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LONG–TERM DEGRADATION OF DILUTE POLYACRYLAMIDE SOLUTIONS IN TURBULENT PIPE FLOW*

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SOLUTIONS IN TURBULENT PIPE FLOW

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ABSTRACT

The long–term degradation behavior of 200 wppm polyacrylamide solution was studied experimentally in a closed recirculatory flow loop at temperatures of 7.2, 25 and 87.8°C. The degradation behavior was found to be strongly dependent on temperature. The results indicate that, with flow shear similar to that encountered in practical DHC pipe flow, polyacrylamide solutions are highly effective and have a reasonable lifetime at chilled water temperature of 7.2°C.

INTRODUCTION

Many district heating and cooling (DHC) systems involve long runs of piping (sometimes miles in length) that convey a working fluid in the heating or cooling mode between heat sources and sinks of the system. If the pressure drop or frictional losses associated with pumping these fluids can be reduced significantly, system operating costs can be reduced. These friction reductions also manifest themselves in the form of upfront capital equipment cost reductions through the use of smaller–diameter pipes and smaller pumps.

Certain additives, when used in very small amounts in conjunction with the proper solvents, yield non–Newtonian working fluids that can reduce the frictional losses in DHC systems by 30–80% relative to those experienced with the Newtonian fluids currently used. However, the degradation of these additives in solution under flow shear is one of the most serious hindrances to their use in practical closed–loop systems. In case of utilization of friction reduction in heating systems, the thermal instability of the additives is an additional problem. Although a number of degradation studies have been reported, they are of limited relevance to practical closed–loop systems; either the tests were performed in single– or multiple–pass capillary tube systems (1–4) or, when closed–loop systems were used, most degradation tests were conducted at room temperature or the duration of the test was very short from a practical point of view (5–8). Therefore, the present study was undertaken to investigate the long–term behavior of dilute polyacrylamide solutions and its effects on turbulent friction and heat transfer in a closed recirculatory flow loop at three temperatures over a 80°C temperature range.

EXPERIMENTAL

A closed recirculatory flow system was used to study experimentally the long–term degradation behavior of dilute polymer solutions under well defined conditions. Argonne's degradation test loop was designed to ensure that additive degradation would be caused predominantly by the wall shear stresses along the length of the test section, with minimal degradation in other parts of the loop. Accordingly, large–diameter feed and return pipes were used in the flow loop, and a tubing pump was used to recirculate the test fluids. The main test section is a straight tube of 0.7747–cm inside diameter and 6.4–m length, in which both pressure drop and heat transfer are measured as a function of circulation time. A more detailed description of the experimental device is given in Choi, Cho and Kasza (9). The polymeric additive used in the present experiments was Separan AP–273 (Polyacrylamide, supplied by Dow Chemical) at 200 wppm in deionized water. A 76– kg quantity of 200–wppm Separan solution was circulated in the degradation test loop at a constant flow rate of 9.53 kg/min. The solvent–based friction velocity corresponding to the fixed circulation rate is 0.195 m/s, which is the friction velocity encountered in a typical DHC system pipeline. Degradation runs were conducted at room temperature for 730 hours, considerably longer than in any of the earlier degradation studies reported in the literature. To investigate the effect of temperature on the degradation behavior, degradation runs were repeated at 87.8°C and 7.2°C.

The percent friction reduction is calculated as

$$FR_{\%} = \frac{\Delta P_N - \Delta P_P}{\Delta P_N} X100 \quad (1)$$

where ΔP_N and ΔP_P are the measured pressure drops for the Newtonian fluid (water) and the polymer solution, respectively, at the same flow rate.

The percent heat transfer reduction is defines as

$$HTR_{\%} = \frac{U_{oN} - U_{op}}{U_{oN}} \times 100 \tag{2}$$

where U_{oN} and U_{op} are the overall heat transfer coefficients for the Newtonian fluid and the polymer solution at the same flow rate.

RESULTS AND DISCUSSION

A 76–kg (167.0–lb) quantity of 200–wppm Separan AP–273 solution in deionized water was circulated in the degradation test loop at a constant flow rate of 9.53 kg/min (21 lb/min) for a period of 730 hours at room temperature (25.0°C) in order to provide baseline degradation data for the low– and high–temperature degradation tests at 7.2 and 87.8°C. The pressure drop and overall heat transfer coefficient are shown as a function of hours of shear in Fig. 1, and percent friction and heat transfer reductions compared with water data are given in Fig. 2.

