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BAUXITE BENEFICIATION MODIFYING FACTORS: A CASE STUDY

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Abstract

The Alumina Rondon project consists of a bauxite mine, beneficiation plant and an alumina refinery, along with its associated logistics. It will be installed in the Rondon do Para municipality in the Para state – northern Brazil. The refinery production capacity is three million tons of alumina per year. For this production, 12 million tons of ROM will be beneficiated, resulting in 8 million tons of washed bauxite. The beneficiation process will occur in a single line plant at 1.500 tons per hour. During the early stages of the project engineering, a characterization study was conducted. Such a study consists in the evaluation and quantification several key aspects of the material needed to proper equipment sizing. To confirm the values of the laboratory scale studies, an industrial scale test was done in the operating bauxite beneficiation plant installed in the Mirai municipality located in the state of Minas Gerais – southeast Brazil. The test was done with two bulk samples obtained from two pilot scale mines. The main aspects evaluated were: product loss, product contamination and effects of residence time in the scrubber.

Introduction

To produce aluminium, it is necessary to refine alumina. In the year of 2013 the total smelting grade alumina (SGA) production was 100 million tons. In the last ten years, the SGA production has doubled. [1] Alumina is refined from bauxite, and usual grades range from 35% to 55% of Available Alumina (AA) in these bauxites. From the circa 200 million tons of bauxite annually refined nearly 20% [2 & 3] are from washed bauxite.

In the Bayer process, the Available Alumina (AA) contained in the bauxite is digested. Along with the AA digestion the Reactive Silica (RS) digestion also occurs. The reactive silica (RS) depends on the digestion temperature. At 150° C (or low temperature process) only the kaolinite is digested, at 250° C (high temperature process) the digestion of quartz also occurs. After its digestion, the reactive silica precipitates as Dessilication Product (DSP) and immobilizes Sodium cations which will have to be replaced by the addition of NaOH – one of the main costs of Alumina production. Thus, the amount of NaOH makeup is directly related with the amount of reactive silica in the ore. So, for bauxite to be considered viable, the amount of AA must justify the consumption of NaOH by the RS. In a first approach, the ratio AA/SR (or module) must be higher than 10.

In this specific case, samples of the Rondon do Para bauxite were analyzed. The ROM grades, are typically 30% AA, 8% RS with a module of 3.8. If this material is wet screened, in ideal conditions, the fraction coarser than 37 μm has 40% AA and 3% RS, with a module of 13. The fraction finer than 37 μm has 7% AA, 20% RS and a Mass Recovery (MR) of 30% of the ROM. The Table 1 – ROM, Product and Reject grades and mass recovery summarizes the values.

Table 1 – ROM, Product and Reject grades and mass recovery

	ROM	Product	Reject
AA	30%	40%	7%
RS	8%	3%	20%
MR	100%	70%	30%

This fact justifies the beneficiation for this specific bauxite. Kaolinite is a clay mineral and is naturally thin. The beneficiation process aims to reduce the particles size to expose or liberate the clay, disaggregate and separate it from the coarser particles. One point of attention is the comminution process. As the separation is done by size, if this process is too intense, naturally coarser particles will be broken and separated as reject.

Given the above, the responsibility of the processing plant is not the product grades or mass recovery, but to efficiently separate the coarse particles from the fine ones. The quality of this separation may be evaluated by the amount of natural coarse fraction lost to the reject (product loss) and the amount of natural fines present in the product (product contamination). The AA and RS grades are consequence of the natural qualities of the ROM or the process route, having the operation little influence on those values. The same applies to the product Mass Recovery (MR), as it is a natural characteristic of the ROM.

Beneficiation unit operations

Crushing

The beneficiation of the Rondon do Para bauxite begins when the mine trucks dump the material in the primary crusher hopper. This hopper may receive simultaneously material from six 32 ton trucks and a loader. The crushing area is the first step in the beneficiation process, and, as such, it must be able to handle the natural variability of the ROM: trucks dump intermittently and ore blocks vary in top size and size distribution. With that, the instantaneous capacity of the crushers must be high enough to deal with this variability and to form an intermediate stock pile to be consumed in case of a crushing shutdown.

The crushers selected for the Alumina Rondon beneficiation plant are from the sizer type. These crushers have been successfully used in bauxite beneficiation, especially with the Amazon bauxite.

