MODELING THE SPATIALLY-UNIFORM HEATING OF LIQUIDS

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An apparatus for achieving the spatially-uniform heating of a liquid up to 80 liters in volume, with a superheating of up to 3-4°C and a pulsed type of boiling, is described; electrolytic heating is employed, the layers next to the electrodes being insulated by means of ion-exchange membranes.

It is already well known that, when liquids are subjected to spatially-uniform heating in the absence of factors promoting the onset of boiling (i.e., when there are no heat-emitting surfaces, when the liquid is extremely pure or has been thoroughly degassed, etc.), considerable superheating relative to the equilibrium temperature corresponding to the pressure over the liquid may occur. Such conditions are obtained in a homogeneous nuclear reactor, and their analysis is a matter of particular interest.

At the same time, the experimental study of boiling under these conditions of heating is largely impeded by the complexity of the apparatus required to model the heating and boiling conditions desired. The apparatus has to be fairly powerful and large in volume, so as to match the characteristics of the proposed homogeneous reactor, since the manner in which boiling takes place depends very greatly on the scale; it is well known, in particular [1], that extremely high superheatings, of the order of tens of degrees, may be attained in a capillary tube, while in large volumes liquids start boiling for very much lower degrees of superheating.

In existing models used to simulate this kind of heating, either infrared radiant heating [2] or simple electrolytic heating of the liquid [3] are employed. In the first case large powers cannot be introduced into the volume; in the second the purity of the liquid cannot be guaranteed (vapor-forming nuclei may be introduced), since the volume under consideration is not protected from the entry of electrolytic gases.

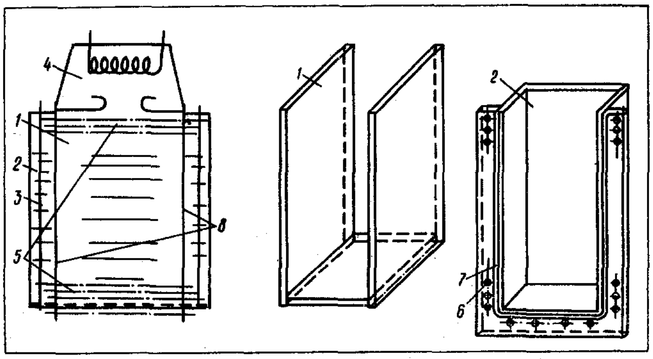

Fig. 1. Arrangement of modeling system: 1) inverted-U-shaped glass vessel; 2) lateral pieces; 3) electrodes; 4) vapor condenser; 5) fixing pins; 6) apertures under the pins; 7) groove for the rubber sealing cord; 8) ion-exchange membrane.

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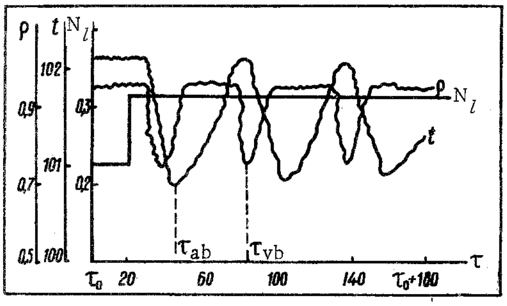

Fig. 2. Temperature and density of the boiling liquid in the vessel in relation to the heating power (ρ, g/cm^3; t, °C; N_l, kW/liter; τ, sec): τ_{vb}) instant of vigorous boiling (shown in Fig. 3a); τ_{ab}) instant of the attenuation of boiling (Fig. 3b).

In this paper we shall describe and illustrate the construction of an apparatus in which the electrolytic mode of heating, used in conjunction with ion-exchange membranes, ensures the spatially-uniform heating of liquid specimens, giving superheatings of up to several degrees.

The arrangement of the apparatus is extremely simple (Fig. 1). However, the actual realization caused considerable technical difficulties when making the rectangular inverted-U-shaped glass vessel (large enough for convenient photography) and sealing it with ion-exchange membranes. A vessel 80 liters in capacity was made from an alkali-free heat-resistant glass of the 13"V" type, stuck together with cold-hardening VK-9 glue, the glued vessel being held (aged) for two months without loading in order to strengthen the glue joint.

