kepada fenomena yang dikenali sebagai rintangan. Namun demikian, kesan ini dapat dikurangkan melalui penambahan dari segi tenaga tambahan ke dalam sistem melalui penggunaan Agen Pengurangan Rintangan (DRA). Kajiselidik ini bertujuan untuk mencari pemahaman dari segi faktor pengaruh panjang paip dan saiz diameter ke atas peratusan pengurangan rintangan berdasarkan kerja makmal. Dalam penyelidikan ini, agen permukaan bercas negatif, Natrium Dodecyl Sulfat (SDS) digunakan sebagai DRA bagi mengkaji tujuan seperti di atas. Radas yang diperlukan dalam eksperimen ini terdiri daripada dua tangki, pam, penunjuk perubahan tekanan, aliran meter, specimen kajian paip dengan rangkaian paip telah dibangunkan. Parameter yang digunakan dalam kajiselidik ini melingkupi kepekatan bahan kimia tambahan (100, 300 dan 500 bahagian per juta), panjang paip (0.5, 1.0, 1.5 dan 2.0m), paip diameter (0.5, 1.0 dan 1.5in.), dan kadar aliran air. Melalui kajian ini, kemungkinan sesuatu penemuan menarik akan diperolehi.

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Re	Reynolds Number
ρ	Density
ν	Velocity
D	Pipe Diameter
μ	Viscosity
%Dr	Percent of Drag Reduction
DRA	Drag Reducing Agent
$\Delta P_{without\ DRA}$	Pressure Drop without DRA
$\Delta P_{with\ DRA}$	Pressure Drop with DRA
α	Micelle Ionization Fraction
X	Weight of SDS

CHAPTER 1

INTRODUCTION

1.1 Background Study

In industrial scales, drag reduction is always highly concerned in the sake of power saving. A considerable effort has been made into exploring and implementing new methods of drag reduction. The primal way to reduce the drag is by installing pump along the piping network. It acquires a great amount in maintenance and energy loss. The pioneer of the idea with an extra energy input to the system to reduce the drag were Toms (Toms, 1948), and has been known since then as the Toms phenomenon. In their pioneering study, they independently observed that at constant pressure gradient, the turbulent flow rate could be increased by the addition of polymer or surfactant to a Newtonian solvent. Ever since, the drag reduction area has evolved tremendously.

1.1.1 Flows in pipe

By definition, a fluid is a material continuum that is unable to withstand a static shear stress. Unlike an elastic solid which responds to a shear stress with a recoverable deformation, a fluid responds with an irrecoverable flow. There are several types of flows in pipe. Each flow has its own characteristics and thus possesses different drag effects. The factor that determines which type of flow is present is the ratio of inertia forces to viscous forces within the fluid, expressed by the non-dimensional Reynolds Number (Re) as shown in Equation 1 below :

$$\mathrm{Re} = \frac{\rho v D}{\mu} \tag{1}$$

Where ρ is the density of fluid,ν is the velocity of fluid, D is the diameter of pipe and μ is the viscosity of fluid (Reynolds*, 1883).*

Generally speaking, fluid flow can be either laminar or turbulent.

(i) Laminar flow

Laminar flow, sometimes known as streamline flow, occurs when the fluid flows in parallel layers (refer to Figure 1.1). There is no disruption between the layers, thus no energy losses to the surrounding, and the flow's velocity is constant. In order for laminar flow to be permissible, the viscous stresses must dominate over the fluid inertia stresses. Fluid flows are laminar for Reynolds Numbers up to 2000 (Reynolds*, 1883).*

