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Effect of fluid velocity, temperature, and concentration of non-ionic surfactants on drag reduction

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Abstract

The drag reduction (DR) and heat transfer efficiency reduction (ER) of non-ionic surfactant as a function of fluid velocity, temperature, and surfactant concentration were investigated. Several types of new surfactants, which contain amine-oxide and betaine, were developed. An experimental apparatus consisting of two temperature controlled water storage tanks, pumps, test specimen pipe and the piping network, two flow meters, two pressure gauges, a heat exchanger, and data logging system was built. From the experimental results, it was concluded that existing alkyl ammonium surfactant (CTAC; cethyl trimethyl ammonium chloride) had DR of 0.6–0.8 at 1000–2000 ppm concentration with fluid temperature ranging between 50 and 60 °C. However, the DR was very low when the fluid temperature was 70–80 °C. The new amine oxide and betaine surfactant (SAOB; stearyl amine oxide + betaine) had lower DR at fluid temperatures ranging between 50 and 60 °C compared with CTAC. However, with fluid temperature ranging between 70 and 80 °C the DR was 0.6–0.8 when the concentration level was between 1000 and 2000 ppm.

Keywords: Drag reduction; Non-ionic surfactant; Heat transfer efficiency reduction; Concentration; Pressure drop

1. Introduction

The rapidly increasing demand for energy in cooling and heating applications has led to renewed focus in developing energy efficient sustainable technologies. To this end, district heating systems are considered as one of the prime candidates for space heating/cooling applications. These systems are regarded as alternative energy systems with significant potential for energy saving [1]. The most commonly used heat transmission method converts recovered heat into hot water and cool water and uses district supply pipeline to transmit the water. Transmission of hot water and cool water requires large amounts of pumping power. Especially, when transmission distance is long or when transmission volume is high, energy savings in fluid transmission become an important issue. In this regard, drag reduction in fluid transport processes has received considerable attention. Drag reduction is achieved by adding small volume of surfactants in the turbulent flow field thereby accelerating the fluid flow and reducing the drag more than compared to conventional methods involving the use of solvents. An overview of drag reducing surfactants and their characteristics is covered in [2]. Reduction of flow resistance using water-soluble high molecule materials to reduce water drag has been researched for a long time [3,4]. In reference [5] Physico-chemical properties and rheological behaviour of surfactants is studied. The results show that rod-like micelles are formed above a characteristic concentration. The drag reduction occurs because the rod-like micelles align in the direction of flow and hence contribute to drag reduction. Hu et al. [6] studied the shear thickening in low concentration surfactant solutions by investigating the properties such as slip,

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Nomenclature

AO	amine-oxide
CTAC	cethyl trimethyl ammonium chloride
DR	drag reduction
ER	efficiency reduction
P	pressure, N/m^2
SAOB	stearyl amine oxide + betaine
Greek	
Δ	difference
η	heat transfer efficiency
Subscript	
A	with surfactant
W	without surfactant

fracture and stability in the shear induced phase. Gasljevic et al. [7] described the phenomenon of micellar structure break-up and recovery in turbulent flows in a drag reducing surfactant solution.

From the applications point of view, Myska and Vik [8], have presented experimental results involving the use of drag reducing surfactants in a small house heating system. They reported no significant reduction in heat transfer. However, they recommend proper precautions be taken concerning bio-degradation of surfactant in long operation heating systems. In another study, a field performance was carried out in Denmark. To achieve economic viability by way of reducing the initial cost, one pipe pulsating system consisting of 7.5 km long pipeline using friction reducing additives was designed and constructed. Results showed that the overall economy is better than the conventional double pipe system [9].

Since then, many studies on reduction of flow resistance, using cationic alkyl ammonium surfactants have been conducted. However, cationic alkyl ammonium surfactants have been found to have higher environmental load and their use has been declining over the years. To overcome this issue, new surfactants have been developed and basic research on these materials is being conducted. In Japan, research on synthesis of cationic amine-oxide surfactants with low environmental load, evaluation on DR effect, and mechanism of correlation between micelle structure and DR (drag reduction) effect have been recently examined by the Ministry of Economy, Trade and Industry. Based on this, basic synthesis experiment was carried out for full-fledged production of DRC-6 and DRH-4 based surfactants, and conditions for manufacturing these two materials were developed [10].

Although research on generation of micelle related with cationic surfactants and non-ionic surfactants has been conducted, the stability and DR characteristics have not been examined. In this study we will present experimental results involving the use of new surfactants. These surfactants were synthesized anew to develop non-ionic amine-oxide + betaine surfactants which have the lowest effect on environment. For these reasons we are interested in examining their drag reduction (DR) and associated heat transfer efficiency reduction (ER) characteristics under various operating conditions.

2. Drag reducing surfactants

2.1. Background and the concept

The rate of micelle generation is one of the important properties of surfactants. Ideally each surfactant should be able to generate stable micelle at an optimal rate. However, usually this is not the case. Therefore, it is necessary to develop intervention strategies to enhance the rate of micelle generation. To this end, chemical composition and structure of conventional surfactants are controlled to ensure generation of stable micelle. Low-toxic and environment-friendly amine-oxide, betaine, sugar and glucamide surfactants have been studied. However, a broad evaluation of DR effect regarding the structure and chemical transformation of surfactants has not been addressed. The formation of a single cylindrical micelle requires that size of hydrophilic head group and size of oleophilic tail group should be kept constant. In order to keep hydrophilicity relatively high to maintain stability of micelle in high temperature area, we increased the size of head group or used the method of forming combined micelle using different-sized surfactants. Through analysis of the structure and composition of stable micelle in their formation stage, it was reasoned that if non-ionic surfactants, which belong to C12 scope and have relatively small size of head group, are applied in addition to the ordinarily used main surfactants belonging to C16 scope, stable micelle would be generated.

2.2. Types of surfactants

The DR and ER performances of one alkyl ammonium surfactant (CTAC) and six non-ionic amine-oxide + betaine surfactants listed below were experimented.

- CTAC; cethyl trimethyl ammonium chloride + Na-salicylate (1:1)
- SAOB; stearyl amine oxide + betaine (1:1)
- SAOBSS; stearyl amine oxide + betaine + Na-sal (4:4:2)
- SAOBGA; stearyl amine oxide + betaine + L-glutamin acid (5:3:2)
- PSAOB-1; POE(II) stearyl amine oxide + betaine (1:1)
- PSAOB-2; POE(II) stearyl amine oxide + betaine (7:3)
- SASOR; stearyl amine oxide + DL-serine (1:1)