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MINERAL DRESSING

Evaluation of Additional Iron Recovery from Iron Ore Tailings

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Abstract—The article demonstrates feasibility of additional iron recovery from the secondary kind of mineral raw materials—dry magnetic separation tailings obtained at crushing and processing factories of Abaza and Irba and wet magnetic separation tailing produced at Abagur processing plant of Evrazruda. Dry centrifugal separation treatment of Abaza tailings –3 mm in size allowed 6.3% of middlings with Fe_{total} and Fe_{mag} contents of 40.4 and 32%, respectively; the result of dry magnetic separation of Irba tailings -5 mm in size is 7.7% middlings with the content of Fe_{total} and Fe_{mag} 39.9 and 30.8%. Wet magnetic separation of Abagur tailings -0.007 mm in size allowed recovery of 0.6 to 1.45% of magnetic fraction with Fe_{total} content of 53.3 and 51.6%, respectively, and Fe_{mag} content of 49.8 and 48.5%. Fitting of modern separators with the magnetic systems based on neodymium–ferrum–boron considerably improves output of the machines (in dry centrifugal separation circuit) and enhances the yield of magnetic product in wet separation of tailings.

Keywords: Tailings, dry centrifugal separation, wet separation, magnetic characteristics, neodymium–ferrum–boron.

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INTRODUCTION

Utilization of iron ore processing wastes is the many-years challenge raised owning to imperfections of early iron ore mining and processing techniques and machinery. Millions tons of tailings containing 1.5–10.0% of mass fraction of lost magnetite iron are discharged and stored at tailing dumps of mines and concentrators.

To date the mining and ore processing operations by Evrazruda known as the largest Siberian mineral processing company, have accumulated about 220 Mt iron ore wastes in tailing dumps of their concentrators. Thereto, three tailing dumps of Abagur concentrator contain above 90 Mt of concentrator slimes over an area of 385 ha. At Mundybash concentrator tailings reached 30 Mt [1].

The waste dumps accumulate more than 24 Mt of tailings at Sheregesh Mine, above 21 Mt at Abaza Mine, and more than 22 Mt at Tei Mine. Annually Evroruda plants discharge 3.5 Mm^3 of dry magnetic separation tailings and 1.6 Mm^3 of wet magnetic separation tailings [2].

Iron recovery is of the prime significance for iron ore operations, though the dump materials also contain nonferrous metals: manganese, copper, zinc, cobalt, etc. Moreover, the tailings can be utilized in production of construction materials, fertilizers and other marketable products.

The appraisal of perspectives for commercial utilization of secondary iron ore reserves at Siberian mines and concentrators is made in research reports of scientists working for Chinakal Institute of Mining [1, 3]. The commercial and ecological practicality to process old iron ore tailings has been verified by design calculations [2].

In general, publications on Siberian tailings are exclusively “diagnosing” in character for tailings of dry separation, in particular. Research works on additional recovery of iron from tailing materials are scarce, while publications on retreatment of wet separation tailings have not been found at all.

In view of the above, of practical importance is the search for efficient processes for retreatment of dump magnetite ores tailings including both dry magnetic separation as a “rough” retreatment at ore preparation plants and wet magnetic separation at large concentrators with the yield of a marketable product. Respective researches were undertaken by professionals of Abagur division, Evrazruda Co., in collaboration with researchers, Kirensky Institute of Physics, SB RAS.

Preparation of test specimens, measurements of magnetic characteristics were made at Kirensky Institute of Physics, the wet magnetic analysis was performed at Abagur concentrator and Kirensky Institute of Physics, semi-pilot dry centrifugal separation was tested at the concentrator. Chemical analysis of initial and test specimens was carried out at the Central Technological Laboratory, Evrazruda Co.

1. NATURE OF MAGNETITE LOSS IN WASTES

The commercial processing and laboratory examination reveal that iron loss in tailings is mainly in magnetite fraction less than 70 μm.

