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FEATURES OF ADJACENT STREAM HYDRODYNAMICS OF THE TWO-PHASE MEDIUM

The analysis of the characteristics of local areas of the slurry flow in the hydrocyclone without perechistki and wall-perechistkoy.

Problem and its connection with scientific and practical tasks. The perspective direction on efficiency increase of water mineral suspension division in a hydrocyclone is a new flow structure formation of the two-phase medium with use of these or another hydrodynamic effects. At the same time the whole current area can be relatively presented in the form of local zones with an individual speed field and firm particle concentration.

The flow past hydrocyclone constructive elements is accompanied by emergence of local pressure losses of the two-phase medium which value is defined by geometrical parameters of a current, concentration of a firm phase in a local zone, intensity of turbulence and interphase interactions. Despite of division efficiency increase, use of hydrodynamic effects can be accompanied by increase of local pressure losses and energy consumption on hydrocyclone acting. In particular it belongs to detachable currents and to opposite directed adjacent streams of the two-phase medium.

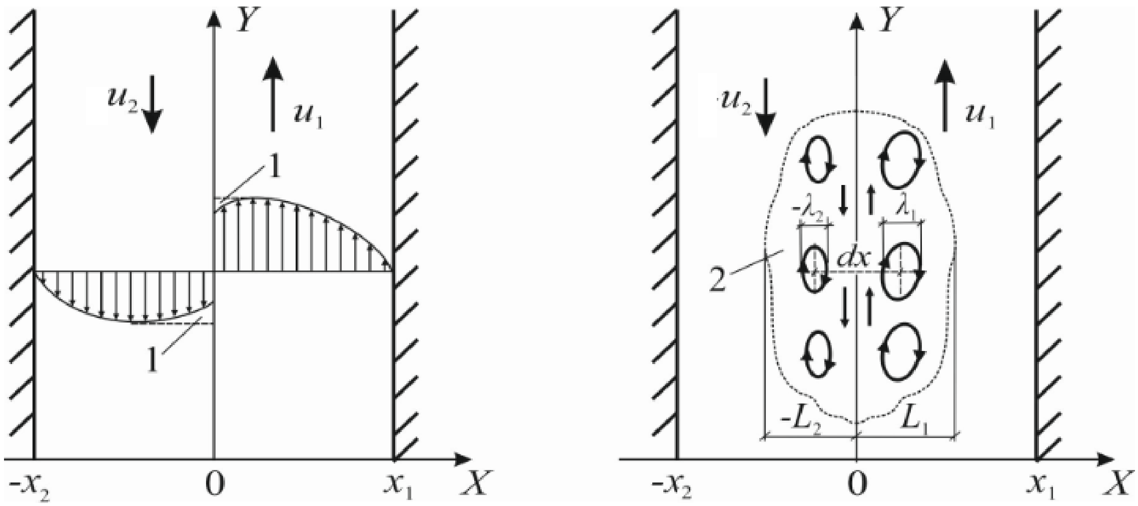
Analysis of researches and publications. One of research tasks at two-phase hydrocyclone current study is functional connection establishments between diffusion coefficients of firm particles and their concentration taking into account intra phase interactions [1, 2]. Nature of these interactions is defined by the size and the direction of a liquid phase speed vector in adjacent layers, and also by their turbulization degree [3].

Paper [4] is devoted to research of laminar two-phase currents on an inclined surface. However the two-layer scheme of a laminar current offered in this paper isn't adapted for turbulent flow, and also doesn't allow investigating feature of adjacent layers interaction with the different value of speed gradient and its direction.

The key hydrodynamic parameter defining interaction nature of adjacent the two-phase layers in local current zones in a hydrocyclone [5] is the value of laminar and turbulent tangential stress [6].