They have several desired characteristics for bauxite processing, such as: self-cleaning, rotate at low speed, fine particles pass without being crushed, dynamically balanced, its dimensions are smaller than equipment with similar production rates, may be installed on rails, etc. These characteristics are beneficial to deal with some of the main bauxite processing issues by reducing problems with the material stickiness and over-crushing avoiding product loss. The other characteristics save investments in building and ease maintenance.

The largest block expected from the mine should not exceed 800 mm, however, if a larger block is dumped into the primary crusher, its geometry and drive make the block rotate until it can be grasped by the teeth of the crusher and be comminuted. This type of event should be an exception, with the mining operation being responsible for preventing these blocks from being fed to crusher. Even though this is not detrimental to the equipment, it causes momentarily reductions in the production rate and should be avoided.

The product of the primary crusher shall not exceed 350 mm and this material will be directly fed into the secondary crusher which reduces the ROM to less than 75 mm. Since both equipments are low in height, they may be installed in the same building with the secondary just below the primary, thus reducing investments in new buildings. The supply of crushed product, in the event of crushing stop, will be maintained by the recovery of crushed material in the stockpile. The crushed material is sent to the washing, screening and classification plant.

Washing and tertiary crushing

The washing plant consists of a single equipment line (silo, scrubber, crushers and screens). The crushed material will be sent by a conveyor belt to a silo. The installation of the silo is necessary to stabilize the material flow sent by crushing. Under the silo, to control the flow to the scrubber, an apron feeder will be installed.

The drum washer or scrubber will be fed with crushed bauxite and water so that its product has 50% solids by weight. The scrubber is designed so that its main variables can be adjusted as needed by the process, that is, if the ROM has more or less clay, or is more or less thick, among others. This is possible by changing the flow of water to be fed into the scrubber, its rotating speed and the level of its discharge. The scrubber overflow is screened in an attached trommel with an opening of 40 mm and the oversize is fed into a pair of crushers. The tertiary crushing stage product should have a top size similar to the trommel aperture. Both flows are fed to the screening circuit.

Screening

The flow is fed to a 6 mm screen; the retained material will form the beneficiation product among with the retained from the next screen. The secondary screen receives the undersize from the primary screen and has a 0.85 mm mesh. The undersize of the secondary screen is fed to the classification circuit.

Classification circuit

The classification circuit receives the pulp from the secondary screen in tanks with 5 minutes of residence time. These tanks allow regulation of the flow and minimizing variations in the percentage of solids in the flow fed to the cyclones. There are tree cyclones batteries, each one receiving the underflow from the previous one in a rougher, cleaner and recleaner circuit. The objective of the cycloning circuit is to remove the fraction finer than 37 μm and with that, indirectly, increasing the AA grades and reducing the RS grades. The last cyclone underflow will be fed to a conveyor filter to be dewatered and will be deposited over the same belt that is carrying the coarser fraction. This product will be fed to the grinding system or may be stockpiled. The cyclones overflow with the filtrate will be directed to the reject dewatering system.

Reject dewatering and disposal

The bauxite beneficiations reject or clay is the finest fraction of the ROM. The pulp containing these solids is fed into a thickener, the overflow is returned to the process water pond and the underflow is fed to a battery of press filters. The filters are composed of vertical plates covered with filter cloth. When they are "closed", the spaces between the plates are filled with pulp filtering water and forming a cake. This cake is pressed for further dehydration.

This cake no longer drains water and will be charged with wheel loaders, to the same trucks that brought the ROM. As the mass recovery processing is approximately 70%, circa one third of the fleet shall return to the mine with reject that will be deposited in mined out stripes. Once deposited the mining cycle continues with the next strip overburden removal. The reject will assist in topographic reconstruction of mined areas. The filtrate is directed to the process water pond. From there this water is pumped to the beneficiation plant.

Water

The ROM is fed into the beneficiation plant with 12% of moisture (water mass / total mass) and is product also has 12% of moisture. The reject, after mechanical dewatering, is sent back to the mine with 25% of moisture. The process outputs have more water than its feed and this make water makeup needed.

Bauxite beneficiation proposed Modifying Factors

An 'Ore Reserve' is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified. [4]

The Modifying Factors are considerations of mining, processing, metallurgical, infrastructure, economic, marketing, legal, environment, social and government conditions that impose changes in the resource once estimated.

In the specific case, the mineral resource was evaluated for AA and SR grades and washing mass recovery. Each of these variables was obtained by washing and testing the washed portion of each geological sample. The set of these results, after modelling, characterized the resource.

