INVESTIGATION THE EFFECT OF CATIONIC SURFACTANT ON HEAT TRANSFER PERFORMANCE IN HEAT EXCHANGER

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ABSTRACT

Drag reducing surfactant fluids are known to suffer from heat transfer capabilities in recirculating system. In this experiment, the main purpose is to investigate the effect of cationic surfactant flow parameter on heat transfer performance in heat exchanger. In the present research, Cetyltrimethylammonium bromide (CTAB) was tested with concentration level of 500 ppm, 1000 ppm and 1500 ppm at 50ºC, 60 ºC and 70 ºC temperature for each concentration level. The experimental result showed that, temperature and concentration effect the heat transfer performance of the CTAB surfactant. At concentration of 1500 ppm, highest heat transfer obtained at temperature of 50ºC. The same results were obtained at temperature of 60ºC and 70ºC with corresponding concentration value of 500 ppm and 1000 ppm. The results also showed that the heat transfer rate with existing of UV light upon cationic surfactant flow enhance the heat transfer rate with 11% increase at 50°C with 1500 ppm, 6% increase at 60°C with 500 ppm and 5% increase at 70°C 1000.

KAJIAN TERHADAP KESAN SURFAKTAN KATION PADA PRESTASI PEMINDAHAN HABA DALAM PENUKAR HABA

ABSTRAK

Cecair pengurangan seretan surfaktan diketahui mengalami kekurangan keupayaan pemindahan haba dalam sistem edaran semula. Dalam eksperimen ini, tujuan utama ialah untuk menyiasat kesan parameter aliran surfaktan kation di dalam prestasi pemindahan haba dalam penukar haba. Dalam kajian menunjukkan, Bromida Cetyltrimethylammonium (CTAB) telah diuji dengan tahap kepekatan 500 ppm, 1000 ppm dan 1500 ppm pada suhu 50ºC, 60ºC dan 70ºC untuk setiap tahap kepekatan. Keputusan eksperimen menunjukkan bahawa, suhu dan kepekatan memberi kesan prestasi pada pemindahan haba surfaktan CTAB. Pada kepekatam 1500 ppm, pemindahan haba tertinggi diperolehi di suhu 50ºC. Kesan serupa telah diperolehi pada suhu 60ºC dan 70ºC dengan tahap kepekatan 500 ppm dan 1000 ppm. Keputusan juga menunjukkan bahawa kadar pemindahan haba dengan kehadiran cahaya UV atas aliran surfaktan kation meningkatkan kadar pemindahan haba dengan 11% peningkatan pada 50°C dengan 1500 ppm, 6% peningkatan pada 60°C dengan 500 ppm dan 5% peningkatan pada 70°C dengan 1000 ppm.

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LIST OF SYMBOLS

T_{hi} - Temperature Hot In

T_{ho} - Temperature Hot Out

T_{ci} - Temperature Cold In

T_{co} - Temperature Cold Out

ΔT_{lm} - Log-Mean Temperature Different

LIST OF ABBREVIATIONS

DRAs - Drag reduction additives

CMC - Critical micelle concentration

PR - Photorheological

UV - Ultraviolet

(OMCA). - O-Methylo-Coumaric Acid

LMTD - log mean temperature difference

CTAB - Cetyltrimethylammonium bromide

ppm - Part per million

CHAPTER 1

INTRODUCTION

1.1 Background Study

Drag reduction is a flow phenomenon in which a reduction of turbulent friction occurs by adding small amount of additives that can greatly reduce the turbulent friction of a fluid. Several types of additives have been studied which causes this drag phenomenon to occur. These includes fiber, polymer and surfactants. From addition of these drag reducing additives (DRAs), it causes a dramatic frictional drag reduction.

The application of drag reduction is very important to industry. The first famous application of drag reducer was in transport of crude oil in trans-Alaska (TAPS or Alyeska) Pipeline in 1979. Drag reduction effects can be used to reduce the system energy consumption, increasing the flow rate and decrease the sizes of pipes and fittings in flow system such as district heating and cooling systems.

Because drag reduction is a reduction in momentum transfer, a corresponding reduction in heat transfer is also experienced by the system. Depending on the application of the drag reduced system, this can be a beneficial or detrimental side effect. In transporting crude oil, heat transfer reduction of drag reduction solutions is beneficial because crude oil need to be heated to keep them flow. This reduce the needs of heat insulation material along the pipeline. However for district cooling and heating system, heat transfer reduction is a major problem since heat exchange is very important where reduced heat transfer is harmful to the system performance. In this study, we are focus on heat transfer performance.

