DNIPRO UNIVERSITY of TECHNOLOGY 1899

Mining of Mineral Deposits
Volume 15 (2021), Issue 1, 42-49

MMD JOURNAL / MINING.IN.UA

UDC 621.9 https://doi.org/10.33271/mining15.01.042

Operational lifetime increase of the pumping equipment when pumping-out contaminated groundwater

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Abstract

Purpose. Solving the problem of increasing the pumping equipment operational lifetime when pumping-out contaminated groundwater in the iron-ore industry by extracting the hard, abrasive part, using magnetic filters based on permanent ferrite magnets.

Methods. To produce spherical hard-magnetic ferrite elements that catch finely-dispersed magnetic and weakly-magnetic abrasive particles when pumping-out contaminated groundwater in the iron-ore industry, barium ferrite powder $BaO \cdot 6Fe_2O_3$ is applied, which is usually used for obtaining hard-magnetic ferrites. Spherical elements for filling a magnetic filtering installation are obtained by the method of spheroidizing the barium ferrite powder in a dragee machine. Sintering of spherical granules obtained from barium ferrite powder is conducted in a high-temperature atmospheric electric box furnace. The sintered spherical elements made of hard-magnetic barium ferrite are magnetized using a magnetic pulsed toroidal-shaped setup in a pulsed constant magnetic field.

Findings. For continuous pumping-out and purification of contaminated groundwater from magnetic, weakly-magnetic and non-magnetic highly abrasive particles with the help of magnetic filters, a scheme of a filtering installation of two sections is pro-posed. A technology for producing spherical permanent magnets from barium ferrite powder has been developed for a filtering installation, which includes a coarse purification column with hollow-spherical permanent magnets of 16-17 mm in diameter and a fine purification column with full-bodied spherical barium ferrite magnets of 6-7 mm in diameter.

Originality. The term of pumping equipment operation is doubled if to eliminate abrasive wear due to the filtering two-section installation by filling with barium ferrite spherical magnets. In the case of changing the filter, idle time is reduced by using the supplementary auxiliary column. The possibility of processing filtration products and their use in the field of construction and metallurgy without environmental pollution is substantiated.

Practical implications. The scheme of magnetic groundwater purification in the iron-ore industry is proposed, consisting of a filtering column of coarse and fine purification from abrasive particles. A technology for producing spherical magnets with different diameters has been developed to ensure the quality of the process. The research results allow to increase the operational lifetime of pumping equipment by eliminating abrasive wear, which will lead to significant savings in the replacement and repair of centrifugal pumps.

Keywords: *pumping equipment, groundwater, wear, barium ferrite, spherical magnet, filter, iron-ore industry*

1. Introduction

Development and improvement of technologies aimed at increasing the operational lifetime of the equipment for pumping-out underground water in the iron-ore industry is very acute and pressing production problem [1]-[3], since the removal of groundwater, formed inevitably both from open pits and underground mines of the mining industry, is accompanied by wear of centrifugal power pumps, suction and transporting pipelines, as well shut-off devices. When exploiting the pumping equipment, abrasive wear mainly occurs, since during the iron ore extraction, insoluble magnetic and weakly-magnetic hard particles are present in the groundwater in a suspended state, which, passing through the system, inevitably penetrate into the gaps of the moving pump surfaces [4]. This leads to a decrease in productivity, the operational lifetime of the parts in their flow channel, to significant operating costs and an increase in the cost of the final mining industry product [5], [6].

The problem of increasing the operational lifetime of equipment is solved by creating new technologies, but more often by improving known ones, although, in general, this

Received: 10 April 2020. Accepted: 22 January 2021. Available online: 5 March 2021

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Published by the Dnipro University of Technology on behalf of Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)
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leads to a significant increase in cost [7]. For example, through the use of more wear-resistant materials for wearing surfaces of power units or the most common strengthening methods, such as surfacing, gas-thermal and electrochemical surface treatment, as well as with the use of modern powder metallurgy technologies [8], [9]. It should be noted that the worn-out parts restoration reduces the cost of equipment repair and reduces production costs, and, accordingly, gives a significant economic effect [10].

The authors of the works [11], [12] point out the main structural-and-technological directions that improve the operating characteristics of withdrawal centrifugal pumps:

– the cavitation process reduction;

– decreasing the rate of the hydroabrasive mixture flow in the impeller cavity, thus reducing the surface wear of the impeller structural elements and increasing the suction capacity of the pump;

– reducing the vibration influence of both the hydroabrasive mixture and the pump as a whole in the process of pumping-out the waste water;

– extraction of a hard, abrasive part of the hydraulic mixture before it enters the impeller cavities and its blades using a hydrocyclone-phase separator.

From the above works, it can be seen that in practice, both methods of restoring worn-out surfaces and structural-and-technological decisions are widely used that contribute to an increase in the operational lifetime of pumping equipment in the mining industry. However, in our view, in order to increase the operational lifetime, ensuring reliability, durability and high productivity of the pumping units used, it is most expedient to use installations that separate the finest, magnetic and weakly-magnetic abrasive particles from the pumped liquid until it enters the working cavity of the pump.

The authors of the work [13] indicate the great potential of possibilities for creating installations separating magnetic and weakly-magnetic particles from the pumped liquid, using permanent ferrite magnets. Hard-magnetic ferrites are ferromagnets with high crystallographic anisotropy, which are mainly produced by using ceramic technology.

