HEAT TRANSFER PERFORMANCE WITH SURFACTANTS AS ADDITIVES

SHAREEN SALWAM

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering (Gas Technology)

Faculty of Chemical & Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

JANUARY 2014

ABSTRACT

Technology of pipeline drag reduction has been advanced for many years. It has improved in increasing the pipeline flow potential in crude oil transportation. In the pipeline system, surfactant solutions that caused drag reduction are capable in lowering the pumping power. In this research experiment, photosensitive cinnamate group derivative compound and polymer surfactant as drag reducing agents were chosen mainly to study on the effect of photosensitive surfactant on the drag reduction and heat transfer performance and also the effect of ultraviolet light irradiation on the heat transfer and drag reduction ability of the surfactants. Water was used as the working fluid in this research and the main equipment used was Rotating Disk Apparatus. Combination of these compounds formed viscoelasticity solution. In this research experiment, rheological measurements, drag reduction and heat transfer reduction percentages were evaluated. In conclusion, these viscoelasticity solutions have a higher drag reduction percentages at higher rotational speed after ultraviolet irradiation. Lower heat transfer reduction percentages were analysed for pure photosensitive cinnamate group derivative after ultraviolet irradiation and polymer surfactant solutions hence, indicated that both solutions are good thermal conductor.

ABSTRAK

Teknologi pengurangan seretan dalam saluran paip telah pun berkembang selama bertahunan. Ia mengingkatkan potensi pengaliran saluran paip dalam pengangkutan minyak mentah. Cecair surfaktan yang berpotensi mengurangkan seretan boleh menurunkan kuasa pengepam dalam sistem saluran paip. Dalam eksperimen penyelidikan ini, komponen fotosensitif kumpulan cinnamate terbitan and surfaktan polimer sebagai ejen pengurangan seretan telah dipilih untuk mengkaji tentang kesan surfaktan fotosensitif terhadap prestasi pengurangan seretan dan pemindahan haba dan juga kesan penyinaran cahaya ultra-ungu terhadap keupayaan surfaktan yang mampu menyebabkan pengurangan seretan dan pengurangan pemindahan haba. Air digunakan sebagai cecair dalam kajian ini dan peralatan utama yang telah digunakan ialah Peralatan Cakera Memusing. Gabungan sebatian ini membentuk cecair likat-kenyal. Ujian reologi, peratusan pengurangan seret dan pemindahan haba telah pun dinilai. Kesimpulannya, cecair likat-kenyal ini mempunyai peratusan pengurangan seretan tinggi pada kelajuan putaran yang lebih tinggi selepas penyinaran ultra-ungu. Peratusan pengurangan pemindahan haba yang lebih rendah telah dianalisis untuk kedua-dua cecair tulen fotosensitif kumpulan cinnamate terbitan selepas penyinaran ultra-ungu dan cecair surfaktan polimer, oleh itu, kedua-dua cecair menunjukkan konduktor haba yang baik.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACA	Sodium salt of 4-phenylazo benzoic acid
CMC_{II}	Second critical value
cmc	Critical micelle concentration
D	Diameter of the pipe
D_i	Inner tube diameter
f	Measured solution friction function
f_s	Solvent friction function
h_i	Inner tube heat transfer coefficient
K	Heat conductivity
L	Pipe length
LDV	Laser-Doppler velocimeter
Nu	Solution Nusselt number
Nu_s	Solvent Nusselt number
Nu_{water}	Nusselt number of the water
$NI^{measured}$	Measured first normal stress difference
$NI^{corrected}$	Corrected first normal stress difference
OHAC	Cationic surfactant oleyl bis(2-hydroxyethyl) methyl ammonium chloride
OMCA	Trans-ortho-methoxycinnamic acid
PIV	Particle image velocimeter
Q	Volumetric flow rate
R	Radius of the disk
Rc	Radius of the cone
Re	Reynolds number
T_s	Torque value achieved for mixture of solution
T_w	Torque value achieved water
V	Telocity of the fluid
V_m	Mean flow velocity
% DR	Drag reduction percentages
% HTR	Percentage of heat transfer reduction
ΔP	Pressure drop
P	Fluid density
μ	Viscosity of the fluid
ω	Rotational speed of the disk
$\mathrm{\omega}$	Angular velocity

