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DETERMINATION OF CEMENT PRODUCTION SLUDGE FILTRATION PROPERTIES

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Abstract

The article considered the advanced design of a spiral screw classifier. The problem and the importance of raw sludge classification is shown. The equipment used for raw sludge classification is described. The ways of dispersed composition concerning sludge solid phase and its separation products are analyzed. The rational constructive and technological parameters of a spiral-screw classifier are presented. The analytical expressions for the following parameters calculation are obtained: the hydraulic resistance of a spiral screw classifier; the equivalent diameter of particles; the share of sludge liquid and solid phase. The example of technological parameters calculation concerning a spiral screw classifier operation is presented. It was confirmed that the size of the classifier outlet is an important design parameter of the classifier and it influences its operation mode in general. An average geometric measurement of a particle according to three mutually perpendicular directions is taken to evaluate the volume of a real particle. The main characteristic of the sludge is the content of a dispersed (solid) phase in it, which is characterized by three mutually related indicators: the solid phase concentration, namely the weight of the solid phase in 1 kg of sludge and the volume fraction of the solid phase, that is, the volume occupied by the dispersed phase in one cubic meter of sludge.

Keywords: Classifier, raw sludge, raw ball mills, milling, regrinding, slurry solid phase, density, particle diameter, hydraulic resistance.

Introduction:

An important condition for a high-quality cement production is the proper preparation of raw mixture by fine grinding and a thorough mixing of raw materials [1, 2]. It is impossible to mill the raw material components in one unit to the desired fineness. Thus, at first raw carbonate and clay along with water and additives are ground in autogenous mills "Gidrofol" to obtain a creamy slurry - the slurry containing 32 ... 45% of water [3]. During the grinding of soft, well water soluble chalk in "Gidrofol" mills such a degree of its grinding is obtained, that the additional grinding is needed only to a certain part (40 ... 50%) of raw sludge. So the sludge coming out of these mills is advisable to split into two products: a major one, which is sent to additional grinding in ball mills and finer raw material (d <200 microns) which can immediately be sent to a sludge pool.

This division (classification) of raw sludge reduces the energy costs for its preparation considerably. In order to classify raw sludge they use high frequency vibrating screens, arc sieves and hydrocyclones [4], but according to the experience of commercial operation these aggregates are of little use for the separation of chalky sludge because of low productivity, the lack of separation precision and the low quality of obtained products. In this regard there is the need to develop a new classifying unit, taking into account the physical and mechanical and filtration characteristics of chalk suspensions.

Since both separation products of raw cement sludge are the target ones and are sent for further processing, the separation process must be a continuous one and with the removal of a solid phase sediment on a filtering (dividing) partition (a sieve). These conditions are met best of all by the unit [5], the inner shell of which also serves as a partition wall (Figure 1). The sludge is fed tangentially into the aggregate, resulting in a suspension flow swirling and simultaneously prevents the formation of a thick sediment layer on the partition (the sieve). Both of these factors intensify the process of sludge separation and provide a sufficiently high performance of the unit.

Main Part

In order to reduce the loss rate of the sludge along a filtering partition the guiding vane is set on its inner surface. This vane has the shape of a spiral helix. So its pitch *So* is associated with the inclination angle *γ* by the following formula:

$$S_0 = 2\pi R_1 tg\gamma. \qquad (1)$$

The industrial and experimental pattern of a screw classifier has the following structural and technological parameters working in a production environment: R_1=0,6 m; R_2=0,075 m; H_c = 0,3 m; H_k = 0,8 m; H = 1,1 m; l = 0,96 m; the width of the guiding lane d ≈0,15 m; the vane inclination angle $[gamma]$ = 5...8°; the classifier volume V_c=0,68 m^3, the partition area $F_{пр}$= 3,16 m^2; the volumetric consumption of the classifier power L_{sl}=200 m^3/h = 0,056 m^3/s; sludge wetness W_{sl} = 40 % = 0,4; filtrate output L_f = 40 m^3/h = 0,011 m^3/h; filtering speed $\upsilon_f \approx$ 0,0035 m/s.