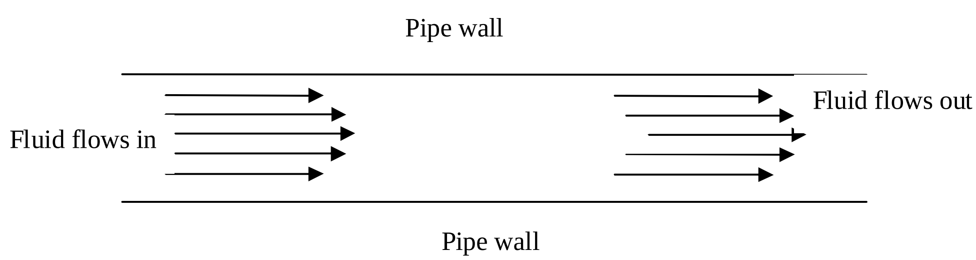

Figure 1.1: Laminar flow pattern in a straight pipeline

(ii) Turbulent flow

Turbulent flow occurs when there is a friction on the wall of the pipe. It's a flow field that cannot be described with streamlines in the absolute sense. However, time-averaged streamlines can be defined to describe the average behavior of the flow. In turbulent flow, the inertia stresses dominate over the viscous stresses, leading to small-scale chaotic behavior in the fluid motion (Refer Figure 1.2).

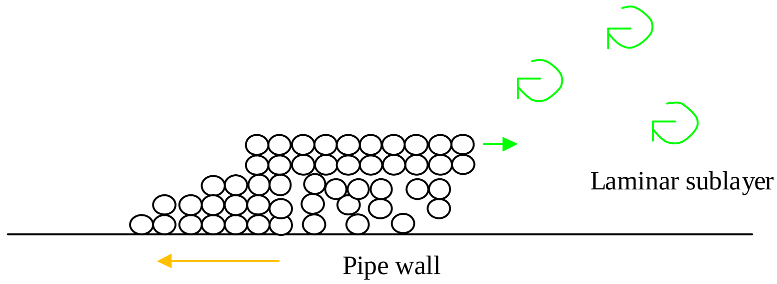

Figure 1.2: Turbulent flows in a straight pipeline

Turbulent flow is typified by a flow with Re above 4000. Energy loses when the flows intercept themselves, and hence slowing down the fluid flow. This phenomenon is attributed to drag effect (Reynolds, *1883)*.

1.1.2 Drag Reduction

Literally, drag reduction is the process of reducing the flow resistance especially in the pipelines, in order to improve the fluid-mechanical efficiency. It is a flow phenomenon by using small amount of additives, which is active agent known as DRA's, to reduce the turbulent friction factor of a fluid. In this research, Sodium Dodecyl Sulfate will be used as a DRA's to reduce the drag effect.

1.1.3 Drag Reducing Agents (DRA's)

Drag reducers or also known as Drag Reducing Agents. DRA's are materials that reduce frictional pressure during fluid flow in a conduit or pipeline. DRA's allows increased flow using the same amount of energy or decreased pressure drop for the same flow rate of fluid in pipelines.

DRA's can be classified into three main groups, which are polymers, surfactants and fibers. A few parts per million (ppm) of the additive can greatly reduce the turbulent friction factor of fluid flow in pipe. One of the ways to compare the effectiveness of a DRA's is through the calculation of the percent drag reduction (%DR).

According to Kang *et al*. (1999), the effectiveness of a drag reducing agent (DRA's) can be defined as:

$$\%\text{Dr} = \frac{\Delta P_{without\ \ DRA} - \Delta P_{with\ \ DRA}}{\Delta P_{without\ \ DRA}} \times 100\% \qquad (2)$$

However, there is no 100% drag reduction occurs.

1.1.3.1 Polymeric Drag Reducing Agents

High molecular weight polymer has been used for quite some time to reduce frictional drag in turbulent flow. These polymers do not pose any environmental threat as they are non-toxic and biodegradable. Although the exact mechanism of the phenomenon of drag reduction is still unclear, it is believed that drag reduction takes place by virtue of the ability of polymer molecules to dampen small-scale high frequency eddies which prevail in the turbulent hydrodynamic boundary layer (Wilkens *et al*., 2007).

Polymeric Drag Reducing Agents get degraded in turbulent flows and lose their effectiveness after a short interval of time or flow. Under high shear conditions, long polymer DRA's chains are permanently broken, thus reducing or eliminating the drag reduction capabilities of the DRA's. It is common practice to re-inject the DRA's downstream of pumping stations (Wilkens *et al.*, 2006).

