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The Study of Glycolic Acid Ethoxylate 4-nonylphenyl Ether on Drag Reduction

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Abstract: Power saving is the major reason to study the problem of drag in transporting system. The performance of glycolic acid ethoxylate 4-nonylphenyl ether as drag reducing anionic surfactant was studied experimentally in closed loop circulation system at room temperature. The major investigated variables is operation flow rate which from 11235 to 78645 Re and the solution concentration (ppm), which 200, 300, 400, 500 and 600, respectively. The selected ratio of testing pipe length to diameter (L/D) is equal to 59. The specific conductivity test was conducted to find the CMC of anionic surfactant. It was found that the CMC occurred within the range of 100 to 200 ppm of solution. The maximum drag reduction can be achieved up to 14%. The critical Re was found at 33705 to 56175. The alignment of micelle with the eddies in turbulent flow was identified as the source of drag reduction in pipes.

Key words: Drag reduction, DRA, anionic surfactant, micelle, CMC, turbulent flow, eddies

INTRODUCTION

The study concerning drag reduction in pipes is rapidly becoming an attraction because of its capability to increase the power saving in transporting fluids through pipes. The term of drag usually refer to the mechanical force that resist the movement of fluid in transporting system and the addition a minute amount of surfactant could dramatically reduce this drag. Any chemical additives that capable to reduce the drag in turbulent flow are known as Drag Reducing Agent (DRA). For the past few years, surfactants are well known as a good DRA. Surfactants are usually organic compounds that are amphiphilic, which contain both hydrophobic groups and hydrophilic groups. Therefore, they are soluble in both organic solvents and water. The main reason of choosing surfactant as DRA is probably because of their ability to form micelle.

Lu *et al.* (1998) found that the Arquad 16-50 capable to reduce drag up to 70% and Kawaguchi *et al.* (2002) showed that the 40 ppm of CTAC surfactants capable to achieved 60% of drag reduction, while Myska and Mik (2004) proved that CTAC capable to achieve up to 72% drag reduction. The study of CTAC as drag reducing agent also mentioned in study of Kang *et al.* (2001), Zhou *et al.* (2006), Sung-Hwan (2007), Ge *et al.* (2008) and Li *et al.* (2008) found that the pressure drop is reduced by 25 to 40% in a presence of 400 ppm of drag reducing anionic surfactant, Sodium Dodecyl Sulfate (SDS). This material also mentioned by Cheng *et al.* (2007), Varade *et al.* (2007) and Duangprasert *et al.* (2008) study.

There are a lot of mechanisms been proposed in literature behind the drag reduction in turbulent flow. Li (1991) defined that the structure of polar group at one end bonds onto side inner wall of pipeline and a non-polar group at the other side smoothes the gas-solid interface between wall and flowing gas thereby reducing gas turbulence at side interface while conducting an experimental work on gas pipelines using drag reducing surfactant, oxylated fatty acid amine.

Lu *et al.* (1998) suggested that drag reduction by surfactant additive is probably caused by suppression of turbulent eddies. Extensional motions dominate in the bursting and growth of these eddies. Kawaguchi *et al.* (2002) believe the drag reducing surfactant changes the structure of turbulent flow and the mechanism of drag reduction in a presence of surfactants additive probably also occurred near the wall. Myska and Mik (2004) studied the behavior of drag reducing agent, which CTAC, Arquad SV-50, DR-0205 and SPE 98330 in term of degradation by age in a simple built up system. They believe degradation behavior of surfactants is the key to understand the mechanism of drag reduction.

In the other hand, Zhang *et al.* (2005) showed that the rheology properties and the micelle formation in drag reducing surfactant probably the key source to understand the mechanism of drag reduction in a presence of surfactants. Li *et al.* (2008) observed that the near-wall vortex structures near the walls in the drag

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reducing surfactant solution flow are changed gradually with drag reduction level and the viscoelasticity of solution. This result has a good agreement with the proposed mechanisms in surfactants solution by Kawaguchi *et al.* (2002) and Zhou *et al.* (2006). Most of the stated mechanisms agree that the micelle formation in surfactant solution damped the structure of turbulent flow and the mechanism is likely occurred near the wall.

MATERIALS AND METHODS

Anionic surfactant: Glycolic acid ethoxylate 4-nonylphenyl ether (GAENE) in liquid form supplied by Sigma-Aldrich (M) Sdn. Bhd also known as nonoxynol-8 carboxylic acid is used as an investigated anionic surfactant in this study. It is non-hazardous and contains impurities of ≤1 wt.% NaCl. The viscosity of this material is independent with the solution concentration and used as supplied. The average-number molecular weight (Mn) of GAENE is 600 and 358.47 g mol^{-1} of Molecular weight (Mw). In this present study, the transported fluid was used is water.

