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UDC 622.7

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HIGH-EFFECTIVE MAGNETIC HYDROCYCLONING EQUIPMENT FOR MAGNETITE ORE PROCESSING

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*

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 dissociation. 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].

Highly effective classification systems are increasingly often represented by hydrocyclones which possess high specific capacity and replace spiral classifiers at the first milling stage. Efficiency of sizing in such machines is governed by the milling circuit efficiency and also by the performance of all subsequent process flows at a concentration factory. The studies aimed at reduction of size of particles effectively separated by hydrocyclones are in progress [2, 3]. Magnetic field allows separating even submicron particles [4].

Hydrocyclones of many designs operate as magnetic separators using the permanent and variable magnetic fields in processing of ferruginous quartzite [1, 5] and regeneration of magnetite suspensions [6]. The effect of these fields is directed to enhancing iron recovery and concentrate quality, as well as to thickening the magnetic product. The fields are created by solenoids or permanent magnets which ensure the gradient of the magnetic field capable to generate the extracting magnetic force, or by cylindrical solenoids for creating volumetric magnetic fields and for magnetizing fine pulp in vortex finder. Another popular idea consists in using magnetic hydrocyclones for removal of magnetic impurities from process fluids [7–11]. It is also proposed to separate water and oil suspensions in magnetic hydrocyclones [12, 13]. Unfortunately, not every design is applicable to processing of magnetic ore.

The most demonstrative example of high-efficient use of a magnetic hydrocyclone (MHC) may be the known facility with the electromagnetic system arranged outside, on the hydrocyclone cone and with the magnetic fraction outlet from the vortex finder [1]. Such type hydrocyclones were proposed for operation at ilmenite placers [14]. The major disadvantages of this facility and this mechanism of magnetic fraction recovery from a rotating flow of suspension is low-quality of separation of polydisperse mineral suspensions composed of particles of different sizes. The magnetic fraction contains both coarse nonmagnetic particles and weakly magnetic aggregates as a result. The cause is the incomplete contraposition of vectors of the magnetic and centrifugal forces in the separation zone, which means that the vectors of the magnetic and centrifugal forces are directed at different angles but to the same side. As a result, the centrifugal forces brings coarse and heavy nonmagnetic impurities to the magnetic fraction [1]. Gang Chen has come nigh unto solving this problem [15].

This study aims to enhance selectivity of nonmagnetic mineral recovery from polydisperse suspension at high specific capacity of magnetic hydrocycloning.

The key objective is the development of a magnetic hydrocyclone capable to ensure magnetic fraction recovery from polydisperse suspension at high specific capacity and separation efficiency without preliminary sizing.

Research procedure and new design of magnetic hydrocyclone

For achieving the preset aim, the magnetic force direction in MHC was changed so as to be opposite to the centrifugal force direction by superimposing the rotating flow of suspension with a magnetic system meant to create such magnetic field that its magnet-like lines intersect the rotating suspension flow [16].

The gradient of the magnetic field inside the MHC body is directed oppositely to the direction of summed up centrifugal force and gravity force vectors, and the outlet of the magnetic product is redirected in the drain tube by means of making outlet holes for concentrate in it.

Optionally, it is possible to adjust MHC mode of operation with the help of a widget meant to adjust the total area of the outlet holes in the drain tube by displacing an insert with slot-type cuts. The insert represents the known pipe-in-pipe assembly.

Figure 1 shows the elevation view of MHC and the direction of the suspension flow in it under the action of the magnetic and centrifugal forces [16].

The equipment consists of a magnetic hydrocyclone body *1* made of a nonconductive material, a drain tube *2* with outlet holes *3*, a magnetic system *4*, an inlet fitting *5* and a vortex finder *6*.

This assembly is coaxially superimposed with a variable magnetic field source so that the magnet-like lines interest the flow suspension rotation in the hydrocyclone cylinder. Moreover, the magnetic field gradient is directed toward the outlet holes. The wanted field pattern is set by a solenoid placed on the hydrocyclone cylinder cap. The variable magnetic field improves mobility of magnetite particles and prevents jamming of MHC with flocs of the concentrate at the magnetic field strengths higher than 15 kA/m.

The magnetic effect on the rotating flow of suspension leads to increased concentration of magnetic particles in the axile zone of the flow and nonmagnetic particles in the periphery of the flow. The magnetic fraction is taken out along the axis of the rotating suspension flow and via the drain tube, and the nonmagnetic fraction is taken off in the opposite direction (via the vortex finder).

During operation of the magnetic hydrocyclone, suspension enters MHC cylinder via inlet fitting *5*, gets into the action zone of the magnetic and centrifugal forces and is set into rotational motion in the separation space. Under the action of the magnetic forces, the magnetic particles concentrate nearby the magnetic system, under the MHC cap, around drain tube *2*, and displace the nonmagnetic particles which, under the action of the centrifugal forces, are pushed toward the MHC walls and, then, to the MHC cone and are removed via vortex finder *6*. The magnetic particles under the action of the magnetic field gradient are displaced to the center of magnetic system *4*, for a concentrated layer and, under the action of the pressure difference of the suspension flows in the MHC cylinder and drain tube, are removed via outlet holes *3* in the drain tube with the flow of finely disperse and defecated suspension.

