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THE ENERGY SAVING TECHNOLOGY OF BENEFICIATION OF IRON ORE

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The qualitative and quantitative evaluation of liberation of economic minerals and the level of contamination of the process products by waste components were carried out for the purpose of analysing the technology level and forecast its development directions.

Concentration of intergrown particles into a separate product for the purpose of subsequent more efficient and selective liberation is one of the reserves for energy saving in the grinding operations.

A pilot selective separator was tested in re-cleaning operations to compare with a standard (conventional) separator. The tests that showed, that a separator with a pulsed magnetic field is an efficient device that allows the realization of an intensive concentration of a large amount of unliberated magnetic particles – consisting of two phases – value minerals and gangue, into several products.

Keywords: Energy consumption; Locked particles; Magnetic separation; Drum magnetic separation; Magnetic ore

INTRODUCTION

Mining operations affect considerably the energy and water balance and ecology of the country. Processes of grinding and concentration of magnetite ore, which are widely applied worldwide for the production of iron concentrates, are energy-, water-, and material-wasteful.

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The energy consumption for ore grinding represents 35 to 72% of the total cost [1]. Specific energy consumption of various mechanical disintegration stages is as follows:

Coarse crushing – 0.3–0.5%;
Middling crushing – 0.8–1.2%;
Coarse and fine grinding – 18–20%;
Ultrafine grinding – 50% and more [2].

Distribution of power consumption among the process needs is illustrated in Fig. 1.

According to the data of numerous publications [3–6], disadvantages of presently used techniques (high energy and water consumption and the decreasing grade of the iron ore concentrates) result from low selectivity of the separating process such as: magnetic separation, classification by hydrocyclones and fine screening. Products of these processes are thus contaminated by unliberated intergrown particles, and all attempts to regrind them without selection are inefficient, and only complicate the ore processing flowsheet.

These problems are experienced also in the magnetite ore beneficiation at the Kostomuksha Mine Combine (joint stock "Karelsky Okatysh") (Fig. 2).

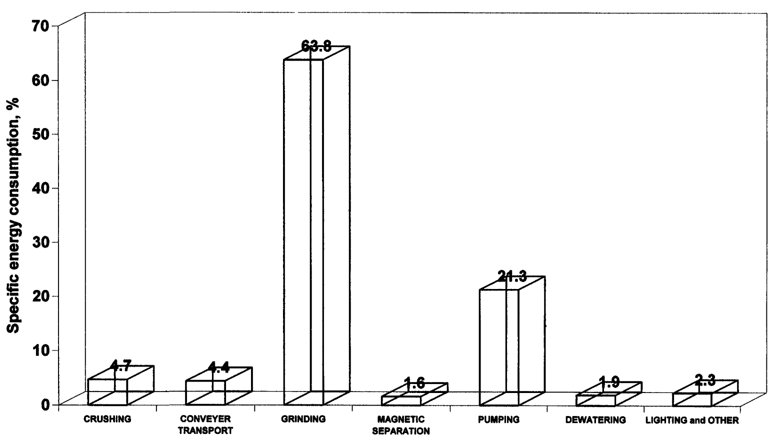

FIGURE 1 Distribution of power consumption among processing needs.

