EVALUATION OF ORE SORTING TECHNOLOGY FOR IRON ORE COARSE PARTICLES *

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Abstract
The recent developments on the sensor detectors together with the higher capacity of the machines, due the high-speed computing recent advances, have made possible extending the application in the mining industry. The use of x-ray fluorescence, x-ray transmission and radiometric sensor based sorting can selectively remove gangue minerals in different size fractions for different minerals. This paper summarizes the potential application of SBS for an iron ore in three size fractions aiming to increase the %Fe after the removal of particles with main gangue minerals associated. Pilot plant tests were carried out with samples of iron ore in different size fractions and different content of hematite and gangues. The use of x-ray transmission sensor showed the possibility to increase the %Fe from about 63% to above 68% for particles below 80mm and 45mm, after the removal of low density particles. The presence of fines on the feed affected the performance of the SBS X-rays transmission machine, especially for the fine fraction feed. The mineralogical determination, carried out to know the association between hematite and gangue minerals, and the density of the particles on the feed, can be used to preview the quality of products of the x-transmission sorting process.
Keywords: ore sorting; Iron ore; Coarse particles.

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1 INTRODUCTION

The sorting technology was introduced in the 1930s and 1940s with limited application in the mining industry due to the low throughputs of the machines and limitations in the state-of-the art sorters. The relatively recent advances in the detector technology coupled with high speed computing capacity (higher capacity of the machines) have made sorting viable for applications in the mining industry (Lessard et al, 2016). The possibility of application of sensor based sorters in the mining industry can meet the need to reduce costs, especially on the scenario of falling ore grades and increasing tonnages.

Different sensors can be used, according to the different characteristics between the minerals to be sorted. The main technology are the X-ray fluorescence, X-ray transmission, radiometric sorting and optical sorting (Knapp et al., 2014: Manouchehri, 2003).

This article aims presenting the potential of using sorting in an iron ore plant to final cleaning the coarse products. Although, there are other possibilities that were not already investigated, the present test work results focus in the application of a dual energy X-ray transmission (DE-XRT) sensor sorting of an iron ore sample from Brazil (Vale mine). The DE-XRT sorters make use of the atomic density differences within a rock particle to differentiate between ore and waste (Lessard et al., 2016). This kind of sensor has been used in airport x-ray screening systems for many years. This technique is based on using two energies of x-ray photons and investigating their attenuation and transmission ratio, when passing through the investigated material independently on its thickness, to provide the material density. This is done with fair accuracy similarly to airport security systems where low-density objects like plastic and wood are coded with separate colour and another colour codes are used for high density objects like metals. Current DE-XRT sorters can process a maximum size about 200mm (Lessard et al., 2016).

2 THEORY

The iron ore deposits of the Quadrilátero Ferrífero (Iron Quadrangle) in Minas Gerais have been intensively mined over the last 40 years, so the remaining high-grade ore reserves became less abundant. Offering a premium quality product to the mineral market can be a key opportunity to keep competitiveness, as the quality of iron product is an important task for the steel industry. Although, more traditional methods as magnetic separation or flotation have higher efficiency than the sorting techniques for producing iron ore concentrate with a high grade and recovery, these methods require a costly fine crushing and grinding circuits which is not required for ore sorting operations.

Ore sorting has been present since the beginning of the mineral industry history, first as hand-sorting, separating the particles according their differences observed by naked eyes like colour, brightness, shape, etc (Varela et al. (2006). As liberation of the ores has been reduced and production scale has been increased, the use of hand-sorting by the mineral industry became impracticable and new technologies has taken its place. Many years later, the development of the automated sorting has started, but the mineral industry have still few examples of applications of sorting technology in the mineral processing plant flowsheets (Salter and Wyatt, 1991). It's known about the application of automated sorting in the mineral processing

