EXPERIMENTAL STUDY OF HEAT TRANSFER BY NITROGEN NEAR THE CRITICAL STATE UNDER SUPERCRITICAL PRESSURE

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An experimental apparatus and test procedure are briefly described. Test curves have been plotted which represent the heat-transfer coefficient as a function of the nitrogen temperature under various values of supercritical pressure and heat load.

Modern heat exchangers in many engineering applications use a carrier at a close to critical temperature and under supercritical pressure. The thermophysical properties of the carrier substance change under these conditions, which has a marked effect on the heat transfer process.

For the study of heat transfer by cryogenic liquids under such conditions, an experimental apparatus was assembled according to the diagram in Fig. 1.

The test liquid and the test pipe were located inside a thick-walled vessel 1 designed to withstand high pressures. The inside diameter of the vessel was 105 mm, the height was 350 mm. The heating surface,

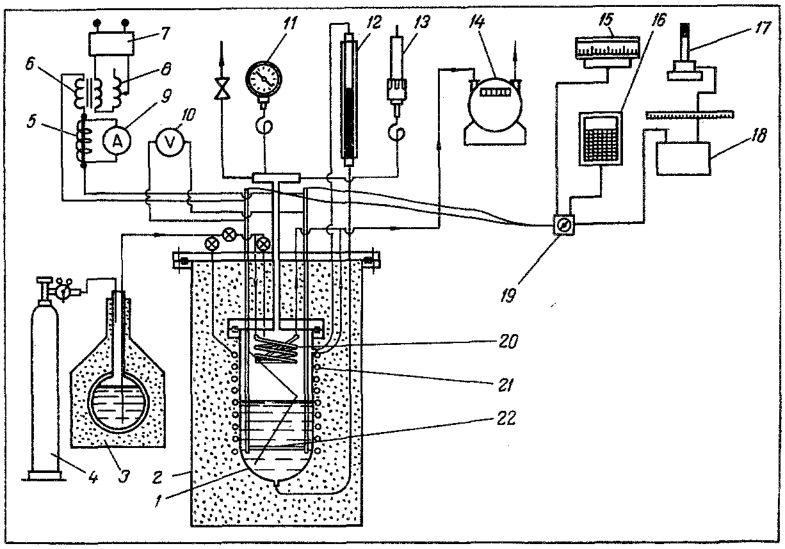

Fig. 1. Schematic diagram of the experimental apparatus: 1) test vessel; 2) insulating jacket; 3) Dewar flask; 4) nitrogen tank; 5) model UTT-5 current transformer; 6) step-down transformer; 7) class 0.5 voltage stabilizer; 8) model RNO-0.5 voltage regulator; 9) ammeter; 10) voltmeter; 11) reference manometer; 12) level gage; 13) safety valve; 14) gas meter; 15) indicating potentiometer; 17) model M 17/1 mirror galvanometer; 18) low-resistance potentiometer; 19) multipoint switch; 20) inner coil; 21) outer coil; 22) test pipe.

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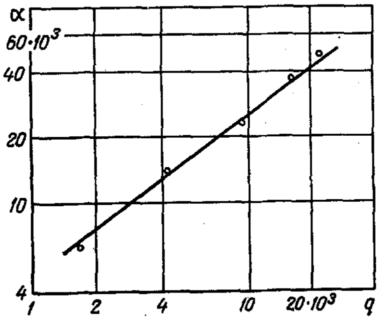

Fig. 2. Heat-transfer coefficient α (W/m^2·deg) as a function of the specific heat load q (W/m^2).

the electrical system, and the measuring system were all assembled on the cover. Liquid nitrogen was supplied to coil 20 inside the vessel. Under stable conditions, this nitrogen carried away the heat supplied to the test pipe and any thermal fluxes entering from the ambient medium.

On the outside the vessel was shielded from external heat sources also by coil 21, The liquid level in the vessel was checked with a level gage 12. A pipe of grade Kh18N9T stainless steel, 2.8 mm in diameter and 80 mm high, served as the test surface. The pipe ends were soldered to tubular copper conductors passing through gaskets in the cover. The test pipe was supplied with alternating current. The temperature of the test liquid was measured at various points along the height and across the section of the vessel. The junctions of copper – constantan thermocouples measuring the temperature on the inside of the pipe were pressed to the wall by a Teflon plug tightly fitting into this pipe.

The thermocouples were spaced in various pipe sections throughout the entire pipe length, uniformly along the generatrix, and their leads were brought the hollow current conductors.

The readings of one thermocouple were shown on a recording potentiometer 16, to indicate whether the process had stabilized. Liquid was poured into the vessel from a Dewar flask 3 by displacing it with gaseous nitrogen from tank 4.

After the vessel had been filled, the power supply was gradually increased to the necessary level. Operating pressure was maintained in the vessel by regulating the flow rate of liquid nitrogen through coil 20.