CHAPTER 1

INTRODUCTION

1.1 Background of study

Drag reduction is an occurrence where particular amount of drag reducing agent (DRA) for instance surfactant, fiber or polymer are added to the flow of solution that will cause dramatic frictional drag reduction (Li et al., 2008). In the industrial application, the effect of drag reduction is very significant as it is favourable in the pipeline systems. In turbulent pipeline flow systems particularly, size of the pumps and energy consumption can be decreased as well as an increase in the flow rate and pumping power can also be saved by DRA addition. Viscoelastic behaviour is observed in the DRA solution flows.

Toms reported about drag reduction effects in the turbulent flow systems using additives in 1948. Addition of low concentration fibrous suspension in the turbulent flow caused reduction in drag compared to the pure solvent turbulent flow and which this is known as Toms Effect.

Formation of micelles by the surfactants in aqueous solutions described the drag reduction where the turbulence intensity is decreased (Toms, 1949). The hydrophobic molecular chains of the surfactant move together while the hydrophilic part form micelles surface as this phenomenon can reduce the unfavourable hydrocarbon-water interface.

Polymers are not appropriate as a DRA in circulating fluid systems such as district heating and cooling due to their degradation by the pumps. On the other hand, capability of forming long cylindrical micelles by the surfactants known to provide persistent drag reduction. The micelles are thermodynamically stable within a range of temperature enabling it to form back if they are interrupted by high shear forces in pumps or valves. The duration is short for the reformation of the micelles even in hot water. Effective heat transfer can takes place in the heat exchanger during this duration as the flow is in turbulent flow (Gasljevic et al., 1998; Wollerstrand et al., 1997; Gasljevic et al., 2001).

1.2 Problem statement and motivation

In the pipeline transportation, drag and skin friction phenomena occur due to the interaction between the fluid and the skin of the body which is the dampened surface. Skin friction happens in the boundary layer near the solid surfaces while turbulence friction happens to the bulk flow of the fluid which eventually decreases the flow rate of the fluid. Higher energy is required to transport the fluid if the flow velocity is higher significantly increases the friction (Shenov, 1984). High polymers and surfactants are the two most classes that used as DRAs (Knight, 2009). Under high shear stress, high polymers will undergo permanent degradation, unlike surfactants after experienced duration of high shear stress, they can actually restore themselves by flat pack, and hence surfactants are selected in recirculation systems as drag reduction agents.

In the heat exchanger, efficiency of heat transfer performance is observed to be lower for drag reducing flows. Measurement on the combination of surfantants solution of heat transfer characteristics has been done and the correlation between momentum and heat transfer was unacceptable because heat transfer reduction rate was detected to be higher than drag reducing rate (Usui and Saeki, 1993). Steiff et al.,(1998) noted that precise consideration had to be given on the influence of drag reducing additives on heat exchangers and recommended on the improvement of the heat exchangers behaviour.

In the previous studies, light-responsive threadlike micelles forming surfactants have been used as drag reducing fluids. Fluids that response upon light irradiation is known as photorheological fluid and the rheological property of the fluid such as viscosity is altered. Cinnamic acid derivative and surfactant containing fluid was irradiated with ultra-violet (UV) light where the viscosity of the fluid had adjusted (Lee et al., 2004). The effect of photorheological by the UV light showed that changes in sizes of micelles in the water. Due to the complication between the chains, long cylinders, also known as wormlike micelles, high viscosity of the fluid produced, while spherical or short cylindrical micelles gave a low viscosity. The length of the micelles can be modified by light irradiation.