The partition wall of the classifier is made of a slit mesh, woven from a shaped section wire covering the transverse wires of a circular section. The mesh cells are the slotted holes at the width of b_1 = 0,5 mm and the height b_2 = 100 mm.

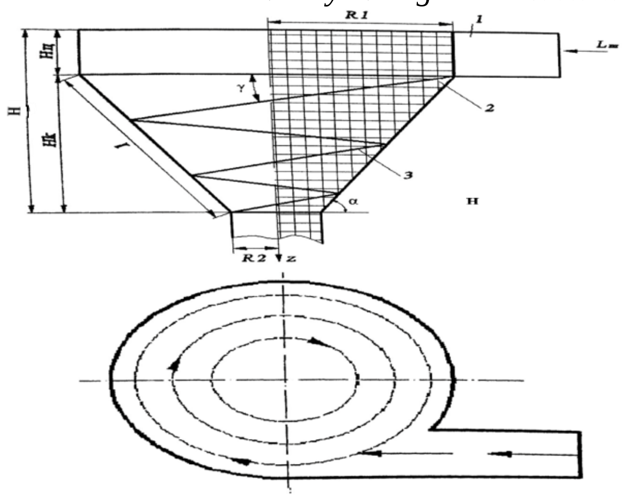

Fig. 1. Centrifugal classifier for the separation of raw cement sludge: 1 - inlet branch, 2 - filtering screen; 3 - directing spiral vane.

Each hole of the mesh is covered (framed) by a frame, the longitudinal sides of which have the width $b_t/2$, and the transversal ones have the width $b_p/2$, where b_t — is the base of the triangular cross section for the longitudinal wires, b_p - the diameter of the cross-tightening wires.

The coefficient of the grid living section, i.e., ratio of the total area of holes to the mesh area can be found by the following formula [6]:

$$\bar{\gamma} = \frac{b_1 b_2}{(b_1 + b_t)(b_1 + b_p)} = 0{,}1 \qquad (2)$$

The hydraulic resistance of the grid can be represented as follows [7]:

$$\Delta\rho = \zeta \frac{p\upsilon_{sp}^2}{2}, \qquad (3)$$

where [rho] = 1000 kg/m^3 is the density of water liquid phase; υ_{sp}, — filtration speed; [zeta] — the mesh local resistance coefficient, which can be estimated by the following formula [8]:

$$\zeta = \frac{(0{,}707\sqrt{1-\bar{\gamma}} - 1 - \bar{\gamma})^2}{\bar{\gamma}^2}. \qquad (4)$$

The separation properties of the mesh are characterized by its resistance to filtration R_r, м$^{-1}$, making the part of Darcy law [9,10], which can be represented as follows for the partition wall:

$$\upsilon_{sp} = \frac{\Delta p}{\mu R_r}, \qquad (5)$$

where [*mu*]— the dynamic viscosity coefficient of the slurry liquid phase, [*mu*] = 0,001 Pa·s.

Substituting the equation (5) in the formula (3), we obtain the following:

$$R_r = \zeta \frac{\rho \upsilon_{sp}}{2\mu}. \quad (6)$$

Formula (6) shows that the resistance of the separation partition to filtering depends on the grid living section ratio and filtration speed. The nature of these relationships is shown on Fig. 2.

The size of the classifier outlet D_2 must be sufficiently precise for a thick sludge flowing out. The volumetric flow rate of thick sludge for liquid outflow from a small hole at a gradual pressure is equal to:

$$L_{ts} \le \mu_0 \frac{\pi D^2}{4} \sqrt{2gH}, \quad (7)$$

where H — the depth of a sludge layer in the classifier, m; $[mu]_0$— opening flow factor equal to 0.6; g - gravity acceleration, m/s^2.

