IOP Conference Series: Materials Science and Engineering

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To cite this article: Rashid R. Sharapov *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **327** 042101

Increasing performance of metallurgical plant

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Annotation. The paper proposes a method for dry separation of enrichment waste (tailings) of Kursk Magnetic Anomaly. A dry scheme for enrichment waste processing is suggested. The work suggests a design of the separator to fractionate the enrichment tailings of a metallurgical plant into quartz sand and iron-containing components to reduce the environmental impact. Using the regularities of the mass transfer of magnetic particles, an analytical expression for their extraction coefficient is derived. The application of the enrichment tailings as the precursor for building materials production is justified. The testing results of the fine-grain concrete with the samples produced by the developed installation are presented.

1. Introduction.

One of the most environmentally harmful industries is metallurgy. The separation of magnetite quartzites during mining and processing works of the Kursk Magnetic Anomaly is accompanied by the accumulation of enormous amounts of enrichment tailings, non-ore materials with a residual magnet content of up to 7–8%. Noteworthy, mining and processing works have accumulated billions of tones of production waste (tailings) that contain a huge amount of both iron-containing components and ores that can be used as building materials, for instance, for preparing fine-grain concretes, as mineral powder. The obtained materials can be also used for building roads, houses, for producing paint, etc.

Currently, mining and processing works use wet schemes of separation and drum separators that have the following weak points: presence of water medium with larger resistance as compared with air medium; water medium has strong counteraction against the movement of magnetic and non-magnetic particles. As a results, a fraction of magnetic particles is lost together with non-magnetic ones. During the separation of low-magnetic materials, there is no magnetic flocculation (formation of reinforced aggregates due to mutual attraction of magnetized particles). There is also a necessity of feeding medium, i.e. water (wastewater). The source of waste and recycle water is the discharge waters of dewatering, desludging and washing machines and enrichment tailings. The contaminants in them are solid particles, hardness salts, ions of heavy metals and organic compounds. Untreated wastewater with suspended impurities and aggregates are a reason of ecological system deterioration with all the negative consequences: the rivers grow shallow dry up, the vegetation withers, the life decays. The purification of wastewater from harmful impurities includes mechanical, chemical, physicochemical and biochemical methods. All these factors cause additional expenses and increase the marketable product cost.

2. Materials and Methods.

An alternative to wet separation is dry separation. From ecological perspective, dry magnetic separation is more reasonable separation method. Absence of the feeding medium provides appreciable economy of water, eliminates the necessity to treat wastewater and allows working without sludge dumps that occupy considerable areas and negatively impact atmosphere and lithosphere. Also, dry separation is the least energy consuming, since it is based on natural property of magnetic attraction of iron ores.

The efficacy of dry separation of metallurgical plant enrichment tailings is possible through combination of magnetic extraction of metallic particles and air turning of the separated material. With due consideration of these requirements, a fluidized-bed separator was developed (see Fig. 1) to study the process of separation of a two-component mix.

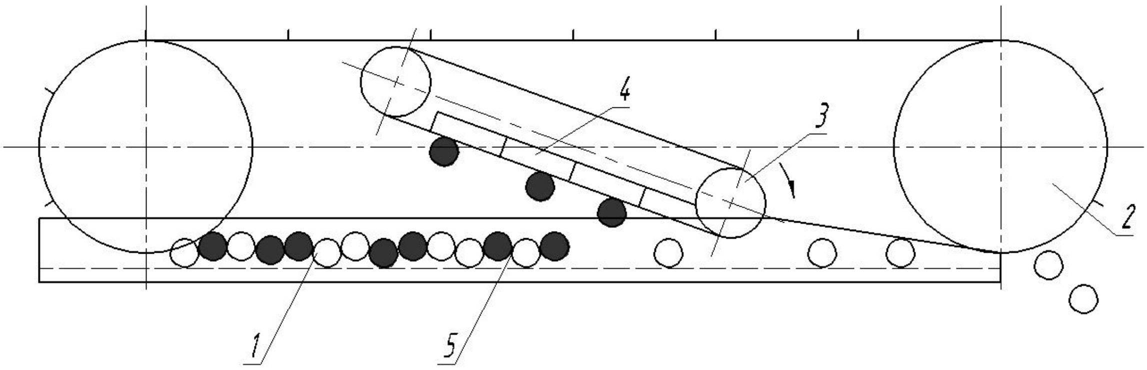

Figure 1. Structural and technological scheme of fluidized-bed separator: 1 – air slide; 2 – drag conveyor; 3 – transporting conveyor; 4 – magnetic system; 5 – fluidized material layer; ● – magnetite particles; ○ – quartzite particles

