COMPARATIVE STUDY BETWEEN THE USE OF CYCLONE AND SPIRAL CLASSIFIER IN THE CLOSING OF GRINDING CIRCUITS[1]

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Abstract

Spiral classifiers and cyclones are the machines used in closing the grinding circuits in mineral beneficiation plants, with the latter having certain advantages that determine its use in large plants to the detriment of the spiral classifier, as is the case of iron ore treatment plants. However, the cyclone's classification efficiency is less than what is shown by the spiral classifier. This fact results in a greater specific consumption of energy during grinding because a large part of the flow relative to the closed circuit consists of particles that are well below the desired granulometry. As such, the new feed is limited because of a restriction in the increase of the circulating load. The circulating load should not ideally consist only of particles that still need to be grind (coarse particles) as this could lead to changes in slurry characteristics that would be detrimental to the grinding process, although the volume of fines in the spiral classifier underflow is sufficient to provide a suitable characteristic in most cases. Therefore, the ideal situation, in a grinding circuit, would be to have the efficiency of the spiral classifier, making use of cyclones, owing to the ease shown by the latter in simplifying the layout. The results of this study show that double stage cycloning could be, in many cases, an alternative for optimizing the classification of the grinding circuit, providing an increase in its capacity.

Key words: Grinding; Cyclone; Spiral classifier; Simulation.

ESTUDO COMPARATIVO ENTRE A UTILIZAÇÃO DE CICLONE E CLASSIFICADOR ESPIRAL NO FECHAMENTO DE CIRCUITOS DE MOAGEM

Resumo

Classificadores espirais e ciclones são os equipamentos utilizados no fechamento de circuitos de moagem em plantas de beneficiamento mineral, sendo que este último possui vantagens que determinam a sua utilização em usinas de grande porte, em detrimento do classificador espiral, como é o caso das usinas de tratamento de minério de ferro. No entanto, a eficiência do ciclone é menor que a apresentada pelo classificador espiral. Este fato implica em um maior consumo específico de energia na moagem, pois, grande parte do fluxo relativo à carga circulante é constituída de partículas que já se encontram abaixo da granulometria desejada. Ocorre desta forma uma limitação da alimentação nova por restrição no aumento da carga circulante. Não é ideal que a carga circulante seja constituída apenas de partículas que ainda necessitam ser cominuídas (partículas grossas), pois desta forma, poderia ocorrer alterações nas características da polpa que prejudicariam o processo de moagem, porém a quantidade de finos no underflow do classificador espiral já é suficiente para proporcionar uma característica apropriada na maioria dos casos. Logo, o ideal seria, em um circuito de moagem, ter-se a eficiência do classificador espiral, utilizando-se ciclones, devido às facilidades que este último apresenta para a simplificação do layout. Os resultados deste trabalho demonstram que o duplo estágio de ciclonagem pode, em muitos casos, ser uma alternativa de otimização da classificação do circuito de moagem, proporcionando um aumento de capacidade do mesmo.

Palavras-chave: Moagem; Ciclone;Classificador espiral; Simulação.

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1 INTRODUCTION

1.1 Presentation

The reduction of energy consumption in a grinding circuit is not restricted just to the changes made in mill, like the optimization of the ball load, for instance. An interesting fact that should be considered is that the grinder capacity, in closed circuit work, is also limited by the circulating load stipulated as the premise, which is generally around 250%.

This way, the energy used in grinding is influenced by the efficiency of the classification operation, which means that if the classifier is not working well, this will limit the new grinding feed rate because of the restriction to the circulating load.

By decreasing the circulating load and consequent reducing the volume of particles in the underflow whose granulometry is below cut size (which ought to be in the overflow), whether through by-pass reduction or improving the classification efficiency, the new circuit feed rate should increase until it once again reaches the circulating load stipulated in the design.

It is easy to see that increasing the new feed rate in the grinder will reduce the specific energy consumption (kW per ton of new feed). Another important feature in the optimization of classification is the fact that, for some ores, there is a tendency for a possible increase in the total recovery at the plant by reducing the generation of lime in the grinding (particles under 10μm in beneficiation of iron ore) through the decrease in the return of finer particles to the grinder and, as a result, a reduction in overgrinding.