During the first eight hours of circulation, the pressure drop decreased from the initial value of 29.6 kPa (4.3 psi) to a minimum of 23.4 kPa (3.4 psi). This may have been due to further mixing within the Separan solution. After reaching this minimum point, the pressure drop gradually increased, arriving at a plateau value of 49.0 kPa (7.1 psi) at 240 hours of shear. From 240 to 730 hours of shear, the pressure drop value changed very slowly from 49.0 to 55.8 kPa (7.1 to 8.1 psi). Even at 730 hours of shear, the pressure drop data represented about 25% friction reduction relative to pure water, as shown in Fig. 2. This is an important finding because a friction reduction of even 10% in DHC systems could result in large annual cost savings. Figure 1 demonstrates that the overall heat transfer coefficient changed rather rapidly from its initial value of 936.4 W/m^2K (164.9 $Btu/hr–ft^2–°F$) and reached a plateau value of 3,235 W/m^2K (569.7 $Btu/hr–ft^2–°F$) at 240 hours of shear. From 240 to 730 hours of shear, it increased gradually, reaching the value of 3547 W/m^2K (624.6 $Btu/hr–ft^2–°F$) at 730 hours of shear. This plateau corresponds to about 22% heat transfer reduction relative to pure water. As shown in Fig. 2, the friction reduction is accompanied by heat transfer reduction. Initially, the percent heat transfer reduction (i.e., 78%) was larger than the percent friction reduction (about 65%). However, at 60 hours of shear, the percent friction reduction was about the same as the percent heat transfer reduction. After this point, the former was consistently larger than the latter by about 5%.

Degradation runs were repeated with 200–wppm Separan solution at 7.2°C and 87.8°C. Low–temperature degradation test results are shown in Fig. 3. Both the pressure drop and heat transfer data clearly show that under DC conditions, Separan underwent negligible degradation under continuous shear for the one–month duration of the test. The heat transfer behavior was similar to that of pressure drop, confirming that pressure drop reduction is always accompanied by heat transfer reduction. Although the heat transfer reduction is not desirable, the advantage of friction reduction outweighs the disadvantage of heat transfer reduction.

It is very interesting to note the dramatic effect of temperature on the degradation rate of 200–wppm Separan solution (see Fig. 4). It appears that the polymer bonds are more easily ruptured at higher temperature. Therefore, the effect of degradation on pressure drop is most pronounced at 87.8°C. At high temperature, the degree of friction reduction decreased in one day from approximately 56% with fresh solution to the asymptotic value of about 6% with shear–degraded dilute Separan solution. However, at low temperature, the level of friction reduction was stabilized at more than 50% for the one–month duration of the test. This important discovery suggests that Separan is currently the most promising additive for closed–loop district cooling systems. However, further experimental study is required to investigate the effects of high wall shear in a centrifugal pump on the degradation of Separan. This ultimate screening and degradation testing will be done in a large–scale DHC system simulator.

CONCLUSIONS

Degradation tests were conducted with aqueous 200 wppm Separan solutions at temperatures of 7.2, 25 and 87.8°C. Degradation test results, including the long–term degradation behavior and its effects on friction and heat transfer coefficients, were presented. The results can be summarized as follows:

1. Dilute Separan solutions degrade rapidly during the early stages of circulation. However, further degradation after the initial rapid degradation is very slow, and the turbulent friction and heat transfer reduction approach asymptotic plateau values.

2. The effect of temperature on the degradation of dilute Separan solution is significant. The plateau value increases with decreasing temperature. At 7.2°C, the degradation rate is negligible, and the plateau value of more than 50% friction reduction can be maintained for the one–month duration of circulation.

3. Friction reduction is always accompanied by heat transfer reduction regardless of the duration of shear. In general, the percent friction reduction is larger than the percent heat transfer reduction with shear–degraded dilute Separan solution.