The extracting capability of the fluidized-bed separator for dry separation depends on the characteristics of the magnetic system and physicomechanical properties of the separated mix particles, and on geometrical parameters of the operation zone as well. The extraction coefficient of magnetic particles η is determined by the correlation of their mass flows at the input of active zone G (x_A) and at its output G (x_O) (Fig. 2):

$$\eta = 1 - \frac{G(x_B)}{G(x_A)} . \tag{1}$$

During the separation of particles in the separation zone, an aerodispersed flow of magnetic particles occurs that moves along the operation zone of the dry-separation fluidized-bed separator with the speed of the drag conveyor, v_k. The concentration of magnetic particles in this flow is distributed along the height of the operation zone quite non-uniformly: it sharply drops from its maximum value in the fluidized layer down to the minimal value in the settlement zone on the transporting conveyor belt.

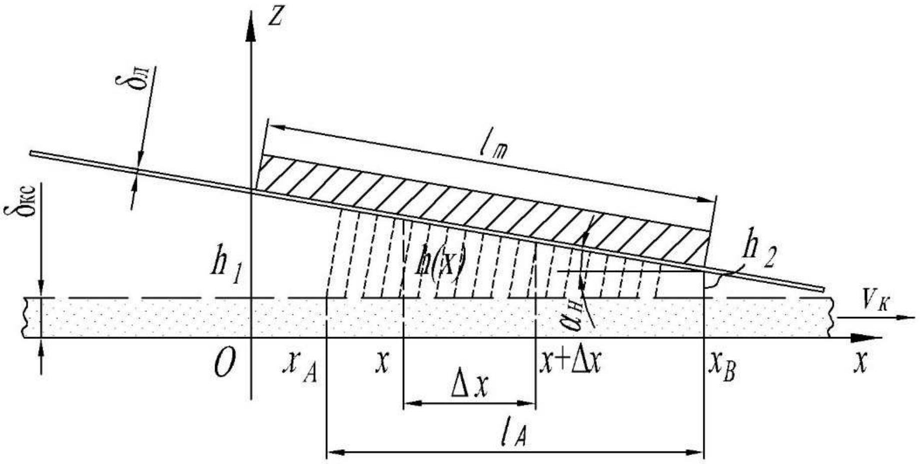

Figure 2. The design scheme for deriving the extraction coefficient for magnetite particles

Let us consider the part of the operation zone of the dry-separation fluidized-bed separator between the lateral sections passing through points *x* and *x+Δx* (see Fig. 2). After the settlement of magnetic particles, their concentration reduces from *C(x)* down to *C (x+Δx)*. The equation of material balance of magnetic particles for the selected part of the operating zone:

$$G(x) - G(x+\Delta x) = \chi C(x) v_{\text{oc}} b \frac{\Delta x}{\cos \alpha_{\text{н}}} = \chi \frac{G(x) v_{\text{oc}} \Delta x}{h(x) v_k \cos \alpha_{\text{н}}} . \qquad (2)$$

Here Δ*x/cos*α is the part of the transporting conveyor belt corresponding to Δ*x*; *G(x)* is the mass glow of magnetic particles passing through the lateral section of the operating zone corresponding to coordinate *x*:

$$G(x) = C(x) b h(x) v_k , \qquad (3)$$

where *h*(*x*) is the height of this section:

$$h(x) = h_1 - x tg \alpha_{\text{н}} , \qquad (4)$$

where *b* is the width of the lateral section.