It should be pointed out that the increase in the plant's recovery and the energy gain in grinding are clear tendencies. However, it should not be expected that the reduction of 5%, for example, in the mass of the fine particles from the circulating load will lead to a 5% increase in the mass of the new grinding feed, since we are "exchanging" fine particles for coarse particles inside the mill, and these larger particles also require more energy during grinding, considering that the degree of reduction will be greater when compared with smaller particles. It is also important to remember that it is not desirable to remove all of the fine particles in the mill feed because, that way, we are influencing the slurry characteristics, a fact that could be detrimental to the grinding process.

The high capacity, in terms of volume or area occupied by the cyclone, is the primary differential that determined its use in closed circuits during iron ore grinding, to the detriment of a more efficient classification device, the spiral classifier.

The production scales currently in use require large capacities from the processing equipment and the size of the spiral classifier makes its use somewhat difficult, given that its capacity is incompatible with that of the big-diameter mills usually employed.

Consequently, more than two spiral classifiers would perhaps be needed in closing the grinding circuit, making the layout more difficult and increasing the cost of the project's implementation.

According to Chaves and Peres (2002), "...whether or not to use a cyclone or spiral classifier is not a matter of indifference. The spiral classifier is more efficient than the cyclone", so, the ideal situation, in the grinding circuit, would be to have the efficiency of the spiral classifier, but using cyclones as they simplify the layout.

1.2 Objectives

This study aims to compare the use of cyclones and spiral classifiers as classification machines for closing the grinding circuits in a pilot plant, analyze the impact of use of each machine on the specific grinding consumption, and suggest a configuration for large-scale circuits in a way that would optimize energy consumption in relation to the new feed circuit.

1.3 Literature Revision

1.3.1 Cyclones and spiral classifiers

In iron ore grinding closed circuits, the most frequently used classification machine is the cyclone.

According to Chaves (2002):

> *"The cyclone has several advantages in relation to other equipment that provide the same service:*
> - *an increased capacity in terms of volume or occupied area,*
> - *ease of operational control,*
> - *relatively stable operation and ready for use in a short period of time,*
> - *easy maintenance, facilitated by a well-made project,*
> - *low investment, which makes it feasible to install back-up units and, therefore, increase the facility's availability.*

The cyclone transforms potential energy (pressure) into kinetic energy (movement) in which two particle separation mechanisms take place: sedimentation in the centrifugal field and drawing out the particles by ascending flow. In the cyclone, "smaller particles can exit through any one of the flows, depending on the quantity of other particles present, the quantity of particles in the mantle, and viscosity of the slurry, etc." (Chaves, 2002). The larger particles only manage to exit through the apex.

The spiral classifier is a kind of sedimentation basin in which the heavy particles quickly fall to the bottom and constitute the underflow.

The lighter particles have a slower speed than that of the fluid and are drawn out to the edge of the basin and spill out by the overflow.

The spiral classifier is more efficient than the cyclone in separating particles because of the differences in operating principles between the two machines.

According to Luz, et al., "spiral classifiers are most often used in small capacity facilities…Their use in large scale facilities loses out to the hydrocyclones because of their larger capacity and versatility."

1.3.2 Modeling of the grinding

The grinding process in a ball mill can be basically presented by the association of two functions, Breakage and Selection, or, to put it in a simpler manner, by individual treatment of each granulometric interval, through modeling of the granulometry resulting from the breakage of the particle size at each interval (Breakage Function) and the speed at which this breakage takes place for each of these sizes (Selection Function).

A simplified kinetic approximation based on the studies of Austin (1984) and Herbst and Bascur (1979), contained in the Usimpac 3.1 software from Caspeo, was used for calibrating the grinding model of this study.

This model uses the aforementioned principles of the Breakage and Selection Functions, but presents a simplification of the kinetic representing the two functions in a single equation:

$$B_{ij}S_j = K_i = K_1 d_i^{\alpha 1} = K_1.\exp\left(\alpha_1 \ln\frac{d_i}{d_1} + \alpha_2\left(\ln\frac{d_i}{d_1}\right)^2\right) \quad (1)$$

Where di is ... uals 1 ... ıd corresponds to the

2 MATERIAL AND METHODS

2.1 Step 1 – Pilot Tests

Using an iron ore sample, two grinding pilot tests were conducted by Vale's Research Technology Center at the Alegria Mine in Mariana, Minas Gerais.

In both tests the mill used, the ball load, the percentage of solids in the feed, and the critical speed percentage were all maintained.

