Optimization of magnetic separation of hematite contained in the depressed product from vazante mine's zinc ore flotation

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Abstract

The mining industry has seen a significant decline in mill feed grade in recent years, resulting in an ongoing build-up of materials not recovered at the mineral processing plants whose economic value has not yet been determined. Tailings dams have been the preferred method of disposal of such materials. However, recent dam breach events and the growing demand for mineral goods have enhanced the appeal of a more effective use of mined materials to prevent tailings accumulation and reduce social and environmental impacts, in line with the environmental, social and governance (ESG) principles that most companies have adopted. Different techniques can be used to recover economically valuable minerals contained in such materials, among which magnetic separation stands out for reasons of cost, production capacity, and recent developments of new equipment and matrices for wet high-intensity magnetic separators. The outcome includes gains in capacity, grade, and recovery yield. This paper assessed the use of a matrix developed by the company Gaustec, called BigFlux, in the magnetic separation of depressed product from the flotation process at Nexa Resources's Vazante mine. Laboratory-scale magnetic separation tests were conducted using standard and an optimized matrix. For a 59% iron concentrate, the metallurgical recovery using such optimized matrix reached 72.6%, up 4% from the figure resulting from the use of the standard matrix, thus indicating that the use of the optimized matrix can improve the magnetite recovery process of the studied material.

Keywords: Magnetic separation; Zinc; Iron; Hematite; ESG.

Otimização da separação magnética da hematita contida no produto deprimido da flotação do minério de zinco da mina de vazante

Resumo

O setor mineral tem observado nos últimos anos quedas significativas dos teores de alimentação das usinas, o que leva a um acúmulo cada vez maior de materiais não recuperados no processo de beneficiamento, que ainda não tiveram a sua economicidade identificada. O método tradicional de disposição destes são as barragens. Com os acidentes recentes e a demanda cada vez maior por bens minerais, a busca pela maior utilização daquilo que é lavrado possui um apelo cada vez maior, pois assim se evita seu acúmulo, reduzindo impactos socioambientais, em linha com as ações de governança ambiental, social e corporativa (ESG) que as empresas têm buscado. A recuperação de minerais com valor econômico contido nestes fluxos é realizada por diferentes técnicas, dentre as quais a separação magnética se destaca, principalmente devido ao custo, capacidade de produção e ao desenvolvimento recente de novos equipamentos e diferentes matrizes para os separadores magnéticos a úmido de alta intensidade, que levam a ganhos de capacidade, teores e recuperação. O objetivo deste trabalho foi avaliar o uso de uma matriz denominada BigFlux, desenvolvida pela empresa Gaustec, na etapa de separação magnética do produto deprimido da flotação da mina de Vazante, da Nexa Resources. Ensaios de separação

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magnética em escala laboratorial foram realizados com as matrizes *standard* e a matriz otimizada. Os resultados indicam que, para um mesmo teor de concentrado de aproximadamente 59% de ferro, a recuperação metalúrgica com a matriz alternativa foi de 72,6%, resultado 4% superior ao obtido com a matriz standard, indicando assim que o uso da matriz otimizada pode trazer ganhos ao processo de recuperação da magnetita do material estudado.

Palavras-chave: Separação magnética; Zinco; Ferro; Hematita; ESG.

1 Introduction

The mining industry has seen a significant decline in mill feed grade in recent years, resulting in an ongoing build-up of materials not recovered at the mineral processing plants, whose economic value has not yet been determined [1,2]. Tailings dams have been the preferred method of disposal of such materials [3]. However, recent dam breach events in Brazil [4] and the growing demand for mineral goods [5] have enhanced the appeal of alternative tailings disposal methods and a more effective recovery of minerals contained in such tailings [3,6-15]. For both economic and socio-environmental reasons, the mining industry has sought to identify these materials' applicability by recovering more products in mineral processing plants. These practices are in line with environmental, social, and governance (ESG) approaches that companies have adopted [16]. In 2021, Brazil processed approximately 3.2 Mt of zinc ore at three mines in the states of Minas Gerais and Rondônia, with an output of around 0.46 Mt of concentrate and approximately 2.74 Mt of tailings [17,18]. Nexa Resources's Vazante zinc mine, whose depressed flotation product is reviewed here, accounts for approximately 50% of the zinc ore processed in Brazil. The mill feed is a silicate ore composed primarily of dolomite, willemite, hematite, and quartz [19-22] and generates around 1.2 Mt of flotation depressed product, actually without economical value, per year.

