Simulation of crushed ore particles movement in the pulp under dynamic effects of high-energy ultrasound

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Abstract
The specialized program, which realizes a numerical analysis and graphical representation of simulation results of changes in pulp solid phase particle size characteristics under the controlled influence of a high-energy ultrasound radiation pressure is presented.
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One of the most important parameters, which has a decisive influence on the qualitative and quantitative indicators of separation beneficiation technology is the degree of minerals disclosure at every stage of the process.

For operational control of this parameter during the technological process it is proposed to use measurable redistribution of pulp solid phase particles under the influence of the dynamic effects of high-energy ultrasound.

Due to the radiation pressure of the high-energy ultrasound in the measurement zone there is a redistribution of crushed ore particles by size. At a constant pulp flow rate the characteristics of this redistribution are determined by the intensity of the ultrasound field and concentration, and characteristics of the pulp solid phase.

Let's consider N crushed ore particles (distributed by the y axis at the initial moment of time), which are displaced by successive steps Δx along the x axis.

Every step of any particle is selected randomly and independently from other steps. However, the probability distribution at selecting of any step is the same. Let's denote by $x(k)$ the coordinate of a particle after k steps. Then [2, 3-6]

$$x(k + 1) = x(k) + \Delta x. \quad (1)$$

By averaging this equation by the set of particles, we obtain

$$\langle x(k+1)\rangle = \langle x(k)\rangle,$$

i.e. average value of $\langle x(k)\rangle$ does not change from step to step, and therefore, is equal to $\langle x(0)\rangle = 0$. The observed value $\langle x\rangle_H$ for a large number of particles

$$\langle x(k)\rangle_i = \frac{1}{N}\sum_{j=1}^{N} x_j(k) \quad (2)$$

is close to zero (x_j - is the coordinate of j-th particle). The bandwidth by which the particles are distributed after k-th step, will be characterized by the quantity $\langle x^2(k)\rangle$.

$$\langle x^2(k+1)\rangle = \langle x^2(k) + 2\langle x(k)\Delta x\rangle + \langle(\Delta x)^2\rangle\cdot \quad (3)$$

Due to independence $x(k)$ and Δx we have

$$\langle x(k)\Delta x\rangle = \langle x(k)\rangle\langle \Delta x\rangle = 0.$$

Let's introduce the notation $\langle(\Delta x)^2\rangle = a^2$. Then from (3) follows

$$\langle x^2(k+1)\rangle = \langle x^2(k)\rangle + a^2,$$

ie the mean square of coordinate grows with each step on the value of a^2.

The observed value of

$$\langle x^2\rangle_i = \frac{1}{N}\sum_{j=1}^{N} x_j^2 \quad (4)$$

varies approximately proportional to the number of steps.

The particles distribution in the band, which occupied by them is more detailed characterized by the distribution function $f(x)$, which determines the particles concentration [1-3, 7, 8].

Here the probability of fact that the coordinate j-th particle after k-th step will be in the interval $x \le x_j \le x + dx$ is given by

$$dW = f(x)dx.$$

The theory of random walks provides a Gaussian distribution for a sufficiently large number of steps k [3]

$$f(x) = \frac{1}{\sqrt{2\pi k a^2}}\exp\left(-\frac{x^2}{2ka^2}\right). \quad (5)$$

The simulated distribution function is obtained by dividing the x-axis on a finite intervals and by counting the number of particles in each of them. If to enlarge the time steps in l times, then the mean square displacement by one step a^2 should be replaced by $a^2 = la^2$, and the number of k steps - by $\tilde{k} = k/l$. Thus $x^2(k) = la^2\cdot k/l = a^2\tilde{k}$.

The character of concentration and particle size distribution change in the field of high-energy ultrasound depends on the density of the particles themselves, the frequency and intensity of the incident radiation [2-4, 9-10]. Let's estimate the influence of ultrasound radiation pressure to concentration change of particle with radius of r. Suppose that in a positive direction of x-axis pulp flows at a rate of V. Let's denote by $n_r(Z,t)$ the concentration of the particle radius of r at a depth of Z at time t. Considering the above mentioned it can be stated:

$$\frac{\partial n_r(Z,t)}{\partial t} = -\frac{\partial}{\partial Z}\left[V_r(Z,t)n_r(Z,t)\right]\cdot \quad (6)$$

In this equation V_r (Z,t) - is the particle displacement speed with radius r and coordinate Z in ultrasonic field. Speed is directed along the axis z, i.e. perpendicular to the flow of pulp. Generally, it depends on the time t, as the concentration of particles changes as a result of ultrasound action, and this leads to a change in the intensity of the ultrasound, which ultimately affects the particle displacement speed. However, this greatly complicates the solution of the equation (6), therefore we will assume that speed depends only on the coordinate Z. Position of the particle in relative units is determined by the axis of ordinates, as well the number of its steps by the abscissa axis.