The prototype magnetic hydrocyclone with internal diameter of 29 mm and with a drain tube having diameter of 5 mm was tested in laboratory using a manmade suspension of a magnetic concentrate and quartz at a ratio agreeable with the content of Fe_{mag} 43.98% at 18% of solid and at the content of 70% of –0.04 mm size. The upper size limit was 0.12 mm. The iron content of the products was determined by an X-ray fluorescent analyzer.

Suspension was fed via the inlet fitting of MHC by a slurry pump at capacity of 800 l/h. The magnetic field was fed with AC current by an autoformer at the field density up to 0.08 T generated in the center of the solenoid.

Results and discussion

The separation test data of magnetic and nonmagnetic particles at different field densities are depicted in **Figs. 1** and **2**.

The results prove that with the increasing field density, the concentrate quality and the iron recovery increase. At the field density of 0.068 T, the beneficiation determinants reach admissible values. The further increase in the field density is unachievable by this equipment because of development of the avalanche magnetic flocculation phenomenon. The larger diameter hydrocyclone models are free from this phenomenon.

The developed equipment enables the real-time automated control over performance of the magnetic hydrocyclones by means of adjustment of current feed in the magnetic system.

The scope of the analysis also embraced the magnetic fraction recovery as function of the feed size. To this end, the magnetic concentrate and quarts mix was sized on a screen with openings 0.04 mm, 0.071 mm and 0.1 mm in size. The other parameters in the tests were constant. The test results are demonstrated in **Fig. 3.**

Low recovery of fines is explained by the weaker magnetic force received by these particles as the magnetic force F_{magn} is directly proportional to their mass which reduces in proportion to the cube of the particle radius: $F_{magn} = \mu_o \chi m_p H_{grad} H$, where H is the magnetic flux density, A/m; m_p is the particle mass, kg; χ is the magnetic susceptibility of the particle substance, units; $\mu_o = 1.256 \cdot 10^{-6}$ H/m is the magnetic constant.

The fluid resistance F_{res} to the particle motion is proportional to the first degree of the particle diameter. Accordingly, as the particle diameter diminishes, the flow resistance halves while the magnetic force drops by 8 times: $F_{res} = 6\pi\eta d_p \upsilon_p$, where η is the dynamic activity coefficient, Pa·s; d_p is the particle diameter, m; υ_p is the particle velocity, m/s.

Consequently, for more complete extraction of fines, the magnetic system of the hydrocyclone is to generate several times higher field density, or it is required to change the machine hydrodynamics.

The probability of extraction of a magnetic particle can be estimated as follows. For the particle to be extracted, it is required that while it is inside the MHC cylinder, the particle is to succeed to cover the distance L from the outer wall to the outlet hole along a spiral path.

The displacement L of a particle relative to the MHC axis irrespective of the circular motion phase of the particle is: $L = R_{MHC} - R_{drain}$, where R_{MHC} is the radius of the MHC cylinder wall, m; R_{drain} is the radius of the drain tube, m.

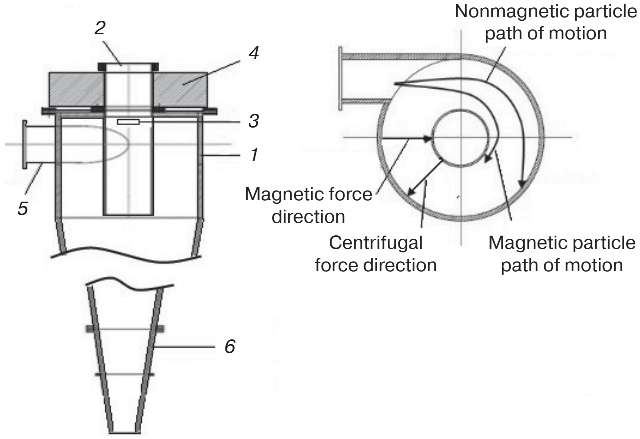

Fig. 1. Magnetic hydrocyclone (elevation view):
1—Magnetic hydrocyclone body; *2*—Drain tube; *3*—Slot-like outlet; *4*—Magnetic system; *5*—Inlet fitting; *6*—Vortex finder

The time of the particle staying in the action zone of the magnetic field versus the MHC geometry and the inlet fitting size is given by:

$$t = \frac{R^2_{MHC} h_{MHC}}{R^2_{inlet} \upsilon_{inlet}},$$

where υ_{inlet} is the water flow velocity in the inlet fitting of MHC; d_{inlet} is the inlet fitting diameter; h_{MHC} is the MHC cylinder height covered by the magnetic field of the required density sufficient for recovery.

