TURBULENCE SLAPPING TECHNIQUE EFFECT ON THE MULTI-PHASE FLOW BEHAVIOR IN PIPELINE

SAW CHIN HOOI

A thesis submitted in partial fulfillment
of the requirement of the award of the Degree of
Bachelor chemical Engineering (Gas Technology)

Faculty of Chemical & Natural Resources Engineering

University Malaysia Pahang

DECEMBER 2010

ABSTRACT

The experiment is concerned with an experimental investigation of the drag reduction in two phase (solid-liquid) turbulent flow over the mechanical chain. A circulating loop for the fluid flow with 0.0381 inside diameter of pipe is set up. The testing length of the system is 1.5m.Wall shear stress reduction performance has been investigated experimentally for various design geometry surfaces including a replica of bent consisting of stainless steel model scales. Attempts to optimize the net drag reduction by varying the design geometry and alignment are also discussed. The study indicated that the presence of turbulence can be reduced under the influence of mechanical chain. But, the effect of mechanical chain decreases as Reynolds Number (Re) increases. The results show that a substantial drag reduction can be achieved by this mechanical chain in aqueous media.

Keywords: Drag reduction, mechanical technique; multiphase solid- liquid flow; geometry, alignment

ABSTRAK

Dalam kajian ini, objektif utama yang ingin ditekankan ialah keberkesanan kehadiran ‘rantai mekanikal’, terhadap perbezaan tekanan yang berlaku dalam sistem paip melintang. Cecair ujikaji yang digunakan dalam kajian ini ialah air paip dan pasir silica. Ukuran bagi diameter paip ialah 0.0381m, manakala untuk ukuran panjang paip ialah 1.5 meter. Parameter yang digunakan dalam kajiselidik ini melingkupi kepekatan pasir silica tambahan (100, 300 dan 500 bahagian per juta), reka bentuk rantai yang deperbuat daripada stainless steel dan air paip dengan nilai halaju yang berbeza-beza. Peratus ‘Drag Reduction (%DR)’, dapat dikira dengan menggunakan data-data perbezaan tekanan yang telah diambil semasa eksperimen dijalankan. Melalui keputusan yang telah diperoleh dari eksperimen, rintangan air didapati dapat dikurangkan dengan pengaruh daripada rantai mekanikal. Namun begitu, apabila Reynolds number meningkat, pengaruh rantai mekanikal terhadap rintangan air didapati berkurangan.

TABLE OF CONTENTS

3 PROJECT METHODOLOGY

4 RESULTS AND DISCUSSIONS

5 CONCLUSION AND RECOMMENDATION

APPENDICES

LIST OF FIGURES

LIST OF NOMENCLATURE

ρ - Solvent density

μ - Absolute viscosity of solvent

L/D - Pipe ratio

D - Internal diameter of pipe

ΔP - Pressure drop in pipe

$\% \, DR$ - Percent of Drag Reduction

L - Pipe length

f - Friction factors

V - Means velocity of solvent

τ - Wall shear stress

Re - Reynolds Number

DRA - Drag Reducing Agents

ppm - Parts Per Million

Q - Volumetric flow Rate, m^3/hr

CHAPTER 1

INTRODUCTION

1.1 Background Study

The stratified multiphase flow regime is frequently encountered in nuclear, oil/gas industries and pipelines. Turbulence control is one of the key points to reduce the resistant of multiphase fluid and to solve the high energy consumption problem. Understanding the turbulent frictional drag that causes the formation of eddies in pipe flows involves challenging scientific problems of significant practical importance. Such unsteady flow has challenged many researchers reserve intense activity for turbulent studies, which can range from basic experimental and numerical research, to the estimation of extensive and complicated turbulence models. In recent years, in particular, considerable efforts have been successfully committed and evolved tremendously to the development of a variety of techniques with the intention to reduce the friction in turbulent wall-bounded flow.

The basic definition of drag reduction is the reduction in the friction pressure loss of a DRA treated commodity when compared to the untreated commodity and it is typically expressed as a percent. Generally, there are two ways of reducing the drag, which are passive and active techniques. The passive way involved with installation and maintenance, while the active way requires certain energy input.