ACKNOWLEDGMENTS

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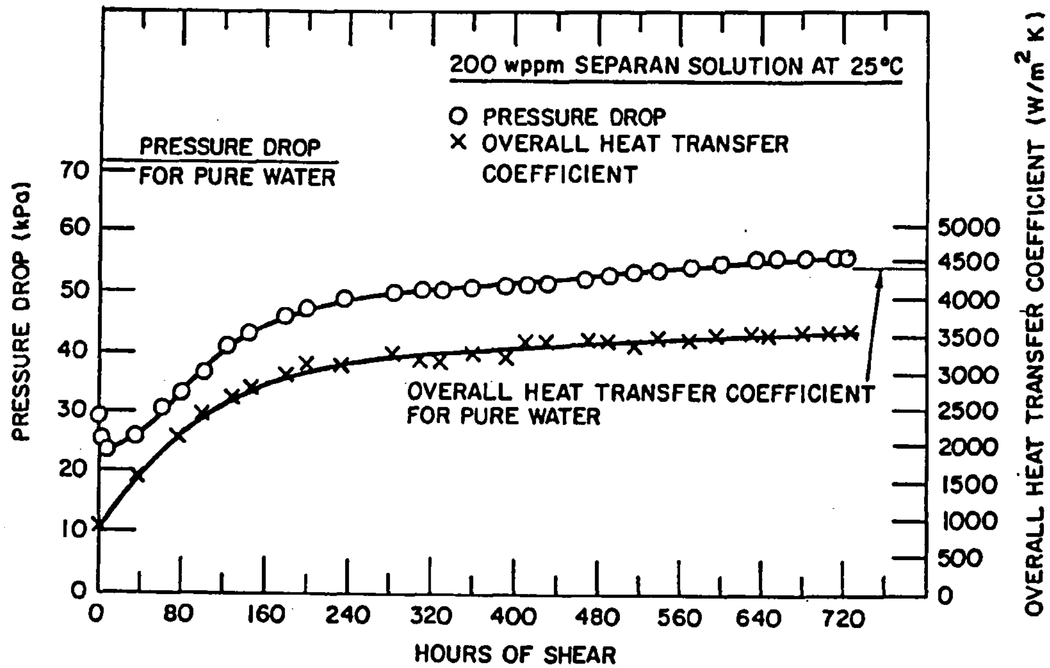


Figure 1. Pressure Drop and Overall Heat Transfer Coefficient as a Function of Circulation Time for 200 wppm Separan Solution at 25°C.

Figure 2. Percent Friction/Heat Transfer Reduction Relative to Pure Water as a Function of Circulation time for 200-wppm Separan Solution at 25°C.

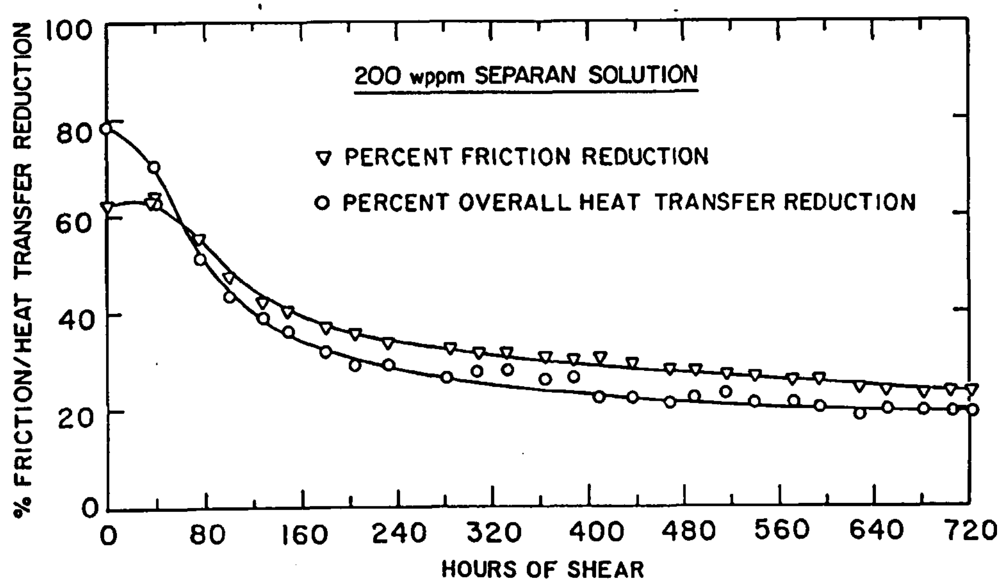
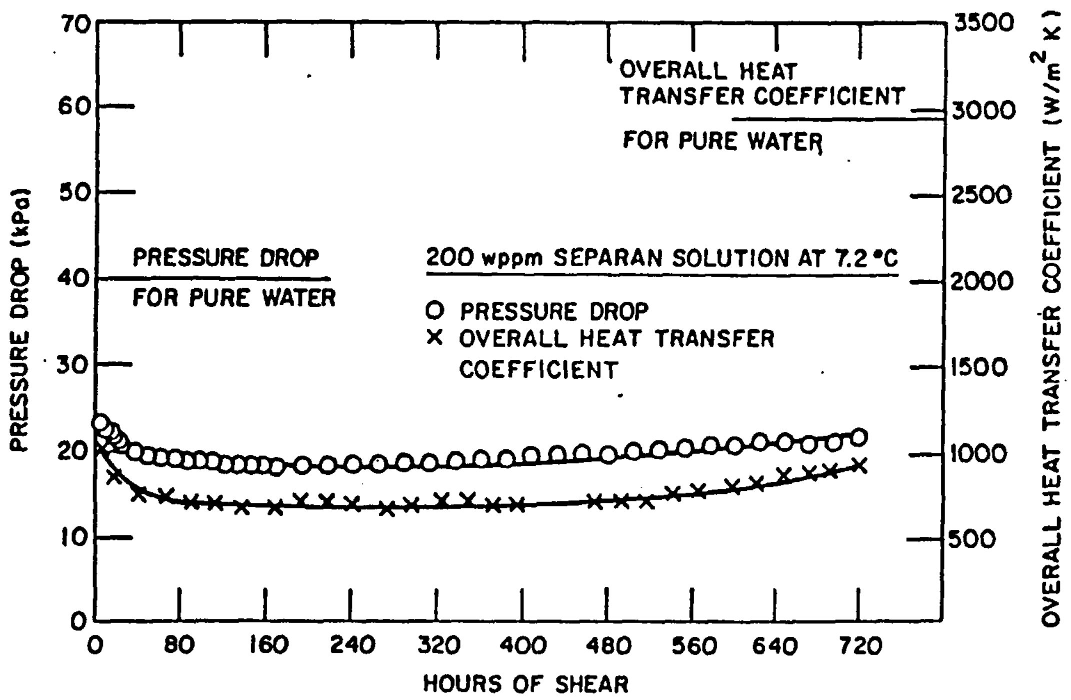