Generally, high polymer and surfactants are two common types of additives used as drag reducer nowadays. However, polymeric additives are susceptible to mechanical degradation makes them unsuitable for circulation system. Surfactants also suffer mechanical degradation but this degradation is temporary because surfactants have ability to repair themselves in times of the order of seconds (Yunying Qi et al.,2000). Therefore, surfactant additives are more appropriate for fluid circulating systems.

There are four common types of surfactants which are cationic, anionic, non-ionic, and zwitterionic. Cationic surfactants are positively charged and typically are effective drag reducers, but are not very biodegradable. Anionic surfactants are negatively charged, which allows them to interact with any positive ions present in solution. Non-ionic surfactants do not have a net charge, and are typically biodegradable. Zwitterionic surfactants also do not have a net charge, but they are different in that they have a positive and negative charge both present on the molecule in different regions. This research focused on testing cationic surfactants.

1.2 Problem Statement

Surfactants is one of the most suitable additives used in fluid circulating system because of their abilty to repair themselves after mechanical degradation. However, the effectiveness of surfactants drag reducer is limited to certain range of temperature and concentration. Along with drag reduction, the heat transfer ability of surfactants solutions is also reduced significantly. The heat transfer reduction must be overcome by temporarily destroying the surfactant micelle structure network. The micelles will reassemble back after leaving the heat exchanger and act again as drag reducing agent. It has been shown that the heat transfer reduction is always slightly larger than the accompanying drag reduction (Aguilar, G. et al., 1999).

1.3 Research Objectives

The main purpose of this research is to investigate the effect of cationic surfactant flow parameter on heat transfer performance in heat exchanger.

1.4 Scopes of Study

In order to achieve the objective of this study, the following scopes have been identified:

- To study the effect of surfactant concentrations on heat transfer performance.
- To investigate the effective temperature of surfactant.

1.5 Rational and Significance

In industrial scales, drag reduction is always highly concerned in the sake of power saving. However, drag reduction phenomenon effect the heat transfer performance. In some cases which is good to the system such as in pipeline and not good in recirculation system. The application of drag reducing additives (DRAs) is greatly decreasing the system energy consumption, increasing the flow rate and decrease the sizes of pipes and fittings in flow system such as fluid circulating systems. Nevertheless, a lot of study and research must be done in order to come out with effective result with optimum cost in drag reduction phenomenon. With this research, it will give benefit to recirculation system on heat transfer performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Drag Reduction

Drag reduction is a phenomenon in which the friction of a liquid flowing in turbulent flow is decreased by using a small amount of an additive. This can decrease pumping energy requirements. Some current applications where drag reduction has been applied include district heating and cooling systems and oil transmission pipelines (Zakin, Jacques L. et al.,2000). Drag reducing additives are effective because they reduce the turbulent friction of a solution. This results in a decrease in the pressure drop across a length of conduit and likewise reduces the energy required to transport the liquid.

The important aspect which give an impacts to the drag reducing additives performance is their ability to self repair (Zakin, Jacques L. et al 1998). This is the ability of additives molecules to return to its original form after its structure has been altered as a result of high shear. High molecular weight polymers degrade when subject to high shear and generally cannot reform. Therefore, they cannot be effective in recirculation systems such as district cooling systems because pumps are required to recirculate the fluid and these pumps apply high shear stress to the fluid. This causes polymer chains to break into smaller segments which do not have the ability to revert to their original form. Surfactants on the other hand are able to repair themselves in a matter of seconds upon degradation from shear. This characteristic makes surfactants a good candidate for recirculation systems.

2.2 Surfactants

Drag reduction caused by surfactant solutions was first reported by Gadd (Gadd, 1966). The term surfactant is derived from the contraction of “surface active agent”. Surface active agents interfere with the ability of the molecules of a substance to interact with one another and, thereby, lower the surface tension of the substance (Perkins, Warren S. 1998).

Surfactants are amphipathic molecules because they have a hydrophilic head group and a hydrophobic tail group shown in Figure 1. The hydrophobic head group is a polar group which is usually ionizable and capable of forming hydrogen bonds. In contrast, the hydrophobic tail group is a nonpolar group which is typically a long chain alkyl group. Due to this unique structure, surfactants show characteristic behaviors when in an aqueous solution. In aqueous systems, when the concentration exceeds a certain value, surfactants molecules gather into assemblies with their polar (head) ends headed towards water and the nonpolar (tail) headed to the centre based on the rule “like dissolves like” (Wang, Yi et al.,2011). The assemblies are called micelles.