Table 1: Mill Data – Pilot Test

Pilot Mill	
Inside diameter of mill (m)	1.54
Length of mill (m)	0.99
Percentage of ball fill (%)	33.00
Percentage of critical speed (%)	64.50
Power (kW)	22.06

In **Test 1**, the grinding circuit closing was done with a spiral classifier.

Table 2: Spiral Classifier Data – Pilot Test

Pilot Spiral Classifier	
Size (inches)	12
Slope (°)	16.00
Number of bars	4.00

In **Test 2**, the grinding circuit closing was done with a cyclone.

Table 3: Cyclone Data – Pilot Test

Pilot Cyclone	
Diameter (inches)	4.00
Apex (mm)	18.00
Vórtex (mm)	37.00
Entrance area (mm)	10 x 45
Conical section (mm)	765.00
Cylindrical section (mm)	555.00
Pressure (kgf/cm²)	1.00

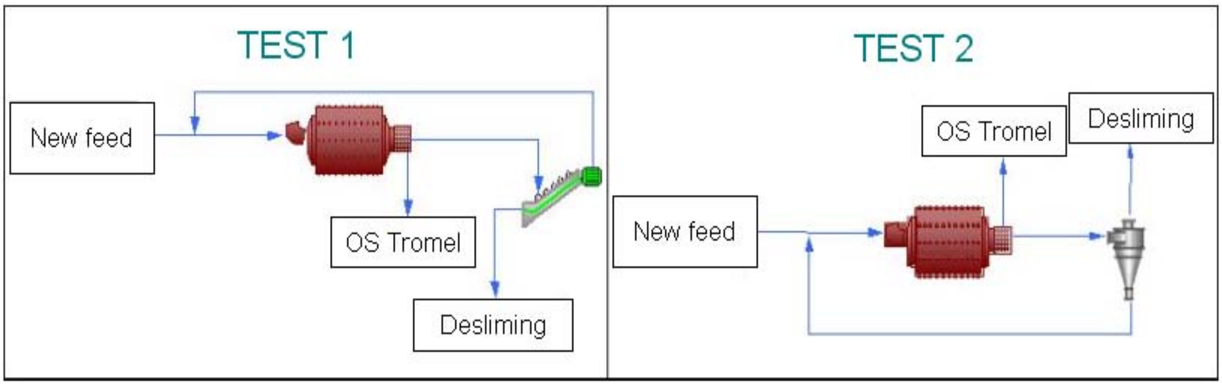

Figure 1: Simplified flow charts referring to pilot tests 1 and 2

The new circuit feed was shown in both tests, confirming that there were no big differences in the granulometry of the feed from one test to the other.

Table 4: New feed of the pilot tests

Size (mm)	% Cumulative Passing	
	Test 1	**Test 2**
12.5	**100**	**100**
10.00	94.40	96.89
8.00	89.70	92.11
3.40	73.70	74.57
2.40	71.00	69.19
1.00	64.40	61.62
0.500	58.80	56.69
0.150	50.00	48.89
0.106	45.50	44.68
0.044	27.30	27.41

The feed rate in each test was controlled so that the classification overflow reached a D95 close to 0.106 mm.

