STRUCTURE OF A FLUIDIZED BED WITH SURFACE BOILING OF THE FLUIDIZING MEDIUM

A. M. Tushin, L. K. Vasanova, and N. I. Syromyatnikov

UDC 536.423.1:66.096.5

It is shown that, compared to free conditions, in a fluidized bed the convective component plays a larger role in the heat-transfer mechanism during surface boiling.

The following are the most significant features characteristic of surface boiling in a liquid fluidized bed.

1. The heat-emitting surface is in contact with moving solid particles and with turbulent eddies in their wake.

2. Given a certain relationship between particle diameter and bed porosity, the pore channels between the solid particles may be smaller than the separation diameter of the vapor bubbles.

When solid particles penetrate into the superheated boundary layer of the liquid, they may initiate the formation of vapor bubbles. At the same time, the turbulent eddies may act to extinguish these vapor nuclei. The crowdedness of the conditions may also affect local characteristics of the boiling process.

Several works [1-4] have dealt with the structure of a liquid fluidized bed near a body immersed in it. These studies have noted the existence of a special zone in which the mean (over time) structural and hydrodynamic parameters differ from those in the remaining volume of the bed. In particular, it was established in [3, 4] that porosity decreases in the radial direction to a value characteristic of the core of the bed within a zone 3.0-8.8 particle diameters in size. Stable circulation of particles over both sides of a horizontal cylinder was observed in [1, 2]. However, the available data does not give a complete picture of the conditions under which boiling of the fluidizing medium might occur. Further study of the structure of a bed of granular material fluidized by drops of a liquid and of features of the boiling process in such a bed should help in the construction of a physically substantiated model of heat transfer under these conditions.

Boiling in a fluidized bed was filmed and photographed on a specially built unit. The bed of granular solid material was fluidized in a vertical plane-parallel channel 8×50 mm in cross section and 250 mm high. The photographs and film record were obtained through optical-glass windows, 30×80 mm inside diameter, installed in the side walls of the channel body 150 mm from the bearing-distributing grate. A heating element in the form of a vertical plate 60 mm long made of glass-textolite covered with copper foil was installed along one of the narrow side walls opposite the window. The heater was supplied with low-voltage alternating current from a step-down transformer. The high-speed filming and photographing were done in transmitted light with an optical system patterned after the Topler scheme, with two objectives. The light source was a continuous-action LG-75 optical quantum generator, along with a DRSh-100-3 high-pressure mercury-vapor lamp with a fluorescent body 0.3 mm in size. An intermediate image of the light source was created with a cylindrical lens, providing a uniformly illuminated linear image of the source. A slit-type forming diaphragm located in the focal plane of the cylindrical lens and simultaneously in the forward focal plane of the collimator made it possible to change the sensitivity of the system within certain limits.

The photographing was done on Mikrat-300 film with a 35-mm "Praktika" camera. The camera has an extension tube 130 mm long and a 50/1.8 objective. Shutter speed ranges from 1/1000 to 1/125 sec. The filming was done with an SKS-1M camera with a 90-mm-long extension ring and an 85/1.5 objective. The film was made on A-2 negative film with a sensitivity of 600-700 under GOST and a speed of 1500 to 4000 frames/sec.

To ensure the requisite optical transparency of the bed during photographing and filming in transmitted light, the experiments were conducted at high values of bed porosity. Attention was focused in the study on the

---

S. M. Kirov Ural Polytechnic Institute, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 42, No. 2, pp. 239-243, February, 1982. Original article submitted April 10, 1981.

 0022-0841/82/4202-0160$07.50

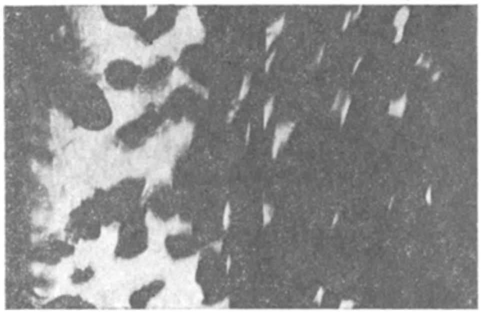

Fig. 1. Structure of boundary region of fluidized bed.

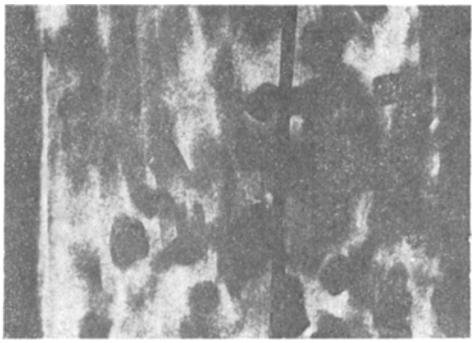

Fig. 2. Pattern of movement of granular material.

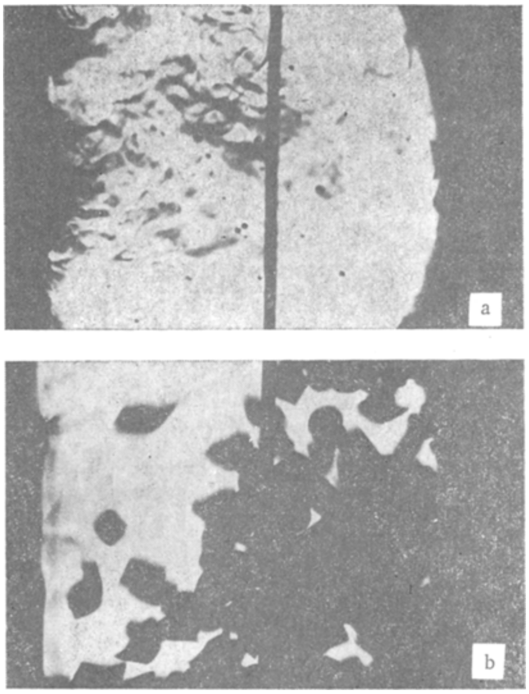

Fig. 3. Surface boiling under free conditions (a) and in the fluidized bed (b).