Mesh analysis of dump tailings from a number of Siberian concentrators (Abaza, Irba) confirmed that iron content in tailings tends to ascend with reduction in material size. For example, tailings of the Abakan concentrator contain 29.96% of Fe_{mag} in -0.07 mm fraction and only 2.4% of Fe_{mag} in 1.25–2.5 mm fraction, namely, the balance magnetite iron is essentially bound with fine fractions [4].

It is known that at magnetite grain size less than 60–70 μm the specific magnetic susceptibility χ, residual specific degree of magnetization σ_r notably come down, but coercive force H_c increases. These relationships for magnetite ores are described in [5, 6]. It is established that magnetic field of a “conventional” dry or wet drum magnetic separator with the magnetic barium ferrite system is not sufficient to recover fine magnetite grains into a concentrate and magnetite “goes away” with tailings and provides higher iron content in them. A number of methods to fight with this phenomenon, viz., increase in magnetic field strength, magnetic pretreatment of the feed: flocculation and deflocculation, etc. are developed and widely implemented.

2. TAILINGS RETREATMENT BY DRY SEPARATION TECHNIQUES

In 2007 the researchers of the Institute of Mining performed industrial tests on production of rough magnetite concentrates from Feofanovsky old magnetite dump tailings at crushing-and-concentrating plant at Sheregesh Mine. When processing two old waste specimens of 16–0 mm in size and grade: $Fe_{total} \sim 15.8$ and 16.3% and Fe_{mag} 9.1 and 10%, respectively, the rough concentrates of $Fe_{total} \sim 37\%$, $Fe_{mag} \sim 30\%$ were obtained at the yield $\gamma \sim 21$ and 27% at different separators. The calculated production cost of concentrates from wastes appeared 5 times lower that the factual production cost of the rough concentrate from the local crude ore [3].

Kirensky Institute of Physics and Abagur concentrator implemented pilot dry centrifugal separation to retreat tailings. The process known since 1960s, was not popular in practice of magnetic separation [7].

In drum separators magnetic field changes its direction versus frequency at a certain point in the drum rotating relative to opposite-sign stationary poles:

$$f = \frac{v}{2S} = \frac{\pi R n}{60 S},$$

where v is velocity of drum surface rotation, m/s; S is a step of magnetic system poles, m; R is drum radius, m; n is number of drum rotation, rpm.

Given that drum rotation velocity is 1–2 m/s and a step of the magnetic system poles is equal to 15–0.2 m, the frequency of variations in the magnetic field direction is 4–8 Hz. Such low frequency induce reorientation of magnetic bunches consisting of ore grains, aggregates, and gangue particles. At high magnetic field frequency, namely, at a high-speed separator mode “bunches” are distorted completely and pure ore grains separate from aggregates and gangue bunches.

In a magnetic drum separator for dry separation the high frequency of variations in magnetic field direction is gained at the expense of increased drum rotation velocity and reduced steps of poles, namely, the magnetic system has appreciable about 230° acceptance angle of the drum and greater number (about 20) of radial alternating polarity poles.

The dry centrifugal separation of fine-ground material (90% of less than 0.074 mm fraction) enabled to yield concentrates of up to 70% iron grade [8]. In [9] it is set forth that the dry centrifugal magnetic separation provides higher results as compared to other known magnetic treatment processes.

The tests were performed on Abakan concentrator tailings of less than 3 mm in size and Irba concentrator tailings of less than 5 mm in size at PBSTs 63/50 semi-commercial dry centrifugal separator with 50 mm pole step and magnetic field intensity on drum surface $H = 103.2$ kA/m. Separation was realized at two drum rotation frequencies: 90 and 120 rpm for Abaza material and 66 and 100 rpm for Irba specimen.

Separation and chemical analysis data are summarized in Table 1: 6.3% magnetite product of 40.4% iron grade, equivalent to the rough concentrate grade at a number of iron ore plants was produced at 122 rpm drum rotation frequency [10].

