Bauxite fines recovery via desliming and concentration

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Abstract

Votorantim is a major producer of primary aluminium and operates an industrial complex in the municipality of Aluminio. This industrial complex comprises an alumina refinery, a smelter and aluminium transformation units. This complex processes bauxite from three different mines. One of these mines is situated in the municipality of Miraí, in Minas Gerais state. This site comprises mining and bauxite washing operations. The washing plant is set to recover the coarse fraction of the bauxite by scrubbing and screening. The fraction finer than 850 µm is rejected to a tailings dam. Several studies concluded that part of this material might be recovered by removing the clay and concentrating the lighter fraction, richer in alumina, by removing the heavy fraction, richer in iron minerals and quartz. The equipment considered for these operations are hydrocyclones and spiral concentrators. This processing route was developed by applied research done in laboratory scale and proven in a pilot application. Recovering this fraction of the bauxite will increase the mass recovery of Miraí plant up to 20%.

Keywords: Bauxite; ore dressing; concentration; fines recovery.

1. Introduction

The Votorantim Group started as a textile factory and was commissioned in 1918 in the municipality of Votorantim, São Paulo state. Since then, Votorantim has been diversifying its activities. Industrial operations now include cement, mining and metallurgy (aluminum, zinc and nickel), steel, pulp, orange juice, and electricity generation.

The aluminium business includes four bauxite mines, a refinery, a smelter and plastic transformation units and a mega project, Alumina Rondon. To produce aluminium, the bauxite is mined and transported by railway to the refinery where up to 1 million tons of alumina can be produced, resulting in nearly 500 thousand tons of metal per year.

From the 230 million tons of bauxite produced every year worldwide, roughly 60 million tons are form beneficiating operations. Bauxite beneficiation is typically done via size separation. The beneficiation of bauxite is done in order to increase the low temperature available alumina grade (THA or total hydrate alumina, the alumina that is recoverable at 150 °C Bayer process), to reduce the reactive silica grade (RS) or both. This type of beneficiation process uses the difference in relative concentration of both materials in different size ranges. Commonly, THA is in coarser fractions and RS, in finer fractions of the run of mine.

This is also the process that is applied in beneficiating the bauxite from Miraí. There, the run of mine bauxite is fed into crushers, disaggregated in a washing drum or scrubber and separated by size in two sets of screens; being the undersize of the first the feed of the second one. Both oversizes are jointly staked as product, and the undersize of the secondary screen is disposed as a pulp in a reject dam.

The mass recovery of each bauxite is a consequence from natural condition of the deposit and the process applied. Since typical operations “wash” bauxite, the material characteristic taken into account is the particle size. If it is coarse enough, it is product and if it is fine, the material is rejected. This approach is justifiable if there is a clear distinction in THA and RS grades along the particle size distribution (PSD). Indeed, if the THA grade is high enough and the RS is low enough up to a certain size, this size should the cut size for the process.

This rationale may be applied in the bauxite found in the municipality of Miraí and implies in a cut size of roughly 850 µm (eventually a little smaller). But, at this cut size, the mass recovery of the operation is just over 40 %. In order to increase this mass recovery, finer particles should be recovered. However, even though the RS grades are low for particles as fine as 40 µm, the THA grades are in the low 30 %, lower than the product at 43 % THA. With the purpose of reaching the same THA values, a concentrating operation must be implemented.

2. Previous work review

Other bauxite mines beneficiate the fine bauxite fraction via classification with hydrocyclones separating the minus 40 µm. This cut is justifiable due to the size of kaolinite particles, mass recovery below 40 µm and size range where hydrocyclones are applicable. Kaolinite reacts with NaOH, being this mineral the RS bearer for the low temperature Bayer process. Kaolinte has 46.6 % of SiO_2 and has $Al_2Si_2O_5(OH)_4$ as chemical formula. This means that if the bauxite has 3.0 % of RS, it actually has 6.4 % of kaolinite. It is relevant to state that not all kaolinite particles are free from gibbsite particles (or available alumina bearing particles) and this lack of liberation limits the amount of separable RS.