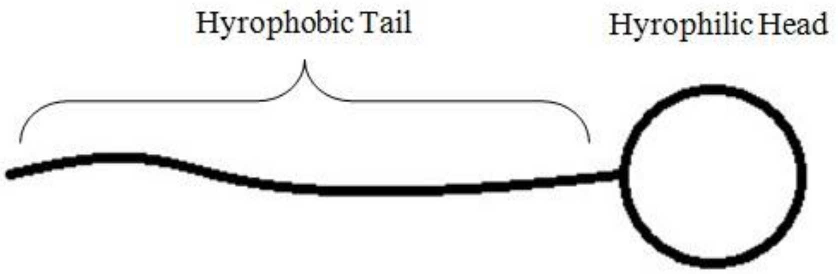

Figure 2.1: Surfactant Structure

There are several types of surfactants which are anionic, cationic, nonionic and zwitterionic surfactants.

2.2.1 Anionic Surfactants

Anionic soap surfactants are water soluble and have a negative charge when in aqueous solutions. They give good drag reduction results when the shear stress is not too high i.e. lower flow rates.However, this surfactants is sensitive to calcium and magnesium ions that present in water tap which can cause precipitation. Anionic surfactants also cause some problems when exposed to air because they have the tendency to form foam (Wang Yi et al.,2011). This can result in complications is many systems that do not have the ability to handle foam formation. Thus they have limited applicability.

2.2.2 Cationic Surfactans

Cationic surfactants, as opposed to anionic surfactants, have a positive charge when immersed in aqueous solutions. These surfactants are not affected by the metal ions in tap water as were the anionic surfactants. Cationic surfactants produce good drag reduction results over a wide temperature range. Some other positive characteristic of cationic surfactants are that they are relatively stable and they have good selfreparability (Zakin, Jacques L. et al.,1998). In drag reduction,cationic surfactants solutions is affected by 4 parameter which are the surfactants structure, counterion, concentration and temperature. For this research, cationic surfactants are used as a drag reducing agent.

2.2.3 Nonionic Surfactants

Nonionic surfactants have no charge on their head groups. These types of surfactants are stable and are able to self-repair quickly after degradation from high shear. One beneficial characteristic of nonionic surfactants is that they are readily biodegradable and less toxic than some other surfactants. However, they are generally only effective as drag reducing agents over a relatively narrow temperature range near their upper consolute or cloud point temperature.

2.2.4 Zwitterionic Surfactants

Zwitterionic surfactants have both negative and positives charges on different location of the molecules. The mixture between zwitterionic and anionic surfactants in certain ratio are most effective drag reducer. Similar to nonionic surfactants, zwitterionic surfactants are also less toxic than most and are rapidly biodegradable Other than that, this surfactants are compatible with all other class of surfactants and are soluble and effective in the presence of electrolytes, acids and alkalies. However, despite their potential as drag reducing agent, limited studies have been carried out.

2.3 Micelles Structure

Surfactants have the ability to group themselves in consistent patterns due to the hydrophobic and hydrophilic components of the molecules. The hydrophobic ends of the surfactants group themselves together when in aqueous solutions because these ends are nonpolar and repel the polar water molecules. Conversely, the hydrophilic or polar ends of surfactants are attracted to the water molecules. This causes the surfactants to form clusters called micelles.

Micelles form into several different shapes including spherical, rod-like, lamellar, and vesicles (M. J. Rosen.,1989). Typically, when the surfactants solution reach a critical concentrations,micelles are spherical or ellipsoidal in shape as shown in **Figure 2.2 (a)**. The critical concentration is called the critical micelle concentration (CMC). Upon reaching their second critical micelle concentration (CMCII), micelles may form into rod-like micelles, which are shown in **Figure 2.2 (b)**. Another method that has been used to promote the formation of rod-like micelles is the addition of salts or conterions to the solution. This disperses the positive repulsive charges on the ionic headgroups and stabilizes the micelles allowing them to grow in size (Zakin, Jacques L. et al.,1999).

In cationic surfactants systems, organic counterions promote growth of threadlike micelles (Zakin, Jacques L. et al.,1998). The threadlike shape of micelles is generally considered a necessity for drag reduction (D. Ohlendorf et al., 1984). Thus, a corresponding reduction in heat transfer is also experienced by the system which is not good to recirculation system. Heat transfer reduction (HTR) can be enhance by destroying the rod-like micellar structure at the entrance of a heat exchanger. The broken up micelle structure loses its drag reducing properties and therefore regains the heat transfer properties as it flows through the heat exchanger. This micelle structure should repair itself through self-assembly after the solution passes through the heat exchanger and regain its drag reducing capabilities again.