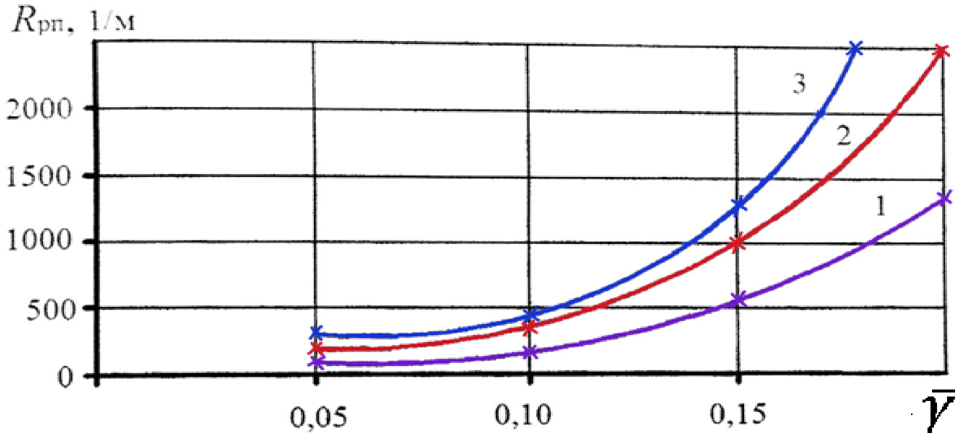

Fig. 2. The dependence of filtration resistance from partition wall I ratio on its living section ratio and filtration speed: 1 —υ_{sp} = 0,002 m/s; *2*—**υ_{sp}= 0,0035 m/s;** *3*—**υ_{sp}= 0,0045 m/s.**

The size of the classifier outlet D_2 must be sufficiently precise for a thick sludge flowing out. The volumetric flow rate of thick sludge for liquid outflow out of a small hole with a gradual pressure is equal to:

$$L_{tsl} \le \mu_0 \frac{\pi D^2}{4} \sqrt{2gH}, \quad (8)$$

When the condition (7) is performed for a hole the Reynolds number makes:

$$Re_0 = \frac{\sqrt{2gH} D^2 \rho_{ts}}{\mu_{ts}} > 10^5. \quad (9)$$

The calculations show that during typical operating conditions of the sludge classifier ($[rho]_{ts}$≈1500 kg/m^3; $[mu]_{ts}$≈ 0,004 Pa·s) the equation (8) is performed (Re_0= 2,8-10^5). Thus, the following condition is obtained from (7) for an outlet hole size:

$$R_2 \geq 0{,}346 \sqrt[4]{\frac{L_{ts}^2}{(H_c + H_k).}} \quad (10)$$

When you choose the size of R_2 it is also necessary to take into account the angle of a guiding spiral vane $[gamma]$.

The properties of raw cement sludge are determined by the properties of the substances forming a solid (dispersion) and a liquid phase.

Determination of sludge characteristics necessary for the calculation of technological parameters of the classifier operation mode

The liquid phase of a cement sludge is water with the dissolved impurities in it.

Pure water has the density [rho] = 1000 kg/m^3 and the viscosity $[mu]$ = 0,001 Pa·s.

The solid sludge phase is chalk which is a soft, easily rubbed sedimentary rock consisting of particles with a highly developed surface area. The content of calcium carbonate, $CaCO_3$ in the chalk makes 98 ... 99% with minor impurities of SiO_2, AI_2O_3 and $MgCO_3$. The chalk density makes 2500 ... 2600 kg/m^3; the volume weight makes 1600 ... 2000 kg/m^3; the humidity makes 15 ... 20%, the compressive strength limit makes 2 ... 6 MPa; the natural slope angle makes 42 ... 45°.

The dispersed phase of the sludge is formed by chalk particles of different shapes and sizes. They take the diameter as a non-spherical particle size of the same density and which has the same generalized geometrical or physical parameters as a real particle.

