PHASE VELOCITY IN A GAS—LIQUID BUBBLE FLOW

O. N. Kashinskii, R. S. Gorelik,
and V. V. Randin

UDC 532.529.6

An experimental method and some results are presented for measurement of gas phase velocity and slip velocity in an ascending gas—liquid flow in a vertical tube.

The structure of a two-phase gas liquid flow is determined to a significant extent by the interaction of the liquid and gaseous phases. The relative velocity (slip velocity) of the gas is one of the fundamental parameters of a two-phase flow. The question of the ascent velocity of an isolated bubble in a liquid at rest has been considered in detail in a large number of studies, reviews of which may be found, for example, in [1, 2]. Under real gas—liquid flow conditions a number of factors may affect the relative gas velocity: gas phase concentration, liquid velocity gradient, closeness of a rigid boundary, liquid velocity pulsations, etc. In presently available methods for calculation of the flow field in a two-phase flow [3, 4] the relative velocity of the gas is the fundamental parameter determining the quantitative effect of the gas phase on the liquid flow. One of the few studies in which direct measurement of slip velocity has been performed in a gas—liquid flow is [5], although the most important region near the wall was not encompassed therein.

Since methods for direct measurement of relative gas velocity are lacking, it must be determined by quite precise measurements of the liquid and gas velocities at a single point, preferably simultaneously to allow for a possible nonsteady state situation. Existing optical methods [6] do not allow measurement of liquid velocity at a local gas content exceeding 1-2% due to nontransparency of the flow. The thermoanemometer which is widely used at present [5] has a quite large sensor (approximately 0.5 mm), which limits its use in the wall region. In connection with this, the present study will use an electrochemical method to determine liquid velocity. A dual probe will be used to measure the phase velocities, consisting of two "face point" sensors [7], the sensitive elements of which are located along the tube axis [5, 8]. The first sensor operates as an electrochemical velocity sensor and electrical conductivity sensor simultaneously, using the method described in [7]. The second sensor is used solely as an electrical conductivity sensor. The indications of the electrochemical sensor depend on the liquid velocity and follow pulsations in that velocity, while the electrical conductivity sensor output has two fixed values depending upon whether the sensor is currently located in the liquid or the gas phase.

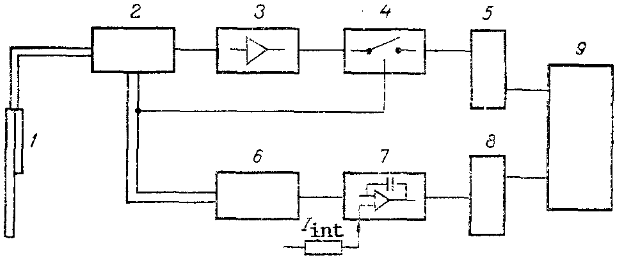

Fig. 1. Diagram of measurement apparatus: 1) sensor; 2) hf circuit; 3) dc amplifier; 4) switch; 5, 8) analog—digital converters; 6) pulse stretcher; 7) integrator; 9) computer.

Thermophysics Institute, Siberian Branch, Academy of Sciences of the USSR, Novosibirsk.
Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 57, No. 1, pp. 12-15, July, 1989. Original article submitted January 4, 1988.

0022-0841/89/5701-0732$12.50

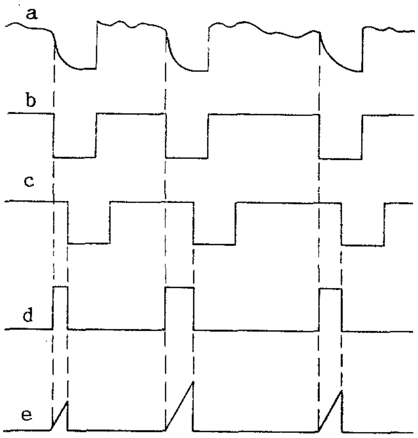

Fig. 2

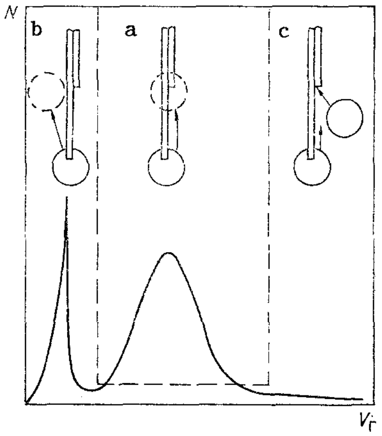

Fig. 3

Fig. 2. Voltage diagram.

Fig. 3. Histogram of bubble velocity distribution.

A diagram of the measurement apparatus is shown in Fig. 1, and a voltage diagram in Fig. 2. The hf circuits apply an ac voltage at 250 kHz to the sensors. Two "phase signals" (Fig. 2b, c) are formed from the hf component of the sensor currents. The upper level corresponds to sensor location in the liquid, the lower, to the gas. The pulse former generates rectangular pulses (Fig. 2d) the duration of which is equal to the transit time of the liquid–gas boundary through the distance between the sensitive elements. An integrator converts these pulses into a voltage (Fig. 2e). At the completion of integration the voltage is retained for a time t_c, sufficient for measurement by an ATsP-8 analog–digital converter, after which the integrator is reset. The integrator input current is set such that for real bubble passage times between the sensors the output voltage ranges over 1-4 V.

