Effect of High-Power Electromagnetic Pulsed and Dielectric Barrier Discharges on Physicochemical and Flotation Properties of Perovskite

Introduction

By 2018 the global titanium reserves amounted to 872 Mt, including 799.15 Mt of proven titanium dioxide reserves. Russia holds 17.3% of the world’s proven reserves occurred in 10 primary deposits (93.4%) and in 10 placers (6.6%) [1]. At the same time, Russia takes only 0.4% in the global production of TiO2 concentrate. In the meanwhile, the Murmans Region, alone, holds three titanium–magnetite ore deposits—Kolvitsa, Pudozh and Afrikanda. The largest primary deposits of perovskite–titanomagnetite ore on the Kola Peninsula and in North Karelia contain great reserves of titanium, rare metals (Nb, Ta) and rare earths [2].

Russia’s Afrikanda deposit features the largest titanium reserves (the total reserves amount to 52.2 Mt, and the average content of TiO2 is 9.2%) and represents a promising source of titanium,

The methods of FTIR, SEM–EDX, microhardness test, electrokinetic potential and contact angle measurements, as well as the sorption and flotation experiments are used to study the influence of high-power electromagnetic pulses (HPEMP) and dielectric barrier discharge (DBD) on the structural, physicochemical and flotation properties of perovskite (Afrikanda deposit).

The analysis of FTIR data shows that short treatment times (t0 = 10–30 s) lead to opposite changes in the surface condition of perovskite: oxidation (hydration) of the surface in case of HPEMP and deoxidizing (dehydration) under DBD.

According to SEM results, the surface of perovskite undergoes destruction as a result of HPEMP and DBD treatment. The surface of some areas of the samples is modified with the formation and opening of deep parallel cracks, most likely due to the polysynthetic twinning typical of perovskite crystals; the sub-parallel pyramidal protrusions are also observed in some surface areas. The determined morphological changes cause softening and a monotonic decrease in the microhardness of the mineral surface with an increase of the HPEMP and DBD (plasma) treatment times (t0 = 0–150 s) by ΔHV ≈ 2–33%.

The effect of HPEMP and DBD on the physicochemical properties of the mineral surface represents a shift in the electrokinetic potential towards positive values, an increase in the contact angle (t0 = 10–30 s), as well as the improved adsorption of the collector and the higher flotation activity of perovskite by ~10–15%.

Keywords: perovskite, electromagnetic pulsed discharges, Fourier-transform infrared spectroscopy, scanning electron microscopy, surface modification, microhardness, zeta potential, contact angle, sorption, flotation

DOI: 10.17580/gzh.2017.02.10

UDC 622.7:621.373:622.765

V. A. CHANTURIYA 1, Chief Researcher, Academician of the Russian Academy of Sciences
I. ZH. BUNIN 1, Leading Researcher, Doctor of Engineering Sciences
M. V. RYAZANSEVA 1, Senior Researcher, Candidate of Engineering Sciences, ryzanceva@mail.ru
I. A. KHABAROVA 1, Senior Researcher, Candidate of Engineering Sciences

1Academician Melnikov Institute of Comprehensive Exploitation of Mineral Resources, Russian Academy of Sciences, Moscow, Russia

References

rare metals and rare earths [3]. The main useful component—titanium—occurs in perovskite and titanomagnetite; perovskite contains (mass percentage): 0.64–2.50 (Nb, Ta)O3, 50.8–56.8 TiO2, 0.12–1.93 SiO2, 0.15–1.30 Al2O3, 0.43–2.00 Fe2O3, up to 1.44 Fe2O, 2.18–10.7 Ln2O3 (sum of REM oxides), 26.3–38.1 CaO, 0.10–2.35 Na2O, 0.07–0.14 TiO2 [4, 5].

**Perovskite** (calcium titanium oxide, formula CaTiO3, chemical composition (Ca, REE, Na)(Ti, Nb)O3 [6]) is a mineral from a large family of perovskites that share a generic formula ABX3 (where the X position can be taken by such anions as O2-, F-, Cl-, Br-, I-, (OH)-, Al, Si, Ti, V, Co, Cr, Mn, Fe3+, Na, Ca, Ba, Sr, Mg, and Mn [6–9]).

