MOPE PROCESSOS MINERAIS

MOPE BREAKING PARADIGMS

Selective Grinding with Open Circuit

RESUMO

Apresentam-se os resultados de testes piloto com moagem seletiva, que consiste na operação de moinho em circuito aberto e com baixo enchimento de bolas. No caso aqui descrito, foram realizados testes de moagem e de flotação com minério sulfetado, comparando os resultados provenientes da moagem seletiva com os da moagem convencional (circuito fechado com ciclones), para o mesmo P80 de moagem. A moagem seletiva mói com maior qualidade (distribuição granuloquímica) e gera maior liberação, permitindo aumentar a seletividade da flotação, incrementando o desempenho metalúrgico, além de reduzir significativamente os custos de operação do moinho (a potência aplicada ao moinho cairia em 20% do seu valor atual). A redução do OPEX e o acréscimo de recuperação metalúrgica apresentaram um ganho liquido conjunto próximo a US$13.000/ano por cada tonelada/hora de minério processado na usina.

ABSTRACT

Here are presented the results of pilot tests using selective grinding, a procedure that consists on the operation of open grinding with low ball filling. In the case described here, grinding and flotation tests were performed with sulfide ore, comparing the results from the selective grinding with the ones from the conventional grinding (closed circuit with cyclones), for the same P80. The selective grinding gives a product with better quality (granulochemical distribution) and generates a more liberated material, allowing an increase in the selectivity of the flotation process, enhancing the metallurgical recovery and reducing, significantly, the mill's operational costs. The reduction in the OPEX and the increase of metallurgical recovery present a net joint gain close to US$13.000/year for each t/hour of processed ore in the plant.

1. INTRODUCTION

The **selective grinding** is an operational procedure studied and defended by MOPE, based on the theories of the *Modelo Operacional,* supported by few, but well succeeded, industrial experiences around the world.

The mill, with low ball filling inserted in an open circuit, allows, on its inside, the heavier (and/or coarser mixed) particles to settle in its bottom (i.e. sulfides). These particles are, then, preferentially hit by the milling bodies, generating a different size distribution, when compared to the conventional grinding.

The selective grinding (open circuit and low ball filling), for the same P80 of a conventional grinding (circuits closed with cyclones and high ball filling), generates less ultrafine particles and spends less energy by milling less quantity of gangue.

MOPE has already tested, with success, the selective grinding in pilot scale with various sorts of ores, such as iron, tantalite, cassiterite and rare earth minerals.

This study aims the demonstration of the benefits in adopting the selective milling in sulfide beneficiation circuits. The name of the plant will not be displayed, once the project is still being deployed.

2. CURRENT OPERATION

The studied plant treats sulfide ore, whose hardness is being increased in big proportions, and, in order to maintain the production rate, the plant finds itself obliged to increase, gradually, the P80 of the Mill discharge. For that, the metallurgical recovery of the plant decreased in more than 2%, compared to its recent past operation.

The presented studies here described aimed the search for options to improve the metallurgical performance of the plant, keeping the current treatment rate.

3. TESTS

3.1 Grinding

Four selective grinding continuous tests in a pilot mill were performed aiming to obtain different P80 values in order to define the ideal grinding point which guarantees a convenient liberation of the material.

Some of the operational parameters used in each one of the tests are listed on **Table 3.1**.

***Table 3.1** – Basic parameters of the grinding tests*

Teste	Enchimento (%)	% de Sólidos	Rotação (RPM)	Taxa (kg/h)
1	30	47,3	39	131,6
2		47,4		144,0
3	25	43,66	41	110,4
4		43,05		102,4

Even though the pulp density is diluted, in the bottom of the mill (grinding zone) it has over 75% solids, as already proved in industrial tests, including sulfide ones.

The feed rate, even being calibrated in a precarious way by the feeding conveyor, was confirmed by sampling the mill's discharge with the aid of a chronometer. The lower rates aim a finer discharge P80.

The assays were performed in a pilot mine, of 0,6 x 0,9 m, sampling the feed (to obtain the F80) and the discharge of the mill, in order to perform granulochemical analysis.

3.2 Flotation

The tests aimed the verification of the flotation performance with the different grinding conditions (current closed circuit and selective milling).

The comparisons between different tests must consider the same proportion of floated mass. Such adjustment was made through the ***COMPARAFLOT***, developed by MOPE (from the main package called **MOPETOOLS**).

