DETERMINING THE INITIAL FILM SEPARATION VELOCITY IN A TWO-PHASE STREAM BY THE DROP INDICATION METHOD

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An experimental method has been developed for determining the separation boundary on the basis of a drop indication in the gas stream, and data are shown on the separation velocity of drops in a two-phase flow through a short channel.

At present the critical velocity of gas flow, at which drops separate from the liquid film surface and are carried away, is determined either by the total flow-rate balance in the channel and in the film, or by the change in the hydraulic resistance of the channel, or visually. None of these methods ensures reliable results when the flow of a two-phase stream in a short channel (channel length comparable to channel diameter) is measured. Indeed, it is very difficult to establish when discharge begins by balancing the flow rate in the channel with the flow rate in the boundary layer, since this involves subtracting large numbers. Because of the small channel length, a change in the hydraulic resistance brought about by the beginning of separation is difficult to record accurately. A visual determination of when separation begins is to some extent subjective, since initially the forming drip layer has a low density and occupies a small volume directly adjacent to the free surface of the film. For a study of film flow in curved channels of nonuniform cross section, where separation may occur within a narrowly localized region, none of these methods yields the true flow pattern and can be used at all.

The method which the authors have used for determining the separation boundary involves a reading of the moisture content in the gas stream and is devoid of all these drawbacks and is thus suitable for measurements with an accuracy entirely adequate for many conditions of two-phase flow.

The method is based on the following principle. Into a gaseous nucleus of two-phase flow one inserts a transducer containing a two- or multielectrode set (Fig. 1) by which drops of moisture in the stream are detected. When a drop of liquid falls on the top surface of the transducer, one of the electrical parameters of this device will change as a result: either the capacitance, which will increase by almost two orders of magnitude on account of the dielectric permittivity of water being so much greater than that of the gas, or the resistance – and in both cases it is absolutely necessary that the transducer electrodes be bridged by the liquid. The design of the measuring circuit depends on the choice of the operating parameter. In the first case the secondary circuit must be sensitive to capacitance fluctuations and must be able to record its slightest changes; in the second case the circuit must respond to the transducer conductance. The authors used a circuit for measuring the electrical conductance of the transducer.

The measuring circuit (Fig. 1) includes the transducer A, an amplifier B with a voltage supply C, a cathode-ray oscillograph D, a reference-voltage generator E with a vacuum-tube voltmeter F for checking the input, and an integrating network G with a needle-indicator instrument H. In order to eliminate the effects of polarization, the transducer circuit is energized from a 0.3-0.8 V 8-10 kHz supply. The modulated pulses generated by moisture drops falling on the active endpiece of the transducer are subsequently amplified, then demodulated, and fed through switch S either to the cathode-ray oscillograph or to the integrating network and the needle-indicator instrument H on which they are recorded. The necessary sensitivity level for this circuit is established by the reference voltage and the amplifier gain

I. I. Polzunov Institute of Boiler and Turbine Engineering, Leningrad. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 20, No. 4, pp. 660-665, April, 1971. Original article submitted March 11, 1970.

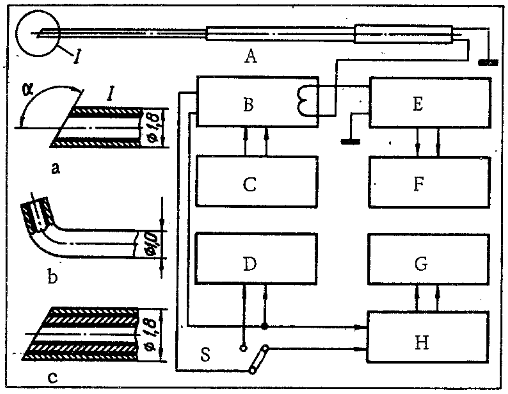

Fig. 1

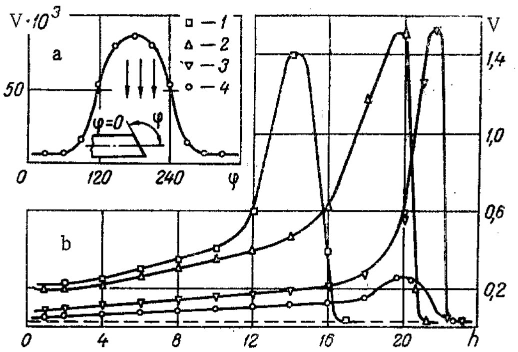

Fig. 2

Fig. 1. Schematic diagram of a measuring circuit for the separation indicator.

Fig. 2. Sensitivity characteristic of the transducer with α = 30° (a), and probing curves for a drip layer with cofluent precipitation (b): water flow rate 3.60 cm³/sec, φ = 180°. 1) V" = 60; 2) 71.0; 3) 110.5; φ = 90°; 4) V" = 110.5 m/sec.