Ceramic hard-magnetic ferrites with a hexagonal structure are widely used in various fields of industry [14], [15], 93% of all produced magnets in world production are barium and strontium ferrites. The advantages of these magnets in comparison with traditional metal magnets are, first of all, high specific electrical resistivity, high coercive force, which ensures the permanent magnets stability, low cost and simplicity of production technology.

The use of installations for separating hard abrasive particles from a liquid will significantly reduce the consumption of expensive metals used in the restoration of worn parts by surfacing and sputtering methods, as well as using powder metallurgy technologies [16]-[19].

Thus, the issue of increasing the operational lifetime of equipment used for pumping-out contaminated groundwater in the mining industry is relevant and can be solved by creating magnetic filters and, accordingly, preventing abrasive wear of the pumping equipment working surfaces.

The work is aimed at solving the problem of increasing the operational lifetime of pumping equipment when pumping-out contaminated groundwater in the iron-ore industry by extracting a hard, abrasive part using magnetic filters based on permanent ferrite magnets.

For achieving the purpose set, it is necessary to solve the following tasks:

– analyse the existing methods of increasing the operational lifetime of pumping equipment in the mining industry;

– develop a technological scheme for continuous pumping-out and purification of contaminated groundwater using magnetic filters;

– develop a composition and technology for producing spherical permanent magnets from barium ferrite powder for a filtering installation.

2. Materials and methods of research

To produce spherical hard-magnetic ferrite elements that catch finely-dispersed magnetic and weakly-magnetic abrasive particles when pumping-out contaminated groundwater in the iron-ore industry, barium ferrite powder $BaO \cdot 6Fe_2O_3$ is applied, which is usually used to obtain hard-magnetic ferrites of 18BA210 grade according to GOST 24063-80 “Magnetically hard ferrites. Grades and main parameters”.

Spherical elements for filling the magnetic filtering installation are obtained by spheroidizing the barium ferrite powder in a DR-5A dragee machine. The real density of barium ferrite powder is several times higher than that of traditional powder materials. Therefore, in order to increase the mass of rolled spherical granules over 150 kg and intensify the compaction processes in a rotating drum, and, consequently, improve the performance of the machine, an electric motor with a power of 2800 W is set, with the rotation frequency of the drum – 0.4 ± 0.04 s^{-1}.

Spheroidization is performed as follows: red-brown barium ferrite powder shown in Figure 2, is poured into the rotating drum of the dragee machine (Fig. 1) and moistened in small doses with a working solution of polyvinyl alcohol (PVA) gel using a spray gun. The initial weight of the barium ferrite powder loading is 50 kg.

Figure 1. DR-5A dragee machine: 1 – rotating drum; 2 – electric motor; 3 – base

Polyvinyl alcohol is a binder in the formation of spherical granules. The flake-like shape of finely-dispersed powder particles with a particle size of 0.3-0.5 μm facilitates their orientation when rolling each subsequent layer to obtain the required sphere diameter. The high crystallographic anisotropy of the rolled particles of each subsequent layer significantly increases the coercive force.

Figure 2. Barium ferrite powder

This makes it possible to obtain future spherical permanent magnets with sufficient magnetic field energy and increased stability when exposed to external magnetic fields, impacts and vibration.

The working solution of PVA gel is prepared as follows: 10 litres of tap water is filled into a steel container with a volume of 15 litres, and then 2 kg of PVA powder is added and thoroughly mixed until a homogeneous turbid colloidal solution is obtained. Then, the solution is slowly brought to a boil with constant stirring to avoid burning. The resulting transparent gel is covered with a lid to prevent moisture evaporation and the formation of a polymerized film on the solution surface, and cooled to room temperature. To obtain a working solution, the concentrate is diluted with water at the rate of one part of the concentrate to one part of water.

The resulting spherical granules of barium ferrite powder are sintered in a high-temperature atmospheric electric box furnace of the CHO-64 type for heat treatment of composite materials and firing of ceramics, as well as refractory material with silicon-carbide heaters (SiC) at a temperature of 1300°C for four hours. This furnace is equipped with a thermal system for withdrawn gases purification. After being hold isothermally, they are slowly cooled together with the turned off furnace with the closed door of the loading chamber. With an increase in the sintering temperature, the density increases, which contributes to an increase in the granules residual magnetization. The coercive force dependence of magnets based on barium ferrite on the sintering temperature has an extremum, the position of which is determined by the dispersion of grinding the initial powder.

The sintered spherical elements made of hard-magnetic barium ferrite are magnetized using a magnetic pulsed toroidal-shaped setup in a pulsed constant magnetic field.

3. Results

For increasing the operational lifetime of the pumping equipment, the authors of the work propose to mount a filtering installation before it – a column filled with magnetic catching elements. Spherical permanent magnets made of barium ferrite, as the most widely used and relatively inexpensive material, are proposed to use as the column filler. Studies on determining the optimal diameter of magnetic catching elements (Fig. 3) reveal that with a magnet diameter of 6-7 mm, the filtering column retains almost 100% of magnetic and weakly-magnetic abrasive particles (Curve *1*). The time of continuous column operation until complete clogging is about 900 hours (Curve *2*). The degree of clogging the filtering elements is determined using a pressure drop manometer located between the filtering column and the centrifugal pump. A sharp increase in the rarefaction degree, recorded by a manometer, indicates a clogging of filtering column.

