HEAT TRANSFER TO EMULSION WITH SUPERHEATING OF ITS DISPERSE PHASE

N. V. Bulanov, V. P. Skripov,
and V. A. Khmyl'nin

UDC 536.24+536.423

The article presents the results of measurements of the heat-transfer coefficient at atmospheric pressure in the heat exchange of thin wires with emulsions consisting of water dispersed in organosilicon liquid PMS-300.

Emulsions are used in engineering for cooling tools and equipment, in the heat treatment of metals, and for many other purposes. Sometimes the greatest effect can be obtained by using emulsions whose disperse phase is superheated on a cooled surface and in the layer adjacent to it [1, 2].

The present article deals with the measurement of the heat-transfer coefficient at atmospheric pressure from the surface of platinum wire to the organosilicon liquid PMS-300 or to an emulsion consisting of water dispersed in the liquid PMS-300. The temperature of the wire was raised to above the boiling point of water, therefore the drops of water in the emulsion could be superheated on its surface and in the adjacent layer. In the experiments we used platinum wire with 0.20-mm diameter, 72 mm long. The wire served simultaneously as heater and as resistance thermometer [2]. The heat-transfer coefficient was determined while the heat-transfer agent (emulsion or liquid PMS-300) was pumped through a heat-insulated glass cylinder with 50-mm diameter, with the heated wire being stretched along the axis of the cylinder. The through-rate of heat-transfer agent was established approximately equal to 0.01 m/sec. At such a flow rate the conditions of heat exchange in the present experiments did not differ much from the conditions with free convection in a large volume [3-5]. Moreover, the temperature of the heat-transfer agent before and after passage through the cylinder did not change by more than 0.1°C.

The emulsion was prepared by intensive mixing of the initial liquids in a thermostat. The initial liquids were distilled water and organosilicon liquid PMS-300 that was not subjected to any additional purification whatsoever. The boiling point of PMS-300 at atmospheric pressure is approximately 300°C. The emulsions were prepared without the use of emulsifiers because we wanted to avoid side effects that the presence of emulsifiers may entail. The obtained emulsions were fairly stable. This was due to the fact that the densities of the initial liquids were close to each other. In all experiments the disperse phase was water.

The dispersity of the emulsion was determined under a microscope POLAM R111 with 600 × magnification. The mean volume diameter of the drops [6, p. 157] was 0.005 mm. The concentration of the emulsion was specified in terms of the volumes of the initial liquids. The experiments were carried out at a concentration of water in the emulsions equal to 0.8 and 3.2 vol. %. After the end of each series of experiments the concentration was determined once more. For that, a small volume of emulsion (∿ 50 ml) was taken, weighed, then the water was evaporated from it and it was weighed again. Knowing the weight before and after evaporation, we found the concentration. Evaporation was carried out at 250°C in a small flask with a long, narrow neck. The error in determining the concentration amounted to ± 0.1%.

Heat transfer was studied with the wire in a vertical position and with the temperature of heat-transfer agent T equal to 40 or 99°C. We measured the following magnitudes: electric current I passing through the wire; voltage drop U on it; the temperature of the heat-transfer agent T (emulsion or PMS-300) at a distance of 20 mm from the central part of the wire;

Section of Physicotechnical Problems of Power Engineering, Ural Science Center, Academy of Sciences of the USSR, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 46, No. 1, pp. 5-8, January, 1984. Original article submitted October 11, 1982.

0022-0841/84/4601-0001$08.50

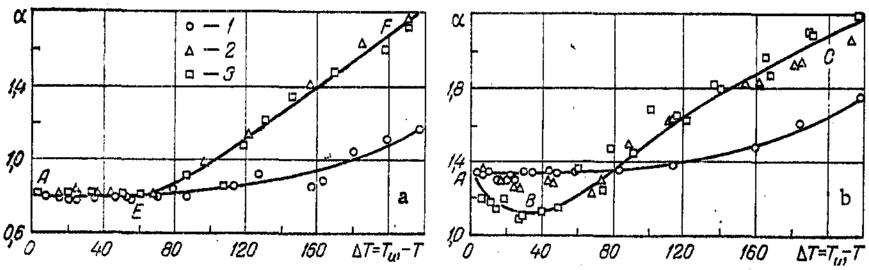

Fig. 1. Dependence of the heat-transfer coefficient α (kW/m² · deg) on the temperature head $\Delta T = T_w - T$ (°C): 1) pure organosilicon liquid PMS-300; 2, 3) emulsions with volume concentration of water in them equal to 0.8 and 3.2%, respectively (a: T = 40°C; b: T = 99°C).

the concentration of the emulsion. From the current I and the voltage U we determined the heat flux $Q = UI$ and the resistance of the wire $R = U/I$. From the resistance R and the calibration curve obtained in separate experiments we determined the temperature of the wire which did not differ noticeably from the surface temperature of the wire T_w. The heat-transfer coefficient was calculated by the formula $\alpha = Q/S(T_w - T)$. Here, $S = \pi Ld$ is the surface area of the wire, L is its length, and d its diameter.

The results of measurements of the heat-transfer coefficient α are presented in Fig. 1.

