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PRACTICE OF USING SPIRAL SEPARATORS IN MAGNETITE ORE DRESSING

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Abstract. The authors developed recommendations for the use of gravity spiral separation in technological schemes for the beneficiation of magnetite quartzite based on the study of the main factors affecting the operation of the spiral separator by making granulometric, chemical, mineralogical and technological analyses of magnetite quartzite beneficiation products in the SVSh-2-1000 spiral separator and conducting experiments to determine the main factors affecting the process.

The possibility of obtaining a concentrate of 12.8% with a mass fraction of Fe_{total} of 55.4% from sands of the second classification stage with a mass fraction of Fe_{total} of more than 68% at the position of the cut-off at the level of 95 mm was shown. It was established that the separation of products on a spiral separator should be carried out in narrow size fractions. It is shown that separation of oversize products with a mass fraction of Fe_{total} of 58.46–61.48% in spiral separators allows obtaining three products - heavy, medium, and light fractions. The heavy and light fractions are concentrates with a mass fraction of Fe_{total} exceeding 67%. The light fraction has the highest content of regrind magnetite. It was established that the pulp viscosity and temperature have a significant impact on the process of beneficiation of magnetite ore pulp in a spiral gravity separator. The effect of temperature on the efficiency of iron recovery from the concentrate was studied. It was found that the maximum iron recovery (74.08%) and its highest mass fraction (68.03%) in the concentrate are achieved at a temperature of 28–30 °C.

A significant decrease in temperature to 5 °C leads to a significant deterioration in performance. In particular, the viscosity of the pulp (with 80% of particles smaller than 0.033 mm) almost doubles (1.96 times). This leads to a decrease in iron recovery by 11.54% (to 62.54%) and a decrease in its mass fraction in the concentrate to 63.48%.

Raising the temperature to 50 °C also has a negative impact on the process, although less pronounced. The pulp viscosity decreases by 1.44 times, but the iron recovery decreases by 7.37% (to 66.71%), and its mass fraction in the concentrate decreases to 66.5%.

Thus, the results of the study indicate a narrow temperature range (28–30 °C), which is critical for ensuring maximum recovery and quality of iron concentrate.

The possibility of producing concentrates with a mass fraction of SiO_2 of less than 2% was proven.

As a result, three areas of application of spiral separation of magnetite products in iron ore beneficiation technologies are recommended: after the second stage of grinding, selective enrichment of oversize and undersize products of fine screening of magnetite concentrate.

The practical significance is that the use of a spiral gravity separator in the beneficiation of magnetite ores allows reducing the grinding load by 10–12% and obtaining concentrates with a mass fraction of Fe_{total} of more than 67% and SiO_2 of less than 2%.

Keywords: spiral separator, oversize, undersize, suspension viscosity.

1. Introduction

Today, the main method of beneficiation in iron ore processing is magnetic. However, additional methods are required to produce high-quality concentrates.

For example, one of them is flotation [1]. This process is effectively used on material with a mineral particle size (<100 microns). Today, it has been considered the optimal process for producing high quality concentrates by extracting fine quartz from magnetite products, as it is almost always possible to create a difference in surface wetting between ore and nonmetallic minerals. However, the high cost of chemicals and their adverse environmental impact were considered to be the main disadvantages of using the flotation process in iron ore beneficiation technologies [2].

As an alternative to improving the quality of magnetite concentrates, it is advisable to consider gravity separation, which is an environmentally friendly technology in contrast to flotation, since the density of rock and ferrous minerals differs by more than 2 times. The use of gravity ore dressing should be considered in the particle size

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range from 0.16 mm to 0.040 mm. In this size range, spiral separators and screw sluices are the optimal equipment for gravity concentration of ore [3, 4].

The gravity spiral separator separates the pulp, which is a mixture of water and suspended mineral particles, into streams with different particle densities [5, 6]. It is a fixed chute with a vertical axis that serves as its support. The pulp is fed into a feeder located at the top of the chute. In spiral separators, the pulp moves along an inclined plane with the particles suspended in it, experiencing resistance created by surface roughness, grooves, and settled particles. The following forces act on a particle moving in a flow: gravity, dynamic flow pressure, friction, and the dynamic effect of the vertical velocity component of vortex water flows formed during turbulent conditions [6, 7].

