MEASUREMENT OF THE VOLUME CONCENTRATION OF PARTICLES IN SLURRY BY MEANS OF TWO-LIQUID DIFFERENTIAL PRESSURE GAUGES

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Methods of measuring the volume concentration of particles are examined with respect to hydraulic transport systems, but all formulas and conclusions can be applied to other two-phase flows, for example, to vertical two-phase heat- and mass-exchange apparatus.

The volume concentration of the disperse phase in a two-phase flow is its important characteristic, since on it depend the velocity of the phases, intensity of heat- and mass-exchange processes, and economic efficiency of the system (apparatus).

Knowledge of the volume concentration is needed both for investigating the two-phase flow and for constant control during operation of the system (apparatus) to maintain the design regime of its operation.

Such flows usually consist of a continuous phase with density $P_c$ (liquid, gas) and disperse phase with density $P_d$ (solid particles; liquid drops immiscible with the medium; gas bubbles).

Figures 1-3 show diagrams of the movement of two-phase flows in vertical and horizontal tubes and diagrams of connecting the two-liquid pressure gauges for measuring the volume concentration of the disperse phase.

The liquid-filled differential pressure gauge includes transparent tubes 2 and vessel 3 filled with an intermediate liquid with density $P_0$ close to the density of the medium and immiscible with it. The upper part of the vessel is filled with air (under pressure), by the delivery or release of which through a branch pipe with a valve at the upper point of the vessel it is possible to change the position of the levels of the interfaces between the liquids with density $P_0$ and $P_c$ in transparent tubes 2 and to arrange them within the location of the scale for measuring their difference $h$. Vessel 3 can be filled with an intermediate liquid with a density both greater than the density of the medium $P_0 > P_c$ and less than it $P_0 < P_c$; in the first case vessel 3 is located lower than the transparent tubes (diagram a) and in the second case higher than the tubes (diagram b).

Figure 1 shows two possible directions of movement of the disperse phase $Q_d$ relative to the tube walls: in the direction of movement of the medium $Q_c$ it corresponds to hydraulic transport, in the opposite direction it corresponds to heat- and mass-exchange apparatus, in which the opposite movement of phases is usually used.

Figure 2 shows diagrams of measuring the average value of the volume concentration in the entire cross section of a horizontal flow of the slurry, and Fig. 3 in different layers of the flow. In the second case tube 1 is equipped with an access hole with a cover 4, on which are installed glands for admitting and moving the tubes into various layers of the flow.

The part of the transparent tubes connected to the two-phase flow at points b and c is filled with a liquid medium with density $P_c$ to height $h_c'$ and $h_c''$, the other part of tubes 2 connected to vessel 3 is filled with a liquid with density $P_0$.

Since the difference of pressures at points b and c is created by liquids having different densities: on the flow side with density of the slurry $P_d$ and on the side of the tube with density $P_c$ and $P_0$, and there are pressure (head) losses on path H, then the interfaces between the liquids with densities $P_c$ and $P_0$ in the transparent tubes are at different levels, at height h. The value of h depends on the volume concentration $\beta$ of the disperse phase in the flow, difference of heights H between points b and c of the pressure tap, density of the media $P_o$, $P_c$, $P_0$, and head losses during movement of the flow on path H, if points b and c are located in different cross sections of the flow (Fig. 1). We will establish the analytical relations between these quantities. For this we will examine the more general case when points b and c are located at different cross sections of the slurry flow at height H (Fig. 1) from one another at which pressure (head) losses occur.

Variant a. A liquid with density $P_0 > P_c$ is used in vessel 3, the vessel is located below the transparent tubes (Fig. 1).

The pressure difference at points b and c:

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with respect to the slurry

\[ P_b - P_c = \rho_d g H + \Delta P_e = (\rho_d H + \rho_d H) g; \]

\[ (1) \]

with respect to the tubes

\[ P_b - P_c = g [\rho_0 h + \rho_c (h_c' - h_c)]; \]

\[ (2) \]

where \( \Delta P_w \) is the pressure losses during movement of the slurry on path \( H \); \( i_c \) is the hydraulic gradient on path \( H \), expressed as the ratio of the head losses of the liquid of the medium on path \( H \), i.e., \( i_c = h_{w_c} / H \).

The density of the slurry is expressed by the dependence

\[ \rho_{sl} = \beta \rho_d + \rho_c (1 - \beta). \]

\[ (3) \]

It is seen from Fig. 1 that

\[ h_c' = h_c + H - h. \]

\[ (4) \]

Solving dependences (1)-(4) simultaneously, we obtain the following general formulas for determining \( \beta \) and \( h \) (for \( \rho_d > \rho_c \) and \( \rho_0 > \rho_c \)):

\[ \beta = \frac{\rho_0 - \rho_c}{\rho_d - \rho_c} \frac{h}{H} = \frac{\rho_c}{\rho_d - \rho_c} \frac{1}{\rho_0 - \rho_c}; \]

\[ (5) \]

\[ h = \left( \frac{\rho_0 - \rho_c}{\rho_d - \rho_c} \beta + \frac{\rho_c}{\rho_0 - \rho_c} \right) H. \]

\[ (6) \]

Preliminary knowledge of \( h \) is necessary for making the scale of the instrument, from which \( h \) will be determined.

If the head losses on the path \( H \) are equal to zero (Figs. 2 and 3) or small and they can be neglected \( (i_c = 0.0) \), formulas (5) and (6) will take the form

\[ \beta = \frac{\rho_0 - \rho_c}{\rho_d - \rho_c} \frac{h}{H}; \]

\[ (7) \]

\[ h = \frac{\rho_d - \rho_c}{\rho_0 - \rho_c} \beta H. \]

\[ (8) \]