Perovskite possesses semiconducting properties, the band gap Eg = 1.2–4 eV [10], the conductivity type is n, the electric conductivity is ~10−7 (Ohm-cm)−1, the thermoelectric coefficient is 7, the carrier concentration is ~4·1011 cm−3 [11]; the mineral is paramagnetic, the magnetic susceptibility is (2.7±13.9)·10−6 emu·g−1, the density is 3.95–4.2 g·cm−3, and the Mohs hardness is 5.5–6 [5].

The processing flowsheet for perovskite–titanomagnetite ore includes a sequence of such operations as [3–5]: crushing, milling, desliming, magnetic concentration of titanomagnetite and calcite flotation of nonmagnetic product; then, washing of reagent in hydrocyclones and perovskite flotation to extract perovskite concentrate with the content of 49–50% TiO2. Regarding the content of titanium (% by mass: TiO2—48, CaO—34–35), the standard perovskite concentrate is similar to the ilmenite concentrate (the common titanium raw material) but the presence of 1–1.2% (Nb, Ta)2O5 and 3.5–4% La2O3 improves the value of the perovskite concentrate as compared with the ilmenite concentrate [3].

Reduction in loss of TiO2 (with perovskite during desliming, washing and calcite flotation) in marketable concentrates is only achievable with direct selective flotation of perovskite in fresh water with agent IM-50, which ensures concentration of the useful component at the content of 48–50% and recovery of 80–83% from nonmagnetic ore fraction [5, 12, 13].

The complexity of production of a high-quality perovskite concentrate at its high recovery is connected with the similar process properties of perovskite, calcite and olivine.

Application of high-energy effects [11, 14–17] in processing of rebellious minerals enables efficient selective disintegration of finely dissemination mineral aggregates, enhances contrast between the physicochemical and flotation properties of minerals, and improves the further separation thanks to formation of hydrophobic and hydrophilic micro and nano phases on the mineral surface. Pioneering experimental research made it possible to substantiate the mechanism of effect exerted by γ-ray and β-particles on flotation of semiconducting minerals—rutile, ilmenite, ilmenomullite, zircon, chalcopyrite, galenite, perovskite, pyrolusite and antimonite [11]. Radiation-induced defects and reduced concentration of electrons on the mineral surface of rutile, ilmenite, chalcopyrite, pyrolusite and antimonite (irradiated in water) increased the adsorption of the flotation agent anion on the mineral surface and enhanced the yield of these minerals in flotation on the average by 2–12% (perovskite—by 9%).

Tests proved the intensifying effect of high-power electromagnetic pulses (HPCEM) and dielectric barrier discharge (DBD) cold plasma on acid leaching [14] and flotation [15] of Lovozero eudialyte concentrate, as well as the modifying effect of electromagnetic pulses on the surface structure and physicochemical properties of Juine ilmenite [16] and sulfide minerals and quartz from different deposits [17]. This study aims to analyze and compare the effects produced by the nanosecond electromagnetic pulses and DBD at atmospheric pressure in the air on the surface structure and morphology, microhardness, electrokinetic potential, contact angle, adsorbability and floatability of Afrikanda perovskite with a view to enhancing flotation of complex perovskite–titanomagnetite ore.

**Experimental**

Testing using procedures [11, 14–18] involved samples of perovskite (formula CaTiO3) in the form of grains extracted from hand specimens of Afrikanda perovskite (Kola Peninsula, Russia) and specially manufactured polished plates approximately 4.5 mm thick. The samples are courtesy of the museum staff members M. Yu. Sidorov, E. A. Selivanova and V. N. Yakovenchuk at the Geological Institute of the Kola Science Center of the Russian Academy of Sciences. The chemical composition and the content of impurities of the samples was determined by the X-ray fluorescence analysis using spectrometer ARL Advant’X (Thermo Fisher Scientific Inc), mass percentage: 48.0 TiO2, 35.5 CaO, 5.41 SiO2, 2.15 CeO2, 1.87 Al2O3, 1.62 Fe2O3, 0.88 Nb, 1.01 F, 0.65 Nd, 0.55 Na2O, 0.39 MgO, 0.33 La2O3, 0.26 Sr, 0.10 V2O5, 0.09 K2O, 0.08 ZrO2, 0.05 Sm2O3, 0.05, Ta2O5, 0.04 BaO, 0.03 Y2O3, 0.03 Cs2O, 0.01 Ni, 0.01 Pb, Pr—not detected, Th—not detected.

