HEAT-TRANSFER RATE ON BOILING IN THE PRESENCE OF SCALING

V. I. Tolubinskii, V. A. Antonenko,
G. R. Kudritskii, and Yu. N. Ostrovskii

UDC 536.423.1

It is found that deactivation of vapor-formation centers is decisive in producing the temperature rise at a heating surface when deposits are formed on it.

It is common for deposits to be produced on the heating surfaces in industrial equipments, which produce the heat-transfer rate. Elucidation of the processes is important, particularly to the design of efficient heat exchangers.

We have examined the causes of altered heat transfer rate on boiling at surfaces where solid deposits are formed. The experiments were performed with distilled water and also with tap water at pressures of 0.05-0.1 MPa. The working surface was the end of a thermal wedge of diameter 1.15 mm. The thermal loads related to the area of this end of the wedge. The apparatus and the methods of measurement have been described previously [1]. A small working surface was used on account of the method of measuring the temperature fluctuations arising from the operation of the evaporation centers. These fluctuations indicate the mechanisms of the processes occurring at the surface as the thickness of the deposits increases.

The temperature fluctuations at the heating surface were recorded with an N030A light-beam oscillograph and were observed in parallel on the screen of an S1-68 oscilloscope. The heat-flux density and the average temperature were measured with a PP-63 potentiometer. Cinephotography in transmitted light was performed with an SKS-1M-16 high-speed camera.

The method was as follows: Before use, the surface was rubbed with fine emery paper and then washed with distilled water and alcohol. Then a voltage regulator was used to set up a thermal mode such that a single evaporation center worked stably at the surface (it was difficult to synchronize the cinematography and the oscilloscopes if several centers operated together). The absence of other centers was checked visually, and also from the temperature-fluctuation curves as observed with the S1-68. The heat flux density was kept constant to ±2% during the experiment.

Figure 1 shows points illustrating the time course of the heat transfer. A layer of friable deposits at the start does not produce an appreciable temperature rise [2], and in some cases the temperature even falls on account of the specific porous structure of the deposits. The formation mechanism for such structures in a boiling solvent has been described [3]. This is also responsible for the absence of a temperature rise during the initial (first) period as the deposits thicken (Fig. 1). However, the structure and density of the deposits are very much dependent on the composition of the dissolved impurities [4]. This is evidently responsible for a certain fall in the heat-transfer rate in period I as observed with distilled water (a difference from tap water in that case was that the deposit consisted not of hardness salts but of compounds of copper and tin deposited as a result of dissolution of the material in the working chamber and the heated element).

In the initial period, a single center operates stably, as is evident from the fluctuation curve (Fig. 2a). At the end of this period, there was brief unstable operation of two centers (Fig. 2b), which lasted for 5-10 min, after which the operation stabilized (Fig. 2c).

During the second period, the temperature rises because the deposits grow. The end of the second period coincides with the sharp rise in the temperature. There may be one or more centers at the surface at this time (Fig. 2d).

Figure 1 shows that the overall reduction in the heat-transfer rate during 7 h of continuous operation due to growth of the deposit layer was only 20% of the overall decrease.

Institute of Technical Heat Physics, Academy of Sciences of the Ukrainian SSR, Kiev.
Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 6, pp. 942-945, December, 1982. Original article submitted October 19, 1981.

0022-0841/82/4306-1360$07.50

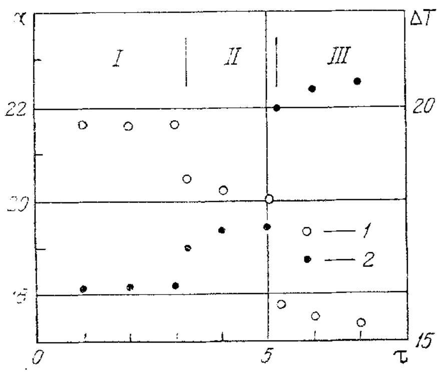

Fig. 1

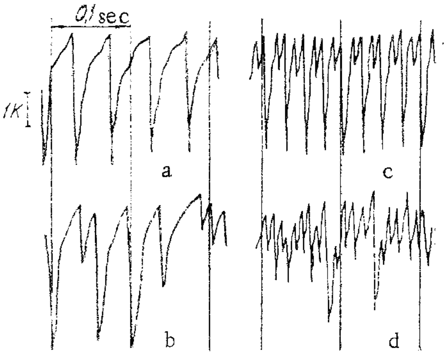

Fig. 2

Fig. 1. Variation in heat-transfer rate, kW/m^2·°K (1); and surface superheating, °K (2); in relation to time in h as the deposit thickens; pressure 0.1 MPa, heat-flux density 350 kW/m^2, tap water.

Fig. 2. Surface temperature fluctuation (Fig. 1): a) one center (period I); b) unstable operation of two centers (transition from period I to period II); c) stable operation of two centers (period II); d) several centers (period III).

The main reason for the fall was evidently a change in the mode of operation of the evaporation centers.

