EFFECT OF DISSOLVED GAS ON FREE-CONVECTIVE HEAT TRANSFER IN n-HEPTANE AT SUPERCRITICAL PRESSURES

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Results are presented from a study of heat transfer for different concentrations of nitrogen dissolved in n-heptane at supercritical pressures in a large volume. The heat transfer takes place in a large volume. It is shown that even small concentrations of the gas may significantly change the heat transfer.

The effect of a dissolved gas on heat transfer at subcritical pressures is well known. The gas, given off as bubbles on the heat-emitting surface, lowers the boiling point and intensifies heat transfer [1]. A large class of heat-exchanging devices works at pressures $p > p_{cr}$, and the heat carrier in these cases sometimes contains dissolved gases. It is interesting to study the dynamics of gas evolution under these conditions and its effect on heat transfer.

The present work reports some results of a study of heat transfer at supercritical pressures in n-heptane previously saturated with nitrogen. The experiments were conducted on a unit which uses a laser diffraction interferometer with the design in [2] (Fig. 1).

The interference pattern on the screen of this instrument is a combination of light and dark bands which, in our case, can be interpreted as lines of equal density or isotherms.

The above method makes it possible, in the case of a large increase in the thermal boundary layer, to visually observe processes occurring in the layer with a change in the temperature of the heater and the interaction of the layer with the evolving gas, which is particularly important in the present case. The heating element 1 and resistance thermometer was a horizontal platinum wire with ∅ 0.1 mm and a length of 42 mm. An electrical current was passed through this wire. The wire was connected to current leads 2 designed so as to compensate for thermal expansion. The wire and leads were placed in the cylindrical, thermostatted working chamber 3, equipped with windows 4 made of optical glass located diametrically. The n-heptane was

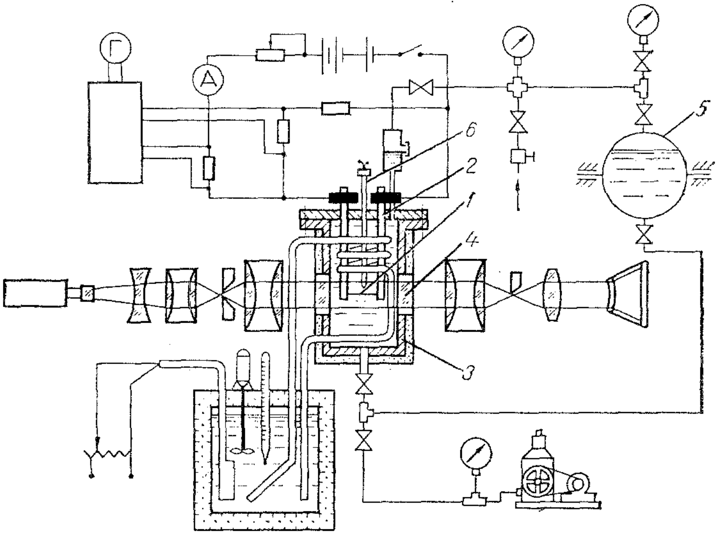

Fig. 1. Diagram of the experimental unit.

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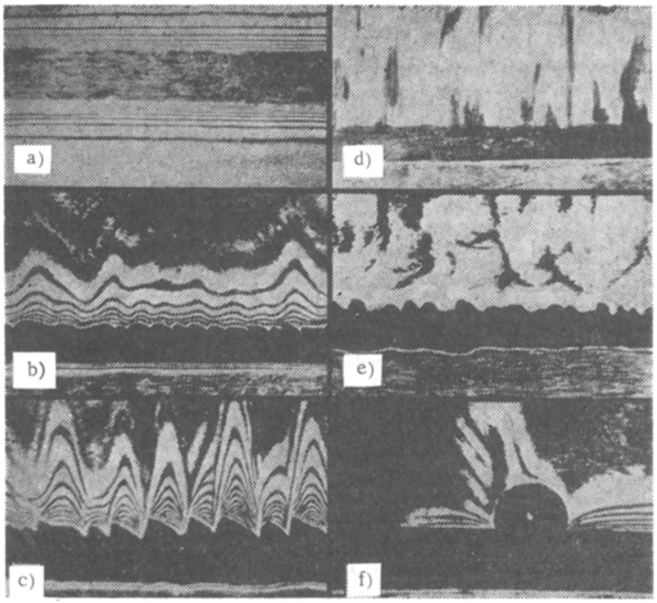

Fig. 2. Interferograms of heat-exchange processes at supercritical pressures in n-heptane (p = 38 bar, t_q = 20°C): a, b, c, d) c = 0; e) $11.3 \cdot 10^3$; f) $15.5 \cdot 10^3$ normal ml N_2/1 kg C_5H_{12}; a) t_{wa} = 41; b = 216; c = 270; d = 337; e = 203; f = 88°C.

saturated with nitrogen beforehand in a container 5 at different pressures and a constant temperature of 20°C. The concentration of nitrogen was determined by calculation. We used chemically pure n-heptane (p_{cr} = 33.6 bar; t_{cr} = 196.6°C) from which water had been removed previously by the distillation method. The temperature of the n-heptane was measured with a Chromel–Copel thermocouple 6 and did not exceed 400°C. The experiments were conducted with a smooth gradual change in the thermal load in the pressure range from 33.6 to 50 bar.