According to Vancko, (1997) drag reduction is only applicable in turbulent flow and is enhanced with decreasing viscosity, increasing Reynolds number and pipe diameter. Provoked by an understanding of the Tom’s effect

(Tom's, 1948), drag reducing additives have been applied to save energy, minimizing the size of pumps and many drag reducers have been found so far (Yu et al., 2004). The prediction of drag reduction and holdup in two-phase pipe flow has been of considerable research interest since the 1930s. Early researcher developed many empirical correlations based on different flow conditions to analyze the flow characteristics, namely, pressure drop.(Beggs and Brill, 1973).

Drag Reducing Agents, DRA's have for several decades been used in the petroleum industry for increasing capacity and reducing the pressure friction loss in pipelines during fluid flow in crude oil, refined products, 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.

Generally, all of the additives can be categorized into three groups; they are polymers, surfactants and fibers. Experiments have shown that the addition of small amount of drag-reducing materials may give a reduction in the pressure friction loss by up to 80-85% in turbulent liquid flow system. DRA in liquids work to reduce frictional pressure loss. It works in turbulent flows only and is influencing the structure of the turbulent boundary layer. The additives added 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 Hestroni, 2008)

Even though there are many papers and reports on pressure drop, dynamic flow pattern and drag reduction, there is still relatively few dealing with the measurements of the turbulent structure of multiphase flows by mechanically modification. In the present study, the influence of the mechanical chain on the characteristics of the flow rate and pressure drop was identified. To build up such design, it is required to obtain a physical understanding of the mechanisms involved, which takes place in turbulent multiphase flows.

1.2 Problem statement

Multiphase flow occurs in almost all producing oil and gas wells and surface pipes that transport produced fluids. The significantly different densities and viscosities of these fluids make multiphase flow much more complicated and complex natural physical phenomenon than the single-phase flow. According to Samwayst et al., (1997), the pressure at any point in a multi phase flow is caused either by the direct hydrodynamic nature of the two-phase flow itself, or by unwanted pressure pulsations from pumps, restrictions/intrusions to the flow or vibrations acting upon the flow loop from external sources.

When a multiphase fluid flows through a pipe, the internal roughness (e) of the pipe wall can create eddying motions of all sizes within the fluid adding a resistance to flow of the fluid. A large part of the mechanical energy in the flow will change into the formation of these eddies which eventually dissipate their energy as heat. This phenomenon then will cause the pressure drop and power losses in pipelines. Many flows in industrial applications are turbulent and thus characterized by dramatically larger pressure drops and larger pumping power requirements than those of laminar flows. Subsequently, it will affect the cost attributes due to higher energy consumption.

1.3 Research objective

The analysis on pressure drop has been given lots of interest because it is directly manipulating the power requirements of the pump to maintain a flow. Power saving is the main reason that attracted many researchers to study the drag reduction phenomenon. Multi-phase drag reduction is still the subject of much research. By referring to the problem statement, present research aim to investigate the effect of addition mechanical chain on multiphase flow in a horizontal galvanized pipe on the ability in reducing drag. The characteristics such as the geometric configurations of flow patterns of the multiphase flow with and without the mechanical technique are described.

1.4 Scopes of the research

There are few important tasks that targeted to be achieving in this research. The scopes of the study consist of:

i. Elucidate the effect of mechanical chain in reducing the drag in turbulent pipe flow with different values of flow rate.
ii. Elucidate the effect of suspended solid in reducing the drag in turbulent pipe flow. Silica sand with concentration of 100 ppm, 300 ppm, 500 ppm and 700ppm is used to investigate the effectiveness in 1.5m pipe length.
iii. Investigate the effects of chain's number and location on the percent drag reduction. It is proposed to use chain number of 5, 4 and 3 in the purpose above.
iv. Design and fabricate the suitable prototype for the mechanical technique.
v. Material to be used is stainless steel plate with 0.5mm and 1.0mm thickness.