Several operations in northern Brazil process their fine bauxite only via hydrocyclones achieving acceptable THA and RS grades and mass recovery. This is also the case of Alumina Rondon, a Votorantim Metais project. The process flow of Alumina Rondon is in image 1. This circuit is in a rougher-cleaner-cleaner configuration, where the underflow of the first cyclone battery is the feed to the second, the underflow of the second feeds the third being its underflow the fine product to be dewatered.

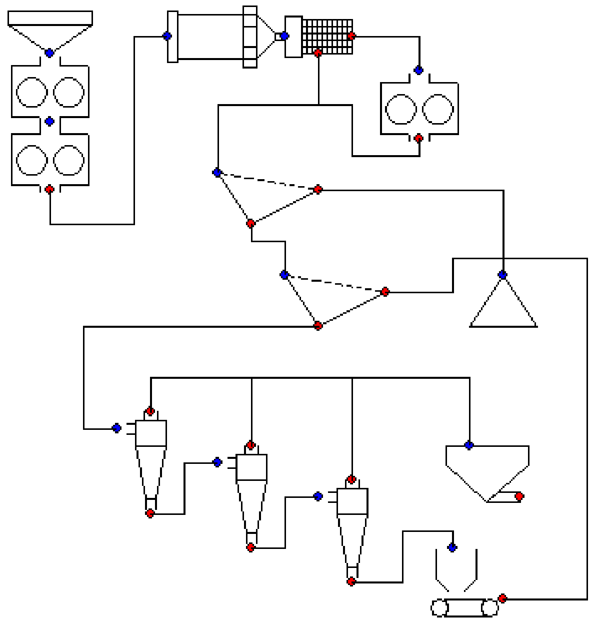

Figure1. Alumina Rondon simplified flow chart.

Other processing routes may include froth flotation and magnetic or density concentration. [source] These operations deal with alternative differentiation characteristics of the material, respectively natural or selectively induced hydrophobicity, magnetic or a combination of factors such as size, specific gravity, shape, rugosity, porosity etc. The combination of these factors describes the behavior of the particle when suggested to a force within a fluid and is referred as the hydraulic diameter of the particle. Such material peculiarities were considered when developing the laboratory approach with the minus 850 µm bauxite from Miraí, as well as similar operations that deal with bauxite from the same region.

In other Votorantim operation, in the municipality of Itamarati de Minas, a processing route, similar to the concept proposed to Miraí fines, was successfully applied to increase the mass recovery of the plant. This concentrating route received the undersize of the product screen, removed the RS rich clay (or the minus 40 µm) in a hydrocyclone battery and concentrated the bauxite in spiral separators separating quartz and iron bearing particles. After concentration, the THA rich fraction, or the lighter fraction, was dewatered and composed the bauxite product of the plant. The fine bauxite recovery circuit is exposed in image 2.

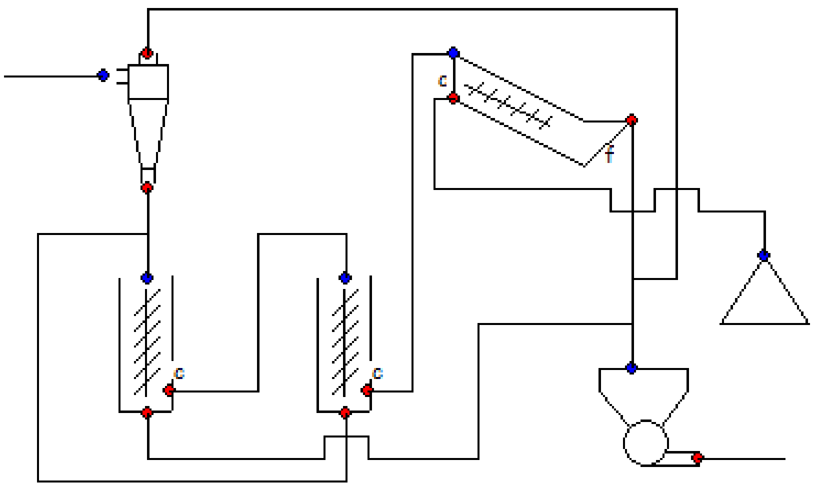

Figure2. Itamarati bauxite fines recovery flow chart.

