An experimental investigation of the hydrodynamic conditions in a three-phase granular layer for direct upward flow of a gas and a liquid has been performed. The floating-up speeds of gas bubbles and pistons have been determined for different operating conditions. A diagram of hydrodynamic conditions has been plotted.

A theoretical analysis of direct upward flow of a gas-liquid mixture through a fixed granular layer was performed in [1], and a number of stipulations concerning the determination of the hydrodynamic conditions have been proposed. Our aim was to check experimentally the proposed inequalities and determine the parameters of the hydrodynamic models necessary for plotting a chart of the operating conditions. There are several known papers on the investigation of hydrodynamic conditions in vertical and horizontal pipes pertaining to two-phase flow [2, 3].

Hydrodynamic conditions were classified in [2] with respect to pressure pulsations at the pipe wall, measured by means of tensometric data units. An electrochemical method was used for this purpose in [3], and the flow conditions were determined with respect to the diffusion current. In all these papers, the motion of the bubbles was considered as a steady-state random process, and the sets of conditions were classified with respect to the type of spectral density. There is a paper [4], perhaps the only one, concerned with granular layers, where the hydrodynamic conditions are investigated by means of electric-contact data units.

Experimental Method and Device

We have investigated the hydrodynamic conditions by means of the capacitance method. This method is virtually inertialess; it is characterized by a high resolving power, and it permits work with any medium and the use of insulated electrode surfaces. This is an important advantage in comparison with other methods. Our method is based on measuring the permeability of the medium at the surface of the data unit. The permeability is related directly to the local gas percentage and the hydrodynamic conditions of the gas-liquid flow in the free volume of the layer. The block diagram of the experimental device is shown in Fig. 1. Gas (air) and water are supplied through a system of rotameters to column 1 by direct upward flow. The column is filled with packing consisting of glass balls. A spherical capacitive data unit is placed inside the layer. The data unit consists of a hollow sphere, where cylinders (first electrode) with needles (second electrode) positioned coaxially inside the cylinders are mounted at five points of the sphere. The sensing elements are mounted flush with the sphere surface. The diameters of the data units match those of the packing balls; they are equal to 18 and 8 mm. Only one set of electrodes is mounted in the 8-mm data unit. The data unit is connected to one arm of the compensating bridge 3, which is supplied from an audiofrequency oscillator with ac current at a frequency of 200 kHz. The bridge unbalance caused by the passage of bubbles is supplied in the form of an analog signal to the input of an IRA-5 computer (4, Fig. 1), where primary processing of the information is performed by means of program 1: interrogation of the data units, zero line shift, and formation of banks. After the necessary amount of discrete information has been
received and processed, the IRA-5 computer transmits the signals in digital code through a communication channel to a Minsk-32 computer (5). The latter performs complete processing, including calculation of the mathematical expectation, the autocorrelation function, and the spectral density, and provides at the ADP the necessary number of diagrams.

It should be mentioned that the use of a hierarchical computer system is very efficient in experimental investigations, since the duration of a single experiment, including processing, does not exceed 3-4 min.

The experimental conditions were as follows: column diameter, D = 100 mm; column height, 2 m; packing, 18- and 8-mm balls. The gas velocity, calculated for the total cross section, was equal to 5-300 m/sec, while the liquid velocity was equal to 1.0-15 cm/sec.

In order to determine the quantitative relationships, the data units were calibrated together with the computer under static conditions. In this, the relationship between the film thickness at the grain surface and the readings of the IRA-5 computer was determined. It was found that this relationship is nonlinear and that the maximum film thickness that can be determined reliably lies within the range 0-1.5 mm.

The experimental investigations were performed for wetted and nonwetted data-unit surfaces. In the latter case, the surfaces of the packing balls and the data unit itself were coated with silicone varnish and were then put into the column.

In order to ensure a sufficiently high statistical reliability of the results of measurements based on the method described in [5, 6], we used the following conditions: recording time, 40 sec; number of recording points, 2000; discreteness interval, 0.02 sec.

The estimate of the autocorrelation function was obtained by means of the computer on the basis of the expression

\[ R(t) \approx R(m) = \frac{1}{N - m + 1} \sum_{n=1}^{N-m} X(n) X(n + m). \]  

(1)

The smoothing-out was then performed by using the spectral window proposed by Hann [5]:

\[ D(t) = \frac{1}{2} \left( 1 + \cos \frac{\tau}{\tau_m} \right). \]  

(2)

After this, the normalized estimate of the spectral density was determined:

\[ \tilde{S}(\omega) = \frac{\frac{2}{\pi} \sum_{t=1}^{N} R(t) \exp(i\omega t)}{\sum_{t=1}^{N} S(\omega)}. \]  

(3)