narrow boundary zone — of the order of ten particle diameters in size. The field of view of the camera included the working section and one of the 0.24-mm-diameter copper-wire leads. The lead served as a reference for purposes of focusing and scaling. The pictures were obtained with different aperture openings and camera positions in order to record both weak and strong optical discontinuities. In obtaining pictures of phenomena occurring in the boundary layer, the curvature of the light rays passing through a medium with a refractive-index gradient might have caused some of the details of the object to be distorted or fall outside the field of view. These losses were compensated for by placing the optical axis of the cameras at a certain small angle to the plane of the heat-emitting surface.

As a result of fairly extensive visual observations, filming, and photographing, it was possible to describe features of the structure of the liquid fluidized bed in the boundary zone both in the presence and absence of heat release on the wall, as well as to obtain an idea of the effect of the fluidized bed on the development of processes in the two-phase boundary layer.

Figure 1 shows a typical photograph reflecting the structure of the boundary region of the fluidized bed near the submerged body. The plate is located on the left side of the frame in the photograph. Clearly visible in the picture is a layer of particles of the order of 2-5 particle diameters. This layer is more porous than the core of the bed. The film record shows that the particle layer is fairly stable, but is sometimes destroyed by particles of the granular material in contact with the surface. Particle movement was followed from their wakes (tracks) in photographs taken with relatively long exposures. Complexes of particles sometimes approach and retreat from the wall. However, movement of material parallel to the surface is the most probable event (Fig. 2). The nonuniform length of the particle wakes is evidence of the presence of a maximum in the velocity field of the fluidizing medium close to the surface.

On the basis of the above, we may define the instantaneous state of the fluidized bed close to the submerged body as a certain realization of a dilute, inhomogeneous system with special hydrodynamic laws different from those which hold in the core of the bed.

To determine the effect of the fluidized bed on the occurrence of surface boiling, we attempted to record the nucleation of vapor bubbles initiated by particles of the granular material. However, despite the presence of a superheated boundary layer of liquid of the order of 0.1 mm thick and the clearness of this layer in the form of a wavy gray band, we were not able to observe the initiation of vaporization. Conversely, surface boiling may be suppressed by the liquid fluidized bed. Turbulent mixing of the fluidizing medium affects the density of active centers of vaporization so that the occurrence of surface boiling is delayed, and development of the boiling process is drawn out.

It was shown by subsequent photographs (Fig. 3) that introduction of the fluidized bed into the flow of boiling liquid leads to a cessation of undeveloped surface boiling due to an intensive exchange of energy and momentum between the core and the bubble-containing boundary layer and, thus, to more intensive condensation of the vapor bubbles. This is accompanied by equalization of the temperature field in the boundary layer, as can be seen from the photographs in Fig. 3b – hot jets formed during bubble condensation lose their pronounced directionality and are eroded.

The level of turbulence created by elements of the dilute system in the boundary zone of the liquid boundary layer affects the formation of the hydrodynamic and thermal boundary layers, which ultimately determines the rate of external heat transfer. Data from the photographs and filming of surface boiling in the liquid fluidized bed and data on the rate and features of heat transfer under such conditions [5-7] lead us to conclude that the role of the convective component in the heat-transfer mechanism is substantial. The fluidized bed affects the development of surface boiling so that the regime of undeveloped boiling is shifted to the region of higher heat-flux values. With developed boiling, when heat is transferred mainly as a result of latent heat of vaporization, there is practically no difference in the rate of heat transfer in the fluidized bed and under free conditions with forced convection.

LITERATURE CITED

1. D. Harrison and J. R. Greis, "Inhibited fluidized bed," in: Fluidization [Russian translation], Khimiya, Moscow (1974), pp. 522-546.
2. E. N. Yanchuk and Yu. N. Shimanskii, "Local heat transfer from a horizontal cylinder to a liquid fluidized bed." Izv. Vyssh. Uchebn. Zaved., Energ., No. 5, 88-91 (1976).
3. E. N. Yanchuk and Yu. N. Shimanskii, "Study of porosity fields in a fluidized bed near the surface of a horizontal cylinder," Izv. Akad. Nauk SSSR, Energ. Transp., No. 2, 124-127 (1975).
4. E. N. Yanchuk and Yu. N. Shimanskii, "Study of the residence time of the fluidizing medium close to a horizontal cylinder in a fluidized bed." Izv. Akad. Nauk SSSR, Energ. Transp., No. 1, 170-172 (1974).
5. N. I. Syromyatnikov, L. K. Vasanova, and A. M. Tushin, "Experimental study of heat transfer in a fluidized bed with surface boiling of the fluidizing medium," in: Boiling and Condensation, Izd. RPI (Riga Polytechnic Institute), Riga (1978), pp. 112-117.
6. A. M. Tushin, L. K. Vasanova, and N. I. Syromyatnikov, "Heat transfer from a transversely located cylinder with surface boiling in a liquid fluidized bed," Inzh.-Fiz. Zh., 36, No. 3, 389-394 (1979).
7. N. I. Syromyatnikov, L. K. Vasanova, and A. M. Tushin, "Features of heat transfer with surface boiling in a fluidized bed," in: Heat Transfer and Hydrodynamics in Boiling and Condensation [in Russian], Institute of Thermophysics, Siberian Branch, Academy of Sciences of the USSR, Novosibirsk (1979), pp. 117-118.