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HEAT TRANSFER AND VAPORIZATION IN THE BOILING OF A SURFACTANT SOLUTION IN STEAM GENERATORS

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Results are presented from an experimental study of heat transfer and vaporization in the boiling of a solution of octadecylene under atmospheric pressure at different heat fluxes and concentrations.

There has recently been a trend toward the use of surface-active agents (SAA) in steam turbines. This development is related to the need to actively influence the process of vapor expansion and control the structure and characteristics of high-velocity flows of supersaturated and moist vapor, which leads to an increase in turbine efficiency and a decrease in the erosion of the through parts of the turbine. One procedure is the introduction of the surfactant octadecylene (ODA) into the vapor flow ahead of the turbine [1-3]. After condensation of the vapor, the ODA may be returned together with the condensate to the turbine. Such use of ODA raises the need to examine the effect of its addition on heat transfer and vaporization on the heating surface. Heat transfer was found to be improved in earlier experiments [4, 5] in which different surfactants were added to a boiling medium. This result is explained by a reduction in the surface tension of the solution and a corresponding increase in the number of centers of vapor formation on the heating surface and the frequency of bubble generation, which leads to intensive agitation of the thermal boundary layer.

In our studies, we used an experimental unit which simulated a vaporizing apparatus of the boiling type [6]. The heating surface was a horizontal copper tube 34 mm in diameter and 120 mm in length, enclosing an electric heater. The vaporizing chamber, 9 liters in volume, was placed in an air thermostat. The dynamics of vapor formation were studied visually and by filming in two projections. Heat flux was determined from the electric power supplied to the working section, and the temperature of the heating surface was measured by the compensation method using six thermocouples placed in the heating surface about its perimeter. The error of the heat-transfer coefficient measurement was no greater than 8-12%. The concentration of ODA in the solution was determined by measuring the intensity of methyl orange coloration of the ODA reaction product extracted with chloroform. The ranges of the parameters: pressure 100 kPa, heat flux 40-120 kW/m^2, ODA concentration 0.3-70 mg/liter.

The main tests were conducted with open-cycle operation of the unit, i.e. the condensate from the condenser was discarded and the level in the vaporization chamber was maintained by making up the solution with distillate heated to 1-2°K below the saturation temperature. Since ODA volatilizes with steam [7], it was also removed from the unit with the condensate. During the experiment, we also measured the temperature of the wall of the heating tube and sampled the solution to analyze the ODA concentration.

The tests with the ODA solution were conducted by vaporizing it over 2-3 h with an initial concentration of 50-70 mg/liter. The tests established that boiling of the solution for 0.5-1.5 h reduces the concentration of ODA in the solution to 0.3-0.5 mg/liter, which corresponds to the sensitivity of the method used to determine the concentration (Fig. 1). The concentration of ODA in the solution decreased quite a bit more slowly in the tests with closed-cycle operation of the unit (return of the condensate from the condenser to the vaporizing chamber), since the ODA was returned to the chamber along with the condensate.

The ODA is vaporized more rapidly from the solution with an increase in heat flux from

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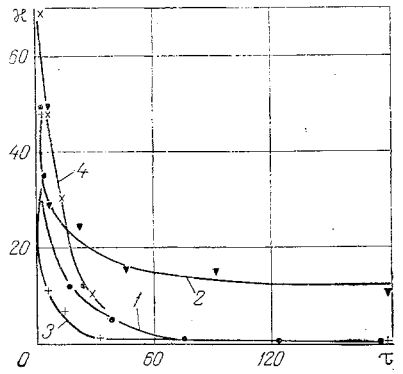

Fig. 1. Reduction in concentration of octadecylene in solution as a function of time of vaporization, P = 100 kPa: 1, 3, 4) q = 40, 80, 120 kW/m², discharge of condensate; 2) q = 40 kW/m², return of condensate to vaporizing chamber, ϰ, mg/liter; τ, min.

