ON THE USE OF HYDRODYNAMICALLY ACTIVE ADDITIVES IN THE REFRIGERATION INDUSTRY

L. Z. Mel'tser, V. S. Kovalenko,
I. T. Él'perin, and L. I. Levental'

UDC 532.542.4

A method of reducing the hydraulic drag is discussed, namely the use of high-polymer surface active additives in the transport of coolants through medium-cold systems.

Studies made in recent years have demonstrated that, by adding very small amounts of certain high-polymer surfactants, it is feasible to reduce the hydrodynamic drag in a turbulent stream of liquid through a pipeline [1, 2, 3]. Several hypotheses have been proposed to explain the nature of this phenomenon, but neither theoretical nor applied research in this field has yielded a complete and definitive answer to the problem concerning the behavior of one or another system with traces of hydrodynamically active additives under various conditions.

It is, therefore, worthwhile to consider the feasibility of applying this method to coolant systems widely used in refrigeration engineering. For this, it is foremost necessary to establish: whether the said effect will also prevail under conditions where the coolant is an aqueous solution of a salt (NaCl, $CaCl_2$, etc.) with traces of surfactant additive, how the brine temperature and the salt concentration will affect this reduction of hydraulic drag, how a trace of surfactant additive will affect the heat transfer, how stable this drag reduction will remain with time, how traces of polymers will affect the corrosion of pipes, how economical and safe this method is, etc.

This study was concerned with some of these aspects. As additive to the brine the authors used polyacrylamide (PAA) of domestic manufacture with a molecular weight of approximately $4.5 \cdot 10^6$. Polyacrylamide is a safe and nontoxic substance [4], it reduces the corrosive wear of the inner pipe surface [5], and is less prone to breakdown than other polymer additives which have been tried recently [6]. On a special apparatus (Fig. 1) we studied the effect of PAA traces on the hydrodynamic drag in turbulent liquids experimentally. This test apparatus consisted of a vessel for preparing the brine specimen, a pump, a pipeline system with a straight segment for measurements, and a regulator for varying the flow rate. The thermal conditions were established by means of a refrigeration system with which the brine in the vessel could be cooled to prescribed temperatures. This apparatus had been designed for liquid flow in either a closed or an open circuit. High-precision laboratory instruments were used for measuring the performance parameters.

The pressure drop across the test segment as well as the temperature and the flow rate of the liquid were fixed for each test. The basic experiment was performed with aqueous solutions of NaCl and $CaCl_2$ salts over the 0-20% range of concentrations. The concentration of PAA was varied over the 0.031-0.17% range. The Reynolds number in this experiment was varied from 17,000 to 80,000, the temperature was varied from +20 to −5°C, and the velocity was varied within 1-6 m/sec.

The effect of a polymer trace on the hydrodynamic characteristics of the liquid was determined by comparing the pressure drops ΔP across the control segment of the pipeline during coolant transport with and without a trace of PAA. As a result, a relation has been obtained between the friction coefficient f and the Reynolds number Re, with the latter calculated from the viscosity of the solution. The kinematic

---

Institute of the Refrigeration Industry, Odessa. Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 25, No. 6, pp. 1064-1069, December, 1973. Original article submitted July 16, 1973.