Expressing the change in the mass flow of magnetic particles through its differential gives:

$$G(x) - G(x+\Delta x) = -(G(x+\Delta x) - G(x)) \approx -dG(x) , \qquad (5)$$

and separating the variables in equation (1) one has:

$$\frac{dG}{G} = -\frac{\chi v_{\text{oc}} dx}{v_k (h_1 - x \text{tg} \alpha) \cos \alpha_{\text{н}}} . \qquad (6)$$

After integrating equation (6), there is:

$$\ln G \Big|_{G(x_A)}^{G(x_B)} = \frac{\chi v_{\text{oc}}}{v_k \sin \alpha_{\text{н}}} \ln (h_1 - x \text{tg} \alpha_{\text{н}}) \Big|_{x_A}^{x_B} . \qquad (7)$$

From relation (7):

$$\frac{G(x_B)}{G(x_A)} = \left(\frac{h_1 - x_B \text{tg} \alpha_{\text{н}}}{h_1 - x_A \text{tg} \alpha_{\text{н}}} \right)^{\frac{\chi v_{oc}}{v_k \sin \alpha_{\text{н}}}} . \qquad (8)$$

After substituting (8) into equation (1), one has the correlation for fraction coefficient of magnetic particle extraction:

$$\eta(d) = 1 - \left(\frac{h_2}{h_2 + l_a \text{tg} \alpha_{\text{н}}} \right)^{\frac{\chi v_{oc}}{v_k \sin \alpha_{\text{н}}}} . \qquad (9)$$

Regarding the length of the active section of the operating zone, l_A included into equation (6), one gets:

$$l_A = -\frac{h_2 - 1{,}115\delta}{\mathrm{tg}\alpha_{\text{н}}} - \frac{1}{2c\sin\alpha_{\text{н}}} l_n\left(\frac{\rho_{\text{M}} g\cos\alpha_{\text{н}}}{\mu_0\chi_{\text{ч}} c H_0^2}\right). \tag{10}$$

For the experimental dry-separation fluidized-bed separator (h_2 = 0.015 m, δ = 0.003–0.013 m, v_k = 0.012–0.028 m/s, $\alpha_{\text{н}}$ = 10–20°, c = 26.17 1/m, H_0 = 37 kA/m, $\chi_{\text{ч}}$ = 6.25, ρ_{M} = 5260 kg/m^3, Φ_{M} = 1.65, g = 9.81 m/s^2, μ_0 = 4π·10^{-7}(kg·m)/(s^2·A^2), $\bar{d}_i = \{2.7; 8.3; 17.2; 31.7; 55\}$ μm, $\mu_{\text{д}}$ = 1.8·10^{-5}Pa·s, $\delta_{\text{л}}$ = 0.003 m) parameter l_A and particle settlement speed on the transporting conveyor belt, $v_{\text{ос}}$ (equation (10)), has the following form:

$$l_A = -\frac{0.015 - 1.115\delta}{\mathrm{tg}\alpha_{\text{н}}} - \frac{\ln(0.183\cos\alpha_{\text{н}})}{52.34\sin\alpha_{\text{н}}}, \tag{11}$$

$$v_{\text{ос}} = 4.472\cdot10^{-4} d^2, \tag{12}$$

where particle size d should be in μm.

With due regard of equations (11) and (12), expression (9) can be rewritten as follows:

$$\eta(d) = 1 - \left(\frac{0.015}{1.115\delta - \dfrac{\ln(0.183\cos\alpha_{\text{н}})}{52.34\cos\alpha_{\text{н}}}}\right)^{\frac{4.472\cdot10^{-4} d^2\chi}{v_k\sin\alpha_{\text{н}}}}. \tag{13}$$

The correlation of theoretical and experimental values of the total magnetic particle extraction coefficient shows that the value of the of their concentration distribution nonuniformity coefficient in the operating zone of dry-separation fluidized-bed separator χ mainly depends on the thickness of the separated mixture in initial, bound state δ. After processing the experimental data, the following dependence was obtained:

$$\chi(\sigma) = 50\delta^2 - 0.15\delta + 0.0224. \tag{14}$$

Substituting equation (15) into (13), one gets a final expression for the fraction coefficient of magnetic particle extraction in the experimental dry-separation fluidized-bed separator.

$$\eta(d) = 1 - \left(\frac{0.015}{1.115\delta - \dfrac{\ln(0.183\cos\alpha)}{52.34\cos\alpha}}\right)^{\frac{4.472\cdot10^{-4} d^2(50\delta^2 - 0.15\delta + 0.0224)}{v_k\sin\alpha_{\text{н}}}}. \tag{15}$$

