From the aforesaid it is possible to draw a conclusion that application of subordinate regulation systems for digger electric drives can not provide demanded non-failure operation of its work. Replacement of subordinate regulation systems by more perfect systems that would take into account dynamic processes is necessary in order to increase reliability of quarry diggers. It is necessary to use mathematical model of interconnected head and lift drives in diggers to synthesize such control systems.

REFERENCES

1. Volkov D.P., Kaminskaya D.A. Dynamics of electromechanical systems in diggers. – Moscow: Mashinostroenie, 1971. – 384 p.
2. Nosyrev M.B., Karyakin A.L. Calculation and modeling of SAU main electric drives in single-ladle diggers. – Sverdlovsk: Publishing house SGI, 1987. – 88 p.
3. Stepanov A.G. Machine dynamics. – Ekaterinburg: UrO RAS, 1999. – 392 p.
4. Gaydukevich V.I., Titov V.S. Random loading of power electric drives. – Moscow: Energoatomizdat, 1983. – 160 p.
5. Poderni R.Yu. Mountain machines and complexes for open works. In 2 v. – V. 1. – Moscow: Publishing house MSGU, 2001. – 422 p.

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ON IMPROVEMENT OF MATHEMATICAL MODEL OF LOOSE MATERIAL PRODUCTION

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On the bases of studying the history of formation of stress fields and densities in fixed layer of cohesive compressed loose material, formation of secondary stress field, appearing in the substance layer under the external action, and determining the conditions of massive destruction the mathematical description of loose material production has been proposed.

According to the modern ideas about the process, loose material (LM) production occurs in the form of stochastic shifts of substance blocks of arbitrary, constantly changing shape with low substance concentration on the boundaries between them [1–3]. Arcs formed at periodic formation and crushing of block structure may take any profiles, however, their average shape should be rather smooth. The process may be presented more simplified in the form of the system of periodically appearing and destructing arcs situated in the whole material volume. In this case lower arcs crushing precedes the crushing of upper ones and so the parameters of LM production are determined in general by the conditions of arc formation over the discharge outlet [1–5]. In connection with the examined mechanism of outflow process the supposition about the fact that substance motion in flared section of outlet zone occurs under the influence of stress field appearing due to discharge outlet opening is seemed to be physically based [2, 3, 6, 7].

The subject of the given investigation is a hydraulic or mass (in foreign terminology «*mass flow*») flow shape of loose material. Such shape is typical for well loose substance (as a rule for those having low humidity and content of fines) and at its presence the area of still material occurs only in the low part of the container (zones *CEM* and *NFD* in Fig. 1). According to the proposed design diagram it is accepted that in the upper cylindrical area *ABCD* the rate and volume density of the material are constant and undergo changes only in flared section *CMND* of outflow zone. The validity of such supposition is confirmed by numerous experimental data of various authors.

To close the combined equation of motion and continuity of steady axis-symmetric outflow of compressible LM in spherical coordinates the stress tensor constituents are presented according to the hypothesis of P.I. Lukyanov [2] about stress redistribution in LM layer at discharge outlet opening, widely used at present by various authors. Expression (1) [7] describing the forces influence on substance layer having the shape of a spatial cone the special case of which is the ratio of Bussinesk-Frelich is used in the given paper [2]:

$$\nabla\sigma_r = \frac{\nu q \cos^{\nu-2}\theta}{2(1-\cos^{\nu}\beta)}. \qquad (1)$$

Here $\Delta\sigma_r$ is the radial stress in material array; ν is the coefficient of distribution ability; q is the vertical stress functioning on the level of discharge outlet plane; β is the slop angle of container walls to the vertical.

Taking into consideration the results of numerous investigations both theoretical and experimental having showed that loose material motion near the discharge outlet is close by the shape to the radial one [2–4, 6], the system may be considerably simplified. Along the lines with constant value of angle θ for the case of radial motion we obtain the following combined equation:

$$\begin{cases} V_r \dfrac{dV_r}{d_r} = -\dfrac{\nu d_0^2 q \cos^{\nu-2}\theta}{4f\rho r^3(1-\cos^{\nu}\beta)} \\ V_r \dfrac{d\rho}{dr} + \rho\left(\dfrac{2V_r}{r} + \dfrac{dV_r}{dr}\right) = 0 \end{cases},$$

where f is the internal fraction coefficient of loose medium.