The bauxite processed in Miraí was subject in several previous works [source] where the ultimate goal was to increase the mass recovery without any negative consequences in the THA and RS grades. Other processing routes proposed for these bauxite fines included several unit operations as described earlier. In the authors' opinion, these options were not further developed and built due to their complexity and capital costs. These were taken into account in this new approach.

3. Process flow diagram definition

The first activity developed to understand the material properties in order to design the flow chart was to obtain the bauxite fines composition per size fraction. This was done by wet screening a typical tailings sample in a series of screens and then analyzing each size fraction by XRF and for THA and RS. The results, as listed in table 1, confirmed the expectation that the coarser particles have higher THA and lower RS grades.

Table 1. Composition of bauxite fines per size fraction and above accumulated.

Mesh	PSD		Grades per fraction					Grades above accumulated				
	Simple Retained	Accumulated Retained	$Al_2O_3^T$	$Fe_2O_3^T$	SiO_2^T	THA	RS	$Al_2O_3^T$	$Fe_2O_3^T$	SiO_2^T	THA	RS
(µm)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
850	0.7	0.7	53.5	11.1	5.2	48.6	1.8	53.5	11.1	5.2	48.6	1.8
600	1.1	1.8	49.9	10.6	11.3	45.3	1.6	51.2	10.8	9.0	46.5	1.7
425	1.9	3.6	45.3	11.9	17.5	40.5	1.5	48.2	11.4	13.4	43.4	1.6
300	3.8	7.5	38.6	13.4	27.0	33.5	1.4	43.3	12.4	20.4	38.3	1.5
212	4.6	12.1	33.9	17.2	30.4	27.6	1.3	39.7	14.2	24.2	34.2	1.4
150	6.5	18.5	30.6	22.1	28.2	23.4	1.1	36.5	17.0	25.6	30.4	1.3
106	5.1	23.7	27.7	25.4	26.5	21.3	0.9	34.6	18.8	25.8	28.4	1.2
75	7.6	31.3	27.3	28.4	19.9	20.9	1.2	32.8	21.1	24.3	26.6	1.2
53	5.1	36.4	27.1	30.4	17.1	21.3	0.9	32.0	22.4	23.3	25.8	1.2
38	4.9	41.3	29.1	30.8	13.0	23.4	1.1	31.7	23.4	22.1	25.6	1.2
20	6.2	47.5	33.1	30.2	8.8	25.5	2.3	31.9	24.3	20.4	25.5	1.3
Bottom	52.5	100	38.6	25.0	10.9	23.6	9.3	35.4	24.7	15.4	24.5	5.5

At first, it is possible to observe that the mass is evenly distributed along the different sizes except for minus 20 µm fraction, which has 52.5 % of the initial mass. Another observation is that only particles coarser than 425 µm have THA and RS grades within the product range. In addition, the mass of particles coarser than 425 µm is 3.6 % of the bauxite fines fraction, or, in typical values, less than 2 % of the run of mine mass.

The iron bearing particles occur through all the PSD, with grades higher than 20 % under 212 µm. As might be also noted, the RS is low throughout all the PSD, with a steep increase below 20 µm. As the XRF measures the amount of silicon atoms in the sample, the difference between RS and SiO_2^T is a fair approach of the quartz quantity in the sample. With this it is possible to assert that the quartz particles are concentrated between 425 and 106 µm.

This sample was also tested via qualitatively XRD and the main minerals and their densities are listed in table 2.

Table 2. Minerals in bauxite fines and their densities.

Mineral	Density g/cm³
Gibbsite	2.3 – 2.4
Quartz	2.6 – 2.7
Hematite	4.9 – 5.3
Kaolinite	2.6

The densities stated above are the true densities of perfect grains of the mineral, and might be used as a reference to interpret the hydraulic diameter of the particle, since that density and particle size have major influence in the hydraulic diameter. There is no objective determination of the hydraulic diameter by reason of the difficulties of measuring each property of the particle and combining them to create a single value for direct comparison. However, it is possible to infer the relative behavior of particles in terms of the hydraulic diameter by doing specific laboratory experiments and a pilot plant test.

