http://dx.doi.org/10.4322/2176-1523.1166

STATISTICAL EVALUATION OF SCRUBBING AND SCREENING OPTIMIZATION IN BAUXITE PROCESSING

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Abstract

In the Miraí processing plant (Votorantim Metais), bauxite is processed with an average feed of 1,000 t/h in a circuit with crushing, scrubbing and screening stages. Two plant unit operations needed optimization: (1) The scrubber promoted not only the attrition and disaggregation of bauxite, but was also its griding; (2) The screened fine products had material with significant amounts of available aluminium (AA) and low reactive silica (RS) contents. In this work, modifications were introduced in the scrubber and screening circuit in order to improve the plant performance. A pulp lifter was installed in the scrubber. In addition, the apertures of the primary and secondary screens were changed. Statistical univariate analysis was used to support the process gain due to the introduced modifications. According to the variance analysis (ANOVA), there was no loss of product quality since the resulting AA, RS and iron (Fe) contents agree with the metallurgical specification and the previous results before the optimization work. The mass recovery increased by 3.88%, which means a gain of 43 t/h for the operation.
Keywords: Bauxite; Scrubbing; Screening; Statistical analysis.

AVALIAÇÃO ESTATÍSTICA DA OTIMIZAÇÃO DAS OPERAÇÕES DE ATRIÇÃO E PENEIRAMENTO NO BENEFICIAMENTO DE BAUXITA

Resumo

Na planta de beneficiamento de Miraí (Votorantim Metais), bauxita é processada com uma alimentação média de 1.000 t/h em um circuito composto por britagem, desagregação em um *scrubber* e peneiramento. Duas operações da planta necessitavam otimização: (1) O *scrubber* promovia não só a atrição da bauxita como também sua fragmentação; (2) O peneiramento descartava material com quantidade significativa de alumínio aproveitável (AA) e baixo teor de sílica reativa (SR). Neste trabalho mudanças foram introduzidas no *scrubber* e no circuito de peneiramento para aprimorar o desempenho da planta. Um sistema de descarregamento foi instalado no *scrubber*. Além disso, a abertura das peneiras primárias e secundárias foi modificada. Análises estatísticas univariadas foram usadas para confirmar o ganho do processo devido às modificações introduzidas. De acordo com a análise de variância (ANOVA), a qualidade do produto não piorou, pois os teores de AA, SR e ferro (Fe) estão de acordo com a especificação metalúrgica. A recuperação mássica aumentou em 3,88%, o que significa um ganho de 43 t/h para a operação.
Palavras-chave: Bauxita; Atrição; Peneiramento; Análise estatística.

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1 INTRODUCTION

Aluminium (Al) is the third most abundant element in the Earth's crust, and bauxite is the commercially most relevant material that comprises this metal. Bauxite contains aluminium hydroxide minerals [gibbsite - $Al(OH)_3$, diaspore - α-AlO(OH) or bohemite - γ-AlO(OH)] and impurities such as clay [especially kaolinite - $Al_2Si_2O_5(OH)_4$], goethite (FeO(OH)), rutile (TiO_2), hematite (Fe_2O_3) and quartz (SiO_2) [1-3].

Brazil is the world's third largest producer (12.7%), after Australia (29.9%) and China (18.2%) [4]. Most of the Brazilian bauxite processing plants employ operations of comminution, classification and solid–liquid separation. A very few processes include gravimetric concentration in order to remove silicates, or magnetic separation to decrease the amount of Fe-bearing minerals [1,5,6].

The product of the bauxite processing feeds the Bayer metallurgical process for alumina (Al_2O_3) production. The Al_2O_3 is then processed by means of Hall–Héroult igneous electrolysis for aluminium (Al) production. In order to feed the metallurgical process, the bauxite needs to display available alumina content (AA) > 30%, reactive silica (RS) < 5% and iron content (Fe) < 30%. Likewise, the Al_2O_3/SiO_2 ratio must be above 10 [1].

The Miraí bauxite plant is located in the Zona da Mata region in Minas Gerais state, Brazil. At this location, bauxite formation profiles have occurred as a result of descending drainage of sedimentary acidic rocks [1,7]. These deposits are mainly composed of gibbsite, kaolinite, quartz (SiO_2) and ilmenite ($FeTiO_3$). There is huge variation in the ore properties within the same ore body, due to variation of the intensity of the laterization process along the slope [8].

It is a common industrial practice to introduce project modifications in order to improve the operation product in terms of mass recovery or content of interesting elements in bauxite plants [6,9,10]. In Bergerman and Chaves' works [9], for instance, the modifications were the installation of spiral concentrators in the bauxite processing plant of the Itamarati de Minas plant with the aim of recovering the profitable fine fraction material that had been discharged. However, the details of most operational works are not published.