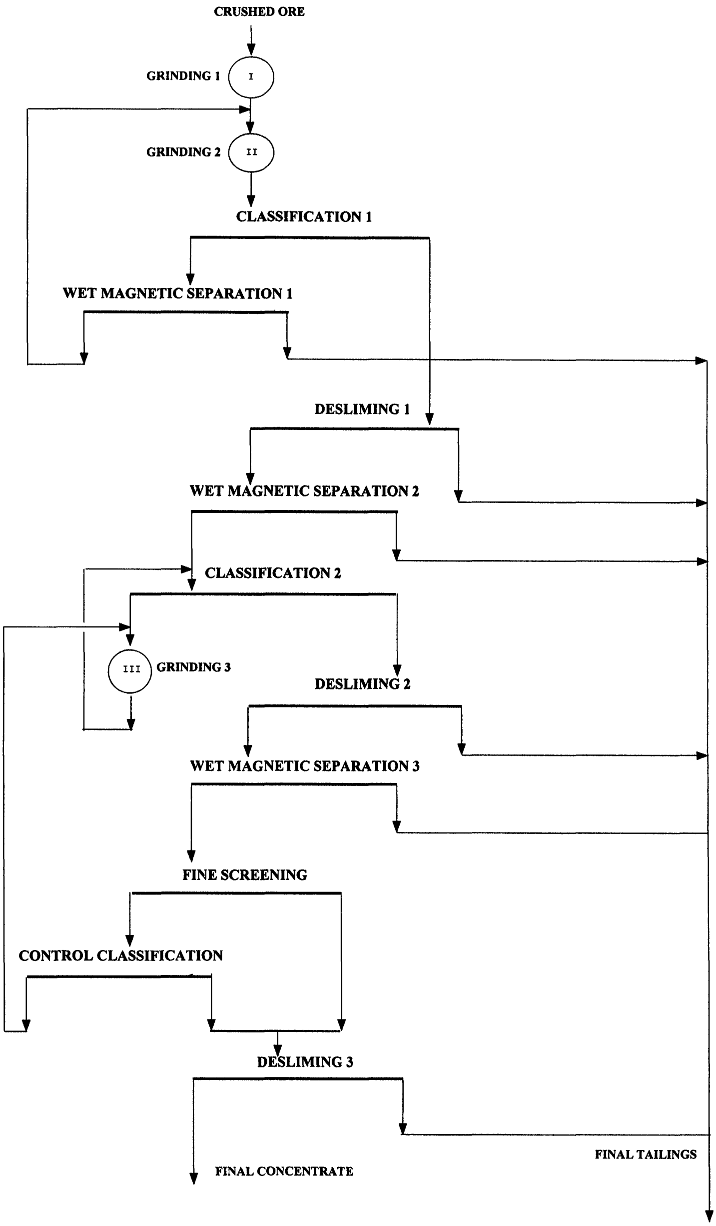

FIGURE 2 Process flowsheet of iron ore beneficiation.

ANALYSIS OF THE TECHNOLOGY LEVEL

The qualitative and quantitative evaluation of the liberation of the economic minerals and the level contamination of the process products by waste components were carried out for the purpose of analyzing the technology level and forecasting its development directions. Most of the process middling products were investigated by Bikbov [7].

The magnetic-fraction tests were carried out using the alternating field separator which produced a wide spectrum of fractions depending on their magnetic properties.

The result of analysis of concentrates of stages II and III of wet magnetic separation (WMS), each of them including primary (main) separation and re-cleaning operations (one re-cleaning in stage II of wet magnetic separation, two re-cleanings in stage III) are given in Table 1.

Total values in Table 1 were obtained by summarizing the partial values of appropriate fractions (including the richer ones), as cumulative values averaged by mass.

It is well known that functions of these operations differ: the primary magnetic separation is used to reject the tailings, while the re-cleaning operations are used to maximise the iron concentration in the magnetic product by means of concentrating intergrown particles into a separate product and eliminating the remaining gangue material (tailings).

To estimate correctly the completeness of agreement of the aforementioned separation operations with their functional purposes is of great importance when analysing the technological process. It is possible to do this by assessing the results of fraction analysis for the products obtained using the present flowsheets and comparing the achieved and potential results.

It can be seen from Fig. 2 that the present concentration technology does not have a single operation that would allow concentration of intergrown particles into a separate product for the purpose of subsequent more efficient and selective disintegration.