Figure 3 Pressure Drop and Overall Heat Transfer Coefficient as a Function of Circulation Time for 200-wppm Separan Solution at 7.2°C.



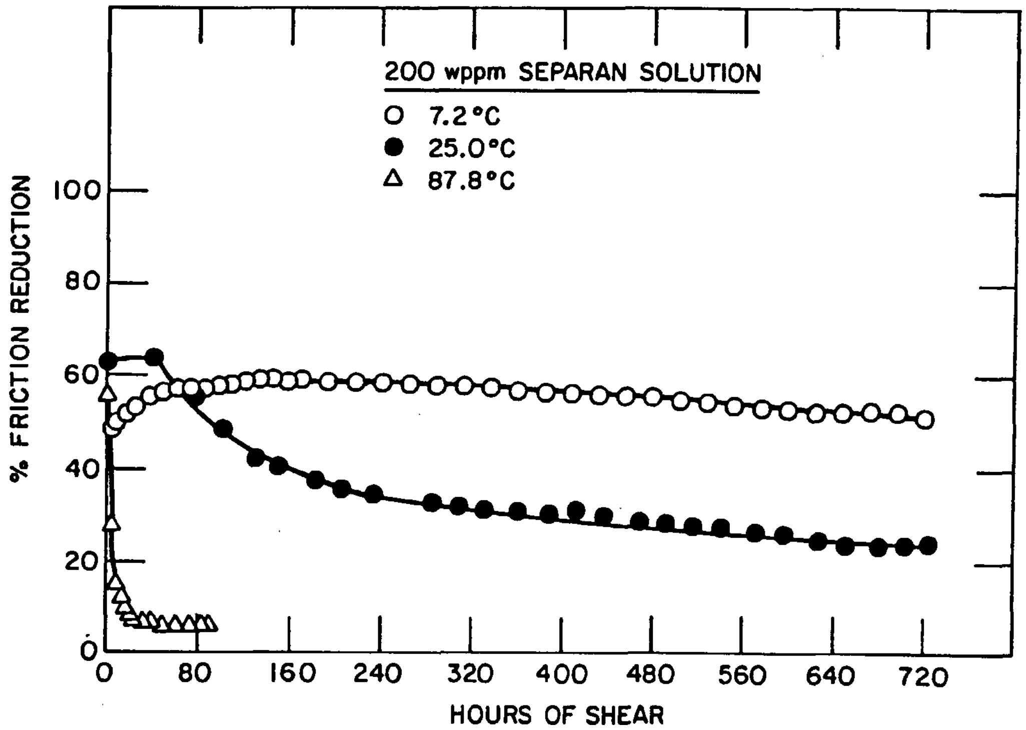


Figure 4. The Effect of Temperature on Percent Friction Reduction as a Function of Circulation Time for 200-wppm Separan Solution.