The process of separation of granular material in the trough of a spiral separator occurs in stages:

1 - vertical stratification of the material and the transition of heavy minerals to the bottom layer and less selectively to small heavy grains. The main separation factors at this stage are grain size and density.

2 - redistribution of grains in the radial direction with the creation of a mineral fan of separation products (concentrate, industrial product, waste) [3]. Particles are separated radially in terms of density and size as the grains move downwards.

The technical literature contains the results of using spiral separators for various ores. However, there is virtually no data on the use of this equipment on magnetite quartzite. It is known that Arcelor Mittal (Canada) uses spiral gravity separators of various diameters to enrich iron ore hematite. This makes it possible to produce marketable iron-containing concentrates. The recovery of Fe_{total} in the concentrates is 83.9–88.1%. These results are achieved by separately enriching narrow fractions by size using different concentrators with different spiral diameters. At the same time, the circulation load is 17–22% [8].

The main problem in the use of spiral separators is the impact of mineral particles smaller than 0.01 mm on the pulp separation process. To improve the understanding of the principles of spiral separators, the fluid movement on the surface of spirals and troughs is currently being studied with regard to hydrodynamic parameters [5, 9, 10]. At the same time, the separation mechanism and the influence of various parameters on the separation process have not been studied, which complicates their regulation and does not allow an objective assessment of the possibility of using spiral separators. And the efficiency of the ore dressing process is largely determined by the ratio of the velocities of light and heavy minerals in the water flow, flow parameters, characteristics and properties of mineral grains, the type and condition of the working surface of the apparatus, i.e., the conditions of mineral grain transportation [11, 12, 14].

Therefore, determining the possibility of using spiral separators in the beneficiation of magnetite quartzite is an urgent practical task.

The aim of this study is to develop recommendations for the use of gravity spiral separation in technological schemes for the beneficiation of magnetite quartzite based on the study of the main factors affecting the operation of the spiral separator.

Research objectives. The research programme included determining the possibility of using a spiral separator in the beneficiation of magnetite ores to increase the mass fraction of total iron in magnetite concentrates to 68% or more and reduce the mass fraction of SiO_2 to 2.5% or less.

2. Methods

To perform the research tasks, samples were taken from different units of technological schemes for ore dressing at «YUZHNIY GOK» Mining and Processing Plant, Central GOK (Mining and Processing Plant).

Namely:

- sands of the second classification stage of section No. 5 of the mill No. 1 of «YUZHNIY GOK» Mining and Processing Plant;
- undersize product of fine screening of magnetite concentrate of Central GOK (Mining and Processing Plant);
- oversize product of fine screening of magnetite concentrate of Central GOK (Mining and Processing Plant).

The granulometric composition of the sampled products is shown in Table 1.

Table 1 – Granulometric composition of the products sent for research

Product name	Size class, mm				
	+0.25	0.25–0.071	0.071–0.056	0.056–0.04	-0.04+0
Sands of the second classification stage	16.79	57.49	9.70	5.07	10.95
Oversize product of fine screening	0.01	9.66	4.65	4.81	80.87
Undersize product of fine screening	-	-	5.48	7.28	87.24

The studies were carried out on SVSh-2-1000 spiral separators (Fig. 1) in the production conditions of the plants.

Figure 1 – Screw separator type *SVSh-2-1000*

The set of studies and tests on the spiral separator at the optimal mode included the determination of

- the mass fraction of Fe_{total} and SiO_2 in the separation products,
- separation product yield;
- performance indicators for solid and pulp;
- the effect of pulp viscosity on separation performance;
- the position of the cut-offs in the chute;
- the angle of inclination of the chutes;
- fluctuations in feed properties during separation.

The installation on which the test was carried out is a single-entry spiral separator operating in a closed cycle with a sump-mixer equipped with a centrifugal pump of the 1GR modification for feed intake and feeding through a discharge pipe equipped with a demagnetising device for floc destruction. The power supply was regulated by a frequency converter. The time for sampling all products was 30 seconds.

3. Experimental part

The results of the technological parameters of separation products at the bench-top unit during the period of determining the effective operating mode in the conditions of «YUZHNIY GOK» Mining and Processing Plant of section No. 5 of the RZF-1 are shown in Table 2.

