

OPTIMIZATION OF THE DRAG-REDUCING EFFECT BY CONTROLLING THE PREPARATION CONDITIONS OF ADDITIVES

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ABSTRACT

The drag-reducing (DR) effect by cationic surfactants has been applied to the water circulation system of general building air conditioning equipment as an energy-saving technology for fluid transportation. Water pipes are usually designed for average flow velocities of 1 to 1.5 m/s, and some cationic surfactants have a DR effect within this range. In recent years, the authors have been examining the application of the DR effect in geothermal heat utilization systems. In such systems, due to the heat extraction from the ground and the operating conditions of the heat pump, the average flow velocity in the heat extraction tube is approximately 0.5 m/s, so there is the problem that a sufficient DR effect cannot be obtained. Aqueous surfactant solutions that induce DR effects are known to exhibit a shear-induced state (SIS). However, the viscosity increase due to the SIS contributes to lowering the DR effect in the low flow velocity region (low Re number region). Furthermore, Zhang et al. state that a SIS is not a necessary element for the DR effect.¹ The purpose of this study was to obtain basic data for developing a DR agent that suppresses the expression of the SIS and can be used in a geothermal heat utilization system.

EXPERIMENTAL PROCEDURE

A mixture of cationic surfactant, oleyl-bis(2-hydroxyethyl)-methyl-ammonium chloride ($C_{18}H_{35}N^+(CH_3)(C_2H_4OH)_2Cl^-$, Lipothoquad O/12 produced by Lion Corporation, Japan) and sodium salicylate (NaSal., $HOC_6H_4COO^-Na^+$) was used as the drag-reducing (DR) agent. The optimal mixing ratio of both is 1:1.5 by molar ratio from the viewpoint of achieving the high DR effect reported by Chou et al.,² and the present research was also based on this rate. The experimental apparatus used for evaluating drag reduction was a recirculation system (Fig 1). Different concentrations of the DR additive were mixed in a tank to prepare solutions. The fluid temperature was kept constant at 15°C in consideration of the actual value of circulating water in ground thermal energy systems. The flow rate and pressure difference in a straight pipe 1.6 m long were measured with an electromagnetic flow meter and an electric differential

manometer, respectively. The Reynolds number was calculated using the properties of water. The friction factor, f , was calculated by the Fanning equation. For convenient comparison of the drag reduction results between the water and test solutions, the DR rate, $DR\%$, was defined as

$$DR\% = \frac{f_w - f_{DR}}{f_w} \times 100, \quad (1)$$

where f_w and f_{DR} are the friction factor of water and that of the solution, respectively; f_w was obtained using the Blasius equation.

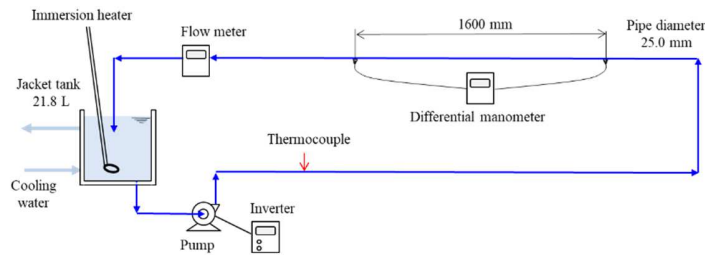


Figure 1: Experimental apparatus

RESULTS AND DISCUSSION

Figure 2 shows the relationship between $DR\%$ and the average flow velocity u . When the surfactant concentration was 500 mg/L (Δ , the set concentration in a normal water pipe), the $DR\%$ at 0.5 m/s was only 7%. While the concentration was 200 mg/L (\circ), the $DR\%$ at the same u was 30%. When the concentration of surfactant was set at 500 mg/L, which is the set value for a normal building air-conditioning circulation system, the $DR\%$ was only 7% at $u=0.5$ m/s. When the concentration was increased to 200 mg/L, the $DR\%$ increased to 30%, but it is expected that it will not show a stable DR effect for a long period of time because it is so diluted.

