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ВЫБОР ПАРАМЕТРОВ ДЕЗИНТЕГРАТОРА ДЛЯ ЭКОЛОГИЧЕСКИ КОРРЕКТНОГО ВЫЩЕЛАЧИВАНИЯ МЕТАЛЛОВ

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Аннотация: Горнодобывающие отрасли технологически развитых стран решают проблему использования уже извлеченного из недр сырья путем выщелачивания металлов в быстроходных мельницах – дезинтеграторах. Целью исследования является доказательство целесообразности совмещения механической активации процессов выщелачивания с активацией химическими реагентами. Широкому освоению механохимической технологии может способствовать разработка математической модели и программное обеспечение процессов переработки в активаторах оптимизированной конструкции, детализация методики определения эколого-экономического эффекта и другие факторы. Методы исследования феномена изменения состояния вещества в дезинтеграторе включают в себя эксперименты и критический анализ процессов новой технологии, показатели которой сравниваются с комплексом показателей традиционной технологи агитационного выщелачивания. Получены количественные показатели феномена изменения состояния вещества при обработке со скоростью вращения рабочего органа (более 250 м/с). Предложена конструкция дезинтегратора, предусматривающая совмещение механохимических процессов выщелачивания с температурным воздействием. Получена база для многофакторной оценки альтернативных технологий, например, активации бетона при проходке шахтного ствола. Предложена экономико-математическая модель определения прибыли от переработки хвостов обогащения и металлургии. Активация процессов выщелачивания в скоростных мельницах (дезинтеграторах) позволяет извлечь теряемые ранее металлы и повысить активность утилизируемых веществ.

Ключевые слова: использование недр, металлы, выщелачивание, дезинтегратор, конструкция, механохимия, температурное воздействие, шахтный ствол.

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Selection of disintegrator parameters toward environmentally friendly leaching of metals

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Abstract: The mining industries of technologically developed countries solve the problem connected with utilization of raw materials extracted from the subsoil by metal leaching in high-speed disintegrator mills, where new technological processes take place under appropriate conditions. The purpose of the study is to prove feasibility of combining mechanical activation of leaching with activation by chemical reagents. The advance of the mechanochemical technology can be facilitated by the development of a mathematical model and a software for processes in activators of an optimized design, as well as by finding the detailed methods for determining the environmental and economic effect, and other factors. The methods for studying the phenomenon of changes in the state of matter in a disintegrator include experiments and critical analysis of the processes of the new technology, with their indicators compared with a set of indicators of the traditional agitated leaching technology. The quantitative indicators of the phenomenon of changes in the state of matter during processing at a rotation speed of the working body more than 250 m/s are obtained. The proposed disintegrator design involves combining mechanochemical leaching processes with temperature effects. A basis is obtained for the multifactorial assessment of alternative technologies, for example, activation of concrete during excavation of a mine shaft. An economic and mathematical model for determining profits gained from treatment of mineral processing tailings and metallurgical waste is proposed. Activation of leaching processes in high-speed disintegrator-type mills makes it possible to extract earlier lost metals and to increase activity of utilized substances.

Key words: subsurface use, metals, leaching, disintegrator, construction, mechanochemistry, temperature effect, mine shaft.

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Introduction

The problem of full utilization of metal-containing raw materials already extracted from the subsurface is becoming increasingly important in the global mining industry [1–3].

The authors of the publications note that, when determining efficiency of mineral extraction, it is more appropriate to take into account not only the resources extracted from the subsoil, but also the substances extracted but non-utilized (for example, ore processing tailings).

The relevance of the development of a technology, as a result of which inactive reserves of metal-containing raw materials are involved in production, is increasing [4, 5]. The breakthrough direction of deep metal recovery is metal leaching with mechanochemical activation of processes in a disintegrator [6–8].

The phenomenon of the increased activity in the disintegrator has been confirmed in various industries. For example, production of artificial stone from silicalcite is 2 times cheaper with a 50% reduction in energy consumption [9, 10]. It is known that processes in solids are more active when their surface area increases. The range of the activity increase depends on the material structure, amplitude and frequency of vibration and oscillations [11–13]. As a result of phase transitions and chemical transformations, thermolysis occurs on high-temperature sites, accompanied by electrification, formation of free radicals and release of gaseous products.

Aims and objectives

It is generally recognized that an effective measure to reduce the hazard of tailings storage is their utilization and return to the natural cycle [14–16]. This can be achieved by transferring metallic components into solution during leaching in a disintegrator.