1.5 **Significant of study**

The main significant of the research is to reduce the turbulent friction drag and power losses problem in pipeline by introducing the mechanical technique. It is a new way to perform drag reduction besides using Drag Reducing Agents. The reduction of the frictional pressure during flow can greatly reduce the cost of pumping power and cost of pumping station units. The mechanism of drag reduction will depend on the addition mechanical technique to the liquid transportation in turbulent flow. This method has the potential of improving the flow in pipelines. It will give a big contribution and benefits to the industries to reduce their annual cost and energy consumption.

1.6 Limitation of the research

The limitations that have been set in the research including following parameters:

a) Type of solid particles and material : Silica sand
b) Flow condition: Turbulent flow (Reynolds Number › 2100)
c) Temperature : Room temperature (25^0C)

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Multiphase flow in pipelines is one of the great challenges in the conventional sciences. Many new technologies have been confronted with multiphase problems. As with most problems in chemical engineering, power plants and the oil and gas industry, the significance in multi-phase flow is due to its extreme importance that are competent of resolving more details in the flow.

Despite the importance of multiphase flows, their understanding is primitive compared to single phase flows. The need to identify and understand basic scientific principles and basic processes which underlie the behavior of these systems represents the motivation for this research project.

2.2 Fluid flows in pipe

By definition, a fluid is a material continuum that is unable to withstand a static shear stress. Unlike elastic solid which respond to a shear or tangential stress with a recoverable deformation, a fluid responds with an irrecoverable flow. A solid can resist an applied shear stress and deformed 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, 2008). Flows in a pipe are considered as internal flow because the fluid is completely bounded by solid surfaces, where the flow is driven primarily by pressure difference. Typically, the flows of real fluids happen in several types of flow regimes. The most common known can be either laminar flow or turbulent flow.

According to Cengel and Cimbala, (2008) the laminar flow is the highly ordered fluid motion characterized by smooth layers of fluid; whereas turbulent flow is the highly disordered fluid motion that naturally occurs at high velocities and is characterized by velocity fluctuation. Transitional flows happens in-between laminar and turbulent. The key parameter to determine the type of flow in pipes is by using the dimensionless Reynolds number (Re), which was established by a British engineer, Osborn Reynolds in the 1880s through experiments.

The dimensionless Reynolds number, (Re) which provides an indication of the ratio of inertia forces in the flow to viscous forces within the fluid. The equation for the Reynolds Number is expressed by

$$\mathrm{Re} = \frac{\text{Inertial forces}}{\text{Viscous forces}} = \frac{\rho V_{avg} D}{\mu}$$

Where ρ is the density of fluid, ν is the fluid characteristic velocity (m/s) and D would be the pipe diameter (m) and μ = viscosity of the fluid (m^2/s). The flow regime, whether laminar or turbulent, is important in the design and operation of any fluid system. Each flow has its own characteristics and thus possesses different drag effects.

At large Reynolds numbers, the inertial forces, which are proportional to the fluid density and the square of the fluid velocity, are large relatively to the 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. Whereas in low or moderate Reynolds number, 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.

2.2.1Laminar Flow

Laminar flow also known as streamline flow, occurs when the smooth, streamline type of viscous fluid travels in an orderly manner along path lines with constant axial velocity and the velocity profile of the flow will remain parallel in the flow direction. In fluid dynamics, laminar flow is a flow regime characterized by high momentum diffusion, low momentum convection, pressure and velocity independent from time. There is no motion in the radial direction and thus the velocity component in the direction normal to the pipe axis is zero. Since the velocity of the flow is constant and the flow is steadily, fully developed, there will be no acceleration in the fluid flow. (Cengel and Cimbala, 2008). The chief criterion for laminar flow is relatively small value of Reynolds numbers, up to 2000. (Reynolds, 1883)

Hoener (1965) defined Laminar flow as “state of flow where the various fluid sheets do not mix with each other”. It also is described laminar as a uniform stable streamline flow without any mixing between layers. It can be consider as a smooth motion of the fluid as the objects goes through it. This type of flow is also known as low friction or viscous flow in which no eddies or turbulence exist. 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).

Abulencia and Theodore, (2009) elucidated that the average velocity of a fully developed laminar flow is about one-half of the maximum velocity flow in a pipe. In turbulent flow, the profile is resembles a flattened parabola and the average velocity is about 0.8 times the maximum velocity. Laminar flow is illustrated in Figure 2.1**.** A laminar flow has a true parabola velocity profile, slightly pointed at the middle and tangent to the wall of the pipe.