In order to reduce flow perturbations introduced by the presence of the device in the stream, the immersed part of the transducer is made as small as 1-1.8 mm in diameter. Transducers with stainless steel electrodes have the contact surfaces polished to a mirror luster. In order to increase the contact surface and, consequently, the quantity of simultaneously recorded moisture drops, the active end of the transducer is inclined at a 120-150° angle to its axis. Tests performed using transducers with different inclination angles of the active surface and with different numbers of electrodes, as shown in Fig. 1a, b, c, have established that the input signal level in the same wet stream increases as the contact surface of the transducer endpiece or as the length of the interelectrode gap increases, but decreases as the width of the interelectrode gap increases.

The results of a cofluent precipitation study are useful in visualizing the effect of a moisture stream on the transducer. The concentration and the size of drops in a drip layer are both nonuniformly distributed in the transverse direction (normal to the transducer wall) as well as in the longitudinal direction (along the stream). Inasmuch as the separation process along a film is a continuous one, any transverse section of the drip layer contains drops of the same diameter but different velocities: drops which have separated earlier move faster than drops which are separating from the film just ahead of a particular section. Since the stream is not long, as a result of turbulent and diffusive mass transfer, the smallest drops are the first ones to move toward the outer boundary of a drip layer – but a few larger drops are also able to drag along. These latter ones were found in our tests to have a diameter of 20-120 μ under normal conditions at a gas-flow velocity of 90-110 m/sec.

In the immediate vicinity of the film there move many large drops at different velocities. As the distance from the film increases, the moisture concentration in the gas stream decreases because of the smaller quantity of drops and their smaller diameter. Such a structure of a drip layer predetermines the interaction between moisture stream and transducer.

At the outer boundary of the drip layer, the stream consisting essentially of small drops only a few microns in diameter flows around the transducer almost without precipitating on its front end. Some of the drops in this region with a medium or large diameter, when striking the front end of the transducer either precipitate here and are then knocked off by the stream, or are broken down into smaller ones which, after being reflected, are carried off in the gas stream. As the transducer is shifted toward the film, the number of large drops falling on its front end increases. The fraction of drops with a high kinetic energy increases here too; interaction of these drops with the front end of the transducer is manifested by their powerful reflection and by the breaking down of those large drops which had remained intact during their precipitation. The reflected and comminuted drops, which are now moving from the transducer against the main stream, quickly lose their velocity and, dragged by the gas stream, they flow around the transducer on two sides. As a result of all these effects, a cloud of secondary drops forms above the front end of the transducer, beginning at the outer boundary of the drip layer, and its density as well as thickness increase as the transducer is moved around.

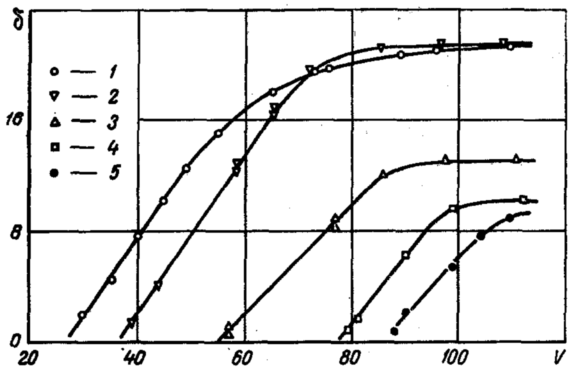

Fig. 3

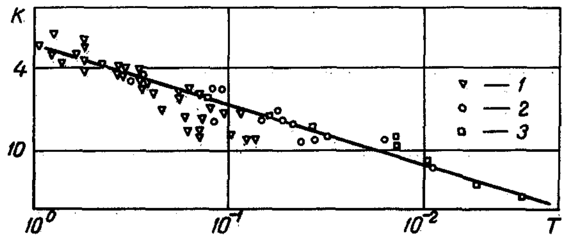

Fig. 4

Fig. 3. Thickness of drip layer as a function of the gas velocity in a cofluent stream: water flow rate: 1) 8.36; 2) 2.51; 3) 0.63; 4) 0.365; 5) 0.19 cm^3/sec.

Fig. 4. Comparison of data on breakaway start for a cofluent stream incident two-phase flow in long and short channels: 1) [2]; 2) [3]; 3) authors' data.

Various sections of the front surface were microphotographed with a flashbulb giving an effective exposure time of 10^{-7} sec; and an analysis of the pictures shows that there is no stable moisture concentration anywhere across the entire thickness of the drip layer. No formation of a continuous film or no significant drop accumulations have been detected. Although there is a large quantity of moisture per transverse section of the transducer adjoining the film region, very little moisture is retained on the transducer surface in the form of powerful droplike perturbations, as noted by the low level of the instrument output signal. The probability of the electrodes being bridged by drops whose diameter is larger than the interelectrode gap length will be proportional to the quantity of such drops in the stream, and under our test conditions was almost nil.

