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BAUXITE BENEFICIATION REJECT DEWATERING AND DISPOSAL

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Abstract

The Alumina Rondon refinery will have a production capacity of 3.0 million tons of smelter grade alumina per year. For this production, approximately, 11.0 million tons of bauxite Run of Mine (RoM) will be necessary. This bauxite must be washed prior being fed in the refinery, and so, the beneficiation plant will dispose 3.0 million tons (dry basis) of bauxite reject. The moisture of this material, at the moment of disposal, may vary from 88% to 25%, depending on the dewatering method. The moisture is a conditionant to the disposal, ranging from discharging the pulp in tailing ponds or back filling mined areas with mechanical dewatered reject.

This study evaluated different ways of treatment, handling and disposal of the reject. The comparison was made in terms of Capital Expenditure (CapEx) and Operational Expenditure (OpEx). The compared indicator is the Net Present Value of the accumulated Free Cash Flow (FCF). This comparison allows to evaluate the best financial solution for the life of the project. The evaluated scenarios included combinations between ways of dewatering the reject (natural settling, thickening, supperfloculaltion and pressfiltering) and ways of diposing it (tailing ponds, heightened tailing ponds and mine back fill). The superflocculation option has the lowest CapEx while back filling mined areas with press filtered reject saves 30% of the value of the base case scenario: direct disposal in tailing ponds without previuos thickening.

Introduction

One of the most significant costs for refining bauxite i.e. producing smelter grade alumina, is the caustic soda (NaOH) makeup. The soda loss is a direct consequence of the amount of reactive silica (RS) in the bauxite presented to the refinery. The soda loss occurs due to the dessilication product formation as exposed in equation 1 which immobilizes sodium cations.

$$3(Al_2O_3.2SiO_2.2H_2O) + 6NaOH + Na_2.X \rightarrow Na_6(Al_6.Si_6.O_{24})\ Na_2.X + 9H_2O \quad (1)$$

The first term of the equations is kaolinite and it is measured by its SiO_2 content, or the reactive silica (RS). As can be seen, for six moles of SiO_2 eight mols of Na cations are immobilized and must be replaced by makeup, beeing this makeup, soda.

The Rondon do Pará bauxite, has natural grades of around 32% of available alumina (AA) and 8% of reactive silica (RS), what implies in a ratio (AA/RS) of 4. When the grades are analyzed per size fraction, it is observed that the RS is concentrated on the minus 37 µm fraction, which contains more than 20% of RS and less than 7% of available alumina (AA), while representing circa 28% of the mass (mass recovery – MR) of the run of mine (RoM). This way, if this fraction is removed from the run of mine, the grades of the washed bauxite become 42% of AA and 3% of RS, with a ratio (AA/RS) of 14. The grades of RoM, washed bauxite and reject are summarized below in table 1, as well as their mass recoveries (MR). A ratio of more than 10 indicates economic viability of the bauxite, as a simple first approach.

Table 1 Grades of interest and relative mass recovery

Material	Available Alumina	Reactive Silica	Mass recovery
RoM	32.0%	8.0%	100%
Washed Bauxite	42.0%	3.0%	72.0%
Reject	6.3%	20.9%	28.0%

The bauxite beneficiation process goal is to remove the finer fraction of the RoM to, indirectly, increase the AA grades while reducing the RS grades. Due to this fact, the bauxite washing reject is a fine clayey material. The reject is mainly composed by kaolinite, and this mineral characteristics such as density, granulometric distribution, particles shapes, etc. make this pulp dewatering not a simple solution.

In current operations, this pulp is disposed in dams or tailing ponds with or without previuos thickening. The main challenges these operations have to handle are: dewatering and transporting this solids. This suspension presents a high increase in viscosity with solids concentration higher than 40% (w/w). This increase in viscosity limits the solids settling rate, making values higher than 40% solids hard to achieve with thickeners. In the same manner, this increase in viscosity makes pumping with centrifugal pumps the preferred solution only up to 43% solids, or 200 Pa. This study is limited to solutions with centrifugal pumping.

The Alumina Rondon project forsees mining 11.0 million tons per year of RoM and will dispose 3.0 million tons of reject in dry basis. Since the moisture of the disposed reject may vary from 88% to 25%, the total amount of reject mass to be treated and disposed may vary from 4.0 Mt to 30 Mt per year. These quantities are much higher if added with the tailings disposal from similar operations in Brazil. If added, MRN, Jururi (globo.com, 2013), Paragominas (Imprensa Oficial do Estado do Pará, 2013) and Miraí (gazetademuriae.com.br, 2013) dispose circa 15 Mt dry basis per year of reject. Assuming a mean moisture content of 65%, the total disposed bauxite reject mass in Brazil is 40 Mt per year, being 25 Mt of water.

During the conceptual engineering phase of the Alumina Rondon project, a trade-off study was conducted on the beneficiation reject dewatering and disposal system. This study was necessary to justify the choice of the project's operation model. The assessment form was to compare the accumulated discounted free cash flow for each option and compare it with the base case: direct disposal in tailing ponds without previuos thickening.