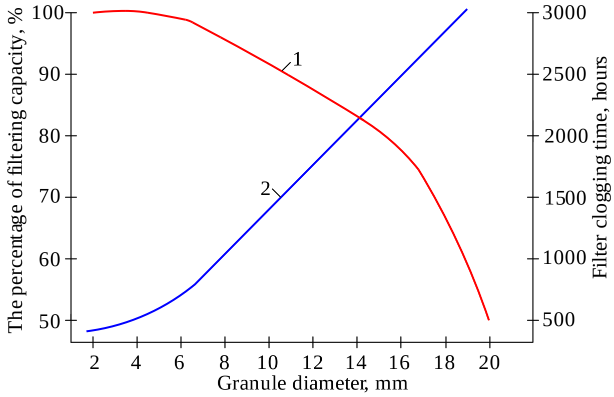

Figure 3. Dependency graph of the percentage ratio of filtering capacity and time until complete clogging of the filter on the spherical magnets diameter

During the research, it has been revealed that for the continuous pumping unit operation when replacing spent filters, it is expedient to place an auxiliary column in parallel, which is connected to the circuit using three-position switch valves. When the filtering column is clogged, the load on the electric motor of the centrifugal pump increases and the capacity of pumping the groundwater decreases. Then, there is an automatic switching of the three-position switch valves, and the groundwater is redirected through the auxiliary column without stopping the pumping process, which is not permissible when deep underground mines are operating.

In general, studies have shown that the production of ceramic magnets from barium ferrite powder with a fairly high magnetic field after magnetization is the most labour-intensive process. In particular, this relates to the initial process of obtaining the required critical mass of the so-called "nuclei", from which spherical granules of the required diameter are formed during rolling, taking into account the shrinkage factor during sintering.

With the constant drum rotation, in the first minutes of the process, the barium ferrite powder rolls into loose, large conglomerates of various sizes, which should be constantly ground in order to obtain dense "nuclei". The presence of free, finely-dispersed barium ferrite powder indicates a lack of PVA binder, which should be added in very small portions. Constant drum rotation and grinding of conglomerates leads to the gradual formation of fine and dense spherical granules up to 2 mm in diameter. The rapidly formed loose granules over 2.5 mm, which are concentrated in the centre of the rotating mass during the drum rotation, are also ground by selecting with a sieve with a mesh of 2.5 mm. The binder overdose leads to sticking together of "nuclei" in several pieces, which are divided into separate components using a sieve. Thus, the process of forming "nuclei" up to 2 mm in diameter from barium ferrite powder can take up to one hour.

The further process of rolling each layer of spherical granules to the required diameter is less labour-intensive. The "nuclei" in a rotating drum are also uniformly moistened with a working PVA solution in small doses and the surface of the rotating mass is evenly sprinkled with barium ferrite powder, using a sieve with 100 μm mesh. The occurrence of free material that does not adhere to the granules and is displaced to the drum rotation axis is a signal to the sufficient addition of powder. After filling the powder, the stage of spheroidization and compaction of the rolled layer begins, which can last from 8 to 18 minutes, depending on the diameter of the formed granules. Moreover, with an increase in the granules diameter, the time of each layer compaction decreases caused by an increase in mass, and, accordingly, the energy upon mutual collision of each granule. The completion of the process of the rolled layer full compaction is evidenced by the rolling of free excess powder and the so-called "sweating" of spherical granules, that is, the displacement of excess liquid onto the surface of the maximally compacted layer. When "sweating" appears, a fresh portion of the powder is added without wetting by PVA and rolled for 5-7 minutes until a smooth hard surface is obtained (2 on the Mohs's scale). Each subsequent layer is rolled in the same way.

When the granules reach more than 4 mm, an overdose of both the PVA binder and the powder has almost no effect, since the granules stuck together have a sufficiently large mass and spontaneously separate when the drum rotates.

In the process of rolling the spherical granules, some of the powder inevitably adheres to the walls of the rotating drum. This layer must be periodically scraped with steel scrapers as its thickness increases over 1 mm. The formed fine compacted particles of splintery and flaky shape in the process of rolling with larger and harder granules gradually turn into new "nuclei", contributing to a continuous process of producing the spherical granules.

Thus, the growth of each granule in diameter when rolling each layer occurs not with the same value. This is conditioned both by the non-uniform wetting of the granules total volume, and by the constant formation of new "nuclei" and their growth. When, after complete compaction of the last layer, the required diameter of the spherical granules is achieved visually, a sieve with a mesh of 9 mm is used to select the required fraction. Moreover, the largest fraction of granules under the action of centrifugal force is displaced towards the centre of the rotating mass.

As a result of spheroidization of barium ferrite powder in a dragee machine, the hard, dense spherical brownish granules are obtained, with an almost smooth surface and a diameter of 9-10 mm, taking into account the shrinkage when sintering. This is shown in Figure 4.

Figure 4. The spherical granules obtained as a result of barium ferrite powder spheroidization: colour – red-brown; surface – smooth, matte

The obtained spherical granules are sintered in 4 stages. Before sintering, granules with a diameter of 9-10 mm are preliminarily dried on stainless steel sheets for a day at room temperature. The filling thickness is 2-3 layers of spherical granules. The dried granules are filled into refractory ceramic containers and loaded into a high-temperature furnace. Sintering is carried out in an oxidizing medium according to a specially developed stage-by-stage mode, which is shown in Figure 5.

