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GRADE IMPROVEMENT OF IRON ORE CONCENTRATE BY APPLYING PLANT AUDITS, STANDARDIZATION AND PROCESS OPTIMIZATION

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ABSTRACT – One of the challenges at iron ore processing plants is achieving a concentrate by the desirable iron grade. It is crucial to implement optimizations for increasing the concentrate quality. In this research, the operation of a case study plant was investigated to find bottlenecks and improve the iron ore concentrate quality. For this purpose, the grinding and magnetic separation stages including ball mills, hydrocyclones and low intensity magnetic separators were investigated. The plant optimizations resulted in the Fe grade improvement of concentrate from 63.50% to 66.1% and reduction of concentrate particle size (P80) from 98 µm to 75 µm.

Keywords: Iron Ore, Optimization, Plant audit, Process Flowsheet.

INTRODUCTION

Iron ore is a vital resource for iron and steel production [1] and it can be processed by magnetic separation methods [2]. Among all iron ores, magnetite ores are naturally suitable for upgrading by low-intensity magnetic separators [3-6]. However, the quality of iron ore varies greatly, and it is typically necessary to control the process to produce an iron ore concentrate with higher Fe grade to meet the requirements of downstream processes. Optimization and improvement of Fe grade can be achieved through process audit [7-10] and it can be applied by a combination of sampling, laboratory analyses, practical measurements [11-12]. Also, the optimization can be formulated based on the process and operating constraints to increase productivity and reach certain product characteristics [13-17]. The modification of grinding and classification circuit could be considerable and improve the quality of the final product [18]. Therefore, the auditing process can be applied as a method for achieving higher throughput, a finer product, or reduced operating costs. The present paper provides insights into the audit method of a case study plant and its role in the improvement of plant operation, product and throughput.

MATERIALS AND METHODS

The process flowsheet and main equipment as well as the feed and product characteristics of the plant are presented in Figure 1. The plant includes two ball mill-

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hydrocyclone circuits and five wet low intensity magnetic drum separators (LIMS) for processing the iron ore.

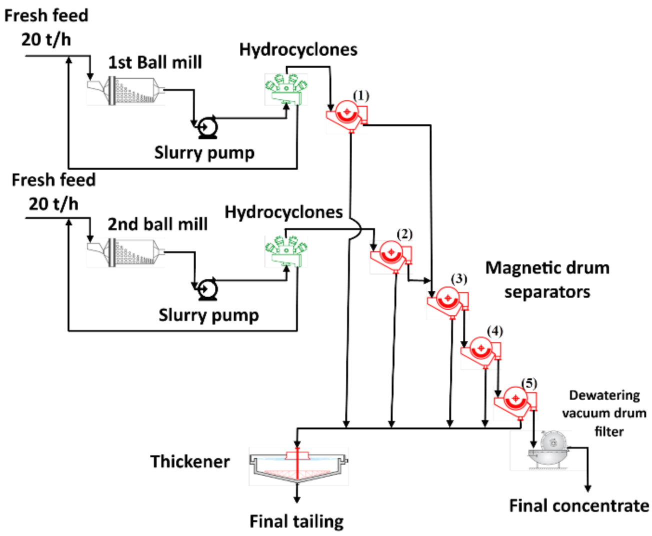

Figure 1 The simplified process flowsheet of iron ore beneficiation plant before optimization

In this flowsheet, the fresh feed (crushed iron ore) is fed simultaneously to two parallel ball mills. The water is added to the ball mills and the operation is done at the wet process. Five magnetic drum separators are in a series and the product of each drum separator is considered as the feed of the next drum separator. In each ball mill, the feed rate is 20 t/h. The magnetic intensity of LIMS was 0.10-0.12 Tesla. Table 1 represents the chemical characteristics of feed and product. Before audits, the Fe grade of concentrate was 63.5% and this amount is less than the typical Fe grade for iron ore concentrate feeding to the downstream pelletizing process. The XRD (X-ray diffraction) analyses showed that magnetite is the main iron-bearing mineral in feed. Quartz and calcite are the primary gangue minerals and the most sulfur-bearing mineral is pyrite. The particle size analysis of fresh feed and final product showed that the F_{80} of fresh feed and the P_{80} of product are 6.2 mm and 99 µm, respectively. The auditing consisted in observations of operating parameters of ball mills, hycrocylones, and drum separators as well as the chemical and physical measurements of the feed and product.