operations like diamonds, carbonates, talc, platinum, rock salt, and uranium ores (Varela et al. 2006).
Ore sorting or sensor-based sorting (SBS) is a sustainable processing technology for the separation of coarse mineral particles (Robben, 2013). SBS can be used in a wide range of process steps, from pre-concentration to final cleaning of products and it is generally divided into four interactive sub-processes involving: ore preparation, ore examination, data analysis and ore separation (Salter and Wyatt, 1991; Varela et al. 2006).
The degree of liberation is a very important criterion to be analysed before carrying out a physical separation, but the concept of liberation itself can’t be considered as a restriction for SBS technology. It should be remembered that the criterion also includes economic liberation aspects, for example for pre-concentration applications the decision of accept or reject a particle can be determined based on grades, where the grade sort criteria change depending on economic conditions (Salter and Wyatt, 1991). Robben 2013, has compared one partition curve of iron ore coarse particle obtained by a dense medium separation method with one partition curve obtained by SBS method, both set to a cut point of 38wt% iron content. His research has showed that for the dense medium separation method the probability of displacement decreases with the difference in iron content to the cut-point. But for SBS the displacement is independent from the iron content, because in the separation force is decoupled from the separation criterion, so inefficiency problems results from separation errors due to some reasons as the number of valves, valve spacing, applied pressure, delay between detection and ejection, etc.
The implementation of ore sorting in the mining industry is increasing but the development of a new project can take many years of studies and evaluations. The innovation cycles in the mineral processing field can take more than 30 years. There is a paradigm in the high capacity mining industry that the sorting machines have low throughput and they cannot be use in large-scale projects. Salter and Wyatt, 1991 mentioned that to solve this problem, for high tonnage applications, multiple streams could be used and nowadays the reasons of the past for not parallel streaming (at lower feed rates) have largely fallen away. Today the availability of cheap and reliable microelectronics allows all the monitor and control done by a single computing unit. For sure, as mentioned by Robben, 2013 every case is different and must be completely studied, passing through a liberation analysis, run-of-mine ore characterization, sorting test work till a complete financial feasibility study.
Many sensors are indicated in the literature as having potential for mineral processing applications like optical cameras, X-ray, infrared, ultraviolet, laser, radiometric, electromagnetic, microwave, eddy current properties, etc (Varela et al. (2006); Robben, 2013).
Kolacz (2014) stated the possibility to use optical and X-ray attenuation imaging in the same equipament. In many applications, the sorting efficiency reaches 95-99% efficiency for easily identified materials and 85-95% for more difficult ones.
Fitzpatrick, in 2008 has described in his PhD thesis, the SBS tests made by CommoDas (current Tomra) for an iron ore that has goethite and martite as the main minerals. They have analysed the application of the inductive electromagnetic sensor and the optical one. Fitzpatrick concluded that colour differences can allow an upgrade in the ore but the inductive sensor have given no positive effect, although further investigation was recommended using samples with higher content of impurities.

3 MATERIALS AND METHODS

Continuous tests were carried out in an industrial Comex SBS machine with X-ray transmission system showed in Figure 1, using four iron ore samples. The samples were obtained from an industrial beneficiation process, named as sample 1 (coarse fraction, -80mm), sample 2 (middle fraction, -45mm) and sample 3 (fine fraction, -16mm). Preliminary tests were done in a closed circuit to calibrate the machine, when the separated fraction after the sorting machine were mixed together and returned back to the inlet. After that, the open circuit tests were carried out, the products were weighted and their chemical composition was analysed.

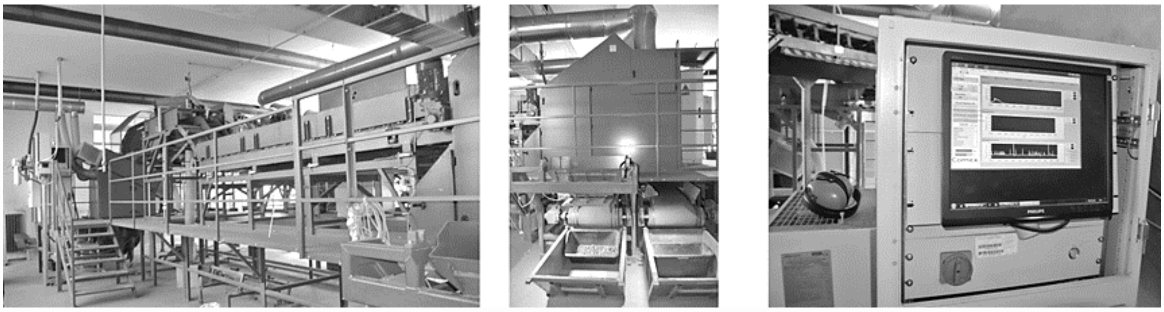

Figure 1: Comex ore sorting machine used for the tests with the iron ore fractions

