UDC 536.25

INFLUENCE OF DEPTH OF EVAPORATION SURFACE ON CONVECTIVE HEAT AND MASS TRANSFER IN EVAPORATIVE COOLING

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Inzhenerno-Fizicheskii Zhurnal, Vol. 9, No. 3, pp. 405–408, 1965

A description is given of an experimental method and laboratory apparatus for investigating the influence of the depth of the evaporation surface on heat and mass transfer in the evaporation of liquid in droplet form from a capillary-porous body. Experimental data on the effect of movement of the phase interface on the temperature profile over the depth of the body are presented.

Problems of heat and mass transfer in the evaporation of liquid from capillary-porous bodies are not only of theoretical interest but also have great practical significance. Because of the complexity of the process there is still no unified opinion on the physics of the phenomenon or on the qualitative influence of mass transfer on heat transfer. Many authors attribute the results of [1–4] to the influence on the heat transfer coefficients of the recession of the surface of evaporation, but very little experimental work has been done on the problem. Below an attempt is made to account experimentally for the influence of the recession zone on the course of the external heat and mass transfer processes.

The experiment was carried out on a wind chamber of rectangular cross section (16 m^2) at a constant air flow velocity of 5 m/sec. The dynamic pressure was measured by a Pitot-Prandtl tube. The necessary value of the air flow velocity was established by a system of special gate valves. The air was heated to 353° K by a 100 kW electrical heater, with automatic temperature control correct to 0.2 deg. The relative humidity of the air was also maintained constant automatically. In the course of the experiment the stability and homogeneity of the flow were quite high. The working material was fractionated quartz sand of different degrees of dispersion (size of sand particles 0.8, 0.4, and 0.6 mm). The sand was placed in a plastic container mounted flush with the lower face of the working section of the wind chamber. Water was admitted to the container through a connecting pipe from a vessel supported on a VTK-500 balance. As evaporation proceeded, the quantity of water was measured with an accuracy of 0.1 deg. To remove air from the test material (sand), it was first charged with water while spread over a gauze, so that all the pores were filled. The absence of air bubbles was established visually. In order to avoid large heat losses, the walls of the container were covered with thermal insulation. A dry layer of test material was created by treating the sand grains with GKZh-94 hydrophobic agent. The thickness of the dry layer was 0, 2, 3, 4, 5, 6, and 8 mm.

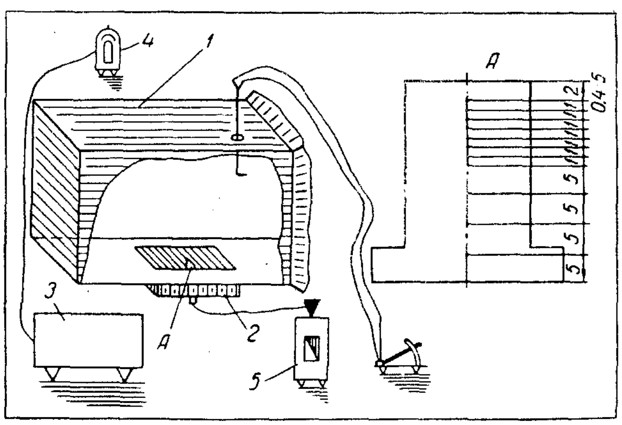

Fig. 1. Experimental setup. 1) wind chamber, 2) working material, 3) PMS-48 potentiometer, 4) M-17 galvanometer, 5) VTK-500 balance; A) distribution of junctions of differential thermocouple over depth of sand.

In view of the strong influence of the recession of the evaporation surface on the heat and mass transfer coefficients, particular attention was paid to the accuracy of maintaining and reproducing the thickness of the dry layer over the entire surface of the body.

The experimental method was as follows. Before the experiment the sand, which completely filled the container, was saturated with water. Then, with the help of specially calibrated templates, the upper layer was removed and replaced by sand, whose grains were coated with hydrophobic agent. In this way the dry layer was accurately reproduced to within 0.2 mm. The exposed surface of the working material was in direct contact with the air flow. The blowing rate was selected so as to exclude entrainment of sand particles. In the course of the experiment we measured the air temperature, the temperature of the container walls, and the water entering the sand. Under steady-state conditions the temperature field was measured over the depth of the sand by means of a 17-junction differential copper-constantan thermocouple. The thermocouple emf was measured by a PMS-48 potentiometer. Use of the differential thermocouple in combination with accurate instruments gave temperature measurements over the depth of the sand correct to 0.01 deg. The thermocouple junctions were spaced 0.4–1 mm apart, so that we were able quite accurately and reliably to establish the surface of evaporation and the temperature field (Fig. 1). The experimental data obtained show that temperature gradient distribution curves all have three characteristic sections. In the first section (dry layer) there is no evaporation. In this section heat is transferred by conduction through the porous structure. The curvature of the profile is due to the presence of a temperature gradient along the x axis.