Recently, heat-transfer properties of drag reducing micellar solutions have been introduced by Shi et al.,(2011). The solution contained cationic surfactant and photoresponsive organic derivative which in a trans-isomer form. These solutions formed numerous threadlike micelles, originally, that was in high viscoelasticity and had high drag reducing properties up to 75%. Photoisomerisation of trans to cis of the solution happened upon UV light irradiation before it enter the heat exchanger. The length of threadlike micelles decreased, thus lowered in viscoelasticity and drag reducing properties causing the fluid to perform effective heat transfer properties. This process is irreversible upon UV light irradiation.

A photoreversible micellar solution has been improved by Shi et al.,(2012) for district heating or cooling systems by using aqueous solution of cationic surfactant and also trans form of azobenzene derivative. In pure water, this solution exhibited viscoelasticity and drag reducing properties up to 80%, conversely lack in heat transfer properties. Before the solutions enter the heat exchanger, under UV light, photoisomerisation of azobenzene group of the solvent occurred from trans to cis as it gained effective heat transfer properties caused by the formation of shorter cylindrical micelles. This process is reversible upon visible light irradiation at the exit of the heat exchanger.

Azobenzene group however is thermally unstable. Generally, photochromic variations will be caused by azobenzene group in the visible range. Even at room temperature, transformation of cis-form of azobenzene group to trans-form will take place. To overcome this issue, studies have been done on the sensitivity of the photochromic cinnamate derivatives. In this research, polystyrene sulfonate, sodium salt (PSS) as polymer surfactant and methyl trans-cinnamate (MTC) are used, as cinnamate group is known to be responsive to UV-Visible light irradiation.

1.3 Research objective

The objectives of the research are:

1. To investigate the effect of photosensitive and polymer surfactants on the drag reduction and heat transfer performance.
2. To investigate the effect of UV light on the heat transfer and drag reduction ability of the surfactants.

1.4 Scope of research

The scopes of study are:

1. Examine on the viscosity of solutions by using Brookfield viscometer.
2. Determine and evaluate the torque values observed for different mixture of solutions from Rotating Disk Apparatus (RDA) by using Thinget Servo software.
3. Analyze the temperature readings difference of heat transfer as RDA used as the temperature regulating system.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter basically contains reviews on previous studies related to effective drag reduction and heat transfer reduction. Firstly, here are discussions on types of fluid flow, drag reduction, drag reducing agents and heat transfer reduction for a better understanding on the current studies. Photoresponsive materials are then also discussed in detail.

2.2 Types of fluid flow

Fluid movement in the pipeline system is classified into three types, namely, laminar, transitional and also turbulent flow. The factors that affect the fluid flow characteristics can be summarized and is expressed in the ratio of inertia forces to viscous forces within the fluid in which it is known as Reynolds number (Re).

$$Re = \frac{\rho V D}{\mu} \tag{2-1}$$

Where,

V = velocity of the fluid (ms^{-1})
D = diameter of the pipe (m)
ρ = density (kgm^{-3})
μ = viscosity of the fluid (Pa.s)

Fluid flows are laminar if the Re is less than 2000 and is turbulent if above 4000. The flow is in transition when the Re is in between 2000 and 4000.

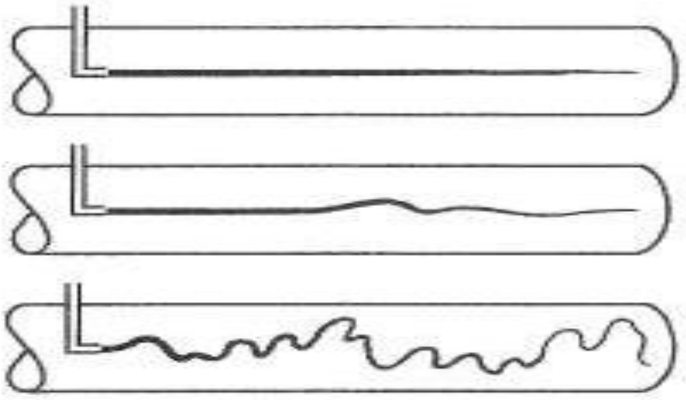

Figure 2-1: Types of fluid flow

Laminar flow which is also known as streamline flow is a type of flow in which the movements of the fluid is smooth or in regular paths and there are no changes with time in the applied boundary conditions as the flow is steady. The fluid properties such as velocity and pressure are remained constant in this flow. When the flow channel is small and the viscosity of the fluid is relatively high, laminar flow is observed in the stream.