In order to check the accuracy of measurements for all parameters, the authors performed control tests with nitrogen boiling under atmospheric pressure. The results of these tests are shown in Fig. 2. The solid line represents the equation

$$\alpha = 0.125 \frac{q_{\mathrm{cr}}^{0,3}}{E} \left(\frac{p}{p_{\mathrm{cr}}} \right)^{0,3} q^{0,7}$$

for nitrogen boiling under atmospheric pressure. Evidently, the test data fit this equation rather closely. One may conclude, therefore, that the results of the experiment were sufficiently accurate. The liquid nitrogen passed through coil 21 during these tests was boiling under atmospheric pressure. No liquid nitrogen was passed through coil 20. The quantity of nitrogen boiling inside the vessel was measured with a gas meter 14. Practically no heat was admitted through the outside surface of vessel 1, exept along thermal shunts. The quantity of heat from external sources was measured in a special test, on the basis of the quantity of nitrogen evaporating inside the vessel without heat being supplied to the test pipe.

Also the heat balance indicated that the heat load on the test pipe had been measured reliably.

We show the test results for two levels of heat load at various pressures. The heat-transfer coefficient α as a function of the nitrogen temperature has been plotted in Fig. 3a, b for $q = 3000$ W/m^2 and $q = 11{,}500$ W/m^2. The pressure was supercritical in all tests.

According to Fig. 3, each curve passes through a peaked maximum. The value of this maximum increases, as the nitrogen pressure approaches the critical level. As the pressure is raised, the temperature corresponding to maximum α also rises but the maximum becomes flatter and is gradually lost.

At a given pressure, the maximum α corresponds to the temperature at which the specific heat of nitrogen c_p becomes maximum (Fig. 3c).

An analysis of these curves has established that within the range of nitrogen temperatures $T_{N_2} < T_m$ (T_m is the temperature corresponding to the maximum c_p at a given pressure) α increases with increasing heat load (Fig. 3b). At heavier heat loads the maxima of α are flatter.

Within the $T_{N_2} > T_m$ range, as the temperature rises, the temperature characteristics of the heat-transfer coefficient tend toward those for gaseous nitrogen far from the critical state.

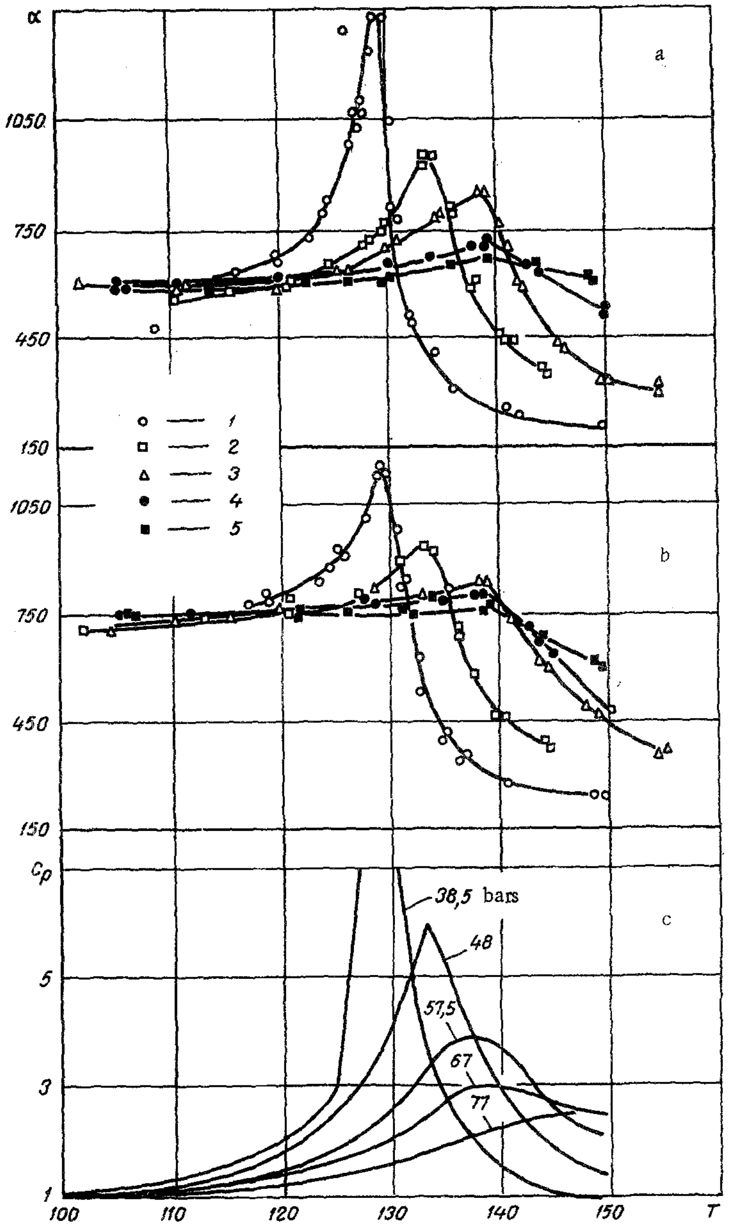

Fig. 3. a, b) Heat-transfer coefficient α (W/m² · deg) and specific heat of nitrogen c_p (kJ/kg · deg) as functions of the temperature T (°K): 1) P = 38.5 bars; 2) 48 bars; 3) 57.5 bars; 4) 67 bars; 5) 77 bars.

A further analysis has shown that these trends remain the same also at other heat load levels.

LITERATURE CITED

1. M. E. Ivanov and N. K. Elukhin, Kislorod, No. 3 (1958).