Considering that the intensity of ultrasonic waves I changes exponentially (initial value I_0), its attenuation coefficient a depends on the frequency of the sound v_0 and considering the analysis carried out in [1], the concentration of particles $n_r(Z,t)$ is determined by the formula

$$n_r(Z,t) = n_0 \frac{e^{\alpha z}}{e^{\alpha z} - \alpha\beta t} St(e^{\alpha z} - 1 - \alpha\beta t), \qquad (7)$$

where $n_r(Z,0) = n_0$, $n_r(0,t) = 0$ - are the initial and boundary conditions;

$$St(X) = \begin{cases} 0, & X < 0 \\ 1, & X \geq 0; \end{cases} \beta = \frac{2r(kr)^4}{27\eta c} I_0(a_1^2 + a_1 a_2 + \frac{3}{4}a_2^2);\ \epsilon_1 = 1 - \frac{\mathrm{rc}^2}{\rho \mathrm{c}^2};$$

$$\epsilon_2 = 2\frac{\rho - \rho}{2\rho + \rho};\ \rho_{\Gamma}, c_{T} -$$

are the particle densityand velocity of ultrasound in the material of particle; p,c – are the density of investigated medium and ultrasound velocity in it.

Below are the simulation results of the crushed ore particles concentration redistribution in the pulp under the influence of high-energy ultrasound radiation pressure in accordance with the above expressions. The developed program realizes a numerical analysis and graphical representation of simulation results of changes in the pulp solid phase particle size characteristics in form, which is illustrated in Fig. 2.

The density of crushed ore particles may vary within a predetermined range (in model example 1.8 - 3.2 g/cm^3 is accepted). Geometry of measurement, source position and intensity of the ultrasonic oscillations, solid phase particles concentration and their size distribution are set before starting the simulation. The simulated measurement zone is represented by a segment of the pipeline, the length and the diameter of which may vary depending on the task and is directly correlated with the strength of the ultrasonic radiation pressure, which in turn is determined by the intensity of its radiation generated by the source (emitter). The measuring range is a defined number of sections of the pipeline, in which the counting of number of particles, which are caught in them is carried out.

The y-axis (Fig. 2) shows the number of processed particles, moreover the deducible scale is automatically extended with an increase in simulation time, i.e. the number of passed particles. Figure 2 shows the simulation results at different time points, which demonstrates the independence of particles size distribution law on their number and simulation time.

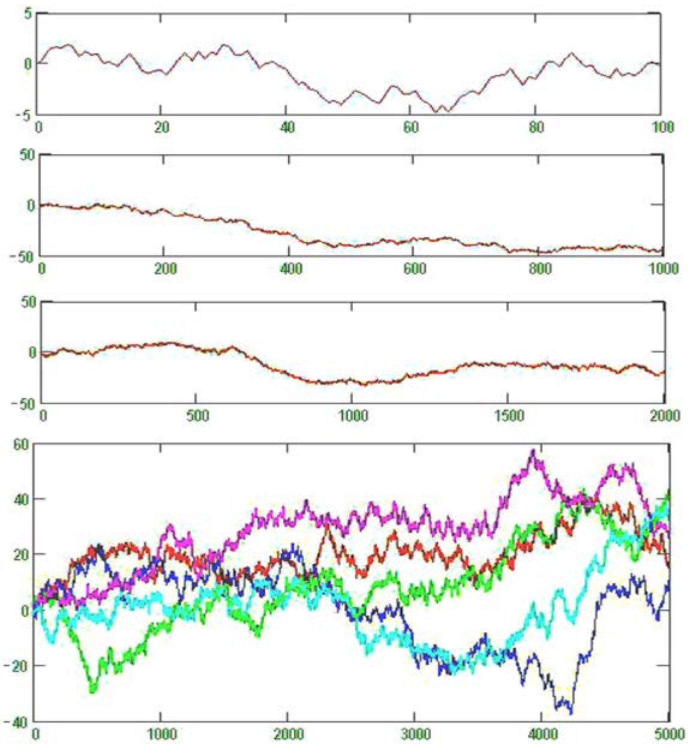

Figure 1. The simulation results of ore particles coordinates change in the pulp with increasing of steps number