Besides that, transitional flow is the mixture of laminar and turbulent flows. This flow type can either change to laminar or turbulent flow. The stability of laminar flows to minor disturbances is reflected as the primary cause of the transformation from transition to turbulence as it is related with sheared flows. Fundamentally, even with constant imposed boundary conditions, this movement becomes unsteady. The flow properties eventually differ in a random and untidy way. At this point, the flow turns to turbulence.

While in turbulent flow, the fluid movements are irregular fluctuations and mixing as the velocity is not constant at any point both in direction and magnitude with time. It also has eddies and current across the cross section of the pipe that rapidly interchange. It is a three dimensional and rotational movement of fluid. Turbulent flow is distinguished by high flow velocity, heat, mass transport and low viscosity characteristics of the fluid due to the turbulent diffusivity. Since the flow pattern of this flow is random and promotes dispersal of velocity fluctuation throughout the fluid surrounding then the involvement is achieved by diffusion. von Karman noted that this type of flow can be created by the fluid flow across solid surfaces or at different velocities by the flow of the fluids layers over one another known as wall Turbulence and free Turbulence respectively. Development of higher shear stresses can occur throughout the fluid if the stress and velocity randomly change with time. This can be the reason of irreversibility or losses as it also develop higher internal energy of the fluid at the outflow of the kinetic energy of turbulent.

2.3 Drag reduction

Reduction of turbulent flow friction phenomenon of a fluid in a pipeline system by adding minor amount of additives is recognized as a drag reducing process. Gadd reported the first drag reduction that caused by surfactant solutions (Gadd, 1996). The main intention to progress the fluid mechanical efficiency is via DRAs. The DRAs were chosen by combining certain cationic surfactants with an appropriate counter ion. In fact, drag reducing effects also shown by some of the non-ionic surfactants. Rod-like micelles are formed by the drag reducing surfactants and their respective cumulative might be exist in the solution. These cumulative rod-like micelles formed network with turbulent current, hence drag is reduced (Shikata et al., 1988). Mechanical deprivation happens to these networks in high shear rate areas, which later cured in lower shear stress areas like in flow through pipes. In the closed-loop district heating and cooling systems, drag reducing surfactants are reflected as an effective way to decrease the pumping power.

Since in the earlier years, many researches have been done to study on the reduction mechanism and ways to overcome it (Knight, 2009). The pressure loss of the solution flow is estimated by calculating the Fanning friction factor, f first in order to calculate the amount of the drag reduction.

$$f = \frac{\Delta PD}{2\rho LV^2} = \frac{\pi^2 D^5 \Delta P}{32\rho LQ^2} \tag{2-2}$$

Where,

ΔP = pressure drop

D = pipe diameter (m)

ρ = density (kgm^{-3})

V = mean flow velocity (ms^{-1})

L = pipe length (m)

Q = volumetric flow rate ($m^3\ s^{-1}$)

The percentage of drag reduction (% DR) is stated as

$$\%DR = \frac{f_s - f}{f_s} x100\% \qquad (2\text{-}3)$$

Where,

f_s = solvent friction function

f = measured solution friction function

By using the von Karman or Prandtl-Karman, the solvent friction factor is obtained.

$$\sqrt{f} = 4.0\log\left(Re\sqrt{f}\,\right) - 0.4 \qquad (2\text{-}4)$$

Where,

Re = Reynolds number

2.4 *Drag reducing agent (DRA)*

The DRA that have been added to the flow of the pipelines can increase the production rate as well as decrease the pumping cost and the corrosion rates in pipelines. According to Jubran et al., (2005), benefits of DRA are reduction in pressure with the subordinated reductions in pressure surge and pipe thickness, pumping power can be saved, improved pipeline capability, and also decreased in the design phase of the pipe diameter and the number or pumping facilities size. The advantages of DRA are momentarily avoiding the capital cost of the new pumping installations and short time implementation (Jubran et al., 2006). The diameter of the pipe, temperature, fluid viscosity and presence of water and or paraffin can affect the DRAs performance. The performance can be evaluated by using the effectiveness which is defined as

$$\text{Effectiveness } (\varepsilon) = \frac{\Delta P_{without\ DRA} - \Delta P_{with\ DRA}}{\Delta P_{without\ DRA}} \qquad (2\text{-}5)$$

There are mainly two types of DRAs namely polymer and surfactant.

