CSITA

ISSN 2414-9055

UDC 519.714: 622.7

DISINTEGRATION OF ORE FLOCCULES BEFORE FLOATATION CONCENTRATION ON THE BASIS OF DYNAMIC EFFECTS OF CONTROLLED HIGH-ENERGY ULTRASOUND

Morkun V.S., ScD, Professor,

Tron V.V., PhD, Associate Professor,

Kryvyi Rih National University

Ravinskaia V. O., MS

PrJSC "Poltavskii GOK"

Abstract: *The object* is to investigate and improve performance indicators of ore floccules disintegration before floatation concentration on the basis of dynamic effects of controlled high-energy ultrasound.

The methods used for this research include analysis of domestic and foreign experience, systematization of available approaches and methods, methods of numerical simulation for synthesis and analysis of mathematical model, methods of mathematical statistics and probability theory for processing the results of experiments, methods of analytical design and computer simulation in the synthesis and analysis of control system, methods of system analysis in the development of control algorithms.

The scientific novelty consists in method for determining optimal parameters of the high-energy ultrasound, which maintains special cavitation mode with the known gas bubble size in the slurry.

The practical significance of the studies includes algorithm and formula for determining optimal parameters of the high-energy ultrasound on the basis of known gas bubble size in the slurry.

The results of the research are as follows. In the process of ore crushing, hematite, martite, iron hydroxide and magnetite particles are fixed on the surface of quartz grains. Yet, the combined mineral particles can be removed from the surface of the useful component grains while processing slurry by means of ultrasound radiation that causes some physical, chemical and physical-chemical processes in the slurry, including cavitation ones. The research work focuses on the mathematical description of cavitation processes in the heterogeneous environment and the generalized model of air bubble dynamics. On the basis of dependencies enabling us to calculate the optimal initial radius of bubbles for the maximum expansion as to the acoustic frequency and pressure amplitude, the optimal parameters of high-energy ultrasound source are determined.

Key words: high-energy ultrasound, particle cleaning, floatation concentration.

Introduction. The quality of technological processes on various stages of iron ore mining and processing can be improved by using the latest information about the technological process while controlling it. In this case, the information on the technological process development can be obtained both by its direct measurement and by using a mathematical model [16-19].

In a number of research works, the decreased iron content in magnetite concentrate is explained by the fixation of ore mineral particles on the quartz surface. As a result of some investigations [1], it is revealed that in the process of ore crushing, hematite, martite, iron hydroxide and magnetite particles of 0.8 micron are fixed on the surface of quartz grains. The stability of the mineral fixation depends on the efforts making them combine and mineral types. The fixed mineral particles are not removed fully from the quartz surface either by intensive radiation or by mechanical rubbing. The iron oxide particles can be removed from the surface of the quartz grains only when processing the slurry by ultrasound.

Materials and methods

1. Research and publication analysis

Under the action of ultrasound in the fluid medium, some physical, chemical and physical-chemical processes occur. They include cavitation, radioactive pressure and acoustic flows [2]. Cavitation is caused by the fact that all fluids are too sensitive to tensile forces. Under the influence of powerful ultrasonic oscillations in the fluid, the areas of contraction and vacuum appear. In the oscillation phase causing vacuum, a great number of gaps in the form of cavitation bubbles appear in the fluid, which close abruptly in the next phase of contraction.

The research work [3] indicates that cavitation processes intensify the cleaning of the ore particle surface from films and stuck pollutants. Under the action of powerful ultrasound in the fluid medium, there appear acoustic flows that intensively stir the slurry, reduce the thickness of the laminar layer at the boundary with the solid body and facilitate the removal of diffusive restrictions [4]. This process plays an important role in ultrasonic cleaning of the ore particle surface from mineral pollutants.

In mineral floatation in water previously processed by ultrasound the extraction of minerals into the froth product increases as

ISSN 2414-9055

compared to the floatation without water processing [5]. The research results of the ultrasound influence on minerals of titanium-zirconium deposits are presented in the research work [6]. It is revealed that the processing during 1-3 minutes with the oscillation frequency of 20 kHz and the intensity of 3.8 W/cm^2 radically activates mineral floatation.