In order to do this study, a sample of the reject was prepared by screening bauxite obtained from boreholes. This material was wet screened and the minus 37 μm fraction was retained for further testing. The tests were conducted at the Universidade de São Paulo (USP) mineral processing laboratory and suppliers laboratories. These parameters are listed below in table 2 and they are the key values for each dewatering and disposal sizing.

Table 2 Rondon do Pará bauxite reject characterization

Value	Measured variable	Source
3.0 t/m³	Reject particle true density	Laboratory tests
87.5%	Moisture* at beneficiation's discharge	Alumina Rondon flowchart
25%	Press filter cake moisture	Laboratory tests
60%	Thickener underflow moisture	Laboratory tests
55%	Moisture after long settling without previous thickening	(C. Bastos, 2012, pers. comm., 19 Nov.)
40%	Moisture after long settling with previous thickening	(A. Delgado, 2012, pers. comm., 14 May)
30%	Moisture after superfloculation	(M. Moura, 2012, pers. comm., 25 July)
22%	Optimal moisture for compactation	Laboratory tests

* All moistures exposed are the total water mass divided by the total mass (solids + water)

Several options were discussed which combine no dewatering, thickening, supperfloculating and pressfiltering with disposing in tailing ponds, piles and use as back fill. The base case is no dewatering and disposing in tailing ponds. In this case, part of the water will be recovered.

This paper intends to expose an economical evaluation of several conceptually possible bauxite reject dewatering and disposal systems studied for the Alumina Rondon project.

METHODS

Disposal methods summary

After the reject was tested, a few conceptual options were discussed and seven of them were chosen for an economic evaluation. This evaluation comprised the equipments sizing, earth movements' estimate, along other. With that it was possible to estimate the Capital Expenditure (CapEx) and Operational Expenditure (OpEx) needed for the first 40 years for each option. These options are possible combinations of dewatering and disposal methods.

Tailing ponds

One of the possible options to dispose the reject slurry is to accumulate it on tailing ponds without previous dewatering – being this the **base case**. These tailing ponds must have enough volume/area to allow low flow speeds for particles settling and clarified water recovery. No chemicals are added. This solution may be considered water intensive, and due to that, a raw water pipeline is needed, along with other structures, such as pumping stations for clarified and rain water collected in the system. This option demands a water reservoir of 2.5 Mm³ to handle the yearly water volume variation.

Every dike has to be built one year before its operation, already with its final height. The first dike will be built next to the beneficiation plant, while the subsequent will be built in already mined areas, depending on the mine sequence.

It is estimated that 14 tailing ponds of 16 Mm³ of useful volume each are needed to contain 3.0 Mt per year reject at 55% of moisture for a 40 years period. These tailing ponds will have 15 meters high on its embankments crest, 6 meters width on the bank top. The internal and external slopes are to be 3 H : 1 V. These characteristics comprise a dike of 1.180 m of maximum external edge and 990 m of internal length at the base of the bank. The total earth moving volumes considered that the tailing ponds, whenever possible, share one or two slopes.

Raised Tailing ponds

This solution is very similar to the one presented above, only considering the option of construction of the tailing ponds by phases. It suggests that the tailing ponds are built up to 5 meters height in the first phase, being raised two times to 10 and 15 meters. The investment needed for the tailing ponds construction is diluted benefiting the cash flow.

Other accessories, like water tailing ponds and piping, have to be built on the same way of the first proposition.

Thickener and Raised Tailing ponds

This solution proposes that the slurry, when exiting the beneficiation plant, is fed in a thickener. In this thickerner part of the water is recovered and the slurry to be disposed has higher solids concentration. As the material to be pumped to tailing ponds has lower amount of water, the total volume disposed is lower, allowing smaller tailing ponds to be built. These tailing ponds were dimensioned with 920 m of maximum external edge and 730 m of internal length at the base of the bank.

Another relevant factor is that the final moisture of the disposed material is reduced, because the slurry, disposed with less water, is able to dry easier.

Nevertheless this is a water intense solution and the construction of a dike 2.5 Mm^3 is still needed. The water dike was dimensioned with 30 m of useful height, 200 m of internal length at the base of the bank and 380 m maximum external edge.

Superfloculation

For this option it is necessary to install a flocculant dosing station on the reject pumping line. Tailing ponds and drainage channels for the released water must be made as well.

Another need of this option is an operation unfamiliar to Votorantim or to the bauxite industry, the farming. This operation consists in turning over the material to expose the inferior layers so they sun dry. These option specificities such as the flocks' rheology, maximum thickness of the disposed layers, drying time and the workability of the material, after it has lost its moisture, are not well known.

Press filters - basis

The use of filters is much disseminated along many industries. Horizontal press filters have the advantage of being able to work with very fine material, because they are able to apply forces superior than vacuum or hyperbaric filters.

This kind of equipment may be indicated to dewater materials such as the bauxite reject. At Alumina Rondon project, the granulometry of the material is expected to be less than 37 µm.

The unloaded cake may be manipulated with mining equipment, such as front end loaders and trucks. Geotechnical tests show that this cake at the moisture of discharge may be disposed in piles and this is the case presented.