1.1.3.2 Fiber Drag Reducing Agents

Fibers in suspension interact and entangle even at low populations and can form bundles or entities that behave differently from the individual fibers. Fibers interlock at moderate concentrations to form three-dimensional structures or networks which in liquid suspension alter the transport properties of the suspension (Duffy *et al.*, 1976).

Wood pulp fibers for example, form flocs and coherent networks which in a pipe produce a plug occupying the entire pipe volume. At low flow velocities, the frictional resistance is greater than for water alone but at higher velocities, fibers pulled from the network damp turbulence and reduce the frictional drag below that for water (drag reduction) (Duffy *et al.*, 1978).

Besides wood pulp fibers, there are also various synthetic polymer fibers. Synthetic polymer fibers are solid, smooth, and have a fixed length and diameter. In contrast, wood pulp fiber dimensions are hollow, rectangular in cross-section, and can collapse to form ribbon-like, flexible structures (Kathryn and Geoffrey, 2007).

1.1.3.3 Surfactant Drag Reducing Agents

Surfactant is a blend of surface active agent. It works as an agent which can greatly lower the surface tension of a liquid even though it presents in a very low concentration. On top of that, it also allows easier spreading, and lowers the interfacial tension between two liquids. The Sodium Dodecyl Sulfate (SDS) which will be used in this study is an anionic surfactant. Figure 1.3 shows the molecular structure of a SDS. It consists of water soluble hydrophilic part, and a water insoluble hydrophobic part.

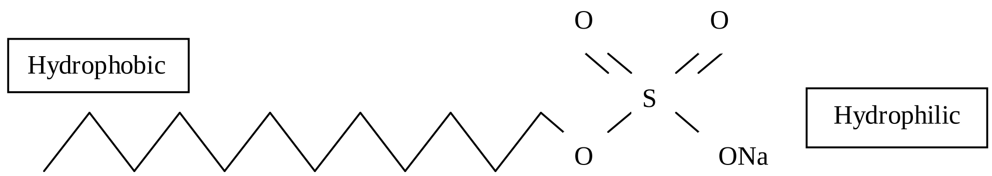

Figure 1.3: Molecular structure of SDS

The drag-reducing surfactant solutions are characterized by the presence of rod-like micelles which are formed by single surfactant molecules above a certain characteristic concentration (Bewersdorff and Gyr, 1990). The drag reduction is caused by anionic, cationic, nonionic, and zwitterionic surfactants.

1.2 Problem Statement

Numbers of experimental investigations have been undertaken to confirm and characterize Toms phenomenon (Toms, 1948). This requires a systematic experimental and appropriate dimensional analysis. To date, there is no general guidelines for the selection of a DRA's for a given liquid flow application. Meanwhile, the effectiveness of a DRA's is also influenced by other factors (pipe wall roughness, pipe length, and pipe diameter). Hence, a follow through study is undertaken to investigate the details on the effect of pipe length and pipe diameter on the effectiveness of drag reduction.

At the same time, the ability of SDS in reducing drag is going to be studied too. Different concentration of SDS will maybe given a different effectiveness of drag reduction. The most suitable concentration of SDS at different condition should be figured out in order to increase the effectiveness of a DRA's, and thus reduce the energy losses in the pipe.

Due to the fiercely increased of the price of natural gas and fuel, power saving is extremely important to save the cost in the plans and the most important, to save our earth from the crisis of natural resources. In this study, a drag reduction guideline are developed that can be used for the engineering design for pipe.

1.3 Objectives

The aim of this investigation is to study the effects of the pipe length and pipe diameter on the ability of SDS to work as a DRA's.

1.4 Scope Of Study

By measuring the pressure drop at specific flow rate, we will:

a) Investigate the effects of the pipe length and pipe diameter on the percentage drag reduction. It is proposed to use pipe length of 0.5 m, 1.0 m, 1.5 m, and 2.0 m and pipe diameter of 0.5 in, 1.0 in and 1.5 in the purpose above.

b) Elucidate the effects and mechanism of DRA's in reducing the drag in turbulent pipe flow. SDS with concentration of 100 ppm, 300 ppm and 500 ppm is used to investigate the effectiveness in various pipe lengths and diameters.