The particle is extracted if it covers the distance $L = R_{MHC} - R_{drain}$ for the time t under the action of the force $F_{extr} = F_{magn} - F_{centr} - F_{res}$, where F_{centr} is the centrifugal force (with only radial component included).

After placement of the appropriate expressions and some transformations, we obtain the equality of a particle to pass the MHC cylinder space and to recover in the concentrate:

$$2(R_{MHC} - R_{drain}) / t^2 = \mu_0 \chi HgradH - \frac{\upsilon^2_\varphi}{r} - 3.5\pi\eta d_p \upsilon_p / 2m_p.$$

Solution of this equality at the preset values of geometrics of the hydrocyclone, for instance, determines the recovery

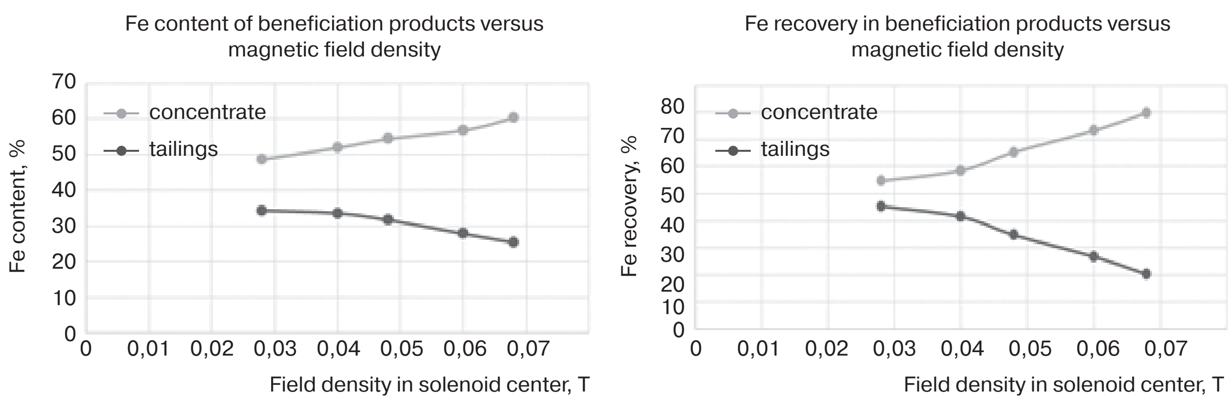

Fig. 2. Fe content and recovery in beneficiation products versus field density generated by MHC magnetic system

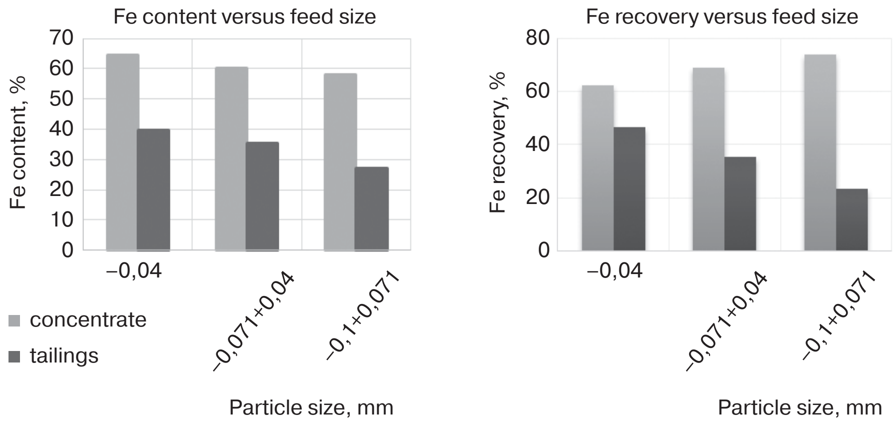

Fig. 3. Fe content and recovery in beneficiation products versus feed size

conditions of the magnetic particles at the varied magnetic field density and particle flow velocity. It is also possible to solve the inverse problem.

Conclusions

The new-developed method and equipment of magnetic hydrocycloning enable extraction of magnetic fraction from polydisperse suspension at high specific capacity and separation efficiency without preliminary sizing of the feed, and are recommended for processing ferruginous quartzite and other types of ores possessing pronounce magnetic properties.

The procedure is proposed for probability estimation of recovery of magnetic particles depending on settings, for instance, at the assigned geometrics of the magnetic hydrocyclone at the varied magnetic field density and the particle velocity. The equality for a particle to overpass the inner space of the hydrocylinder and to go to concentrate is presented.

The use of the magnetic hydrocyclone as a sizes of mill outlet products can enable avoiding overgrinding of dissociated grains of magnetite and, thereby, can enhance magnetite recovery and cut-down milling cost at the same time.

It is intended to use the magnetic hydrocyclone to extract medium- and weak-magnetic materials if the magnetic field density is increased, which is achievable with introducing superconductive materials in the magnetic system.

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