DISTRIBUTION OF THE VELOCITY PROFILES OF THE LIQUID PHASE IN A GAS – LIQUID FLOW WITH SMALL GAS CONTENTS

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Artilce [1] gives the results of measurement of the friction at the wall of a channel under bubble conditions, in a wide range of Reynolds numbers. It is shown that the concept of laminar flow conditions has no meaning when it is applied to the flow of a two-phase mixture, since, even with very small Reynolds numbers, the level of the pulsations of the friction is high, and the spectrum of the pulsations of the friction is continuous. In this case, the mean friction is much greater than the calculated; here the value of the resistance coefficient is not a single-valued function of the Reynolds number. The present article gives the results of measurement of the velocity profiles of the liquid phase, carried out using an electro diffusion method. It is shown that, with Reynolds numbers corresponding to turbulent flow conditions, the profile of the velocity in a two-phase mixture is close to turbulent and does not depend on the gas content.

With Reynolds numbers corresponding to laminar flow conditions, the velocity profile of a two-phase flow differs strongly from the characteristic laminar velocity profile of a one-phase liquid. It is fuller, close to turbulent, and, in this sense, depends on the gas content. This result is in complete agreement with the data of [1].

The determination of the phase velocities in a gas–liquid flow is of undoubted interest from the point of view of constructing calculating models and methods for such flows.

At the present time, with measurement of the velocity of the liquid with a thermoanemometer, film-type pickups are usually used. It is obvious that, in a gas–liquid flow with dimensional gaseous inclusions measuring less than 1 mm, the dimensions of the sensing element and the bubbles of gas are commensurate, and it is practically impossible to measure the velocity of the liquid without breaking down the structure of the flow. In addition, the use of the thermoanemometric method in the investigation of gas–liquid flows is complicated to a considerable degree by unavoidable errors brought about by evaporative cooling of the pickup with the passage of the bubbles of gas.

The electrodiffusion method [2] has a number of undoubted advantages from this point of view, since the sensing element in such a pickup has a dimension of less than 100 μm. There is no effect of evaporation. The essence of the method consists in measuring the rate of an oxidation–reduction reaction, taking place under diffusional conditions. The sensing elements, a microcathode and an anode, considerably greater in surface area, are arranged in the flow of the electrolyte and, together with the electrolyte, make up an electrochemical cell. The reaction takes place under diffusion conditions; the value of the saturation current I_s is a function of the velocity of the liquid in the neighborhood of the micropickup cathode and does not depend on the voltage V. Under these circumstances, the concentration of working ions at the cathode is close to zero, i.e., the cathode is polarized.

We used a $(0.1\text{-}1)10^{-2}$ N solution of potassium ferricyanide and ferrocyanide $K_3Fe(CN)_6$ and $K_4Fe(CN)_6$ in a 0.5 N background solution of NaOH in distilled water. Under diffusion conditions, the following reaction takes place at the cathode:

$$Fe(CN)_6^{3-} + e \rightarrow Fe(CN)_6^{4-}$$

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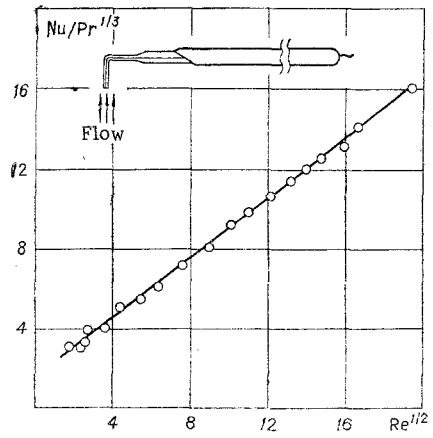

Fig. 1

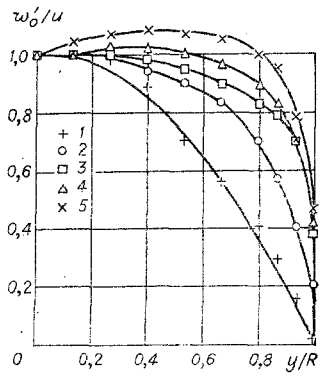

Fig. 2

and the working ions are the ions $Fe(CN)_6^{4-}$; at the anode there is a reverse reaction with the formation of $Fe(CN)_6^{3-}$. The polarized pickup-cathode consists of a platinum wire with a diameter d = 50 μm, soldered into a glass shell; the overall diameter of the pickup is ~100 μm. The end is ground in such a way that the working platinum element is flush with the glass shell. The pickup is oriented in the flow as shown in Fig. 1. Under diffusion conditions, there is a mass-transfer process between the flow and the polarized pickup-cathode, obeying the laws of hydrodynamics and mass transfer in the neighborhood of the frontal point of the end of a cylinder around which longitudinal flow is taking place, and, in accordance with [3],

$$Nu = 0.753 Pr^{1/3} Re^{1/2}, \quad (1)$$

where Nu = BR/D; Pr = ν/D; Re = WR/ν; W is the velocity of the liquid; R is the radius of the glass shell of the pickup; Φ is the Faraday constant;

$$B = \frac{I}{C_\infty \Phi F} \quad (2)$$

is the mass-transfer coefficient; F is the area of the platinum electrode; ν is the kinematic viscosity; D is the diffusion coefficient; I is the value of the limiting diffusion current; C_∞ is the concentration of $Fe(CN)_6^{3-}$ ions in the solution. The value of the current, not measured in the experiments, can be calculated using (1), (2), the mass-transfer coefficient, and the velocity of the liquid.