3. Research.

To study the dependence of the total magnetic particle extraction coefficient on the thickness of the initial layer of the separated mixture, let us assume for equation (3) the following: d = 29.8 μm, α = 15°, v_k = 0.02 m/s. Then,

$$\eta = 1 - \left(\frac{0.015}{1.115\delta + 0.034}\right)^{76.72(50\delta^2 - 0.15\delta + 0.0224)}. \tag{16}$$

From equation (15) it follows that with increasing separated mixture layer thickness, the extraction coefficient increases (Fig. 3). This is explained by both growing magnetomotive force and increasing particle concentration in the settlement zone. The maximum divergence is in point δ = 3 mm and amounts to 5.9%.

The dependence of the magnetic particle extraction coefficient on the drag conveyor movement speed follows from equation (15) at d = 29.8 μm,σ = 0.008 m, $\alpha_{\text{н}}$ = 15°:

$$\eta = 1 - 0.347^{\frac{0.037}{v_k}} . \tag{17}$$

According to equation (17), the magnetic particle extraction coefficient with the increase in the drag conveyor movement speed drops (Fig. 4), which is explained by the decrease in the mixture residence time in the active zone of the dry-separation fluidized-bed separator.

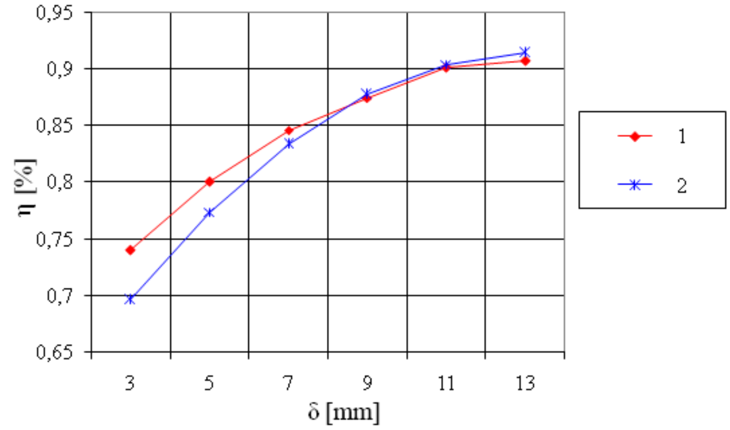

Figure 3. Dependence of the magnetic particle extraction coefficient on the layer thickness of the separated mineral mixture: *1* – values calculated using equation (16); *2* – experiment

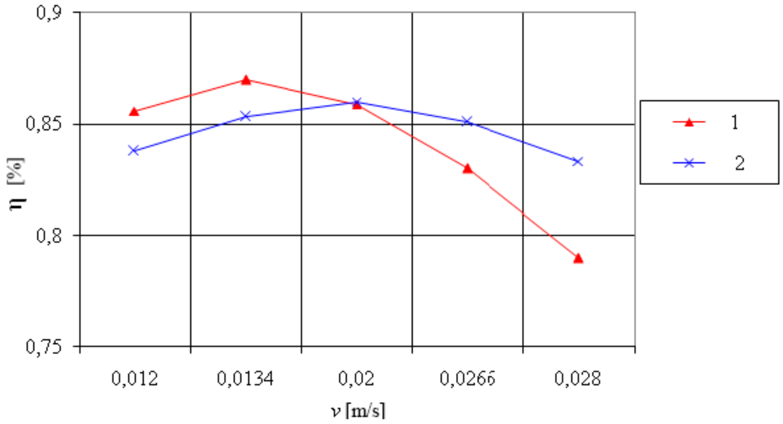

Figure 4. Dependence of the magnetic particle extraction coefficient on the drag conveyor movement speed: *1* – values calculated using equation (17); *2* – experiment

Maximum discrepancy of theoretical and experimental values of the extraction coefficient is manifested at the movement speed of $v = 0.028$ m/s and amounts to 5.16%.