Table 2 – Technological parameters of separation products (замените запятые)

GS power supply		Position of the cut-off, mm	Concentrate (heavy product)		Product 2+3		Productivity, t/h
Pulp density, g/l	Mass fraction of Fe_{total}, %		Product yield, %	Mass fraction of Fe_{total},%	Output, %	Mass fraction of Fe_{total}, %	
1300	55.4	95	12.8	68.4	87.20	53.49	1.39
		140	16.5	66.6	83.5	53.2	1.49
		170	34.8	65.9	65.2	50.1	1.26
		190	41.2	65.5	58.8	50.5	1.29

The results of testing on a spiral separator showed that it is possible to obtain a heavy fraction with a mass fraction of Fe_{total} of 55.4% and a mass fraction of Fe_{total} of 66.6% from sands of the second classification stage with an output (from the operation of 16.5%) and a cut-off position of 140 mm, respectively. To obtain concentrates (heavy product) with a mass fraction of iron exceeding 68%, the cut-off position should be 95 mm. In this case, the concentrate yield was 12.8%.

The granulometric characteristics of the obtained concentrates with a mass fraction of Fe_{total} of 66.6% and Fe_{total} of 68.4% are given in Table 3.

Analysing the data in Table 3, it can be concluded that in both concentrates, the highest yield (32.7–33.6%) is the -0.056 mm fraction with a high mass fraction of iron (69.2%). The second highest yield fraction of -0.125 mm (26.7%) has a mass fraction of 66.5% iron. In general, concentrates are characterised by a natural increase in the mass fraction of Fe_{total} with a decrease in particle size. At the same time, the bulk of the product is concentrated in the fraction size range of -0.071 mm and below, which is important for optimising separation.

Table 3 – Particle size distribution of spiral separator concentrates (запятые)

Product	Size fractions mm	-1 +0.5	-0.5 +0.2	-0.2 +0.125	-0.125 +0.071	-0.071 +0.063	-0.063 +0.056	-0.056 +0.04	-0.04 +0
Concentrate Fe_{total} – 66.6, %	Yield, %	0.2	3.8	14.0	26.7	14.0	1.8	32.7	6.8
	Mass fraction of Fe_{total},%	50.8		63	66.5	67.1	69.1		69.2
Concentrate Fe_{total} – 68.4, %	Yield, %.	0.9	2.6	13.3	24.9	15.4	0.3	33.6	9.0
	Mass fraction of Fe_{total},%	63.0		65.7	67.4	68.8	69.4		68.3

If fractions larger than 0.125 mm are removed from the products, the quality of the concentrates will be higher in terms of iron. Mineralogical analysis of the concentrate samples confirmed that magnetite is concentrated mainly in the finest-grained material, i.e. fractions of -0.04+0 mm and -0.063+0.04 mm, and is represented by monomineral particles with a small number of growths. In the coarser-grained material, magnetite is found both in free form and as inclusions in quartz particles, sometimes of magnetite-quartz composition. Quartz is redistributed in the composition of the material of particle size fractions with an inverse pattern. The largest amount of quartz is in the particle size fractions larger than 0.125 mm, where it forms intergrowths with magnetite, and less often with silicates and carbonates. In the material with a particle size of less than 0.1 mm, quartz is mainly represented by monomineral particles. In the material of fine-grained fractions, mono-mineral particles of hematite or its fusions with magnetite are occasionally observed. Silicates and carbonates are present in small amounts.

The results of the granulometric and mineral analyses of the obtained concentrates showed that further separation of the products on a spiral separator should be carried out on narrow fractions. Therefore, at the next stage, studies were carried out to determine the feasibility of gravity beneficiation in spiral separators of the fine screening product of magnetite magnetic industrial product in the conditions of Central GOK (Mining and Processing Plant). The test results are shown in Table 4.

The research results show that the separation of oversize products with a mass fraction of Fe_{total} of 58.46–61.48% in spiral separators allows obtaining three products - "heavy", "medium" and "light" fractions. In this case, the "heavy" and "light" fractions are concentrate. To obtain concentrates with a mass fraction of Fe_{total} above 67%, it is necessary to maintain the conditions for the formation of different flows on the surface of the spiral, which was achieved by changing the position of the cut-off.

The granulometric composition of the screw separator fractions obtained on the spiral separator is shown in Fig. 2.

