Contribution to the Problem of Heat Transfer in Low-Boiling Liquids

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Abstract: The heat flux density (W cm^{-2}) in liquid argon, oxygen, nitrogen, neon, and hydrogen was measured as a function of temperature differences under conditions similar to those in a thermosiphon. Thin varnish layers effect essentially higher values of heat flux density.

So far, the problem of heat transfer in liquids is solved only partially, especially in the range of boiling liquids. Whereas heat transfer at free convection is sufficiently described by considering some properties of the liquid state, particularly viscosity, thermal conductivity, and density, in the case of boiling liquid features characterizing the two-phase state must be additionally taken in account, especially evaporation heat and surface tension. In both the cases the geometrical conditions of the system have to be considered, but in the case of boiling liquid the quality of the transferring surface is decisive.

Recently, some papers appeared on cryogenic liquids. The authors of the present paper[1] measured the transfer on tubes at pressures up to 5 atm. Weil and others[2] dealt with the heat transfer in liquid neon in the case of thin wires at high pressures. In the range of burn-out, Sciance[3] measured the heat transfer in liquid oxygen and nitrogen; the influences effected by the quality of the surfaces are excluded by reducing. In the present paper, we treated another aspect of the problem.

In our measurements of the heat-transfer efficiency as a function of temperature difference in the so-called thermosiphon, we observed some peculiarities.[4] To understand this behavior, we measured the heat-transfer coefficients in liquid argon, oxygen, nitrogen, neon, and hydrogen as a function of temperature difference. The measuring arrangement allows the observation of heat transfer under conditions very similar to those in a thermosiphon.

Figure 1 shows the apparatus schematically. Starting from room temperature, a metal block is immersed in the low-boiling liquid, and during the cooling process its temperature is measured as function of time. From this dependence the heat transfer coefficient α may be determined.

$$\alpha = \frac{C(T)}{F\Delta T}\frac{\mathrm{d}T}{\mathrm{d}t}$$

where $C(T)$ = the heat capacity of the metal block depending on temperature T, F = the transferring area, ΔT = the temperature difference between block and boiling liquid, and $\mathrm{d}T/\mathrm{d}t$ = the velocity of cooling.

In order to have available a sufficiently high heat capacity even at hydrogen temperatures, the block consists mainly of lead (1). A stainless-steel jacket (2) avoids changes in surface quality with time of the metal block. The bore in the center of the block has a soldered copper inset (3) for the lead resistance thermometer (4). The block is suspended by a stainless-steel tube (5), which also contains the wires for the thermometer.

In Figure 2 are plotted the values of heat flux density (W cm^{-2}) measured at the surface of the metal block as a function of the temperature difference between the block and boiling liquid. They represent average values of many runs, the scattering being particularly large in the range of unstable film boiling. For all investigated liquids, the curves have the same general feature; deviations, however, are observed regarding the position as well as regarding the height of the maxima. The maxima occur at temperature differences of about 25°, and values of about 4 W cm^{-2} are reached.

With large temperature differences, in the range of stable film boiling (Leidenfrost phenomenon), the values become higher with higher thermal conductivity of the gas. We observed the maxima at temperature differences higher than those formerly found by us[1] and other authors.[5] On the other hand, we obtained maximum values lower than those in the mentioned papers. It should be mentioned that the present values were obtained with falling temperatures, whereas those in the earlier papers were reached with rising temperatures. Above all, these deviations are caused by the other geometrical conditions and by the quality of the transferring surface.

In order to investigate the influence of surface quality on heat transfer, the block was coated with varnish layers, the thicknesses of which varied between 10 and 100 μm.

As a typical example, in Figure 3 the values for heat flux density of liquid oxygen as a function of temperature difference are plotted, the thickness of the layer being a parameter. For comparison, the values measured for the block without a layer (taken from Figure 2) are given as a dashed curve.

The varnish layer on the block effects essentially higher values of heat flux density as a function of temperature difference in the maxima, broadened maxima, and their occurrence at higher values of temperature

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(3) C. T. Sciance, C. P. Colver, and C. M. Sliepcevich, *ibid.*, **12**, 395 (1967).

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(5) E. L. Park, C. P. Colver, and C. M. Sliepcevich, *Advan. Cryog. Eng.*, **11**, 516 (1966).

