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Reduction of Pumping Energy Losses in District Heating and Cooling Systems

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Final Report

Department of Energy Project

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Reduction of Pumping Energy Losses in District Heating and Cooling Systems

Introduction

This project was designed to find effective surfactant friction reducing additives for use in district heating systems with temperatures of 50 to 90°C and effective additives for district cooling systems with temperatures of 5 to 15°C. Heat transfer measurements in conventional shell and tube heat exchangers and in plate heat exchangers were also carried out to see how seriously these surfactant drag reducing additives reduce heat transfer coefficients.

Experimental

The turbulent drag reduction experiments were carried out in two pumping loops described in References 1-4. The low temperature loop was suitable for temperatures ranging from 2°C to 100°C and the high temperature loop from 30°C to 150°C. Their Reynolds number ranges are 15,000 up to 300,000. Pressure drop measurements in smooth stainless steel test tubes with diameters of 0.106 and 0.243 inches were made utilizing appropriate entrance and exit kinetic energy loss corrections (4). Turbulent flow test data

for deionized water lay close to the von Karman equation predictions and repeatability was excellent.

Cationic surfactants with aromatic counter-ions are well-suited for these applications as they have reasonable temperature ranges of effectiveness and, while they do lose their drag reducing effectiveness when exposed to high shear stresses, they regain their drag reducing effectiveness when they enter a lower shear region.

While a large number of commercial quaternary ammonium salt surfactants and counter-ions were examined for the high temperature experiments, the experiments focused on eight of them using sodium salicylate as counter-ion. They are listed in Table 1. Surfactants tested for district cooling systems are listed in Table 2.

Results and Discussion

The experimental results have been reported at national and international meetings (Refs. 1-3, 5, 6). A summary of the results follows. More details are in these papers, a copy of each of which is attached as a supplement.

1. Effect of Alkyl Chain Length on Upper Temperature Limit.

The length of alkyl groups in the quaternary ammonium salts was varied from 10 to 22 carbons using excess salicylate as counter ion (in a ratio of 5 mmoles/12.5

mmoles). The upper temperature limit increased continuously from 10°C with C₁₀ to 120°C with C₂₂ (4). Thus, proper selection of the alkyl chain length can provide effective drag reduction up to any desired temperature in this range.

2. Effect of Alkyl Chain Structure on Lower Temperature Limit

The presence of unsaturation in the alkyl chain in the quaternary ammonium salt was found to decrease the lower temperature limit for effective drag reduction with no apparent effect on the upper temperature limit (4). Thus, several cationic surfactants containing unsaturated alkyl chains in combination with excess sodium salicylate were effective drag reducers down to 2°C, the lowest temperature we were able to test (3).

3. Scale-Up of Small Tube Test Results to Larger Tubes.

Most measurements were made in 0.106 and 0.243-inch diameter tubes. A procedure proposed by Granville (7) for scale-up of polymer drag reducing systems was used for the surfactant drag reducers. Good agreement in scale-up predictions from the 0.106-inch tube data with measurements in the 0.243-inch tube was obtained. Further scale-up to the data which we obtained in Argonne's 6-inch tube also gave reasonable agreement but the assumption of equal wall shear stress could only be approximated as the small tube wall shear stresses were considerably higher than those in the 6-inch tube. We believe this scale-up procedure is satisfactory, but there are several others

which should also be tested to see if even better agreement can be obtained.

4. Heat Transfer Coefficients for Friction Reducing Surfactant Solutions

Preliminary measurements of heat transfer coefficients at high temperatures (up to 120°C) were made in a tube-in-tube and in a chevron plate heat exchanger (6). Heat transfer coefficients in the tube-in-tube exchanger were reduced as much as 90% or more at high temperatures. In the plate exchanger, the heat transfer coefficient reduction was smaller but still appreciable (10 to 50%). Further studies of schemes to reduce the loss in heat transfer or to redesign exchangers to avoid significant reductions in heat transfer are needed.

5. Corrosion Effects

Corrosion of metals commonly used in district heating and district cooling systems in contact with surfactant additives was studied (8). Pitting susceptibility and corrosion rates of carbon steel, 304 stainless steel, copper, 90% copper-10% nickel and 60% copper-40% zinc were measured. Exploratory efforts to find suitable corrosion inhibitors were also carried out.

In general, surfactant additives which did not contain chloride ion had no adverse effect on corrosion. The presence of chloride increased the susceptibility to pitting of stainless steel in tap water. At high temperatures, several of the corrosion

inhibitors tested appeared to be compatible with representative surfactants containing chloride but only hydrazine eliminated pitting susceptibility of stainless steel. Hydrazine, while still used in the U.S., is banned in several countries as it is a suspected carcinogen. The use of deionized, deaerated water was at least as effective in reducing corrosion problems as the addition of corrosion inhibitors. Reduction in corrosion problems can also be accomplished by replacing chloride ion present in some surfactant additives with a more benign anion such as acetate.

Conclusions

1. A number of surfactant drag reducing additives systems suitable for use in district heating systems at temperatures as high as 110°C have been demonstrated.
2. A number of surfactant drag reducing additives systems suitable for use in district cooling systems at temperatures as low as 2°C were discovered.
3. A procedure for scale-up of measurements of systems in diameters of 0.10 to 0.25 inches to tubes of 6 inches in diameter correlates the available data well.
4. Heat transfer coefficients in drag reduction systems are reduced up to 90% in tube-in-tube exchangers but are reduced only 10 to 50% in plate exchangers.

5. Control of corrosion in surfactant systems is no more difficult than in pure water systems. If corrosion inhibitors are to be used, compatibility with the surfactant may be a problem.

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Table 1
Surfactant Additives and Results

<u>Additives*</u>	<u>Supplier</u>	<u>T_{max}, °C</u>	Maximum Wall
			Shear Stress <u>at τ_{max}, Pa</u>
Arquad 16-50	Akzo Chemical	60	300
Arquad 18-50	Akzo Chemical	90+	210
Arquad S-50	Akzo Chemical	80-	180
Arquad T-50	Akzo Chemical	70	220
Arquad R-50	Akzo Chemical	90	170
Kemamine Q-2983C	Humko Chem. Div., Witco	100+	150
Kemamine Q-2803C	Humko Chem. Div., Witco	110	125
Ethoquad R12/75	Akzo Chemical	90+	200

* Surfactant concentration was 2000 ppm.

In each case 2000 ppm of sodium salicylate was also added.

Table 2

Low Temperature Drag Reducing Surfactants

Effect of Variation of Cation with Sodium Salicylate as Anion on Critical
Wall Shear Stress (Molar Ratio = 1:1.5; cation concentration = 5 mmoles/liter)

<u>Cation</u>	Lowest Temp. for Significant Drag <u>Reduction, °C</u>	Critical Wall Shear Stress <u>at T_{min}, Pa</u>
Arquad 12-50 (1606 ppm/1200 ppm)	10	20
Arquad S-50 (1726 ppm/1200 ppm)	2	95
Ethoquad R/12-75 (2150 ppm/1200 ppm)	2	100
Ethoquad 0-12 (2000 ppm/1200 ppm)	2	150

NOTE: Anion is (sodium) salicylate whose concentration is 1200 ppm, giving a surfactant:
salicylate molar ratio of 1:1.5.

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