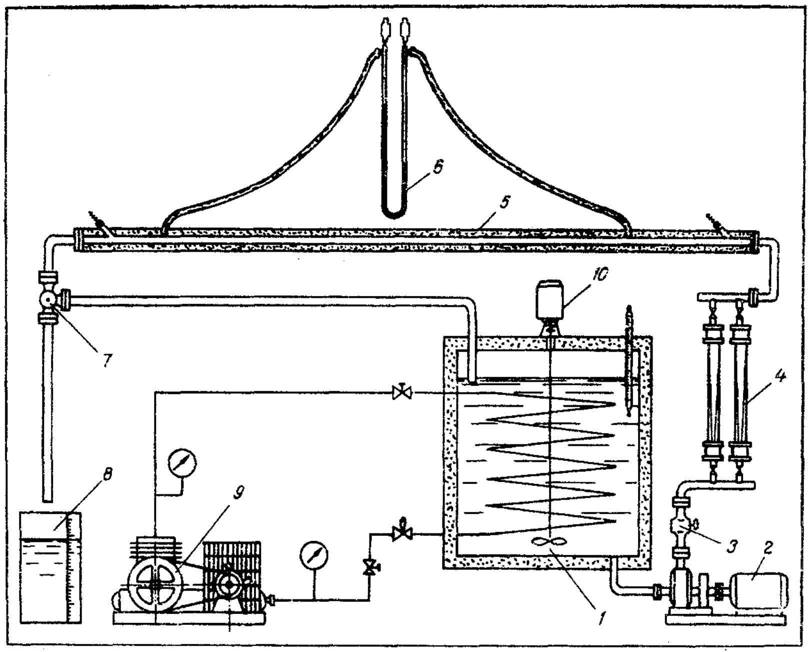

Fig. 1. Schematic diagram of the test apparatus: 1) vessel for preparing the solution, 2) pump, 3) regulating valve, 4) rotameter, 5) control segment, 6) differential manometer, 7) tee fitting, 8) graduated vessel, 9) refrigerator, 10) mixer.

viscosity of a 10% $CaCl_2$ solution is shown in Fig. 2 as a function of the temperature and of the PAA concentration. The density of the brines in this experiment was almost the same with and without traces of PAA. The hydraulic drag coefficient was calculated according to the Darcy–Weisbach equation

$$\Delta P = f \frac{l}{d} \frac{\omega^2}{2} \rho.$$

It has been established in earlier experiments with traces of PAA in NaCl solutions [7] that, as a definite "threshold" value of the Reynolds number is reached (Re_{thr}), the friction coefficient is lower when the salt solution contains a trace of polymer than when it is pure. This threshold value of the Reynolds number depends on the polymer concentration: a higher concentration results in a lower threshold. Similarly, a higher salt concentration at a constant polymer concentration has also been found to lower the threshold value of the Reynolds number [7].

The reduction of the frictional drag in a brine due to a trace of PAA in it is best characterized by an effectiveness index

$$E = \frac{f - f_P}{f} 100\%.$$

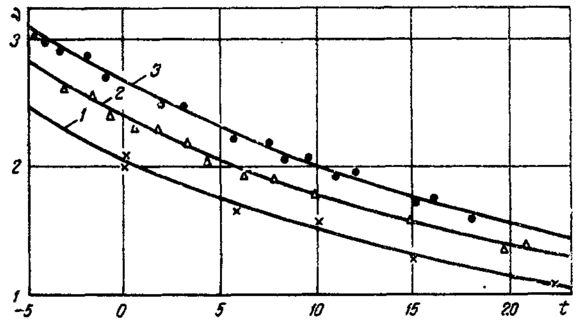

Fig. 2. Kinematic viscosity as a function of the temperature, for a 10% $CaCl_2$ solution with various concentrations of PAA: 1) $C_{PAA} = 0$, 2) $C_{PAA} = 0.07\%$, 3) $C_{PAA} = 0.1\%$.