The details of the electrophysical parameters of electromagnetic treatment (HPEMP and DBD) and the treatment conditions of perovskite samples are given in [14–17]; the treatment duration range is t = 10–150 s. In case of high-power EMP, the front, duration and amplitude of output voltage pulse were ~3–8 ns, 30–50 ns and 70 kV, respectively; the electromagnetic field strength and current in the electrode gap 7 mm long were 10–17 V/m and ~1011 A/m2, respectively [14, 15], the frequency of nanosecond pulses was 375 Hz. For preventing fragmentation of the polished sections and to eliminate dispersion of particles ~50 μm in size in high-voltage pulses, the HPEMP treatment conditions for perovskite samples before testing their microhardness, structure and physicochemical properties (electrokinetic potential and contact angle) included the front, duration, output voltage pulse amplitude and pulse repetition rate of 2–5 ns, 4–10 ns, 25–30 kV and 100 Hz, respectively.

For enhancing efficiency of the electromagnetic pulses, the milled samples of perovskite were moistened with distilled water at an S : L ratio of 5 : 1. Then, the samples were placed on a thin dielectric base surface on the side of the grounded electrode. The air gap left between the surface of the top mineral layer and the surface of the active electrode (~0.1–0.2 mm) allowed a periodic spark discharge. After high-voltage EMP treatment, the samples were dried in the air and were kept in the rare atmosphere up to the analysis and flotation tests.

The electrode voltage in DBD generator cell was 20 kV, the pulse duration was 8 μs, the pulse-leading edge duration was 300 ns, the pulse repetition rate was 16 kHz, and the electrode gap was 5 mm long [14–17]. In the conditions of cold nonequilibrium plasma of DBD in the air, the gas temperature in the work zone of the discharge cell was not higher than the dielectric barrier discharge and was at the level of the room.
temperature for \( t_{\text{treat.}} = 10\times60 \text{ s} \). The temperature of electrons in micro discharge was a few eV at the electron density of 10\(^{14} \text{ cm}^{-3} \) and current density of 10\(^2 \text{ A cm}^{-2} \); the discharge current was varied from 0.1 to 1 mA [16, 17]. Before DBD the samples of perovskite were not moistened.

The change in the surface structure and morphology of perovskite after treatment by electromagnetic pulses was analyzed using the Fourier-transform infrared spectroscopy (FTIR, spectrometer Nicolet-380 (USA) with Smart Diffuse Reflectance) and electron microscopy SEM–EDX, scanning electron microscope LEO 1420 VP with energy-dispersive micro analyzer INCA Energy 350). During the microscopic studies, perovskite grains were fixed on an electroconductive base surface and spattered with thin carbon layer, which prevented from an excessive electric charge.

The IR spectra of perovskite were registered in a range from 4000 cm\(^{-1} \) to 400 cm\(^{-1} \) (spectral resolution 4–6 cm\(^{-1} \), 100 scans); the intensity of the characteristic lines in the IR spectra varied from spectrum to spectrum, for this reason, the estimate of the relative intensity of the spectrum lines used the ratio of the optical density of each line to the optical density D of line 442–494 cm\(^{-1} \).