With the transducer oriented at an angle φ = 60-90°, one observes an increasing number of pulses with an increasing amplitude (Fig. 2a) produced by an oblique impact of drops on the active endpiece, as a result of which drops with a diameter smaller than the interelectrode gap length become deformed and bridge the electrodes. The length of time for such a process is 0.15-0.17 msec, as has been measured on the cathode-ray oscillograph screen.

As the angle is increased up to 180°, a stable accumulation of moisture appears on the active endpiece in the form of a swollen film or a very large dangling drop spread over the entire endpiece surface. These formations are made up primarily of the smallest drops, which the eddies drag into the wake behind the transducer and deposit on the back surface. Measurements have shown that the process of moisture accumulation on the back surface takes place anywhere within the drip layer and is most intensive at the outer film boundary, where the moisture stream consists predominantly of small drops.

A probing characteristic typical for a drip layer is shown in Fig. 2b. Tests were performed with cofluent precipitation in a short rectangular channel (length of the film flow region up to the instrument location was 250 mm) having a cross-section area 58 × 136 mm and film flow induced along one of its wide walls. The maximum level of the output signal corresponded to the outer boundary of the drip layer when the transducer was oriented with its active end along the stream (φ = 180°), which can be explained by the just described mechanism of moisture accumulation on the transducer endpiece. On the diagram are shown the probing curves for the drip layer at three values of mean air stream velocity. It is evident here that, as the air velocity decreases, the peak output signal with its right edge corresponding to the drip layer boundary shifts toward the film behind this drip layer boundary. In practice, the transducer can be used with a wide range of angles φ (Fig. 2a). At φ = 180°, however, the right edge of the peak becomes steepest and this is very favorable for recording the critical thickness of a drip layer on whose outer boundary the moisture concentration is extraordinarily low with the boundary itself blurred.

The critical velocity of separation will be determined by a change in the thickness of the drip layer adjacent to the free surface of the film. Thus, we measure the thickness of the drip layer – while the liquid flows at a constant rate – beginning at a gas velocity known to be higher than the separation velocity. The drip layer thickness determined in this way for five different liquid flow rates is shown in Fig. 3. On the assumption that the layer thickness is a monotonic function of the gas velocity, the separation boundary will be determined by that maximum gas velocity at which the drip layer thickness is still zero. This velocity corresponds to the point where the curve of drip layer thickness versus gas velocity $\delta = f(V'')$ intersects the axis of abscissas and is easily determined from the data in Fig. 3.

A comparison between our results and those obtained by other authors can be made on the basis of the flow instability diagram for two-phase streams in an appropriate system of coordinates [1]. Tests results for air–water mixtures [2] and vapor–water mixtures [3] are shown in Fig. 4 plotted according to the critical evaluation in [1]. Our test points fall within the same region as the points obtained by other authors for long channels and they lie close to the straight line representing the relation $K = 3T^{-0.308}$. The trend of this line indicates that the beginning of the separation process is determined by the parameters of the gas and the liquid phase at any given point on the separation surface; the effect of channel geometry should be a subject of additional studies.

NOTATION

φ	is the angle between drip flow and the plane of longitudinal symmetry in the transducer, deg;
α	is the angle between the longitudinal axis and the active endpiece of the transducer, deg;
V	is the voltage at the instrument output terminals, V;
h	is the distance along the normal to the wall, mm;
δ	is the thickness of the drip layer, mm;
V''	is the mean velocity of the gas stream, m/sec;
$T = \frac{V_0'}{c\sqrt{gD}}\left(\frac{\gamma'}{\gamma'-\gamma''}\right)^{0,5}$;	
$K = \frac{V_0''\sqrt{\gamma''}}{\sqrt[4]{g^2\sigma(\gamma'-\gamma'')}}$;	
V_0', V_0''	are the reduced velocities of the liquid and the gas, respectively, m/sec;
γ, γ''	are the densities of the liquid and the gas, respectively, kg/m^3;
g	is the acceleration of gravity, m/sec^2;
σ	is the surface tension, kg/m;
$c \approx 0.32$	is a constant;
D	is the channel diameter, m.

LITERATURE CITED

1. S. S. Kutateladze, B. P. Pokusaev, I. G. Malenkov, I. L. Sorotkin, V. E. Nakaryakov, and V. N. Stern, ISME Semiinternational Symposium, Tokyo (September 4-8, 1967).
2. L. Ya. Zhivaikin, Khim. Mashinostr., No. 6 (1961).
3. N. A. Mozharov, Teploénergetika, No. 2 (1959).