The three samples were characterized for the ore sorting tests as follows:

- ⇨ Size distribution.
- ⇨ Chemical analyses.
- ⇨ Mineralogical analyses using optical microscope of reflected light, aiming to quantify the iron and gangue minerals and their association.
- ⇨ Particle density. About 30 particles of each size fraction were sampled for density determination. Each particle was immersed in water to measure its weight loss to calculate its density. Furthermore, the sample was ground for chemical analyses.

The association between the iron and gangue minerals and the particle density distribution were done aiming the calibration of the sorting machine and to preview the results.

4 RESULTS

The chemical analyses and the size distribution of the three samples are shown in Table 1 and on Figure 2.

Table 1: Chemical analyses of the three samples

Sample	Fe (%)	SiO_2 (%)	P (%)	Al_2O_3 (%)	Mn (%)	TiO_2 (%)	CaO (%)	MgO (%)	PPC (%)
Coarse fraction (-70+40 mm)	62,90	1,91	0,094	0,47	0,109	0,026	2,30	1,55	3,20
Middle fraction (-40+16 mm)	63,36	5,59	0,08	0,65	0,126	0,032	0,77	0,52	1,32
Fine fraction (-16+8 mm)	63,68	6,49	0,03	0,53	0,264	0,031	0,47	0,31	0,91

* *Technical contribution to the 20º Simpósio de Mineração, part of the ABM Week 2019, October 1st-3rd, 2019, São Paulo, SP, Brazil.*

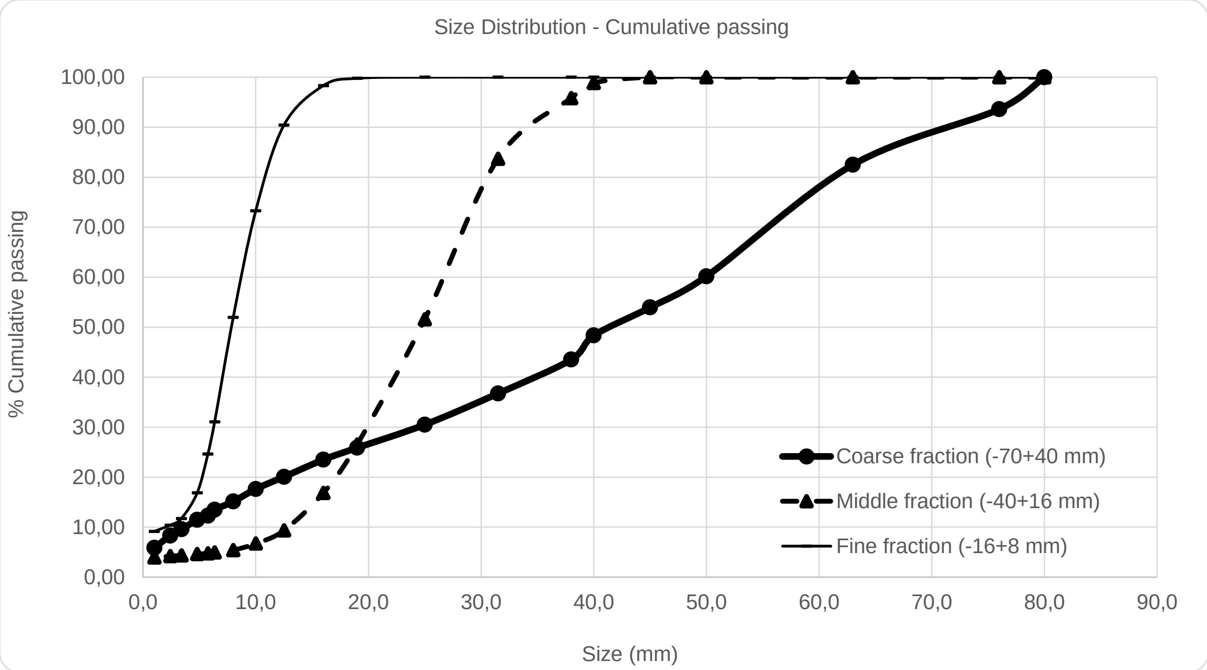

Figure 2: Size distribution of the three samples

Figure 3 shows the mineralogy analyses of the samples. Hematite and magnetite are the main Fe minerals in the three samples.