The microhardness of the mineral was determined using the Vickers Test (HV, MPa; USSR State Standard GOST 2999-75) [15–17]; microhardness tester PMT-3M; the load on the indenter was 100 g, and the loading time was 10–15 s. The flow potential (\( \xi \)-potential, mV) of mineral particles (size \( \leq 50 \mu \text{m} \)) was determined on Microtrac ZETA-Check Zeta Potential Analyzer. The surface contact angle (\( \theta \)) of the polished sections before and after energy effects was measured using the drop technique, with a distilled water drop with a diameter of 2–3 mm lying on the flat surface [15–17], with the help of a digital optical microscope and image analysis program ImageJ with DropSnake and LB-ADSA plugins [18].

The procedure of estimating adsorption of a complexing flotation agent—capryl hydroxamic acid [12, 13, 19]—at the surface of perovskite before and after treatment by HPEMP and DBD included agitation of a mineral sample with the agent solutions, filtration of the solid phase, washing, drying of the filtrate and analysis of the mineral surface by the diffuse reflectance infrared Fourier Transform Spectroscopy (spectrometer IFA-

### Flotation

Flotation of the test samples (1.0 g, particle size \( \sim 40 \mu \text{m} \)) was carried out in a flotation cell of 20 ml: the samples were agitated in water for 1 min, then the collector was fed (capryl hydroxamic acid, 200 g/t); the mineral and the agent contact time was 1 min; pH of the medium was brought to 5.5 by adding the aqueous solution of \( \text{H}_2\text{SO}_4 \); after that MIBK was added as a frother to interact with the mineral for 0.5 min; the froth product was separated for 2 min.

### Results and Discussion

**Fourier Transform Infrared Spectroscopy.** The infrared spectrum of perovskite (without treatment by HPEMP or DBD) included lines in the range of 400–800 cm\(^{-1} \), conditioned by variation of structural groups in the crystal lattice of the mineral, and lines in the range of 900–4000 cm\(^{-1} \), connected with the presence of the impurities C–O, O–H, and metal (Me)-O groups localized on the mineral surface [5, 9, 20–22].

The IR spectrum analysis identifies some adsorption band crests as follows: the band crest at 458 cm\(^{-1} \) responds with valence vibrations (\( \nu \)) of the bonds Ti–O–Ti in TiOl; at 468 cm\(^{-1} \)— \( \nu \) Ti–O–Ti; at 554–570 cm\(^{-1} \)— \( \nu \) Ti–O in TiO\(_2\)–octahedrons; at 570 cm\(^{-1} \)— \( \nu \) Ti–O–Ti; at 650–655 cm\(^{-1} \)— vibrations of the bond Fe–O in FeO; at 655 cm\(^{-1} \)— \( \nu \) Fe–O; at 710 cm\(^{-1} \)— valence vibrations of the bond \( \nu \) Ti–O–Ti in TiO\(_2\); at 730 cm\(^{-1} \)— Ti–O; at 760 cm\(^{-1} \)— Ti–O–Ti.

In the IR spectrum range of 900–4000 cm\(^{-1} \), the recorded characteristic bands at 906 cm\(^{-1} \) and 946 cm\(^{-1} \) relate with vibrations of the bond O–O (peroxo-groups); at 931–1338 cm\(^{-1} \)— vibrations of the bond Ti–OH; at 1121 cm\(^{-1} \)— Fe–OH; at 1413 cm\(^{-1} \)— Fe–OH; at 1145 cm\(^{-1} \)— \( \nu \) Fe–O; at 1423 cm\(^{-1} \)— \( \nu \) Fe–O; at 1456 cm\(^{-1} \)— valence vibrations of the bond Fe–O; at 1650 cm\(^{-1} \)— stands with the deformation vibrations of the bond O–H in H\(_2\)O (hydroxyl groups disturbed by the hydrogen bond inside the mineral particles); the wide medium-intense band at 3400–3354 cm\(^{-1} \) characterizes the valence vibrations of the bond O–H in H\(_2\)O (free groups of OH on the mineral surface).

