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THE PROCESS OF SEDIMENTATION OF SOLID PARTICLES OF THE GRINDING SLUDGE

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ABSTRACT

Thousands of tons of grinding slimes are formed every month at the mechanical engineering enterprises (especially at bearing plants) and metallurgy ones, which are processing metals. Slimes are practically not processed at present, but exported to special landfills or dumps, worsening the environment. Slimes of abrasive metal processing can be a raw material base for powder metallurgy, as they contain 60-80% of metal particles. It is necessary to carry out the solid particles separation by density process at the slimes washing stage to increase the homogeneity of metal powder, which is extracted from grinding slimes of abrasive metal processing. The fluid flow consumption through the vertical nozzles, which allow keeping solid particles in a suspended state, is determined in this work on the basis of theoretical studies of the solid particles deposition process of grinding slimes.

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Introduction. The solution to the environmental pollution by gaseous, liquid and solid industrial waste problem is still relevant and a priority at the present time. To this end, it is necessary to solve the environmental production safety problems by improving technologies and equipment, carrying out engineering and technical measures of natural resources reproduction [1].

During metal processing at machine-building and metallurgical enterprises, a large number of metal-containing are formed, and, as a result, metal-containing waste is accumulated [2]. Grinding slimes are not processed as a rule, and are exported to special landfills. Slimes of abrasive metal processing contain 60 to 80% metal particles and can be used for powder metallurgy. The use of production waste allows not only to save natural raw materials, but also to improve the ecology of the region where the enterprise is located [3].

The technology of solid particles (metal and abrasive) separation in the washing solution flow, proposed in [4], uses the metal and abrasive particles separation by density principle. Because of the different densities, particles of the same size will be on different horizontal levels. The horizontal movement velocity of the particles will be determined by the washing solution flow rate. The purpose of this work is to study the solid particles deposition process of grinding slimes in the washing solution to determine the operating parameters of the sluice box, providing solid particles transportation in a suspended state.

Problem statement and mathematical model. A mathematical model of the particle density separation process is described in [5, 6]. The modeling parameters are the sluice box size, the fluid consumption to the horizontal flow and vertical jets, the distance between the vertical jets along the sluice box length, the liquid flow height in the sluice box.

Consider the option when a solid particle is injected into a liquid with an initial velocity of zero. The particle begins to move rapidly, and the ratio of forces acting on it is described by the equation [7, 8]:

$$ma = A - F_C = F_И \tag{1}$$

We will write down the value of each component of the equation (1):

1. $ma = \frac{\pi d^3}{6} \cdot \rho_T \cdot g$ – the force of gravity, which is equal to the particle mass.
2. $A = \frac{\pi d^3}{6} \cdot \rho_{ж} \cdot g$ – Buoyancy force, which is equal to the liquid volume mass displaced by the particle according to Archimedes ' law.
3. $F_C = \varphi \cdot \frac{\pi d^2}{4} \cdot \frac{\varpi_{OC}^2}{2\rho_{ж}}$ – resistance force, which is directly related to the cross section of the particle $S_Ч = \frac{\pi d^2}{4}$.
4. $F_И = \frac{m \cdot d\varpi_{OC}}{d\tau}$ – inertial force,

where m – particle mass, kg;
d – solid particle diameter, m;
ρ_T – solid particle density, kg / m^3;
$\rho_{ж}$ – liquid density, kg / m^3;
φ – resistance coefficient;
ϖ_{OC} – solid particle deposition velocity, m / s;
τ – deposition time, sec.

With the increase of the solid particles deposition rate the drag force also increases, with the aim to reduce the acceleration of the particle. After a certain period of time, the acceleration becomes zero.

When the particle deposition rate is constant, the forces acting on it will be presented as:

$$ma - A - F_C = 0 \tag{2}$$

Equation (2) can be presented in more detail:

$$\frac{\pi d^3}{6} \cdot \rho_T \cdot g - \frac{\pi d^3}{6} \cdot \rho_{ж} \cdot g - \varphi \cdot \frac{\pi d^2}{4} \cdot \frac{\varpi_{OC}^2}{2\rho_{ж}} = 0$$

The particle deposition velocity can be derived from this equation:

$$\varpi_{OC} = \sqrt{\frac{4(\rho_T - \rho_{ж}) \cdot d_ч \cdot g}{3 \cdot \rho_{ж} \cdot \varphi}} \tag{3}$$

It is impossible to calculate the deposition velocity of a solid particle from equation (3) at once, because it is necessary to take into account the resistance coefficient φ, and its data directly depend on the additional deposition conditions.

There are three modes of deposition: turbulent, transient and laminar. The liquid flows around the solid particle in a special way in each of them. A deposition mode area is determined by the Reynolds criterion:

$$\mathrm{Re} = \frac{\varpi_{OC} \cdot d_ч \cdot \rho_{ж}}{\mu_{ж}}, \tag{4}$$

where $\mu_{жс}$ – dynamic viscosity of the liquid, Pa·s.