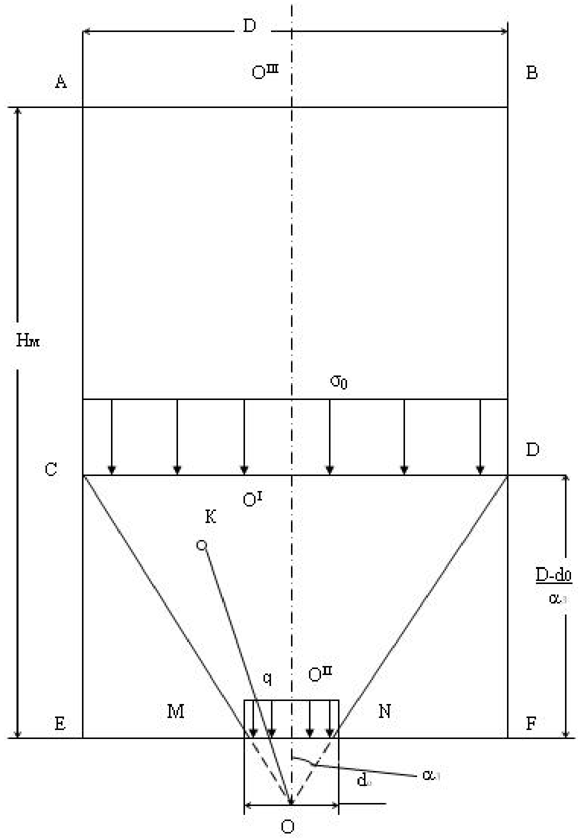

Fig. 1. *Scheme to the computation of stress and rates fields of moving LM layer*

Taking into account steady motion condition of incompressible loose material to the boundary of outflow cone $V_r=V_0$ and $\rho=\rho_0$ at $r=D_0/(2\mathrm{tg}\alpha_3\cos\theta)$ the values of searched functions take on the following form:

$$V_r = V_0 - \frac{\nu d_0^2 q \cos^{\nu}\theta \mathrm{tg}^2\alpha_3}{f\rho_0 V_0 D^2(1-\cos^{\nu}\beta)}\ln(2r\cos\theta\mathrm{tg}\alpha_3/D);$$

$$\rho = \rho_0 V_0 / V_r(D/d_0\cos\theta\mathrm{tg}\alpha_3). \qquad (2)$$

Here α_3 is the angle determining the accelerated motion area of LM; d_0 is the diameter of discharge outlet; D is the array diameter.

The analysis of the obtained expressions (2) shows that the rate of particles motion increases steadily as approaching to the discharge outlet and the value of volume density has the minimum at $r=D/(2\exp\theta\mathrm{tg}\alpha_3)\exp[f\rho_0 V_0^2 D^2/(\nu d_0^2 q\cos^{\nu-2}\theta\mathrm{tg}^2\alpha_3)-1/2]$. The rate of LM motion near symmetry axis is higher and volume density is a bit lower than in fringe region. This circumstance as well as the increase of loose material volume density as approaching to the arc surface formed over the plane of discharge outlet corresponds to the modern ideas about the outflow process of loose material from the container [2–4, 6, 7] and experimental data [2, 3, 7, 8]. Material density increase as it approaches to the arc surface may be explained by flow obstruction in the conditions of radial motion.

To obtain the numerical values V_0 let us consider [7] substance stressed state in the point O'' (Fig. 1). When opening discharged outlet its layer is plastically deformed and loose material begins to move. In this case, in our opinion, the values of volume density, rate of particles motion and vertical stress change correspondingly from ρ_0, 0 and q for static bed to ρ_v, V_v and 0 for steady motion.