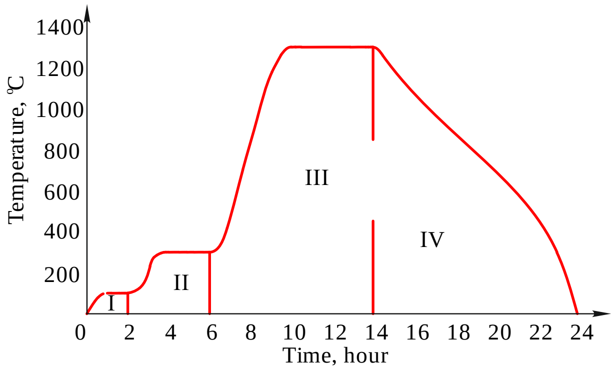

Figure 5. The mode of stage-by-stage sintering of the spherical granules produced from barium ferrite powder

At the first stage of sintering, the temperature rises to 90-100°C within 0.5 hours and isothermal holding occurs at this temperature for 1.5 hours. Thus, spherical granules volume is completely heated and the molecular moisture remaining after atmospheric drying is completely removed.

At the second stage, the temperature is increased to 300 ± 15°C within 1.5 hours and isothermal holding is also performed for 2.5 hours. Slow heating and holding contributes to uniform heating and maintaining the integrity of spherical granules without the formation of microcracks on the surface during decomposition, as well as to removing of organic components in a gaseous form (mainly a PVA-based binder).

With further gradual heating to 1300 ± 15°C for four hours (the third stage of sintering), the final burning off occurs of organic substances and chemically bound water contained in one of the barium ferrite components – iron oxide. With isothermal holding for four hours, not only grain growth is observed, but also an increase in the degree of their orientation and, accordingly, their magnetization.

After isothermal holding, the sintered spherical granules, in order to avoid the formation of microcracks and complete cracking, are cooled to a temperature of 300°C for nine hours together with the furnace with the closed door (the fourth stage of sintering). The containers removed from the furnace are additionally cooled to room temperature in still air.

A decrease in the spherical granules diameter during sintering from 9-10 to 6-7 mm, caused by an increase in density to 4.6-4.8 g/cm^3, provides a higher residual magnetization, as well as a higher squareness of the hysteresis loop [20] and, consequently, the maximum magnetic energy of ferrite spherical granules field after magnetization. Thus, the complete cycle of sintering is 24 hours, resulting in dense, hard spherical granules of black-graphite colour, shown in Figure 6.

Figure 6. The loosely poured spherical granules after sintering: color – black-graphite; surface – smooth, shiny

The sintered ferrite granules are filled into a magnetically permeable plastic container and magnetized using a magnetic pulsed toroidal-shaped setup, the schematic diagram of which is shown in Figure 7.

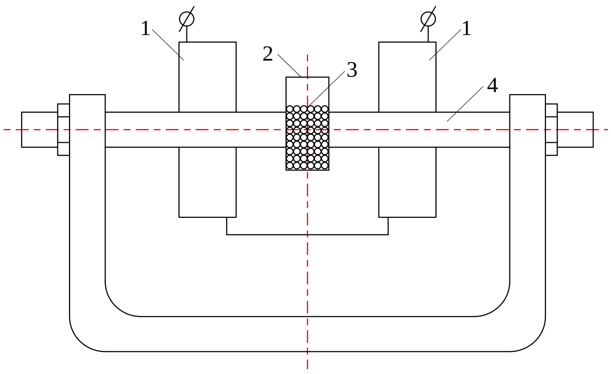

Figure 7. Schematic diagram of a magnetic pulsed toroidal-shaped setup: 1 – electromagnetic coils; 2 – plastic container; 3 – magnetisable spherical granules; 4 – core made of magnetically soft steel

A plastic container *2* with sintered spherical granules of barium ferrite *3* is installed between the electromagnetic coils *1* and fixed with a movable core *4*. Then, a pulsed direct current of 10-15 A is passed through the windings of the coils, as a result of which the granules are permeated with a magnetic field of 55-75 kA/m, which is by 5-8 times higher than the coercive force of the ferromagnet. Magnetization in weaker fluxes of magnetic fields leads to a decrease in magnetic energy by 10-15%. The pulse duration is 1 second. When exposed to a magnetic field, the granules are oriented along it by the axes of lighter magnetization, which is facilitated by the initial flaky shape of barium ferrite powder. When spheroidizing, the degree of orientation reaches 60%, and subsequent sintering increases by 15%.

As a result of barium ferrite powder spheroidization using PVA gel solution as a binder, and then drying, sintering in an oxidizing atmosphere with three isothermal holdings, and magnetization using a pulsed, direct current, spherical magnets are obtained, shown in Figure 8.

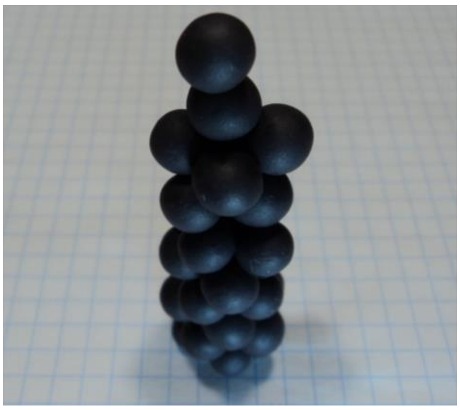

Figure 8. The spherical granules after magnetization, which have a sufficient magnetic field to catch magnetic particles

Spherical magnets have a sufficient magnetic field to catch magnetic and weakly-magnetic particles, as indicated by the ability to form various figures of simple configuration from them.