The following process occurs when a liquid boils and the deposits scale: The operation of an evaporation center is accompanied by the formation of a solid deposit nearby on account of evaporation. The geometry of the heating surface alters as the layer thickens. The layer gradually reduces the size of the depression that generates the vapor bubbles. This reduces the bubble generation frequency, since more time is required to attain the superheating needed to start the growth of a new bubble after the detachment of the previous one, as was observed. For example, during the first period (for the case shown in Fig. 1) the bubble generation frequency fell from 65 to 38 sec^{-1}. When the size of the depression ceases to correspond to the superheating, the center no longer generates bubbles. The heat-transfer rate is then naturally much reduced, and consequently there is a sharp rise in the surface temperature. Then one or more new centers begins to operate when a certain superheating is reached, whose geometry corresponds to the new threshold value ΔT. Approximate equality of the threshold superheatings is characteristic of these new centers (Fig. 2c).

Further thickening deactivates the new centers and, correspondingly, produces a fresh rise in temperature.

Therefore, formation of these solid deposits in the initial period deactivates the centers and substantially reduces the heat-transfer rate.

The results can be extrapolated to an extended surface with developed boiling whenever the deactivation affects the heat-transfer rate substantially. For example, for water boiling at atmospheric pressure, the deactivation in the initial period has a substantial effect on the heat-transfer rate if the heat flux density exceeds 100-200 kW/m^2. Naturally, a difference of an extended surface from a microsurface is that there is no sudden change of temperature, because there is no simultaneous deactivation of a large number of centers, which will differ in individual characteristics and also in deposition conditions. However, the rate of reduction in the heat-transfer coefficient should exceed that due merely to increase in the thermal resistance of the deposit. At lower heat-flux densities there is a very considerable contribution from natural convection in the gaps between the evaporation centers, and the reduction in the heat-transfer rate is then largely due to the thickening of the low-conductivity deposits.

This effect is important only in the initial stage of deposition. When the scale thickness is considerable, the deactivation is less important, and the thermal resistance of the deposit plays an increasing part in reducing the heat-transfer rate.

LITERATURE CITED

1. V. I. Tolubinskii, Heat Transfer on Boiling [in Russian], Naukova Dumka, Kiev (1980).
2. I. V. Krivov and E. V. Alkhutova, "Effects of porous iron-oxide deposits on the heat-transfer conditions at heated surfaces," Mosk. Energ. Inst., No. 474, 85 (1980).
3. N. G. Rassokhin, L.P. Kabanov, S. A. Tevlin, and V. A. Tersin, "Thermal conductivity of iron-oxide deposits," Teploenergetika, No. 9, 12 (1973).
4. S. A. Tevlin, "Evaluation of the accumulation of impurities from the cooling medium at heat-transfer surfaces on boiling," Teploenergetika, No. 8, 71 (1978).

IMPACT OF AN EVAPORATING DROP ON A HEATED WALL

Yu. A. Buevich and V. N. Mankevich

UDC 536.24:536.423.1

The interaction of a superheated surface with a drop impinging upon it is treated in the quasistationary approximation, neglecting dissipative effects.

The cooling of heat-transfer surfaces by jets of dispersed liquid and by other streams carrying drops is widely employed in contemporary power engineering, metallurgy, cryogenics, and other branches [1-5], and has therefore been studied intensively. Primary attention has been paid to experimental study of the motion and heat transfer of a dispersed flow with the surfaces being cooled under conditions approximating those of industry [6-11]. Many fewer papers have been published on the analysis of elementary interactions of single drops with walls, which determine the main features of real cooling processes. Aside from numerous studies of the evaporation of drops lying on a surface, and their impact with walls without a phase transition, we point out that the dynamic and thermal interaction of drops with a surface complicated by evaporation was studied in [12-18].

As a drop approaches a superheated wall, the part of the surface of the drop facing the wall absorbs heat, which is expended mainly in evaporating liquid. The vapor which is formed is squeezed out of the thin layer between the drop and the wall, which leads to an increase in the pressure in it and to the production of forces which impede the motion of the drop. If other conditions remain the same, and the initial kinetic energy of the drop is high enough or the wall temperature is low enough, the thickness of this layer may become less than the height of the roughness protuberances on the wall or the range of the forces of molecular attraction, so that the drop comes into direct contact with the wall. For a low kinetic energy or a high wall temperature the drop is slowed down before this layer becomes sufficiently thin; as a result the drop (or the smaller drops which result from its fragmentation) rebounds from the surface. The critical values of the energy and temperature correspond to the well-known heat-transfer crisis [1-18]. The analysis of the conditions for the onset of this crisis is of primary interest for applications.

Basic Assumptions. The combined nonlinear and unsteady problems of hydrodynamics and heat-conduction theory with unknown boundaries which arise in the theoretical study of this phenomenon are exceptionally complex, and a constructive analysis is possible only by making very substantial simplifications. We completely neglect the initial underheating of the drop up to the saturation temperature, the radiation heat flux to it, ordinary hydrodynamic resistance to its motion, the change in mass of the drop in the collision process, and the corresponding reaction. We assume that all the mechanical and thermophysical parameters of the liquid and vapor or the vapor—gas mixture are constant and uniform, corresponding, i.e., to the saturation temperature or to a certain mean temperature in the vapor layer. We assume that the wall temperature is independent of the evaporation of the drop, which is admissible if the heat capacity and thermal conductivity of the wall material are high enough [16, 18]. In addition, in analyzing the motion and heat transfer in the vapor layer we neglect the de-

---

Ural State University, Sverdlovsk. Moscow Institute of Chemical Machinery. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 6, pp. 945-955, December, 1982. Original article submitted September 11, 1981.

0022-0841/82/4306-1362$07.50