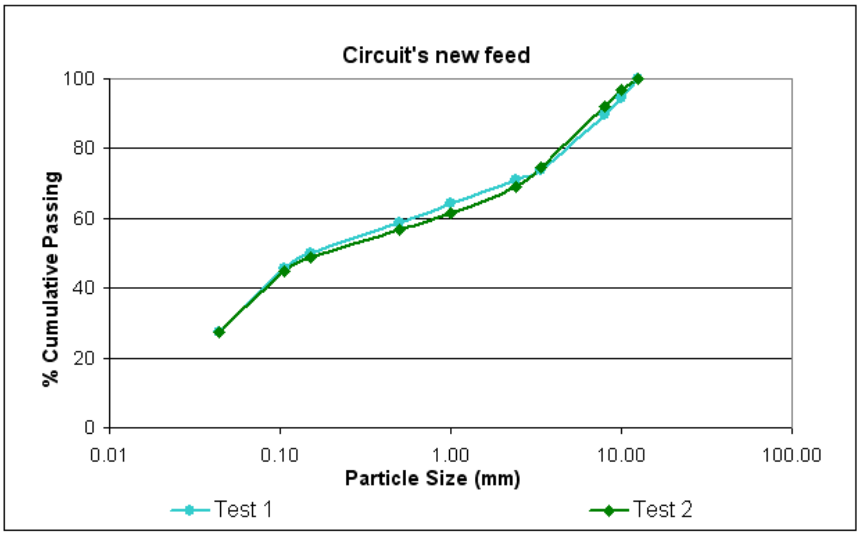

Figure 2: Granulometry of new feed in tests 1 and 2

2.2 Step 2 – Calibration and Simulation

The data collected in each test were reconciled through mass balance after which the mill was calibrated using a kinetic model (for being a kinetic model and there not having been significant changes in the mills, in slurry characteristics, or in the ore, the same mill calibrations were used in Tests 1 and 2).

The partition curves for the cyclone and spiral classifier, both in pilot scale, were then determined.

Using Usimpac software, version 3.1, made the mass balance, mill calibration and partition curve determinations for the classification equipment.

2.3 Step 3 – Simulation of the Partition Curve for a 26-inch Cyclone

The granulometric curve and density value in reference to the cyclone feed in Test 2 were sent to Krebs so the expected efficiency curve could be determined, through simulation, considering an industrial operation with 26-inch cyclones, a hypothetical feed rate of 1, 250 ton/h, and D95 in the overflow close to 0.15 mm.

A manufacturer was asked for the efficiency simulation of an industrial cyclone rather than using Usimpac because it was not deemed coherent to develop a scale for a 26-inch cyclone by using the calibration of a 4-inch cyclone.

In this way, the influence of the cyclone diameter was corrected in comparison with an industrial circuit since the 26-inch machine would be more appropriate than a 4-inch machine in this type of operation.

An efficiency curve was also requested in the event that a second cycloning stage was to be effected, with the underflow from the simulated first stage being used as feed.

2.4 Step 4 – Simulation of the Industrial Grinding Circuit

Simulations of the industrial grinding circuit were done with 1 and 2 classification stages, maintaining the grinder calibration (kinetic model) and, for the purpose of simplification; the efficiencies provided by the manufacturer for 26-inch cyclones were also retained.

3 RESULTS

3.1 Pilot Tests

In the pilot testing, the circuit with a spiral classifier showed a capacity of 3.50 ton/h, with a 3.03 ton/h circulating load (underflow mass), whereas the circuit with cyclone showed a 3.05 ton/h new feed with a 6.68 ton/h circulating load (underflow mass).

Table 5: Summary of Pilot Test Results

Mass Balance and Calibrations of the Pilot Tests					
Flows		Test 1 – Spiral Classifier		Test 2 - Cyclone	
		Calibrated	Mass Balance	Calibrated	Mass Balance
1	New Feed (t/h)	3.50	3.50	3.05	3.05
2	**Total Mill Feed (t/h)**	7.42	7.43	9.72	9.73
3	**Mill discharge (t/h)**	7.42	7.43	9.72	9.73
4	**Feed Classification (t/h)**	7.20	7.21	9.56	9.62
5	**OS Trommel (t/h)**	0.22	0.22	0.16	0.11
6	**Final Product (t/h)**	3.28	3.28	2.89	2.94
7	**Closed Circuit (t/h)**	3.92	3.93	6.67	6.68

The calculated power for the test mill under test conditions was 22.06 kW, in which case the specific consumption in Test 1 was 6.3 kW/ton/h, while in Test 2, it was 7.2 kW/ton/h.

The parameters for the calibration of the pilot mill are shown below:

Table 6: Parameters obtained in the pilot mill calibration

Specific rate of breakage per component (K1E)	Exponent 1 per component for the size dependance of K	Exponent 2 per component for the size dependance of K
0,65	0,65	-0,027

The premise of D95 being close to 0.106 mm in the classification overflow was used in both cases. In Test 1, 94.32% below 0.106 mm in the overflow was obtained and, in Test 2, this value was 93.43%.

In Test 2 (cyclone), the percentage below 0.106 mm in the classification underflow was approximately twice the value found in Test 1: 49.72% for Test 2 against 25.23% in Test 1.