The results of laboratory bench tests during 3000 hours on purification of contaminated groundwater from abrasive particles confirm the possibility of using permanent magnets as catching elements. The required frequency of replacing the filtering column contents is every 800-900 hours of continuous operation of the experimental filtering installation. At the same time, studies of the centrifugal pump working surfaces confirm a practical absence of abrasive wear, which contributes to an increase in the operational lifetime of pumping equipment up to two times.

Thus, the research results have shown the possibility of using magnetic spherical granules produced from barium ferrite in the iron-ore industry for purification of groundwater contaminated with fine magnetic and weakly-magnetic abrasive particles in order to protect centrifugal pumps from abrasive wear, and, thereby, increasing the lifetime of their exploitation.

4. Discussions

Magnetic filters based on barium ferrite have a number of advantages over metal permanent magnets, namely:

– they are cheaper by 6-10 times;

– there is not a shortage in raw materials ($BaCO_3$, Fe_2O_3);

– simplicity of ceramic producing technology;

– high coercive force, and, therefore, high stability with repeated reversal magnetization, resistance to external influences, corrosion resistance in corrosive liquids;

– high hardness;

– low real density (up to 5 instead of 8 g/cm^3 in metal magnets).

The disadvantages include high brittleness in the case of small-section magnets with an elongated axis and the inadmissibility of the working solution freezing in the pores of ceramic magnets.

In addition, when testing an experimental magnetic filtering installation, in which spherical magnets of only 6-7 mm in diameter made of barium ferrite are used as a catching filler, a rapid (800-900 hours) clogging is observed of the voids volume between freely filled spherical magnets and filtration products. As a result, the load on the centrifugal pump rapidly increases and there is a need for frequent replacement and regeneration of magnetic catching elements, which leads to an increase in the cost of the groundwater purification process.

Based on these data, it is decided to divide the purification process into two stages: preliminary purification with the use of larger spherical magnets where coarser inclusions of abrasive particles are captured, and the final purification with the use of above studied spherical magnets with a diameter of 6-7 mm to capture dust-like magnetic and weakly-magnetic particles.

An improved scheme of a magnetic filtering installation using two stages of contaminated groundwater purification is proposed (Fig. 9). This scheme makes it possible to reduce the frequency of filtering magnetic elements replacement by increasing the voids volume between the spherical magnets in the filter of preliminary coarse purification.

Purification in the process of pumping-out contaminated groundwater with magnetic and weakly-magnetic abrasive particles is as follows. Contaminated water is sucked in through the water-intake pipe *1* and fed to the filtering column of coarse purification *2*.

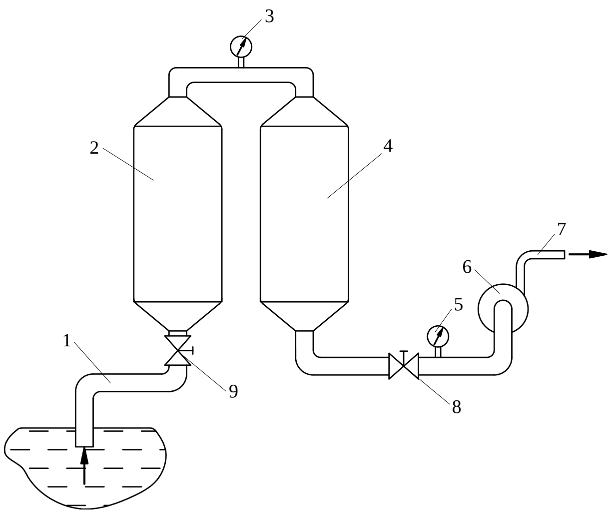

Figure 9. Scheme of a magnetic filtering installation: 1 – water-intake pipe; 2 – filtering column of coarse purification; 3 – pressure drop manometer at the stage of coarse purification; 4 – filtering column of fine purification; 5 – pressure drop manometer in the filtering installation; 6 – centrifugal pump; 7 – pipe for water discharge; 8, 9 – three-position switch valves

The filtering column of coarse purification is filled with large spherical magnetic granules, where large magnetic and weakly-magnetic abrasive particles with a particle size of more than one millimetre are captured. Using the pressure drop manometer *3* at the stage of coarse purification, the degree of pressure drop over time is controlled, and its readings indicate the degree of clogging of the coarse purification filtering column. Final purification of groundwater takes place in a filtering column of fine purification *4* filled with spherical magnetic granules with a diameter of 6-7 mm. Using the pressure drop manometer *5*, the degree of clogging over time of the entire filtering installation is controlled. With the help of three-position switch valves *8* and *9*, the flow of the pumped-out liquid is redirected to the auxiliary columns when the used filtering columns become clogged.

Thus, the centrifugal pump *6* receives water that is almost completely purified from abrasive particles, and which is discharged through the water discharge pipe *7*. In the case of a steady filtration process, the installation with magnetic spherical granules is capable of capturing not only magnetic and weakly-magnetic particles, but also the finest non-magnetic abrasive particles that are retained in the fine purification filtering column between the magnetic particles.

Spherical magnets made of barium ferrite of 16-17 mm in diameter can be used as a filler for the coarse purification filtering column. In order to reduce the filler mass and save the barium ferrite powder, it is proposed to produce the hollow spherical granules (Fig. 10a). They can be produced according to the production technology of spherical magnets with a diameter of 6-7 mm, but the following restriction should be guided – the thickness of the granule shell $(D – d)/2$ must be more than half of the inner diameter d. If this condition is met, the possibility of cracking and deformation of granules during sintering is excluded.