According to Mcdonald and Helps,(1954) in laminar flow or streamline flow, the fluid particles moving in the form of lamina sliding over each other, flow in concentric laminar which vary in speed progressively from zero velocity at the wall to maximum velocity in the axial stream. The lamina near the flow boundary moves at a slower rate as compared to those near the center of the flow passage. This type of flow occurs in viscous fluids, fluids moving at slow velocity and fluids flowing through narrow passages.

2.2.2 Turbulent Flow

On the other hand, turbulence describes as a state of chaotic, stochastic property changes, constant agitation and intermixing of fluids particles such that their velocity changes from point to point. The disorderly and rapid fluctuation in turbulent flows, merely known as eddies increases the momentum and energy transfer between the fluid molecules. Formation of eddies with different length scale in pipe flow causes fluctuation in parameter values like velocity, temperature and pressure even when the flow is steady. This process continues and eventually creates structures that are small enough that molecular diffusion becomes important and viscous dissipation of energy finally takes place. The swirling eddies transfer mass, momentum and energy much more rapidly compared to molecular diffusion, resulting in higher friction factor, heat transfer coefficient and mass transfer coefficient (Cengel and Cimbala, 2008)

Typically, viscous stresses within a fluid tend to stabilize and organize the flow, whereas excessive fluid inertia tends to disrupt organized flow leading to chaotic turbulent behavior. The phenomenon is a complex, unsteady flow and occurs at Re above 4000.

The conditions establishing the transition from laminar to turbulent flow in pipes with steady flow were first described by Reynolds (1883). Transition of the fluid is made at certain point when the velocity of the fluid increases. Speed has become a major factor in forming the turbulence in pipelines. This changeover to some extent is governed by the inner forces of the molecules involved, when the forces of acceleration are greater than the inner forces that hold molecules together, unsteady vortices appear, eddies are formed and drag fluctuates. The effect of these turbulent eddies is to mix the flow and to create a turbulent profile in the pipe which is more uniform.

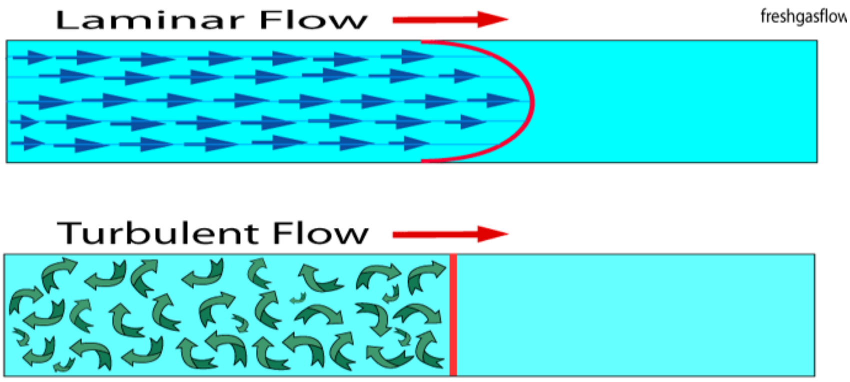

Figure 2.1: Laminar and Turbulent Flow profiles in circular pipe.

2.3 Drag reduction

Drag reduction is a flow phenomenon by which small amounts of additives, e.g. a few weight parts per million (wppm), can greatly reduce the turbulent friction factor of a fluid or fluids (Gadd, 1971). As a result of the addition of small amounts of certain materials to the liquid phase, reduction of the pressure gradient in turbulent pipe flow happened. The aim for the drag reduction is to improve the fluid-mechanical efficiency using active agents.

According to Savin (1964), drag reduction can be defined as the increase in pump ability by reducing the flow resistance of a fluid caused by the addition of small amounts of another substance to the fluid. it causes the reduction in the pressure drop over some length of a pipeline. It is a flow phenomenon by using small amount of additives, which is active agent known as DRA’s to reduce the frictional resistance/drag.