CHAPTER 2

LITERATURE REVIEW

Drag reduction is the most widely known effect of turbulent flows. It is important to the increase of industrial production rates and to the reduction of transportation costs. However, since the drag reduction effect decreases as the additives degrade due to the mechanical shear and high turbulent intensity, drag reduction has been limited to relatively short-term industrial applications. Minimizing degradation is thereby a key issue in taking advantage of this technology. In turbulent flow, drag reducing agents (DRA's) act to disrupt turbulent structures.

2.1 Theory of Drag Reduction

Frictional pressure drop, or drag, is a result of the resistance encountered by flowing fluid coming into contact with a solid surface, such as a pipe wall. There are generally two types of flow; laminar and turbulent. The friction pressures observed in laminar flow cannot be changed unless the physical properties of the fluid are changed. The current class of DRA's does not change fluid properties and hence they are effective only in turbulent flow. In most petroleum pipelines, the liquid flows through the pipeline in a turbulent regime. Therefore, current DRA's can perform very well in most pipelines (Sarkhi and Hanratty, 2001).

In a turbulent flow regime, the fluid molecules move in a random manner, causing much of the energy applied to them to be wasted as eddy currents and other indiscriminate motion. DRA's work by an interaction of the polymer molecules with the turbulence of the flowing fluid.

In order to understand how drag reducers decrease the turbulence, it is necessary to describe the structure of turbulent flow in a pipeline. The illustration shown in Figure 2.1 below shows a typical turbulent flow in a pipeline that has three parts to the flow, laminar sublayer, buffer region and turbulent core (ConocoPhillips, 2008).

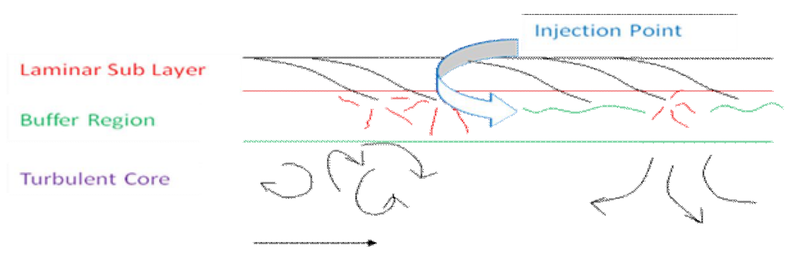

Figure 2.1: Segments of Turbulent Flow in Straight Pipeline

Figure 2.1 shows the turbulent core in a pipe. It is the largest region and includes most of the fluid in the pipeline. This is the zone of the eddy currents and random motions of turbulent flow. Nearest to the pipeline wall is the laminar sub layer. In this zone, the fluid moves laterally in sheets. Between the laminar layer and the turbulent core lies the buffer zone.

Buffer zone is very important because this is where turbulence is formed first. A portion of the laminar sub layer, called a "streak", will occasionally move to the buffer region. There, the streak begins to vortex and oscillate, moving faster as it gets closer to the turbulent core. Finally, the streak becomes unstable and breaks up as it throws fluid into the core of the flow. This ejection of fluid into the turbulent core is called a turbulent burst. This bursting motion and growth of the bursts in the turbulence core results in wasted energy (ConocoPhillips, 2008).

DRA's interfere with the bursting process and reduce the turbulence in the core. The polymers absorb the energy in the streak, like a shock absorber, thereby reducing subsequent turbulent bursts. As such, DRA's are most active in the buffer zone. The additives which can cause drag reduction effect can generally be divided into three types; polymers, surfactants and fibers. Each group has different working mechanisms to reduce the drag flow of fluid.

2.2 Drag Reducing Agents (DRA's)

Drag reducing agents is the additives which can reduce drag in turbulent flow with a very low concentration, with comparison to the drag in turbulent flow of the pure solvent. These low concentration suspensions mostly show negligible effect in laminar flows (Sher and Hetsroni, 2008). The DRA's can be split into three groups: polymers, fibers and surfactants.