The difference between spheroidization of hollow and full-bodied granules is that foam polystyrene granules with a diameter of 5-7 mm (Fig. 10b), used in the foamed plastics production, can be used as the initial "nuclei".

As in the process of the full-bodied granules spheroidization, the most labour-intensive process is the initial stage of rolling barium ferrite powder onto foam polystyrene granules. Wetting of light granules with a PVA working solution leads to their sticking together. Therefore, it is necessary to constantly alternate wetting, sprinkling with barium ferrite powder and destruction of adhered conglomerates, until a critical shell mass is obtained, at which no adhesion of granules is observed. The further process of hollow granules spheroidization until the required diameter of 19-20 mm is obtained, taking into account shrinkage during sintering, does not differ from the full-bodied granules production. In the case of a steady process, small "nuclei" with a diameter of 1-2 mm may occur from the fragments formed at the initial stage, which are separated by a sieve with a mesh of 3 mm in diameter and used as "nuclei" for full-bodied granules.

Sintering of hollow granules with a diameter of 19-20 mm is accompanied by an increase in the time of temperature rise from 100°C and isothermal holding at 300°C by 2 hours. This necessity is conditioned by the formation of a larger gases volume and their slow release through the granule shell pores during the foam polystyrene decomposition.

According to the research performed, it has been found that the use of a filtering installation with a supplementary preliminary column of coarse purification enhances the effectiveness of pumping-out groundwater due to a decrease in the replacement frequency (from 800 to 3000 hours) for regeneration of filtering elements, and an increase in the operational lifetime of the pumping equipment before scheduled repair, more than twice.

Used magnetic filters can be regenerated. Currently, the authors of the paper are conducting research on the regeneration of used filters, aimed at preserving the environment and ecological safety, where the possibility of processing filtration products and their use in the field of construction and metallurgy is being studied. Research is aimed at the use of a non-magnetic component in construction as a filler for production of heavy and road cement-concrete mixtures [21]. Steel can be obtained from the magnetic component after granulation with the addition of coke powder by the direct reduction method and bypassing blast furnace remelting [22], [23].

The pumped-out water, purified from mechanical magnetic, weakly-magnetic and non-magnetic impurities, provided its permissible content of soluble salts, can be discharged into rivers and water bodies. This technology helps to preserve the environment without contaminating vast areas used for settling sumps.

5. Conclusions

Thus, the research performed was aimed at increasing the operational lifetime of pumping equipment in the mining industry, taking into account the analysis of existing methods.

A technology for producing spherical permanent magnets from barium ferrite powder for a filtering installation has been developed which includes a coarse purification column with hollow-spherical permanent magnets of 16-17 mm in diameter and a fine purification column with full-bodied spherical barium ferrite magnets of 6-7 mm in diameter.

The dependence of the percentage ratio of the filtering capacity and the time until complete clogging of the filter on the diameter of the spherical magnets has been studied, as well as their optimal parameters have been determined. It is indicated that with a spherical magnet diameter of 6-7 mm, the degree of purification reaches almost 100%, and the operating time until complete clogging is 900 hours.

A stage-by-stage mode of sintering the spherical granules obtained from barium ferrite powder has been developed, which ensures their high quality.

For continuous pumping-out and purification of contaminated groundwater from magnetic, weakly-magnetic and non-magnetic highly abrasive particles with the help of magnetic filters, a scheme of a filtering installation of two sections is proposed, which is able to increase the operational lifetime of pumping equipment in the mining industry.

Acknowledgements

The authors of the paper express their sincere gratitude to the Volodymyr Dahl East Ukrainian National University represented by the rector, Professor O.V. Porkuyan for support in funding and conducting research in the laboratories of the university.

References

[1] Pivnyak, G., Samusia, V., Oksen, Y., & Radiuk, M. (2015). Efficiency increase of heat pump technology for waste heat recovery in coal mines. *New Developments in Mining Engineering*, 1-4. https://doi.org/10.1201/b19901-2

[2] Yelemessov, K., Krupnik, L., Bortebayev, S., Baskanbayeva, D., & Igbayeva, A. (2020). Polymer concrete and fibre concrete as efficient materials for manufacture of gear cases and pumps. *E3S Web of Conferences*, (168), 00018. https://doi.org/10.1051/e3sconf/202016800018

[3] Krupnik, L., Yelemessov, K., Bortebayev, S., & Baskanbayeva, D. (2018). Studying fiber-reinforced concrete for casting housing parts of pumps. *Eastern-European Journal of Enterprise Technologies*, *6*(12(96)), 22-27. https://doi.org/10.15587/1729-4061.2018.151038

[4] Dolganov, A., & Timukhin, S. (2016). *Gidroabrazivnyy iznos rudnichnogo vodootliva*. Moskva, Rossiya: Izdatel'skiy dom Akademii Estestvoznaniya.

[5] Yoganandh, J., Natarajan, S., & Kumaresh Babu, S. (2015). Erosive wear behavior of high-alloy cast iron and duplex stainless steel under mining conditions. *Journal of Materials and Performance*, *24*(9), 3588-3598. https://doi.org/10.1007/s11665-015-1611-1

[6] Verichev, S., Mishakin, V., Nuzhdin, N., & Razov, E. (2015). Experimental study of abrasive wear of structural materials under the high hydrostatic pressure. *Ocean Engineering*, (99), 9-13. https://doi.org/10.1016/j.oceaneng.2015.03.001

[7] Akopov, E.Yu. (2016). *Obosnovanie i vybor metodov povysheniya resursa pogruzhnykh tsentrobezhnykh nasosov*. Ph.D. Thesis. Moskva, Rossiya: Natsional'nyy issledovatel'skiy tekhnologicheskiy universitet "MISiS".