2.4.1 *Polymer*

Monomers are smaller chemical units that repetitively join together covalently to build a large macromolecule known as polymer through a process of polymerization. Polymers are characterized in many forms based on the different distribution of monomer units in the polymer chain (Goddard and Ananthapadmanabhan, 1993). In nature, polymers are abundantly to be found. Protein and nucleic acids are natural polymers that present inside human body. Polysaccharide and cellulose are other natural polymers that exist in structural component of plants. Synthetic polymer is produced by addition or condensation process, each combined monomers will produce water during each reaction as a byproduct. Examples of synthetic polymers are plastic and adhesives.

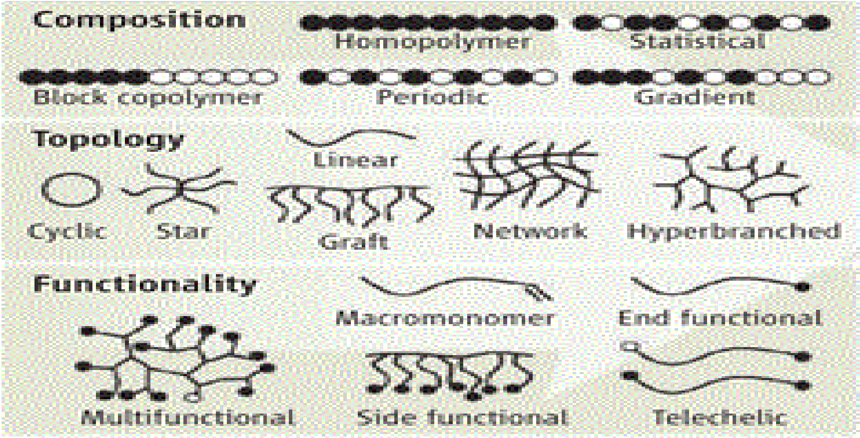

Figure 2-2: Types of polymer

The addition of poly(methyl methacrylate) to the solvent monochlorobenzene by Toms in 1948, showed that the combined fluid experienced in less resistance to the flow compared to the pure solvent (Prajapati, 2009). Reduction of the turbulent flow can be achieved as much as 80% equivalent to maximum drag reduction asymptote by addition of very small concentration (ppm level) of long chain, flexible polymer to a solvent (Virk, 1975) where the friction factor decreases below ordinary Newtonian turbulent flow. No drag reduction is observed at Reynolds number less than the onset value.

When more concentrated polymer solution is added, drag reduction happens by extension of the laminar region. This means that no laminar-turbulent transition is noticed and the friction factor is lower than the ordinary Newtonian turbulent flow at the same Reynolds number as the laminar like behaviour is dragged to an extended laminar region. As the critical wall shear stress is reached, the drag reduction increased with flow rate (Patterson et al., 1969 and Hoyt, 1986). At this point the rate of degradation of the polymer happens, higher than the polymer is replenished in the wall region, thus no longer effective drag reduction.

Basically, as polymer concentration increases until a definite concentration is achieved, the drag reduction also increases at a constant velocity. This concentration is known as saturation concentration. Drag reduction will fall if the polymer concentration is above the level of saturation concentration (Goren and Norbury, 1967 and Kenis, 1971). Damping of more turbulent eddies is caused by the increasing number of polymer molecules as the concentration increases which increases reduction of drag also. When the fluid reached saturation concentration level, drag reduction is reduced due to the increase in the solution viscosity.