Figure 1a shows the results of measurements of α to heat-transfer agents heated to 40°C. It can be seen from the figure that α is weakly dependent on the concentration of the emulsion, and in the range of temperature differences ΔT from 0 to 60°C the heat-transfer coefficients for emulsion and for the liquid PMS-300 practically coincide. It may therefore be assumed that the intensity and the nature of heat exchange practically do not change here when we change over from the pure liquid PMS-300 to emulsion. We want to point out that with $\Delta T < 60$°C the surface temperature is lower than the boiling point of water, and the heat exchange with the emulsion is determined chiefly by free convection. The small difference between α for emulsion and α for PMS-300 is a consequence of the small difference between their thermophysical properties because the emulsions used here had small concentrations of water.

At the temperature difference $\Delta T = 60$°C there begins an abrupt increase of the heat-transfer coefficients α for emulsions (section EF, Fig. 1a). Such an increase is due to the turbulization of the surface layer of the heat-transfer agent caused by the boiling up of drops of water on the heating surface. With increasing temperature, the number of drops boiling up increases as well as the degree of turbulization of the surface layer caused by each drop that boils up. However, the number of superheated and boiling up drops increases with increasing concentration. The weak dependence of α on the concentration therefore seems to be somewhat unexpected. But it must be pointed out here that when the concentration of the water drops increases, there is, in addition to the positive effect of turbilization of the surface layer, also the negative effect caused by the increasing volume of vapor formed when the drops of water boil up. The forming vapor shields the heat-releasing surface, and this impairs the conditions of heat exchange. With the concentrations that were studied, the positive and negative effects apparently compensated each other, and the coefficient α was not dependent on the concentration.

Furthermore attention should be drawn to the astonishing fact that the abrupt increase of α begins practically immediately after the heat-releasing surface has attained the boiling point of the disperse phase (water). That means that the drops of water begin to boil up already at the smallest superheating. In connection with that we point out that for a number of pure liquids (water was not investigated) with heat exchange under conditions analogous to ours, we find delay in boiling [3-5], and the superheating of the liquid in the layer near the wall attains many tens of degrees. In heat exchange with emulsion, where the boiling liquid is dispersed and its direct contact with the heating surface is impeded by the layer of the dispersed medium, it would seem that a large delay of boiling up of the drops of water should be expected, as well as coincides between the dependence of α on ΔT for emulsion and the curve for pure PMS-300, also in the range of small and moderate superheating. However, this was not confirmed by our experiments.

Figure 1b shows the results of measurements of the heat-transfer coefficient α to heat-transfer agents heated to 99°C. There are no fundamental differences in heat exchange with PMS-300 heated to 40 and to 99°C. In both cases the heat-transfer coefficient increases slightly with increasing ΔT. However, the nature of heat exchange with emulsions changes greatly in dependence on whether they are heated to 40 or to 99°C. This is so because when the temperature of the emulsion is equal to 99°C, the drops of water are heated practically to the temperature of equilibrium boiling of water. At this temperature the forming vapor condenses badly when leaving the heating surface, and it is shielded much more than previously at $T = 40°C$. The conditions of heat transfer become poorer, the coefficient α drops (section AB). At high superheating, where the nature of the boiling up [7] of the drops of water is explosive, the layer next to the wall is intensely turbulized, and the heat-transfer coefficient again increases rapidly (section BC). The dependence of α on the concentration of water is here very weak, too.

In conclusion, it should be pointed out that the intensity of heat exchange with emulsions in both cases greatly increases at temperatures of the heat-releasing surface close to the temperature of maximum superheating T_m of the disperse phase, i.e., water ($T_m = 310°C$). The value of α is 1.3-1.5 times greater than for a pure disperse medium (PMS-300) or for an emulsion with small ΔT, and such an increase of intensity is attained with small concentrations of water in the emulsion (0.8 vol. %).

NOTATION

α, heat-transfer coefficient; $\Delta T = T_w - T$, temperature head equal to the difference between the temperature of the heat-releasing surface T_w and the temperature of the heat-transfer agent in the bulk T.

LITERATURE CITED

1. N. V. Bulanov, V. P. Skripov, and N. A. Shuravenko, "Method of cooling a surface with a liquid heat transfer agent," Inventor's Certificate No. 653501 M. cl.^{2} F28F13/02, Byull. Izobret., No. 11, 136-137 (1979).
2. N. V. Bulanov, V. P. Skripov, and N. A. Shuravenko, "Heat transfer to emulsion with high superheating of its disperse phase," Inzh.-Fiz. Zh., 42, No. 2, 236-238 (1982).
3. L. V. Biryukova, N. N. Danilov, and E. N. Sinitsyn, "Superheating of pure liquids and of binary solutions in convective heat exchange with thin wire," in: The Thermophysics of Metastable Systems, Ural Science Center, Academy of Sciences of the USSR, Sverdlovsk (1977), pp. 16-22.
4. V. P. Skripov and N. V. Bulanov, "Heat exchange under conditions of strong inhibition of boiling," in: Hydrodynamics and Heat Exchange, Ural Science Center, Academy of Sciences of the USSR, Sverdlovsk (1972), pp. 41-50.
5. V. P. Skripov and N. V. Bulanov, "Convective heat exchange of a metastable liquid with inhibition of boiling," Inzh.-Fiz. Zh., 22, No. 4, 614-617 (1972).
6. F. Sherman (ed.), Emulsions [Russian translation], Khimiya, Leningrad (1972).
7. V. P. Skripov, E. N. Sinitsyn, P. A. Pavlov, et al., The Thermophysical Properties of Liquids in the Metastable State (Handbook) [in Russian], Atomizdat, Moscow (1980).