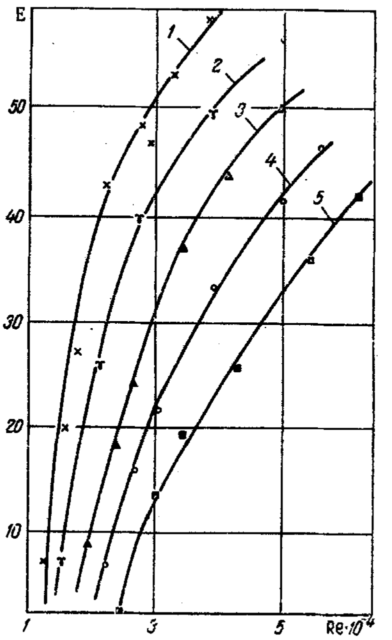

Fig. 3

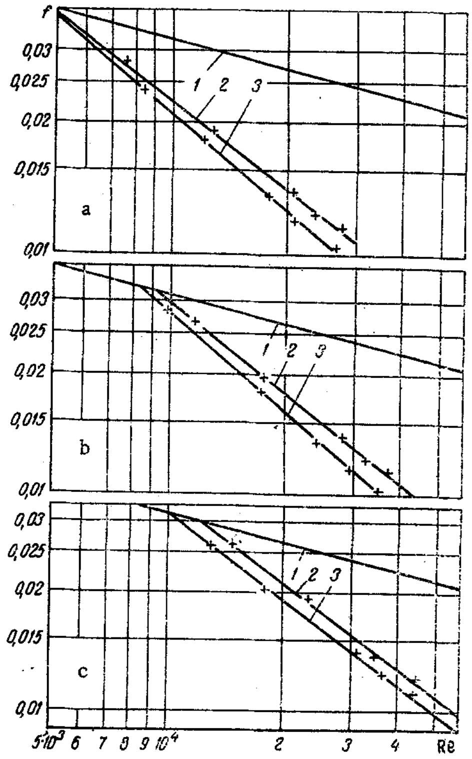

Fig. 4

Fig. 3. Drag reduction as a function of the Reynolds number, in a stream of a 10% NaCl solution with various concentrations of PAA additive: 1) C = 0.170%, 2) C = 0.130%, 3) C = 0.078%, 4) C = 0.055%, 5) C = 0.031%.

Fig. 4. Friction coefficient as a function of the Reynolds number, for a 10% $CaCl_2$ solution in water, at various concentrations of the PAA additive and at various temperatures: (a) t = −3°C, (b) t = +10°C, (c) t = +20°C; 1) C_{PAA} = 0, 2) C_{PAA} = 0.07%, 3) C_{PAA} = 0.1%.

The test data on the effectiveness of polymer additives are shown in Fig. 3 in the form of E = f(Re) curves. The graph indicates that the effectiveness of PAA increases with its concentration and also with the Reynolds number.

Data were also obtained on how the temperature of brines affects the drag reduction. The relation f = f(Re) is shown in Fig. 4 for a 10% $CaCl_2$ solution in water at various temperatures. An analysis of the curves in Fig. 4 indicates that at lower temperatures the PAA additive becomes more effective in reducing the hydraulic drag. At lower temperatures the value of Re_{thr} becomes lower too, which is analogous to the effect of increasing the concentration of salt and PAA.

The range of the polymer effectiveness is largely extended by the feasibility of lowering the threshold Reynolds number not only by increasing the concentration of salt and PAA in solutions but also by lowering the temperature of the transported liquid. This creates new technical possibilities and can ensure a successful use of hydrodynamically active additives in refrigeration systems with NaCl and $CaCl_2$ brines as coolants. The effects of polymer additives on the heat transfer in brines are still unknown. With the data in [8, 9, 10] for pure water taken as a basis, it may be assumed that a trace of polymer will also reduce the heat transfer from the coolant whenever it reduces the friction coefficient. This, according to [9], has to do with the physical mechanism of this phenomenon, namely with an increased thickness of the laminar sublayer in a turbulent stream. This negative effect of high-molecular additives on the heat transfer can be compensated by artificial turbulization of the stream in the heat transfer zone.

It is interesting to note that, according to available data in [11], the use of polymer additives also improves the performance characteristics of pumps and raises their efficiency.

One of the most serious negative aspects to be considered in assessing the practicality of technical applications here is, certainly, the attendant breakdown of the polymer [2, 14], which depends on the particular grade of material, on its concentration in the solution, on the thermal conditions, and on the mechanical effects on the transported liquid. Preliminary studies have shown that the breakdown abates at lower temperatures.