2.2.1 Drag Reduction by Polymers

It has been observed that adding a small amount of specific high molecular weight polymer known as "Drag Reducers" under turbulent pipe flow condition can drastically decrease the friction pressure gradient and thus, increase pumping capacity (Shah *et al.*, 2006). Experiment evidences show that the polymer increases the thickness of the viscous sub layer and the transition zone. The mechanism of this boundary layer effect is not yet fully understood, but supporting experimental evidences have been given by Fortuna and Hanratty (1971), Rudd (1971), Kumor and Sylvester (1792) and Astria (1969).

Warholic *et al.* (2001) in their work reported that turbulent fluctuations normal to the pipe wall have been measured to be significantly reduced in the presence of DRA'S. Virk (1975) analyzed the drag reduction performance of numerous polymer solutions reported in the literature. He found that all tended towards a maximum drag reduction. He found that polymer-turbulence interaction occurs in the location of peak turbulence production indicating an interference with turbulent bursting processes. Sylvester and Brill (1976) studied polymer DRA'S in annular flow in a 0.0127-m diameter horizontal pipe and they found drag reduction of up to 37% ah high flow rates if the DRA'S was not recycled. In the other hand, Greskovish and Shrier (1971) studied polymer DRA's in a 0.038-m diameter horizontal pipe. They reported drag reduction of 40 – 50% in air-water slug flow. They attributed this to a reduction in frictional losses as opposed to accelerational changes within the slug. Other studies also found out that a reduction of interfacial roughness can also reduce pressure drop (Glassmeyer, 2003) and also that, a change in flow pattern is expected to reduce pressure drop (Al-Sarki and Hanratty, 2001).

2.2.2 Drag Reduction by Fibers

The reduction of drag in turbulent pipe flow by the addition of fibers has many practical applications. Numbers of studies have been done by Kerekes and Dougles (1972), Hoyt (1972), Vaseleski and Metzner (1974). The phenomenon of drag reduction in turbulent fiber suspensions has stimulated considerable interest in recent years and it plays a significant practical importance to the papermaking industry.

Mewis and Metzer (1974) found that fibers exhibit very high resistance to extensional deformations in turbulent flow conditions. In turbulent flow conditions, eddies are constantly stretched by the action of velocity fluctuations, which will be suppressed by fibers. This phenomenon can modify the entire turbulence in a direction that could lead to a reduced level of radial momentum transfer to give drag reduction.

Kale and Metzer (1976) established the origin of drag reduction in the region of the flow very close to pipe wall where eddies are mainly of dissipative type and form the viscous zone of pipe flow turbulence. It thus appears that an interaction between viscous eddies and fibers could be a possible cause for drag reduction in turbulent flow.

2.2.3 Drag Reduction by Surfactants

A surfactant can be classified according to its charged group located in hydrophilic probe (head). The head of an anionic surfactant carries a charge, while nonionic surfactant does not carry any net charges. Anionic surfactant can be classified into several groups comprising of anionic, cationic and zwitterionic. Figure 2.2 shows a typical representation of structure of a surfactant. (Chemicalland21, 2008).

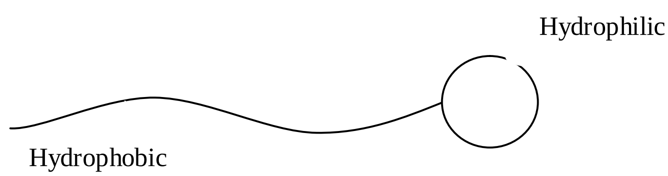

Figure 2.2: Particular type of molecular structure of a surfactant

(i) Anionic

It is the surfactant with a negatively charged head. Commonly encountered anionic surfactants are SDS, soaps, and fatty acid salts.

(ii) Cationic

It is the surfactant with a positively charged head. Commonly encountered cationic surfactants are benzalkonium chloride (BAC) and benzethonium chloride (BZT).

(iii) Zwitterionic

It is the surfactant with two oppositely charged groups. Commonly encountered zwitterionic surfactants are dodecyl betaine and dodecyl dimethylamine oxide

(iv) Nonionic

It is the surfactant which does not carry any net charges. Commonly encountered nonionic surfactants are like alkyl polyglucosides and fatty alcohols.