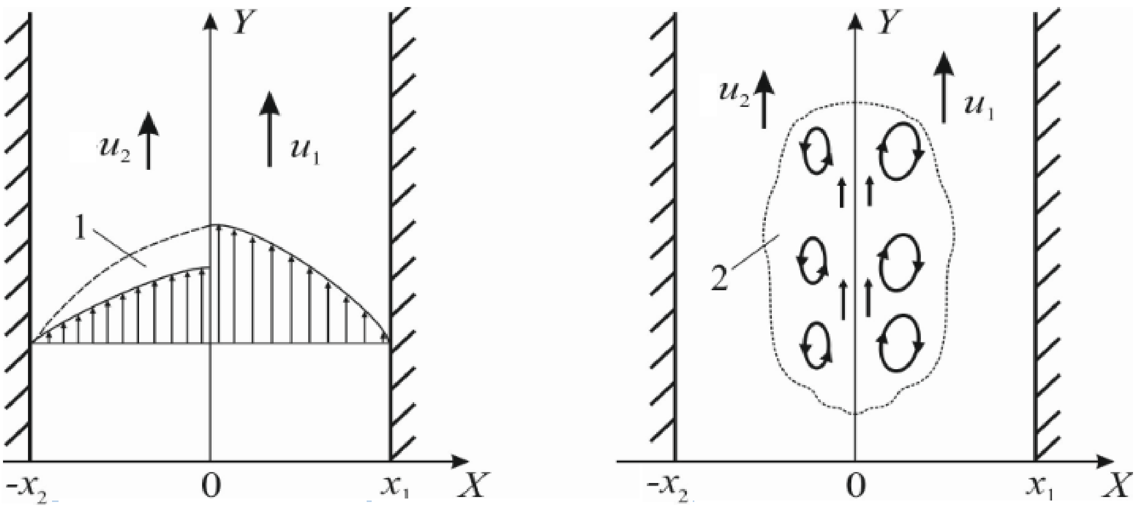
Problem definition. The purpose of this paper is hydrodynamics features research of the two-phase adjacent streams.

Statement of a material and results. Let's consider a counterflow and direct-flow current of the two-phase medium (the Newtonian liquid and the suspended firm particles) between two solid surfaces (fig. 1, 2).



a) b)

Fig. 1. Speed diagram (a) and the circulation scheme (b) on relative border section of counter flow currents of the two-phase medium:
1 – transitional zone of the slowed-down current; 2 – local zone of a counter flow current;
L_1, $-L_2$ – the characteristic values of local zones of counter flow currents;
λ_1,$-\lambda_2$ – characteristic diameters of whirlwinds in local zones;
u1, u2 – average speeds of counter flow currents



a) b)

Fig. 2. . Speed diagram (a) and the circulation scheme (b) on relative border section of the two-phase direct-flow currents:
1 – transitional zone of the accelerated current; 2 – local zone of a direct-flow current;
u_1, u_2 – average speeds of direct-flow currents

Speed increase of the two-phase medium at its counter flow (fig. 1, a) will be observed in the range from $x = -x_2$ to $x = -L_2$ and from $x = x_1$ to $x = L_1$. And on a local zone border (fig. 1, b) at $x = -L_2$ and $x = L_1$ the speed value accepts the maximum value then it decreases as approaching to relative limit of streams section (axis 0Y). The last fact is connected with energy increase of losses on friction at interaction of counterflow currents.

As $u_1 > u_2$, in a local zone of a counterflow current it is formed the bigger volume of circulation on relative limit of streams section (fig. 1, b). At the same time tangent value components of the Newtonian liquid strain tensors τ is directly proportional to its dynamic viscosity μ and the derivative speed of shift du/dx (a tangent component of deformation speeds tensor), i.e.

$$\tau = \mu \frac{du}{dx}. \qquad (1)$$

At a direct-flow current of the two-phase medium (fig. 2, a) the increase in its speed will be observed in the ranges from $x = -x_2$ to x = 0 and from $x = x_1$ to x = 0, and along relative border of streams section (fig. 2, b) it is formed the small circulation volume due to insignificant distinction of currents speeds that leads to value τ decrease in comparison with a counterflow current.