Lumley came with a theory about drag reduction in 1969. He stated that the stretching of randomly coiled polymers increase the effective viscosity. By consequence, small eddies are damped which leads to a thickening of the viscous sub layer and thus drag reduction. Gadd, (1971) proposed a new theory which argues that drag reduction is caused by elastic properties rather than viscous. He came to this hypothesis by observing drag reduction in experiments where polymers were active at the centre of the pipe, where viscous forces do not play a role. His arguments that the elastic properties of polymers cause shear waves to prevent the production of turbulent velocity fluctuations at the small scales. Virk et al., (1970) observed that the amount of drag reduction is limited by an empirical asymptote, called the Virk asymptote.

Drag reduction phenomena in multiphase flow are still far from being well understood in spite of the numerous investigations. Based on the research carried out by Kang et al., (2004), they evaluated the effect of a commercial DRA on turbulence in multiphase flow. DRA was able to reduce the turbulence at the gas-liquid interface, which led to a decrease in the interfacial pressure drop and friction factor. It was noticed that the interfacial friction factor reduced by a maximum factor of 57% with the addition of DRA. The effectiveness of the interfacial pressure drop component reached values as high as 72% at superficial gas and liquid velocities of 8 and 1 m/s with 50 ppm of DRA.

In multiphase flow, percent drag reduction (%DR) can defined as the ratio of reduction in the frictional pressure difference when the flow rates are held constant to the frictional pressure difference without DRA, as shown in Eq. (1) (D.Mowla et al., 2006).

$$\%\,\mathrm{DR} = \frac{\Delta\mathrm{Pb} - \Delta\mathrm{Pa}}{\Delta\mathrm{Pb}}\ x\ 100\% \qquad \textbf{(1)}$$

Which ΔP_b is the frictional pressure difference before adding the additives, N/m^2 and ΔPa is the frictional pressure difference after adding additives, N/m^2.

2.4 Drag Reducing agents (DRA's)

Drag reducing agents were first documented in the middle of the last century and has been wide used in existing systems for its benefit in increasing production (without mechanical modification), reduction of operating costs such as pumping power, reduction of pipe pressure while maintaining productivity, and boosting refinery handling (Vancko, 1997).

As per Nijs (1995), drag reducing agents (DRA's) are type of flow improvers with typically long chain or high molecular weight (106~108) polymers that are suspended in a solvent which prevent bursts that create turbulence in the core and interfere with the turbulence being formed, or reduce the degree of turbulence.

Based on the research carried out by Kang (2004, 2001), he concluded that the DRA effectiveness depends on many parameters such as oil viscosity, pipe diameter, gas and liquid velocities, oil composition, water cut, pipe inclination, DRA concentration, type of DRA, shear degradation of the DRA, temperature, and pH. These properties control the distribution of fluid interfaces, which reflects the mechanism of momentum, heat and mass transfer among the fluids; and thus inducing different pressure drop.

Myska and Zakin (1997) explain that the additives are differentiating from each other due to the extensive dissimilarity between flow behaviors and their drag performance in liquid. These factors include the influence of preshearing, the effect of mechanical shear on degradation, and the influence of tube diameter, maximum drag-reduction effectiveness, and the shape of their mean velocity profiles. The differences suggest that the mechanisms for causing drag reduction may be different for the two types of additives.

For the past decades, there is numbers of successful techniques proposed for reducing turbulent friction drag. To name a few, there is modifying the fluid structure, such as the addition of polymers (long-chain molecules) (Lumley, 1973; Virk, 1975), fibers or surfactants (Abdul Bari, 2009), the addition of suspended solid particle and even approaches was done by modifying the surface geometry, explored by direct numerical simulations, include longitudinal microgrooves or riblet-covered surface in turbulent flows (Choi et al., 1993; Walsh 1982).

2.4.1 Drag Reduction by Polymers

The additives, which cause drag reduction, can be split into three groups: polymers, surfactants and fibers (Hormoz, 1984). Since Toms (1948) first discovered the idea of drag reduction (DR) when he studied the effect of polymer added into a turbulent Newtonian fluid, it was used as a core for researchers to further discover and develop effective drag reduction agents (DRA).