Analysis of the data shows that the "heavy" fraction contains 80.98% of the -0.04 mm class. This indicates a significant fineness of particles, which is typical for heavy minerals that are well crushed and contain ore components. The "medium" fraction has a slightly lower content of -0.04 mm class - 78.59%, which also indicates the predominance of fine material, but with a lower proportion of fine particles than in the heavy fraction. The "light" fraction is characterised by the highest content of the -0.04 mm class - 95.47%. This means that it contains re-ground magnetite, which has a much lower specific gravity than larger particles and is therefore concentrated in this fraction.

Table 4 – Results of technological tests of the fine screening product of magnetite magnetic product under the conditions of Central GOK (Mining and Processing Plant) (запятые)

No. of items	Name of fractions (products)	Mass fraction of solid in the pulp, %.	Yield, %.	Mass fraction of Fe_{total}, %.	Mass fraction of SiO_2, %.	Clay content - 0.040 mm, %.
1	heavy	56.8	8.1	65.4	6.8	72.3
	average	41.0	38	45	22.9	66.0
	light	9.3	53.9	66.9	11.8	80.3
	Outgoing product	25.00	100	58.46	15.61	74.2
2	heavy	57.6	11.2	68.4	5.9	70.6
	average	46.6	36.1	46.5	25.2	64.7
	light	8.5	52.7	67.8	11.7	80.5
	Outgoing product	25.00	100	60.18	15.92	73.7
3	heavy	47.0	12.8	68.5	4.4	77.5
	average	40.4	25	41.9	34.6	50.4
	light	6.5	62.2	67.9	9	89.8
	Outgoing product	25.00	100	61.48	14.81	79.8
4	heavy	60.5	17.1	63.9	9.4	70.3
	average	51.6	35.9	47.1	31.1	56.6
	light	5.05	47	67.5	12.1	83.0
	Outgoing product	25.00	100	59.56	18.46	71.3
5	heavy	63.1	13.8	63.6	9.5	67.5
	average	39.9	25.4	50.7	23	68.6
	light	10.5	60.8	66.1	12.1	71.3
	Outgoing product	25.00	100	61.84	14.51	70.1

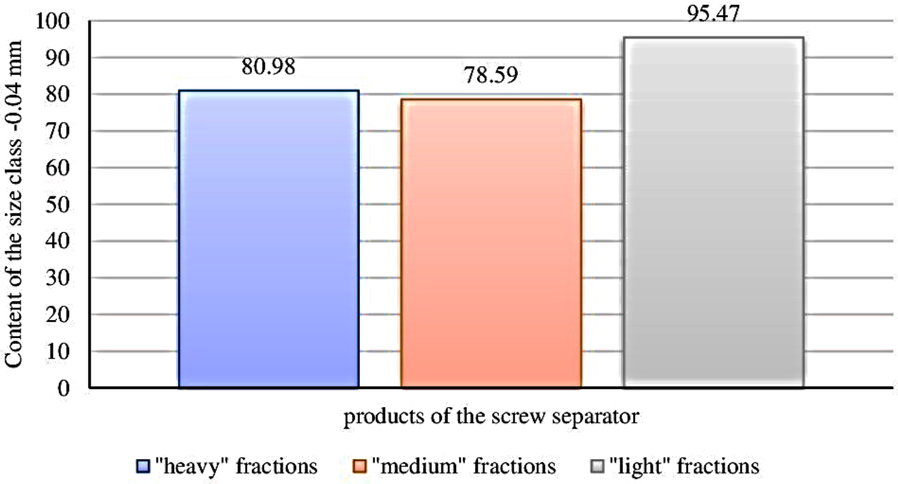

Figure 2 – Distribution of the -0.04 mm class - "heavy", "medium", "light" fractions of the combined products of the screw separator

The gravity separation product, which is represented by rich and poor magnetite, hematite and quartz growths and ore-free grains in the amount of 40.4–46.6% of the operation, is recommended to be sent for further grinding to the main beneficiation cycle to open the growths and further magnetic beneficiation. The ability to recover up to 60% of the finished product makes it possible to significantly reduce the amount of more complex product that is sent for further grinding. The volume of grinding is sufficient to open up minerals and improve the quality of the product. Based on the results of the research, it is possible to recommend the installation of a screw separator for gravity beneficiation of the oversize product.