If the volume is selected as this parameter, the equivalent diameter of the particles makes:

$$d_{ev} = \sqrt[3]{\frac{6V_c}{\pi}}. \quad (11)$$

One may take the geometric mean of particle measurements along three mutually perpendicular directions during the evaluation of a real particle volume:

$$V_c \approx \sqrt[3]{l_1 l_2 l_3}. \quad (12)$$

The particle diameter equivalent to a surface area is calculated by the following formula:

$$d_{es} = \sqrt{\frac{4S_c}{\pi}}. \quad (13)$$

During the simulation of suspension process separation the most appropriate parameter for an equivalent diameter determination of an irregular shape particle d_{ed} is the sedimentation speed of gravitational sedimentation.

The fineness of the raw sludge solid phase grinding is characterized by grain (dispersed) composition of particles, the content of ΔD_i in separate fractions, i.e. the sums of particles, the size of which is in the range of (d_{i-1}, d_i), where *i*- is the order number of a fraction.

It is believed that the particles belonging to the same fraction are of the same size, equal to:

$$\bar{d}_i = \frac{d_{i-1}+d_i}{2}. \quad (14)$$

The integral functions of distribution along the passage are the analytical characteristics of the disperse composition

$$D(dl) = \sum_{k=1}^{i} \Delta D_k, \quad (15)$$

And the residue:

$$R(d_i) = 1 - D(d_i), \quad (16)$$

as well as the differential function of particle distribution by sizes:

$$\varphi(d) = D(d). \quad (17)$$

In order to approximate the distribution function by the sizes of sludge particles and the products of its separation we will use the log-normal law*:*

$$D(d) = \varphi(t); \quad (18)$$

$$\varphi(d) = \frac{lge}{\sqrt{2\pi} d lg\sigma} \exp\left(-\frac{t^2}{2}\right); \quad (19)$$

$$\Delta D_i = \varphi(\bar{d}_i)\Delta \mathrm{d}; \quad (20)$$

$$\varphi(\bar{d}_i) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} \exp\left(-\frac{z^2}{2}\right) dz, \quad (21)$$

$[phi](\bar{d}_i)$ – probability integral whose values are determined according to the tables [11].

$$t = \frac{\lg(d/d_{0,5})}{lg\sigma};\ \sigma = \frac{d_{0,84}}{d_{0,5}} = \frac{d_{0,5}}{d_{016}}. \quad (22)$$

Here d_p is the mesh size, which allows the passage of the p-th fraction of the sieved material mass, m, in particular, $d_{0,5}$— the median size of particles which allows the passage of half of the material, m.

An average volume (mass median) particle size is calculated by the following formula:

$$d_a^v = \sum_{i=1}^{N} \bar{d_i}\, \Delta D_i, \qquad (23)$$

where N is the number of fractions.

During the study of suspension separation process an average surface size of particles is used.

In order to calculate it one needs to know the fractional distribution of particles along their surface area.

Substituting conditionally the real particles with the spherical ones of equal volume, let's find the total area of the particle surface for i-th fraction:

$$S_i = \pi \overline{d_i^2} N_i, \qquad (24)$$

Where:

$$N_i = m\Delta D_i / (\frac{\rho_T \pi \overline{d_i^3}}{6}),$$

N_i— the number of particles concerning the i-th fraction of the material and m—the sample mass.

The total surface area of all particles in the sample is equal to:

$$S = \sum_{i=1}^{N} S_i = \frac{6m}{\rho_T} \sum_{i=1}^{N} \frac{\Delta D_i}{\overline{\overline{d_i}}}. \qquad (25)$$

In order to determine the disperse composition of the sludge solid phase and the products of its separation they are dried and screened along fractions via a special set of sieves. They use microscopic and sedimentation analysis or laser granulometry for the particles with the sizes of less than 40 microns.

The disperse composition of solid phase particles in a source sludge is shown in Table 1.

The function distribution parameters (17) and (18) approximating the particulate composition shown in the Table. 1, can be roughly estimated by test values ΔD_i ($d_{0,5}$≈200 mcm, [sigma]= 2,67), and more precisely - by least square method.