Depressed product from zinc ore flotation was stored in the Vazante Mine's Aroreira dam. This dam is no longer operating to receive this flow of material. Currently, the entire depressed product from the flotation process is thickened and filtered for subsequent dry storage in piles. Part of the material contained in the Aroreira dam is reclaimed and fed into the processing plant to recover the remaining zinc content. Several studies on the recovery of different minerals from tailings dams have been conducted; their focus was the recovery of zinc [23], iron [1,24,25] and dolomite [26]. In view of the outlook for higher iron grades in the ROM material, an industrial magnetic concentration test unit has been in operation since 2021.

Vinhal et al. [1] assessed hematite recovery from Aroeira dam using magnetic separation; this material's characteristics are similar to those of the current flotation process depressed product. The studied sample's initial iron grade was 7.96%. Laboratory tests conducted using a wet high-intensity magnetic separator (WHIMS) with an 8,000 G magnetic field and rougher and cleaner stages delivered a 52% iron concentrate and 70% metallurgical recovery. The authors do not indicate which matrix they used in testing. Notwithstanding the satisfactory results obtained by the authors, there is still room for optimization as the cited study's focus was not magnetic separation but the production of briquettes for the steel industry. Therefore, the magnetic separation operation was not optimized.

Several authors have demonstrated a series of new technologies that could enhance magnetic separation processes through the development of new characterization techniques [27], equipment's [28-34] and the use of different matrices in high-intensity magnetic separation [35-39]. Such alternatives may result in significant gains in capacity, fines recovery, quality, and metallurgical recovery, as they make use of existing capacity and require low capital investment. These matrices change the magnetic separation gradient and allow a better recovery of fine particles.

This study used laboratory tests to compare matrices usually used in WHIMS with the optimized geometry matrix described by Rocha et al. [36], called BigFlux. It also assessed the effect of using the BigFlux matrix on the recovery of hematite contained in the Vazante Mine's Aroeira dam.

2 Materials and method

The material used in this study was collected from the Aroeira Tailings Dam, located at Nexa Resources's Vazante site, state of Minas Gerais. A sample weighing approximately 20 kg was sent to the University of São Paulo's Mineral Processing and Waste Treatment Laboratory (LTM/USP). It should be noted that this is the same sample used by Vinhal et al. [1] in their study. For this reason, no detailed mineralogical description was made herein as this material has already been described in detail in the cited reference. All tests were conducted at LTM, except for density determinations, particle size analysis by laser diffraction, and chemical analyses, as described below. Initially, the sample was homogenized using an elongated pile and then split in aliquots.

Different aliquots from the same sample were used to determine the density through the helium pycnometer method in a Micrometrics AccuPyc II 1340 device at USP's Technological Characterization Laboratory (TCL), whereas particle size distribution was established by sieving and laser diffraction using the Malvern Mastersizer 2000 equipment. The X-ray fluorescence method was used for chemical analysis at ALS laboratory in Belo Horizonte.

Magnetic separation tests were conducted by means of a Inbras/Eriez laboratory-scale wet high-intensity magnetic separator (WHIMS). The material was initially concentrated under different fields using 2.5 mm standard and 1.1 mm BigFlux matrices in order to confirm the suitability of fields selected in a previous study stage, according to Vinhal et al. [1] findings. Figure 1 illustrates the process used for both matrices.

After the field suitability confirmation, the remaining tests followed a standard route consisting of two stages (rougher and cleaner), as shown in Figure 2.

An assessment of total error was conducted for each test, including sample preparations, magnetic separation, and chemical analyses, in line with the route given in Figure 2. Three tests were conducted for this purpose with the 2.5 mm standard matrix under the same conditions. Later, also with the standard matrix, additional tests were done with two dispersants (Clariant – E/PE MIN 313 and 314) at a dosage of 600 gr/ton. Such additives aimed to clean the particles surface. Then, a last stage of tests evaluated the different matrices, as follows: (1) 1.10 mm and 1.50 mm standard matrices, (2) a 0.40 mm x 0.60 mm expanded metal matrix, and (3) the 1.10 mm BigFlux matrix.

3 Results and discussion

Table 1 provides the chemical analysis results for the initial sample and compares them with results achieved by Vinhal et al. [1]. The material density is 3.1 g/cm^3. Figure 3 illustrates the particle size distribution results obtained by means of sieving and laser diffraction analysis.