Retreatment of Irba tailings at 66 rpm drum rotation frequency yields 9.4% additional recovery of intermediate product of 35.6% iron grade. The secondary retreatment of this product at higher drum rotation (100 rpm) improves iron content up to 39.9% with 7.7% yield relative to the initial mass, but iron loss at more speedy separation mode is notably greater [11].

To conclude, the dry centrifugal separation is an efficient process for additional iron extraction from dry separation tailings.

Table 1. Centrifugal separation of dry separation tailings

Initial feed	Product	Yield, %	Content, %		Drum rotation frequency, rpm
			Fe_{total}	Fe_{mag}	
Abaza tailings	Magnetic	7.4	36.4	26.9	90
	Nonmagnetic	92.6	12.0	0.7	
	Magnetic	6.3	40.4	32.0	122
	Nonmagnetic	93.7	12.0	0.7	
	Initial	100.0	13.8	2.5	
Irby tailings	Magnetic	9.4	35.6	25.5	66
	Nonmagnetic	90.6	11.3	0.6	
	Initial	100.0	13.6	3.0	
	Magnetic	81.9	39.9	30.8	100
	Nonmagnetic	18.1	16.2	8.0	
	Initial	100.0	35.6	25.5	

Table 2. Magnetic analysis of Abagur tailings

Sample	Size fraction, mm	Product	Yield, %	Content, %	
				Fe_{total}	Fe_{mag}
Tailings, section 1	$-1+0.2$	Magnetic	1.9	16.15	12.82
		Nonmagnetic	98.1	6.91	0.63
		Initial	100	7.22	0.87
	$-0.07+0$	Magnetic	0.56	53.3	49.85
		Nonmagnetic	99.31	9.34	0.29
		Initial	100	9.64	0.57
Tailings, section 2	$-1+0.2$	Magnetic	2.02	17.3	13.6
		Nonmagnetic	97.98	8.7	0.96
		Initial	100	9.05	1.23
	$-0.07+0$	Magnetic	1.45	51.61	48.46
		Nonmagnetic	98.55	10.17	0.31
		Initial	100	10.92	1.03

3. ADDITIONAL IRON RECOVERY BY WET MAGNETIC SEPARATION

At the wet magnetic treatment plants the state of the art is higher as compared to dry separation plants at rough processing stages, as a consequence, magnetite iron loss in tailings is lower. According to Abagur concentrator data the content of magnetite iron in dump tailings was less than 1% in 2013. Reduction in iron loss by 0.1% saves 4.5 thousand t of ore per a year (two train sets). However old slimes accumulated in tailing dumps contain much greater amount of magnetite iron considering imperfections of earlier time technology and machinery. In 2013 professionals of Abagur concentrator and researchers of Kirensky Institute of Physics undertook tests on additional extraction of iron from dump tailings in sections 1 and 2. Magnetite iron content in tailings of section 2 appeared higher than that in section 1, as thickening and filtration of concentrates produced at both sections is performed in section 2, so section 2 discharged “richer” tailings to the dump.

In Table 2 the data are reported on the wet magnetic separation of two Abagur tailing fractions ($-1+0.2$ and $-0.07+0$ mm) in magnetic field $H = 175$ kA/m.

It is explicit that in $-0.07+0$ mm fraction containing $Fe_{mag} \sim 0.6\%$ (tailings of section 1) and $\sim 1\%$ (section 2) the recovery reaches from 0.6% (section 1) up to 1.45% (section 2) with the yield of 50% Fe_{mag}.concentrate.

The resultant concentrate grade characterizes magnetic parameters. The magnetic characteristics of Abagur specimens were measured at the automated vibrating magnetometer in magnetic fields up to 800 kA/m, measurement errors being $5 \cdot 10^{-8}$ A·m^2 for an electromagnetic moment, 40 A/m for field, and 0.1 mg for mass of test specimens. The procedure for measurement of magnetic properties at a vibrating magnetometer is described in [12].