After fabrication, each pickup was calibrated in special test stands. The calibration of one of the pickups is shown in Fig. 1. The final calculating dependence for all the pickups has the form of formula (1) with a coefficient determined during the process of calibration. For the pickup, the results of whose testing are shown in Fig. 1, the coefficient is equal to 0.8.

The concentration and the dimensions of the gaseous inclusions are very small, the frequency of the pulsations of the current in the pickup, as experiment has shown, is rather low, and the velocity can be calculated on the assumption that the process is quasi-steady-state.

The method used for investigating the spectral characteristics of the friction is given in [2]. At the present time, we are doing work on the study of the spectral characteristics of the velocities of the liquid in such flows.

The velocity of the liquid phase was measured in a unit which is described in detail in [1]. The electrical signal from the polarized pickup-cathode and the anode was fed through an electrodiffusional amplifier to the input of an electronic computer or to a recording instrument (an automatic-recording potentiometer or a loop oscillograph). In the experiments, the value of the diffusion current was measured. The experiments were made under bubble-flow conditions with volumetric mass flow rates of the gas contents β = 0.01-0.1. In accordance with visual observations and photographs, the dimensions of the bubbles here varied within the limits 50-500 μm, depending on the mass flow rate of the gas and the liquid. It is shown in [1] that, in the above range of gas contents, in the region of small Reynolds numbers (Re < 3000) there are flow conditions with high values of the shear stresses at the solid surface compared with calculated values.

In spite of the fact that the Reynolds numbers corresponded to laminar flow conditions, the level of the pulsations of the friction in the experiments was very high; the ratio of the mean-square pulsational

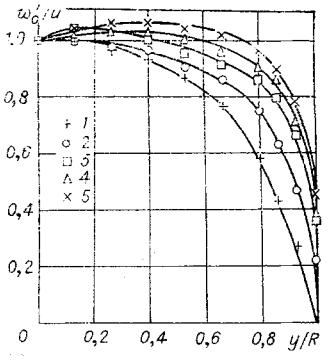

Fig. 3

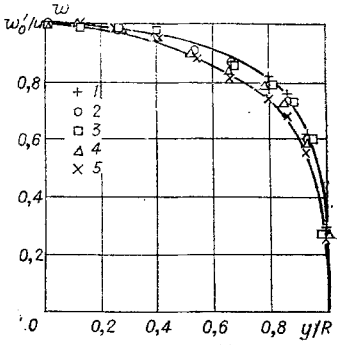

Fig. 4

friction to the mean friction rose with a decrease in Re. Under these conditions, the value of the resistance coefficient is not a single-valued function of Re, but obviously depends to a considerable degree on the mean size of the bubbles in the zone near the wall. The hypothesis has been advanced that, with small Re, a considerable role is played by the transverse transfer of momentum due to the chaotic motion of the bubbles, brought about by a different kind of hydrodynamic force. Such flow conditions, arbitrarily called "microturbulent" bubble conditions, are of definite interest, in view of which experiments were made on the measurement of the velocity profiles of the liquid phase in a two-phase mixture with small gas contents. Under these conditions, the bubbles do not accumulate at the electrodiffusional pickup and, in actuality, the velocity of the liquid phase is recorded. Figures 2-4, respectively, give the results of measurements of the velocity profiles of the liquid phase for laminar (Re = 1920-2060), transitional (Re = 2400-2600), and turbulent (Re = 6400-6800) flow conditions for the gas contents ($1 - \beta = 0$; $2 - \beta = 0.005$; $3 - \beta = 0.025$; $4 - \beta = 0.045$; $5 - \beta = 0.07$). Here $Re = (W'_0 + W''_0)d/\nu$; W'_0 and W''_0 are the reduced velocities of the liquid and gas phases; d is the diameter of the tube; ν is the viscosity of the liquid; u is the velocity at the axis of the channel.

The separation of the conditions into laminar, transitional, and turbulent is arbitrary, and the boundaries of the transition are taken for the conditions of one-phase flow. From Fig. 4 it can be seen that, in the region of large Reynolds numbers, the profiles of the velocity in a two-phase liquid obey the usual laws for turbulent single-phase flows, i.e., $W'_0/u = (y/R)^{1/n}$, where $1/n = 1/6 \ldots 1/7$. With Reynolds numbers corresponding to the conditions of a transition from laminar flow to turbulent (see Fig. 3), the velocity profiles differ considerably from the profiles for a single-phase liquid.

With arbitrarily laminar flow parameters (Re = 1920 or less), the divergence of the results of the experiments from data obtained for a single-phase liquid becomes very accentuated.

On the velocity profile with a gas content equal to $\beta = 0.07$, there appear characteristic sections with a velocity greater than at the axis. With the remaining gas contents, the profile is fuller than with the flow of a single-phase liquid; this deformation is very appreciable, even with negligibly small concentrations of the gas phase. The results presented are in complete agreement with the data obtained in [1] on the mean and pulsational characteristics of friction at the wall.

Thus, the results of [1] and of the present work argue the need for a review of the concepts with respect to the mechanism of the flow of a gas–liquid mixture under bubble conditions in the region of small Reynolds numbers.

LITERATURE CITED

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