The resistance coefficient φ is determined by the formulas [7]:

– for laminar motion $\text{Re} \le 1{,}85$

$$\varphi = \frac{24}{\text{Re}}, \tag{5}$$

– for the transient mode of the particle deposition 1,85 < Re < 500

$$\varphi = \frac{18{,}5}{\text{Re}^{0{,}6}} \tag{6}$$

– for the turbulent mode of the particle deposition $\text{Re} > 500$

$$\varphi = 0{,}44 \tag{7}$$

The transformation of equations (4):

$$\varphi = \frac{4}{3} \cdot \frac{(\rho_T - \rho_{жс})}{\rho_{жс}} \cdot \frac{d_ч \cdot g}{\varpi_{OC}^2}. \tag{8}$$

Next, multiply the right and left parts by a number Re^2 and, after some transformations, we obtain:

$$\varphi \cdot \text{Re}^2 = \frac{4}{3} \cdot \frac{g \cdot d^3 \cdot \rho_{жс} \cdot (\rho_T - \rho_{жс})}{\mu_{жс}^2}, \tag{9}$$

where the dimensionless set of the right part of expression (9) is Archimedes ' criterion:

$$Ar = \frac{g \cdot d^3 \cdot \rho_{жс} \cdot (\rho_T - \rho_{жс})}{\mu_{жс}^2} \tag{10}$$

From equation (9) we determine:

$$\text{Re} = 1{,}15 \cdot \left(\frac{Ar}{\varphi}\right)^{0{,}5} \tag{11}$$

Substitute in the formula (11) the coefficient φ value from the expressions (6–8) we obtain the following equations to determine Re:

– for laminar mode

$$\text{Re} = \frac{Ar}{18}, \tag{12}$$

– for the transient mode

$$\text{Re} = 0{,}152 \cdot (Ar)^{0{,}715} \tag{13}$$

– for the turbulent mode

$$\text{Re} = 1{,}74 \cdot (Ar)^{0{,}5} \tag{14}$$

Accordingly, deposition regimes can also be characterized by the Archimedes criterion:

– for laminar mode

$$Ar \le 33 \tag{15}$$

– for the transient mode

$$33 < Ar < 8{,}3 \cdot 10^4 \tag{16}$$

– for the turbulent mode

$$Ar > 8,3 \cdot 10^4 \quad (17)$$

To calculate the irregular shape particles deposition rate, it is necessary to take into account the deviation from the spherical shape, for which the calculation of the shape coefficient ψ is introduced. For spherical type particles value $\psi = 1$, and for the particles of another form $\psi < 1$.

Taking into account the coefficient ψ, the formulas (12–14) for determining the number Re will take the following form:

– for laminar deposition mode

$$\mathrm{Re} = \frac{\psi \cdot Ar}{18}, \quad (18)$$

– for the transient mode

$$\mathrm{Re} = 0,152 \cdot (\psi \cdot Ar)^{0,715}, \quad (19)$$

– for the turbulent mode

$$\mathrm{Re} = 1,74 \cdot (\psi \cdot Ar)^{0,5}. \quad (20)$$

Research results. Based on the described process the solid particles deposition in the liquid will determine: the criterion of Archimedes, the Reynolds criterion, the resistance coefficient and deposition rate for the metal and abrasive particles of the grinding sludge during such initial data:

$d_M = 50 - 200 \cdot 10^{-3}$ – the metal particles diameter, m;

$d_a = 14,6 - 272 \cdot 10^{-3}$ – abrasive particle diameter, m;

$\rho_M = 7800$ – metal particle density, kg /m^3;

$\rho_A = 2400$ – abrasive particle density, kg /m^3;

$\rho_{жс} = 1000$ – density of liquid (water), kg /m^3;

$g = 9,81$ – acceleration of gravity, m /s^2;

$\mu_{жс} = 1004 \cdot 10^{-6}$ – dynamic viscosity of the fluid (water) at a temperature of 20 °C, Pa·s.

The values of the Archimedes criterion Ar, the Reynolds criterion Re, the coefficient of resistance φ and deposition rate ϖ_{OC} for the metal and abrasive particles of the grinding sludge are shown in table 1.

Table 1.

d_M, м	Ar_M	Re_M	φ_M	ϖ_{OCM}, m/s	d_a, м	Ar_M	$\mathrm{Re}_м$	φ_M	ϖ_{OCM}, m/s
0,00005	8,272	0,4596	52,223	0,0093	0,000015	0,0424	0,0024	10188,16	0,00016
0,0001	66,178	3,0461	1,077	0,091	0,00014	37,386	2,0246	10,843	0,0154
0,0002	529,42	13,181	0,227	0,2802	0,00027	274,18	8,415	5,0601	0,0314

It is necessary to insert vertical jets of liquid with lifting speed in the direction of the precipitating particles, so that metal and abrasive particles are in a suspended state.

The velocity of the fluid through the nozzle is determined by the formula:

$$v_0^y = \frac{4 \cdot Q_y}{\pi \cdot (dw)^2 \cdot N}, \text{ m/s.} \quad (21)$$

From formula (21) we express the flow rate of the vertical flow through the nozzles:

$$Q_y = v_0^y \cdot \frac{\pi \cdot (dw)^2}{4} \cdot N, \text{ m}^3\text{/s} \quad (22)$$

The values of the liquid consumption through the injector are shown in table 2.

Table 2.

d_M , м	$\varpi_{OCм}$, м/с	$Q_{Yм}$, м^3/с	d_a , м	$\varpi_{OCм}$, м/с	Q_{Ya} , м^3/с
0,00005	0,009228	1,159*10^{-6}	0,0000146	0,000162	2,035*10^{-8}
0,0001	0,090856	1,141*10^{-5}	0,00014	0,015377	1,931*10^{-6}
0,0002	0,280239	3,52*10^{-5}	0,000272	0,031374	3,941*10^{-6}

Thus, the results of calculations of the deposition rates of metal and abrasive particles presented in tables 1 and 2 make it possible to choose the value of the liquid consumption in the vertical jets of the washing solution coming through the nozzles.

Conclusions. In this paper, we obtain a mathematical relationship that allows us to determine the consumption value of the vertical flow of liquid through the nozzles, allowing keeping the solid particles in a suspended state and transporting them along the length of the sluice box. This will determine the location of the separator according to the height of the washing flow and separate the moving metal and abrasive particles by density.

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