Hence, material mass flow may be finally presented in the following way [7]:

$$Q = \frac{\pi D d_0^2}{2}\left[\begin{matrix} \dfrac{\nu q \rho_0}{f(d_0^2 - D^2)(1-\cos^{\nu}\beta)} \times \\ \times \dfrac{1-\cos\alpha_3}{1+\cos\alpha_3}\ln(d_0/D) \end{matrix}\right]^{0,5}. \qquad (3)$$

For practical use of the ratio (3) it is necessary to estimate the value of stresses q at the level of discharge outlet at arc structure formation and outflow process termination. Studying the static bed of loose material in elastic equilibrium state is rather difficult problem. The direct statement of elasticity theory problem presupposing determination of displacement, deformation and stresses components, as coordinate functions, in mechanics of granulated solids is substituted, as a rule, by simpler one in which deformations are not considered and additionally to the equilibrium equations the experimentally valid [2, 3, 9, 10] requirement of maximum stressed state presence in each point of the examined area, that is the fulfillment of Coulomb-More criterion, is introduced. Statistically definable system in this case is considerably simplified. It has the following form for a plane problem:

$$\begin{cases} \dfrac{\partial\sigma_x}{\partial x} + \dfrac{\partial\tau_{xy}}{\partial y} = 0, \\ \dfrac{\partial\tau_{xy}}{\partial x} + \dfrac{\partial\sigma_y}{\partial y} = \rho g, \\ (\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2 = \sin^2\phi(\sigma_x + \sigma_y + 2H)^2, \end{cases} \qquad (4)$$

here σ_x, σ_y, τ_{xy} are the components of stresses in rectangular coordinate system; H is the tension ultimate strength; ϕ is the angle of internal friction.

At present almost all used calculation methods of stress distribution in static bed of granulated solids are more or less simplifications of differential equation system of limiting stressed state (4). To analyze the limiting state of static bed – active and passive, it is sensible to use mathematically strict method of system (4) solution elaborated for soil mechanics problems by V.V. Sokolovskiy [10]. He stated the main boundary problems, formulated the boundary conditions, developed the notion about singular points, in which fracture conditions are located and suggested the effective methods of numerical integration for all kinds of soil mechanics problems. However, applying this method to calculation of stress field in real connected materials located in capacities certain complexities occur. Particularly, in substance massif possessing a certain value of initial shear strength, except the areas where LM is in limiting stressed state, there are unlimited zones the sizes and stress distribution character in which are still not definite. The method itself does not discount the material compressibility and the influence on formation of rigid foundation bed.

In the given paper the boundary conditions on LM surface are determined and computing method of unlimited area parameters (sizes, shapes and stress distribution) for connected incompressible and compressible granulated solids at rubbing with guarding surface is proposed. To describe the compressibility of coal concentrates of different humidity the expression $\rho g=A\sigma_y^2+B\sigma_y+M$ the validity of which is shown in [11, 12] is applied.

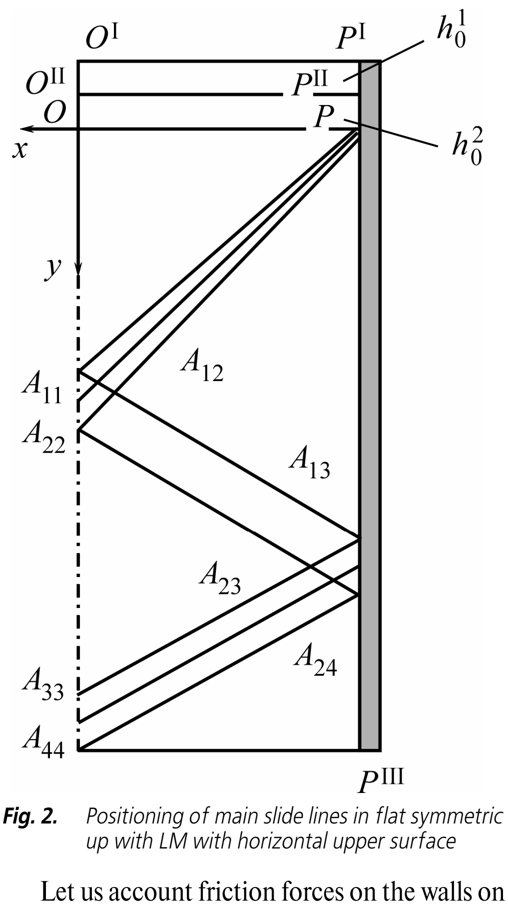

Fig. 2. *Positioning of main slide lines in flat symmetric bin filled up with LM with horizontal upper surface*