[8] Biloshytskyi, M., Tatarchenko, H., & Biloshytska, N. (2019). Restoration of the tribotechnical pairs in equipment of mining industry. *Mining of Mineral Deposits*, *13*(3), 68-75. https://doi.org/10.33271/mining13.03.068

[9] Voynash, S.A., Gaydukova, P.A., & Markov, A.N. (2017). Rational route choosing methodology for machine parts restoration and repair. *Procedia Engineering*, (206), 1747-1752. https://doi.org/10.1016/j.proeng.2017.10.708

[10] Zhang, H., Zhang, X., Liu, Z., & Miao, Q. (2017). Understanding theories and methods on equipment operational reliability assessment. *2017 International Conference on Sensing, Diagnostics, Prognostics, and Control (SDPC)*, 367-370. https://doi.org/10.1109/sdpc.2017.76

[11] Povetkin, V., Kerimzhanova, M., Orlova, E., & Bukaeva, A. (2018). Sovershenstvovanie oborudovaniya dlya transportirovki gidrosmesi v obogatitelnom proizvodstve. *Gornyy Informatsionno-Analiticheskiy Byulleten'*, (6), 161-169. https://doi.org/10.25018/0236-1493-2018-6-0-161-169

[12] Ovchinnikov, N. (2018). Eksperimental'nye issledovaniya vliyaniya gidroabrazivnogo iznosa razlichnoy stepeni elementov rabochego kolesa na vibratsionnoe sostoyanie elektronasosnogo agregata. *Gornyy Informatsionno-Analiticheskiy Byulleten'*, (1), 158-165. https://doi.org/10.25018/0236-1493-2018-1-0-158-165

[13] Gusakov, V.G. (2017). *Natsional'naya akademiya nauk Belorussii: entsiklopedicheskiy spravochnik*. Minsk, Belarus: Belaruskaya navuka.

[14] Vinnik, D.A., Zherebtsov, D.A., Mashkovtseva, L.S., Nemrava, S., Bischoff, M., Perov, N.S., Semisalova, A.S., Krivtsov, I.V., Isayenko, L.I., Mikhailov, G.G., & Niewa, R. (2015). Growth, structural and magnetic characterization of al-substituted barium hexaferrite single crystals. *Journal of Alloys and Compounds*, (615), 1043-1046. https://doi.org/10.1016/j.jallcom.2014.07.126

[15] Vinnik, D.A. (2016). Production of barium lead hexaferrite single crystals from the flux. *Bulletin of the South Ural State University. Series Metallurgy*, *16*(1), 7-12. https://doi.org/10.14529/met160101

[16] Varmazyar, A., Allahkaram, S.R., & Mahdavi, S. (2018). Deposition, characterization and evaluation of monolayer and multilayer Ni, Ni-P and Ni-P-Nano ZnOp coatings. *Transactions of the Indian Institute of metals*, *71*(6), 1301-1309. https://doi.org/10.1007/s12666-018-1279-y

[17] Vlasova, E., Kovalenko, V., Kotok, V., & Vlasov, S. (2016). Research of the mechanism of formation and properties of tripolyphosphate coating on the steel basis. *Eastern-European Journal of Enterprise Technologies*, *5*(5(83)), 33-39. https://doi.org/10.15587/1729-4061.2016.79559

[18] Biloshytskyi, M., Tatarchenko, H., Biloshytska, N., & Uvarov, P. (2017). Tekhnolohiia otrymannia poroshku midi z vidkhodiv promyslovosti. *Naukovi Notatky*, (59), 27-31.

[19] Beloshitskiy, N.V., & Beloshitskaya, N.I. (2016). Retsikling – put' polucheniya novykh materialov i tekhnologiy v poroshkovoy metallurgii. *Wschodnioeuropejskie Czasopismo Naukowe*, *8*(7), 5-10.

[20] Zinovik, M.A., & Zinovik, E.V. (2012). O forme petli magnitnogo gisterezisa toroidal'nykh ferritovykh elementov. *Tekhnika v Silskohospodarskomu Vyrobnytstvi, Haluzeve Mashynobuduvannia, Avtomatyzatsiia*, *25*(1), 91-98.

[21] Piddubnyi, S.V., & Biloshytskyi, M.V. (2019). Zastosuvannia vidkhodiv vyrobnytstva dlia vyhotovlennia dorozhnoho tsementobetonu. *Visnyk Skhidnoukrainskoho natsionalnoho universytetu imeni Volodymyra Dalia*, *8*(256), 57-61. https://doi.org/10.33216/1998-7927-2019-256-8-57-61

[22] Tsvik, G., Sandoval, I., Braun, U., & Farkhadi, A. (2006). Postoyannoe sovershenstvovanie tekhnologii pryamogo vosstanovleniya zheleza. *Chernye Metally*, (5), 17-20.

[23] Kirichenko, I.S., & Aleksakhin, A.V. (2016). Razvitie mirovogo i otechestvennogo proizvodstva zheleza pryamogo vosstanovleniya. *Molodoy Uchenyy*, (2), 85-90.