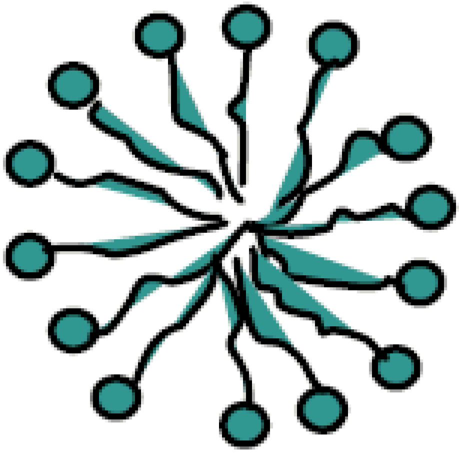

Figure 2.2 (a). Spherical micelle structure.

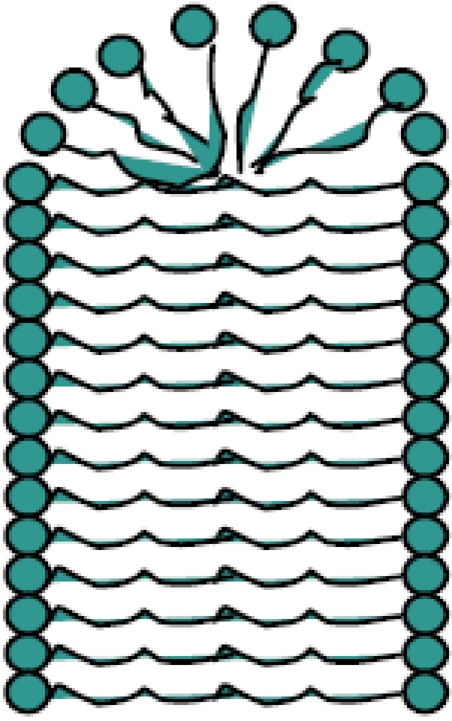

Figure 2.2 (b). Rod-like micelles.

2.4 Destruction of Micelles Structure

Temporarily alter the surfactant structure at the entrance of a heat exchanger is one method to obtain Newtonian (water like flow) behavior in order to enhance heat tranfer ability. By destroying the micelles structure, the solution loses its drag reducing behavior and regain heat transfer ability in the heat exchanger. There are five different methods to temporarily destroy the micelles structure.

The first method is by placing a pump at the entrance of the heat exchanger. High shear energy provide by the pump would temporarily destroy the surfactants micelles structure (Wang Yi et al.,2011). This method is very convenient. However, it is not always possible in existing systems and represents a significant design constraint.

The second method is to sharply increase the fluid flow velocity at the entrance of the heat exchanger. When the flow velocity of the solution through a heat exchanger reaches a certain level, heat transfer enhancement is observed (Pollert et al.,1996). Thus increasing the flow velocity of surfactant solutions at the entrance of or inside the heat exchangers so that the critical shear stress is exceeded will also destroy the micelle nanostructure.

The third method is by insertion of small destructive devices such as static mixers, honeycombs, or meshes at the entrance to the heat exchanger (Li, P. W et al.,1999). The destructive devices can generate large shear and extensional stresses on the surfactant solution to destroy the micelle nanostructure. These devices are simple, cheap, and can reasonably be installed into any type of drag reduction system. However, the pressure drop penalty may be large.

The fourth method is to use photorheological (PR) surfactants as drag reducers (Wang Yi et al.,2011). The ideal result would be to reduce drag reduction ability in the heat exchanger to enhance heat transfer and then regain their drag reduction ability at the outlet of the heat exchanger without large energy input. Recently Raghavan’s group has developed new photorheological counterions which are commercially available and relatively inexpensive (Raghavan, S. R. et al.,2007). One of their new PR counterions is the sodium salt of trans-O-Methylo-Coumaric Acid (trans-OMCA). They found the trans-OMCA/CTAB system is viscoelastic but, when the trans-OMCA is photoisomerized to cis-OMCA by irradiation with ultraviolet (UV) light, the fluid viscosity is largely reduced and viscoelasticity is lost. This is because the change in the counterion from trans to cis configuration causes micelles to rearrange into much smaller ones.

The fifth method is to use ultrasonic energy by destroying the surfactant nanostructure at the heat exchanger entrance by creating cavitation bubbles in the fluid flow (Qi Y et al.,2003). When these cavitation bubbles collapse, they can mechanically degrade the surfactant structure. While this method does not impart additional pressure drop penalties to the flow as it does not change the flow field, however, it does take a great deal of energy to breakdown the micelle nanostructure and it is difficult to transmit ultrasonic energy effectively to a large-scale flowing system (Qi Y et al.,2003).