For analyzing structural changes of the surface of perovskite under the impact of HPEMP and DBD, four characteristic lines were selected in the infrared spectra of the mineral: at 442–

---

Eurasian Mining. 2022. No. 1. pp. 45–51
noncrystallographic planes and the slot-like cavities and flaws in perovskite matrix. Optically uniform grains of perovskite are nonuniform in the SEM–BSE images and are composed of two phases (Fig. 1): a bright phase (Prv-I) having the composition of (Ca$_{0.92}$Na$_{0.05}$Ce$_{0.03}$Nd$_{0.03}$O$_{2.02}$)$_{1.00}$O$_{0.00}$ and a dark phase (Prv-II) having the composition of (Ca$_{0.96}$Na$_{0.02}$Ce$_{0.02}$Nd$_{0.01}$O$_{0.7}$)$_{1.00}$O$_{1.00}$. The interfaces of these phases are complex, curved, noncrystallographic, probably epigenetic, connected with the redistribution of the components in metasomatic recrystallization, as a result of which perovskite undergoes accumulation of loparite NaCe(Ti,Nb)$_2$O$_6$, increase in the contents of Na and REE, and redistribution of Th and Nb. The slot-like cavities (having the composition of (earth carbonates from ancylite group fill the finest flaws which subparallel pyramidal spikes (see Fig. 48)).

Rare earths in the form of inter-grain and intra-grain cracks (Fig. 1) grow through the whole volume of perovskite: these are ancylite phases (Brt) completely replaced by micro cryptocrystallitic aggregates of iron hydroxides (limonite Fe$_{3}$(OH)$_{2}$OO$^{2-}$) and hydroxamic acid.

The changes in the surface morphology of perovskite treated by DBD (t$_{DBD}$ = 50 s) are connected with the defects in the form of inter-grain and intra-grain cracks (Fig. 2c) and, similarly to HPEMP, pyramidal spikes on the surface (Fig. 2d).

As a result of the action exerted by strong electric field, micro discharge, ozone and chemically active particles generated in the dielectric barrier discharge plasma [17, 23], the surface of the test perovskite samples softens and their microhardness decreases with the longer treatment time from $HV = 912$ to 663 MPa at t$_{DBD}$ = 0 and 150 s, respectively.

This manner, the short-term (t$_{DBD}$ = 10–30 s) electromagnetic pulses are effective both in disintegration (formation of micro cracks and unsaturated chemical bonds) and in modification of surface structure of perovskite.

The electrokinetic potential of perovskite changes non-linearly (nongradually) subject to time of the pulsed electromagnetic treatment. As a result of short-term (t$_{EM-BD}$ = 10–50 s) impact of HPEMP, the negative values of the electrokinetic potential decrease from $–85.4$ mV (t$_{EM-BD}$ = 0 s) to $–83.9$ mV and $–77.2$ mV at t$_{EM-BD}$ = 10 and 50 s, respectively. Under the impact of DBD, the potential gradually decreases to $–77.5$ mV at t$_{DBD}$ = 10 s and to $–75.4$ mV at t$_{DBD}$ = 50 s.

With increasing duration of the pulsed electromagnetic treatment (both in case of HPEMP and DBD), the contact angle Q of perovskite surface changes nongradually: at t$_{DBD}$ = 30 s, it increases from 75° (t$_{DBD}$ = 0 s) to 80.5° (HPEMP) and 77.5° (DBD). Probably, the found effect of the increased hydrophobic behavior of the mineral surface as a result of the short-term (t$_{DBD}$ = 10–30 s) energy deposition can improve the adsorption and flotation properties of the mineral. The proved changes in microhardness, electrokinetic potential and contact angle of perovskite surface agree with the experimental data obtained for eudialyte [15] and ilmenite [16].

Adsorption and flotation properties of perovskite. The FTIR spectroscopy proved that the short-term (t$_{DBD}$ = 10 s) treatment of eudialyte by HPEMP and DBD improved adsorption of agent Flotinor at the mineral surface [15]. Moreover, it was found that the adsorbability of eudialyte relative to the collecting agent (sodium oleate) was improved when NaO1 was combined with a regulating agent (sodium sulfate Na$_2$SO$_4$) thanks to the preliminary pulsed electromagnetic treatment (HPEMP) of the mineral particles at t$_{EM-BD}$ = 10–100 s [15]. In all tests with HPEMP and DBD, the decrease in the negative electrokinetic potential of eudialyte resulted in the increased adsorption of the anionic collector and consequently, in the increased extraction of eudialyte in flotation concentrate [15].