Підвищення термінів експлуатації насосного обладнання при відкачуванні забруднених ґрунтових вод

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Мета. Рішення завдання підвищення термінів експлуатації насосного обладнання при відкачуванні забруднених ґрунтових вод у залізорудній промисловості, за рахунок виділення твердої, абразивної частини з використанням магнітних фільтрів на основі постійних феритових магнітів.

Методика. Для отримання сферичних магнітотвердих феритових елементів, що уловлюють дрібнодисперсні магнітні та слабкомагнітні абразивні частинки при відкачуванні забруднених ґрунтових вод у залізорудній промисловості, використовували порошок фериту барію $BaO \cdot 6Fe_2O_3$ застосовуваний для отримання магнітотвердих феритів. Сферичні елементи для наповнення магнітної установки, що фільтрує, отримували методом сфероїдизації порошку фериту барію в дражирувальній машині. Спікання сферичних гранул, отриманих з порошку фериту барію, виконували в високотемпературній атмосферній електричній камерній печі. Намагнічування спечених сферичних елементів з магнітотвердого фериту барію виконували за допомогою магнітної імпульсної установки тороїдальної форми в імпульсному постійному магнітному полі.

Результати. Запропоновано схему фільтрувальної установки з двох секцій для безперервної відкачки та очищення забруднених ґрунтових вод від магнітних, слабкомагнітних і немагнітних високоабразивних частинок із використанням магнітних фільтрів. Запропоновано технологію отримання сферичних постійних магнітів з порошку фериту барію, для фільтрувальної установки до складу якої входять: колона грубої очистки з пустотілими сферичними постійними магнітами діаметром 16-17 мм і колона тонкої очистки з повнотілими сферичними магнітами з фериту барію діаметром 6-7 мм. Результати проведених досліджень дозволять збільшити термін експлуатації обладнання, що відкачує, внаслідок усунення абразивного зносу, що призведе до значної економії коштів на заміну і ремонт відцентрових насосів.

Наукова новизна. Термін експлуатації насосного обладнання збільшується у два рази, внаслідок усунення абразивного зносу, за рахунок двосекційної фільтрувальної установки з наповненням їх сферичними магнітами з фериту барію. Час простоїв при заміні фільтра зменшується за рахунок додаткової резервної колони. Обґрунтована можливість переробки продуктів фільтрації і використання їх у галузі будівництва і металургії, без забруднень навколишнього середовища.

Практична значимість. Запропоновано схему магнітного очищення ґрунтових вод залізорудної промисловості, що складається з фільтра-колони грубої і тонкої очистки від абразивних частинок. Розроблено технологічний процес виготовлення сферичних магнітів різних діаметрів для забезпечення якості процесу.

Ключові слова: *насосне обладнання, ґрунтові води, знос, ферит барію, сферичний магніт, фільтр, залізорудна промисловість*

Повышение сроков эксплуатации насосного оборудования при откачивании загрязненных грунтовых вод

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Цель. Решение задачи повышения сроков эксплуатации насосного оборудования при откачивании загрязненных грунтовых вод в железорудной промышленности, за счет выделения твердой, абразивной части, с использованием магнитных фильтров на основе постоянных ферритовых магнитов.

Методика. Для получения сферических магнитотвердых ферритовых элементов, улавливающих мелкодисперсные магнитные и слабомагнитные абразивные частицы при откачивании загрязненных грунтовых вод в железорудной промышленности, использовали порошок феррита бария $BaO \cdot 6Fe_2O_3$, применяемый для получения магнитотвердых ферритов. Сферические элементы для наполнения магнитной фильтрующей установки получали методом сфероидизации порошка феррита бария в дражировочной машине. Спекание сферических гранул, полученных из порошка феррита бария, производили в высокотемпературной атмосферной электрической камерной печи. Намагничивание спеченных сферических элементов из магнитотвердого феррита бария осуществляли с помощью магнитной импульсной установки тороидальной формы в импульсном постоянном магнитном поле.

Результаты. Предложена схема фильтрующей установки из двух секций для непрерывной откачки и очистки загрязненных грунтовых вод от магнитных, слабомагнитных и немагнитных высокоабразивных частиц с использованием магнитных фильтров. Предложена технология получения сферических постоянных магнитов из порошка феррита бария, для фильтрующей установки, в состав которой входят: колона грубой очистки с пустотелыми сферическими постоянными магнитами диаметром 16-17 мм и колона тонкой очистки с полнотелыми сферическими магнитами из феррита бария диаметром 6-7 мм.

Научная новизна. Срок эксплуатации насосного оборудования увеличивается в два раза, вследствие устранения абразивного износа, за счет фильтрующей двухсекционной установки с наполнением их сферическими магнитами из феррита бария. Время простоев при замене фильтра снижается за счет дополнительной резервной колонны. Обоснована возможность переработки продуктов фильтрации и использование их в области строительства и металлургии, без загрязнений окружающей среды.

Практическая значимость. Предложена схема магнитной очистки грунтовых вод железорудной промышленности, состоящая из фильтра-колонны грубой и тонкой очистки от абразивных частиц. Разработан технологический процесс изготовления сферических магнитов разных диаметров для обеспечения качества процесса. Результаты проведенных исследований позволят увеличить срок эксплуатации откачивающего оборудования вследствие устранения абразивного износа, что приведет к значительной экономии средств на замену и ремонт центробежных насосов.

Ключевые слова: *насосное оборудование, грунтовые воды, износ, феррит бария, сферический магнит, фильтр, железорудная промышленность*