The Miraí plant has been operating since 2008 with an average feed of 1,000 t/h. Figure 1 presents the Miraí plant flowsheet. After two crushing steps, the material is fed into the scrubber, which promotes disaggregation of the ore and the removal of clay minerals rich in reactive silica [11]. Some operational problems were observed in the Miraí plant that motivated this work: (1) when the scrubber was fed with gneissic type ore (normal bauxite variation on site), it promoted not only disaggregation of the bauxite but also its griding of the ore. This fact usually results in significant material loss; (2) the first module of the secondary screen was overloaded; (3) finally, there was a low recovery of fine ore, which exhibited considerable AA grade in the fraction between 0.84 mm and 0.54 mm (from 34.0 to 41.0%), low RS content (<3.5%) and low Fe content (<15%).

The purpose of this study was to statistically analyse the influence of the project modifications carried out in the scrubber and screening circuit of the Miraí plant, considering the quality of the final product and the plant mass recovery.

2 MATERIALS AND METHOD

2.1 Plant Modifications

In order to prevent the retention of coarse gneissic particles (Figure 2) in the scrubber, an unloader system was installed, composed of a grate and a pulp lifter.

In addition, lifters and grates were installed in the scrubber with the purpose of quickly transporting the material out of the equipment (Figure 3). This was intended to decrease the pulp volume inside the scrubber and, as a result, decrease the residence time of the ore therein.

In addition, the screen openings were modified as shown in Figure 4. The screen openings of the first stage

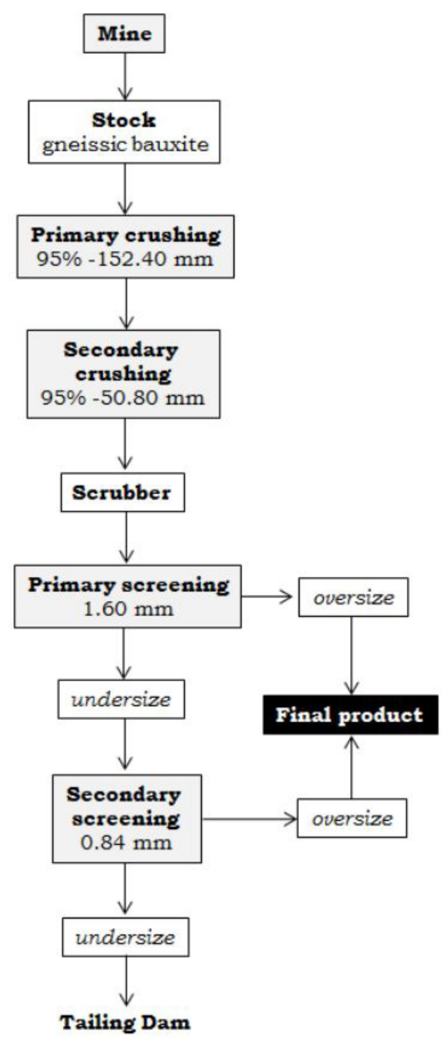

Figure 1. Simplified Miraí plant flowsheet.

were increased while those of the second were reduced. Central cleats down the spray lines were also installed on the screens. These cleats are formed from polyurethane materials with dimensions 305 mm long x 38 mm wide x 50 mm thick. The objective of these changes was to improve the ore washing and increase the bauxite residence time in every module.

Figure 2. Coarse gneissic particles retained inside the scrubber.

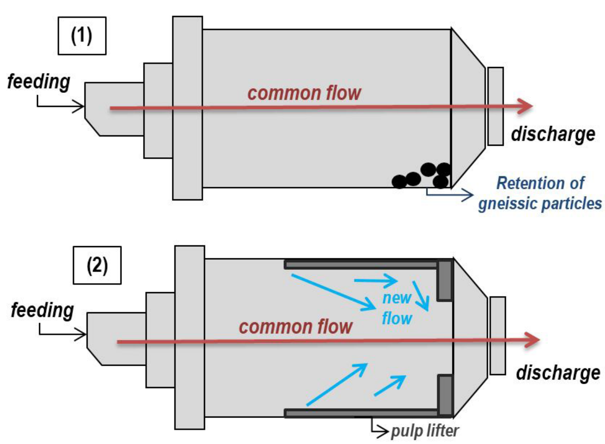

Figure 3. Unloader system installed into the scrubber.