The dependence of the extraction coefficient on angle α follows from equation (15) when $d = 29.8$ μm, $\delta = 0.008$ m, $v_k = 0.02$ m/s:

$$\eta = 1 - \left(\frac{0.015}{0.009 - \frac{\ln(0.183 \cos \alpha_{н})}{52.34 \cos \alpha_{н}}} \right)^{\frac{0.479}{\sin \alpha_{н}}} . \tag{18}$$

Dependence (18) is extremal. At first, during the increase in the magnetic system, the inclination angle increases up to $\alpha = 13°$, the magnetic particle extraction coefficient rises; a further increase of magnetic system inclination angle α decreases the magnetic particle extraction coefficient (Fig. 5).

Maximum discrepancy of theoretical and experimental values of the extraction coefficient manifests at the magnetic system inclination angle α = 10° and amounts to 9.0%.

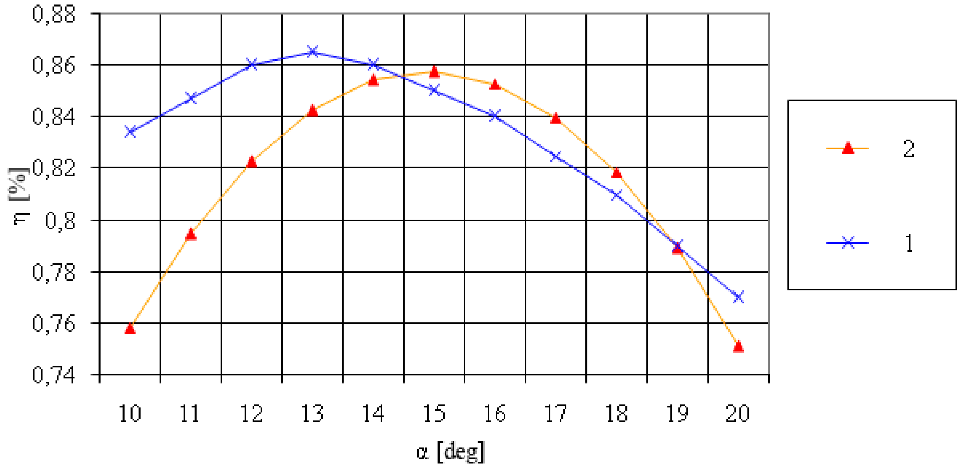

Figure 5. Dependence of the magnetic particle extraction coefficient on the magnetic system inclination angle: *1* – values calculated using equation (18); *2* – experiment

The dependencies of the magnetic particle extraction coefficient in the main domain of structural and technological separator parameters σ, v_k and $\alpha_{н}$ qualitatively and quantitatively agree well (with the accuracy of up to 9.0%) with the factorial experiment curves. The absence of growth regions and non-extremal character of theoretical curves is obviously explained by the approximated character of currently applied engineering methods for describing magnetic field of separators and properties of fluidized bulk materials.

Industrial approbation of the application of finely ground enrichment tailings as the mixture components was carried out at the production of fine grain concrete and asphalt concrete.

The additives to fine grain concrete were represented by the enrichment tailings with the fineness of 2% of residue on the 0.315-mm sieve. Mineral fillers were introduced into concrete in the amounts of 5, 10 and 15% of the cement mass. The introduction of larger amount was ineffective, and the strength of the specimen reduced. The fillers have show positive results as compared to the specimens from control lot with the introduced amount of 5 and 10%. The increase of the strength was noted for concretes with the fillers from the materials under study. The bending tensile strength and compression strength increased by 20%. After the introduction of 10% of the filler, there is similar distribution of the strength characteristics with lesser strength increase. The application of 15% of the filler is effective for the enrichment tailings; the strength of the material is virtually equal to the material without the filler, and the efficacy is represented by the economy of cement.

4. Conclusions

To increasing the performance of a metallurgical plant for separation of enrichment tailings, high efficacy can be reached when using the devices that use a magnetic principle of particle extraction and air turning of the separated material. To perform the experiment, an experimental fluidized-bed separator was developed and built. The experimental studies prove that the dry-separation fluidized-bed separator has larger efficacy versus conventional separators and exceeds 90%. The finely ground enrichment tailings were practically proven to be effective in building material production.

5. Acknowledgments

The article was prepared within the development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shoukhov, using the equipment of High Technology Center at BSTU named after V.G. Shoukhov.

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