The spectral curves of the initial and treated (by HPEMP and DBD) samples of perovskite are shown in Fig. 3.

The spectral analysis reveals some features in the profiles of diffusive reflectance IR spectra of micro powdered perovskite, which characterize the mechanism of the agent adsorption at the mineral surface. In the spectrum of the initial sample (t$_{DBD}$ = 0 s), there is a series of bands which describe attachment of capryl hydroxamic acid at perovskite surface:

- absorption at 2850 cm$^{-1}$ and 2930 cm$^{-1}$—valence vibrations in the bond C–H of satisfied hydrocarbons; the bands at 1510 cm$^{-1}$ and 1550 cm$^{-1}$ characterize complexing with titanium, and the bond at 1610 cm$^{-1}$ is reflective of physisorption of hydroxamic acid.

Fig. 1. (a) SEM (BSE) image of perovskite surface: two phases in perovskite grains (Prv-I, with REE, and Prv-II), britholite-(Ce) (Brt) and titanite (Tit); (b) ameboid grain of limonitic pyrite (Lmt) in the cavity filled with calcite (Cal), titanite (Tit), britholite-(Ce) (Brt), calcioancylite-(Ce) (CaAnc) and ancylite-(Ce) (Anc)
The spectral curves of the HPEMP-treated samples ($U_s = 70$ kV) have a similar set of crests but the integral intensities of the bands related to the adsorbed collector increase by 1.1–1.2 times as compared with the initial sample (see Fig. 3a).

The DBD treatment of perovskite induces some essential changes in the IR spectra (see Fig. 3b): additional bonds appear at 1450 cm$^{-1}$ and 1516 cm$^{-1}$ integral intensity grows in the spectrum range of 1180–2130 cm$^{-1}$, which points at the increased adsorption activity of the mineral surface relative to capryl hydroxamic acid. The bond at 1516 cm$^{-1}$, probably, is reflective of the fact that the main form of the reagent attachment at the DBD-modified mineral surface is the complex compound of hydroxamic titanium [5].

Considering the test data on modifying effect exerted by the pulsed electromagnetic discharges on the physicochemical properties of perovskite, namely, the decrease in the negative values of the electrokinetic potential of the mineral (shift towards positive values), the increase in the contact angle and the improved adsorption of the collector, it was decided to analyze the influence of HPEMP ($t_{\text{treat.}} = 60$–120 s) and DBD...


\( t_{\text{test}} = 10\text{-}150 \text{ s} \) on floatability of the mineral with capryl hydroxamic acid.

After preliminary electromagnetic treatment (HPEMP and DBD), owing to the change in the structure and chemistry of the mineral surface, enhanced hydrophobic behavior and improved adsorbability, the total extraction of monomineral fraction of perovskite in flotation froth grows by \(~10\text{-}15\%\): HPEMP—\( \varepsilon \equiv 90\% \) (\( t_{\text{test}} = 60 \text{ s} \)) and \(~95\% \) (\( t_{\text{test}} = 120 \text{ s} \)) (Fig. 4a); DBD—\( \varepsilon \equiv 90\text{-}93\% \) (\( t_{\text{test}} = 10\text{-}30 \text{ s} \)) and \( \varepsilon \equiv 95\% \) (\( t_{\text{test}} = 100 \text{ s} \)) (Fig. 4b). The determined parameters of energy effects and the reagent regime of flotation can be used to stimulate flotation efficiency of perovskite ore of Afrikanda deposit.

Conclusions

The analysis of the data on spectroscopy (FTIR) and scanning electron microscopy has proved the effect of the pulsed electromagnetic and electric discharge (HPEMP, DBD) treatment on the surface structure, morphology, microhardness, physicochemical and flotation properties of Afrikanda perovskite. Apparently, the structural changes of the mineral surface under impact (\( t_{\text{test}} = 10\text{-}30 \text{ s} \)) of high-voltage electric fields of high-power nanosecond electromagnetic pulse (HPEMP) and dielectric barrier discharge (DBD) in the air are conditioned by oxidation (hydrometallurgy) of the surface (in case of HPEMP) and, vice versa, by deoxidizing (dehydrometallurgy) of the surface (in case of DBD).