The ion-exchange membranes, 100 × 40 cm in size, were specially made in the Scientific-Research Institute of Plastics on the basis of MK-40 cation-exchange membranes.

On the side of the vessel the membranes lie close to the ground-glass ends; on the side of the lateral pieces carrying the electrodes they are fixed to the metal of the lateral pieces through a rubber cord, the whole construction being held together with pins. For complete sealing we found that it was sufficient to use three pins at the top and three at the bottom, so that a free space was left, suitable for observing and photographing the processes taking place in the vessel. In addition to this, four pins hold the construction together at the bottom (base, see Fig. 1).

When the apparatus was first set in action, we noticed a slight inflow from underneath; however, this later ceased, and during two years operation with boiling liquid the apparatus exhibited no leakage.

As model liquid we used ordinary tap water, which was poured into the apparatus through a Schottky filter. We added Na_2SO_4 to the water (up to a concentration of 0.07 N). For this concentration the membranes conducted to the same extent as the solution, so that heat was evolved uniformly in the volume and the membranes did not constitute heat-emitting surfaces. No penetration of the electrolytic gases through the membranes was observed. No evolution of gas from the glued joint appeared after several days operation.

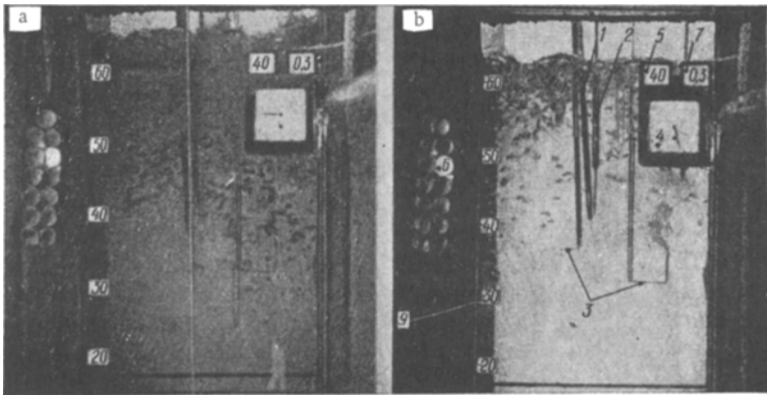

Fig. 3. Motion-picture frames illustrating boiling in the modeling apparatus: 1) monitoring mercury thermometer; 2) thermistor; 3) tubes containing ink; 4) electric timer; 5) display indicating the number of the series of experiments; 6) display indicating the number of the particular experiment in a specified series; 7) display indicating the approximate heating power per liter; 8) photomultiplier collimator; 9) scale up the side of the vessel (in cm).

After preliminary boiling for 1.5-2 h in order to degas the solution and the membranes, superheatings of between 1 and 4°C were attained, depending on the heating power.

A characteristic phenomenon, indicating the efficiency of the apparatus as a model for studying conditions corresponding to the spatially-uniform heating of liquids, was the development of a pulsed form of boiling at a certain specific heating power N_l (power per liter): on superheating by about 2°C, the liquid started boiling vigorously; then the superheating diminished, and for a certain time ($\tau \approx$ 30-60 sec, where $\tau = \tau(N_l)$) hardly any boiling occurred at all, until the necessary superheating again developed and the cycle restarted. Figure 2 clearly shows the peaks in the temperature and density of the liquid recorded in the vessel under these boiling conditions. Figure 3 shows the photographs of the two corresponding moments in the boiling of the liquid: vigorous onset of boiling (Fig. 3a) and subsequent period of increasing degree of superheating (Fig. 3b). We see from the figures that the difference in the vapor content of the liquid is extremely great.

We shall later publish some results obtained with this modeling apparatus.

Note in Proof. A Soviet Patent No. 243749 (BO, No. 17, 1969, p. 46) has now been obtained for the apparatus here described.

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