To explain the reasons for the kinetics facilitation we suggest three hypotheses:

1) ultrasound makes the selective removal of particles possible [7];

2) ultrasound cavitation can modify the mineral particle surface by means of creating micro- and nano-bubbles and enhance the fixation of bubbles-particles [8];

3) ultrasound can influence on the probability of particles collision.

Thus, the analysis of the scientific sources reveals the efficiency of ultrasound application for intensifying the processes and solving certain technological problems in useful mineral concentration. The range of ultrasound application is great and its potential is not realized. The prospect of applying acoustic methods provides the opportunity of the efficient concentration upgrading.

2. Research results

The proportion between the mixture density and the volume fraction of the air α, according to the cavitation model considered in [9, 10] is described by the formula:

$$\frac{\partial}{\partial t}(\rho) = -(\rho_1 - \rho_{vap})\frac{\partial}{\partial t}(\alpha), \qquad (1)$$

where ρ is the mixture density, ρ_l is the fluid density, ρ_{vap} is the air density, α is the volume fraction of the air. The volume fraction of the air α is determined as follows:

$$\alpha = f\frac{\rho}{\rho_{vap}}. \qquad (2)$$

The mass transfer rates are defined by such equations, if $p \le p_{vap}$ we have [9, 10]:

$$R_e = C_e\frac{v_{ch}}{\sigma}\rho_1\rho_{vap}\sqrt{\frac{2(p_{vap} - p)}{3\rho_1}}(1 - f), \qquad (3)$$

otherwise:

$$R_c = C_c\frac{v_{ch}}{\sigma}\rho_1\rho_1\sqrt{\frac{2(p - p_{vap})}{3\rho_1}}f, \qquad (4)$$

where v_{ch} is the characteristic frequency, which is the approximation to the local turbulent geometry, C_e and C_c are empiric constants.

The general rate of the interphase mass transfer per volume unit considering the bubble density when applying the assumption about the equal bubble size is determined on the basis of the cavitation the Zwart-Gerber-Belamri model [11]:

$$R = \frac{3\alpha\rho_{vap}}{R_b}\sqrt{\frac{2}{3}\frac{(p_{vap} - p)}{\rho_1}}, \qquad (5)$$

where R_b is the bubble radius; p_{vap} is the air pressure. In the equation (5) the mass transfer rate of a unit volume is connected with the air phase density ρ_{vap} only. This equation is subject to the bubbles growth. To apply it to the process of bubble popping we use this generalized expression [9]:

$$R_e = F\frac{3\alpha\rho_{vap}}{R_b}\sqrt{\frac{2}{3}\frac{(p_{vap} - p)}{\rho_1}}\,sign(p_{vap} - p), \qquad (6)$$

where F is the empiric calibrated coefficient. The rate of one bubble mass change is obtained as follows

$$\frac{dm_b}{dt} = 4\pi R_b^2\rho_{vap}\sqrt{\frac{2}{3}\frac{(p_{vap} - p)}{\rho_1}}. \qquad (7)$$

For n_b of the bubbles per volume unit, the volume fraction of the air is determined by the formula:

$$\alpha = V_b n_b = \frac{4}{3}\pi R_b^3 n_b. \qquad (8)$$

With the growing volume fraction of the air, the density of the area where the bubbles appear increases. To simulate this process Zwart-Gerber-Belamri [11] suggested changing α to α_{nuc}(1-α) in (6). As a result, we obtain the following form of the cavitation model for $p \le p_{vap}$:

$$R_e = F_{vap}\frac{3\alpha_{nuc}(1 - \alpha)\rho_{vap}}{R_b}\sqrt{\frac{2}{3}\frac{(p_{vap} - p)}{\rho_1}}, \qquad (9)$$

otherwise:

$$R_c = F_{cond}\frac{3\alpha\rho_{vap}}{R_b}\sqrt{\frac{2}{3}\frac{(p - p_{vap})}{\rho_1}}. \qquad (10)$$

We can achieve the stable cavitation mode as shown in [12] if the acoustic frequency is small (<1 MHz) and the pressure amplitude is much smaller than the air static pressure (101 kPa). Under these conditions, a bubble is in a steady cavitation state and oscillates near its initial radius on a periodic basis. To describe this process, we suggest using the empiric equation based on the Keller-Herring model [9, 13]:

ISSN 2414-9055

$$R_0 \equiv \ 3\{MГц\}\frac{um}{f_0^{lin}}, \qquad (11)$$

where R_0 is the bubble radius, micron; f_0^{lin} is the acoustic frequency. It should be noted that under higher pressure the reaction of bubbles depends on the amplitude of the acoustic field pressure to a greater degree and, thus, the equation (11) is not possible under these conditions of “inertial cavitation”.