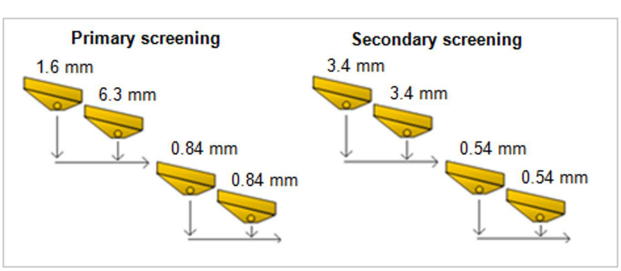

Figure 4. Screening circuit (1) before and (2) after the opening modification.

2.2. Sampling and Product Characterization

The effect of the introduced modifications was investigated by comparing two groups of samples collected before (February 2013 to July 2013) and after the project (December 2013 to March 2014). The sampling was accomplished on the conveyor belts located just after the secondary crushing and after the two-step screening (final product).

Samples composed of 135 L of material from the plant feed and 180 L of final product pulp were taken weekly using buckets and paddles. The material was dried, homogenised and divided into 5 kg portions. The collected samples were submitted to chemical (AA, SR and Fe) and particle size analyses. The particle size analyses was performed by wet screening with apertures of 50.8, 25.4, 1.68, 0.841, 0.707, 0.595 and 0.420 mm. Another portion of the sample was pulverized and submitted to X-ray fluorescence (MiniPal equipment) to determine the total SiO_2 and Fe_2O_3 contents. For the AA analyses the samples were leached with sodium hydroxide (NaOH) and the leached pulp was centrifuged (3,000 rpm) and filtered. The AA content in the supernatant was then analysed by titration (Metrohm) with sodium glutamate. The solid residues of this step were leached with hydrochloric acid (HCl) and the pulp centrifuged (3,000 rpm), collected, homogenised and filtered. The supernatant SR content was analysed by inductively coupled plasma mass spectrometry (ICP-MS), through the ALCAM pattern.

2.3 Statistical Analyses

Variance analyses (ANOVA) [12] was used to evaluate, separately, as the univariate statistical method, the effect of the operation modifications on mass recovery, as well as AA, SR and Fe contents. ANOVA was performed using a completely randomized design. The significance level (α) used was 0.05. The statistical analyses was accomplished in two groups of results that were collected before and after plant modifications, each one comprising, normally, 137 points. The normal confidence intervals were also calculated for the mass recovery. In addition, the particle size distributions of the samples, before and after modifications, were compared using t confidence interval (3 samples) with $\alpha = 0.05$.

3 RESULTS AND DISCUSSION

A descriptive analyses of the collected data dispersion was graphically performed by means of boxplots (Figure 5). Regarding the mass recovery, an average dispersion in every month was observed, indicating that the ore particle size distribution has no significant variation within the same month. The data distribution was asymmetric and the presence of outliers was observed. For the months of February and March, these points were very close to each other, suggesting the occurrence of anomalous daily variations.

However, in May the outlier was inconsistent with the ore behaviour regarding dispersion, median and interquartile ranges. This may indicate the occurrence of sampling or data recording errors corresponding to this point.

Anomalous variations might be related to several factors such as: daily failures in primary or secondary screening; variation in the amount of gneissic fragments in the bauxite feed; unexpected increase in the plant feed that affects the ore crushing, scrubbing and screening (in February 2013, for instance, the average feed was 1077.9 t/h with a standard deviation of 373.1 t/h, showing a high feed variation); temporary defects in sieve spray washing; and screening inefficiency. All of these result in a final product that is full of large particles, or elevated amounts of clays. After the plant modifications, the average values of mass recovery are higher in three of the four considered months. However, the data dispersion is similar before and after the modifications. In addition, the outliers are relatively close to the upper and lower limits.

Concerning the AA boxplots (Figure 5), a large AA content variation can be seen before the project for all the months analysed. Although the distribution is considered to be relatively symmetrical within a month, the AA grade does not display a behaviour pattern and large variations for the considered months can be observed. After the introduced modifications, the AA content became more dispersed and asymmetrical.

Thus, the descriptive analyses (Figure 5 and Table 1) indicate that the processed bauxite exhibits an intrinsic variability. According to [8], this variability is a result of the ore geological formation in the Miraí region, in which there is a huge variation of the ore properties within the same ore body and between different ore bodies due to differences in the intensity of the laterization process.

Table 2 presents the ANOVA results for the comparison of AA, RS and Fe contents, as well as mass recovery before and after the plant modifications. The Shapiro–Wilk test was used to validate the data as normal.

The hypotheses considered for all analyses were: H_0 (there is no evidence of the project's influence on the analysed parameter) and H_1 (there is evidence of the project's influence on the analysed parameter).