The analysis of the results of the studies showed that, in addition to the position of the cut-off, the formation of flows in spiral separators is influenced by the viscosity coefficient of the medium [17]. Work [15] shows that a decrease in the viscosity of the suspension leads to a significant increase in the pulp flow, and this, accordingly, affects the separation of mineral particles in a spiral separator. To confirm this conclusion, we conducted full-scale experiments at different flow rates through the oversize product with a mass fraction of solid of 40% and three temperature conditions – 5 °C, 30 °C, 50 ° C. The results of the studies are presented in Table 5.

Table 5 – Technological indicators of gravity beneficiation of magnetite pulp with a size of 80% of class - 0.033 mm at different temperatures (запятые)

Temperature	Material	Separation rates, %.		
		Yield of the product	Mass fraction of Fe_{total}	Fe_{total} recovery
5 °C	Concentrate	61.87	63.48	62.54
	Light fraction	38.13	61.70	37.46
	The initial product	100	62.8	100
28–30 °C	Concentrate	68.38	68.03	74.08
	Light fraction	31.62	51.49	25.92
	The initial product	100	62.8	100
50 °C	Concentrate	63.00	66.5	66.71
	Light fraction	37.00	56.50	33.29
	Final product	100	62.8	100

The obtained practical results (Table 5) confirm the statement that the viscosity of the pulp affects its velocity.

A significant effect of temperature on the viscosity and, accordingly, gravity concentration on screw separators of magnetite pulp of different sizes was found.

As follows from the analysis of the research results, the maximum iron recovery from the concentrate is observed at a temperature of 28–30 °C. At a temperature of 5°C, the mass fraction and recovery of iron in the concentrate are minimal.

Thus, when the temperature decreases from 28–30 °C to 5 °C, the viscosity of the pulp with a size of 80% class - 0.033 mm increases by 1.96 times. At the same time, the recovery of total iron in the concentrate decreases by 11.54% - from 74.08% to 62.54% with a simultaneous deterioration in the quality of the concentrate - the mass fraction of total iron in the concentrate decreases from 68.03% to 63.48%.

When the temperature is increased from 28–30 °C to 50 °C, the viscosity of the pulp with a size of 80% of the class - 0.033 mm decreases by 1.44 times. At the same time, the recovery of total iron in the concentrate decreases by 7.37% - from 74.08% to 66.71% with a simultaneous deterioration in the quality of the concentrate - the mass fraction of total iron in the concentrate decreases from 68.03% to 66.5%.

In order to obtain magnetite concentrates with a mass fraction of SiO_2 of less than 2%, the separation of the undersize product of fine screening of magnetite magnetic industrial product was studied in the conditions of PJSC "Central Mining and Processing Plant in a spiral separator

The granulometric composition of the undersize product and the distribution of the mass fraction of Fe_{total}, SiO_2 by size class with accumulation are shown in Table 6.

Table 6 – Granulometric composition of the undersize product and distribution of the mass fraction of Fe_{total}, SiO_2 by size class

Size class, mm	Output, %	Mass fraction, %		Yield by "-", %	Mass fraction with accumulation in "-", %	
		Fe_{total}	SiO_2		Fe_{total}	SiO_2
+0.05	5.48	60.97	13.5	100.00	70.77	2.29
-0.05+0.04	7.28	70.83	2.4	94.52	71.34	1.64
-0.04+0.032	13.14	70.80	2.3	87.24	71.39	1.58
-0.032+0	74.1	71.49	1.45	74.10	71.49	1.45
Total	100	70.77	2.29			

The mineralogical analysis of the material of the initial samples of the undersize product for research showed the following:

The particle size fraction of +0.05 mm is mainly composed of magnetite (82.3 vol%) and quartz (11.9 vol%). Other minerals include ore minerals (hematite, pyrite, goethite and hydrogite - 2.2 vol%) and non-metallic minerals (cummingtonite, ribekite, calcite, aegirine, biotite - 3.6%).

The particle size fraction of -0.05+0.04 mm consists of 95.4% magnetite and 2.1% quartz. The amount of other ore and non-metallic minerals in it is 1.3 vol% and 1.2 vol%, respectively.

The particle size fraction of -0.04+0.032 mm contains even more magnetite (96.4 vol%) and less quartz (1.8 vol%) compared to the previous ones. The amount of other ore and non-metallic minerals is 1.1 vol% and 0.7 vol%, respectively.

The particle size fraction of -0.032 mm differs from other classes by the highest content of magnetite - 97.9%. The amount of quartz is 1.1 vol%; the content of other ore and non-metallic minerals is 0.6 vol% and 0.4 vol%, respectively.