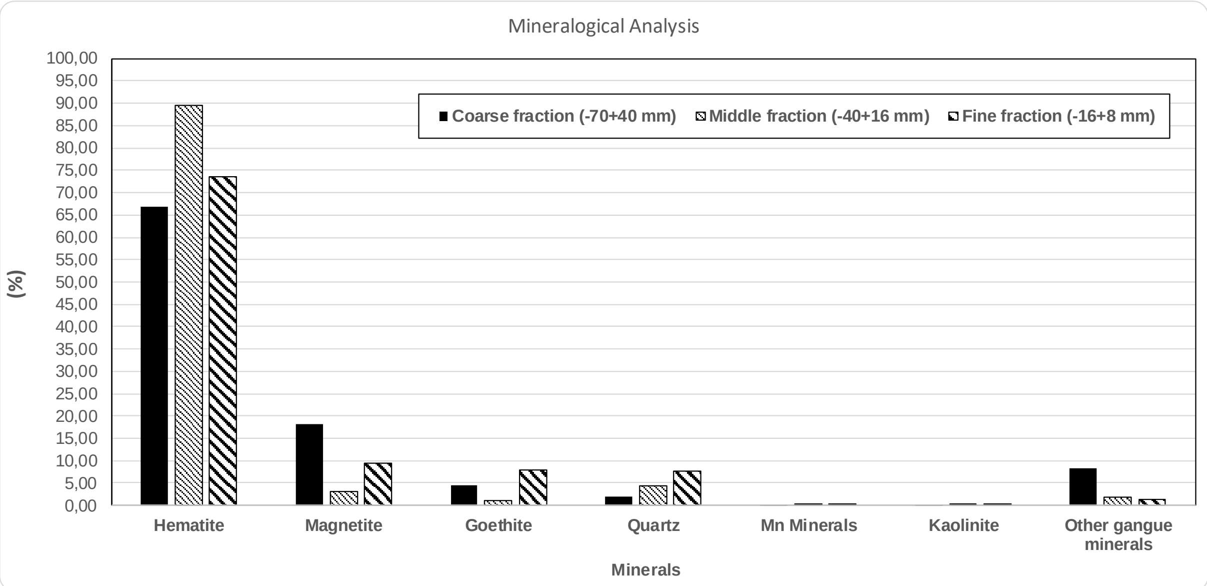

Figure 3: Mineralogical analysis of the samples

The main gangue minerals of low density are quartz, manganese and kaolinite. The association between Fe minerals and gangue minerals is shown on Figure 4.