Let's examine a firm particle migration with an equivalent diameter $d_0 < \lambda_1$ ($d_0 < \lambda_2$) in a local zone of a counterflow current (fig. 1, b) in the range from $x = -L_2$ to $x = L_1$. We will consider that the particle repeats the Newtonian liquid behavior. The observation time of a firm particle migration in a considered local zone is

$$t > \frac{(L_1 + L_2)^2}{D}, \qquad (2)$$

where D – diffusion coefficient of a firm particle [7].

During a period τ_1 the firm particle is in area $0L_1$ and moves in the positive direction along an axis 0y with an average speed of u_1, and during a period τ_2 it is in area - $L_2 0$ and moves in an opposite direction with an average speed of u_2. At the same time firm particle shift along ordinate axis during $t = \tau_1 + \tau_2$ will be defined as

$$y = u_1\tau_1 - u_2\tau_2. \qquad (3)$$

Let $\tau_1 = \overline{\tau_1} + \Delta\tau_1$ and $\tau_2 = \overline{\tau_2} + \Delta\tau_2$, where $\overline{\tau_1}, \overline{\tau_2}$ – expectation τ_1 and τ_2, and $\Delta\tau_1 = \Delta\tau_2$ – deviations from them. Then at $t = 0$, $y = 0$ we will receive

$$y = u_1\overline{\tau_1} - u_2\overline{\tau_2} + u_1\Delta\tau_1 - u_2\Delta\tau_2. \qquad (4)$$

As $\overline{\tau_1} = t\frac{L_1}{L_1 + L_2}$ and $\overline{\tau_2} = t\frac{L_2}{L_1 + L_2}$, under a condition: $u_1L_1 = u_2L_2 = const$ the first two members in the equation (4) are equal zero. Then

$$\begin{cases} \bar{y} = u_1 \dfrac{L_2 - L_1}{L_2}\Delta\tau_1; \\ \bar{y}^2 = u_1^2 L_1^2 \left(\dfrac{L_2 - L_1}{L_1 L_2}\right)^2 \overline{(\Delta\tau)^2} \end{cases} \qquad (5)$$

Therefore, having determined the left part value of the system second equation (5), it is possible to calculate the average square value in the particle spent time function in the current certain area.

At firm particle migration in a local zone of a direct-flow current (fig. 2, b) its movement happens in the positive direction along an axis 0y with average speeds of u_1, u_2, and shift value along an coordinate axis during time $t = \tau_1 + \tau_2$ is determined by a formula

$$y = u_1\tau_1 + u_2\tau_2. \qquad (6)$$

Setting expectations $\overline{\tau_1}$, $\overline{\tau_2}$ and deviations from them $\Delta\tau_1 = \Delta\tau_2$ by analogy to a case of a counterflow current, at $t = 0$, $y = 0$ we receive :

$$y = u_1\overline{\tau_1} + u_2\overline{\tau_2} + u_1\Delta\tau_1 + u_2\Delta\tau_2 . \qquad (7)$$

Then under a condition: $u_1L_1 = u_2L_2 = const$ the system of the equations (5) has a form:

$$\begin{cases} \bar{y} = u_1 \dfrac{L_1 + L_2}{L_2} \Delta\tau_1; \\ \bar{y}^2 = u_1^2 L_1^2 \left(\dfrac{L_1 + L_2}{L_1 L_2} \right)^2 (\Delta\bar{\tau}_1)^2. \end{cases} \qquad (8)$$

Ratios (3), (6) for the firm particle shift value along an axis $0Y$ don't consider vortex character of the two-phase medium near relative limit of streams section (fig. 1, 2). Accepting the movement speed of a stream vortex center equal to the average speed, for a firm particle shift values at a counterflow current of the two-phase medium we receive:

$$\begin{cases} y_1 \approx u_1\tau_1 - 0{,}5\lambda_1 \sin\left[\dfrac{(u_1 + u_2)\tau_1}{0{,}5\lambda_1} \right]; \\ y_2 \approx u_2\tau_2 - 0{,}5\lambda_2 \sin\left[\dfrac{(u_1 + u_2)\tau_2}{0{,}5\lambda_2} \right]; \\ y = y_1 + y_2 \end{cases} \qquad (9)$$