Let us account friction forces on the walls on the basis of analysis of conditions in singular point P (Fig. 2). In this case the value of angle φ (between the direction σ_1 and axis x) is changed from $\varphi_1=\pi/2$ (for load case) or $\varphi_1=0$ (for the case of passive stressed state) to the value φ_w, depending on the kind of stressed state and angle of deviation of reduced stress on the wall of bin. The angle of deviation is supposed to be equal to the angle of external friction that is shear stresses on bin wall are supposed to be fully developed. This hypothesis is accepted in many attempts to improve Jansen formula [3, 13, 14] as well as confirmed experimentally [3, 13]. The value of angle φ as it is shown in the paper [10] for the case of active stressed state in the container on left and right walls is equal correspondingly to $\varphi_w=\beta-1/2[\arcsin(\sin\phi_w/\sin\phi)-\phi_w]$ and $\varphi_w=\beta+1/2[\arcsin(\sin\phi_w/\sin\phi)-\phi_w]$. Here β is the slope angle to the axis OX, ϕ_w is the angle of external friction.

Magnitude σ along segment P^IP^{II} for the case of active stressed state is determined according to the expression [10]:

$$\sigma=\frac{\sigma_y+H}{1+\sin\phi}\exp[(\pi-2\varphi_w)\,\mathrm{tg}\phi]. \qquad (5)$$

This value is less than magnitude σ in point P at $\varphi_1=\pi/2$ that results in obtaining negative values at defining the components of stress. This implies that boundary conditions as well as parameters of unlimited bed should be determined subject to the expression (5).

From the condition $\sigma_x=0$ and expression (5) we obtain the reduced stress at the boundary of two zones (active case):

$$\sigma_y+H=H\frac{1+\sin\phi}{1+\sin\phi\cos2\varphi_w}\exp[(2\varphi_w-\pi)\,\mathrm{tg}\phi].$$

Height of unlimited area (h_0) (Fig. 2) is determined from the condition of vertical stresses continuity ($\sigma_y=\rho gh_0$) for incompressible loose material in point P [15, 16]:

$$h_0=\frac{H}{\rho g}\left\{\frac{1+\sin\phi}{1+\sin\phi\cos2\varphi_w}\exp[(2\varphi_w-\pi)\,\mathrm{tg}\phi]-1\right\}. \qquad (6)$$

Height of unlimited zone O^IP^IPO for compressible material is found out from the expression:

$$h_0=\frac{6\sigma_y}{2A\sigma_y^2+3B\sigma_y+6M}, \text{ где}$$

$$\sigma_y=H\left\{\frac{1+\sin\phi}{1+\sin\phi\cos2\varphi_W}\exp[(2\varphi_w-\pi)\,\mathrm{tg}\phi]-1\right\}. \qquad (7)$$

From the condition of component continuity and expression $\sigma_y=\rho gh_0^1$ for incompressible granulated solid we obtain the magnitude of unlimited area height without friction with guarding walls (Fig. 2) $O^IP^IP^{II}O^{II}$ [15, 16]:

$$h_0^1=\frac{2H\sin\phi}{\rho g(1-\sin\phi)}. \qquad (8)$$

For compressible material the height of this zone is determined by the expression:

$$h_0^1=\frac{2H\sin\phi}{\rho g_{cp}(1-\sin\phi)}=$$

$$=\frac{2H}{\frac{A}{3}\left(\frac{2H\sin\phi}{1-\sin\phi}\right)^2+\frac{B}{2}\left(\frac{2H\sin\phi}{1-\sin\phi}\right)+M}\frac{\sin\phi}{1-\sin\phi}. \qquad (9)$$

Vertical stress distribution for incompressible and compressible materials correspondingly in unlimited area O^IP^IPO (height of zone is computed by the expressions (6) and (7)) in area OPA_{11} is determined in the following way:

$$\sigma_y = \rho\, g(h_0 + \gamma)$$

and $\sigma_y = \frac{3}{4}\frac{2 - B(h_0 + y)}{A(h_0 + y)} + \left\{ \frac{9}{16}\left[\frac{2 - B(h_0 + y)}{A(h_0 + y)}\right]^2 - \frac{3M}{A} \right\}^{0.5}.$