4. RESULTS AND DISCUSSIONS

4.1 Grinding

Table 4.1 *– Grinding tests results*

Teste	F80 (µm)	P80 (µm)	Wio (kWh/t)	% material >100#
1	4600	300	26,57	43,8
2	4600	337	26,35	46,4
3	4600	211	23,90	33,6
4	4600	191	24,20	28,8

After the execution of the pilot test and the knowledge of its parameters (F80, P80, feed rate, rotation speed of the mill, weight of the ball charge, etc.), it is possible to determine the Wio (Operational Work Index) resulted from this operation. The Wio value can be extrapolated to the industrial scale with bigger correlation when compared to a regular Bond test made in bench scale (Wi or BWi, Bond Work Index).

MOPE relies on the software ***PROMIL.Wio*** to make such calculations. A ball filling of 25% proved itself to be the most appropriate (lower Wio) when it comes to a better use of the selective concept of the grinding (a bigger layer of free pulp favors the sedimentation of the material inside of the mill).

4.1.1 Selectivity and Energy Consumption

The ball filling level of 25% provides a more efficient grinding (**Table 4.1**).

Industrial experiences indicate that the optimum ball filling level is between 18 and 25%, as illustrated in **Figure 4.1**, extracted from the book: "***Engenharia da Cominuição e Moagem em Moinhos Tubulares"***, *A. Yovanovic, 2006*.

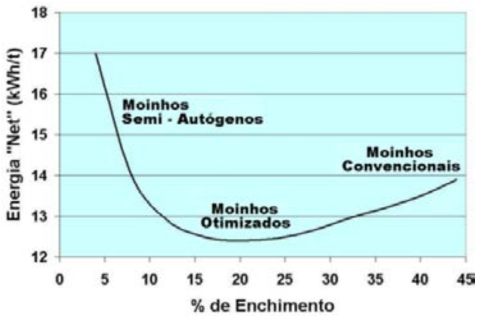

Figure 4.1 *– Filling level (Modelo Operacional)*

At **Table 4.1** it is observed that the obtained Wio for 30% of filling (26,5 kWh/t, tests 1 and 2) is higher than the one obtained using 25% of balls (24 kWh/t, tests 3 and 4). The current mill would generate a P80 of 245 µm, operating with 25 to 26% of balls, maintaining the current rate. In order to obtain a P80 of 211 µm, there is the option of increasing the ball charge to 30%.

The industrial implementation of this condition would generate a significant cost reduction on the operation of the mill, equivalent to US$4.331/year for each ton fed to the mill.

4.1.2 P80 and Size Distribution

Two grinding tests reached a P80 close enough to the one observed in the current plant (even with a different kind of grinding).

Without considering the chemical analysis, it is already possible to observe a significant difference between both grinding forms: selective or closed circuit with cyclones.

Even with the **same P80**, the grinding circuit closed with cyclones (plant) generates 35% of mass passing in 400#, while the selective grinding (open circuit and low ball filling) generates only 30%.

In **Figures 4.2** and **4.3** are displayed comparative graphs where it is observed that the selective grinding generates less ultrafine particles and distributes more mass in the intermediary sizes, more suitable for flotation.

The bigger quantity of ultrafines in the standard grinding is due to the effect of the circulating load, generated mainly by the inefficiency of the separation made by the cyclones (due to the difference in the specific gravity of the ores).

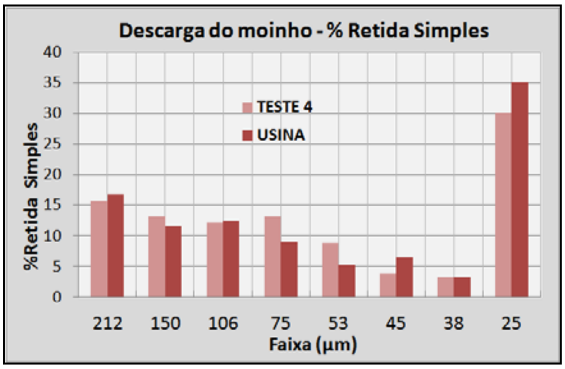

Figure 4.2 – *Comparative Size Distribution*

In addition to the gains from the reduction of the consumption of energy and balls, the selective grinding provides better liberation of the sulfides by applying more energy to it, once it has higher specific gravity and sinks to the bottom of the mill, unlike what happens in the standard grinding.