For the AA variance analyses, the p-value found was 0.07 (Table 2). This value is greater than the chosen value (0.05), which indicates that the H_0 hypothesis is accepted. Therefore, the project modifications did not influence the product AA grade.

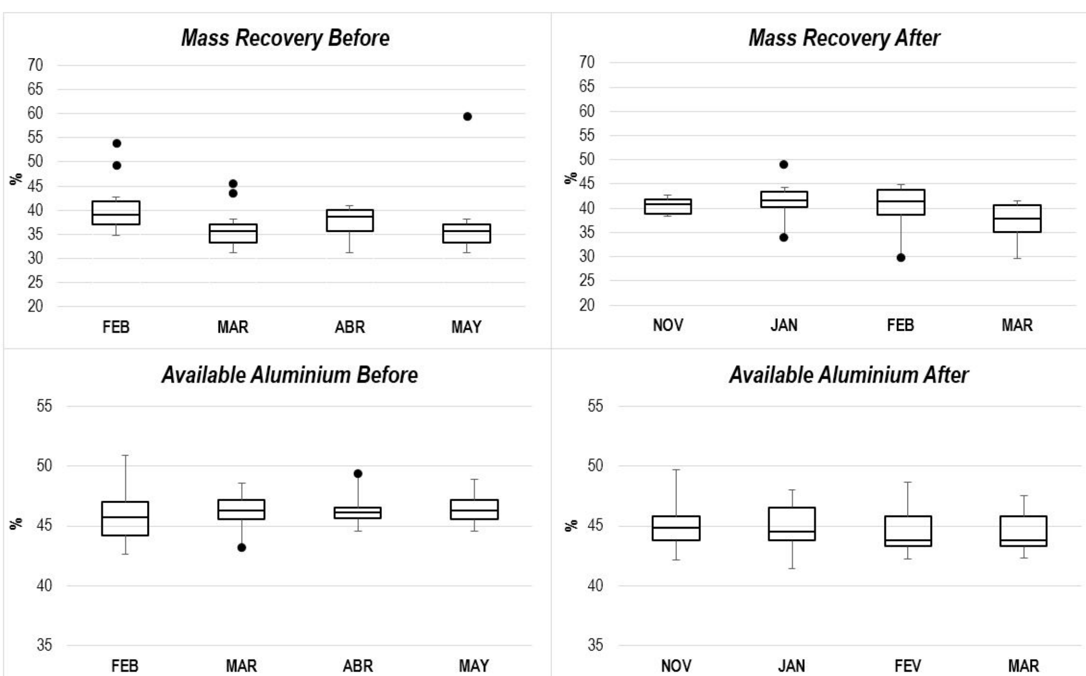

Figure 5. Boxplots of mass recovery and available aluminium (AA) content before and after the operation modifications.

Table 1. Descriptive statistics results

Detail	AA		RS		Fe		Mass Recovery	
	Before	After	Before	After	Before	After	Before	After
Average (%)	45.50	45.10	2.32	3.00	13.58	11.71	37.54	41.42
Variance (%)	2.82	4.30	0.34	0.39	1.78	2.12	18.04	16.19

Regarding the RS and Fe content, the p-value (0.0000) is less than 0.05, so H_0 is rejected. This result indicates that there was an increase in the product RS grade from 2.32% to 3.00% (Table 1) after the plant modifications. However, the RS content was preserved within the Bayer process specification (<5%). On the other hand, the Fe grade decreased from 13.58% to 11.71%, indicating an improvement in the plant product quality.

Similarly, the p-value yielded for the mass recovery (0.0000) is much lower than the chosen value (0.05). This outcome implies that the changes carried out in the scrubber and screen increased the plant mass recovery. In order to validate that this increase in the mass recovery resulted in a real gain for the plant, normal confidence intervals were calculated. Considering 95% of confidence, the mass recovery is [38.4 ± 1.0]% before and [41.2 ± 0.7]% after the modifications. The average mass recovery presented an increase of 3.9%. Considering 450 t/h of product, there was a production growth of 43 t/h.

Figure 6 presents the particle size distribution of the products of the primary and secondary screens before and after the design modifications. The curves constitute an average (and confidence interval) of three weeks of sampling before July 2013 and after December 2013.

There is a reduction of slime production in the primary screen as well as higher slime retention in the secondary screen after the project. This result indicates that the installation of the pulp lifter system at the scrubber decreased the ore comminution and reduced the ore residence time in the equipment; these findings are confirmed by the increase of coarse particles in the size distribution of the product of the primary screen. In addition, the secondary screen overload decreased, improving the material cleaning and clay mineral removal.