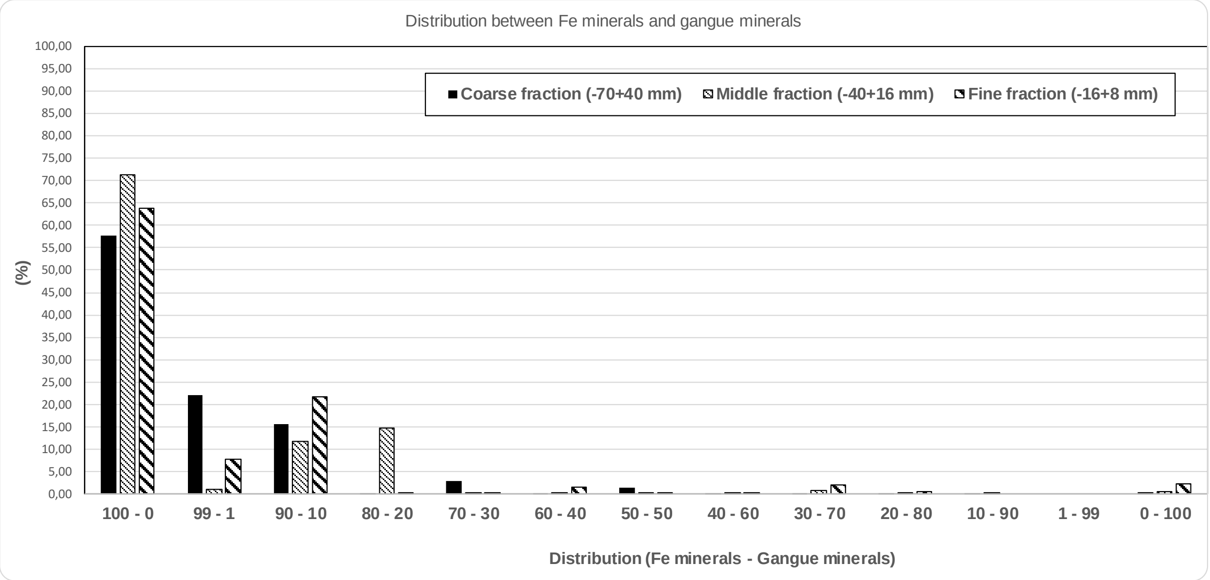

Figure 4: Distribution between the Fe minerals and the gangue minerals

The analyses 100-0 means the distribution of particles with 100% of Fe minerals and 0% of gangue minerals. More than 70% of particles is these three samples have maximum 1% of associated gangue minerals. It shows the possibility to increase the %Fe in these three samples after removing of maximum 30% of particles with 10% to 100% of association.

Figure 5 shows the distribution of density and %Fe of particles for the investigated samples. The results indicate that the removal of 15% to 20% of particles with density lower than 4,12 t/m^3 can increase the %Fe in the samples to values above 68%.

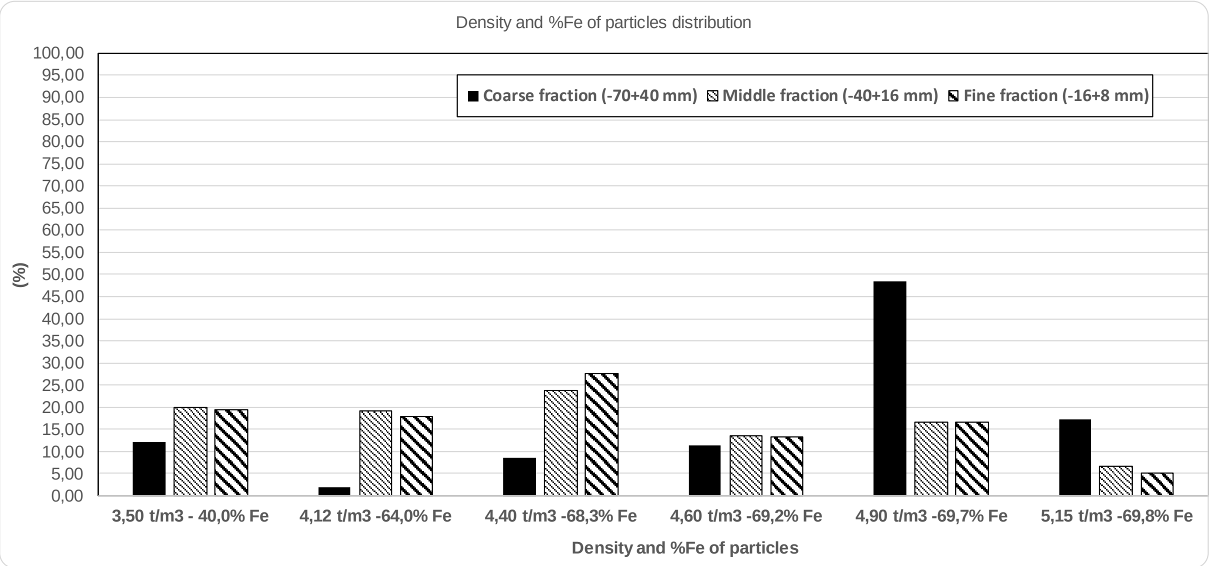

Figure 5: Distribution of density and %Fe of particles

The analyses on Figures 4 and 5 were used for the initial calibration of the SBS machine used during the tests.