Closed loop system: The built up closed loop circulation system was used to study the performance of GAENE as drag reducing agent in turbulent flow. The closed loop made up from PVC pipes with diameter equal to 0.0254 m and the length is equal to 4 m including the length of testing section, 2 m. The schematic flow of this circulation system is shown in Fig. 1. This system consists of pump, tanks, flow meter and pressure gauges. T1 with maximum load 420 L used as a storage solution before the experiment begin. T2 is temporary tank for solution before the recirculation process. Ultraflux Portable Flow Meter Minisonic P used to measures the flow rate of fluid in pipe. This portable flow meter was placed about 1 m before the testing section to ensure the fluid flow rate are fully turbulent and capable to detects changes in flow rates as low as 0.001 m sec^{-1}. Baumer pressure gauges used to detect the pressure drop in pipes before and after the addition of GAENE in closed loop circulation system.

Each pipe section was completed with control valve while, the bypass pipe was used to control the flow rate in circulation system where, the fluid was pumped through the entire system by Precision pump with maximum load 6.5 m^3 h^{-1}. The discharge pipes were prepared for cleaning purpose.

The most important in closed loop circulation is the testing section which consists of three pressure gauges. Each pressure gauge was placed with a gap in length about 0.5 m.

Experimental procedure: An experimental run consisted of establishing the fluid Reynolds number (Re) with and without the anionic surfactant. For each run, the pressure drop measurement were carried out based on surfactant concentration (Vppm) at ratio of pipe length to pipe diameter (L/D) equal to 59.

The friction factor of water alone in pipes was recorded before the measurement for pressure drop with the chemical additives. This is to verify the appropriateness of the experimental system.

The investigated solution was pumped from T1 by circulation pump (P2) through entire closed loop system. The pressure drop in pipe with the addition of surfactant was conducted for 200, 300, 400, 500 and 600 ppm concentration varied with fluid Re from 11235 to 78645. Each experiment was conducted at room temperature.

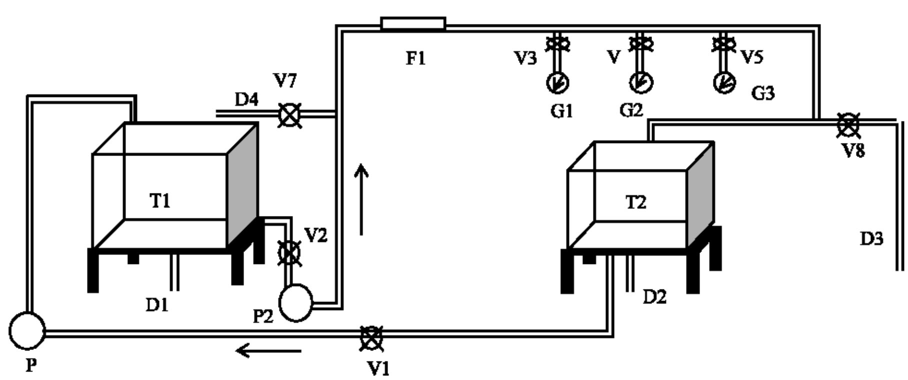

Fig. 1: The schematic of closed loop system. V1 to V7: Value, P1, P2: Pump, T1: Solution tank, T2: Temporarily tank, G1, G2, G3: Pressure gauge, D1, D2, D3: Discharge pipe, D4: Byypass pipe and F1 Flowmeter

RESULTS AND DISCUSSION

Basic mathematical description: The fluid flow in pipe was measured using Eq. 1. Equation one is universally used to distinguish the laminar and turbulent flow, where the relation of Re with the velocity and viscosity of fluid are defined as:

$$Re = \frac{\rho V L}{\mu} \quad (1)$$

The symbol ρ is fluid density, μ is kinematics viscosity of fluid, V is velocity and L is the length characteristic, in fully filled pipe, L usually the pipe diameter. The friction factor values of tap water in pipe was calculated based on fanning friction factor equation and defined as

$$C_f = \frac{2\tau_w}{\rho V_{avg}^2} \quad (2)$$

where, defined that the wall shear stress in a fully developed pipe flow is related to the pressure drop by the following equation:

$$\tau_w = \frac{D\Delta P}{4L} \quad (3)$$

where, D is pipe diameter and ΔP is the pressure drop in pipe while, Blasius developed an asymptote to define the relation of friction factor and Re for fully developed turbulent flow in pipes. The relation is defined by the Eq. 4

$$f = 0.0791 Re^{-0.25} \quad (4)$$

It is observed that the maximum possible of friction factor in pipes where the drag reduction is insensitive to the drag reducing agent properties is given by the following equation:

$$f = 0.59 Re^{-0.58} \quad (5)$$

In the other hand, the friction factor of laminar flow in pipe defined as:

$$f = \frac{16}{Re} \quad (6)$$

The drag reduction of pipe flow for incompressible fluid system is obtained based on pressure drop and defined as:

$$DR\,(\%) = \left(\frac{\Delta P_b - \Delta P_a}{\Delta P_b}\right)100 \quad (7)$$

where, ΔP_b is the value of pressure drop of tap water before the addition of chemicals additives and ΔP_a is the value of pressure drop after the addition of chemical additives in turbulent flow. The drag reduction in turbulent flow for surfactant solutions always had been related to Critical Micelle Concentration (CMC). In analyzing the CMC, equation below are needed to converts the molarity of solution into concentration in ppm unit:

$$M = \frac{C\rho}{Mw} \quad (8)$$

where, M (mol L^{-1}) is molarity, C (ppm) is concentration, Mw (g mol^{-1}) is molecular weight and ρ (kg L^{-1}) is the fluid density.

Verification of circulation system: Figure 2 shows the friction factor of water in pipe compared with friction factor of Blasius and Virk asymptote. It is clearly shown that the fanning friction factor of water lies near the Blasius asymptote and far from the Virk asymptote and laminar equation. This is proved that the experimental system appropriate and suitable to use to investigate the performance of GAENE as drag reducing agent. In addition, this calibration also shows that the flows in testing section are fully turbulent.

Drag reduction in pipe: Figure 3 shows the drag reduction obtained of GAENE solution against Re with concentration varied from 200 to 600 ppm in pipe. The optimum fluid Re for maximum drag reduction to occur is within the range of 22470 and 33705. It is clearly shown