Since it is necessary to add a corrosion inhibitor to the circulating water in actual fluid transportation, two corrosion inhibitors, A and B (c.i.-A and c.i.-B) were tested in the present study with a surfactant concentration of 500 mg/L. The addition of either corrosion inhibitor did not adversely affect DR; on the contrary, c.i.-B greatly increased $DR\%$ in the low-velocity region. C.i.-A is of the type that dissociates in water to form ions, while c.i.-B forms a complex.

Figure 3 shows the equilibrium flow properties when adding different concentrations of c.i.-B to the DR agent (a mixed aqueous solution of 500 mg/L Lipothoquad O/12 and 300 mg/L sodium salicylate). The higher the amount of c.i.-B added, the lower the viscosity of the aqueous solution, and the shear-induced state was exhibited only slightly in the high shear rate region. The addition of c.i.-B had some effect on the rod-like micelle structure formed by the surfactant and the counterion.

ACKNOWLEDGEMENTS

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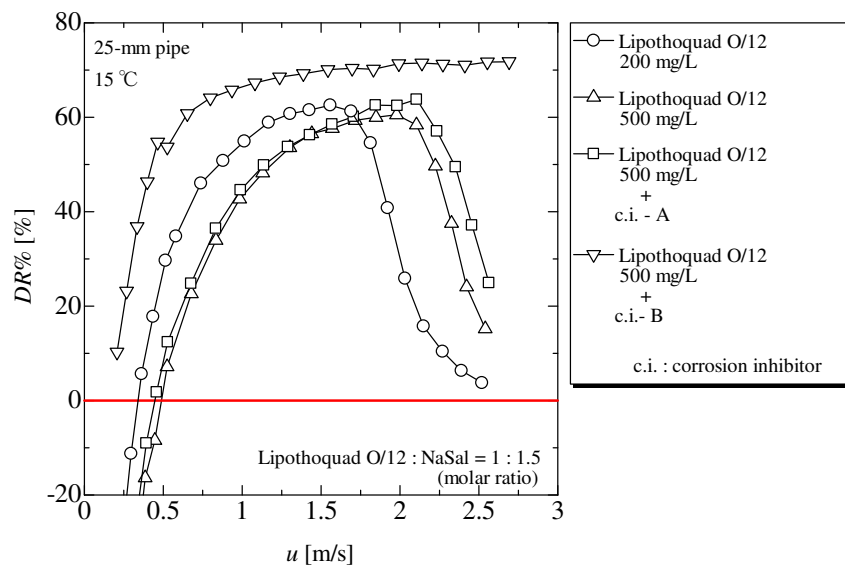


Figure 2: Effect of the addition conditions of the DR agent and corrosion inhibitors on the DR effect

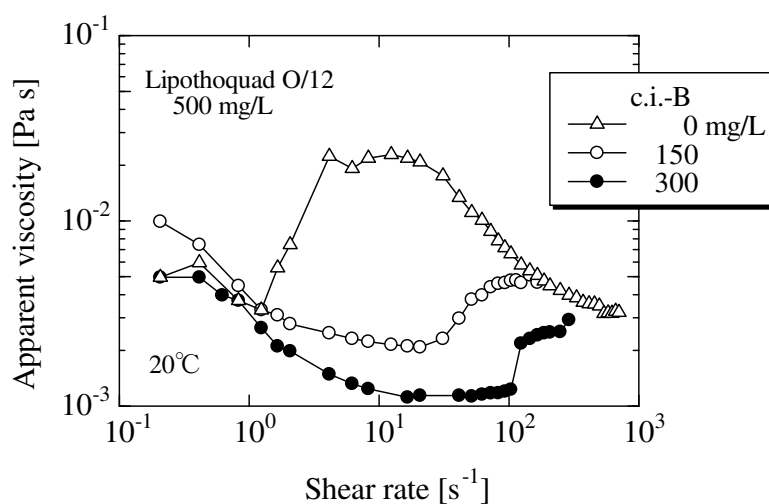


Figure 3: Equilibrium flow properties of the DR additive with different concentrations of c.i.-B measured by a cone-plate rheometer (IR-200).