The low frequency component of the current (Fig. 2a), corresponding to operation of the first sensor in the electrochemical velocity sensing regime, is amplified by a dc amplifier, through which a constant bias is also applied to the sensor. The amplifier output voltage passes through an electronic switch controlled by the "phase signal" of the first sensor, and is applied to an analog–digital converter. The converted signals are processed by an automated measurement-computation program using an "Élektronika-60" computer. This measurement system permits simultaneous measurements of the liquid and gas phase velocities at a single point of the channel section. The small geometric dimensions of the sensors (0.04-0.05 mm) made it possible to perform measurements in the immediate vicinity of the wall.

The method described in [5, 8] was used in processing the results. We can distinguish three cases of bubble passage through the double sensor (Fig. 3):

a) the bubble is pierced by both sensors, and while it is moving between the sensors no bubbles are pierced by the second sensor; the "start" and "stop" signals are generated by one and the same bubble;

b) a bubble which has been pierced by the first sensor does not arrive at the second; in this case after a certain delay time the pulse former switches off the negative rectangular pulse analogous in form to the signal of the second sensor, after which the former is ready to receive a new signal;

c) before a bubble pierced by the first sensor reaches the second one, another bubble is pierced by the second one.

Only the first case provides true information on the gas phase velocity, the other two cases producing false signals. A method analogous to the multichannel analyzer method of [5] was used to determine gas phase velocity. A histogram of the bubble distribution over velocity was defined numerically and then output to a color graphic display. A typical histogram is shown in Fig. 3. The peak on the left corresponds to low velocity, i.e., lengthy bubble passage times, as shown in Fig. 3b. This portion of the histogram was rejected. Moreover, all points with a probability of less than 5%, created by background noise (Fig.

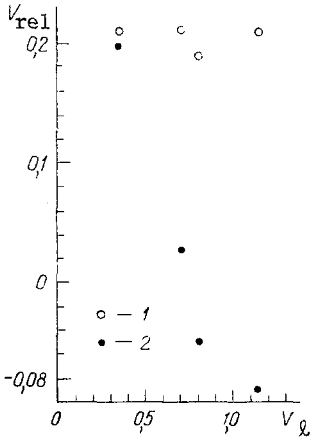

Fig. 4. Relative velocity vs liquid velocity: 1) in flow core; 2) at wall. V_{rel}, V_ℓ, m/sec.

3c), were also eliminated. In determining bubble velocity only bubbles falling within the rectangle delineated by the dashed line were considered.

Measurements were carried out in an ascending bubble flow in a tube 42.3 mm in diameter. The measurement section was located at a distance of 4.5 m from the point of gas introduction. The gas was fed into the flow through the perforated lateral surface of the cylinder at the tube entrance through orifices 0.15 mm in diameter. The mean diameter of gas bubbles in the measurement section was 2 mm.

To obtain reproducable results it was necessary to perform statistical averaging over a large number of bubbles. At each point 4000 bubble transitions through the sensors were analyzed. Some 2500-3000 measurements by the above technique were selected for determination of gas phase velocity. Depending upon the local gas content, measurements at a single point required 10-40 min.

To verify the validity of the method the flows were photographed simultaneously while illuminated by two strobe lamps with a specified interval between flashes. The photographs were then used to determine gas bubble velocity. The velocity of the gas phase measured in this manner coincided with results of the double sensor measurements within ±5%.

The measurements revealed that in the general case the relative velocity of the gas bubbles depended on the position of the measurement point. Far from the wall the bubble velocity was approximately constant (Fig. 4) and corresponded to bubble ascent velocity in a free volume [1, 2]. At the same time bubbles located in the wall layer had a lower relative velocity on average, which depended significantly on the relative liquid velocity. With increase in liquid velocity the relative velocity may take on negative values. It should be noted that relative velocity was defined as the difference between bubble velocity and liquid velocity at a point the coordinate of which coincided with the center of the bubble. Relative to this point the bubble has a negative slip velocity. Since in the wall layer a high liquid velocity gradient exists, with respect to points located closer to the wall than the bubble center, the slip velocity is positive.

The effect of decrease in relative gas bubble velocity near the wall was described qualitatively in [3], although no quantitative information was provided therein.

LITERATURE CITED

1. O. V. Voinov and A. G. Petrov, Progress in Science and Technology. Series Liquid and Gas Mechanics, Vol. 10 [in Russian], Moscow (1976), pp. 86-147.
2. G. B. Wallis, Int. J. Multiphase Flow, 1, 491-511 (1974).
3. Y. Sato, M. Sadatomi, and K. Sekoguchi, Int. J. Multiphase Flow, 7, 167-190 (1981).
4. N. Clark and R. Flemmer, Ind. Eng. Chem. Fundam., 24, No. 4, 412-418 (1985).
5. A. Serizawa, I. Kataoka, and I. Michiyoshi, Int. J. Multiphase Flow, 2, No. 1, 235-246 (1975).
6. F. Durst, B. Schonung, K. Selanger, and M. Winter, J. Fluid Mech., 170, 53-82 (1986).
7. V. E. Nakoryakov, A. P. Burdukov, O. N. Kashinskii, and P. I. Geshev, Electrodiffusion Method for Study of Local Turbulent Flow Structure [in Russian], Novosibirsk (1986).
8. R. A. Herringe and M. R. Davis, J. Fluid Mech., 73, Pt. 1, 97-123 (1976).
9. I. Zun, Int. J. Multiphase Flow, 6, 583-588 (1980).