As expected for the depressed product from zinc flotation, lead and zinc grades are low, whereas the iron grade is 8.53%. Here, the chemical analysis results were very similar to those of a previous study by Vinhal et al. [1], which confirms that the samples used in both studies have the same origin and were properly sampled. As the mineralogical analysis results obtained by Vinhal et al. [1] indicate that the main iron-bearing mineral is hematite, it is possible to conclude that around 12% of the sample consists of hematite, showing a great potential to increase product recovery by recovering this mineral, not to mention the possibility of delivering a low-carbon-emission material for steelmaking applications. Regarding particle size, the sieving and laser diffraction results are not the same, as expected since measurements are based on different particle properties. Nevertheless, such results are similar enough to validate the combined use of both methods to assess the amount of finer than 10 µm fraction in the sample. The material is 100% smaller than 0.40 mm, with a P_{80} figure of approximately 0.15 mm. It contains a significant number of fines, with the fraction below 10 µm corresponding to around 30%.

Tables 2 and 3 present the results of magnetic separations under different field intensities. It should be noted that there was no significant increase in metallurgical recovery for fields above 10,000 G to justify the drop seen in iron grade. Therefore, according to previous studies by

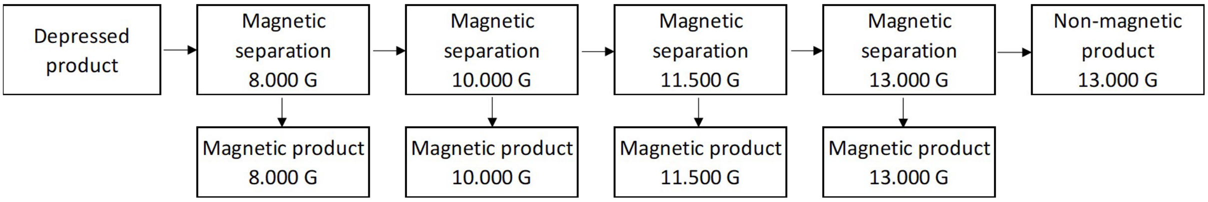

Figure 1. Magnetic separation under different fields using 2.5 mm standard and 1.1 mm BigFlux matrices.

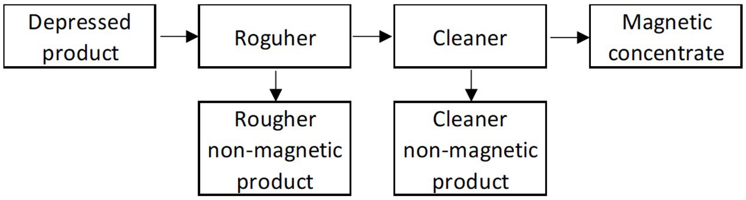

Figure 2. Standard route for magnetic separation testing.

Table 1. Chemical analysis results for the initial sample

	Al_2O_3	CaO	Fe	MgO	Mn	Pb	SiO_2	Zn
	%	ppm	%	%	%	%	%	%
FRX ALS	1.22	23.80	8.53	16.90	0.07	0.22	4.76	>1.50
FRX Vinhal et al. [1]		25.87	8.00	21.89			3.21	1.90
ICP Vinhal et al. [1]	0.63	24.34	7.96	17.08	0.07	0.45	3.15	1.74

