



ELSEVIER

Contents lists available at ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

Experimental study on drag reduction performance of mixed polymer and surfactant solutions


 Dongjie Liu^a, Qinghui Wang^a, Jinjia Wei^{a,b,*}
^a State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, No. 28, Xianning West Road, Xi'an 710049, China

^b School of Chemical Engineering and Technology, Xi'an Jiaotong University, No. 28, Xianning West Road, Xi'an 710049, China

ARTICLE INFO

Article history:

Received 17 July 2017

Received in revised form 17 January 2018

Accepted 26 January 2018

Available online 4 February 2018

Keywords:

Drag reduction

Cationic surfactant

Nonionic polymer

Synergistic effect

Temperature

ABSTRACT

In this work, the mixed aqueous solutions of cationic surfactant – cetyltrimethyl ammonium chloride and non-ionic molecular polymer – polyacrylamide were tested to verify the speculation about their intensification possibilities of drag reduction performance. Sodium salicylate (NaSal) was used as the counter-ion salt. Six different combinations of mixed solution concentrations were tested at different temperatures ranging from 25 °C to 50 °C. Pure surfactant and polymer solutions were tested as control couples. It was found that the curves of mixed solutions could be divided into enhanced drag reduction zone, stable drag reduction zone and destroyed drag reduction zone. Surfactant molecules form micelles round polymer chains. Then the two additives form a kind of reinforced concrete structures, which were more complex and more effective in restrain vortices, leading to the intensification of drag reduction in enhanced zone and stable zone compared to pure surfactant solutions at low temperatures. The addition of polymers also increased drag reduction efficiency in destroyed zone by providing a wider range of Reynolds numbers. In addition, the results indicated that temperatures were more influential than concentrations, raising the temperature to change the structures of solution is more effective than increasing the quantity of structures.

© 2018 Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.

1. Introduction

It is well known that the addition of small amounts of additives can cause a significant drag reduction effectiveness in turbulent flow (Toms, 1948). The phenomenon can reduce energy consumption and has immense applied value in industry. Now, applications of drag reduction can be found in different industrial areas, such as oil industry (Burger et al., 1980; Lucas et al., 2009; Morgan and McCormick, 1990; Motier et al., 1996; Ousterhout and Hall, 1961; Sellin and Ollis, 1980; Thomas and Armando, 2005), sewage systems (Sellin and Ollis, 1980), heating systems (Choi et al., 2000; Myska and Mik, 2003; Suzuki et al., 2005; Wang et al., 2011) and fire fighting (Figueredo and Sabadini, 2003).

Bubbles, polymers and surfactants are three main types of additives in drag reduction, polymers and surfactants are considered to

be the most efficient ones (Bismarck et al., 2004). However, they have their own advantages and disadvantages. Polymers cause a drag reduction effectiveness by adding few parts per million by weight, but the mechanical degradation of polymer molecules is an important factor that influences its application. The greatest strength of surfactants is its reversible mechanical degradation characteristic (Bewersdorff and Ohlendorf, 1988; Ohlendorf et al., 1986), however, surfactants need concentration above the critical micelle concentration (CMC) to form micelle structures, which can form the shear-induced structures (SIS) further due to shear stress, resulting in the decrease of drag reduction effectiveness of surfactant. For example, the value of CMC for pure CTAC at 30 °C is 1.3 mmol/L (Bayissa et al., 2017; Rosen, 1989). The addition of salt can low the value of CMC. In CTAC/NaSal system, the value is 0.209 mmol/L at 30 °C (Ohlendorf et al., 1986). CMC increases with the

* Corresponding author.

 E-mail addresses: 1464172699@qq.com (D. Liu), 1403131721@qq.com (Q. Wang), jjwei@mail.xjtu.edu.cn (J. Wei).
<https://doi.org/10.1016/j.cherd.2018.01.047>

0263-8762/© 2018 Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.

increase of temperature. In CTAC/NaSal system, the value of CMC is 0.25 mmol/L at 40 °C and 0.306 mmol/L at 50 °C (Ohlendorf et al., 1986). Because of the complementarity between polymers and surfactants, we want to combine them to form a mixed solution and complement on each other to get a better drag reduction effect.

Cationic surfactants and anionic surfactants are two main types of surfactants. At very early time, scholars tested anionic surfactants in drag reduction. Pilpel (1956) investigated that the aqueous solutions of sodium and potassium oleate showed viscoelastic properties when electrolytes were added. Alcohol was also added to test the rheological properties. Results showed that the change from spherical to cylindrical micelles was brought about mainly by the added salts and alcohols. Although Pilpel did not study the drag reduction performance about this surfactant, the viscoelastic properties already showed that sodium oleate can be used as drag reducers. Savins (1966) is the first scholar who tests the drag reduction performance of anionic surfactant. He used a soap system (0.2% sodium oleate, 10% KCl) and the results showed that the drag reduction rate can be up to 82%. Tsujii et al. (1984) tested the aqueous solutions of an anionic surfactant, partially neutralized alkenylsuccinate. Results showed that the solution showed striking spinnability and Weissenberg effect, the viscoelastic solutions of the agent were much more surface active than the normal ones. But the optimum PH for this kind of surfactant was 6, the solution was acidic and the steel pipeline would be corroded, so it could not be used in steel pipes. Moreover, the hardness tolerance of the anionic surfactant is also an important phenomenon that limit the usefulness of anionic surfactant (Stellner and Scamehorn, 1989a,b). Aqueous solution of anionic surfactants generally cause precipitation in hard water containing divalent cations such as calcium or magnesium ions (Homendra and Devi, 2004; Hu and Tuvell, 1988). So until now, most scholars choose cationic surfactant in research.