Table 2 shows the results from the tests as global mass balances. These results were obtained after the calibration and optimization of the SBS machine.

Table 2: Global mass balance of the tests on the SBS X-ray transmission machine

Coarse fraction (-70+40 mm)	Mass (%)	Fe (%)	SiO_2 (%)	P (%)	Al_2O_3 (%)	Mn (%)	TiO_2 (%)	CaO (%)	MgO (%)	PPC (%)
Feed	100,00	62,90	1,91	0,094	0,47	0,11	0,03	2,30	1,55	3,20
Concentrate	64,06	69,05	0,95	0,056	0,17	0,04	0,02	0,17	0,07	0,07
Tailing	35,94	51,95	8,22	0,043	0,16	0,17	0,02	5,65	3,62	8,47

Middle fraction (-40+16 mm)	Mass (%)	Fe (%)	SiO_2 (%)	P (%)	Al_2O_3 (%)	Mn (%)	TiO_2 (%)	CaO (%)	MgO (%)	PPC (%)
Feed	100,00	63,36	5,59	0,075	0,65	0,13	0,03	0,77	0,52	1,32
Concentrate	65,30	68,15	1,51	0,051	0,51	0,06	0,04	0,14	0,10	0,41
Tailing	34,70	54,33	18,93	0,057	0,46	0,10	0,03	0,60	0,45	1,40

Fine fraction (-16+8 mm)	Mass (%)	Fe (%)	SiO_2 (%)	P (%)	Al_2O_3 (%)	Mn (%)	TiO_2 (%)	CaO (%)	MgO (%)	PPC (%)
Feed	100,00	63,68	6,49	0,035	0,53	0,26	0,03	0,47	0,31	0,91
Concentrate	52,15	65,68	4,04	0,023	0,41	0,18	0,03	0,40	0,26	0,72
Tailing	47,85	61,50	9,16	0,047	0,66	0,36	0,03	0,54	0,36	1,11

The results in Table 2 show that the removal of low density particles for the coarse and the middle fractions, can increase the %Fe from about 63% to above 68% as predicted for the distribution of density and %Fe of the particles. However, the amount of the removed particles was higher than the expected, due the amount of fines in the feed, which affected the performance of the SBS X-ray transmission machine.

The negative effect of the fines on the feed was confirmed during the tests with the fine fraction (-16mm). The best quality of the concentrate was close to 65% Fe, even after the removal of almost 48% of low density particles.

Figure 6 shows the percentage of gangue minerals in the feed, the concentrate and the tailings for all three samples. The results indicate the high performance of the SBS X-ray machine, where about 80% of the gangue minerals were removed for all three size fractions.