Carrying out a dense liquid separation test assisted in developing the process flow. This test consists in placing the material in a fluid with a controlled density and letting it float or settle. In this case, particles put in a solution of bromoform - $CHBr_3$. The bromoform was diluted with ethanol so that the solution density was 2.5 g/cm³. In this solution, it was possible to separate the particles in three groups: the buoyant, the slow settling and the fast settling fractions. This test was done with discrete particle sizes and the fractions smaller than 38 µm were not tested. With size reduction, other forces start to have a relevant influence in the particle mobility in a fluid, and, for this case, particles smaller than 38 µm could not be efficiently separated. In table 3 follow the composition of each fraction.

Table 3. Buoyant, fast and slow settling fractions in bromoform solution.

	Fraction	Mass recovery from bauxite fines	THA	RS
	+300 µm			
1	buoyant	4	55.0	1.3
2	slow settling	2.6	18.8	1.9
3	fast settling	0.8	14.2	0.7
	-300 +106 µm			
4	buoyant	4.9	54.9	1.4
5	slow settling	6.2	15.2	0.7
6	fast settling	5.1	7.6	0.4
	-106 +38 µm			
7	buoyant + slow settling	10.2	34.3	1.2
8	fast settling	7.5	5.3	0.4

A possible product from a separation process that relies on density differences is the combination of the results listed in lines 1, 4 and 7. This material, by doing a weighted average from obtained grades, has 43.9 % THA and 1.3 % RS. Lines 1 and 4 are results from size ranges where the separation process was efficient enough to allow distinction between buoyant and slow settling. The result in line 7 is from finer material and its separation was less effective, resulting in poorer product.

The laboratory tests did not included dewatering tests since this phenomenon has lower complexity and might be accessed through existing models or by operating references. References [source] show that the moisture of clay free bauxite fines is between 15 to 20 % regardless of the dewatering equipment used, e.g. belt filter, dewatering screen etc.

From the results obtained in the tailings technological characterization, a pilot essay was designed. This pilot test included a hydrocyclone for clay classification and spiral concentrator for iron and quartz separation. When a spiral concentrator is fed a dilute pulp mixture of minerals of different specific gravities and sizes, the low hydraulic diameter particles are more readily suspended by the water and attain relatively high tangential velocities so that they climb toward the outer rim of the spiral trough. At the same time, the higher hydraulic diameter, non-suspended grains migrate along the spiral surface at the lowest portion of the spiral cross section. In this case, small hydraulic concentrate is selectively directed into the spiral trough near the outside of the spiral surface through the use of adjustable product splitters. The splitters allow three products to be obtained: small, mixed and high hydraulic diameter particles.

The objective of this test was to obtain a richer in THA material in the small diameter fraction. Other products of this test included the clay fraction in the hydrocyclones overflow, the iron richer fraction in the higher diameter of the spiral and a mixed material, richer in quartz. This processing route was inspired by the dense liquid tests.

The processing route comprehended:

1. Desliming at 40 µm in hydrocyclones;
2. Underflow concentration in a rougher spiral;
3. Low hydraulic diameter of the rougher spiral concentration in a cleaner step;
4. Intermediate material from the rougher spiral concentration in a scavenger step;

The samples from the pilot test were obtained by simultaneously collecting the products from each stage. With that, it was possible to access the following mass partition estimation.

As may be seen in table 4, for a typical sample and in the cyclone, rougher-cleaner spiral configuration the product obtained had THA and RS within product ranges, resp. 41.3 % and 3.16 %.

Table 4. Grades obtained in the pilot test for a typical sample.