There are no shear stresses in unlimited zone $O^{II}P^{I}O$ and area OPA_{11} (Fig. 2). Horizontal stresses in upper part $O^{I}P^{I}P^{II}O^{II}$ (height of zone is calculated by the expressions (8) and (9)) are equal to zero and in the bottom $OPP^{II}O^{II}$ ($h_0^2 = h_0 - h_0^1$) their values are defined by the following formula [19]:

$$\sigma_x = \frac{1 - \sin\phi}{1 + \sin\phi}\sigma_y - \frac{2H\sin\phi}{1 + \sin\phi}.$$

Using the obtained results let us specified the boundary conditions along the axis *OX* located at the depth of h_0 from the surface of material [16]. For the case of horizontal upper surface of filler in the area OPA_{11} (Fig. 2) two families of parallel lines form slide lines grid. Value of angle φ is constant: at active stressed state $\varphi = \pi/2$ and at passive stressed state $\varphi = 0$. Stress distribution in the area OPA_{11} is determined for incompressible material at active stressed state by the formula

$$\sigma = \frac{\sigma_y + H + \rho g y}{1 + \sin\phi}.$$

The ratio showing stress distribution in real compressible medium:

$$\sigma = K + \left\{ K^2 - \frac{3[(M - BH/2 + AH^2/3)y + \sigma_y + H]}{Ay(1 + \sin\phi)} \right\}^{0.5},$$

where

$$K = -\frac{3[B(1 + \sin\phi)y/2 - 2AyH(1 + \sin\phi)/3 - (1 + \sin\phi)}{2Ay(1 + \sin\phi)^2}.$$

In zone $A_{11}PA_{22}$ one family of slide lines represents the curves passing through the point *P*, and another one represents logarithmic spirals.

To calculate values x, y, σ and φ in finite number of nodal point $A_{i,j}$ along slide lines by their magnitudes in neighbor node points $A_{i-1,j}A_{i,j-1}$ the derivatives are changed by finite differences [10, 16]:

$$x_{i,j} = \frac{y_{i-1,j} - y_{i,j-1} + x_{i,j-1}\mathrm{tg}(\varphi_{i,j-1} + \varepsilon) - x_{i-1,j}\,\mathrm{tg}(\varphi_{i-1,j} - \varepsilon)}{\mathrm{tg}(\varphi_{i,j-1} + \varepsilon) - \mathrm{tg}(\varphi_{i-1,j} - \varepsilon)},$$

$$y_{i,j} = y_{i-1,j} + (x_{i,j} - x_{i-1,j})\,\mathrm{tg}(\varphi_{i-1,j} - \varepsilon),$$

$$\varphi_{i,j} = \frac{\sigma_{i,j-1} - \sigma_{i-1,j} + 2\mathrm{tg}\phi(\sigma_{i,j-1}\varphi_{i,j-1} + \sigma_{i-1,j}\,\varphi_{i-1,j}) + \rho g(D - C)}{2/\mathrm{tg}\phi/(\sigma_{i,j-1} + \sigma_{i-1,j})},$$

$$\sigma_{i,j} = \rho g C - 2\sigma_{i,j-1}(\varphi_{i,j} - \varphi_{i,j-1})\,\mathrm{tg}\phi + \sigma_{i,j-1},$$

where

$$C = y_{i,j} - y_{i-1,j} - \mathrm{tg}\phi(x_{i,j} - x_{i-1,j}),$$

and $D = y_{i,j} - y_{i,j-1} + \mathrm{tg}\phi(x_{i,j} - x_{i,j-1})$.

Carrying out sequential calculations by the scheme of first boundary problem starting with known values of desired quantities on the boundaries it is possible to find their magnitudes in all areas of interest.

In points of contact of apparatus walls by slide lines values σ and y are determined by the scheme of the second boundary problem by known values x and φ for active stresses state (along symmetry axis $\varphi = \pi/2$, $x = 0$, and along the wall $\varphi_w = \beta + 1/2[\arcsin(\sin\phi_w/\sin\phi) - \phi_w]$, $x = R$). In this case the corresponding expressions have the following form:

- along apparatus wall

$$y_{i,j} = y_{i,j-1} + (x_{i,j} - x_{i,j-1})\,\mathrm{tg}(\varphi_{i,j-1} + \varepsilon), \qquad (10)$$

$$\sigma_{i,j} = \rho g D - 2\sigma_{i,j-1}(\varphi_{i,j} - \varphi_{i,j-1})\,\mathrm{tg}\phi + \sigma_{i,j-1};$$