Toms, B. A. (1948) found that the injection of a concentrated solution of polyacrylamide and sodium acrylate into an air-water flow in a horizontal pipe changed an annular pattern to a stratified pattern by destroying the disturbance waves in the liquid film. Drag reduction of 48% was measured for mean concentrations of 10-15 wppm. Greskovich and Shrier (1971) tested high molecular weight poly-alphaolefin DRA's for gas-condensate two-phase flows and observed drag reductions up to 65%. These polymers are typically used for oil flows. The polymers modified the multiphase flow pattern.

Long chain polymers were initially used as drag reducing additives for turbulent flow. It has been noticed that when traces of high molecular weight polymer are dissolved in the pipeline it causes a reduction in Reynolds stress and velocity fluctuation normal to the wall. (Warholic et al., 1999).

When polymer was injected into the pipeline, these long chain polymers interact with small scale flow disturbances that develop into large scale turbulent structures. These interactions interfere with the development of large scale turbulent flow structures resulting in a reduction in the amount of turbulent flow in the pipe. Polymers affect the macrostructure of the turbulence. This reduction in turbulence results in a reduction in the frictional pressure loss for given flow rate.

Benzi (2009) reviewed the progress in understanding the phenomenon of drag reduction with polymers in wall bounded turbulence. He explained that the amount of drag reduction as a function of polymer concentration can be qualitatively and quantitatively due to the fact that polymer can be stretched up to a maximum length. Eventually for infinite concentration, the drag reduction will reach a maximum.

Polymer solutions are widely used for many applications, i.e. the oil, food, cosmetics and chemical industry. The general guidelines for the selection of a DRA for a given multiphase flow application do not exist. The most important requirement is that the DRA is soluble in the liquid. In aqueous systems, hydrolyzed polyacrylamide and polyacrylate are used. Polyacrylamide is a long-chain synthetic polymer that acts as a strengthening agent, binding soil particles together.

Virk and Baher (1970) examined the effect of Reynolds number on polyacrylamide and polyethylene oxide drag reduction. 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).

Wilkens et al., (2007) reviewed that high weight polymer has been used to reduce frictional drag in turbulent flow. They believed that drag reduction takes place by virtue of the ability of polymers molecules to dampen small scale high frequency eddies which prevail in the turbulent hydrodynamics boundary layer. Generally, higher molecular weight polymers perform much better than identical but lower molecular weight polymers. A major drawback of polymer solutions is the degradation in high shear flows. This degradation is caused by the pump and piping system. Injecting the polymers downstream of the pipeline booster pumps can minimize this effect.

Al-Yaari et al., (2009) conferred that the significant pressure drop reduction after the addition of drag reducing polymer (PDRA) could be due to the decrease in turbulence intensity that increases droplets coalescence rate and a gravity force dominates leading to stratification of water phase.

Al-Sarkhi and Abu-Nada (2005) have investigated the effect of drag reducing polymer on annular flow pattern in 0.0127 pipelines. The maximum drag reduction of 47% with concentration of only 40 ppm in the pipeline was observed. The result showed a maximum drag reduction that is accompanied (in most cases) by a change to a stratified pattern for which the concentration of drops in the gas phase is zero or close to zero.

Al-Sarkhi and Soleimani (2004) conducted a series of experiments to investigate the effect of drag reducing polymer on two phase flow pattern in a horizontal 2.54 cm pipe. The characteristics of two phase flow with and without drag reducing polymers were described. It is noted that the interfacial shear stress decreases sharply by adding polymers and flow pattern map is changed.

Sarkhi and Soleimani (2004) studied the addition of drag reducing polymers alters flow pattern transition. By the additional of small amounts of drag reduction additives to the fluid flowing in multiphase fluid, it showed that the added substance lead to the decrease of turbulent frictional drag in pipelines. It has been noted that the pressure drop reduction occurs in almost all flow pattern configurations. Most importantly, the maximum drag reductions occur when there is a change from annular flow to stratify.

2.4.2 Drag Reduction by Fibers

Fibers are long cylinder-like objects with high length to width ratio. They orient themselves in the main direction of the flow to reduce drag. Several studies have been undertaken to investigate the effect of fiber on the turbulent friction in fluids flow (Lin Kerekes and Dougles 1972; Hoyt, 1972). The phenomenon of dag reduction in turbulent fibers suspension has simulated considerable interest in recent years and it plays a significant importance to the papermaking industry.