In an overall assessment of positive as well as negative factors affecting both the technology and the economics of hydrodynamically active additives, one may point out the following. Traces of polymer added to the brine in room refrigerator systems will sometimes reduce the heat dissipation on the brine side. Such a reduction of heat transfer will occur in brine evaporators, where the overall heat transmission coefficient is determined by the rate of heat transfer on the brine side. In this case, as has been mentioned earlier, the coolant stream in the evaporator can be turbulized locally by artificial means. During heat transfer in wall-mounted batteries, where the heat transfer rate is limited by the heat released on the gas side, a reduction of the heat transfer coefficient on the coolant side will not have any appreciable effect on the overall heat transmission coefficient. In a total evaluation of the effectiveness of polymer additives, it is rather important to consider also the protective action of PAA which reduces the corrosive wear of surfaces of system components.

The use of PAA can be very advantageous in already developed central cooling systems. Here the cold brine can be transported in such a way that both effects, the reduction of hydraulic drag and the reduction of heat transfer, will improve the apparatus performance.

Such systems include, for instance, existing air conditioners installed in mines where straight portions of the ductwork run 5000 m or longer.

In one budding branch of engineering, namely in refrigerated distillation of sea and mineral water, the use of surfactants may appreciably reduce the cost of transporting brine over long stretches. Some side effects are, moreover, also noteworthy here. Thus, according to the data in [12], the presence of surfactant traces enhances the formation of crystal hydrates in distillers of the hydrate type, and it significantly enhances the processes in the tailwater column, where a surface film of brine must be removed from the hydrates. This applies also to the respective processes occurring in freeze-type distillers [13].

Further research should yield more precise data on heat transfer and, especially, on polymer breakdown — such data are necessary for a definitive determination of the possible effectiveness of using PAA as a hydrodynamically active additive to coolants.

NOTATION

Re is the Reynolds number;
Re_{thr} is the threshold Reynolds number;
f is the friction coefficient in a brine;
f_p is the friction coefficient in a brine with a trace of polymer;
ΔP is the pressure drop, N/m^2;
ω is the mean (discharge) velocity, m/sec;
d is the pipe diameter, m;
l is the length of the control segment, m;
ν is the kinematic viscosity, m^2/sec;
ρ is the density, kg/m^3.

LITERATURE CITED

1. I. T. Él'perin, Author's Disclos. No. 169,955, Byull. Izobret., No. 7 (1965).
2. J. Hoyt, Trans. ASME, Theoretical Principles of Engineering Design, No. 2 (1972).
3. G. I. Barenblatt, V. A. Gorodtsov, and V. N. Kalashnikov, in: Heat and Mass Transfer [in Russian], Minsk (1968), Vol. 3.
4. M. N. Savitskaya and Yu. D. Kholodova, Polyacrylamide [in Russian], Izd. Tekhnika (1969).
5. V. M. Novikov, Abstract Dissert., Minsk (1973).
6. V. A. Bazilevich, A. N. Shabrin, and L. V. Grzhimalovskaya, Hydromechanics [in Russian], Izd. Naukova Dumka, Kiev (1972), Ed. 21.
7. L. Z. Mel'tser, I. T. Él'perin, L. I. Levental', and V. S. Kovalenko, Refrigeration Engineering and Technology [in Russian], Izd. Tekhnika, Kiev (1972), Ed. 15.

8. M. K. Gupta, A. B. Metzner, and J. P. Hartnett, "Turbulent heat transfer characteristics of viscoelastic fluids," Internatl. J. Heat and Mass Transfer, 10, No. 9 (1967).
9. S. S. Kutateladze and E. M. Khabakhpasheva, Inzh. Fiz. Zh., 18, No. 6 (1970).
10. V. N. Kalashnikov, Yu. D. Raiskii, and A. Z. Temchin, Prikl. Mekhan. i Tekh. Fiz., No. 6 (1968).
11. V. A. Avnapov and P. K. Norkin, Izv. Akad. Nauk SSSR, Ser. Tekhnicheskaya, No. 6 (1968).
12. A. A. Krasnov, Abstract Dissert., Bakinskii Gosud. Univ., Ufa (1970).
13. I. N. Medvedev, Abstract Dissert., Moscow (1965).
14. I. T. Él'perin and L. I. Levental', Teploénergetika, No. 10 (1971).