With this option more the water is recovered and it may be considered low water consumption. This makes the raw water pipe unnecessary and the whole industrial water system can be diminished.

Thickener and press filters

The filtration cycle has, in its first step, the loading phase. The loading ends when the amount of solids gets to a maximum limit inside the filter chamber, not allowing more slurry to be loaded. The necessary time for this loading depends on the solids flow to the interior of the chamber, as the slurry flow is limited by the filtering cloth; another option to decrease the loading time is the increase of the solids concentration in the slurry.

Due to this fact, and to the number of necessary filters for the operation, manufactures suggest the inclusion of thickeners as the first step of the reject system. The inclusion of thickeners would decrease the need of filtering area.

The simplification of the production line, with the reduction of equipments in series, increase the system availability. When a thickener is installed, the whole operation become dependent of its availability, diminishing the system availability. In the filtration system, due to the processing capacity of each filter, the installation of multiple devices in parallel is necessary, which increases the availability of the plant. This occurs because the idle capacity of an equipment can meet increases in demand resulted from the shutdown of another.

Press filter and back fill

This kind of solution, similar to that mentioned (press filter), changes only in the final form of reject disposal. This option contemplates the disposal of the filtered cake in exhausted stripes as back fill.

The cake is loaded in trucks, which had brought the RoM, with the help of wheel loaders. These trucks take the material back to the exhausted stripes and make there its final disposal. The main difference is that the fleet to build a pile is not needed and the necessary equipment is in synergy with the mine equipment.

Estimating method

This estimation was made on Free Cash Flow (FCF) comparisons. This method allows evaluating, in one indicator, expenses in CapEx, OpEx and fiscal benefits. The Free Cash Flow (FCF) calculation is shown below on table 3.

Table 3 Free cash flow Calculation

Operation	Value
(-)	OpEx
(-)	Depreciation
(=)	Gross Profit
(-)	Taxes
(=)	Liquid profit
(+)	Depreciation
(-)	CapEx and Sustaining
(=)	FCF

The figures employed for this estimation were taken from the FEL2 CapEx Estimation done for the Alumina Rondon project.

The calculation was made to compare, in a relative way, the scenarios listed previously. It is worth mentioning that all values are negative; different form of expenses. So, the values exposed are the relative savings when compared to the base case. The table below illustrates the relative savings for the first three years of operation.

Table 4 Free cash flow Example

Solution	FCF 2015	FCF 2016	FCF 2017
Tailing ponds	0%	0%	0%
Raised tailing ponds	19%	14%	9%
Thickener and raised tailing ponds	18%	11%	4%
Superflocculation	55%	45%	36%
Press filter and pile	10%	9%	8%
Thickerner and press filter	12%	7%	4%
Press filter and back fill	14%	13%	11%

Net present value of the accumulated FCF or FCF*

After the FCF for each option for the 40 years of operation was obtained, their present value (2013 as basis) was calculated with a 10% per year discount rate. Then, these values were accumulated, that being, for the first year only its value is presented, for the second year, the sum of the first and the second, for the third year, the sum of the first, second and third and so on. This accumulation is designed as FCF*.

FCF* comparison

Once the FCF* estimation was made, a comparison graphic was plotted. On this graphic it is possible to observe the savings for each method when compared to the base case in terms of the net present value of the accumulated free cash flows.

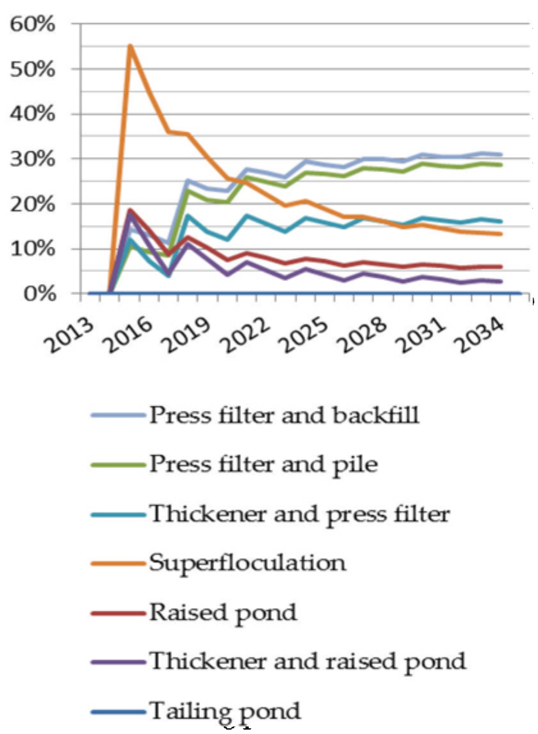

Figure 2 FCF* savings evolution

Results

With the considerations above mentioned, it is possible to justify the press filter and back fill the preferred choice. This option saves 30% of the total value that would have to be spent on the base case, reduces the complexity of the operation and the water intake in several million tons.

This application of press filter may be considered usual, since there are many similar (Outotec, 2013) and extensive test work was conducted. This study is at conceptual engineering level, this means that the expected imprecision limit is 25% and should be used as a guideline to further developments.

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