PROMISING NEW METHOD OF FLUIDIZED-BED PROBING

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A method of fluidized-bed probing using optical fibers is described. Some data are given on the effect of gas velocity on the frequency and ascent velocity of the bubbles.

For technological processes using a fluidized bed of granular material, the fluidizing agent is most often gaseous. As is known [1], there then arises an inhomogeneous structure characterized by the appearance of gas bubbles in the bed, which has a significant (and sometimes determining) effect on the processes that occur. In industrial systems, foreign bodies (heat-exchanger tubes, constructional elements, etc.) are usually present in the apparatus when the bed of solid particles is fluidized, and these play an important role in the chemical processes and heat and mass transfer that occur. It is of considerable interest to investigate the structure and hydrodynamics of the inhomogeneous bed in these conditions, especially in the vicinity of the elements immersed in the bed.

The motion of gas bubbles in inhomogeneous fluidized beds has been studied by various methods: photography of surges at the bed surface [2], transmission of x-ray beams through the bed [1, 3], immersion of various sensors in the bed [4], etc. Introducing additional foreign elements in the bed does not always guarantee that sufficiently complete information will be obtained on its structure. In addition, in the x-ray probing of a fluidized bed the necessary exposure time is several minutes [3], and therefore it is impossible to record brief contacts between the continuous phase and the surface of bodies immersed in the bed. Moreover, the x-ray method can only be used to investigate the bed structure when the equipment is not too large – of diameter up to 100 mm [1, 3].

There has been much interest in the method of establishing the presence of absence of the electrical circuit composed of the electrically conducting fluidized-bed particles and the surface of a body (e.g. [5], an organic-glass plate in which copper electrodes are mounted flush with the surface). Signals obtained on a display panel using a low-inertia neon lamp give a clear picture of the bubble motion around the plate and allow a number of hydrodynamic characteristics of the bed to be established. Regrettably, the use of this method is limited to electrically conducting granular materials (often of very high density).

Modern technological processes involving fluidized beds operate with the most diverse granular materials, including catalysts based on aluminum oxide and other dielectrics, often of low density. In the present work, an attempt is made to develop a method of investigating the structural parameters of an inhomogeneous fluidized bed in the vicinity of foreign bodies that are immersed in it, irrespective of the nature and the properties of the granular material.

The method rests on the use of light-fiber technology – flexible optical fibers (light conductors) operating on the total-internal-reflection principle. In their finished state, optical fibers have the property of conducting light without signal loss or distortion, which has been used [6, 7] to automate a number of processes.

In the present investigation, optical fibers are used to investigate the structure of a fluidized bed consisting of glass microspheres of diameter 0.2-0.8 mm in the vicinity of a horizontal glass tube (diameter 37 mm) immersed in the bed. The ends of 65 optical fibers are led along a duralumin cylinder, pass through its wall, and are mounted flush with its outer surface (at the corners of squares of side 8.5 mm). The opposite ends of the optical fibers are inserted into a plane rectangular plate (a display panel) at the same spacing (Fig. 1). Each point (the end of an optical fiber), transmitting light from the surface of the tube, corresponds to a given point on the plate (the opposite end of the optical fiber). The light-transmission equipment (the sensor–probe) is fitted in a horizontal glass tube, placed in the region of the fluidized bed to be investigated. To illuminate the vicinity of the tube and facilitate the transmission of optical information to the display panel, a lamp is fitted close to one end of the tube.

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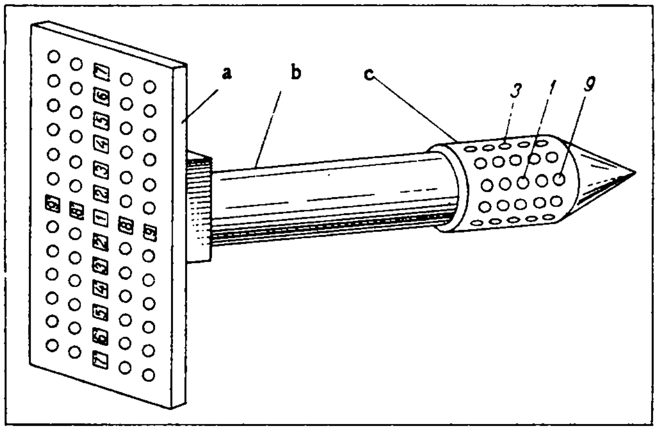

Fig. 1. Light-transmission equipment (sensor–probe) and the disposition of the light-conversion elements (1-9; 1'-9') on the display panel: a) display panel; b) cylinder for optical fibers; c) probe.