Traditional methods of processing substandard metal-containing minerals allow separating marketable products from tailings, but toxic tailings remain unused and create a problem connected with the environmental protection [17–19]. The most promising approach is combination of chemical treatment and activation in a disintegrator. The advantages of the technology are the acceleration of the leaching process and the increased metal recovery.

The aim of this paper is to identify new ways to optimize the design of the disintegrator to increase completeness of the use of extracted mineral resources.

Materials and methods

The quantitative values of metal recovery parameters are determined experimentally in the laboratory disintegrator. The recovery rates in the disintegrator are compared with agitation leaching.

Based on open access publications and on the authors' own experience, the theory and practice of the phenomenon of change in the state of matter during processing in the disintegrator are characterized. Information about the effectiveness of increasing the activity of substances in mechanoactivation is supported by the results of using the technology in the related sectors of national economy, including the indicators of zinc and lead extraction in the supercritical drum mill.

The critical analysis of the main directions of improving the design of disintegrators differentiated by the type of the impact made on treated materials is carried out. A new direction of increasing the efficiency of activation of materials by combining mechanochemical effects with temperature effects and regulations for its use in mining practice is proposed. The principal possibility of application of the disintegrator technology in manufacture of concrete lining during sinking of mine workings is substantiated by the example of constructing a vertical mine shaft. The adequacy of mechanochemical activation in leaching is proved by the experimental results of metal extraction from tailings of non-ferrous ores of Sadon [8], coal of Russian Donbass and ferruginous quartzites of KMA into solution [20].

The model of determining the profit gained from processing of mineral tailings and metallurgical waste by the proposed technology is developed, and the directions of technology development with mechanochemical activation are outlined. Based on the theoretical and practical results of the research, the conclusion is made about the expediency of using the method of mechanochemical activation in leaching as a possibility for compensating losses of using traditional processing technologies.

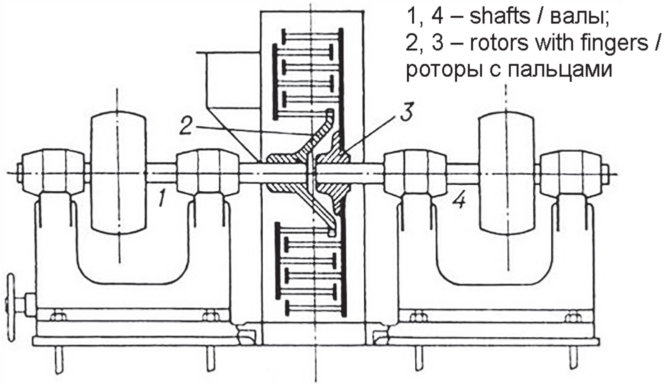


Fig. 1. Diagram of activator–disintegrator
Рис. 1. Схема активатора–дезинтегратора

Results

The condition of the leached raw material becomes optimal when the speed of the disintegrator rotors reaches 250 m/s. The principle of mechanoactivator operation is illustrated in Fig. 1.

The dynamics of physicochemical processes in solids is determined by the area of their active surface. The interaction processes are more intensive when the active surface area is large [2, 8]. One of the methods of stimulation is combined activation in an acidic medium. In this case, if the rotor rotates at a high speed for 60 min, extraction of metals can be increased almost twofold. This is due to the fact that a high rotor speed promotes more intensive mixing and contact of particles, which accelerates chemical reactions. In addition, activation of sulphide cinders in a high-speed mill in the presence of aqueous solutions of NaCl or NaOH also contributes to an increase in metal recovery up to 10%. This happens because the aqueous solutions of NaCl or NaOH create favourable conditions for dissolution and subsequent extraction of metals from sulphide cinders. Therefore, combined activation in an acidic medium and activation of sulphide cinders in the presence of aqueous solutions of NaCl or NaOH are the effective methods for increasing metal recovery. These methods can significantly improve efficiency of metal recovery processes, which is important for various industries, including metallurgy and mineral processing.

The results of tailings activation in a supercritical drum mill for 10 min are presented in Table 1.