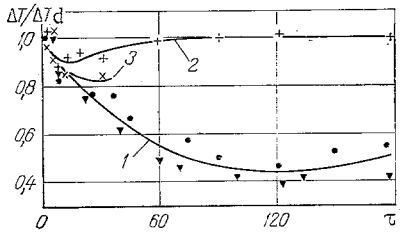

Fig. 2.

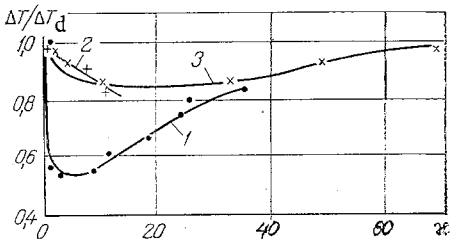

Fig. 3.

Fig. 2. Change in relative temperature head over time with boiling of an octadecylene solution, P = 100 kPa; 1, 2) q = 40, 80 kW/m², $\varkappa_0$ = 50 mg/liter; 3) q = 120 kW/m², $\varkappa_0$ = 70 mg/liter.

Fig. 3. Effect of concentration of octadecylene on the relative temperature head, P = 100 kPa: 1) q = 40; 2) 80; 3) 120 kW/m².

40 to 80 kW/m². Thus, the concentration of ODA decreases to $\varkappa$ = 0.3-0.5 mg/liter in 1.5 h at 40 kW/m² and in 0.5 h at q = 80 kW/m² (Fig. 1). The ODA concentration decreases even more rapidly at a heat flux of 120 kW/m².

The completed studies of the effect of ODA content on heat transfer showed that the wall—liquid temperature head decreases when it is introduced into the boiling medium, i.e. heat transfer is increased (Fig. 2). Data on temperature head is shown in the graph as a relative quantity — in relation to the temperature head in distillate boiling.

It follows from the figure that the dependence of the temperature head on vaporizing time (and, accordingly, with a decrease in the concentration of ODA) is of an extreme nature: the head increases after decreasing for a certain period of time, with the value of ΔT_i approaching the value in distillate boiling. The amount of time over which the head decreases sharply depends on the heat flux.

The heat-transfer rate obtained when ODA is added in solution also depends on the heat flux. Thus, at the extreme fluxes of 40 kW/m² and 80 kW/m², heat transfer is increased by factors of two and 1.1, respectively. Comparing this data with the data in Fig. 1, it can be seen that the heat-transfer maximum corresponds to the attainment of an ODA concentration of 3-10 mg/liter, depending on the heat flux. With further vaporization, the concentration of ODA decreases and then remains roughly constant, and heat transfer deteriorates. This is evidently connected with a reduction in the concentration of ODA adsorbed on the heating surface.

Figure 3 shows the results of the experiments in the form of the dependence of the temperature head on the concentration of ODA. It follows from the graph that the heat-transfer maximum corresponds to an ODA concentration of 3-10 mg/liter in the solution, with heat-transfer deteriorating at higher concentrations.

We conducted an experiment in which we added a moderate quantity of ODA to a clean vaporizing chamber that had been washed with isopropyl alcohol and distillate. The initial concentration of ODA (measured 1 min after its introduction) was 2.5 mg/liter. There was a brief improvement in heat transfer. This supports the conclusions reached from the initial tests to the effect that an ODA concentration of 3-10 mg/liter has to be maintained in the solution to preserve a stable adsorption film of the SAA on the heating surface.

In conclusion, it should be noted that addition of ODA to the distillate and the associated increase in heat transfer are accompanied by a change in the dynamics of vaporization — the separation diameters of the vapor bubbles decrease and the total number of such bubbles increases. The dimensions of the bubbles and the frequency of their separation are restored over time as the ODA is vaporized from the chamber. The heat-transfer maximum corresponds to the minimum vapor-bubble separation diameter and the maximum number of vapor bubbles.

NOTATION

q, heat flux, kW/m^2; P, pressure, kPa; ΔT_i, temperature head during solution boiling, K; ΔT_d, temperature head during distillate boiling, K; $\varkappa$, solution concentration, mg/liter; $\varkappa_0$, initial concentration, kg/liter; τ, time, sec.

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