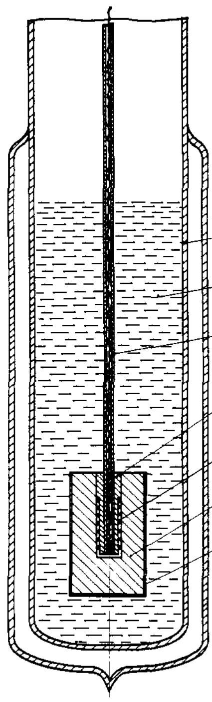

Figure 1. Apparatus: (1) lead block, (2) stainless-steel jacket, (3) inset, (4) resistance thermometer, (5) suspending tube, (D) dewar vessel, (L) liquid.

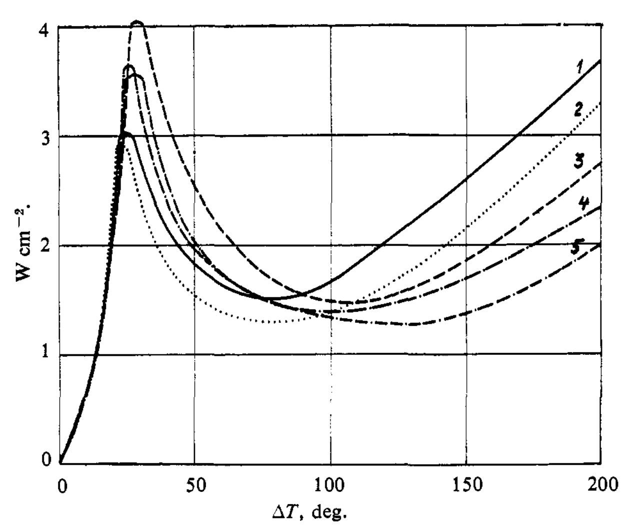

Figure 2. Heat flux density as a function of temperature difference: (1) hydrogen, (2) neon, (3) oxygen, (4) nitrogen, (5) argon.

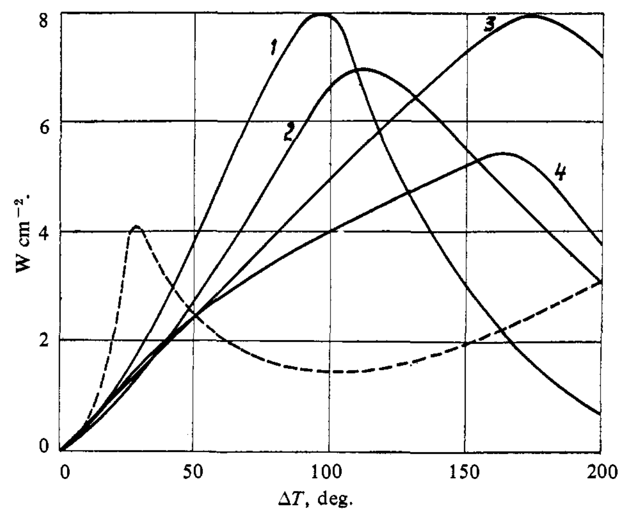

Figure 3. Heat flux density for various thicknesses of varnish layer: (1) 10 μm; (2) 20 μm; (3) 35 μm; (4) 100 μm; dashed curve, no varnishing.

differences. It is noteworthy that the heat transfer is considerably influenced even by very thin varnish layers. As is indicated by curve 3 in Figure 3, obviously, not only the thickness of layer is decisive.

For the interpretation of our observations points of view must be taken into account as follows: (1) the varnishing changes the microstructure of the surface, as is confirmed by direct visual observations of bubble formation; (2) the low heat conductivity of the varnish layer effects an additional thermal resistance. Calculation, however, shows that the temperature difference at maximum may be enlarged only by a few degrees.

Our measurements indicate that coating of a metal surface with an isolating layer allows essentially higher heat flux densities to be obtained without film boiling beginning. Obviously, the low heat conductivity of the isolating layers limits the heat flux density at transfer. The large variations of heat-transfer coefficients indicate that the layer changes the mechanism of heat transfer.

By coating metallic surfaces with isolating substances, heat transfer in boiling liquids may be changed in a definite manner. From such observations further information on the processes of heat transfer may be expected.