Votorantim Metais/CBA bauxite residue: challenges and solutions

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Abstract

Bauxite residue is a worldwide challenge for alumina refineries. Economic disposal for new residue disposal areas, increasing the life of the existing ones, as well as the utilization of bauxite residue as raw material in other industries remains an ongoing struggle, even after more than 100 years of Bayer process existence. No economically viable solution for large scale utilization has been developed yet. Votorantim Metais/CBA's bauxite residue disposal area's life ends in 2019 and there is no possibility for expansion. To avoid a new dam being constructed for its present wet disposal operation, a study was made to evaluate changing the disposal method and its benefits. The installation of press filters using the existing dam presented the best performance, increasing the bauxite residue disposal life to 2050. In parallel, in cooperation with Votorantim Cimentos, a technology to process and use up to 30 % of bauxite residue as raw material in cement production was developed. Good quality cement was produced and the developed technology showed economic benefits for both Votorantim Cimentos and Votorantim Metais.

1. Introduction

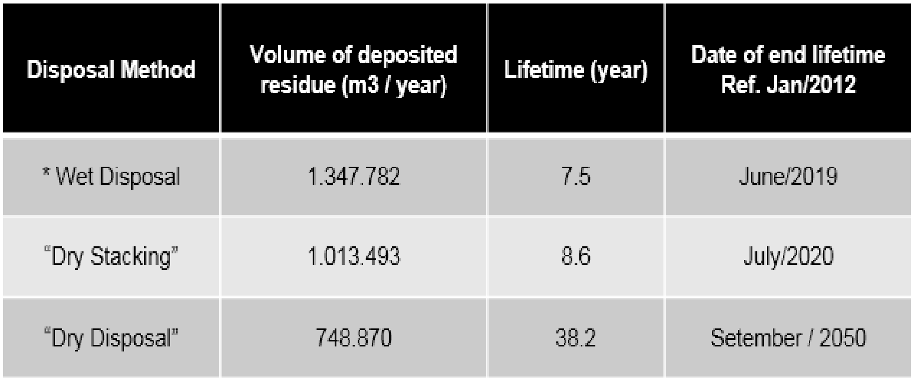
The Bayer Process dissolves gibbsite present in Bauxite with hot caustic soda to produce aluminum oxide. The remaining insoluble residue is separated by settling and increasing, filtration. After residue washing for alumina and caustic recovery, the washed residue is transferred to the disposal area. Companhia Brasileira de Alumínio (CBA) produces 420 ktpy of aluminum, generating about 600 ktpy of bauxite residue. This residue is pumped to a disposal area (dam), named Palmital, with remaining disposal capacity until 2019. Currently, the disposal area (Figure 1) contains about 2 million cubic meters of supernatant water. This study is to evaluate alternatives to increase the bauxite residue dam capacity and develop technology to make possible the use of bauxite residue in the cement production.

Figure 1. Companhia Brasileira de Alumínio dam (Palmital).

2. Concept Study

The bauxite residue disposal area was raised to its final elevation in 2008 and will have exhausted its useful volume, 30 million cubic meters, in 2019. The principal dam is 1 000 meters long and 102 meters high. The construction of a new disposal area will require a high investment and due to the local topography it has to be constructed far from the refinery. Obtaining the necessary environmental licenses for a new disposal area will also present a range of challenges. In the face of this scenario, a study was conducted in 2012 to identify and evaluate alternatives to increase the lifetime of the existing disposal area by means of changing the disposal method (Table 1).

Table 1. Disposal method comparison.



Disposal Method	Volume of deposited residue (m3 / year)	Lifetime (year)	Date of end lifetime Ref. Jan/2012
* Wet Disposal	1.347.782	7.5	June/2019
“Dry Stacking”	1.013.493	8.6	July/2020
“Dry Disposal”	748.870	38.2	Setember / 2050

"Dry Stacking" (60 % of solid content) and "Dry Disposal" (75 % solid content) were the alternative disposal methods considered in this study. Comparing different methods to the current CBA wet disposal method, Dry Disposal provided the longest disposal area lifetime (Table 1).

2.1. Dry disposal

“Dry Disposal” consists of the deposition, spreading and compaction of the residue with earthmoving equipment [3]. To make this possible, it is necessary to dewater the residue before disposal to a solid content in the range of 75 % to 80 %. Press filter technology is applied to achieve this range of solids content.

2.1.1. Press filter pilot test

A pilot test using a Filter Press (Figure 2) was performed to evaluate the performance of the equipment and set the specifications to design the full scale facility and produce bauxite residue for geotechnical evaluation (Figure 3) [3]. The filter press was fed with a suspension of bauxite residue with 45 % of solid content and 8 500 kg of residue with 75 % of solid content were produced.