According to the analysis the material of the undersize product sample contains (vol%): magnetite - 96.6; quartz - 1.9; other ore - 0.8 and other non-metallic - 0.7. The degree of disclosure (%) of magnetite is 97.8; quartz - 29.5; other ore - 32.5; other non-metallic - 24.9. Growths are present in all size classes. For quartz and other ore and non-metallic minerals, there is a tendency to increase the number of "rich" growths compared to "poor" ones in the direction from coarse to fine size classes. For magnetite, the opposite trend is observed. The results of separation of the undersize product into three fractions at different angles of inclination of the spiral are given in Tables 7, 8.

Table 7 – Test results in the conditions of the CGPF of Central GOK (Mining and Processing Plant)

Density, g/l	Separator feed			Heavy product			Medium product			Light product		
	Fe_{total}	Fe_{mag}	SiO_2	Fe_{total}	Fe_{mag}	SiO_2	Fe_{total}	Fe_{mag}	SiO_2	Fe_{total}	Fe_{mag}	SiO_2
Spiral separator, inclination angle 15$^{(0)}$ $^{(}$flat) demagnetisation coil in operation												
1270	69.5	67.0	3.48	70.67	68.4	2.29	69.3	66.4	3.68	69.2	66.9	3.67
Spiral separator, inclination angle 20 $^{\circ}$(flat) demagnetisation coil in operation												
1270	69.43	66.8	3.74	70.77	68.0	2.14	69.2	66.4	3.62	68.81	67.0	
1320	69.1	66.8	4.15	68.75	66.4	4.36	68.6	66.0	4.41	69.36	67.2	3.54

Table 8 – Results of enrichment of the undersize product of fine screening on a spiral separator

No. of items	Enrichment product	Output, %	Mass fraction, %		Recovery, %	
			Fe_{total}	SiO_2	Fe_{total}	SiO_2
1	Output product	100	69.50	3.48	100	100
	Heavy fraction	14.66	70.67	2.29	14.91	9.66
	Light fraction	85.34	69.3	3.68	85.09	90.34
2	Output product	100	69.43	3.74	100	100
	Heavy fraction	14.67	70.77	2.14	14.95	8.40
	Light fraction	85.33	69.2	4.01	85.05	91.60

The results of studies on a spiral separator showed the possibility of reducing the mass fraction of SiO_2 in the concentrate from 3.48–3.74% to 2.29–2.14% at a spiral angle of 15 degrees and 20 degrees, respectively. To study the possibility of obtaining concentrates with a mass fraction of SiO_2 of less than 2%. the heavy fraction of the spiral separator was sieved with a grain size of 0.032 mm. The screening products were sent for chemical and mineralogical analysis. Sieving results are presented in Table 9.

Table 9 – Granulometric composition of heavy fractions of the separation of the undersize product of fine screening of sample 1 on spiral separators (запятые)

No. of items	Size class, mm	Product yield, %	Mass fraction of Fe_{total}, %	Mass fraction of SiO_2, %
1	+0.032	23.64	68.99	4.6
	-0.032+0	76.36	71.19	1.58
	Total	100	70.67	2.29
2	+0.032	55.4	70.38	2.5
	-0.032+0	44.6	71.27	1.7
	Total	100	70.77	2.14

The results of mineralogical analysis showed that in general, the material of the spiral separator concentrate contains (by volume): magnetite - almost 96.0; approximately the same amount of quartz and other ore minerals (hematite, pyrite, goethite, hydrogethite), respectively, 1.5 and 1.4; and other non-metallic minerals (calcite, cummingtonite, ribekite, biotite, aegirine) - 0.9.

The size class of +0.032 mm contains about 91 vol% of magnetite in the form of "free" fragments and about 3.5% in the form of growths. among which the poor ones are five times more abundant than the rich ones, and 2% of quartz. Among other ore minerals, the material of the +0.032 mm class contains hematite, pyrite and iron hydroxides.

The -0.032 mm size class contains about 97 vol% of magnetite in the form of "free" fragments and about 1.5% in the form of growths, among which the poor ones predominate, with 0.7% of quartz and 0.8% of other ore minerals. They are mainly represented by magnetite growths. Rich quartz nodules predominate among them.