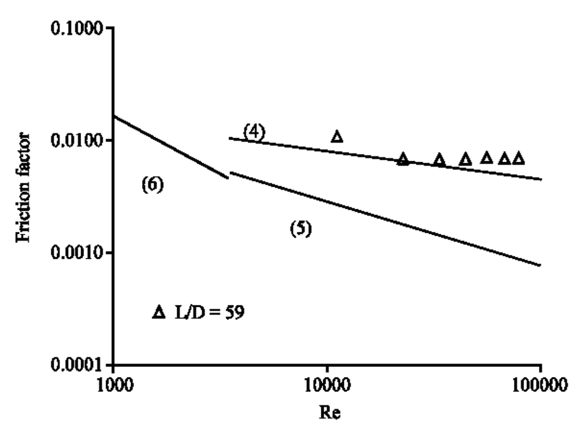

Fig. 2: Friction factor of water without additive

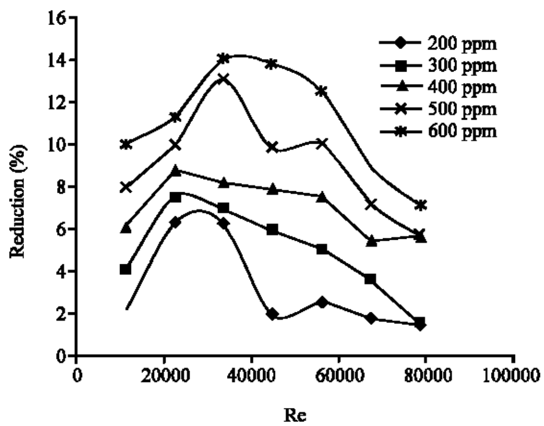

Fig. 3: The drag reduction in L/D equal to 59

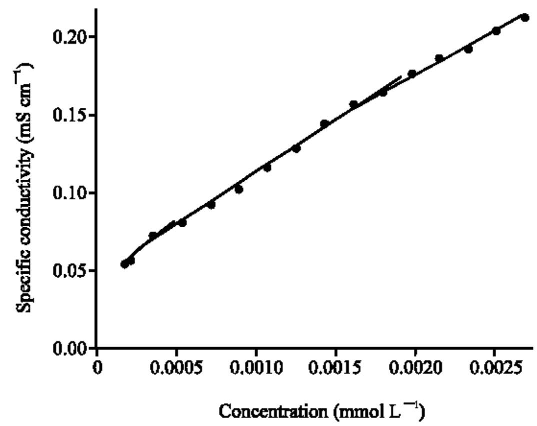

Fig. 4: The micelle behavior of GAENE solution

that the drag reduction is initially increases as the fluid Re increases but began to decreases when fluid Re reach to optimum value. In addition, the drag reduction obtained in pipe varied with the concentration of solution. At 200 ppm of solution the maximum drag reduction obtained is 6%. The drag reduction increased about 2% when the concentration increased to 100 ppm. At 600 ppm, the maximum drag reduction obtained is 14%. From the observation of figure, the drag reduction valued probably reach to minimum if the fluid Re keep increasing without any changes on solution concentration.

CMC of GAENE solution: For the past few years, there are a lot of opinion been discussed about the mechanism behind this phenomena. It is believed that the key source of drag reduction in surfactant solution is the formation of micelle in solution. Where, the presence of micelle in solution can be analyzed through graphing method. The Critical Micelle Concentration (CMC) of GAENE can be found by plotting the specific conductivity obtained from GAENE solution against the concentration as shown in Fig. 4. The CMC is the concentration of solution for first appearance of micelle. From figure, it is clearly shown that the second slope occurred at 0.00045 mmol L^{-1} or 120 ppm. The second slope in figure indicates the CMC of GAENE solution. Any changes of slope occur after the second slope of surface tension against concentration plot indicates the changes of micelle structure in solution. Since the surface tension varied with the specific conductivity of surfactant solution, it is worth presumed that the changes of slope in specific conductivity may indicate the same meaning as in surface tension. Thus, the third slopes occurred in GAENE solution at 0.00165 mmol L^{-1} or equal to 450 ppm proved there are changes of micelle structure in solution.

The changes of micelle structure effect the drag reduction in pipe. However this statement needs more attention in the future.

The maximum drag reduction increased about 5% at 500 ppm compared to 400 ppm, where the maximum drag reduction increased from 300 to 400 ppm is only 1 to 2%. The possible reason of this phenomenon is the changes of micelle structure at 450 ppm of solution improved the performance of GAENE as drag reducing agent.

Drag reduction mechanism: The turbulent flows are formed from random and rapid fluctuations of swirling regions known as eddies. These fluctuations provide additional mechanism for momentum and energy transfer. Each eddy dissipates its energy through viscous shear with its surroundings and eventually disappears. This is the reason of energy loss in pipelines where always interpreted as pressure drop in pipe. The decreased of drag reduction after the optimum value of fluid Re related to capability of micelle to suppress the eddies occurred in turbulent flow. When fluid Re increasing, the eddies in turbulent flow become stronger thus required more micelle to suppress the eddies. As the concentration of solution increases, the network of micelle became stronger thus more eddies can be damped.

When fluid circulated through the closed loop system, the micelle align with the eddies in turbulent flow. As the concentration of surfactants increases, the length of micelle formed also increases. As a result, the skin friction between the flowing fluid and the solid boundary is reduced. Thus less energy required to transfer the fluid to its receptacle. The extensional motions dominate in the bursting and growth of eddies. With the addition of GAENE solution, the apparent extensional viscosity is greatly increased, thus increasing the resistance of the fluid in eddies to extensional flow and suppressing eddy growth.

The rheology properties of micelle such as its capability to reform after the degradation process also important in understanding the mechanism of drag reduction. This is because, most of the micelle network after the circulation process became weaker and this affects its performance as drag reducing agent. Some of the study shows that the mechanisms of drag reduction related to wall shear stress, the velocity fluctuation in turbulent flow, the effect of co-solvent on solution and the experimental condition such as temperatures. In the future, this issue may become interesting.

CONCLUSION

From the experimental study it can be concluded that glycolic ethoxylate lauryl 4-nonyl phenyl ether can be consider as a good drag reducing agent. The result of discussion leads to conclusion that the concentrations of solution play important role in reducing the drag in turbulent flow. The optimum fluid Reynolds number for maximum drag reduction to occur is within the range 22470 and 33705. The critical micelle concentration occurred at 100 ppm and at 450 ppm the structure of micelle began to changes.

RECOMMENDATIONS

The present study can be improved toward more excellent results. It is highly recommended to study the performance of this anionic surfactant in term of solution ages, the effect of co-solvent and the effect of pipe scale. It is also recommend to keeps the concentration of anionic surfactant below 1000 ppm to avoid the environmental loads.

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