Table 7: Granulometries in reference to the classification equipment

%Accumulated Underflow						
Size (mm)	Pilot Spiral Classifier			Pilot cyclone		
	Feed	Underflow	Overflow	Feed	Underflow	Overflow
3.4 mm	100.00	100.00	100.00	99.42	99.17	100.00
1 mm	97.18	94.82	100.00	97.15	95.89	100.00
0.5 mm	93.34	87.78	100.00	93.2	90.87	99.84
0.15 mm	70.32	46.33	99.05	73.51	62.85	97.72
0.106 mm	**56.67**	**25.23**	**94.32**	**63.09**	**49.72**	**93.43**
0.045 mm	32.77	7.83	62.63	34.45	20.12	66.99

A comparison of the partition curves obtained from the tests is shown below:

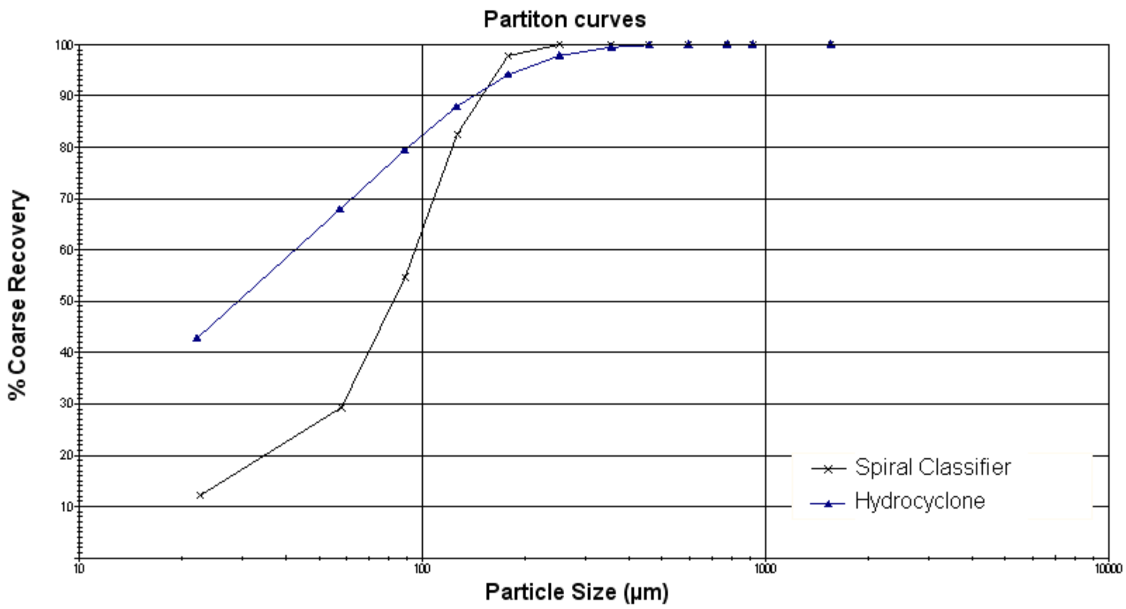

Figure 3: Partition curves of the spiral classifier and cyclone in the pilot test