Thus, the results of studies on a spiral separator proved the possibility of obtaining concentrates with a mass fraction of SiO_2 of less than 2%, provided that the heavy fraction is separated by a grain size of 0.032 mm.

4. Results and discussion

As a result of our research, we recommend three areas for the use of spiral separation of magnetite products in iron ore dressing technologies.

The first is the extraction of a marketable magnetite concentrate with a mass fraction of total iron exceeding 68% after the second grinding stage, which will reduce the load on the mills by an average of 10–12% of the second stage and avoid further regrinding of magnetite.

The second is the production of a marketable magnetite concentrate with a mass fraction of iron exceeding 67% from the oversize products of fine screening of magnetite magnetic industrial product.

In this case, the technological scheme provides for the separation of the oversize product using a spiral separator into three fractions. The "heavy" and "light" fractions are marketable concentrate. and the "industrial product" is returned to the main technological scheme of magnetite ore beneficiation for the second stage of grinding. When testing this scheme in industrial conditions, a commercial concentrate with a mass fraction of total iron of 63.45% was obtained from the oversize product with a mass fraction of total iron of 67.5%. Losses of total iron with tailings amounted to 5.93%.

The third is the production of magnetite concentrates with a mass fraction of SiO_2 of less than 2%. In this case, the technological scheme with the use of a spiral separator should include the following technological operations: classification of the undersize product in hydrocyclones and further concentration of sands on a spiral separator.

Testing of this scheme in industrial conditions showed that the initial product for spiral separation is hydrocyclone sands with a mass fraction of iron of 70.09% and quartz of 2.94%. After separation in a spiral separator, a heavy fraction of 12.42% was obtained, which is a high-quality concentrate, as it has a mass fraction of total iron of 71% and SiO_2 of 1.8%. The light fraction after separation has a mass fraction of total iron (Fe_{total} = 69.87%), but the mass fraction of SiO_2 is 3.22%. After combining with the hydrocyclone drain, a concentrate of 87.58% was obtained with a mass fraction of Fe_{total} - 70.14% and SiO_2 - 2.71%.

These recommendations are in line with the findings of other researchers. For example, Richards [4] reports that gravity separation of minerals in spiral separators is effective for beneficiation of various types of ore with a material size of less than 0.1 mm, provided that the input products are divided into "narrow" size fractions.

Paper [13] notes the peculiarity of flow formation in a spiral separator. Our research has confirmed this position and proved that the position of the cut-off for the formation of a concentrate flow should be at the level of 95 mm.

Paper [8] presents data obtained at two iron ore processing plants, showing that the recovery curves of iron carrier minerals, silica and alumina in the spirals of the main, pre-treatment and control separation are similar and demonstrate a systematic decrease in the recovery of large particles. The results of the analysis of these data also show similarities in the size distribution of iron, silica and alumina carriers in the feedstock of the concentrator spiral circuit and an unusual shape of the recovery curves of these minerals by size on different spirals. This is consistent with the developed recommendations for removing the light fraction in a spiral separator as a concentrate.

Thus, the studies conducted confirm the effectiveness of using a spiral gravity separator for the beneficiation of magnetite ores, and further work can be focused on a more detailed analysis of the impact of spiral separator parameters on the quality of the final product.

5. Conclusions

As a result of the studies carried out under industrial conditions, using spiral gravity separation from sands of the second classification stage with a mass fraction of Fe_{total} of 55.4%, a commercial concentrate of 12.8% was obtained with a yield of Fe_{total} over 68% at a cut-off position of 95 mm.

It was established that the separation of products on a spiral separator should be carried out in narrow size fractions.

As a result of separation of oversize products with a mass fraction of Fe_{total} of 58.46–61.48% in spiral separators under industrial conditions, three products were obtained: heavy, medium, and light fractions. The heavy and light fractions are concentrates with a mass fraction of Fe_{total} greater than 67%. The light fraction has the highest content of regrind magnetite.

The possibility of obtaining commercial high-quality magnetite concentrates with a mass fraction of SiO_2 of less than 2% without the use of flotation from undersize products of fine screening of magnetite concentrate was proved.

As a result of experimental studies, it was found that the pulp viscosity and its temperature have a significant impact on the process of beneficiation of magnetite ore pulp in a spiral gravity separator. It was found that when the temperature decreases from 28–30 °C to 5 °C, the viscosity of the pulp with a size of 80% of the -0.033 mm class increases by 1.96 times. At the same time, the recovery of total iron in the concentrate decreases by 11.54% - from 74.08% to 62.54% with a simultaneous deterioration in the quality of the concentrate - the mass fraction of total iron in the concentrate decreases from 68.03% to 63.48%.