When polymer is added to the turbulent flow in pipeline, the polymer chain is been stretched by the high shear state of the turbulent flow itself. Due to this, the effective viscosity in the buffer layer of turbulent flow is increased by increasing elongational viscosity (Hinch, 1977 and Metzner and Metzner, 1970). According to Lumley (1973), reduction in the wall friction will cause the buffer layer thickness to increase. Thus, the streamline fluctuation is disturbed causing modification of velocity profile and re-dispersion of the shear in the boundary layer. The idea of elastic energy storage was introduced by Tabor and de Gennes (1986) where the partially stretched polymer molecules are used as critical part in drag reduction. The transformation of elastic energy, stored by these partially stretched polymer molecules, to kinetic energy is observed in the buffer layer of turbulent flow, hence drag is reduced (White and Mungal, 2008).

Based on Yang and Duo (2008) report, the coherent turbulent structures in drag reducing flows has been studied and informed by using advances in instrumentation and visualization techniques for better understanding of turbulent arrangements in the drag reducing flow. The experiments were done by using laser-Doppler velocimeter (LDV), particle image velocimeter (PIV) and visualization methods. The measurement of polymer drag reducing flows were stated by Rudd (1972), followed by Reischman and Tiederman (1975), then Berner and Scrivener (1979) and Berman (1986). In this measurement observation had been done on the velocity fluctuation and energy spectrum in streamline direction. As a result, the root mean square of streamline velocity in drag reducing flows is slightly higher than that in Newtonian fluid flows and from high frequencies to low frequencies, the energy is redistributed.

From the experiments results, decreased in the fluctuation in the wall normal direction caused drag reduction, hence, the Reynolds shear stress is decreased. The total shear stress of the fluid without the presence of polymer reducing agents is higher than the sum of Reynolds shear stress and viscous shear stresses. Intensely inhibition of all frequency by the energy of the normal velocity component was found by Wei and Willmarth (1992) and redistribution of the frequencies from higher level to lower level is observed.

Moreover, study on the influence of polymers on the streak spacing, bursting frequency and Reynolds shear stress have been done by using flow visualization technique. In the near wall region, the velocity field varies during a burst which could expose the mechanism of the drag reduction and can explain the basic turbulent structures relationship. The effects of the polymers on structure of turbulent have learnt by using visualization method. The report showed that there are difference in the streaking spacing and bursting rates in drag reducing flow compared to the Newtonian flow (Donohue et al., 1972). The viscous sub layer was more stable when polymer solutions were present and as the drag reduction increased, the average non dimensional spacing between streaks also linearly increased. However, in these experiments, the method for assuming the time between the bursts was not precise due to the lacking of the measurements correspond to the turbulent velocity (Luchik and Tiederman, 1988).

Researches have been done to overcome this problem by using PIV that could afford quantitative measurement information of the effect of the polymer additives on the near wall turbulent structures. Decreased in the created turbulence by the wall is observed that caused drag reduction when PIV is applied to a channel flow with polymer additives (Warholic et al., 2001). A reduction in the number and strength of near wall vertical structures and a coarsening of the low speed velocity streaks, resulting in the significant changes of the near wall structure of turbulence have been studied when PIV is used in a drag reducing flat plate boundary layer flow (White et al., 2004).

Still, polymer especially high molecular weight polymers can easily degrade permanently when exposed to high shear or extensional stress (Patterson et al., 1969). As the molecular weight increases, the rate of mechanical degradation also increases. This very reason made sure that polymers are not applied in recirculation system where high shear stresses in pumps irreversibly damage the high molecular weight polymers.

2.4.2 Surfactant

Surfactants have the capacity to absorb at surfaces and interfaces as they are surface active agents (Prajapati, 2009). The amount of reduction in surface tension of water can be determined by the surface density of the surfactant molecules. By adding the surfactant, the surface tension of the solvent stopped lowering as the molecule starts to form micelle in the bulk solution. Critical micelle concentration (cmc) defined as the concentration at which micelles begin to appear. According to Wang et al., (2011), micelles are forced to move nearer to each other if the concentration rises. Due to the electronic repulsions, the system energy is increased. The micelles then tend to form non spherical shapes in order to maintain the system energy at lower energy level when the concentration reaches a second critical value (CMC_{II}). Formation of vesicles or dislike shapes will occur in some cases and they tend to create long cylindrical shapes known as rodlike or wormlike micelles.