Table 1 The chemical analysis of feed and product

Composition	wt. (%)								
	Fe_{total}	FeO	S	P	MgO	CaO	Al_2O_3	SiO_2	TiO_2
Fresh feed	48.11	17.62	1.54	0.02	6.15	3.18	2.34	11.54	1.13
Product	63.50	22.05	0.23	<0.01	0.90	0.94	1.14	5.86	0.26

RESULTS AND DISCUSSIONS

Modification of equipment arrangement

At the process flowsheet, the tailings streams of all separators were forwarded to the dewatering thickener and the iron and water content measurements showed that it is possible to recycle the tailings of the final magnetic separation stage to the process because it mostly contains high volume of water and low solid content. In Figure 2, the grinding circuit of the first ball mill was changed from a close to open circuit. The hydrocyclones overflow of the first grinding stage is forwarded to the magnetic drum separators and the hydrocyclones underflow is considered as the feed of the second ball mill. In fact, the second ball mill acts as the regrinding mill. Due to this change, the proper balls' size and distribution for each ball mill was proposed and implemented.

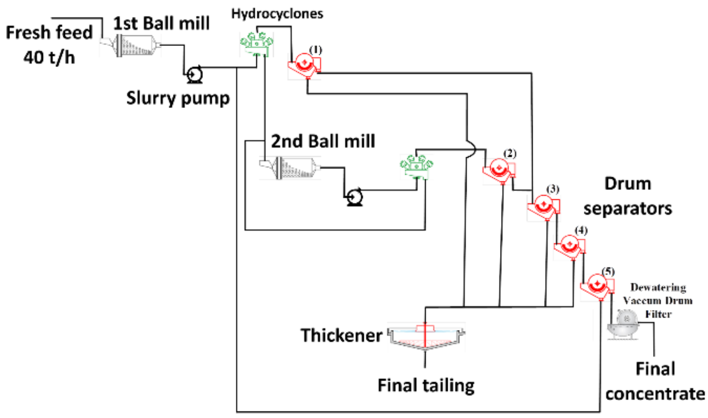

Figure 2 The process flowsheet of the case study plant after modifications

Liberation degree studies of iron minerals

The iron distribution in different size fractions of the concentrate was studied (Figure 3). The iron distribution at the coarse-sized fractions is lower than that of the other-sized fractions, which is the main reason for the failure to achieve the higher Fe grade at the final concentrate. The effects of the particle size reduction on the iron mineral liberation were investigated by grinding the feed samples to the d_{80} of 75, 53 and 45 µm and running Davis tube tests for magnetic separation. The results of Davis tube tests are presented in Table 2. It is clearly understood that the P_{80} of concentrate should be reduced to 75 µm for achieving the higher Fe grade.

Table 2 Davis tube tests on the case study iron ore

Sample	Particles Size	Fe grade (%)			Concentrate mass (%)	Fe recovery (%)
		Feed	Concentrate	Tailing		
Iron ore	d_{80}=75 µm	49.62	67.20	15.49	66	89.38
	d_{80}=53 µm	48.54	68.67	15.70	62	87.7
	d_{80}=45 µm	48.94	68.22	17.48	62	86.43

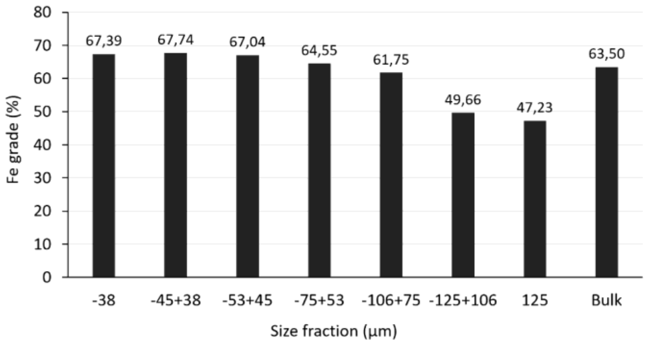

Figure 3 The iron distribution in different size fractions of iron ore concentrate

Grinding conditions of ball mills

The operating conditions of two ball mills are presented in Table 3, before and after modification in the process flowsheet.