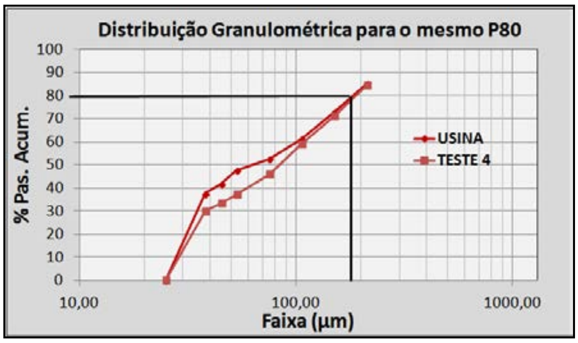

Figure 4.3 – *Comparative Size Distribution of different grinding methods for the same P80*

The P80, as indicative element of a comminution operation in heterogenic ores, is insufficient if it does not consider the different liberation degrees obtained by different grinding methods. The selective grinding spends less energy and gives a product of higher quality, when compared with the standard grinding method.

4.1.3 Granulochemical Distribution

In **Figure 4.4**, it is displayed a comparative graph where it can be seen that the selective grinding generates less ultrafine sulfides and distributes them in the intermediate sizes, more suitable for flotation.

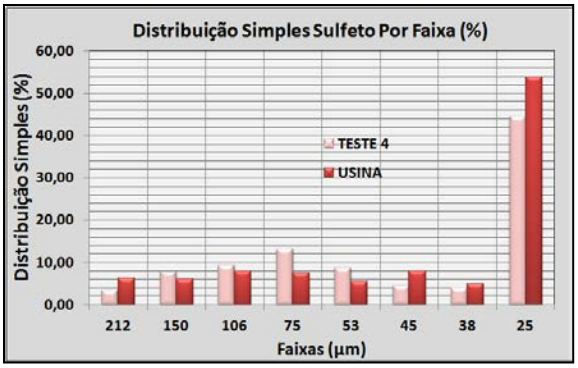

Figure 4.4 – *Comparative Granulochemical Distribution of different grinding methods for the same P80*

4.1.4 Grinding and Liberation

In possession of two digital microscopes (one of them displayed in **Figure 4.5**), it was made a liberation analysis of the products of the mill discharge, in order to show in which size the sulfide would be reasonably liberated from the gangue, for each grinding test (therefore, for each P80).

Figure 4.5 – *MOPE's digital microscope*

The liberation of the sulfides occurs in different sizes, due to the variation in the P80. Still, for the same P80 (test 4 compared with the test with the material coming from the plant), the selective grinding would lead to a better liberation of the sulfide.

Comparing the liberation of both selective and standard ground materials, it were obtained the results displayed in **Table 4.2**, where it can be seen that, in the selective grinding, the liberation of the sulfide begins to take place in coarser sizes than at the standard grinding.

***Table 4.2** – Estimated Liberation*

Análise de Liberação (Descarga do Moinho)			
microns	mesh	Usina	TESTE 4
µm	#	P80 195 µm	P80 191 µm
595	28	40,76	15,63
420	35		
300	48		(7,26)
210	65	(20,24)	
150	100		84,37
105	150		
74	200	59,24	
53	270		
44	325	(79,76)	(92,74)
37	400		
22	-400		

Sem Parênteses	% Massa
Entre Parênteses	%Cobre Acumulado

For the same P80, the selective grinding allows that 84,37% of the mass is ready to be floated for having acceptable liberation conditions, while only 59,24% of the mass generated by the current grinding form presents itself under the same conditions.

Still, in the values presented in parenthesis at the **Tabela 4.2**, it is shown that a bigger ammount of sulfide is ready to be floated in the test 4 (92,74%), in comparision to the values of the plant (79,76%), for the same P80.

4.2 Flotation

4.2.1 Evaluation Methods and Parameters

According to the *Modelo Operacional*, after reaching the minimum flotation time in the plant (effective residence time in the plant is bigger than or equal to the required to achieve full recovery of the stage), the metallurgical recovery is function of the proportion of concentrated mass. In other words, more concentrated mass equals to more recovery.

$$R = ALFA * Rcm^{BETA}$$ **(1st Law of the *Modelo Operacional*)**

where R is the metallurgical recovery of the evaluated substance (in this case, the sulfide) and Rcm is the mass concentration ratio (fed mass / concentrated mass).