The pilot test confirmed a volume reduction of 40 % in the bauxite residue and showed a caustic soda and alumina recovery of 92 %.

Figure 2. Pilot test press filter.

Figure 3. Press filter residue cake.

2.1.2. Disposal test

Using the Press Filtered Residue generated by the pilot equipment, deposition, spreading and compaction processes were simulated. An area inside the dam surrounding the already disposed residue (Figure 5) was prepared and a test was performed to determine the angle of repose, stacking density, ease of handling and geotechnical characterization of the bauxite residue (Figures 6 to 8).

Figure 5. Prepared area.

Figure 6. Stacking.

Figure 7. Angle of repose test.

Figure 8. Spreading test.

Compaction testing was performed using a ditch filled with bauxite residue from the pilot plant and passing an excavator fourteen times over it.

It was to possible to achieve 99 % of compaction values higher than 70 % of solids, and an angle of repose of 35^o for the material was determined.

2.1.3. Palmital geotechnical evaluation

A key point to change the Palmital disposal method is the behavior of the existing residue when covered by the press filtered residue [3].

Geotechnical evaluation was performed to evaluate the existing residue properties and determine the capacity to support the Press Filtered Residue (Figures 9 and 10).

Particle Size, CPTu (Cone Penetration Test), PPDT (Pore Pressure Dissipation Test), VT (Vane Test), SPT (Standard Penetration Test), Shelby and many other analyzes were performed in different points inside the dam to evaluate the stability of the system.

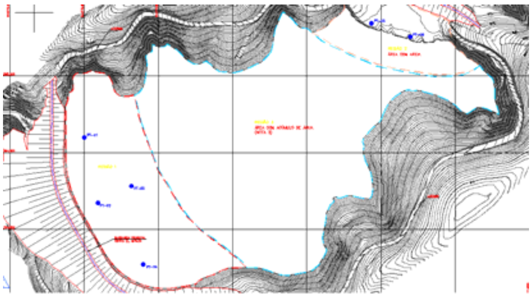


Figure 9. Location of the sampling points inside the dam.

Figure 10. Geotechnical sampling equipment.

2.2. Bauxite residue disposal project

Using the geotechnical parameters, a new design of the bauxite residue disposal area (Figure 11) was developed to utilize all of the available area. This project will increase the Palmital lifetime, allowing continued disposal until 2050. Increase the recovery of caustic and alumina from bauxite residue and postponing by 31 years the investment in building a new disposal area.

To achieve this goal the following steps have to be considered:

- 1st step: Construction of an initial landfill over natural ground in the left and right edges of the reservoir (Figure 11).
- 2nd step: Dry disposal (forming a stack) of the residue from press filter over the initial landfill (Figure 12).
- 3rd step: Dry disposal (forming a stack) of the residue from press filter within the reservoir (Figure 13).
- 4th step: Dry disposal (forming a stack) of the residue from press filter over the stack formed in the 2nd step, with final crowning at the final elevation of the basin (Figure 14).

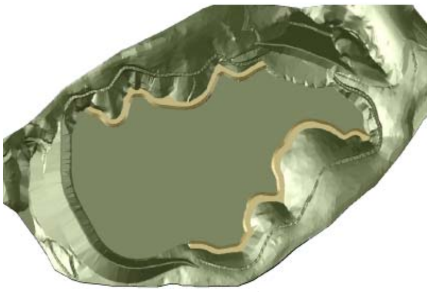


Figure 11. 1st Step.

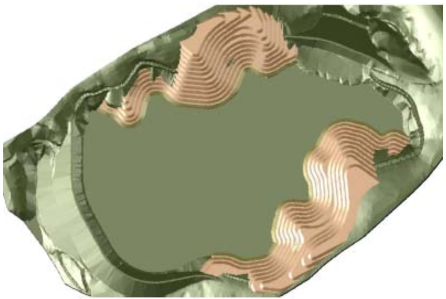


Figure 12. 2nd Step.

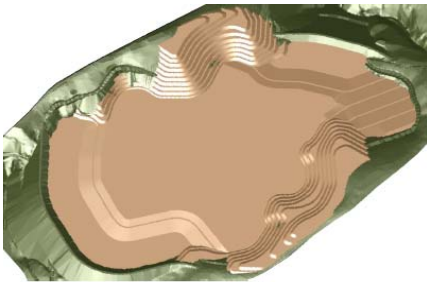


Figure 13. 3rd Step.

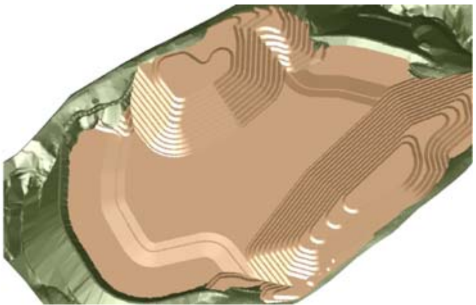


Figure 14. 4th Step.