In the work by K. J. Carvell [13], the author obtains the expressions allowing us to calculate the initial bubble radius for the maximum expansion depending on the acoustic frequency and pressure amplitude:

$$R_{optimal} = \frac{1}{\sqrt{0.0327F^2 + 0.0679F + 16.5P^2}}, \qquad (12)$$

where P is the pressure amplitude for the acoustic sinusoidal wave, MPa, f is the frequency, MHz; $R_{optimal}$ is the initial optimal bubble radius, micron. For instance, if f= 1 MHz, P = 1 MPa, the optimal bubble radius is 0.2454 micron.

Having transformed the dependency (12), we obtain the quadratic equation which contains the function of the optimal frequency for a certain bubble size:

$$0.0327F^2 + 0.0679F + 16.5P^2 \quad \frac{1}{R_{optimal}} = 0, \qquad (13)$$

in which $F(R)$ with the known pressure P can be defined from the expression:

$$F(R) = \frac{0.0679 \pm \sqrt{0.0679^2 - 4 * 0.0327 * (6.5P^2 - \frac{1}{R})}}{2 * 0.0327}. \qquad (14)$$

Thus, the cavitation mode with the known gas bubble size $R_{optimal}$ is achieved under the influence of the high-energy ultrasound with the frequency $F(R_{optimal})$ on the slurry. Let us indicate the function of bubble size distribution by $f(R)$. In this case, the value $f(R)\,dR$ determines the fraction of the bubbles the size of which is from R to $R + dR$.

Table I shows the values of the function $f(R)$ used in the calculation. The function $f(R)$ graph is shown in Fig.1 [14].

Table 1. Values of gas bubble distribution function

Index	Value					
R,cm	0.0003	0.0005	0.001	0.002	0.005	0.010
$f(R)$,cm^{-1}	0.54	2.73	5.45	33.0	54.5	10.8
R,cm	0.015	0.020	0.025	0.030	0.035	0.040
$f(R)$,cm^{-1}	4.9	2.12	1.09	0.65	0.41	0.21

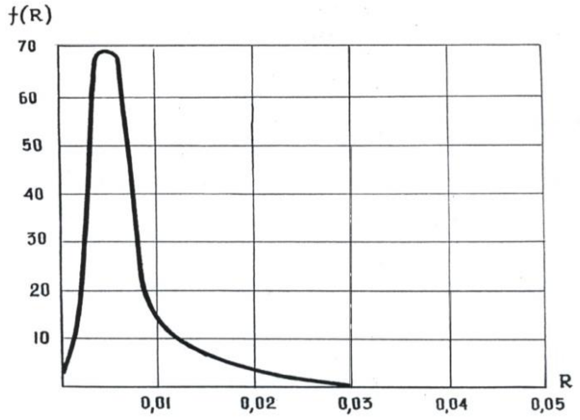


Figure 1. Graph of air bubble size distribution function

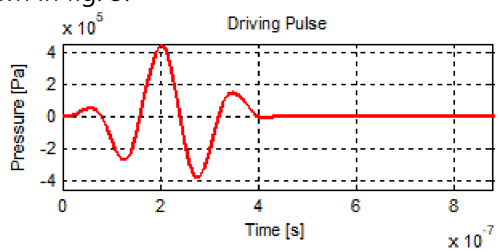
To simulate the acoustic signal propagation in the heterogeneous medium in the conditions of the changeable sound speed and the changeable density, the method k-space is used [15]. For the two-dimensional medium without losses, the equation looks like [15, 16]

$$\rho(r)\frac{\partial u(r,t)}{\partial t} = \nabla \ \ p(r,t),$$
$$\frac{1}{\rho(r)c(r)^2}\frac{\partial p(r,t)}{\partial t} = \nabla \ \ u(r,t)', \qquad (15)$$

where u is the vector of the speed oscillation of the acoustic fraction with the components u_x and u_y, p are fluctuations of the acoustic pressure, $\rho(r)$ is the medium density, $c(r)$ is the sound speed in the medium; r is the vector of the coordinates (x, y). The wave equation of the second order looks as follows [15, 16]

$$\nabla \ \frac{1}{\rho(r)}\nabla p(r,t) \quad \frac{1}{\rho(r)c(r)^2}\frac{\partial^2 p(r,t)}{\partial t^2} = 0. \qquad (16)$$