All the process operations in the flowsheet, including re-cleaning magnetic separation, are based on rejecting tailings only, whilst the magnetic products, being mixtures of liberated valuable minerals and

TABLE 1 Magnetic-fractions analysis results of magnetite concentrates from II and III stages of wet magnetic separation (WMS)

Fractions	Particle size, nm	II stage WMS, one recleaning step						III stage WMS, recleaning in two steps					
				Content, %						Content, %			
		Yield, %		Fe		SiO_2		Yield, %		Fe		SiO_2	
		Partial	Total	Partial	Total	Partial	Total	Partial	Total	Partial	Total	Partial	Total
Strongly-magnetic	−0.045	4.24	4.24	68.74	68.74			20.21	20.21	70.32	70.32	1.69	1.69
		10.34	14.58	68.54	68.69			6.91	27.12	69.98	70.14	2.02	1.77
		3.27	17.85	68.14	68.51			10.83	37.95	69.98	70.1	2.4	1.95
								12.14	50.09	68.24	69.65	3.71	2.38
	+0.045	21.56	39.41	67.64	68.03			6.43	56.52	68.84	69.56	3.63	2.52
		6.26	45.57	67.5	67.96		5.32	9.37	66.09	67.04	69.2	5.34	2.93
								6.72	72.81	65.71	68.87	7.09	3.31
	average		**45.57**		**67.96**		**5.32**		**72.81**		**68.87**		**3.31**
Middlings (intergrown particles)	−0.045	4.68	50.35	64.76	67.66	4.50		12.04	84.85	60.69	67.70	13.08	4.70
		4.23	54.58	61.48	66.65	12.50							
	+0.045	17.68	72.26	59.40	64.88	15.20		15.15		47.53			
		16.84	89.10	36.45	59.50	45.77							
	average	**43.43**		**50.60**		**25.73**		**27.19**		**53.36**		**30.72**	
Tailings		10.90		11.50		72.30							
Initial sample			100		54.80		14.39		100		64.45		8.64

still unliberated intergrown particles circulate from one stage to another, reducing the efficiency of the process.

In the meantime, it follows from Table 1, that the concentrates of stages II and III of magnetic separation, even with coarse grinding less than 0.045 mm, up to 26.76% and 50.10%, respectively already include large amounts of material – 45.57% and 80.0% respectively with total basic content of iron of 68.0% (achieved usually in a complete plant process at particle size 95.0% less than 0.45 mm), but are contaminated with unliberated intergrown particles.

Most of the middling products were assessed by the same method. Qualitative and quantitative evaluation of the degree of liberation of the mineral and the degree of contamination of the products of iron ore beneficiation is given in Table 2.

It can be seen from Table 2, that the final concentrate is also contaminated with intergrown particles by 10.45% by mass with the iron content of 50.2%. Elimination of these locked particles would allow to produce a high-grade product with iron content of 69.0 to 69.5% and silica content of 3.02%.

The hydrocyclone, underflow, directed into the stage III of the grinding contains 57.35 to 65.41% of the already liberated material with an iron content of more than 68.0%. This material is does not require further size reduction, and the concentration of intergrown particles to be comminuted is only 42.65 to 34.59% with the iron content of 46.0 to 38.5%.

Such a component of the hydrocyclone underflow increases the consumption of energy by a factor of two or more, and is characterized by the worsening of the conditions for disintegration of locked particles. It can be seen from the results of the magnetic-fraction analysis of the tertiary grinding stage discharge, containing 44.27% of unliberated locked particles with an iron content of 48.32%.

It is thus visible, that the present technology of iron ore beneficiation (Fig. 2) possesses numerous disadvantages that violate the main principle of beneficiation namely "do not over crush, do not over grind. Inefficiency of the technology also results in the concentrate grade, and the complication of a flowsheet by expensive auxiliary processing operations such as fine screening and control classification by hydrocyclones.

TABLE 2 Qualitative–quantitative evaluation of liberation degree of the ore mineral and contamination degree of the products in the operations of iron ore processing