The relative shares of solid phase sludge are equal to:

$$\Delta D_i^s = \frac{s_i}{s} = \frac{\Delta D_i/\overline{d_i}}{\sum_{i=1}^{N} \Delta D_i/\overline{d_i}}, \qquad (26)$$

and the expression for the average surface particle size can be put down as follows:

$$d_a^s = \sum_{i=1}^{N} \overline{d_i}\,\Delta D_i^s = \frac{1}{\sum_{i=1}^{N} \frac{\Delta D_i}{\overline{d_i}}}. \qquad (27)$$

For the particles of the sludge solid phase corresponding to Table 1 d_a^v= 302 mcm, d_a^s = 147,5 mcm.

Table 1. Grain composition of raw cement sludge particles.

Particle fractions **(**d_{i-1}, d_i**)**, mcm	0…50	50.. 100	100...150	150...250	250...400	400...600	>600
Average size of particles dt**,** mcm	25	75	125	200	325	500	800
Mass shares of fractions, ΔD_i	0,05	0,11	0,14	0,20	0,25	0,15	0,10
Integral distribution function along the passage D	0,05	0,16	0,30	0,50	0,75	0,90	1

A specific surface area of particles may serve as the generalized characteristics of the raw sludge solid phase dispersion. It shall be equal to the total area of particle surface located in a unit of weight or a solid phase volume:

$$S_{sa}^s = \frac{S}{m} = \frac{6}{\rho_s} \sum_{i=1}^{N} \frac{\Delta D_i}{\overline{d_i}} = \frac{6}{\rho_s d_a^s}, \text{м}^2/\text{кг}; \qquad (28)$$

$$S_{sa}^v = \frac{S}{V} = \frac{\rho_s S}{m} = \frac{6}{d_a^s}. \qquad (29)$$

For the solid phase of discussed above sludge (Table. 1) S_{sa}^s=16,27 m^2/kg, S_{sa}^v =40678 m^2/m^3.

The main characteristic of the sludge is the content of dispersed (solid) phase therein, which is characterized by three interrelated parameters: solid phase concentration C_v^{sl} kg/m^3, i.e. the solid phase mass in 1 m^3 of sludge; the mass fraction of disperse phase C_{mv}^{sl}, kg/kg, i.e. the solid phase mass in 1 kg of sludge and the volumetric share of the solid phase C_v, m^3/m^3, i.e. by the volume, occupied with disperse phase in 1 m^3 of sludge.

The numerical characteristics of the solid phase content are related by the following relations:

$$C_v^{sl} = \frac{C_{mv}^{sl}}{\rho_{so}};\; C_m^{\text{Ш}} = \frac{C_{mv}^{sl}}{\rho_{sl}}. \qquad (30)$$

Here [rho]$_{so}$,[rho]$_{sl}$ - the densities of the solid phase and the sludge, kg/m^3.

The important characteristics of the sludge is also humidity W_{sl}, i.e. the relation of the liquid phase to the sludge mass:

$$W_{sl} = 1 - C_m^{sl} = \left(1 - C_{mv}^{sl}\right)\rho/\rho_{sl}, \tag{31}$$

as well as the relative part (the share) of the sludge volume occupied by the liquid phase - porosity:

$$\xi = 1 - C_v^{sl}. \tag{32}$$

The density of the sludge is expressed in terms of moisture content and the density of its components:

$$\rho_{sl} = \frac{\rho \cdot \rho_{so}}{(\rho_{so} - \rho)W_{sl} + \rho}. \tag{33}$$

The concentration of the solid phase can be expressed through the slurry density:

$$C_v^{sl} = \frac{\rho_{so}(\rho_{sl} - \rho)}{\rho_{so} - \rho}, \tag{34}$$

and using the formula (29) one may express other indicators of a solid phase. The mass consumption of sludge and its solid phase are determined by the following formulae:

$$Q_{sl} = L_{sl}\rho_{sl}; \tag{35}$$

$$Q_{sl}^{so} = Q_{sl}C_{so}^{sl}. \tag{36}$$

The rheological properties of the sludge are largely determined by its viscosity [7]:

$$\mu_{sl} = \mu\left(1 + 2{,}5C_{so}\frac{\rho_{sl}}{\rho_{so}} + 0{,}0275\left(C_{so}\frac{\rho_{sl}}{\rho_{so}}\right)^2 \exp(16{,}6)\, C_{so}^{sl}\frac{\rho_{sl}}{\rho_{so}}\right). \tag{37}$$

