TEMPERATURE FIELD OF AN ACTIVE BOILING CENTER

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UDC 536.24

Results are presented from an experimental study of the temperature field in the vicinity of an active center. It is established that the temperature field is directly related to the boiling center operating regime.

It is generally accepted that in liquid boiling under normal conditions bubble formation occurs in active centers, which as a rule are formed by microdepressions (pores) on the heater surface [1, 2]. However, the action mechanism of such centers has not been studied in detail for various boiling conditions. In [3] with the aid of high-speed motion-picture photography of a depression in a transparent heater, the present authors established the existence of at least four different bubble formation regimes. Below we will offer results of a study of heater temperature distribution in the vicinity of an active center.

The experiments used a tin boiling surface in the form of a 20-mm-diameter disk 5.5 mm thick, with an artificial boiling center at its center — a conical depression 0.14 mm in diameter and 5 mm deep.

Two groups of copper—constantin thermocouples (A and B) were mounted in the tin disk to determine the temperature field in the vicinity of the active center. The A group was placed on the plane surface in contact with the boiling liquid, while the B group was installed at points on a parallel plane within the disk at a depth equal to that of the pore. The thermocouples of each group were located at equally spaced points along radii of circles with centers on the pore axis. The first thermocouples were installed directly at the bottom and mouth of the conical depression with the remaining ones at intervals of 1, 2, and 3 mm. In all eight thermocouples were used. The absolute temperatures of the thermocouples were determined with a carefully calibrated PPTB potentiometer, while oscillatory characteristics of the temperature field (amplitude, frequency, phase) at corresponding points of the heater were determined from oscillograms made with an S1-69 oscilloscope.

To eliminate the effect of electrical current upon thermocouple indications indirect heating of the heater surface was used. Repeated liquid boiling followed by cooling of the surface in a cooling agent was used to produce different liquid penetration depths within the pore before commencing measurements. The liquids studied were distilled water, ethyl alcohol, and mixtures of these two.

The following results were obtained. Initially, as the disk was heated the temperature values at the pore bottom T_1 and mouth T_2 practically coincided. This remained the case until convective heat exchange developed between the heater and the liquid contacting it (region I, Fig. 1). During this stage the liquid temperature T_0 increases to T_{sat}, while the pore wall temperature increases to some value T^*, which is dependent on how much the pore is filled with liquid. The start of stage II boiling corresponds to development and breakaway of bubbles from the mouth of the depression. This stage is characterized by an unsteady regime of center operation and oscillations in the pore wall temperature. The amplitude of these oscillations increases with depth, reaching a maximum at the bottom of the pore. The average value $\overline{T}_1$ increases, while $\overline{T}_2$ decreases (II, Fig. 1). In this stage the temperatures of surface points near the center also oscillate. At some moment the temperatures T_1 and T_2 within the pore as well as temperatures at adjacent points cease oscillating and the boiling center operates in a stable steady state regime. The temperature head $\Delta T = T_1 - T_2$ then becomes constant for fixed thermal flux q (region III, Fig. 1), while with increase in thermal load the temperature of the pore bottom T_1 increases, and the mouth temperature T_2 remains constant within the limits of experimental uncertainty, so that the value of the temperature head ΔT in this stage depends directly upon q.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 53, No. 4, pp. 544-546, October, 1987. Original article submitted June 27, 1986.

0022-0841/87/5304-1116$12.50

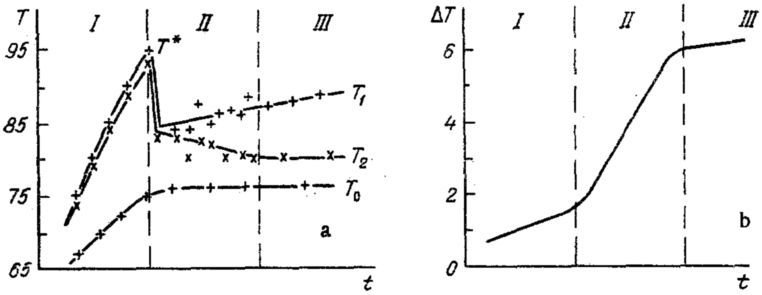

Fig. 1. Temperature of liquid T_0, pore bottom T_1, pore mouth T_2 (a) and temperature head $\Delta T = T_1 - T_2$ between pore bottom and mouth (b) for ethanol boiling. ΔT, T, °C.

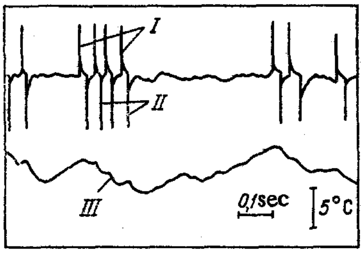

Fig. 2. Relation of fluctuations of heat liberating surface temperature in vicinity of active pore to bubble formation in unsteady regime: I) bubble development; II) bubble breakaway; III) surface temperature.