For the Alumina Rondon Mineral Reserve to be estimated, several Modifying Factors were applied to the Mineral Resource estimation. The beneficiation plant or processing plant modifies the resource in three ways:

1. Product loss;
2. Product contamination; and
3. Product recovery mesh.

The first and the second are correlated and are due to imperfections of sizing. The estimated loss in screening is irrelevant, since screens have physical limits that prevents coarser fraction to be present in the finer fraction (product loss). On the other hand some of the finer particles will be present in the scree oversize (product contamination). It is significant to state that contamination is the presence of the fraction that reduces the total AA grades and increases the RS grades, i.e. the minus 37 µm fraction.

In the classification circuit this effect is more relevant, since that in this kind of separator, coarser particles have higher probability to be directed to the underflow and finer, to the overflow, but none have zero probability of being in either flow. In this way it is expected to find coarse particles in the reject and reject in the product flow.

The third Modifying Factor relies in the fact that the Mineral Resource was evaluated in 150 µm, that is, the samples were washed in this aperture and the AA and RS grades along with the mass recovery were estimated for this mesh. Since it is practical to recover material up to 37 µm the reported mass and grades from the Mineral Resource also had to be modified by this factor.

Industrial test

In order to materialize what was designed in the basic engineering flow chart, an industrial test was performed. The main objectives of this test were to measure the Modifying Factors resulting from bauxite beneficiation and to evaluate operational conditions.

The test was done with two bulk samples of what is going to be the ROM of the Alumina Rondon bauxite mine. The samples were obtained from two different pilot mines opened in the Rondon Norte plateau. The samples were mined in areas that represented the average characteristics of the material to be mined when the industrial operation is installed. Each sample had 1,000 tons and this mass was transported for 2,500 km to an operating beneficiation plant owned by Votorantim Metais in the city of Mirai.

The Mirai beneficiation plant is similar to what is projected for the Alumina Rondon beneficiation plant. Mirai's processing circuit start with two crushers, a primary and a secondary, a silo, a scrubber and two sets of screens. The screens oversize is the product. The secondary screen undersize, the material finer than 0,85 mm, in the Mirai beneficiation plant is discarded, differently from what will be done with the same fraction in the Alumina Rondon beneficiation plant.

The plant capacity depends on the feeding ore characteristics. The feed rate is adjusted by the screening quality; if the ROM has a higher content of fines the feed must be diminished. This is due to the screen capacity being proportional to the amount of undersize material. The main processing parameter is the residence time in the scrubber. Altering the residence time by altering the feed rate, is the most direct form to control the total energy applied to the ore. This energy is needed to disaggregate the clay from the coarser particles (product contamination), but too much energy comminutes the material causing product loss. So that the beneficiating conditions of the projected Alumina Rondon plant are simulated, the residence time in the scrubber was set to two conditions: four times the designed residence time (six minutes) and the designed residence time (1.5 minutes).

With the first condition it was possible to evaluate the effects of "over-scrubbing" the bauxite. The expected product recovery was markedly higher than the one obtained in the four minute test. The particles size distribution and grades evaluated from several samples obtained during the test proved that, not only the expected fine fraction was passing through the secondary screen, but also a significantly amount of the natural coarse fraction was comminuted and was passing through the 0.85 mm screen.

In the second test – feeding in a rate that resulted in the designed residence time – it was possible to observe the conceived operating conditions. The disaggregation happened visually as expected and the product samples indicated low contamination with clay.

Given that, in the Mirai plant, the beneficiation ends in the screens, it was not possible to test the classification circuit. However, particles classification, especially in cyclones, is a well-studied subject in the ore dressing discipline. So, with a well characterized feed, it is possible to simulate, at a high confidence level, the output of such a system. For the feed characterization several samples were taken during the industrial coarse circuit test.

Results and Similar Operations

During the industrial test, several samples were taken from several points from the circuit as listed below:

- Primary crusher product;
- Secondary crusher product (or scrubber feed);
- Primary screen oversize;
- Secondary screen oversize;
- Beneficiation product (taken from a conveyor belt that receives both oversizes); and
- Secondary screen (or reject).