The morphological changes of the mineral surface represent deep parallel cracks which appear as a consequence of polysynthetic twinning typical of perovskite crystals, and subparallel pyramidal spikes produced by energy deposition. These defects induce softening of the mineral surface and monotonic decrease in its microhardness with longer time of the electromagnetic and cold plasma treatment on the whole by \( \Delta H_{\text{VM}} = 27\text{-}33\% \).

The tests have proved the modifying effect exerted by HPEMP and DBD on the physicochemical properties of the mineral, represented by the shift of the electokinetic potential towards the positive values, by the increase in the contact angle at \( t_{\text{test}} = 10\text{-}30 \text{ s} \) and by the improved adsorption of the collecting agent, which enhances floatability and total extraction of monomineral fraction of perovskite in flotation froth by \(~10\text{-}15\%\).

Acknowledgments

The authors express their gratitude to Candidate of Geological and Mineralogical Sciences E.V. Koporulina and to Candidate of Engineering Sciences N.E. Anashkina for their help in the experimentation.

The study was supported by the Ministry of Science and Higher Education of the Russian Federation, Project No. 13.1902.21.0018, Agreement No. 075-15-2020-802.

References

HIGH-EFFECTIVE MAGNETIC HYDROCYCLONING EQUIPMENT FOR MAGNETITE ORE PROCESSING

Introduction

The annual output of iron-bearing ore processing in Russia exceed 200 Mt, which calls for continuous improvement and effectivization of processing process charts, technologies and equipment. The highest expenses in mineral mining and processing are connected with mineral milling and disassociation. Milling is interlinked with hydraulic sizing of mill flows within the mill—sizer circuit. The sizer gives coarse particles which may contain dissociated iron back to the mill, which implicates losses of the overground magnetic mineral with fines in the circuit of magnetic concentration. In his time, P. E. Ostapenko proposed to replace sizes by magnetic separators as in that case the re-milling circuit obtained the coarse aggregates with the lowest content of iron. Thus, the identified problem necessitates engineering of a machine capable to combine the functions of hydraulic sizing and magnetic separation [1].

A new method and equipment for magnetic hydrocycloning are proposed, which make it possible to extract the magnetic fraction from a polydisperse suspension with a high specific productivity and separation efficiency without preliminary classification by size.

An alternating magnetic field source is coaxially superimposed on top of the hydrocyclone so that the magnet-like lines intersect the suspension flow rotating in the cylindrical part of the hydrocyclone. In this case, the gradient of the magnetic field inside the body of the hydrocyclone is directed opposite to the direction of the summed vectors of the centrifugal force and gravitational force, and the magnetic fraction (product) is redirected through a drain tube for the concentrate outlet. It is possible to adjust the operating mode of the magnetic hydrocyclone for adjusting the total area of the outlet holes in the drain tube by moving an insert with slot-like cuts, which changes the overlap area of the holes.

The magnetic hydrocyclone is recommended for processing ferruginous quartzite and other types of ores with pronounced magnetic properties. The results of the effective separation of magnetic and nonmagnetic particles at different magnetic field densities are presented, and the dependence of the magnetic fraction recovery on the size of the initial suspension feed is described.

A method is proposed for estimating the possibility of extracting magnetic particles at preset parameters, for example, the geometric dimensions of the magnetic hydrocyclones at the varied values of the magnetic field density and particle flow velocity. The formula for the calculation is given, which establishes the equality, when the particle overcomes the internal space of the hydrocyclone and is extracted into the concentrate.

Keywords: magnetic hydrocyclone, separation selectivity, magnetic fraction, iron ore beneficiation, magnetic force, centrifugal force, iron content

DOI: 10.17580/em.2022.01.10