- along symmetry axis

$$y_{i,j} = y_{i-1,j} + (x_{i,j} - x_{i-1,j})\,\mathrm{tg}(\varphi_{i-1,j} - \varepsilon), \qquad (11)$$

$$\sigma_{i,j} = \rho g C - 2\sigma_{i-1,j}(\varphi_{i,j} - \varphi_{i-1,j})\,\mathrm{tg}\phi + \sigma_{i-1,j}.$$

The proposed method supports continuity of stress components in whole massif of the filler. Using it for computing flat conic apparatus the boundary conditions along symmetry axis should be left without changes and those along the wall should be written

$$\varphi_w = \beta + 1/2[\arcsin(\sin\phi_w/\sin\phi) - \phi_w],\ y = \mathrm{tg}\beta x.$$

Substitution of the given expression into (10) and (11) results in obtaining the desired results. In the case of asymmetric container the boundary conditions are written along both guarding surfaces and calculation is carried out for the whole LM massif.

To account compressibility of loose material let us substitute:

$$\rho_{i,j-1} g D = (A\sigma_y^2 + B\sigma_y + M)D,$$

where $\sigma_y = \sigma_{i,j-1}(1 - \sin\phi\cos 2\varphi_{i,j-1}) - H,$

$$\rho_{i,j-1} g C = (A\sigma_y^2 + B\sigma_y + M)C,$$

where $\sigma_y = \sigma_{i-1,j}(1 - \sin\phi\cos 2\varphi_{i-1,j}) - H.$

into recurrent expressions (10) and (11).

The analysis of the results obtained when using the described method shows that as in approximate methods [17, 18] at increasing material layer height the magnitude of pressure monotonous increment decreases step-by-step and its absolute magnitude tends to a limit. These results are not conformed to the data of series of experimental researches for the capacities of finite height showing that pressure diagrams are extreme with minimal values at the top of filling and at the bottom of revetment wall [14, 19]. Authors' assumption in paper [19] are seemed to be true that. They explain unconformity of experimental data to the theoretical calculations by no account of influence of a significant factor – rigid base limiting filling below.

To solve the problem the conditions of material layer forming close to the bottom of the container should be considered. There are no retarding forces along the symmetry axis therefore the value of angle φ is constant and amounted to $\pi/2$. Along the bin wall the reduced stress under the influence of friction forces deviates, value φ is a bit higher φ –

$$\varphi_w = b + 1/2[\arcsin(\sin\phi_w/\sin\phi) - \phi_w]$$

and remains constant till transition zone limited by slide line $A_{44}A_{24}$ (Fig. 2). Here the influence of rigid base results in additional change of angle φ from magnitude φ_0 corresponding to the beginning of transition zone y_0 to $\varphi_k=\pi/2+\varepsilon$ (maximum possible magnitude determined by the position of the first family slide lines) by the parabolic law [15].

To realize the proposed computing method the algorithm and software approved by the example of humid carbon-containing material were developed. Distribution of volume density magnitude of humid coal charge (W_t^r=9 %) by the data [20] and our calculations (the magnitude of physical-mechanical properties are given in papers [11, 12] for the container of 7 m height) is presented in Fig. 3.

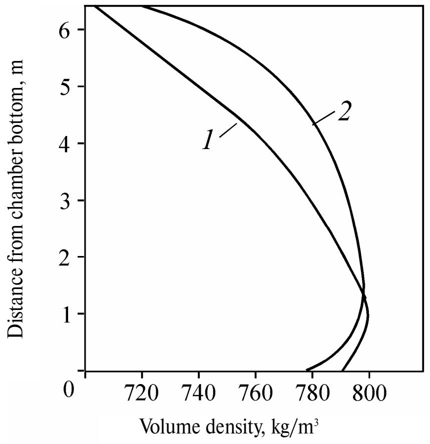

Fig. 3. *Distribution of cleaned coal density (W_t^r=9,0 %) by the height of coking chamber: 1) by experimental data; 2) subject to rigid bottom influence*

The presented data are used for defining design parameters of apparatus flared section. The dependence of dimensionless LM consumption on slope angle of apparatus wall is stated. As transmitting from flat-bottom bin to the conic one with a minor cutout of a cone the consumption increases achieving maximal value approximately at magnitude of 25° and then decreases. This decrease of rate may be explained by narrowing active outlet zone and as a result reduction of its capability. Its qualitative conformance to the experimental data given in papers [2–4] used by M.B. Generalov for refinement of the model of the material outflow from the bin with flat bottom is obvious.