The dimensionless complex $C_{so}p_{sl}/p_{so}$ included in the formula (36) is expressed through the densities of the sludge components and its moisture content:

$$C_{so}^{sl} \cdot \frac{\rho_{sl}}{\rho_{so}} = \frac{(1 - W_{sl})}{(\rho_{so} - \rho)W_{sl} + \rho}.$$

Thus, the system of methods proposed by us allows to calculate all basic technological parameters of sludge taking into account the separator structure and its mode of operation.

For example, the spiral classifier is characterized by the following indicators: $[\text{rho}]_{so} = 2500\frac{\text{кг}}{\text{м3}}$; $[\text{rho}]_{sl} = 1000\frac{\text{кг}}{\text{м3}}$;

$W_{sl} = 0{,}4$; $[\text{rho}]_{sl} = 1562{,}5\frac{\text{кг}}{\text{м3}}$; $C_{mv}^{sl} = 937{,}5\frac{\text{кг}}{\text{м3}}$; $C_v^{sl} = 0{,}375$; $C_m^{sl} = 0{,}6$;

$\zeta = 0{,}625$; $Q_{sl} = 87{,}5\frac{\text{кг}}{\text{с}}$; $Q_{sl}^{so} = 52{,}5\frac{\text{кг}}{\text{с}}$; $\mu_{sl} = 0{,}0038$ Па · с.

Summary: The main factors determining the physical-mechanical and filtration properties of the sludge is the solid phase content Q_{sl}^{so} and its dispersion, expressed in terms d_a^v, which are calculated according to this method and make a significant influence on the classifier operation mode.

Conclusions: Thus, we developed an improved design of the conical spiral screw classifier to remove solid particles from the cement production sludge the size of which is larger than 200 microns.

The method of the classifier basic technological parameter calculation is developed.

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References

1. Butt, Y.M., 1976. The technology of cement and other binding materials. Stroyizdat, p. 407.
2. Duda, V., 1981. Cement. Stroyztdat p. 464.
3. Lootens, D., P. Hébraud, E. Lécolier and H. Van Damme, 2004. Gelation, Shear-Thinning and Shear-Thickening in Cement Slurries. Oil & Gas Science and Technology – Rev. IFP, 59: 31-40.
4. Bogdanov V.S., A.S. Ilyin and I.A. Semikopenko, 2007. The processes in the production of building materials and products. Belgorod "Vezelitsa" p. 512.
5. The screw classifier. The patent for utility model № 109022 issued on 10.10.2011; Authors: Bogdanov V.S., Sharapov R.R., Teterin K.K.
6. Bogdanov V.S., R.R. Sharapov, K.K. Teterin and V.A. Pelenitsyn, 2012. Investigation of sludge solid particle separation process in a screw classifier. Bulletin of BSTU named after V.G. Shukhov, (3): 67-70.
7. Altschul, A.D. and P.G. Kiselev, 1975. Hydraulics and aerodynamics. Stroyizdat, p. 323.
8. Idelchik, I.E., 1975. Handbook on hydraulic resistance. Machinery, p. 559.
9. Dick I.G., O.V. Matvienko and T. Neesse, 2000. The modeling of hydrodynamics and separation in a hydrocyclone. Technical foundations of chemical engineering, 34 (5): 478-488.
10. Zhukov V.P., G.G. Mezhunov and V.E. Mizonov, 2005. Identification of a closed grinding cycle model. Chemistry and Chemical Engineering, 48 (6): 79-81.
11. Statistical methods for the processing of empirical data, recommendations, 1978. The publishing house for standards, p. 232.

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