The result of the simulation of cavitation processes under the ultrasound impact (the impulse amplitude is 0.45MPa, the impulse length is 2.75 of the cycle, the frequency is 6.25MHz) is shown in Fig. 2. The result of the simulation of cavitation processes under the ultrasound impact (the impulse amplitude is 0.25 MPa, the impulse length is 5.5 of the cycle, the frequency is 5MHz) is shown in fig. 3.



ISSN 2414-9055

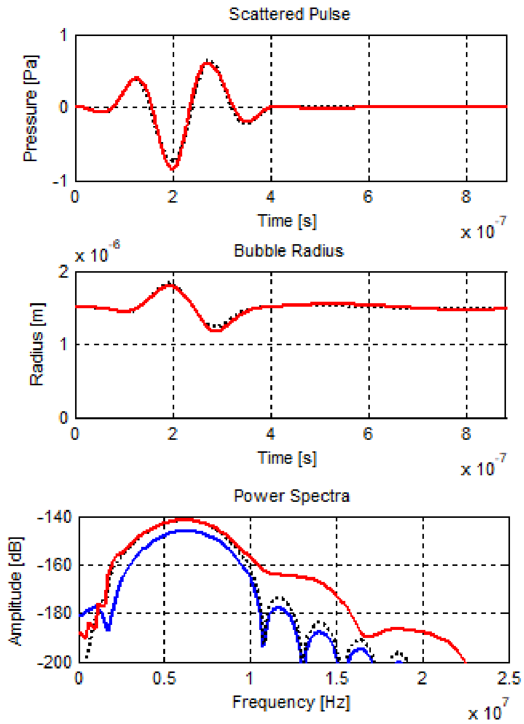


Figure 2. Results of simulation of cavitation processes under high-energy ultrasound impact

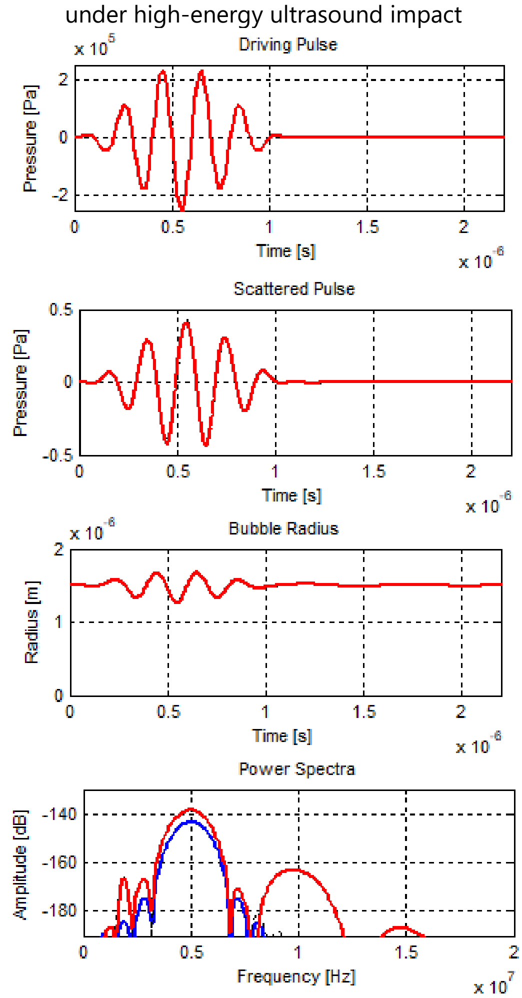


Figure 3. Results of simulation of cavitation processes under high-energy ultrasound impact

Conclusion

The analysis of the major directions and approaches to intensifying ore concentration has revealed that application of high-energy ultrasound of certain intensity for preliminary iron ore slurry processing enables increase of the useful component output in the floatation product by disintegrating ore floccules.