If we carry out the process in the reverse direction, i.e., gradually reduce the thermal flux, we again obtain the three stages referred to in the opposite sequence.

In further experiments the causes of surface temperature pulsations in the unsteady bubble formation regime were clarified. To do this the signal from one of the thermocouples was passed through a "Topaz" tensoamplifier to one input of an S1-69 oscilloscope, while the other input was driven by a signal proportional to the rate of change of resistance of a photoresistor upon which the region of space directly surrounding the pore mouth was focused. The oscillograms obtained provided information on the time of development and breakaway of bubbles and the temperature of one point on the heater surface. The inertia of the thermocouple did not allow observation of a detailed pattern of temperature change during the various stages of individual bubble growth. Therefore the oscillograms shown in Fig. 2 characterize a "mean" temperature of the surface point.

It proved to be the case that the surface temperature oscillations correspond to the bubble formation process. When bubbles appear above the boiling surface the temperature decreases. During the latency period the surface temperature increases slowly. In the steady state vapor formation regime the temperatures of various surface points remain constant.

One can judge from the amplitude of the temperature changes and their absolute values at various points on the heater where the most intense liquid evaporation occurs. It was established that for unsteady bubble formation regimes bubble growth occurs mainly because of liquid evaporation within the pore, while in the steady state a liquid layer adjacent to the external heater surface evaporates. This is confirmed by the result obtained in [3], that liquid does not enter a pore operating in the steady state. On the other hand, in unsteady regimes periodic filling of a portion of the pore by liquid occurs.

Thus, the experiments show that the temperature field in the vicinity of the boiling center is directly related to its operating regime. The steady-state regime corresponds on the average to a lower temperature of the external heater surface and greater temperature difference between bottom and mouth of the pore than does the unsteady regime.

In conclusion, we will note that the features of unsteady and steady state vapor formation of microdepressions in a heater surface described herein are in satisfactory agreement with the theoretical model developed in [4].

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HEAT EXCHANGE IN A FLAT SOLAR COLLECTOR WITH HEAT PIPES AND HONEYCOMBED FILL

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UDC 536.248.2

A flat solar collector with honeycombed fill and a system of heat pipes has been developed.

Existing systems for collecting and converting solar energy consist of the following basic elements: the solar collector, a heat storage system, a standard heat source, and a unit for controlling the operation of the system. The solar collector absorbs and converts solar radiation into thermal energy, which is then transferred to the user or is stored. The heat-transfer agents can be a liquid or air, depending on the problems addressed by the system.

A design of a solar collector with high efficiency operating in both liquid and air systems without significant design modifications has extensive practical applications. Such a universal construction is possible with the use of heat pipes in a solar collector; the high efficiency is achieved also by using a special honeycombed fill between the absorber and the collector coating. A diagram of such a collector is shown in Fig. 1.

A collector of this type has the following advantages.

1. The total thermal resistance between the surface of the channel wall and the heat-transfer agent is reduced. In a traditional collector the fluid flow in the channels is laminar, as a result of which the heat-transfer coefficient is very low — of the order of several tens of $W/(m^2 \cdot K)$. The inner surface is also limited. As a result the temperature differential between the absorber and the heat-transfer agent increases, which increases the losses of heat from the collector. They can be lowered by increasing the fluid flow rate or by replacing the parallel system of channels with a serial system. This increases the hydraulic resistance and increases the energy consumed by the pump circulating the heat-transfer agent. The use of heat pipes removes this problem. The thermal resistance of a heat pipe is low, and the efficiency of heat tranfer from the condenser to the heat-transfer agent can be increased by finning its outer surface.

2. The versatility of the design lies in the fact that air or water can be pumped through the heat exchanger. Different variants of the design can be obtained by varying the number of fins placed on the condensers of the heat pipes as well as by varying the ratio of the lengths of the evaporator and condenser.

3. In a traditional solar collector the distribution of liquid from the collecting channel to separate channels is nonuniform. This makes it difficult to regulate the head of the heat-transfer agent and to determine the corresponding temperature at the collection inlet. The efficiency of the collector drops at the same time.

A collector with heat pipes consists of two parts: the absorber with the heat-pipe evaporators and a system of heat-pipe condensers, which constitute the heat exchanger. The heat-

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Vrotslav Polytechnical Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 53, No. 4, pp. 546-552, October, 1987. Original article submitted February 25, 1986.

0022-0841/87/5304-1118$12.50