Dependences of volume flow of well loose medium (f=0,577; ν=3; α_3=24°; ρ=3000 kg/m³) on diameter of discharge outlet from cylindrical apparatus with the diameter of 0,5 m are resented in Fig. 4. As it follows from the figure the computing data are in good accordance with the data obtained experimentally. More detailed comparison of theoretical and experimental results and estimation of the proposed model adequacy are given in paper [7].

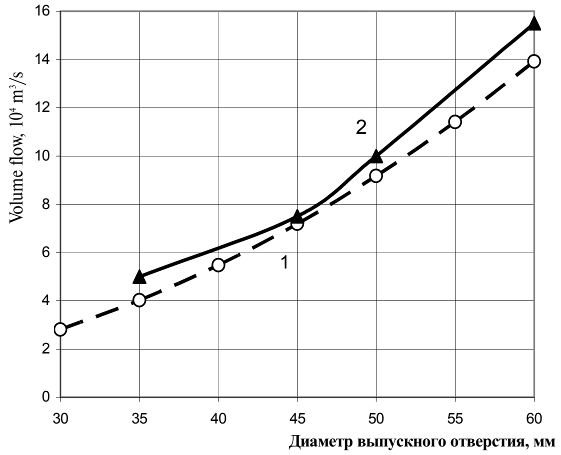

Fig. 4. *Dependence of volume flow of metal balls on discharge outlet diameter: 1) computing, 2) experimental of A.V. Katalymov. Computing dependences describe adequately the experiment at significance point 0,05*

The proposed method of computing stresses and volume densities in steady bed of loose material takes into account presence of characteristic zones (limiting and unlimited), influence of rigid base and based on mathematically strict theory of limiting stressed state. The results obtained with its help correspond to the experimental data and modern ideas about the character of static stresses distribution in loose material storages.

REFERENCES

1. Fialkov B.S., Plitsyn V.T., Maksimov V.E. Control of loose material outflow. – Alma-Ata: Nauka, 1981. – 148 p.
2. Lukyanov P.I. Apparatus with moving granular layer. – Moscow: Mashinostroenie, 1974. – 184 p.
3. Katalymov A.V., Lyubartovich V.A. Dispensing loose and viscous materials. – Leningrad: Khimiya, 1990. – 240 p.
4. Generalov M.B. Loose materials outflow from apparatus // Teoreticheskie Osnovy Khimicheskoy Tehnologii. – 1985. – V. 19. – № 1. – P. 53–59.
5. Proshunin Yu.E. On probability of arch formation at loose material outflow from apparatus // Mathematical and Economical Models in Operational Control of Manufacturing: Subject collection of scientific-technical papers. – Moscow: Electrika, 1997. – Issue 6. – P. 14–17.
6. Jennike E.V. Storage and production of loose materials. – Moscow: Mir, 1968. – 164 p.
7. Proshunin Yu.E. On construction of determinate mathematical model of carbon-containing loose materials outflow // Gorniy Zhurnal. – 2004. – № 10. – P. 82–84.
8. Keneman F.E. On free outflow of granular material // Bulletin of USSR AS. TSD. Mekhanika i Mashinostroenie. – 1960. – № 2. – P. 70–77.
9. Klein G.K. Structural mechanics of granular materials. – Moscow: Stroyizdat, 1977. – 256 p.
10. Sokolovskiy V.V. Granulated solid static. – Moscow: Fizmatgiz, 1960. – 244 p.
11. Proshunin Yu.E. On defining apparent density of coal charge in coke oven // Koks i Khimiya. – 1994. – № 2. – P. 14–19.
12. Shkoller M.B., Proshunin Yu. E., Nikolaeva V.Z., Shabarshova Yu.V. Physical-mechanical properties of coal charge ZSMK depending on humidity and compacting pressure // Koks i Khimiya. – 1988. – № 10. – P. 15–17.