The surfactant molecules form worm-like micellar structures in turbulent flow if the surfactant concentration is relatively higher than the critical micelle concentration and also if the temperature of the system is greater than the critical micelle temperature. The Krafft temperature which is also known as critical micelle temperature is the minimum temperature at which surfactants form micelles. Due to this, the properties of the solvent are altered and the solution shows viscoelasticity behaviour.

By definition, micelle is an accumulation of surfactant molecules that disperse in a fluid. A surfactant body consists of hydrophilic head and hydrophobic tail. Micelles form when the hydrophilic head regions move towards one another in contact with the surrounding solvent, isolating the hydrophobic tail regions in the center, which this occurrence is known as normal phase micelle. Conversely, when the hydrophilic head regions move towards the center of the micelle and the hydrophobic tail regions are spreading out, inverse micelles formation occur. The factors namely concentration, temperature, pH and ionic strength of the surfactants will determine the shape and the size of a micelle.

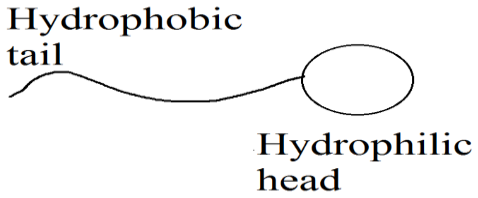

Figure 2-3: Schematic of a surfactant molecule

There are three main types of surfactants namely, anionic, nonionic and cationic surfactants. Anionic surfactant is most commonly used surfactants. This surfactant has negatively charged group on its hydrophilic part, like sulphonate, sulphate or carboxylate. Anionic surfactants are used to make basic soaps. It is sensitive to hard water.

Besides that, nonionic surfactant is basically made of non-charged hydrophilic by polycondensation of ethylene oxide in the presence of a polyethylene chain. It is suitable for cleaning purpose and is not sensitive to hard water.

If the hydrophilic part of the micelle is positively-charged, it is known as cationic surfactant. It cannot be used for washing purpose but will speed up to the surfaces where they might give antistatic, soil repellent, softening and anti-bacterial or corrosion inhibitory effects.

Drag reduction by surfactants has been observed and there are three theories about it. The mechanisms revolve around the area of dampening turbulent swirl currents and cross directional flow, hence energy loss is lessened. At the first stage, when the surfactant is added to the solvent, it will form rod-like micelles that become entangled.

These formed micelles have elastic properties which can delay the cross flow (Fontaine et al., 1999).

An increased in the extensional viscosity is noticed that caused by the structural micelles at second stage. This is accountable for the dampened eddy effects (Shenoy, 1984).

Lastly, elongation of these micelles happens in the direction of the flow causing the viscous sub layer of the flow to be thickened. The cross directional flow and eddy currents are then be in conflict with the thickened sub layer (Kostic, 1994).

Anionic surfactant as drag reducer needs a very high concentration about a few thousands ppm to perform, but this will eventually give problems to the environment and also leads to large costs. This surfactant will form foam with air in the aqueous solution (Radin et al., 1969 and McMillan et al., 1971). Anionic surfactant is not suitable most aqueous applications because they are sensitive to calcium and magnesium ions exist in most tap water which results in precipitation. It is to be found that in water the drag reduction was highly lost when the critical shear stress present for these surfactants. The drag reduction was fully obtained after the shear stress was lowered below the critical, unlike the polymer drag reducers which permanently degrade under high shear stress, noted by Savins.

Since nonionic surfactants do not carry any charges, they are less affected by the other ions. Nevertheless, only in a narrow temperature range around their cloud point, nonionic surfactants will show reduction. Straight chain alkyl groups of nonionic surfactant are found to be effective by Zakin and Chang (1985) as at temperatures around cloud point, 1% concentration of nonionic surfactant of some mixture proved to be effective drag reducers. The mixtures had the chemical structure of C18H35-(OCH2-CH2)*n*-OH. Addition of a multivalent salt such as sodium sulfate can cause the cloud point to be lowered or by decreasing the value of n. Thus, the temperature of the drag reduction can be lessened to the temperature below the cloud point.

