Calculation of optimal intensity of ultrasonic vibrations for removal of oxide films from the surface of ore pulp particles

V. A. Iodis, *Candidate of Technical Sciences, Leading Researcher*[1], *e-mail: iodisva@mail.ru*

[1] *Scientific Research Geotechnological Center, Far Eastern Branch of Russian Academy of Sciences, Petropavlovsk-Kamchatsky, Russia.*

In the processing of oxidized, refractory ores, the removal of oxide films from the mineral surface is an important task. Oxide films create a passivating effect leading to the transition of the metal surface into an inactive state, which slows down physical and chemical processes, such as bacterial oxidation process. In order to avoid this effect, it is advisable to act on the surface of the crushed ore with ultrasonic radiation. The analysis of Russian and foreign inventions — technologies of ore processing using ultrasound has shown acceleration of mass transfer in the process of ore leaching, significant intensification of the leaching/oxidation process, increase in the degree of extraction of valuable metals, reduction in the duration of the process as a whole. However, due to the high energy consumption of the ultrasonic treatment process, it is important to determine the optimal value of ultrasonic intensity at which the oxide films are removed from the ore grains, but the grains are not destroyed, not crushed. In this work we calculated the optimum value of ultrasonic vibration intensity capable of removing oxide films from the surface of cobalt-copper-nickel sulfide ore particles in order to avoid creating a passivating effect on their surface. As the calculation showed, the optimal value of the ultrasound intensity lies in the range from 17 to 28 W/cm^2, at a frequency of ultrasonic vibrations of 22000 Hz.

Key words: ultrasonic vibrations, intensity, sulfide ores, oxide films.

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Introduction

Removal of films of oxide compounds from the surface of minerals is an important task in the processing of oxidized, finely disseminated and other refractory ores. The appearance of oxide films on the surface, in particular metal sulfides, creates an effect that leads to the transition of the metal surface into an inactive, passive state. This effect significantly slows down physical and chemical processes, such as the direct bacterial oxidation process. Traditional methods of mineral surface cleaning from secondary mineral formations, such as chemical, thermal treatment, mechanical scrubbing, often do not provide the necessary degree of cleaning especially from films located in microcracks. In order to avoid passivating effect, it is promising to use ultrasonic radiation on the surface of milled ore [1–6].

Analysis of previous studies

The analysis of Russian patented technologies of ore leaching/oxidation using ultrasonic action showed that when using ultrasonic treatment of pulp (a mixture of crushed ore and distilled water) the process of leaching/oxidation is intensified due to the occurrence of cavitation in the pulp, and the percentage of metal recovery increases two and more times. In the considered methods ultrasonic pulp treatment was carried out with intensities from 1 to 70 W/cm^2 for removal of oxide films, destruction of ore particles (grinding) [7–13].

Patent review of foreign developments also showed acceleration of mass transfer in the ore leaching process with the use of ultrasonic treatment, increased recovery of valuable metals (Au up to 98%, Ag up to 87.47%, Cu up to 81%), reduced process duration in general.

In the considered methods, patented abroad, ultrasonic influence on pulp was carried out with specific volume intensities from 1.75 to 5.3 kW/m^3, specific intensities 0.5–4 W/cm^2, at output power of oscillations 30– 800 W, duration from 5 to 200 min, and at leaching of refractory high-sulphur gold ore the process lasted 18 hours. As noted by the authors of the foreign inventions, process intensification occurs due to the removal of microfilm from the surface of the mineral(s), formation of microcracks in the mineral(s), their pulverization [14–20].

However, the process of ultrasonic impact is rather energy-intensive, so the purpose of this work is to calculate the optimum value of ultrasonic vibration intensity, at which the grains of sulfide cobalt-copper-nickel ore are not subjected to destruction, grinding, but only remove oxide films from the surface of ore particles pulp.

Materials and research results

When exposed to ≥22 kHz ultrasound, rapidly alternating expansions and contractions occur in the pulp, adding negative or positive sound pressure to the constant statistical pressure of the pulp. In the negative sound pressure phase, cavitation vapor-gas bubbles (undissolved gases in the pulp) are formed.

Bubbles, by the nature of their impact on the activated process can be divided into three groups — small bubbles (cavitation nuclei), at collapse of which no shock wave is formed in the pulp; cavitation bubbles, collapse of which is accompanied by the formation of shock waves; large bubbles (long-lived), pulsation of which causes small changes in pulp pressure.

Four stages in the development of the cavitation process can be distinguished:

1. No cavitation. Stage occurring at insignificant amplitudes of sound pressure and as a consequence small amplitudes of linear-radial oscillations of small bubbles.

2. Cavitation onset (initial stage). The stage that takes place when the sound pressure amplitude (positive pressure) rises to 10^5 Pa. At this stage, the nonlinearity of oscillations is manifested, consisting in a significant excess of the rate of bubble radius decrease in compression over the rate of bubble stretching in expansion. This leads to an increase in the pressure of the vapor-gas mixture inside the bubble up to $2 \cdot 10^6 \div 4 \cdot 10^6$ Pa and results in the formation of a shock wave with a small pressure amplitude and damped at the distance of ≈ 5 ÷ 10 μm [21].