According to Duffy et al., (1976), the fibers in suspension interact and entangle at low populations. It then forms 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.

Abdul Bari et al., (2009) proved that the solubility condition for any material to be classified as drag reducing agent is not a dominating factor. They also clarified that drag reducing fibers are the safest and cheapest drag reduction agent compare to surfactants and polymers which some of the surfactants caused problem to the environment in high consumption

Lee et al., (1974) studied turbulent drag reduction in homogeneous mixture of polymeric solution and fibers. Their results indicated a maximum drag reduction of the order of 95%. They further observed that the polymer possesses the ability to augment the drag reduction of the fiber suspension, although by itself it may not result a reduction of the drag. The addition of fibers to a degraded polymer solution has been found to have a high percentage drag reduction more than use degradation polymer alone.

Mevis and Metzr (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 modifies the entire turbulence in a direction that could lead to a reduced level of radial momentum transfer to give drag reduction.

Lin et al., (2006) who studied on the distribution of fiber suspension made a conclusion that with suspended fiber, the flow rate is higher compared to the one without at the same pressure drop in Newtonian fluid. The lower relative turbulent intensity and the Reynolds stress in the fiber suspension prove that the fibers can suppress the turbulence.

2.4.3 Drag Reduction by surfactants

Drag reduction by surfactants is usually explained by the surfactant's ability to form long, cylindrical micelles, which are often called wormlike or threadlike micelles. 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. Figure 2.2 shows a typical representation of structure of a surfactant. Surfactant molecules form micelles that are thread-like under conditions such as high concentrations or the presence of certain counterions. A small amount of a certain kind of surfactant causes very marked drag reduction in a pipe flow (Gyr and Bewersdorf , 1995; Zakin et al., 1998).

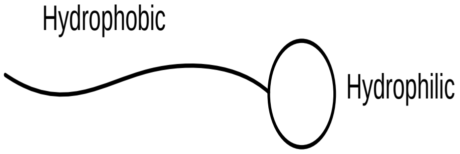

Figure 2.2: Particular type of molecular structure of a surfactant

A number of authors have stated that the existence of thread-like micelles is necessary for surfactants to be drag-reducing. Variations in the structure and quantity of the quaternary ammonium surfactant and the counterion have major effects on micellar structure. When the surfactant forms micelles, the positive charges of the head groups of cationic surfactants are closely packed on the micelle surface and tend to repel each other. (Lu et al., 1997a, b, 1998).

According to Yu et al., (2004), the long life characteristics surfactant can be used as promising drag reducer in district heating and cooling system.

The surfactant additives dampen the turbulent vertical structures which decrease the turbulent shear stress and frictional drag.

Lin et al., (2000) gave the first example of a drag-reducing yet nonviscoelastic dilute surfactant solution. This system was non-viscoelastic only in the case of excess counter-ion concentration. For lower counterion/surfactant concentration ratios their system was both drag reducing and viscoelastic. Lin et al. concluded that the threadlike micellar microstructure, which is generally believed to be necessary for drag reduction, is apparently unchanged due to the excess counterions.

H.A Abdul Bari and R.B. Mohd Yunus et al., (2009) investigated the effect of addition small amount of Sodium Lauryl Ether Sulphate (SLES) surfactants and solid particle into the transported kerosene. Their experiment shows that percentage of drag reduction is increase by increase the suspended solid particle concentration, suspended particle size, surfactants concentration and solution velocity.

Chara et al., (1993) found higher-level streamwise flow fluctuations near the wall in a surfactant solution pipe flow than those of water flow, though the radius flow fluctuation was reduced. Itoh et al., (1997) also reported that high-level streamwise fluctuation exists in a surfactant solution duct flow and that low streak structures of surfactant solution flow in the near-wall region become larger than those of water flow.

Kawaguchi et al., (1996) reported an interesting flow structure observed in a surfactant solution flow. The turbulent shear stress in a measuring cross section of a surfactant solution flow becomes almost zero and the viscous stress exists only in the near-wall region, though high-level velocity fluctuations can be observed.