Table 1

Extraction of elements to solution
Извлечение элементов в раствор

	Hydrochloric acid (HCl) concentration in solution, %																				
	Zn	Pb	Fe	Zn	Pb	Fe	Zn	Pb	Fe	Zn	Pb	Fe	Zn	Pb	Fe	Zn	Pb	Fe	Zn	Pb	Fe
	3			5			7			9			11			15			19		
Recovery without activation, %	6	20	10	15	30	16	24	38	21	29	43	24	33	49	30	35	53	31	40	58	34
Recovery with activation, %	28	25	23	41	39	38	51	44	50	68	51	60	73	55	70	82	60	71	82	67	78

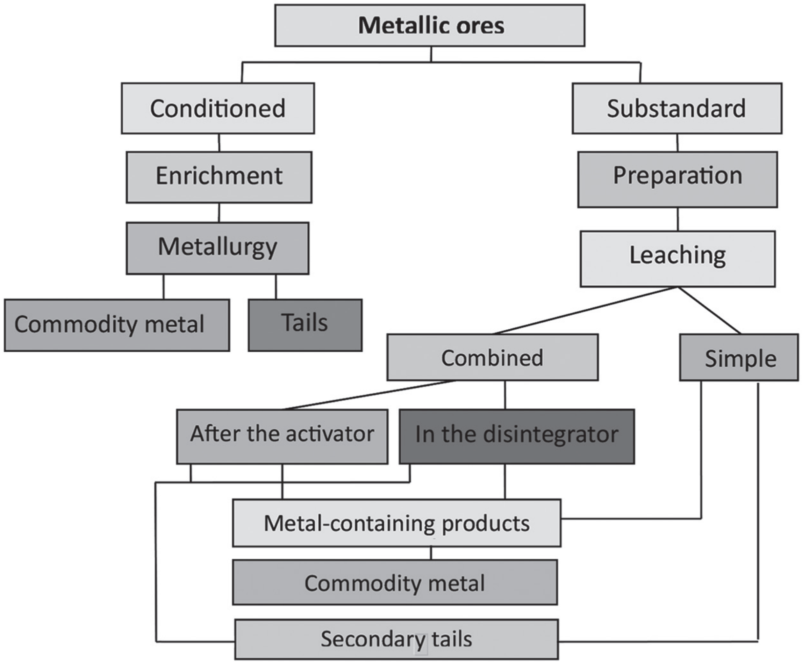


Fig. 2. Technological flowchart of metal extraction from mineral processing tailings
Рис. 2. Технологическая схема извлечения металлов из хвостов обогащения

Mechanical activation of tailings in high-speed machines allows for a 10–20% increase in the throughout recovery of zinc, lead and iron from waste by enhancing conditions for recycled products.

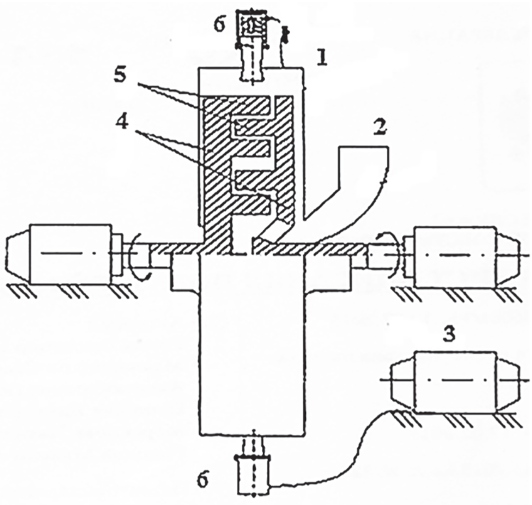
A schematic diagram of the process circuit with the disintegrator is shown in Fig. 2.

Over the decades of application, the design of disintegrators has undergone significant improvements [21]. Electroacoustic emitters are fixed along the perimeter of the working chamber, and the disintegrator is equipped with an electronic generator (Fig. 3).

When processed in the disintegrator, homogeneity of the mixture increases, which improves the quality of concrete.

The effectiveness of mechanochemical activation of leaching was confirmed by experimental processing of tailings of Sadon non-ferrous ore [8] and ferruginous quartzites of KMA. During the studies, the recovery of metals from the tailings was found to range from 20% to 70% of their original content. This means that a significant portion of metals can be recovered from tailings, making their processing more efficient and economically viable. In order to achieve background level of residual metal content, the number of processing cycles needs to be increased because each recycling cycle allows extracting additional metals and reducing their residual content in the tailings. In view of this, an increase in the number of processing cycles contributes to fuller recovery of metals and to reduction of their residual content up to the background level.