The conducted investigation of the regularities of cavitation development allows forming the method of determining the optimal frequency of high-energy ultrasound to maintain cavitation processes in the slurry to disintegrate floccules and, thus, increase the efficiency of the floatation ore concentration.

References

1. Hrytsai, Yu.L., Pedan, M.V., Heresimova, Z.D. Investigation of fixation of disperse ore minerals on quartz surface while processing ferruginous quartzites. Moscow: Nedra [in Ukrainian], 1980.

2. Hubin, H.H., Yarosh, T.P., Skliar, L.V. Generalization and analysis of possibility to use ultrasound oscillations in mineral processing. Mineral concentration, no. 62 (2016): 150-162.

3. Hlembotska, V.A., Sokolov, M.A., Yakubovich, I.A. Ultrasound in mineral concentration. Alma-Ata: Nauka Kaz. RSR, 1972.

4. Ahranat, B.A., Kirilov, O.D. Ultrasound in hydrometallurgy. Moscow: Metalurhiia, 1969.

5. Ahranat, B.A., Khan, H.A., Panteleieva, N.F., Elbert, A.V. Floatation in water treated by ultrasound. Intensification of metal extraction from ores in ultrasound field. Moscow: Metalurhiia, 1969.

6. Akopova, K.S., Dokshina, I.D., Tiutiunnyk N.D. Change of properties of mineral by ultrasound. Ultrasound methods of intensifying technological processes. Moscow: Metalurhiia, 1970.

7. Kondratiev, S.A. Flotation method. Russian Patent 2243824, 2005.

8. Zhou, Z.A., Zhenghe, X., Finch, J.A., Masliyah J.H., Chow, R.S. Miner. Eng. 22 419, 2008.

9. Kozubková, M., Rautová, J., Bojko M. Mathematical model of cavitation and modelling of fluid flow in cone. Procedia Engineering, no. 39 (2012): 9-18.

10. Singhal, A.K., Li, H.Y., Athavale, M.M., Jiang, Y. Mathematical basis and validation of the full cavitation model. Proceedings from ASME FEDSM '01. New Orleans, Louisiana, 2001.

11. Zwart, J., Gerber, A.G., Belamri, T. Two-Phase Flow Model for Predicting Cavitation Dynamics. Proceedings from: The Fifth International Conference on Multiphase Flow. Yokohama, Japan, 2004.

12. Zhong, Hu. Comparison of Gilmore-Akulichev equation and Rayleigh-Plesset equation on therapeutic ultrasound bubble cavitation. Extended abstract of Doctor's Thesis. Paper 13458.

13. Carvell, K. J., Bigelow, A. T. Dependence of optimal seed bubble size on pressure amplitude at therapeutic pressure levels. Ultrasonics, no. 51.2 (2011): 115-122.

14. Morkun, V.S., Potapov, V.N., Morkun, N.V., Podgorodetskiy N.S. Ultrasound control of crushed material characteristics in ASC of concentration production. Kriviy Rih: Mineral, 2007.

15. Makoto, T. A k-space method for coupled first-order acoustic propagation equations. Acoustical Society of America. 111 (1), Part 1 (2002): 53-63.

16. Pierce, D. Acoustics: An Introduction to its Physical Principles and Applications. Acoustical Society of America. Woodbury, New York, 1989.

17. Morkun, V., Morkun, N., Tron, V. Distributed control of ore beneficiation interrelated processes under parametric uncertainty. Metallurgical and Mining Industry, no. 8 (2015): 18-21.

18. Morkun, V., Morkun, N., Tron, V. Model synthesis of nonlinear nonstationary dynamical systems in concentrating production using Volterra kernel transformation. Metallurgical and Mining Industry, no. 10 (2015): 6-9.

19. Morkun, V., Morkun, N., Tron, V. Distributed closed-loop control formation for technological line of iron ore raw materials beneficiation. Metallurgical and Mining Industry, no. 7 (2015): 16-19.

20. Morkun, V., Morkun, N., Tron, V. Formalization and frequency analysis of robust control of ore beneficiation technological processes under parametric uncertainty. Metallurgical and Mining Industry, no. 5 (2015): 7-11.