REDUCTION OF HYDRODYNAMIC RESISTANCE BY SURFACTANTS

I. L. Povkh, A. B. Stupin,
V. M. Dobrychenko, and S. N. Maksyutenko

UDC 532.135

Experimental results are given on reducing the hydrodynamic resistance in a flowing liquid by adding surfactants; the effects are ascribed to micelles.

Much importance attaches to reducing hydrodynamic resistance via additives; the technique has various practical applications, although little is known about how the additives affect the turbulent flow. Macromolecular compounds can give up to 80% reduction in the hydrodynamic resistance, for example.

High polymers are not the only such materials however; some surfactants can do the same. This was first observed for napalm moving in flame throwers [1]. Results have been reported [2] for aluminum dioleate in toluene and sodium oleate in water, where there was 30% resistance reduction. Potassium chloride added to the aqueous sodium oleate solution increased the effect. There is also considerable resistance reduction from special hard-water soaps [3]. Here we report experiments with aqueous solutions of a mixture of cetyl trimethyl ammonium bromide and 1-naphthol. We examined the effects on the pressure drop in a tube from the component ratio, the overall concentration, the temperature, and the age of the solution. Soap solutions show no molecular destruction, which gives them an advantage over polymer solutions.

There are only a few papers on the topic, and the number of results is very small, so it is difficult to trace the basic trends in resistance reduction by surfactants. Also, the mechanism is entirely uncertain.

Our purpose was to examine the effects of colloidal surfactants on the resistance and to relate the effect to the critical micelle formation concentration.

We used the apparatus described in [4]; Fig. 1a shows the magnitude of the effect $\Delta\lambda/\lambda$ as a function of the Reynolds number for various concentrations of common soap. There is a marked reduction in resistance above a certain critical Reynolds number, and the magnitude of the effect (up to 65%) increases with the Reynolds number and the solute concentration. Resistance begins to be reduced as soon as the laminar flow gives way to a turbulent one, i.e., the threshold Reynolds number coincides with the critical one. In the laminar range, the additive has an adverse effect, which increases with the concentration, on account of the increased viscosity.

The curves for the various concentrations meet the abscissa at different points, which is due to variation in viscosity and hence in the critical Reynolds number. The effect tends to a limit as the flow rate increases. Common soap includes substances that adversely affect the capacity of the surfactant to reduce the resistance, while giving a false impression of the true surfactant concentration, so the tests with soap solutions merely confirm that surfactants can reduce the resistance.

More rigorous results were obtained with pure substances and distilled water. Figure 1b shows $\Delta\lambda/\lambda$ as a function of concentration C of the surfactant. We used pure sodium palmitate and mixtures of sodium palmitate and potassium stearate in various ratios.

The pure sodium palmitate begins to reduce the resistance at a certain initial concentration (C = 0.065%); the value of $\Delta\lambda/\lambda$ increases with the concentration and attains its maximum of $\Delta\lambda/\lambda$ = 28% at a

---

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 27, No. 4, pp. 682-686, October, 1974. Original article submitted October 10, 1973.

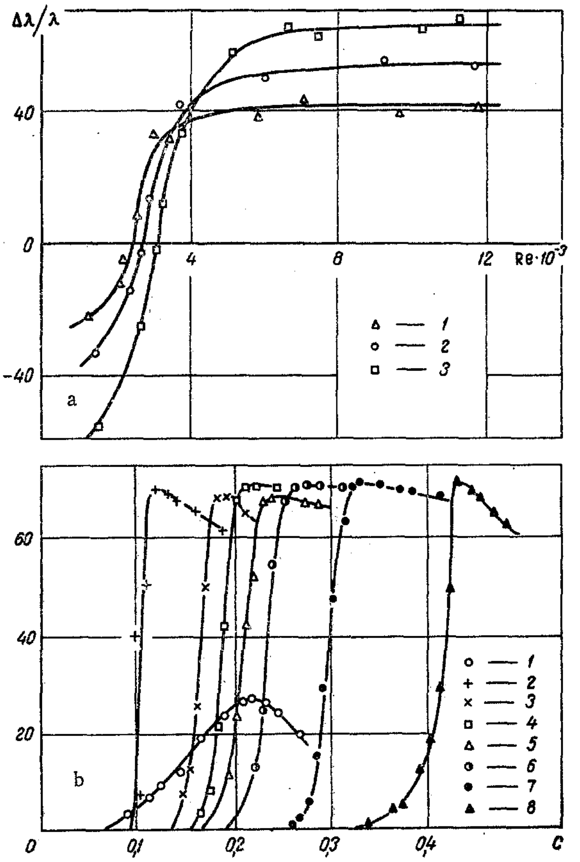

Fig. 1. Resistance reduction $\Delta\lambda/\lambda$ (%) in a tube of diameter 6 mm as a function of Reynolds number deduced for the viscosity of the solvent: a) ordinary soap solutions for C (%) of: 1) 0.5; 2) 0.8; 3) 1.1; b) sodium palmitate (%) + potassium stearate (%): 1) 100 + 0; 2) 90 + 10; 3) 70 + 30; 4) 60 + 40; 5) 55 + 45; 6) 50 + 50; 7) 40 + 60; 8) 30 + 70.

certain optimal concentration (C = 0.22%). The effect then begins to fall. This dependence of $\Delta\lambda/\lambda$ on the concentration agrees qualitatively with the data for weak polymer solutions.