Products of fraction-analysis	Iron content in the product investigated, %	Liberated magnetite particles		Contaminating components	
		Quantity, %	Iron content, %	Quantity, %	Iron content, %
Rod mill discharge	29.92			Rich	
				semi-grains – 7.21	62.23
				semi-grains – 69.83	35.45 (18.0–33.7)
				Tailings – 22.96	11.34
Ball mill 2 discharge	39.85	5.62	66.69	Rich	
				semi-grains – 5.62	61.80 (61.4–62.9)
				semi-grains – 94.38	32.85 (13.1–61.5)
Hydrocyclone 1 underflow	32.233	7.39	65.93	semi-grains – 58.16	41.40 (29.7–59.6)
				Tailings – 34.45	9.83
Desliming 1 underflow	40.80	30.20	65.82	semi-grains – 40.48	46.10 (23.2–56.9)
				Tailings – 29.32	7.75
Hydrocyclone 2 underflow	59.06	57.35	68.76	semi-grains – 42.65	46.00 (19.3–59.6)
Ball mill 3 discharge	59.22	55.73	67.87	semi-grains – 44.27	48.32 (15.2–60.9)
Desliming 2 underflow	62.83	74.13	68.53	semi-grains – 25.87	46.49 (20.7–60.1)
Screen overflow	63.52	67.32	69.2	semi-grains – 29.48	56.10 (55.1–61.5)
				Tailings – 3.20	12.38
Screen underflow	63.54	86.32	69.49	semi-grains – 13.38	55.30 (13.9–61.6)
Hydrocyclone 3 underflow	58.11	65.41	68.00	semi-grains – 34.59	38.51 (16.4–62.9)
Hydrocyclone 3 overflow	67.37	90.50	69.62	semi-grains – 9.5	45.86
Desliming 3 underflow (final concentrate)	67.92	89.55	69.99	semi-grains – 10.45	50.20 (18.3–60.6)

The main reason for these drawbacks is poor performance of the re-cleaning magnetic separation process and their unsuitability for a given objective such as selection of unliberated particles at each stage of magnetic separation so that they can be concentrated, then liberated more selectively and reconcentrated [7].

Analysis of existing technological flowsheets shows that similar disadvantages are common in the practice of the magnetite ore beneficiation worldwide [8].

Typical examples are: Lebedinsk, Stoilensk, Mihailovsk, Olenegorsk, Kostomuksha, Nizhniy-Tangil and Kachkanar mine complexes, Russia; Sokolovsk-Sorbaisk, Kazakhstan; Krivoy Rog and Poltavskiy plants, the Ukraine; Savage River; Australia; Adams, Sherman; Canada; Sicartsa, Mexico; Atlantic City, Minnesota, USA; Malmberget, Kiruna, Sweden.

The tasks of improving the process technology, reducing the energy and water consumption and upgrading the final concentrate, in magnetite ore beneficiation, are associated with the design and implementation of efficient magnetic separations for successful selection of locked particles and their effective regrinding and reconcentration.

SELECTIVE MAGNETIC SEPARATORS

These problems are not new; they have being discussed for the last 40 to 50 years. New types of re-cleaning separators were designed by many companies and institutes such as Eriez Magnetics (USA) Sala (Sweden), Roxon (Finland), Fisher (Switzerland), Mehanobrcherment (the Ukraine), Mehanobr, Uralmehanobr, Gipromashobogacshenie (Russia). However, progress achieved in this field has not seen so far, employed in world-wide beneficiation practice.

There are two ways to realize this energy-saving approach. For this purpose, a material flow to be re-ground should be reduced by removing either the already recovered, liberated magnetite grains from the flow or by removing locked particles for re-crush in a separate grinding circle.

In order to increase the concentration efficiency and reduce the process energy consumption it is necessary to increase the selectivity of magnetic separation after the second grinding stage. Magnetic separation should be accomplished firstly on conventional magnetic separators, and then on the re-cleaning one with improved selectivity.

When designing efficient re-cleaning separators for concentration of iron intergrain particles an application of alternating, pulse and another non-homogeneous magnetic fields is the most promising approach. Important conditions are high throughput and compatibility of the separators with the present plant technology.

Taking into account these common requirements, a re-cleaning magnetic separator with a pulse magnetic field was designed and constructed.

The test separator has a special magnetic system with additional rotating permanent magnets, compared with standard units. The rotating magnetic field fecilitates breakage of magnetic flocks. It is thus possible to produce a concentrate of a higher grade in the 2nd stage for further re-concentration in the 3rd stage. The middlings (intergrown particles) are returned for regrinding and recover either in stage 2 or in a specially arranged regrinding circuit in an additional mill.