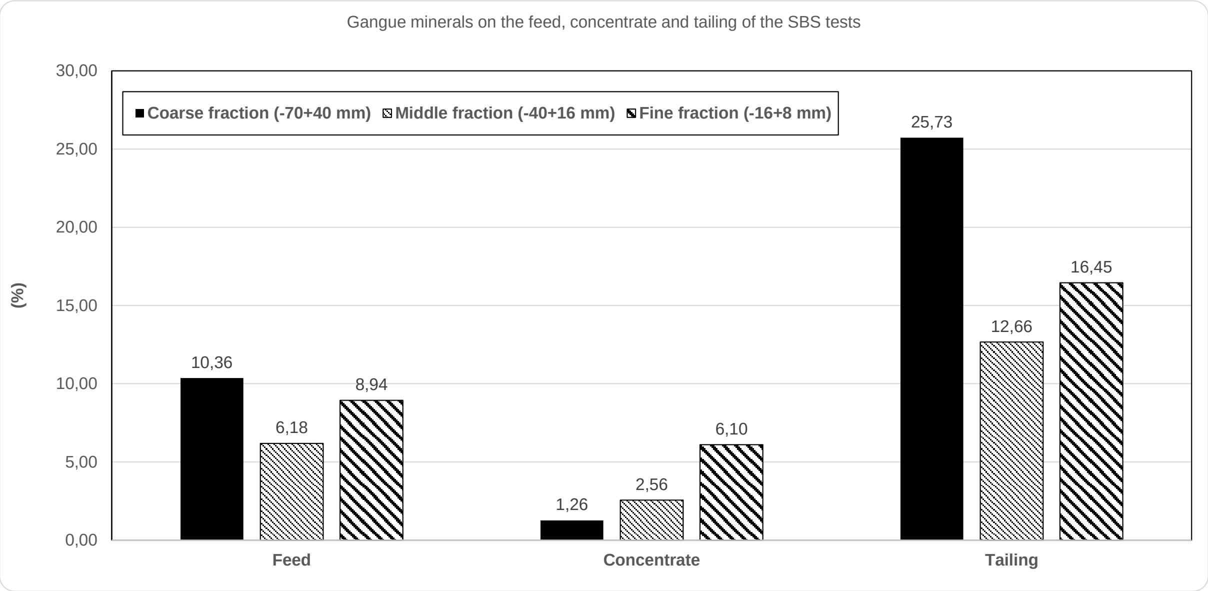

Figure 6: Gangue minerals in the feed, concentrate and tailings after testing

* Technical contribution to the 20º Simpósio de Mineração, part of the ABM Week 2019, October 1st-3rd, 2019, São Paulo, SP, Brazil.

5 CONCLUSIONS

Significant improvements of Fe content in the iron ore can be achieved by applying the X-ray sorting technology. SBS using X-ray transmission can be applied for coarse (-80mm) and middle (-45mm) fractions of iron ore, aiming to increase the %Fe from about 63% to above 68% after the removal of about 35% of low density particles. The removed particles contain about 52% Fe associated with gangue minerals. The presence of fines in the feed affected the performance of the SBS X-ray transmission machine, especially for the fine fraction (-16mm), where the best quality was about 65% Fe after the removal of 48% of low and middle density particles. It is therefore important to screen properly the feed material before SBS application.

REFERENCES

1 Bohme, R.C. The development of a Radiometric sorter for South African gold ores. International Journal 34, 417-428, 1983.
2 Dalm, M., Buxton, M. W. N., Ruitembeek, V., Voncken J. H. L. Application of near-infrared spectroscopy to sensor-based sorting of a porphyry copper ore. Minerals Engineering 19, 7-16, 2014.
3 Fitzpatrick, R. The development of a methodology for automated sorting in the minerals industry. PhD thesis in earth resources, University of Exeter, UK. 306 p., 2008.
4 Knapp, H., Neubert, K., Schropp, C., Wotruba, H. Viable application of sensor-based sorting for the processing of mineral resources. ChemBioEng Rev. 3, p.86-95., 2014.
5 Kolacz, J. Sensor based sorting with signal pattern recongnition: the new powerful tool in mineral processing. XXVII International Mineral Processing Congress, Santiago-Chile, p.106-115, 2014.
6 Lessard, J., Bartram, K., Sweetser, W., Figueroa, J., Mchugh, L. Bridging the gap: Understanding the economic impact of ore sorting on a mineral processing circuit. Minerals Engineering 91, p.92-99, 2016.
7 Lessard, J., de Bakker J., Mchugh L. Development of ore sorting and its impact on mineral processing economics. Minerals Engineering 65, 88-97, 2014.
8 Manouchehri, H.R. Sorting: possibilities, limitations and future. http://pure.itu.se/portal/files/299975/articles. 2003.
9 McGraw, D.J. Ore sorting review. In: Vale Exploration Canada internal report, 2014.
10 Robben, C. Characteristics of sensor-based sorting technology and implementation in mining. PhD thesis, RWTH Aachen University, Germany. 218 p., 2013.
11 Robben, C., Takala, A., Rantamaki, M. Interdiciplinary sensor based-sorting process design and project development. In: 7th Sensor-based sorting & control, Aachen, Germany, 2016.
12 Salter, J.D., Wyatt, N.P.G. Sorting in the minerals industry: past, present and future. Minerals Engineering 4, 779-796., 1991.
13 Varela, J.J., Petter, C.O., Wotruba, H. Product quality improvement of Brazilian impure marble. Minerals Engineering 19, 355-363, 2006.