In the mixed solution, polymer macromolecules and micelle structures will form new structures called aggregates (DaRocha et al., 1999). The interaction between polymers and surfactants begins at a surfactant concentration called critical aggregation concentration (CAC), which is lower than CMC (Deo et al., 2007; Goddard and Ananthapadmanabhan, 1993; Jonsson, 2003). We can also know from the articles that for the system ionic polymers with oppositely charged ionic surfactants, CAC has been reported to be several orders of magnitudes lower than CMC. For the group referred to the interaction of nonionic polymer and ionic surfactant, CAC is the same or close to CMC (Diamant and Andelman, 1999; Goddard and Ananthapadmanabhan, 1993; Hansson and Lindman, 1996). There are two types of interaction between polymers and surfactants: electrostatic interaction and hydrophobic interaction. Electrostatic interaction always exists in polymer-surfactant system with opposite charge. For the systems with no opposite charge, hydrophobic interaction is the main interaction. Increase the degree of hydrophobicity of polymer can show a better interaction (And and Zana, 1996; Krister et al., 1996; Thuresson et al., 1995). The interaction is influenced by several factors such as the types of polymers and surfactants, molecular weight and chain flexibility of the polymers (Kausch and Tirrell, 1989; Rouse, 1953), PH of the solution and temperature (Feitosa et al., 1996; Jonsson, 2003).

We can find the combination of polymers and surfactants in many studies. Some scholars have been working on the interactions between polymers and surfactants. Several studies found that anionic surfactants were much more effective in binding to nonionic polymers (Fishman and Eirich, 1971; Jiang and Han, 2000; Ma and Li, 1989). Abdulbari and Hawege (2015) and Mohsenipour and Pal (2013c) tested the drag reduction performance of the combination of anionic surfactant and nonionic polymers.

In order to explain the mechanism of the interactions between polymers and surfactants, the Necklace model and the Ruckenstein model were proposed (Nagarajan, 1980; Ruckenstein et al., 1987). People also tried to study the influence of interactions on drag reduction. Mohsenipour and Pal (2013a) suggested that the addition of surfactant to polymer always increased the extent of drag reduction, especially at low polyethylene oxide (PEO) concentration and high surfactant concentration. Matras and Kopiczak (2015) observed the existence of drag reduction zones and investigated the influence of pipes diameter.

Moreover, people found that the addition of a surfactant into a polymer solution could improve the resistance of polymer chains against shear degradation (Gasljevic et al., 2007; Kim et al., 2000; Mohsenipour and Pal, 2013b; Suksamranichit and Sirivat, 2007; Suksamranichit et al., 2006; Zhang et al., 2005).

In previous studies, researchers usually focused on the interactions between polymers and surfactants, although there were other scholars who researched drag reduction performance of mixed solutions, they only observed the existence of drag reduction zones and investigated the influence of pipes diameter. Nobody cares the differences between the mixed solutions and pure solutions in drag reduction performance and why the differences exist. Furthermore, the efficiency of polymers and surfactants in drag reduction is influenced by temperatures, especially for polymers, but nobody have ever studied about the influence of temperatures for mixed solutions. Polymers are difficult to dissolve at low temperatures and easy to degrade at high temperatures because of thermal degradation. So at proper temperatures, the mixed solution may have the best performance. Cationic surfactants are more generally applicable, so we choose cationic surfactant as the object. The aim of this work is to investigate the intensification of drag reduction effect caused by the mixtures of cationic surfactant and nonionic polymer solutions, and to investigate the influence of temperature on drag reduction for polymer-surfactant solutions.

2. Measurements and materials

2.1. Test facility

A schematic diagram of the experimental apparatus is shown in Fig. 1. It was a closed loop system consisted of a storage tank, a heater, a centrifugal pump, a setting chamber, a smooth two-dimensional (2D) channel, a diffuser and other measurement instruments. The fluid flow in the closed loop system was forced by the stainless steel centrifugal pump, and the flow rates were adjusted by an inverter. The fluid was pumped into one of the two parallel pipes where the flow rates were measured by electromagnetic flowmeters (L-mag B Type, Xi'an Xu Sheng Instrument Co. Ltd). The diameters of the pipeline corresponded to different measurement ranges (0.7–3 m³/h and >3 m³/h, measuring accuracy of 0.001 m³/h and 0.01 m³/h respectively). The 2D channel was 10 mm in height (H), 125 mm in width (W) and 3 m in length. We could make sure that in the center of the spanwise distance was a two-dimensional flow because the aspect ratio of the channel was more than 7 (Dean, 1978). 2D channel is used instead of cylindrical tube because 3D flow field can be simplified to 2D flow field, which is easier to measure. The results of 2D channel can also be extended to 3D field flow. Moreover, 2D channel is convenient to use PIV measurement system if it is needed. Before the test section, there was a fully developed section which was long enough (1.5 m) to ensure that the flow was fully developed. The test section had two pressure holes, spotted in the wall with a distance of 1.1 m. The pressure drop of the test section was measured by a differential pressure transmitter (Transmitters with Capacitive Sensor, Chang Hui Automation System Co, Ltd., measuring range of 0–10 kPa and measuring accuracy of 5 Pa). During the experiment, a 6 kW heater was used to change the fluid temperature and keep it constant with an accuracy of ±0.1 K. There were 2 pairs of thermocouples in our experiment system. One pair was in the tank and another pair was in the test section. In the test section, the thermocouples were stick to the wall in the entrance of the section. We could know the temperature from the digital display devices which were linked to the thermocouples. In our experiment, temperature is related to the test section.

Download English Version:

<https://daneshyari.com/en/article/7005949>

Download Persian Version:

<https://daneshyari.com/article/7005949>

[Daneshyari.com](https://daneshyari.com)