Mechanochemical activation of leaching processes involves mechanical and chemical methods to increase activity of tailings components. This allows for faster leaching and higher metal recovery efficiency. As a result, processing of tailings becomes more efficient and ensures re-



1 – housing / корпус;
2 – inlet pipe / входной патрубок;
3 – electronic generator / электронный генератор;
4 – discs / диски;
5 – fingers / пальцы;
6 – electroacoustic emitter / электроакустический излучатель

Fig. 3. Scheme of mechanical activation with electroacoustic action
Рис. 3. Схема механической активации с электроакустическим воздействием

covery of more metals, which is important for various industries, including metallurgy and mineral processing. Therefore, mechanochemical activation of leaching processes is a promising method for treatment of tailings of non-ferrous ores and ferruginous quartzites. This method significantly increases efficiency of metal recovery and reduces residual content of metals up to the background level, which makes processing more economically viable and environmentally safe.

After activation, processing tailings can be used as binders in building materials because the increase in the activity of components by 20–25% significantly improves the strength characteristics of concrete products. As a result, concrete structures become more durable and resistant to mechanical loads. Activated tailings can be added to the composition of concrete to improve its physical and mechanical properties. The increased activity of the components contributes to a better bonding of particles, resulting in the increased compressive and tensile strength. This is particularly important for the structures that are subjected to high loads, such as bridges, buildings and industrial structures. In addition, the use of tailings as binder components helps reduce the cost of concrete production because tailings are a by-product of the mining industry and can be reused, making the process more cost-effective and environmentally friendly. Therefore, activated tailings are a promising material for improving the strength characteristics of concrete products, which opens up new opportunities for their application in the construction industry.

The disintegrator design is selected by choosing the best indicators of the variants according to the scheme (Table 2).

The purpose of the research is to obtain the dependence of the lead and zinc extraction from crushed minerals on the content of reagents in the leaching solution, on the ratio of L : T and on the leaching time.

The levels and intervals of variation of the independent factors were obtained from the experimentation in accordance with the three-level Box–Behnken design.

The different types of leaching differently prepared materials along with the dynamics of the independent factors are shown in Table 2.

Table 2

Leaching prepared feedstock at different variation ranges of independent factors

Выщелачивание подготовленного сырья при различных пределах изменения независимых факторов

Independents factors	Levels and variation ranges of factors			
	Zero level, $X_i = 0$	Interval variation	Upper level, $X_i = -1$	Lower level, $X_i = 1$
Agitation leaching of pulverised materials				
Sulphuric acid content of H_2SO_4, X_1, g/L	6.3	4.6	10.2	2.6
Salt content of NaCl, X_2, g/L	93	77	145	24
Ratio of liquid to solid, X_3	7.5	3.1	10.3	4.2
Leaching duration, X_4, h	0.64	0.38	1.04	0.27
Agitation leaching of dry preactivated feedstock				
Sulphuric acid content of H_2SO_4, X_1, g/L	6.3	4.7	10.6	2.7
Salt content of NaCl, X_2, g/L	93	73	144	26
Leaching duration, X4, h	0.64	0.38	1.01	0.27
Rotor speed, X_5, Hz	121	73	205	54
Leaching simultaneously with activation in disintegrator				
Sulphuric acid content of H_2SO_4, X_1, g/L	6.3	4.7	10.6	2.3
Salt content of NaCl, X_2, g/L	97	74	144	26
Rotor speed, X_5, Hz	122	74	210	53
Ratio of liquid to solid, X_3	7.4	3.2	11	3
Agitation leaching of feedstock activated in disintegrator with leaching solutions				
Sulphuric acid content of H_2SO_4, X_1, g/L	6.3	4.6	10.5	2.4
Salt content of NaCl, X_2, g/L	96	73	153	26
Rotor speed, X_5, Hz	127	72	208	54
Leaching duration, X_4, h	0.64	0.38	1.01	0.265
Leaching by repeated passage of leaching solutions in disintegrator				
Sulphuric acid content of H_2SO_4, X_1, g/L	6.4	4.1	10.2	2.1
Salt content of NaCl, X_2, g/L	81	74	165	19
Rotor speed, X_3, Hz	123	76	204	48
Number of processing cycles, X_4, units.	5.2	2.1	7.3	3.2

The regressional analysis of the experimental results is carried out in Mathcad.

Conclusions

By comparing the calculated values of metal recovery at rational parameters of leaching modes and with regard to the indicators of energy consumption for the process and taking into account wear and tear of equipment, the best variant of leaching the metal-containing materials is determined.

The design of the disintegrators is improved by comparing the results of leaching technologies based on new physical, technical and technological processes. The proposed technology is a step towards solving the problem of increasing completeness of the subsoil utilization by production of metal-containing materials that cannot be utilized with traditional technologies.

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