3. Developed cavitation. At the stage of developed cavitation, an increase in the sound pressure amplitude leads to a significant increase in the shock wave pressure amplitude at the collapse of cavitation bubbles. At this stage, vapor-gas bubbles are formed in large numbers, instantly grow and collapse, while the pressure of the vapor-gas mixture in the bubbles increases to $3 \cdot 10^8$ Pa, the temperature of the vapor-gas mixture of the bubble increases to 6000 K, and the walls of the bubbles move towards each other with a velocity of 250÷340 m/sec. Shock waves are formed [21, 22].

4. Degenerative cavitation. When the sound pressure amplitude rises above a critical value, cavitation bubbles reach critical sizes. At these sizes, their degeneration into large bubbles – long-lived (100–1000 μm), occurs oscillating around their maximum size [21]. Bubbles of this group do not have any serious effect on the pulp, but they have a great shielding effect and prevent the propagation of ultrasonic waves.

It is known that the largest number of cavitation cores (nuclei) is located near microcracks and irregularities in the surfaces of pulp particles containing oxide films [20]. Therefore, the impact action of the process will be most concentrated near the particle irregularities of the ultrasonic treated pulp and will result in the removal of oxide films.

The intensity of ultrasonic waves, W/m^2 is determined:

$$I = \frac{\rho_o \cdot \upsilon_w \cdot u_{ov}^2}{2}, \qquad (1)$$

where ρ_o – density of sulfide ore, kg/m^3; υ_w – ultrasonic wave velocity in the medium, m/s.

Derive from expression (1) the amplitude of oscillatory velocity:

$$u_{ov} = \sqrt{\frac{2 \cdot I}{\rho_o \cdot \upsilon_w}}; \qquad (2)$$

Then the amplitude of sound pressure will be equal to:

$$\Delta\rho_a = \sqrt{2 \cdot I \cdot \rho_o \cdot \upsilon_w}; \qquad (3)$$

To achieve the destruction of ore pulp particles, it is necessary that the pressure generated by ultrasonic vibrations exceeds the limit of their tensile strength [22, 23], i. e.:

$$\sigma_{op} \le n\sqrt{2 \cdot I \cdot \rho_o \cdot \upsilon_w}; \qquad (4)$$

Deriving from expression (4) the intensity of oscillations, we obtain:

$$I \ge \frac{\sigma_{op}^2}{2 \cdot n^2 \cdot \rho_o \cdot \upsilon_l}, \qquad (5)$$

where υ_l – longitudinal wave velocity in the ore pulp particle, m/s.

The longitudinal wave velocity in the ore particle can be determined:

$$\upsilon_l = \sqrt{\frac{E - E \cdot \mu}{\rho_o - \mu \cdot \rho_o - 2 \cdot \mu^2 \rho_o}}, \qquad (6)$$

where μ – Poisson's ratio; E – Young's module, Pa.

The final expression for calculating the intensity of ultrasonic vibrations for destruction, crushing of sulfide ore grains is obtained:

$$I \ge \frac{\sigma_{op}^2}{2 \cdot n^2 \sqrt{\dfrac{E \cdot \rho_o - E \cdot \rho_o \cdot \mu}{1 - \mu - 2 \cdot \mu^2}}}. \qquad (7)$$

According to the expression (7) we calculated the intensity of ultrasonic vibrations for the destruction of rocks (**Table**), close in properties to cobalt-copper-nickel sulphide ores. [24, 25].

The results of calculation according to formula (7) are presented on the graph of dependence of ultrasonic vibration intensity on the tensile strength of ore grains (**Figure**).

The graph shows that the optimum value of ultrasonic vibration intensity, at which sulfide ore grains are not subjected to destruction, grinding, but only remove oxide films from the surface of ore particles pulp lies in the range of 17 W/cm^2 ≤ I ≤ 28 W/cm^2. The frequency

Table
Properties of ore

№	Type of ore	$\sigma_{op} \cdot 10^6$, Pa	$E \cdot 10^{11}$, Pa	ρ_o, kg/m^3	μ
1.	Massive sulphide ore	5.9 – 9.8	5.5	4860	0.22
2.	Densely disseminated sulphide ore	5.9 – 9.8	5.5	3800	0.2

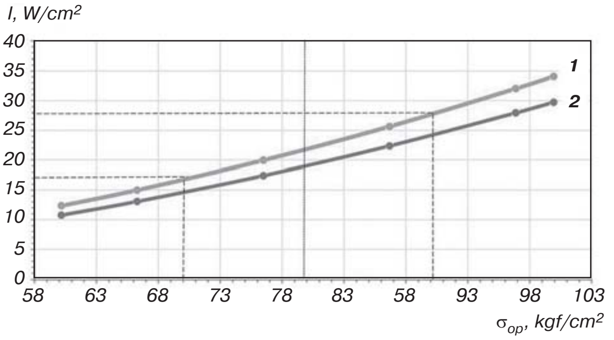

Figure. Graph of dependence of ultrasonic vibration intensity on the tensile strength of ore grains

of ultrasonic oscillations is also important. According to the authors [26] increasing the frequency of ultrasonic oscillations from 22 to 44 kHz reduces the dispersion efficiency by 10 times, so the frequency of 22 kHz can be considered optimal.

Conclusion

The conducted research shows that to remove oxide films from the surface of sulfide ore pulp particles to avoid the creation of passivating effect on their surface, the value of the optimum intensity of ultrasonic vibrations should lie in the range from 17 to 28 W/cm^2, at a frequency of ultrasonic vibrations 22000 Hz.

For more accurate determination of values of ultrasonic vibration intensity, duration of ultrasonic influence it is necessary to carry out experimental studies of the process.

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