The first test lasted for four hours and the second, lasted for one hour. These samples where then analyzed for particle size distribution and a mass balance was made. The coarse fraction mass recovery was evaluated by using the equation below:

$$\text{Product} / \text{Feed} = (f - r) / (p - r) \qquad (1)$$

Feed	Feed mass flow (dry tons per hour)
Product	Product mass flow (dry tons per hour)
Reject	Reject mass flow (dry tons per hour)
f	Characteristic of the flow (%) e.g. mass recovery from a particular size fraction
p	Characteristic of the flow (%)
r	Characteristic of the flow (%)

This equation was calculated for four size fractions and the results follow below in table 2.

Table 2 – Product mass recovery estimated by the Product / Feed equation

Size (mm)	Mass Recovery (%)
+6,35	66.4
-6.35 +0.840	65.4
-0.840 +0.037	66.5
-0.037	66.1
Average	**66.1**

The mass recovery was also estimated by measuring the trucks mass in a road scale. The measured values follow in table 3.

Table 3 – Product mass recovery by road scale

Feed mass	850.1 tons
Product mass	382.0 tons
Mass Recovery (%)	**44.9%**

Finally, the value predicted from the Resource Model [5] is **49.0%**.

Still for the coarse fraction, the screens overflow was laboratory washed and the total amount of -0.037 mm present in the product was, in the average of 15 samples, **1.7%** ± 0.9% of its total mass, with no values exceeding **3.5%**.

For the fine fraction, i.e. [0.840, 0.037] mm, the product loss and contamination were evaluated by modeling the Alumina Rondon cyclone circuit. This model, with the predicted operating conditions, such as pulp solids content, cyclone feed pressure among other, stated a **15%** of product loss (mass lost / initial product mass) with a **5%** contamination (-0.037 mm mass in the product / recovered product).

The Rondon do Para bauxite has the size distribution exposed in table 4 below. This distribution enables calculating the weighted value of product loss and contamination for the total product (coarse and fines).

Table 4 – Product particle size distribution

Size (mm)	Mass retained, simple
+0.840	82%
-0.840 +0.037	18%

Similar bauxite beneficiation operations, such as Mirai itself with the Zona da Mata ore and Mineracao Rio do Norte (MRN) have operational product loss and contamination values as exposed in the table below 5 below,

Table 5 – Product loss and contamination

Operation	Product loss	Product contamination
MRN	5%	5%
Mirai*[1]	*[2]	3%

*[1] only coarse product.
*[2] reconciliation program under development.

Discussion

The mass recovery evaluation for a short period of operation test depends heavily on the approach. The Product / Feed equation allows evaluating the relation with different size fractions, thus reducing the uncertainty. This method is widely used when direct information about the flow is not available. The mass measured with the road scale is a direct measure of the mass fed and produced. However, since the test run for one hour (really short period), the system loading had a high effect on the produced mass. It is estimated that the system loading time of the Mirai plant is about 20 minutes. This effect impacts the scrubbing phenomena. The first particles fed stayed inside the scrubber until it started to overflow. So they had to stay there for a longer period than the regime period, thus receiving more energy and being comminuted. This fact was observed by roundness of the product particles.

In the other hand, the mass recovery evaluated by the Product / Feed equation was higher than the one predicted by the Resource Model. This may be explained by the fact that the Resource samples are from four inch (0.10 m) diameter drill holes, size quite different from the ROM top size found in the feed of the test, roughly 1.5 m. Other fact that follows the same reasoning is that the Resource samples are crushed at one inch prior washing, while the beneficiation secondary crusher has a four inch top size.

Remarkably, the analyzed AA and SR grades from the beneficiation product were better than those predicted by the Resource model, as may be seen in table 6 below.

Table 6 – MR, AA and RS in the Resource Model and industrial test

Operation	Resource Model	Industrial test	Variation
Mass Recovery	49.0%	66.1%	135%
Available Alumina	38.4%	41.3%	108%
Reactive Silica	2.4%	1.5%	62%

This may be explained by the intensity of the scrubbing action when compared with the laboratory worker action over the laboratory screen. The scrubber is a 4 meter in diameter by 8 meter long equipment and the intensity of the scrubbing forces inside it are expected to be more intense than those applied by the laboratory worker.

The proposed Modifying Factors for the Rondon do Para beneficiation process are:

Table 7 – Proposed Modifying Factors

Size fraction	Product loss	Product contamination
+0.840	0%	5%
-0.840 +0.037	15%	5%

This test increased the knowledge about bauxite processing and ore dressing as a whole. More tests, varying feed rates and water ratios in the scrubber feed should be conducted to better understand the effects on residence time and rheology of the pulp inside the scrubber.

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