However, there is an overlap of the t confidence intervals for the particle size distribution curves in both sieves, before and after the project (Figure 6). Accordingly, although the size distribution curves are different, it is not

Table 2. ANOVA results

	Source of Variation					
	AA			**RS**		
	Between groups	**Within groups**	**Total**	**Between groups**	**Within groups**	**Total**
SS	11.55	1033.01	1044.56	23.92	83.71	107.63
df	1	272	273	1	233	234
MS	11.55	3.80		23.92	0.36	
p-value		0.07			0 .0000	
	Fe			**Mass Recovery**		
	Between groups	**Within groups**	**Total**	**Between groups**	**Within groups**	**Total**
SS	169.32	401.4	570.72	1032.71	4655.47	5688.18
df	1	211	212	1	272	273
MS	169.32	1.90		1032.71	17.12	
p-value		0 .0000			0 .0000	

Note: SS: sum of squares, df: degrees of freedom, MS: mean of the square, p-value: probability.

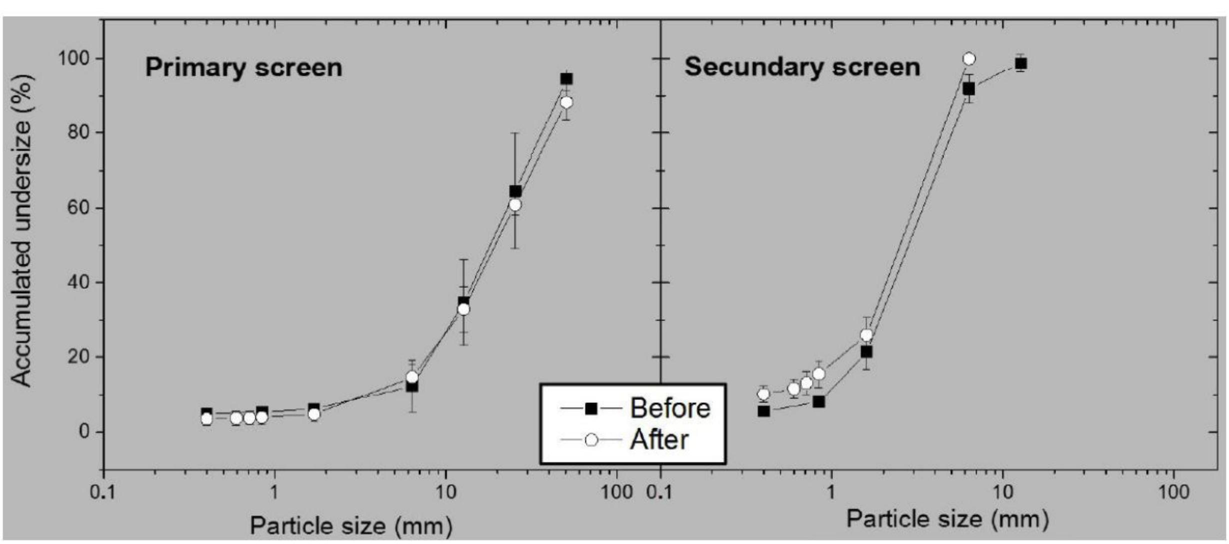

Figure 6. Particle size distributions for primary and secondary screens before and after the project.

possible to statistically support, with a confidence level of 95%, that the modifications resulted in particle size distribution changes.

4 CONCLUSIONS

The effect of the Miraí plant modifications to the scrubbing and screening steps on the AA, SR and iron contents, as well as mass recovery, was statistically analysed. According to the descriptive analyses (boxplots), the bauxite exhibits an intrinsic variability in its AA content due to the local geological context, which cannot be related to the plant modifications introduced.

The ANOVA analyses revealed that the plant adaptations did not reduce the quality of the processed product since the AA grade was not affected. The RS content increased from 2.32% to 3.00%; however, the final value is in agreement with the Bayer process specification (<5%). In addition, the iron content of the product decreased from 13.58% to 11.71%.

Lastly, the plant mass recovery increased by 3.88%. Therefore, the project resulted in a gain of 43 t/h in product production. Univariate statistical analyses, even though considered a simple method, can be used for product quality control in a plant, facilitating quick and daily decisions, and making them more reliable.

Acknowledgements

The authors acknowledge the Votorantim Metais Company, which permitted the project development, carried out the chemical analyses and authorized the publication of the results. We are also grateful for the collaboration of the engineer Everton de Melo Dias, and the chemical laboratory technicians of Votorantim Metais (Mirai and Itamarati de Minas operation).

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Received: 8 June 2016
Accepted: 3 Aug. 2016