THE TEST RESULTS

The test separator was tested in re-cleaning operations in order to compare it with a standard conventional separation. Drum diameters, tank-configuration types, specific feed rate (per meter of drum length) of the separators to be compared were similar.

The results of tests are given in Table 3.

The concentration efficiency is calculated as;

$$E = \frac{Y \times (\beta - \alpha) \times 72}{\alpha \times (72 - \alpha)},$$

where

Y is the concentrate yield, %; β is the iron content in the concentrate, %; α is the iron content in the feed, %.

It follows from Table 3 that the test separator (with shorter drum length) with a pulse magnetic field meets demands for the re-cleaning magnetic separation.

The following technological results have been achieved:

- high concentrating efficiency of 26.92 to 32.39% when re-cleaning the magnetite concentrate of different size (comparerd with concentration efficiency of the conventional separators – 4.62 to 13.99%, e.g. is 2.08 to 7.01 times higher);

TABLE 3 The results of comparative testing of the test separator with pulse magnetic field and standard separator

Deposit product size	Products	Separator with pulse magnetic field				Standard separator				Advance in iron content, %	Ratio $E_{pilot}/E_{standard}$
		Yield, %	Iron content, %	Recovery, %	Concentration efficiency, %	Yield, %	Iron content, %	Recovery, %	Concentration efficiency, %		
Estyninsk, spiral classificator overflow, 39% less 0.074 nm	Concentrate	88.22	62.46	92.98	26.92	98.64	58.93	99.76	5.85	3.53	3.53
	Middlings	11.78	35.30	7.02	–	–	–				
	Tailings	–	–	–		1.36	13.6	0.24			
	Feed	100.0	59.26	100.0		100.0	58.27	100.0			
Mangetitovaya, spiral classificator overflow, 44% less 0.074 nm	Concentrate	80.2	61.59	87.07	32.39	96.68	57.07	99.68	4.62	4.52	4.52
	Middlings	19.80	37.00	12.93		–	–				
	Tailings	–	–	–		1.32	13.97	0.33			
	Feed	100.0	62.92	100.0		100.0	56.50	100.0			
Estyuninsk, hydroclone overflow, 95% less 0.074 nm	Concentrate	83.29	67.53	85.93	29.15	98.31	65.90	99.68	13.99	13.99	2.08
	Middlings	16.71	55.18	14.07	–	–	–				
	Tailings	–	–	–		1.69	12.50	0.32			
	Feed	100.0	64.82	100.0		100.0	65.00	100.0			

- increased separation ability to concentrate the locked particles into several products (mass recovery of 11.78 to 19.80% with the iron content of 35.3 to 55.18%, whilst mass recovery of tailings rejected by the conventional separator is of 1.32 to 1.69% with the iron content of 12.5 to 13.97%);
- an increase in the iron concentrate quality at different size: of 61.59 to 67.53% of iron, compared to 57.07 and 65.9% with standard separator (what is 4.52 to 1.63 times as higher). This allows to increase the vector without significant cost increase particularly when the flowsheet is short, for instance with single- or double-stage or grinding.

The test separator with a pulse magnetic field with the drum length of 2.5 m drum diameter of 0.9 m was compared with conventional unit during the next series of test.

The separators were tested in stage II of the re-cleaning magnetic separations 3 at the Kostomuksha Mine Combine.

The results of the comparative tests are given in Table 4.

The concentration efficiency of the separator with pulse magnetic field was three times higher, than that of the conventional reports 11.16%, 3.78% respectively.