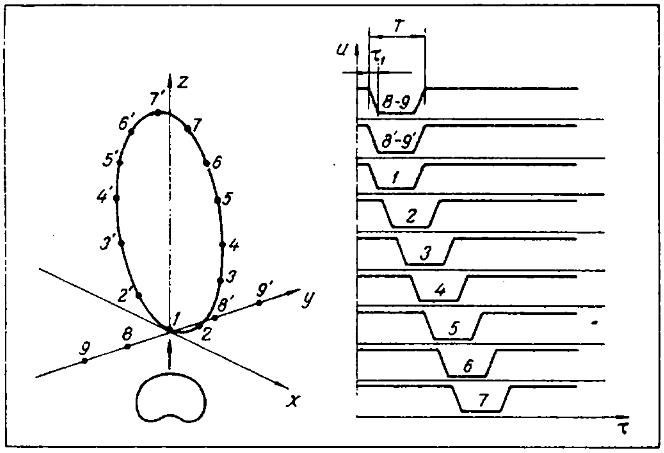

Fig. 2. Time sequence of pulses for a tube surface in a symmetric flow of bubbles. The figures correspond to the numbering of the light converters on the display panel.

When the continuous phase is in contact with the tube surface, the ends of the optical fibers on the display panel are not illuminated; if, however, a gas bubble is in contact with any point of the tube surface (in the region covered by the ends of the light fibers), then the ends of the corresponding light fibers light up on the display panel.

Information obtained from the display panel may be recorded by means of a motion-picture camera (the present investigation uses a Pentaflex camera with a frame speed of 94 sec^{-1}). However, the processing of the resulting data on motion picture film is very lengthy, because of the need to develop the motion picture film and to interpret the results frame by frame.

Rapid and more accurate processing of the information obtained is achieved by using an electronic circuit to convert the optical signal to an electric signal. The location of the light-conversion elements (SF2-2 photoresistors) with respect to the optical fibers on the display screen is shown in Fig. 1.

A time sequence of pulses obtained when the tube surface is in a symmetric flow of bubbles is shown in Fig. 2. The bubble passes to point 1 and leads to a pulse of a given duration; when the bubble reaches the second point, the pulse obtained is of the same form but at a time lag of τ related to the duration of bubble motion between the two points. The pulse length T from the given point characterizes its time of contact with the bubble.

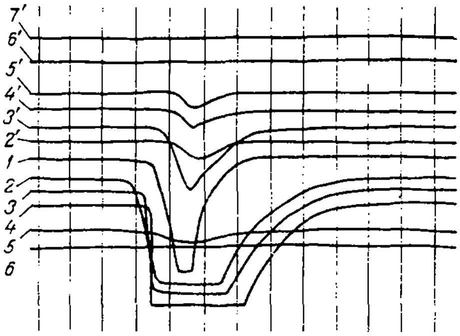

Fig. 3. Real oscillogram characterizing the bubble flow around a tube of diameter 37 mm. The bed is of glass microspheres of diameter 0.2-0.8 mm; the tape speed is 250 mm/sec; w = 0.2 m/sec.

The electric signals obtained on conversion of the light signals are amplified in amplitude (and current) using a multichannel amplifier and recorded on a K-105 multichannel loop oscillograph (recording on UV-type light-sensitive paper). A typical real oscillogram is shown in Fig. 3.

Using the method outlined, it is possible to record and estimate the velocity v_b of bubble motion around the surface of a body immersed in a fluidized bed (and also to judge the components of the bubble ascent velocity); the local frequency of contact of the discrete and continuous phases $\varphi_{c.p}$ with the surface of the body; the shape and geometric dimensions of the gas bubbles; the proportion of the time f_0 in which the surface is in contact with gas bubbles.

