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HEAT EXCHANGE IN CONDENSATION OF R227 COOLANT ON INCLINED TUBES PLACED IN A GRANULAR BED

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Heat exchange in condensation of R227 coolant on inclined tubes placed in a granular bed has been investigated experimentally. The plots of the heat-transfer coefficient as a function of the temperature head for different angles of inclination of the tube have been given.

The processes of phase transition on surfaces located in granular media have been of increasing interest in recent times. Such processes occur in the case of extraction of the heat of deep-seated formations with the so-called "underground chamber," when thermal methods of intensification of oil recovery by pumping a vapor into the critical area of formation are employed, in the chemical industry in packed columns and chemical reactors with granular catalyst beds, in regenerative heat exchangers, in heat pipes, etc.

There are experimental [1–3] and theoretical [4, 5] works on studying heat exchange in condensation on vertical and horizontal tubes placed in a granular bed. In practice, however, we have condensation processes on surfaces located at a certain angle to the gravitational vector.

In [6–8] on investigation of the process of condensation on smooth inclined tubes, it has been shown that the angle of inclination exerts a significant influence on the heat-transfer coefficient. The mutual direction of the surface-tension forces and the gravity force determines the hydrodynamics of flow of a condensate film and consequently the intensity of heat exchange. In this work, we present results of experimental investigation of heat exchange in condensation of the vapor of R227 coolant on a tube placed in a granular bed and arranged at different angles of inclination to the horizon. Charges of glass spheres of diameter d = 0.8 and 1.1 mm were employed as the granular bed.

The experiment has been conducted on an automated bench whose diagram is presented in Fig. 1. The body of the bench consisted of two cylindrical vessels located at an angle to each other. One vessel acted as a hot-water boiler 1, whereas the other acted as condenser 2. Windows with quartz glasses were installed in the shell of the condenser and the hot-water boiler for visual observation of the process and monitoring of the liquid level. Coil pipe 13 from a copper tube, to which hot water was supplied by thermostat 10, was installed in the cavity of the hot-water boiler. The vapor formed as a result of boiling arrived at the working portion 3 of the condenser; as the working portion, we employed a copper tube of outside diameter D = 8 mm and length L = 400 mm with cover 22 from a network closed by plugs at the ends. A granular bed 24 consisting of glass spheres was charged into the cavity between the cover and the tube.

In condensation, heat was removed from the working portion by cooling water arriving from a constant-level tank 5. The flow rate of the water was controlled by valve 6. The working portion was set up at different angles to the horizon with the use of the hinged support 14.

In the course of the experiment, we measured the following parameters: a) the temperature of cooling water at the inlet and outlet of the working portion (by Chromel-Copel thermocouples); b) the temperature of the working-portion wall (with the use of ten Chromel-Copel thermocouples caulked-in in two cross sections of the tube); c) the pressure in the working volume (by a Sapfir pressure transducer); d) flow rate of the cooling liquid (by an RS-5 flowmeter).

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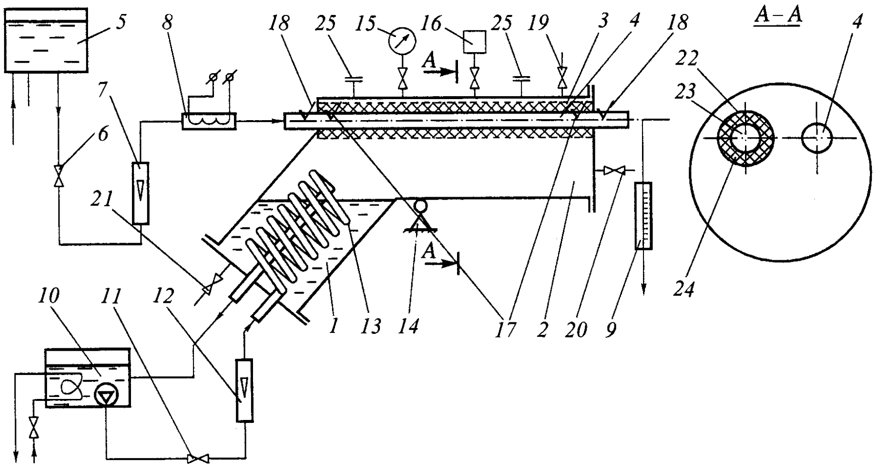

Fig. 1. Diagram of the experimental setup: 1) hot-water boiler; 2) condenser; 3) working portion; 4) tell-tale pipe; 5) constant-level tank; 6, 11, and 19–21) valves; 7 and 12) rotameters; 8) heater; 9) flowmeter; 10) thermostat with a pump; 13) coil pipe; 14) hinged support; 15) manometer; 16) Sapfir pressure transducer; 17 and 18) thermocouples; 22) network; 23) working tube; 24) granular bed; 25) unions for extension of thermocouples.