The practical significance of the research results is that the use of a spiral gravity separator in the beneficiation of magnetite ores can reduce the grinding load by 10–12% and produce concentrates with a mass fraction of Fe_{total} of more than 67% and SiO_2 of less than 2%.

In the future, it is necessary to model and optimise the process of extracting fines in spiral streams of small thickness, which will reduce the loss of a useful component with waste and improve the quality of magnetite concentrates, namely, reduce the mass fraction of SiO_2 in them. Based on the verification of the developed model, it is possible to develop a scheme for the spiral gravity concentration of iron ore.

Conflict of interest

Authors state no conflict of interest.

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ПРАКТИКА ВИКОРИСТАННЯ СПІРАЛЬНИХ СЕПАРАТОРІВ ПРИ ЗБАГАЧЕННІ МАГНЕТИТОВИХ РУД

Олійник Т., Румницький Д., Скляр Л.

Анотація. Мета та завдання. Розробка рекомендацій щодо застосування гравітаційної спіральної сепарації в технологічних схемах збагачення магнетитових кварцитів на підставі вивчення основних факторів, що впливають на роботу спірального сепаратора.

Методи дослідження. В дослідженнях були застосовані: гранулометричний, хімічний, мінералогічний та технологічний аналізи продуктів збагачення магнетитових кварцитів в спіральному сепараторі СВШ-2-1000, експерименти з визначення основних факторів що впливають на процес.

Основні результати. Показано можливість отримання з пісків II стадії класифікації з масовою часткою $Fe_{заг}$ 55,4% концентрату 12,8% за виходом з масовою часткою $Fe_{заг}$ більше 68% при положенні відсікача на рівні 95 мм. Встановлено, що розділення продуктів на спіральному сепараторі необхідно проводити на вузьких за крупністю фракціях. Показано, що сепарація надрешітних продуктів з масовою часткою $Fe_{заг}$ 58,46–61,48% у спіральних сепараторах дозволяє отримати три продукти – важку, середню та легку фракцію. При цьому продукти - важка та легка фракція є концентратом з масовою часткою $Fe_{заг}$ більше 67%. Для легкої фракції встановлено найвищий вміст переподрібненого магнетиту. Встановлено, що в’язкість пульпи та її температура має вагомий вплив на процес збагачення рудної магнетитової пульпи у спіральному гравітаційному сепараторі. Досліджено вплив температури на ефективність вилучення заліза з концентрату. Встановлено, що максимальне вилучення заліза (74,08%) та його найвища масова частка (68,03%) в концентраті досягаються при температурі 28–30 °C.

Значне зниження температури до 5 °C призводить до істотного погіршення показників. Зокрема, в'язкість пульпи (з 80% частинок розміром менше 0,033 мм) зростає майже вдвічі (у 1,96 рази). Це спричиняє зменшення вилучення заліза на 11,54% (до 62,54%) та зниження його масової частки в концентраті до 63,48%.

Підвищення температури до 50 °C також негативно впливає на процес, хоча й менш виражено. В'язкість пульпи зменшується в 1,44 рази, але вилучення заліза знижується на 7,37% (до 66,71%), а його масова частка в концентраті - до 66,5%.

Таким чином, результати дослідження вказують на вузький температурний діапазон (28–30 °C), який є критично важливим для забезпечення максимального вилучення та якості залізного концентрату.

Доведена можливість отримання концентратів з масовою часткою SiO_2 менш 2%.

Висновки та практичне значення. Рекомендовано три напрями використання спіральної сепарації магнетитових продуктів у технологіях збагачення залізних руд: після II стадії подрібнення, селективне збагачення надрешітного та підрешітного продуктів тонкого грохочення магнетитового концентрату.

Практичне значення полягає у тому, що використання спірального гравітаційного сепаратора при збагаченні магнетитових руд дозволяє знизити навантаження на подрібнення на 10–12% та отримати концентрати з масовою часткою $Fe_{заг}$ більше 67% та SiO_2 менш 2%.

Ключові слова: спіральний сепаратор, надрешітний, підрешітний, в’язкість суспензії