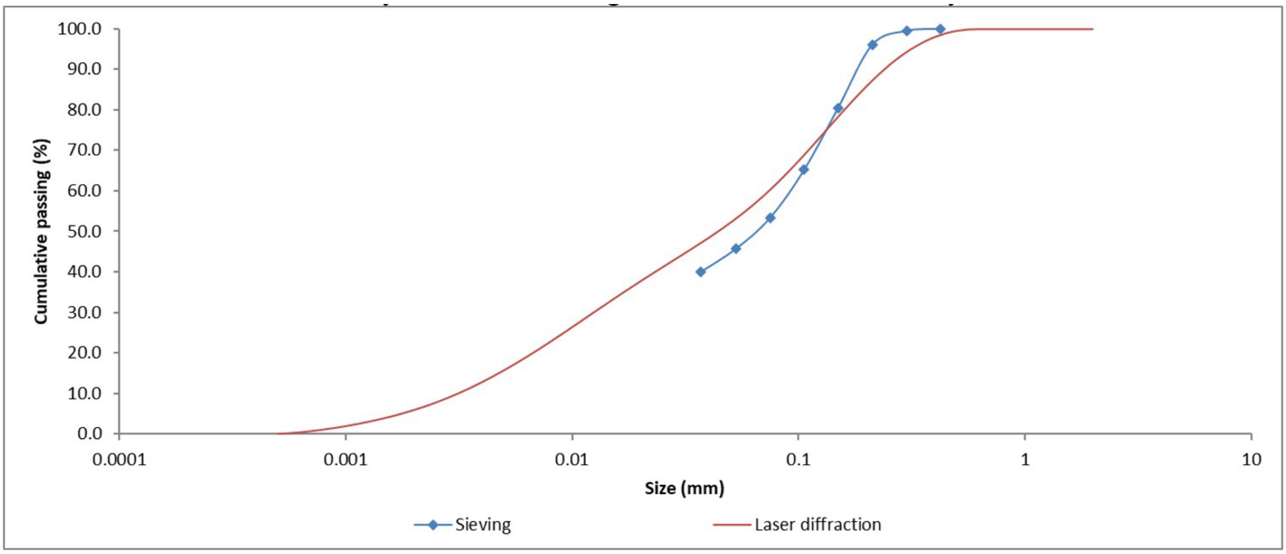

Figure 3. Particle size distribution.

Table 2. Magnetic separation using WHIMS and 2.5 mm standard matrix with different fields

Fraction (mm)	Mass		Grade							Distribution (%)						
			Al_2O_3	CaO	Fe	MgO	Mn	Pb	SiO_2	Al_2O_3	CaO	Fe	MgO	Mn	Pb	SiO_2
	g	%	%	%	%	%	%	%	%							
Magnetic 8.000 G	57.3	11.6	1.09	5.21	50.85	4.22	0.03	0.21	3.83	10.3	2.5	72.0	2.9	5.4	10.6	8.8
Magnetic 10.000 G	9.3	1.9	2.32	12.40	29.87	9.82	0.08	0.23	7.54	3.6	1.0	6.9	1.1	2.1	1.9	2.8
Magnetic 11.500 G	8.8	1.8	2.82	20.20	10.31	15.90	0.10	0.26	9.80	4.1	1.5	2.2	1.7	2.6	2.0	3.5
Magnetic 13.000 G	8.2	1.7	2.48	21.20	8.01	15.60	0.10	0.24	10.25	3.3	1.5	1.6	1.5	2.3	1.8	3.4
Non-magnetic	411.5	83.1	1.16	26.90	1.69	18.90	0.07	0.23	4.94	78.7	93.5	17.2	92.8	87.6	83.7	81.6
Calculated total*	**495.1**	**100.0**	**1.23**	**23.90**	**8.17**	**16.92**	**0.07**	**0.22**	**5.03**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Analyzed total**	**503.4**		**1.22**	**23.80**	**8.53**	**16.90**	**0.07**	**0.22**	**4.76**							

*Calculation based on the weighted average of each particle size fraction; **Chemical analysis result for the head sample.

Table 3. Magnetic separation using WHIMS and 1.1 mm BigFlux matrix with different fields

Fraction (mm)	Mass		Grade							Distribution (%)						
			Al_2O_3	CaO	Fe	MgO	Mn	Pb	SiO_2	Al_2O_3	CaO	Fe	MgO	Mn	Pb	SiO_2
	g	%	%	%	%	%	%	%	%							
Magnetic 8.000 G	60.5	12.2	1.21	5.29	49.99	4.33	0.03	0.21	4.18	12.1	2.7	74.9	3.1	6.2	11.7	10.6
Magnetic 10.000 G	12.1	2.4	2.64	16.60	18.96	12.60	0.08	0.26	8.35	5.3	1.7	5.7	1.8	2.9	2.9	4.2
Magnetic 11.500 G	1.5	0.3	***	***	***	***	***	***	***	-	-	-	-	-	-	-
Magnetic 13.000 G	1.2	0.2	***	***	***	***	***	***	***	-	-	-	-	-	-	-
Non-magnetic	421.0	84.8	1.19	26.60	1.86	18.80	0.07	0.22	4.82	82.6	95.6	19.4	95.0	90.9	85.4	85.1
Calculated total*	**496.3**	**100.0**	**1.22**	**23.61**	**8.13**	**16.78**	**0.06**	**0.22**	**4.80**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Analyzed total**	**503.9**		**1.22**	**23.80**	**8.53**	**16.90**	**0.07**	**0.22**	**4.76**							

*Calculation based on the weighted average of each particle size fraction; **Chemical analysis result for the head sample; ***Insufficient mass for analysis.