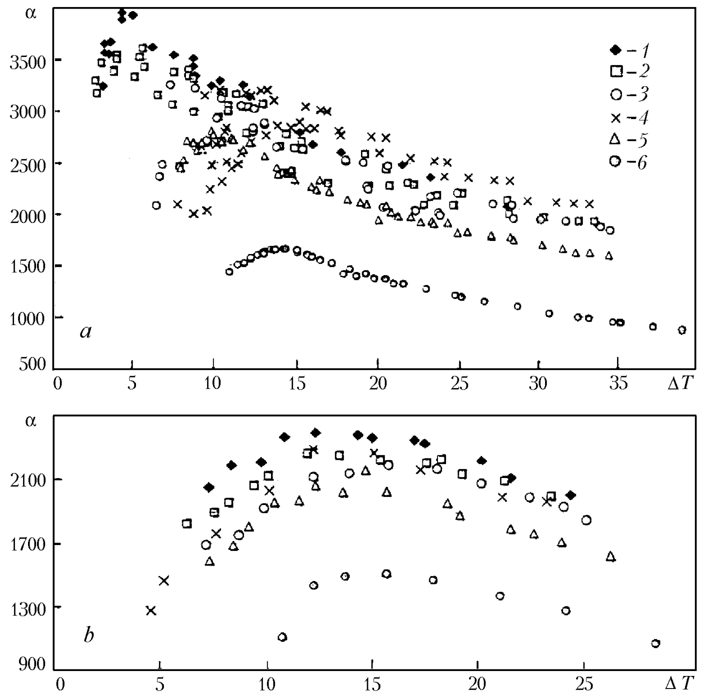

Fig. 2. Heat-transfer coefficient in condensation of R227 coolant vs. temperature head for the charge of d = 0.8 mm (a) and 1.1 mm (b): 1) angle of inclination 0; 2) 5; 3) 10; 4) 30; 5) 60; 6) 90^o.

The data of the measurement enable us to calculate the saturation temperature (from the P–T dependence), the average temperature of the tube wall — as the arithmetical mean temperature at ten points, the heat-flux density q (from the change in the enthalpy of water), and the temperature head ΔT — as the difference between the wall temperature and the saturation temperature.

Figure 2 gives experimental data in the form of the plot of the heat-transfer coefficient α as a function of the temperature head ΔT for charges of 0.8 and 1.1 mm. It is clear from the plots that stratification of the experimental

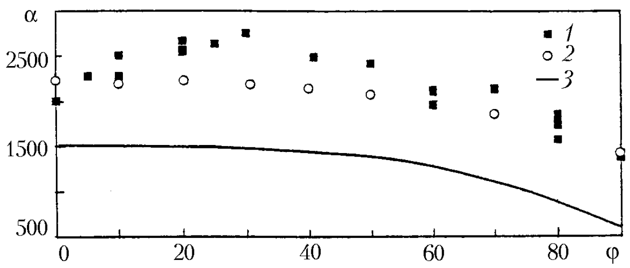

Fig. 3. Heat-transfer coefficient vs. angle of inclination at $\Delta T = 20^{o}$C: 1 and 2) spheres of $d = 0.8$ and 1.1 mm; 3) tube without a charge.

results depending on the angle of inclination of the portion occurs. For individual angles of inclination we can single out two zones of different behavior of the heat-transfer coefficient with change in the temperature head. When the values of the temperature head are low, the heat-transfer coefficient first increases to a certain maximum value with temperature head, but then further increase in ΔT leads to a decrease in the intensity of heat transfer. In our opinion, such a character of the dependence of α on ΔT is attributable to the change in the hydrodynamics of condensate-film flow.

When the flow rates of the condensate are low, the size of the charge particles exceeds the thickness of the film and the particles exert no influence, in practice, on the liquid flow. As the flow rate of the condensate increases due to the capillary pulling of the liquid at the site of contact of the particles with the tube surface and due to the beginning of suction of the condensate by the charge, the average film thickness decreases, which leads to an increase in the heat-transfer coefficient.

The film thickness must have a certain minimum value for suction of the condensate by the charge; therefore, when the flow rates are low, suction occurs only in the lower part of the tube, where we have a local thickening of the film. Further increase in the flow rate leads to an increase in the tube perimeter on which suction of the condensate occurs. As has been noted in [2], the film thickness is the same almost on the entire perimeter of the tube; only in the upper part is it larger than on the lateral and lower parts of the tube. Subsequent increase in ΔT results in the fact that the charge cannot remove the entire condensate formed from the heat-exchange surface; the film thickness increases and the heat-transfer coefficient accordingly decreases.

The fact that the heat-transfer coefficient, in the presence of a charge, is much higher than that for a smooth tube is attributable to the phenomenon of suction noted for the first time in [2, 3].

Figure 3 gives results of experimental investigations in the form of the dependence $\alpha = f(\varphi)$ for ΔT = idem. It is clear from the plots that for a charge of 0.8 mm the heat-transfer coefficient is maximum for an angle of inclination φ approximately equal to 30^{o}. For a charge of 1.1 mm the regularity of $\alpha = f(\varphi)$ is nearly the same as that for a smooth tube [9]: the heat-transfer coefficient is virtually independent of the angle of inclination in the range of them from 0 to 40^{o} and it decreases for angles larger than 40^{o}.

Thus, the above results of experimental investigation in condensation of the vapor of R227 coolant on a tube placed in a granular bed and arranged at angles of inclination from 0 to 90^{o} show that the granular bed intensifies heat exchange. The maximum values of the heat-transfer coefficient for these dimensions of the granular bed have been obtained for an angle of inclination of the working portion of $\varphi = 30^{o}$.

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NOTATION

D, diameter of the tube of the working portion, mm; *d*, diameter of an element of the granular bed, mm; *L*, length of the working portion, mm; *P*, pressure, Pa; *q*, heat-flux density, W/m^2; *T*, temperature, ^{o}C; α, heat-transfer coefficient, W/(m^2·K); ΔT, temperature head, ^{o}C; φ, angle of inclination of the working portion to the horizon, deg.

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