While surfactant that has both positive and negative charges in the head group is known as a zwitterion surfactant. The difference between the charges caused the presence of dipole moment in the head group.

Furthermore, for cationic surfactant, the alkyl chain length is dependence by the upper temperature limit for effective drag reduction. Recover of the drag reduction can be achieved when the temperature is decreased below the upper critical temperature level. The lower temperature limit is influenced by the solubility of the surfactant (Rose and Foster and Chou et al.,). At low temperature, the solubility of long chain surfactants improved by unsaturation of the alkyl chain, hence, drag is reduced (Rose and Foster and Rose et al., and Chou et al.,). Studies had been done on the drag reduction effectiveness of mixed cationic surfactant systems (Chou and Zakin and Lu et al.,). The results obtained shows that for short chains cationic surfactants, the effective drag reduction temperature range is at lower temperatures while for long chains, the drag reduction temperature range prolongs to higher temperatures. When the long chain and short chain surfactants are mixed together, the temperature range can be extended. By doing this, the lower temperature limit of the long chain surfactant can be lowered while there will be only slightly decreased in upper temperature limit. Therefore, this type of surfactant is suitable for both heating and cooling as it has extensively ranges of temperatures (Chou and Ge and Ge et al.,).

2.5 Heat transfer reduction

In crude oil pipelines that use DRA, heat loss to the atmosphere can be kept at minimum level while maintaining the flow of the oil at lower pumping power. Thus, thermal insulation cost of the pipelines can be declined (Jubran et al., 2007).

Research on the heat transfer, drag reduction and fluid characteristics for turbulent flow polymer solution in pipes has been done by Matthys (1991). In the presence of the drag reducing agent, the problem of the decrease convective heat transfer is studied. Major reduction happened in the convection heat transfer caused by the addition of the DRAs as drag is decreased. The main reason of this situation is lack of studies on the polymer solutions heat transfer to the viscoelastic flows complexity. He also mentioned that the macroscopic and correlation work were available for purely viscous non-Newtonian fluids but not for viscoelastic non-Newtonian fluids with presence of drag reducing agents in the flows.

Drag reducing solution is capable in heat transfer reduction as well (Knight, 2009). The micelles that formed are in viscoelasticity state and are believed to be responsible of thermal resistance between the fluid and the wall that has been part of the heat transfer mechanism. The percentage of heat transfer reduction (% HTR) is stated as

$$\% \text{ HTR} = \frac{Nu_{s-}Nu}{Nu_s} \text{ x } 100\ \% \qquad (2\text{-}6)$$

Where,
Nu_s = solvent Nusselt number
Nu = solution Nusselt number

The Nusselt number for the flow in tubes is calculated by using the following equation.

$$Nu = \frac{h_i D_i}{k} \qquad (2\text{-}7)$$

Where,
h_i = inner tube heat transfer coefficient ($Wm^{-2}.K^{-1}$)
D_i = inner tube diameter (m)
K = heat conductivity ($Wm^{-1}.K^{-1}$)

There will be minor insulation has to be utilized on the oil pipelines if DRAs are added to the flow as the oil needed to be heated so that it can turn into less viscous compound, hence the flow will be smooth. At times, in district heating and cooling systems, heat transfer is essential for the system to be functioned properly. A central location is used in this system to heat or cool a primary flow loop of water, which later as it exchange heat with a secondary flow loop of water, then pumped to the neighboring buildings.

The individual building is heated or cooled using this secondary flow loop, it is housed in. Larger heat transfer area is needed when the operating or capital cost is reduced due to the drag reduction, resulting declination of higher reduction in heat transfer. The main motive that cause this system to develop in Europe and United States for decades is waste heat energy from electrical power generation plants is used to heat the primary water used for circulation. The need for single heating and cooling units are eliminated