Vinhal et al. [1], using the 8,000 G field was recommended for the next stage. When performing tests using the BigFlux matrix, the output mass from 11,500 G and 13,000 G fields was small and could not be analyzed.

Table 4 shows the results of three test repetitions under the same conditions using 2.5 mm standard matrix. The results show a minor relative deviation.

Table 5 shows the results of tests using different matrices and chemical additives, whereas Table 6 present the chemical analysis of concentrates from the cleaner stage.

The results given in Table 5 indicate that the route based on the 2.50 mm standard matrix delivered a concentrate with 57.7% iron and 68% metallurgical recovery. The use of different standard matrices (1.50 and 1.10 mm) did not result in significant changes in grade and recovery. The use of chemical additives led to an approximately 2% rise in metallurgical recovery without meaningful change in grade. The expanded matrix produced a significant increase in metallurgical and mass recoveries, although with a significant grade reduction.

Table 4. Test repetitions under standard conditions using 2.5 mm standard matrix

Test	Mass recovery (%)	Fe (%)	Metallurgical recovery (%)
1	9.6	55.91	67.3
2	9.8	57.49	68.2
3	9.9	59.56	68.5
Average	9.8	57.7	68.0
Deviation	0.1	1.8	0.6
Relative deviation	1.1	3.2	0.9

Table 5. Magnetic separation using different matrices and chemicals

Condition	Mass recovery (%)	Fe (%)	Metallurgical recovery (%)
2.5 mm standard matrix - Rg and Cl – average from 3 tests	9.8	57.70	68.0
2.5 mm standard matrix - Rg and Cl with additive 313	9.5	56.48	69.1
2.5 mm standard matrix - Rg and Cl with additive 314	10.1	58.25	70.8
1.5 mm standard matrix - Rg and Cl	9.4	56.40	67.1
1.1 mm standard matrix - Rg and Cl	8.6	59.24	65.5
Expanded matrix - Rg and Cl	12.7	48.55	75.7
1.1 mm BigFlux matrix - Rg and Cl	10.0	58.93	72.6
Previous study by Vinhal et al. [1]	10.0	52.00	65.3

Table 6. Chemical analyses of concentrates from the cleaner stage

Condition	Grade						
	Al_2O_3	CaO	Fe	MgO	Mn	Pb	SiO_2
	%	%	%	%	%	%	%
2.5 mm standard matrix - Rg and Cl - average from 3 tests	0.91	3.07	57.65	2.68	0.02	0.21	3.18
2.5 mm standard matrix - Rg and Cl with additive 313	0.98	3.25	56.48	2.85	0.02	0.20	3.29
2.5 mm standard matrix - Rg and Cl with additive 314	0.98	3.00	58.25	2.63	0.02	0.22	3.30
1.5 mm standard matrix - Rg and Cl	1.03	3.36	56.40	2.89	0.02	0.21	3.34
1.1 mm standard matrix - Rg and Cl	0.78	2.21	59.24	2.04	0.02	0.19	2.73
Expanded matrix - Rg and Cl	1.29	5.58	48.55	4.52	0.03	0.21	4.36
1.1 mm BigFlux matrix - Rg and Cl	0.81	2.49	58.93	2.23	0.02	0.20	3.05

The BigFlux matrix proved to be the most interesting option. It led to an increase in the final concentrate grade from 57.5% to 58.9% and the metallurgical recovery from 68% to 72.6%. This is an interesting outcome as it delivers a cleaner concentrate without reducing the mass recovery in the process. It should be noted that the concentrate grade could be further optimized by seeking higher iron and lower contaminant grades. For instance, the use of one additional cleaner stage, removal of the finer fraction, and execution of distinct magnetic separations for coarse and fine materials could be considered. Also, regrinding the material could increase the liberation of coarse particles.

4 Conclusions

This study addressed the possibility of recovering hematite from zinc flotation depressed material. The studied samples had an iron grade of 8.5% and approximately 12%wgt of hematite. Different matrices for wet high-intensity magnetic separation were assessed. A standard matrix, usually employed in such separation processes, delivered a final concentrate with 57.5% iron and 68% metallurgical recovery. The use of an optimized geometry matrix resulted in a final concentrate with 58.9% iron and 72.6% metallurgical recovery. The process's mass recovery amounted to 10%. Such results point to a significant potential of higher product recovery by producing an iron concentrate with potential steelmaking applications, positive socioenvironmental impacts, and low carbon emissions.

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