Table 3 presents magnetic characteristics of the initial feed and the new−extracted magnetic product of $-0.07+0$ mm in size. For comparison the researchers report the parameters of the concentrate, whose tailings were subjected to additional magnetic fraction extraction. It is important to state that magnetic characteristics are close; the specific saturated magnetization σ_s of the fraction is a bit lower, coercive force H_c is higher thanks to higher content of “fine” particles.

Table 3. Magnetic characteristics of initial samples and magnetic products of separation ($-0.07+0$ mm fraction)

Sample	Product	σ_s	σ_r	σ_H	H_c	χ, 10^{-4} m^3/kg		
		A·m^2/kg			kA/m	H_{max}	χ_{max}	χ_H
Tailings, section 1	Initial	1.61	0.146	1.3	9.7	9.9	0.79	0.05
	Magnetic	57.3	6.33	50.4	5.18			
Tailings, section 2	Initial	1.51	0.129	1.23	8.8	10.8	0.83	0.05
	Magnetic	61.3	7.48	54.1	5.9			
Concentrate	Initial	75.4	7.71	68.3	4.02	9.0	1.31	0.07

The analysis of the data in Tables 2 and 3 reveals that the magnetic product produced from $-1+0.2$ mm tailing fraction contains less Fe_{mag} amount than the product produced from $-0.07+0$ mm tailing fraction, the difference is ~3.9 times in section 1 and ~3.6 times in section 2. The magnetic fraction yield in the coarser fraction is higher 2.7 times in section 1 and by 0.5% in section 2.

The specific saturated magnetization σ_s of the fine magnetic fraction is 4.2 times higher in section 1 and 4.9 times higher in section 2; σ_s of $-1+0.2$ mm fraction of the magnetic product is 13.6 A·m^2/kg in section 1 and 12.5 A·m^2/kg in section 2.

Values of the specific magnetic susceptibility χ (fields of the maximum and χ magnitude in $H=175$ kA/m) are also close, excluding maximum χ on the concentrate.

The measurement data on the magnetic characteristics of the magnetic fractions produced from the dump tailings confirmed high iron content in them. The proportionality is pointed out between the magnetite iron content and magnetic characteristics.

CONCLUSIONS

The tests were performed on additional extraction of iron from iron ore processing wastes, namely dump tailings of dry magnetic separation of Abakan and Irba ores and the wet separation tailings produced at Abagur concentrator.

Abakan tailings of $-3+0$ mm fraction, Irba tailings of $-5+0$ mm in size were subjected to the dry centrifugal separation with the yield of 6.3% intermediate, containing 40.4% Fe_{total} and 32% Fe_{mag} (for Abaza tailings) and 7.7% intermediate, containing 39.9% Fe_{total} and 30.8% Fe_{mag} (for Irba tailings).

The development of the dry magnetic drum separator specified with drum length of 200 cm, neodymium–iron–boron magnetic system, and high-speed engine, Mekhanobr-tekhnika, enabled appreciable increase in production capacity, higher grade of the extracted product, and a wider application scope.

The yield of the experimental wet magnetic separation of$-0.07+0$ mm tailing fraction (Abagur concentrator) is 0.56–1.45% of magnetic product containing up to 53% Fe_{total} and 50% Fe_{mag}. The tests were carried out in magnetic field of $H=175$ kA/m at PMB 90/250 separator, where the neodymium–iron–boron magnetic system was replaced for barium ferrite magnetic system.

The application of separators equipped with neodymium–iron–boron magnetic system through all the technological process could increase the magnetic product yield up to 2% in the wet separation of dump tailings. Additional treatment of dump tailings with both dry and wet separation processes is estimated as would–be profitable exactly at concentrators where tailings are produced.

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