For a direct-flow current of the two-phase medium we write down:

$$\begin{cases} y_1 \approx u_1\tau_1 - 0{,}5\lambda_1 \sin\left[\dfrac{(u_1 - u_2)\tau_1}{0{,}5\lambda_1}\right]; \\ y_2 \approx u_2\tau_2 - 0{,}5\lambda_2 \sin\left[\dfrac{(u_1 - u_2)\tau_2}{0{,}5\lambda_2}\right]; \\ y = y_1 + y_2. \end{cases} \qquad (10)$$

For probability density determination of a firm particle finding in a point with coordinates *x, y* in the timepoint t in a local zone of counterflow and direct-flow currents of the two-phase medium it is possible to use the equations of Fokker-Plank-Kolmogorov [8]:

$$\begin{cases} \dfrac{\partial\omega}{\partial t} = D\dfrac{\partial^2\omega}{\partial x^2} - U_1\dfrac{\partial\omega}{\partial x} \quad \text{of } x \succ 0; \\ \dfrac{\partial\omega}{\partial t} = D\dfrac{\partial^2\omega}{\partial x^2} + U_2\dfrac{\partial\omega}{\partial x} \quad \text{of } x \prec 0, \end{cases} \qquad (11)$$

where ω – function of probability density; U_1, U_2 – firm particle speeds.
Additional conditions to the equation system (11) are:

$$\begin{cases} \dfrac{\partial\omega}{\partial x} = 0 \quad \text{of } x = L_1; \\ \dfrac{\partial\omega}{\partial x} = 0 \quad \text{of } x = -L_2. \end{cases} \qquad (12)$$

Formation of vortexes close to relative border section of the two-phase medium streams leads to appearance of longitudinal and cross pulsation components of phase speed. At the same rime, the greatest these pulsations values are characteristic for a counterflow current as in this case an exchange process of an impulse and energy between opposite directed streams are more intensive, than at a direct flow. Thus, even at a laminar movement mode of the two-phase medium, distinction of speed gradients and the direction of the currents divided by relative border, can lead to appearance of turbulent adjacent layer mixing. Then the parameters L_1, L_2 and λ_1, λ_2 will characterize macro - and turbulence micro scale accordingly.

Expression (1) represents laminar tangent tension. For turbulent flow the value of tangential tension are defined as [9]

$$\tau_t = -\rho\overline{u'v'}. \qquad (13)$$

where ρ – the Newtonian liquid density; u', v' – longitudinal and cross pulsation components of the Newtonian liquid speed.

The value of turbulence intensity in a local zone of the two-phase counterflow and direct-flow currents is determined by formulas [3, 7]:

$$I_1 = \frac{\sqrt{3^{-1}\left(\overline{u_1'^2} + \overline{\mathrm{v}_1'^2}\right)}}{u_1} = \left(\frac{\lambda_1}{L_1}\right)^{1/3}; \tag{14}$$

$$I_2 = \frac{\sqrt{3^{-1}\left(\overline{u_2'^2} + \overline{\mathrm{v}_2'^2}\right)}}{u_2} = \left(\frac{\lambda_2}{L_2}\right)^{1/3}, \tag{15}$$

where $\overline{u_1'^2}$, $\overline{u_2'^2}$ – longitudinal mean square pulsation components of stream speed; $\overline{\mathrm{v}_1'^2}$, $\overline{\mathrm{v}_2'^2}$ – cross mean square pulsation components of stream speed.

Conclusions and directions of further researches:

• The tangential tension increase of viscous liquid on section relative border of counterflow currents of the two-phase medium in comparison with a direct-flow current is connected with a bigger difference of streams speeds and more intensive vortex formation of a liquid phase accordingly;

• Considerable exchange intensity of an impulse and energy between the adjacent two-phase layers at its counterflow current in a hydrocyclone leads to local loss increase of pressure and energy consumption for the hydrocyclone action.

Further researches of authors will be directed on research of fields of a concentration fineness of firm particles in counterflow and direct-flow streams of the two-phase medium.

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