ALFA is the theoretical point where this curve cuts the vertical axis (Recovery axis) and BETA represents the leaning of this curve. The smaller the BETA, more the curve is elevated and, so, with the same concentrated mass proportion (Rcm), the metallurgical recovery would be raised, characterizing the growth of selectivity of the flotation condition that was evaluated.

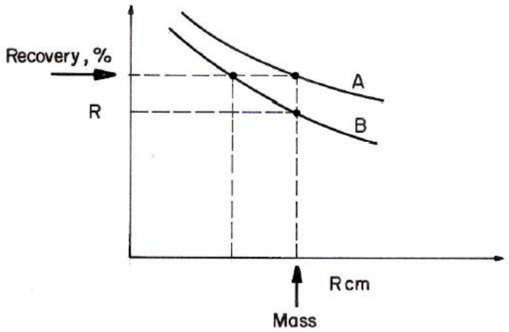

***Figure 4.6** – First Law of the Modelo Operacional (Flotation)*

Applying the first Law of the *Modelo Operacional* it is possible to evaluate different tests under the same perspective. So, the comparisons between different tests must consider the same proportion of floated mass.

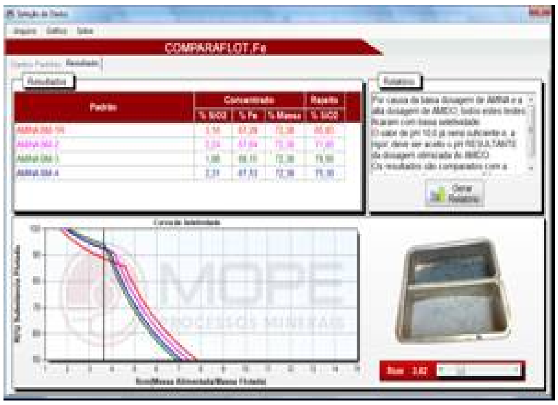

***Figure 4.6** – Software **COMPARAFLOT** (MOPETOOLS)*

4.2.2 Evaluation Plant/Tests

The flotation tests performed after the selective grinding, for a P80 similar to the current one from the plant, are here compared with a similar batch test that was performed with the pulp that feeds the Rougher stage in the plant.

It is highlighted the high enrichment of th foam in the selective grinding tests, when compared to the concentrates of the tests performed with the plant feed. It is due to the better liberation of the sulfides provided by the selective grinding.

At **Table 4.3**, are presented the obtained results, adjusted by the software COMPARAFLOT with the same proportion of floated mass (11,36%) and with the same feed grade.

Table 4.3 *– Comparison between the flotation results*

Teste	Beta	R% a 11,36% de massa
Teste 3: P80 211	-0,110	83,9
Teste 4: P80 191	-0,109	84,1
USINA: P80 195	-0,131	82,1

The tests fed with the material ground selectively present bigger selectivity (value of the selectivity index BETA), reason why the it obtains 2% of metallurgical recovery higher than the test performed with the material from the plant. Taking this gain as a reference, the additional profit was of US$8.750/year per ton/hour of processed ore in the plant.

5. CONCLUSIONS

The selective milling grinds with higher quality (granulochemical distribution) and generates more liberation, allowing an increase in the selectivity at the concentration operations of different kinds of ores, enhancing the metallurgical performance, in addition to significant reduction in costs at the grinding stage.

At the studied case, the reduction in the mill's OPEX and the increase of metallurgical recovery present a joint net profit around US$13.100/year for each t/h of ore processed in the plant.

The closed circuit paradigm is each day closer to its end. New projects could already consider this new kind of comminution. Plants in operation could have surprising benefits, especially nowadays, with the high costs of energy. The power applied to the mill would be reduced in 20%.

Other projects developed by MOPE follow the same concepts of selective comminution and pre-concentration, generating excellent results. The *Pedra de Ferro* project (BAMIN) obtained expressive results, being acknowledged by the magazine *Minérios & Minerales* and awarded with the prize *Prêmio Excelência*, in 2010.

TECHNICAL STAFF

MOPE Process Team – Philippe, Laís, Aline, Alexis and Pedro (at F. Gorceix). Still, with participation of Thaís, André and Noé, from the office team.

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