The experimental results obtained at a pressure of 38 bar and t_q = 20°C are shown in Figs. 2 and 3. Dissolved gas was nearly absent, since it had been previously removed by evacuation and boiling of the working chamber. No transitional regimes of "quasiboiling" were observed. A thermal boundary layer in the form of interference bands was formed around the wire from the moment of load application (Fig. 2a). The weak convective flows are symmetrically arranged relative to the cross section of the wire and its length. An increase in t_{wa} is accompanied by deformation of the thermal boundary layer, and intensive laminar convection is clearly expressed through ascending flows which shift in the horizontal direction to one side and then the other (Fig. 2b and c). The boundary-layer deformation is evidently due to destabilization of the interface between the heated layer and the core of the liquid due to a sharp difference in their physical properties. A further increase in the temperature of the wire is accompanied by a transition from laminar to turbulent convection (Fig. 2d). The dependence of the heat flux on the temperature head is shown in Fig. 3a.

The heat-transfer coefficient has a slight maximum near the pseudocritical temperature.

At low concentrations of nitrogen in the n-heptane (c = 163 and 1000 normal ml N_2/1 kg C_5H_{12}) there is a deterioration in heat exchange when t_{wa} is above 170°C (Fig. 3a and b). This is probably due to the fact that the gas evolved next to the heater envelops it and prevents its cooling. At high gas concentrations, heat transfer decreases when heat flux is low. This can be explained by a change in the physical properties – especially λ – when gas content increases. Gas evolution begins with an increase in t_{wa} and the thermal boundary layer is destroyed. Easily visible are structures similar to bubbles which differ sharply in density from the liquid (Fig. 2e) and are not completely spherical. Their cross section is roughly equal to the diameter of the wire. These "bubbles" pulsate actively, the frequency of the pulsations increasing with an increase in q. Visually, the process resembles the boiling of a subheated liquid. The evolved gas agitates the boundary layer above the wire and strongly intensifies heat transfer. It can be seen from Fig. 3a (c = 4000, c = 11,300 normal ml N_2/1 kg C_5H_{12}) that the section characteristic of boiling at $p < p_{cr}$ appears. At higher heat fluxes, heat transfer deteriorates sharply because the gas fills the entire zone about the heater.

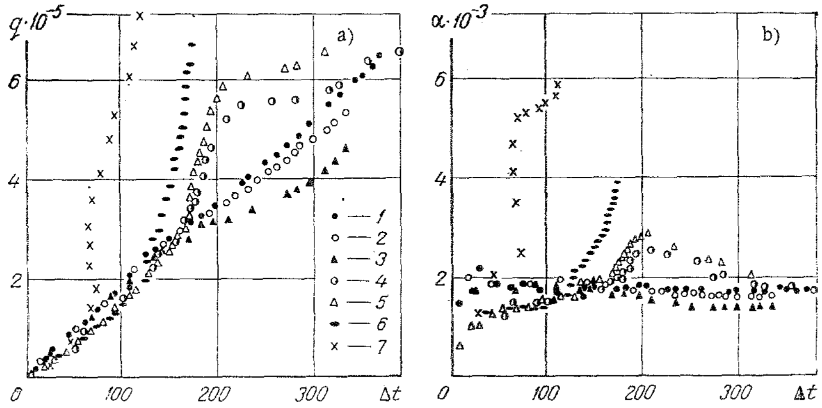

Fig. 3. Dependence of heat flux q ($J/m^2 \cdot sec$) (a) and heat-transfer coefficient α ($J/m^2 \cdot deg$) (b) on the temperature heat Δt (°C) for different concentrations of nitrogen in n-heptane: 1) c = 0; 2) 163; 3) 10^3; 4) $4.0 \cdot 10^3$; 5) $11.3 \cdot 10^3$; 6) $15.5 \cdot 10^3$; 7) $16.3 \cdot 10^3$ normal ml N_2/1 kg C_5H_{12}.

It should be noted that the temperature at which intensive gas evolution begins at gas concentrations near equilibrium may be much lower than the temperature associated with the maximum specific heat (Fig. 3a, c = 15,500, c = 16,300 normal ml N_2/kg C_5H_{12}) and reaches the latter only at heat fluxes which several times exceed q at c = 0. In this case, the heat-transfer process resembles normal boiling, the bubbles are nearly spherical, and heat exchange between the bubbles and the liquid occurs in the same manner as with normal vapor–gas bubbles [2].

The completed study allows us to conclude that the effect of a dissolved gas on heat exchange may find practical application in heat exchangers working at pressures $p > p_{cr}$, especially since the presence of dissolved gases has a positive effect on reducing high frequency pressure fluctuations in heated channels, as this occurs at subcritical pressures [3, 4].

NOTATION

c, concentration, normal ml N_2/1 kg C_5H_{12}; q, heat flux, $J/m^2 \cdot sec$; α, heat-transfer coefficient, $J/m^2 \cdot sec \cdot deg$; λ, thermal conductivity of the liquid; p_{cr}, critical pressure, bar; t_{wa}, t_q, temperatures of wall and liquid (far from the heating surface), °C; t_m, temperature corresponding to the specific-heat maximum at constant pressure, °C; $\Delta t = t_{wa} - t_q$, temperature head, °C.

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