TABLE 4 The comparative tests results of standard and experimental separators in the second recleaning step of III stage of wet magnetic separation

Separator type	Products	Content of particle size 0.05 mm	Yield, %	Iron content, %	Recovery, %	Increase in iron content, %	Concentration efficiency,%
Conventional (standard)	Concentrate	79.50	99.46	63.22	99.93	0.30	3.76
	Middlings	–	–	–	–		
	Tailings	46.50	0.54	8.03	0.07		
	Feed	78.85	100	62.92	100		
Experimental test separator (test series 1)	Concentrate	80.00	97.37	63.83	98.75	0.91	11.16
	Middlings	54.24	2.63	29.24	1.25		
	Tailings	–	–	–	–		
	Feed	78.85	100	62.92	100		
Experimental test separator (test series 2)	Concentrate	75.00	95.93	65.88	97.50	1.06	15.73
	Middlings	55.10	4.07	39.84	2.50		
	Tailings	–	–	–	–		
	Feed	73.90	100	64.82	100		

Satisfactory recovery of locked middling particles was achieved in the pulse field separator (mass recovery of 2.63% with iron content of 29.24%);

There was no recovery of locked middling particles in the conventional separator, and only insignificant amount of tailings of 0.54% with iron content of 8.03% was rejected;

The increase of iron content into the concentrate in a single re-cleaning stage by the pulse field separator is 0.91% (compared with 0.3% achieved by the conventional separator.

The tests were conducted as a high feed pulp density within 45 to 50% by mass of solids.

Comparative tests of the two units of the separator with a pulse magnetic field and conventional reporter were carried out at a magnetic benefication plant with three stage ore grinding, to ensure their operating reliability.

The separators were tested at re-cleaning operations of magnetic separation at the third, fifth, and sixth stages of concentration.

The tests showed that the separation with a pulse magnetic field, under the same feed rate, as the conventional separator is one efficient device that allows intensive selection of a large amount of unliberated magnetic particles, consisting of two phases, namely the valuable mineral and the gangue, into several products.

In the third stage of separation the re-cleaning of the magnetic product by the test separator produced a middling fraction of 19.4 to 22.4% whilst the conventional unit rejected tailings of 7.7 to 8.0%.

In the fifth stage of separation the yield locked particles from the test separator was 11.7%, while from conventional unit the yield of tailings was 2.84%.

In the sixth stage of separation the yield of locked particles from the test separator was 21.1%, while from the conventional separator the yield of tailings was 4.0%.

All tests have indicated that the concentration efficiency of the test separator was 1.26 to 1.85 times higher than that of the conventional unit iron content of the concentrate was also higher.

For instance, in the sixth stage, where the thickening of the concentrate was carried out before filtration, the iron content of the final concentrate was carried was 0.65% higher, and the concentration efficiency was 1.43 times higher compared to the conventional reporter 0.79% and 14.55% respectively.

CONCLUSIONS

Long-term experience in the design and development of novel magnetic separators and their large scale testing in three beneficiation plants at different stages of magnetic products allowed the following conclusions to be drawn:

1. A novel drum-type magnetic separator with a pulse magnetic field is a highly efficient and productive re-cleaning device for wet concentration of the unliberated particles of magnetite and gangue at all stages of the iron ore beneficiation technology.
2. Within the framework of the existing practice of mineral beneficiation new re-cleaning separator with a pulse magnetic fields has a potential to introduce a new energy-saving technology of beneficiation of the magnetite ore by step-wise circulation of locked particles, subsequent selective liberation and then their reconcentration. The amount of the material to be ground in the final stages is thus reduced by 50%. This would thus allow to shut down one part of four ball mills in two adjacent circuits. The electric energy-saving for the two circuits will thus be:

   $$2000 \times 7300 = 14\,600\,000\,\text{kWh},$$

   where 2000 kW is the electric power of ball mill drive; and 7300 h is the annual operational time of the plant.

   Consequently, the energy saving in 12 circuits will be 87 600 000 kWh per annum.
3. The separators with a pulse magnetic field can be used in various applications in intermediate stages. The most promising direction of development of both the process technology and equipment is the step-wise selection of coarse-grained concentrates, with the purpose of significant improvement in the concentrate grade and energy consumption.

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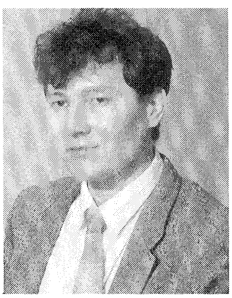
V. V. Karmazin

For biography see *Magn. Electr. Sep.* **8**(3) (1997), 159.



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