The method also allows the size of the transitional region (from the continuous to the disperse phase) to be estimated in the case when a gas bubble approaches (or leaves) the surface of a body immersed in the fluidized bed.

To illustrate the potential of the given model, some results of probing an inhomogeneous bed in the vicinity of a horizontal tube of diameter 37 mm are given in Fig. 4; the results were obtained for fluidization in an apparatus of diameter 300 mm and height 3000 mm; the apparatus was fitted with a perforated lattice, the fraction of live cross section being 2.5% (hole diameter 2 mm), and the tube was 262 mm from the lattice. The static height of the bed was 400 mm, and the initial fluidization velocity w_0 = 0.25 m/sec. Curve 1 in Fig. 4a shows that with increase in fluidizing-agent velocity w the frequency of bubble replacement at the frontal region of the tube increases rapidly at first and then, with further increase in w, more slowly. Curve 2 characterizes the frequency of dislodgement of the relatively immobile "cap" of solid particles on the upper part of the horizontal tube (point 7 in Fig. 2). As would be expected, at low fluidizing-agent velocity, when the bubbles are small, they are not able to dislodge the particles lying along the upper generatrix of the tube. With increase in fluidizing-agent velocity to w = 0.5 m/sec, marked periodic dislodgement of the solid-particle "gap" appears. Further increase in gas velocity is accompanied by increase in bubble size and frequency.

In Fig. 4b the dependence of the gas-bubble velocity v_b on the fluidizing-agent velocity w along the axis of the fluidized bed (curve 3) and close to the inner wall of the apparatus (curve 4) is shown. At small w, when the bubbles are small, their ascent velocity around the tube surface is approximately the same in the axial region of the apparatus and at the periphery (at the edge of the experimental tube). With increase in w, the bubble ascent velocity rises in accordance with their increase in size — at first rapidly and then more slowly. The bubble ascent velocity v_b is higher along the bed axis than at the wall of the apparatus, which indicates that motion of the air occurs predominantly in the axial regions of the bed.

Note that at small fluidizing-agent velocity w the greatest value of $\varphi_{c.p}$ is observed in the lateral region of the tube (Fig. 4a). The oscillograms obtained are in good agreement with experimental results [1] on the local heat-transfer coefficient α at the perimeter of a horizontal tube: at small gas velocities the largest values of α are in fact observed in the lateral region of the tube, and the smallest at the frontal and edge regions. The potential of the present method is not exhausted by the information already given. Analysis of the oscillograms obtained allows a more complete picture to be obtained by the structure of the inhomogeneous fluidized bed. In particular, in interpreting the oscillograms, downward motion of the individual bubbles is observed (downward motion associated with coalescence of the bubbles was noted in [1]).

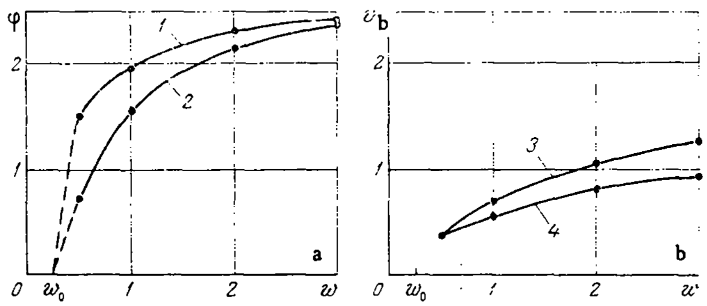

Fig. 4. Effect of gas velocity w, m/sec, on the local frequency (a) and velocity of bubble motion (b): 1) frequency, sec^{-1}, of bubble replacement at point 1; 2) frequency of "cap" dislodgement at points 6-7; 3) bubble velocity, m/sec, along the fluidized-bed axis; 4) bubble velocity at a distance of 20 mm from the wall of the apparatus.

The information obtained using the given method may be recorded and generalized by various means, ranging from frame-by-frame analysis of motion picture film to the use of analog and digital computers connected directly to the sensitive elements of the circuit.

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