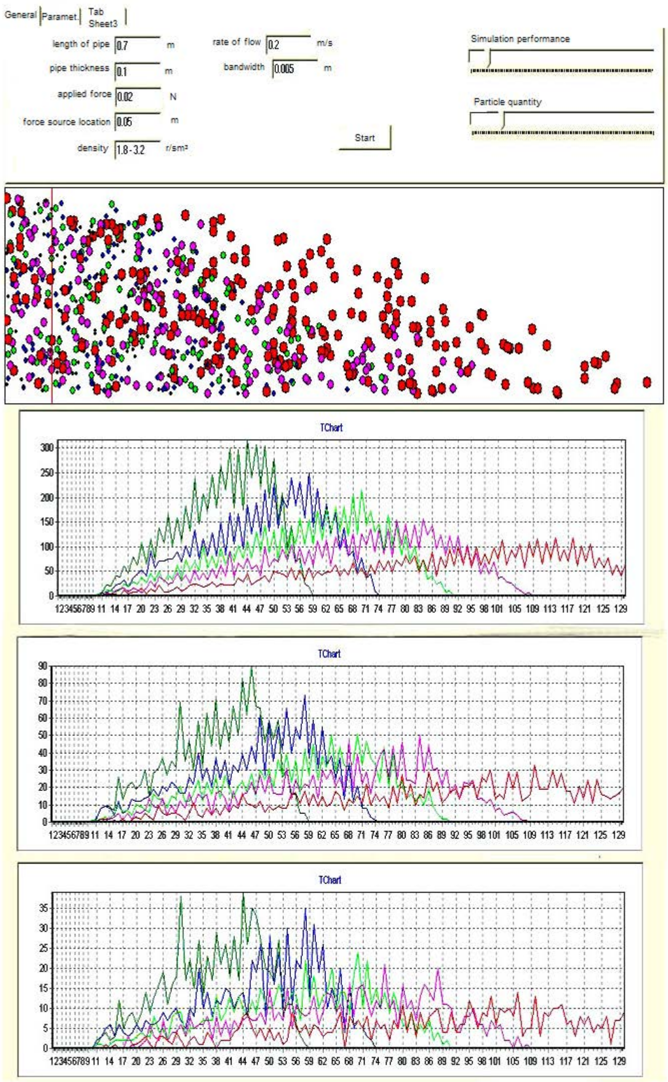

Figure 2. The simulation results of redistribution of crushed ore particles concentration of five size fractions in the pulp flow under the influence of the high-energy ultrasound radiation pressure.

Conclusions

The developed specialized program realizes a numerical analysis and graphical representation of simulation results of changes in pulp solid phase particle size characteristics under the controlled influence of high-energy ultrasound radiation pressure. The program simulates the pulp solid phase particles distribution function by dividing the *x*-axis on a finite intervals and counting the number of particles in each of them at certain time points.

References

1. Morkun, Vladimir. Ultrasonic characteristics testing of crushed materials and ore crushing-classification processes adaptive control based on it. Dr. Sc diss., Krivyi Rih Technical University, 1999.
2. Medvedev D.A., Kupershtokh A.L., Pruuel E.R., Satonkina N.P., Karpov D.I. Modelling of physical processes and phenomena on PC: the manual. Novosibirsk: Novosib state. Univ., 2006.
3. Truhan S.N. Modeling the diffusion by Monte Carlo method. Available at: http://www.exponenta.ru/educat/systemat/truhan.
4. Landau L.D., Lifshits Ye.M. *Teoreticheskaya fizika. Mekhanika sploshnykh sred* [Theoretical physics. Continuum Mechanics], Moscow, GITTL, 1954.
5. Morkun V., Morkun N., Pikilnyak A. (2015). The study of volume ultrasonic waves propagation in the gas-containing iron ore pulp, Ultrasonics, No 56C, p.p.340-343.
6. Morkun V., Morkun N., Pikilnyak A. (2014) Ultrasonic facilities for the ground materials characteristics control, Metallurgical and Mining Industry, No2, p.p. 31-35
7. Morkun V., Morkun N., Pikilnyak A. (2014). Modeling of ultrasonic waves propagation in inhomogeneous medium using fibered spaces method (k-space), Metallurgical and Mining Industry, No2, p.p. 43-48.
8. Tikhonov O.N. Zakonomernosti effektivnogo

razdeleniya mineralov v protsessakh obogashcheniya poleznykh iskopayemykh [Laws of effective separation of minerals during mineral processing]. Moscow: Nedra, 1984.
9. Bergman L. *Ultrazvuk i yego primeneniye v nauke i tekhnike* [Ultrasound and its application in science and technology], Moscow, Foreign literature publishing, 1957.
10. Rosenberg L. D. Powerful ultrasonic source. Physics and techniques of powerful ultrasound, Moscow: *SCIENCE*, 1967.
11. Grinman, I., Blyakh, G. Control and regulation of ground product particle size distribution. Alma Ata: Nauka, 1967.
12. Love A. Mathematical theory of elasticity. Moscow: ONTI, 1935.
13. Viktorov I.A. Sound surface waves in solids. Moscow: Nauka, 1981.
14. Courant R. Equations of mathematical physics. Moscow: Mir, 1964.
15. Cox T., Cox M. Multidimensional scaling.London: Chapman & Hall, 1994.
16. Floyd R.W. (1962). Algorithm 97: Shortest path. Communications of the ACM, No5(6), p.345

Noncontact NDT method of crushed ore particle size and density distribution in the pulp flow

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