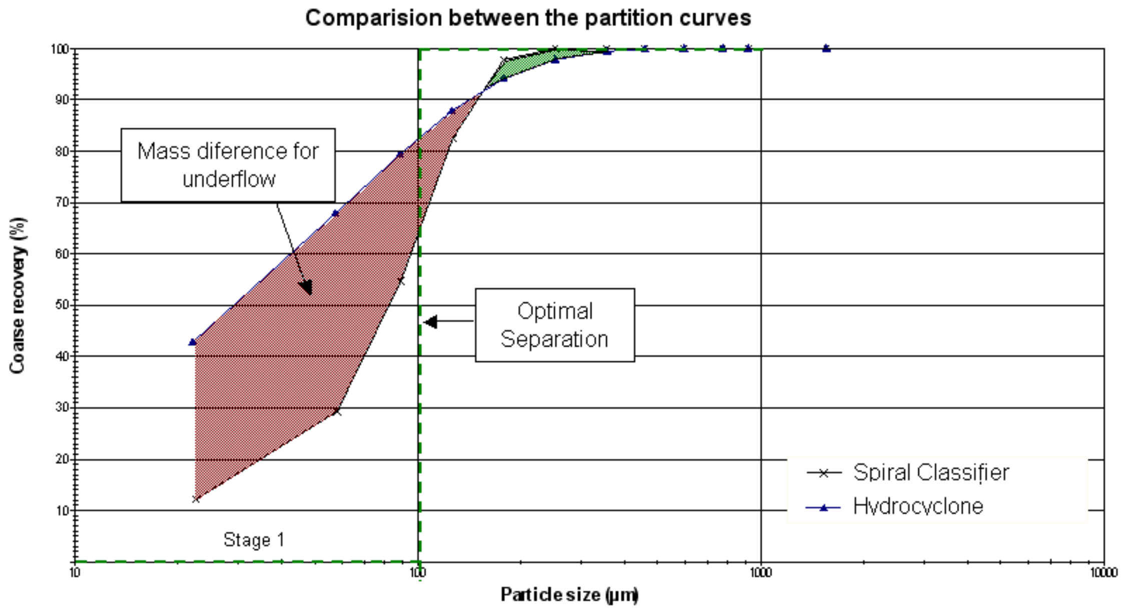

Figure 4: Comparison between the efficiency of the spiral classifier and cyclone in the pilot tests

The following graph shows the difference in efficiency presented by the spiral classifier in relation to the cyclone. It can be seen that the partition curve of the spiral classifier is closer to the perfect separation when compared to the curve from the cyclone.

3.2 Simulation of Industrial Operation

Below are the simulated partition curves for the 26-inch cyclone for 1 and 2 classification stages. The cut to overflow (D95 in the OF), which was considered as the premise, was 0.15 mm. The percentage of solids in the feed for both Stage 1 and

Stage 2 was 55% and the value used in the cyclone UF was 77% in Stage 1 and 75% in Stage 2.

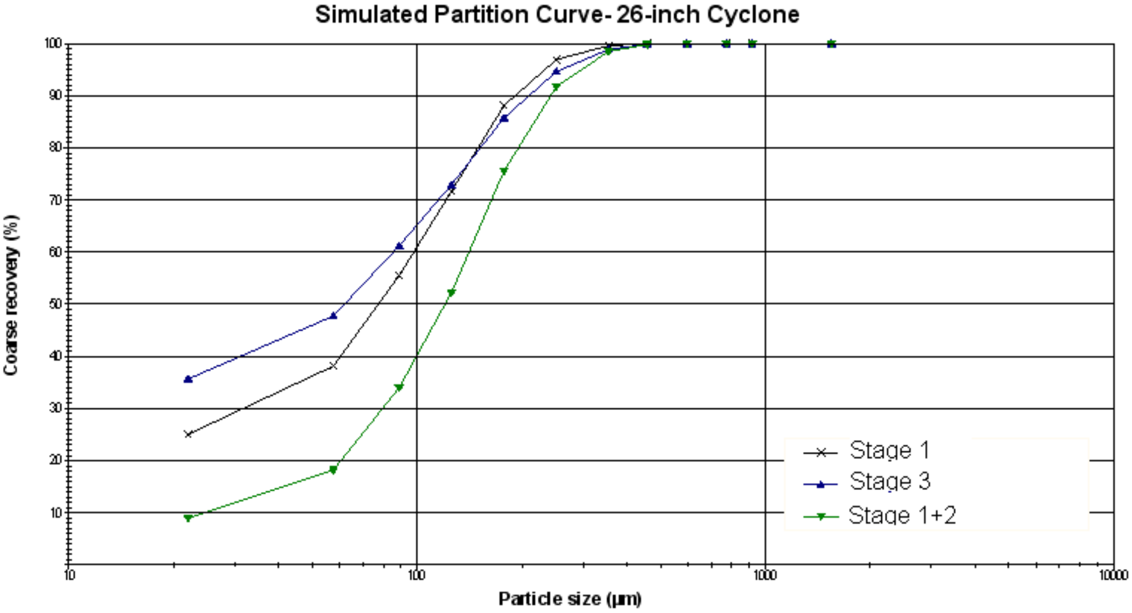

Figure 5: Simulated partition curves for a 26-inch cyclone

It was noted that the partition curve in the double stage cycloning (Stage 1+2) presented better efficiency than the curves relative to Stage 1 and Stage 2 separately. The figure below illustrates the difference in mass directed to the underflow when double stage cycloning was used.