13. Walters J.K. A Theoretical Analysis of Stresses in Silos with Vertical Walls // Chemical Engineering Science. – 1973. – V. 28. – P. 13–21.
14. Bushmanova O.P., Revuzhenko A.F. Investigation of Jansen problem // Physical-Technical Problems of Minerals Development. – 1981. – № 3. – P. 3–15.
15. Proshunin Yu.E. On calculation of stress field in steady bed of loose material // Physical-Technical Problems of Minerals Development. – 2004. – № 5. – P. 1–9.
16. Proshunin Yu.E. Use of limiting stressed state theory for defining coal charge density // Koks i Khimiya. – 1995. – № 10. – P. 8–12.
17. Cowin S.C. The Theory of Static Loads in Bins // Journal of Applied Mekhanics. – 1977. – V. 44. – № 9. – P. 409–412.
18. Takami A., Syoten O. A Theory of the Pressure Distribution in Powder in Equilibrium in a Cylindrical Vessel // Powder Technology. – 1974. – V. 10. – P. 295–301.
19. Ignatov V.I., Bykov E.N., Shulev A.S. On distribution of filling pressure on revetment wall // Osnovaniya, Fundamenty i Mekhanika Gruntov. – 1973. – № 5. – P. 41–43.
20. Ukhmylova G.S. Development of technology of batch partial loading // Koks i Khimiya. – 1992. – № 4. – P. 51–55.

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SEMI-EMPIRICAL CONTROL METHOD OF SOLID WASTES OF MEDIUM AND HIGH ACTIVITY

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Semi-empirical method has been developed to monitor medium and high level solid radioactive wastes based on direct measurement of wastes radioactivity and nuclide composition in lorry body. The energy range of measurements was from 80 to 3000 keV. The radioactive waste activity was from 10^6 to 10^{12} Bq. The proposed method was certified and measurement of basic errors were determined that not exceeding 60 %.

Introduction

According to the current regulations monitoring radioactive nuclide composition and activity of solid radioactive wastes (SRW) is a necessary procedure [1]. When detecting the listed characteristics for medium and high level SRW there appear a number of problems connected with, performance of all operations distantly and with minimal personnel involvement on the one hand [1, 2]. On the other hand, the objects measured (counter samples) often are of complex geometrical form as well as irregular material and activity distribution over the content of sample. This causes significant uncertainty of results in monitoring SRW activity.

The purpose of the given paper was to develop gamma-spectrometric method of monitoring activity and nuclide composition of medium and high level SRW including the appropriate methodical and metrological equipment.

Gamma-spectrometric method of monitoring activity and nuclide composition of medium and high level SRW

The method developed is based on direct measurement of waste activity and nuclide composition by gamma-spectrometer with extended uncertainty (P=0,95) not more than 60 % in the energy range from 80 to 3000 keV and activity range of SRW from $10^6...10^{12}$ Bq/kg. Measurements are made in the geometry corresponding to a lorry body intended for wastes of the given type.

The essence of the suggested measurement method consists in registration and subsequent analysis of instrumental gamma-radiation spectrum of SRW counter samples by means of Monte-Carlo method [3, 4]. In the first stage on the basis of instrumental spectra of sample standard sources of gamma-radiation the dependence of gamma-radiation registration efficiency on its energy is to be determined in the «point» geometry. Hereafter, using datum statistic model, the gamma-radiation registration efficiency on its energy for the «lorry body» geometry (volume sources in terms of absorption) is simulated. In simulation the geometrical body parameters, density and element composition of radioactive wastes and material of lorry body are used.

Monitoring SRW, in terms of the suggested method, is performed in the course of successive technological operations which are preceded by semi-empirical efficiency calibration of spectrometric track. For this purpose the wastes are loaded into the body; the weight of loaded SRW is defined; the body with SRW is placed on the radiation monitoring place. With the help of gamma-spectrometer the calculation rate for discrete energy of SRW gamma radiation is measured in the specified energy range. Measurements are performed in one of the two geometries, their schemes being presented in Fig. 1, 2. «Simple» geometry assumes a single measurement of SRW radiation by detector placed above the body (Fig. 1).

In «averaged» geometry (Fig. 2), to consider irregularity in distribution of SRW activity over the body volume