Curves 2-8 of Fig. 1b show $\Delta\lambda/\lambda$ for aqueous solutions of the sodium palmitate and potassium stearate mixtures with various proportion, the effect is much increased by the use of a mixture and attains its maximum ($\Delta\lambda/\lambda$ = 72%) for all ratios. Higher mixture concentrations are required to produce the effect as the proportion of potassium stearate increases.

A sodium palmitate concentration in the range of C = 0.09—0.0975% is required to produce the effect in the mixed solutions, so the sodium palmitate plays the main part; on the other hand, the potassium stearate considerably accentuates the reduction (up to 72%) and in some way catalyzes the resistance reduction.

We determined the critical micelle formation concentration by measuring the electrical resistance [5] to relate the reduction in hydrodynamic resistance to the micellar structure.

Figure 2 shows the results; it is currently considered [6] that low concentrations (up to the first kink) produce true solutions of soap-like surfactants, i.e., the surfactant is present in molecular (ionic) form. At higher concentrations, the individual molecules spontaneously clump together, with the hydrocarbon radicals linked by van der Waals forces within the core of the micelle, while the polar groups are directed into the water phase. The bulk properties of the solution are much affected by these micelles, in particular the electrical resistance. The first kink (Fig. 2) corresponds to micelle production, and the

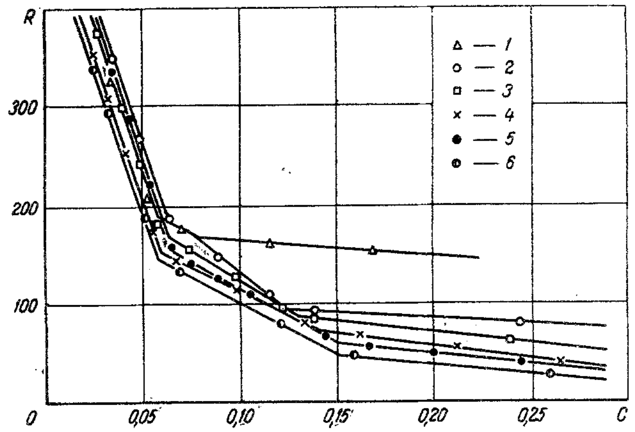

Fig. 2. Reduction in resistance R (Ohms) as a function of concentration C (%) for sodium palmitate (%) + potassium stearate (%): 1) 100 + 0; 2) 90 + 10; 3) 70 + 30; 4) 50 + 50; 5) 30 + 70; 6) 0 + 100.

corresponding concentration is called the first critical concentration, where one gets Hartley micelles, which are spherical groups of molecules or ions.

The sizes of the micelles increase with the surfactant concentration, and the hydrocarbon chains tend to become more and more parallel. The result is that the micelles become of rod or plate forms. This point corresponds to the second kink on the curve, namely the second critical concentration.

The following explanation may be proposed. Low sodium palmitate concentrations produce spherical micelles, which become rods at higher concentrations; potassium stearate increases the number of free ions in such a solution, and this increases the number of counter ions linked to the micelles, so the charge on the latter is reduced. This reduces the effective electrolytic work against the repulsive forces needed to inject a micelle-forming ion into a charged micelle. This therefore facilitates micelle formation, and thus accentuates the resistance reduction. As the potassium stearate concentration increases, the magnitude of the effect remains the same, but the effect itself shifts to higher concentrations.

The reason would appear to be that potassium stearate cannot produce rod micelles of the size needed to reduce the resistance. A confirmation is that potassium stearate alone increases the hydrodynamic resistance.

Figures 1b and 2 show that the resistance is reduced only at surfactant concentrations above the first critical point, which indicates that the effect is related to the micellar structure.

It has been claimed [7] that a surfactant acts on a turbulent flow by rendering the surface hydrophobic, with the resulting slip and viscosity reduction in a thin layer near the wall. We consider that the resistance is reduced because of the rod micelles, as is evident from the variation in the critical concentration, so we suppose that the resistance is reduced by a mechanism analogous to that suggested [8] for weak polymer solutions.

NOTATION

C, concentration; R, electrical resistance; Re, Reynolds number; λ, resistance coefficient.

LITERATURE CITED

1. G. Karol Mysels, Chem. Eng. Propr. Symp. Ser., 67, No. 111 (1971), p. 45-49.
2. G. K. Patterson, J. L. Zakin, and J. M. Rodriguez, Industrial and Engineering Chemistry, 61, No. 1, January (1969), p. 22-30.
3. Jacques L. Zakin, Michael Porch, Aviel Brosh, and Moshe Warshavsky, Chem. Eng. Propr. Symp. Ser., 67, No. 111 (1971), p. 85-89.
4. I. L. Povkh and A. B. Stupin, Inzh.-Fiz. Zh., No. 1, 59-65 (1972).

5. Practical Colloidal Chemistry [in Russian], Vysshaya Shkola, Moscow (1972).
6. K. Shiroda, T. Nakagaway, B. Tamamushi, and T. Isemura, Colloidal Surfactants [Russian translation], Mir, Moscow (1966).
7. I. T. El'perin, B. M. Smol'skii, and L. I. Levental', Izv. AN BSSR, Ser. Tekh., No. 3, 42-48 (1965).
8. I. L. Povkh and A. B. Stupin, Zh. Prikl. Mat. Tekh. Fiz., No. 1, 63-68 (1972).