		Mass recovery	THA	RS	Fe2O3T
1	Feed	100.0	26.3	8.34	17.7
2	Overflow	53.1	18.9	13.4	21.1
3	Underflow	46.9	34.7	2.59	13.9
4	Rougher feed	46.9	34.7	2.59	13.9
5	High	6.10	11.6	1.32	33.6
6	Intermediate	9.30	25.3	2.43	17.9
7	Low	31.5	41.9	2.88	8.83
8	Cleaner feed	31.5	41.9	2.88	8.83
9	High	3.10	23.0	0.70	16.1
10	Intermediate	10.4	45.5	1.61	10.5
11	Low	18.0	43.1	3.99	6.61
12	Scavenger feed	9.30	25.3	2.43	17.9
13	High	1.02	13.1	0.30	30.7
14	Intermediate	2.00	20.0	0.68	14.5
15	Low	6.3	29.0	3.33	16.90
10+11+15	Product	34.7	41.3	3.16	9.64

More interestingly than evaluating the grades, is to check if the obtained densities are as expected, i.e. within gibbsite range for product, quartz range for intermediate and closer to hematite for the reject. Table 5 shows these densities values and the expectation is confirmed.

Table 5. Product specific gravities.

	Specific gravity		
	Rougher	Cleaner	Scavenger
High	3.21	2.60	3.22
Intermediate	2.61	2.39	2.52
Low	2.40	2.34	2.44

The less dense material is the low hydraulic diameter product of the cleaner step. On the other hand, the denser are the high diameter product from the rougher and scavenger steps.

The pilot plant results established that the proposed processing route is effective in separating the gibbsite bearer particles from other sufficiently to have a product with acceptable grades. The next step is to build a single processing line in the beneficiation plant in order to demonstrate the processing rout at full scale. This will also enable the operators to learn from the equipment and how to deal with feed variability prior having the necessary number of equipment to process the whole reject.

The proposed industrial plant flow chart is in image 3 and includes a hydrocyclone, a rougher-cleaner arrangement for spiral concentrator and dewatering screens.

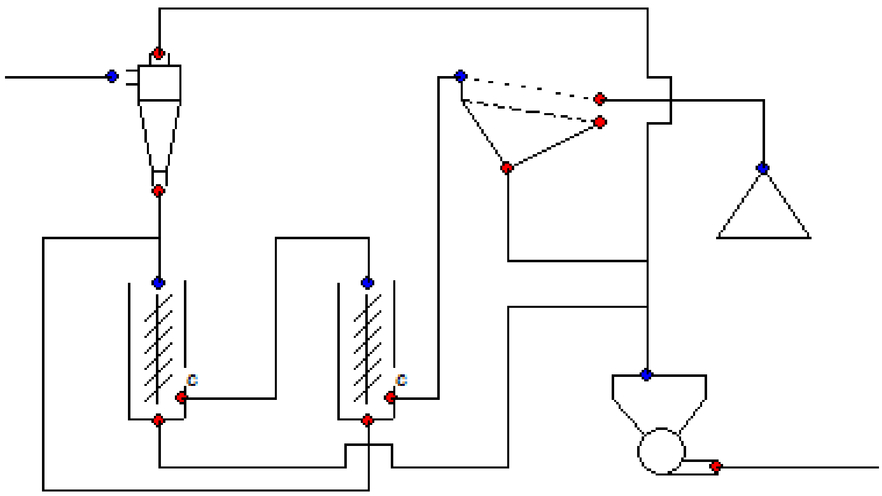

Figure 3. Proposed flow diagram for Miraí fines recovery circuit.

4. Conclusion

The laboratory tests and the pilot run demonstrated that it is possible to obtain a fine bauxite product similar to the one obtained in the coarse fraction. The coarse fraction characteristics follow in Ttable 6.

Table 6. Miraí bauxite characteristics.

Characteristic	Unit	Value
THA	(%)	44.0
RS	(%)	3.0
Total Alumina	(%)	48.0
Total Silica	(%)	11.0
Alumina bearer	(%)	gibbsite
Total Organic Carbon	(%)	0.2
Iron	(%)	12.5
Settling Rate (HX)	(m/h)	30
WI	(kWh/st)	11
Moisture	(%)	12
PSD	P95 (mm) P05 (mm)	50 1.0