The second section is the transition zone. Here a qualitative change takes place, since in this section liquid is evaporated. Analysis of the experimental curves indicates that, in this section, moisture is not evaporated in a plane parallel to the exterior contour of the body but in a certain layer of finite size.

The third section is the moist sand zone. There is no evaporation, but all the heat does not go into the phase transition, part is spent on heating the sand; therefore on the given section the temperature gradient profile is a straight line. Here heat transfer is realized by conduction.

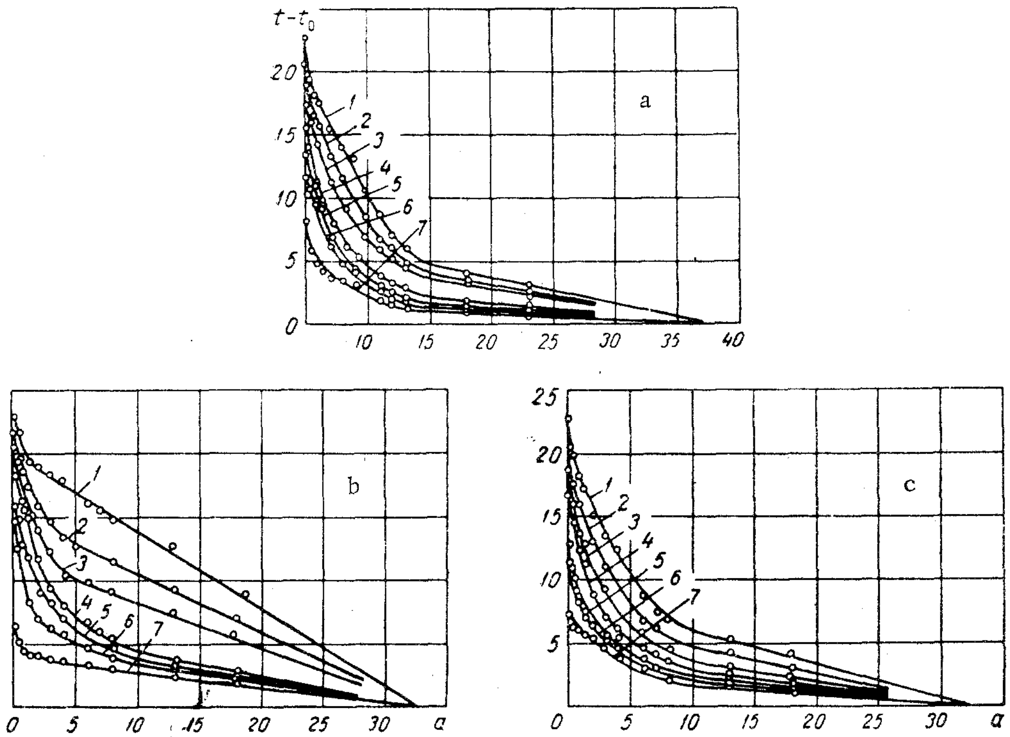

Fig. 2. Profile of temperature gradient distribution $t-t_0$° C over depth a of sand in mm: a) particle size 0.8 mm; b) 0.6; c) 0.45; 1) evaporation from exposed surface; 2) thickness of dry layer 2 mm; 3) 3; 4) 4; 5) 5; 6) 6; 7) 8 mm.

Analysis of the curves obtained shows:

1. With increase in the depth of the phase transition zone the curves move higher and higher, while preserving all their characteristic features. As the dry layer gets thicker, the hydraulic resistance of the porous structure increases. At the same time, the pressure inside the porous material and the evaporation temperature increase, which is clearly confirmed on all the graphs by the upward displacement of the points of inflection of the curves.

2. As the porosity of the sand increases, so does its thermal resistance, since the effective heat conductivity of the dry layer decreases. Correspondingly, the temperature drop in the dry layer increases, as may be seen from Fig. 2.

3. At the same thickness of the dry layer, with increase in particle diameter the heat flow through the porous medium, and hence the flow rate of coolant, increases.

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