Table 3 The operating conditions of ball mill circuits, before and after modifications

Operating conditions	First ball mill		Second ball mill	
	Before	After	Before	After
Ball filling ratio (%)	26	30	28	30
Ball charge size (mm)	60	70	60	40
Fresh feed rate (t/h)	20	40	20	-
Power draw (kW)	~510	~600	~460	~500
Solid content (%)	81	75	81	75

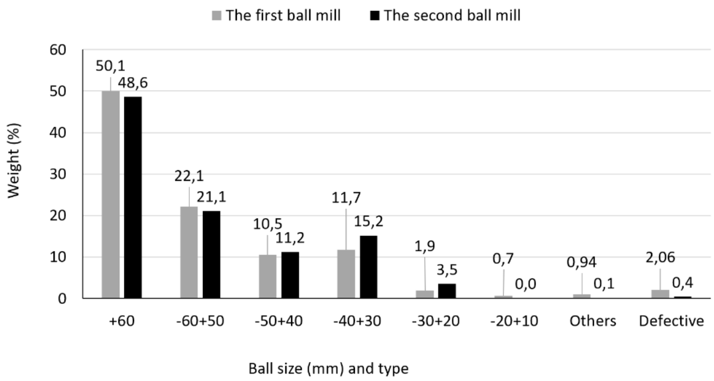

Figure 4 The balls size distribution inside ball mills by taking samples

The suitable solid content inside the ball mills was changed from more than 81% to 70%-75%. The ball samples were taken from the inlet, outlet and middle locations inside ball mills to modify the grinding operation in ball mills. The results of balls size distribution are illustrated in Figure 4. The balls inside both ball mills are bigger than 60 mm and, there is a low number of small balls. The optimum make-up ball size for each ball mill was found according to the new operating and feeding conditions. The ball size was determined by using the Bond equation [19] which is as the equation (1).

$$B = \left(\frac{F}{K}\right)^{\frac{1}{2}}\left(\frac{S*Wi}{Cs*\sqrt{D}}\right)^{\frac{1}{3}} \quad (1)$$

Where B is the ball diameter (mm), F is the F_{80} of feed (µm), K is the grinding correction coefficient, S is the density of bulk mass (g/cm^3), Wi is the specific energy consumption (kWh/t), Cs is the mill rotational speed (%) and D is the internal mill diameter (m). The calculated make-up ball size for the first and second ball mills were 70 and 40 mm, respectively. The balls' size distribution was corrected based on the Bond recommendation [19]. After modifications, the particles' size of the first ball mill output increases from 165 to 217 µm, which is due to the rise of feed rate from 20 to 40 t/h. In the second ball mill, the particles' size of the mill output decreased from 205 to 138 µm, due to the higher ball charge and the lower mill feed size.

Modifications of drum separators

The main problems related to drum separators were non-uniform feeding to the whole length of the drum separator, presence of blockages in the tailing orifice of some separators, and absence of washing water and cleaning scrapers on the discharge lip of the concentrate on each drum separator. It was observed that the concentrate product of the first drum separator is discharged at one point inside of the next drum separator tank and it causes an uneven feed distribution through the whole effective length of the drum separator. Consequently, it affects separation efficiency and the unsymmetrical wear of the drum surface lining as well. This problem was solved by adding a new pipeline in front of the drum separator to dispense the slurry feed to the whole length of the drum separator.

CONCLUSION

In this research, an iron ore beneficiation plant was audited to find optimizations for improving the iron ore concentrate quality. Before optimizations, the Fe grade of concentrate was 63.5% with P_{80} of 98 µm. The chemical analyses and mineralogical studies (XRD) showed that the main iron-bearing mineral is magnetite. The main reasons for the low Fe grade of iron ore concentrate were the insufficient liberation of iron minerals from gangues and inappropriate performance of magnetic separation stages. Davis tube tests on the ground feed samples with different particle sizes showed that the feed sample should be ground to d_{80} of 75 µm to achieve an iron ore concentrate with the minimum Fe grade of 66%. Two grinding circuits of ball mills were rearranged from operating in parallel to a series. The solid content inside ball mills was readjusted and reduced from 81% to 75% and the balls' size distribution in ball mills was optimized based on the mill feed size. The P_{80} of the final concentrate was reduced from 98 to 75 µm. The efficiency of separators was increased by optimizing the uniform feeding on the drum's surface. Also, the tailings streams of final drum separator were recycled to the process instead of removing from the circuit to have more dilution on the drum separators feed.

Conclusively, all these modifications led to an increase in the Fe grade of the final concentrate from 63.5% to 66.1%.

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