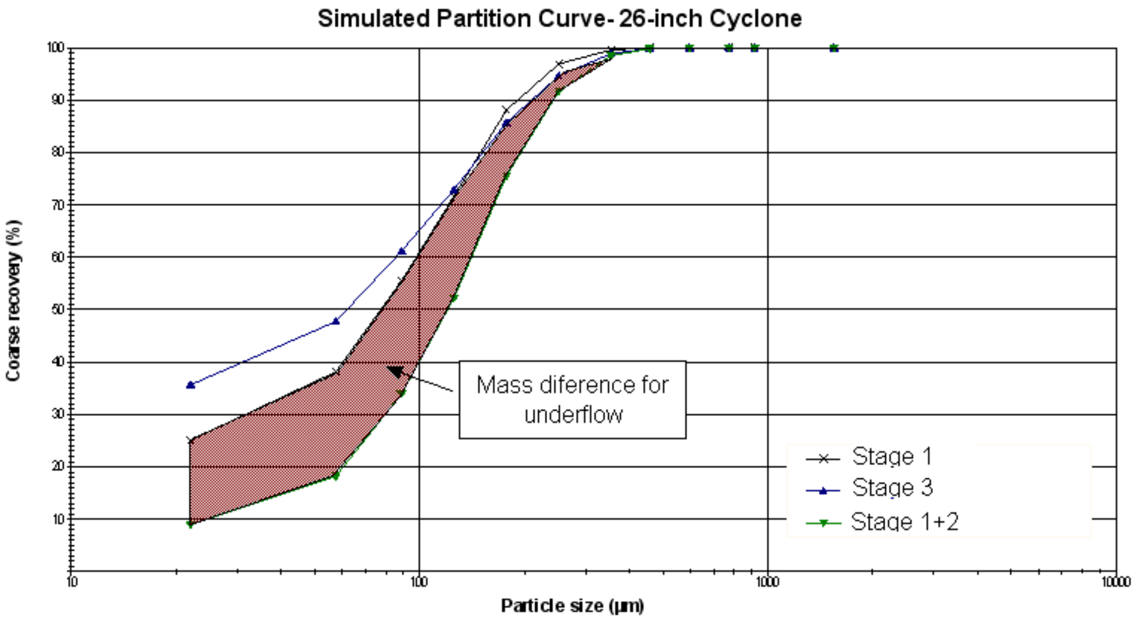

Figure 6: Comparison between the efficiency of a single classification stage and double classification stage for a 26-inch cyclone

Two grinding circuits were simulated from the partition curves derived from the 26-inch cyclone, using single and double classification, in accordance with the flow charts below.

The premise used was that of an 18 x 29-foot mill, with 70% critical speed, 35% fill, and calculated power of 4086.66 kW. The feed granulometry was the same used in Test 1.

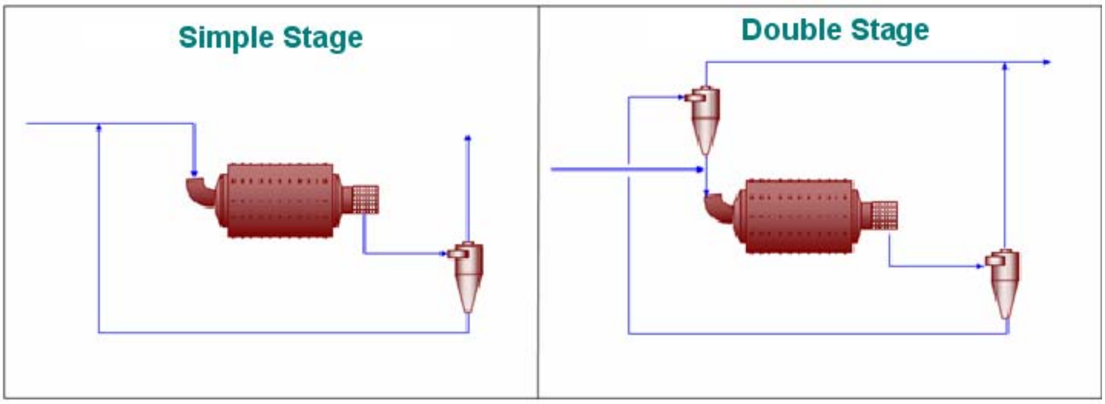

Figure 7: Simplified flow charts of the industrial circuits of simulated grinding

The following table summarizes the values obtained from the simulation:

Table 8: Results of Industrial Simulation

Industrial Circuit Simulation				
		Double Stage		
Parameters	1 Stage	Restriction by New Feed	Restriction by Mass in the UF	Restriction by % of Closed Circuit
%>0.15 in the Overflow	7.50	7.69	7.46	7.53
New Feed	900.00	900.00	985.00	1020.00
Mass in the Underflow	1813.88	1235.99	1812.49	2084.29
Closed Circuit	202.00	137.00	184.00	204.00
% Solids in Total OF (Feed Desliming)	---	28.64	24.71	23.31
Specific consumption in the mill (kw/ton/h)	4.54	4.54	4.15	4.00

4 DISCUSSION AND CONCLUSIONS

The results from the pilot tests demonstrate the superiority of the spiral classifier in relation to the cyclone in terms of separation efficiency, which is reflected in the efficiency of the circuit as a whole (see Table 5).

In the spiral classification test, the reduction in the volume of fine particles in the total mill feed (new feed plus the closed circuit) did not change the characteristics of the slurry in such a way as to influence the grinding process. This observation can be proven by confirming that the calibration of the mill remained the same in both Tests 1 and 2 (Table 6).

A simplification was used by keeping the 26-inch cyclone partition curves fixed during the industrial circuit simulation. Therefore, the values shown in Table 8 should be seen as tendencies and not as absolute values.

The tendency for an increase of efficiency in grinding is confirmed by observing the similarity between Figure 4 and Figure 6, which determines that the use of double stage cycloning, to a certain extent, simulates the gain provided the spiral classifier operation when it was compared with the cyclone in the pilot test. Although it cannot be stated that a double stage cycloning will give identical results to those of a spiral classifier, the reduction in specific energy consumption in grinding is certainly undeniable for the ore in question.

Nonetheless, these analyses depend on the new granulometry of the feed and the kinetic of the grinding, which is to say on the characteristics of the ore, because, in the event that the grinding process fails to generate a reasonable amount of fines, there is a risk that the optimization of the classification could significantly change the characteristics of the slurry and negatively influence the grinding process. However, in this case, a spiral classifier also could not be employed, given that this fact is unlikely.

The use of two classification stages results in the reduction of the percentage of solids in the slurry with regard to the final product of the grinding circuit. However, the simulations reveal that this reduction is not a point of concern since the feed in the next step (desliming), in iron ore processing, is done with close to 20% solids.

Therefore, avoiding adding water from the classification cyclone overflow to the desliming feed back, has already presented a percentage of solids close to the value normally used, as shown in Table 8.

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BIBLIOGRAPHY

1 CHAVES, A. P.; Teoria e Prática do Tratamento de Minérios – Volume 1. 2ª. Edição. São Paulo, São Paulo: Signus Editora Ltda., Brasil Mineral: 1999. 265 p.
2 CHAVES, A. P.; PERES, A. E. C. Teoria e Prática do Tratamento de Minérios – Volume 3. 2ª. Edição. São Paulo, São Paulo: Signus Editora Ltda., Brasil Mineral: 1999. 265 p.
3 SILVA, K. C.; SOUZA, E. S.; FIGUEIREDO, J. C.; MENDES, P. J. S. Determinação e Utilização das Funções Quebra e Seleção na Moagem de Minério de Ferro, In: XXXVII Seminário de Redução de Minério de Ferro e Matérias-Primas, VIII Simpósio Brasileiro de Minério de Ferro, 2007, Salvador. Anais…São Paulo: Associação Brasileira de Metalurgia e Materiais, 2007.
4 BERALDO, J. L. Moagem de Minérios em Moinhos Tubulares. São Paulo, São Paulo: Editora Edgard Blücher Ltda, 1987, cap.1, p 6.
5 AUSTIN, L.G. KLIMPEL, R.R., and LUCKIE, P.T., Process Engineering of size reduction: ball milling. AIME, New York, 1984, Chap. 4.8.
6 BRGM, Caspeo, USIM PAC.: Unit Operation Model Guide version 3.1.1.0. Caspeo. 3 avenu Claude Guillemin – BP 6609, 45060, Orleans, Cedex 2, France. BRGM is the author of USIM PAC. Copyright BRGM 1986-2004 Caspeo 2004-2006
7 LUZ, A.B., SAMPAIO, J.A., ALMEIDA, S.L.M., *Tratamento de Minérios*. 4.ed. Rio de Janeiro: CETEM/MCT, 2004. 867p