3. Palmital Preparation

Before starting the Press Filter operation, the Palmital area needs to be prepared. A bathymetry survey conducted in 2012 indicated the existence of 2 million m³ of supernatant water. At least 75 % of this water will need to be removed to enable the disposal of press filtered bauxite residue over the existing residue.

3.1. Palmital water

Palmital water characterization showed a low concentration (0.4 to 0.6 g/L) of sodium fluoride, sodium chloride, sodium sulphate and sodium oxalate. The water also contains 30 g/l of Total Alkalinity (TA), 12 g/L of Total Caustic, both expressed as Na_2CO_3, and 8 g/L of Al_2O_3.

3.1.1. Use of Palmital water in the alumina refinery

Palmital water can be removed from the lake and used in the refinery. Some options to use this water in the alumina production process were identified. The best alternatives were a) replace the condensate and industrial water used in the lime hydration processes; b) replace the industrial water used in the flocculant dilution process; c) replace the industrial water used in the refinery red side gaskets.

3.1.1.1. Water in flocculant preparation

In order to verify the impact of using Palmital water in the flocculant dilution process, tests were performed replacing the industrial water by Palmital water and the solids settling rate was compared. The preparation of the flocculant is made in two-step dilutions. First, the flocculant is diluted to 1 % than a second dilution to 0.3 %. Figure 15 shows a significant improvement in the residue settling rate when industrial water is used in the first dilution, and Palmital water in the second dilution. These figures validate the replacement of industrial water by Palmital water in the second dilution besides an improvement in the flocculant effectiveness.

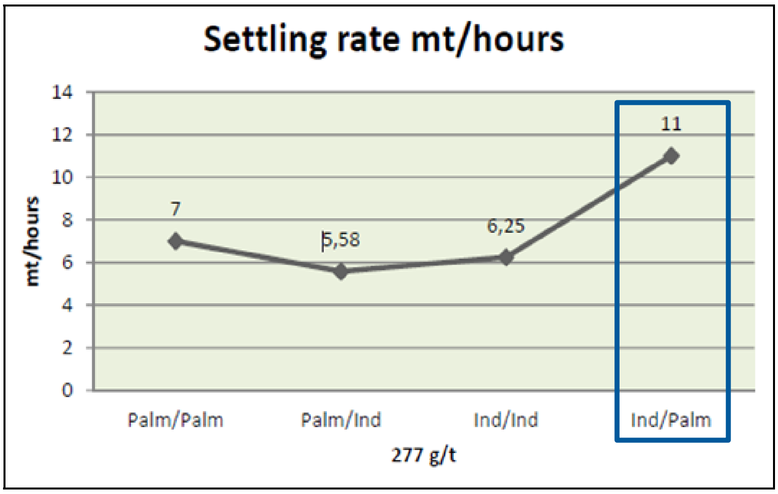


Figure 15. Settling rate.

3.1.1.2. Water use in lime hydration

The Lime hydration process was conducted in the refinery mixing condensate and industrial water to achieve a controlled temperature [2]. A plate heat exchanger was installed to heat Palmital water using live steam (Figure 16) to the desire temperature. It allowed the replacement of 100 % of condensate and industrial water by Palmital water.

3.1.1.3. Gasket water

Industrial water used in the refinery red side gaskets could be replaced by Palmital water. To avoid problems with solids present in the water a security filter was installed (Figure 17).

3.2. Palmital conquest landfill

An initial landfill (Figure 18) is currently being constructed with the sand produced in the refinery and the press filtered residue will be deposited over this sand layer.

Figure 16. Plate heater.

Figure 17. Palmital water security filter.

Figure 18. Palmital initial landfill.

4. Impurities

The replacement of the condensate and industrial water by Palmital water will increase the input of impurities in the refinery and the reduction of caustic losses by using press filter will reduce the impurities purge [2]. Both effects can contribute to elevate the refinery impurities content.

However, a new bauxite source, called Barro Alto, with a high purity level, is being introduced in the bauxite blend feeding the plant. A balance was done to predict the behavior of the impurities in the plant and determine the actions that should be taken to avoid production and quality problems.

4.1. Sodium carbonate

The use of Palmital water in the points mentioned before will bring more sodium carbonate to the refinery. A high level of sodium carbonate in the pregnant liquor can affect negatively the aluminum hydroxide precipitation yield [2]. It is very well known that sodium carbonate can be converted in sodium hydroxide according to the causticization reaction as showed below:

$$Na_2CO_3 + Ca(OH)_2 = NaOH + CaCO_3 \tag{1}$$

A side stream causticization unit using bauxite residue filtration liquor will be installed to guarantee the causticity of the pregnant liquor and the precipitation productivity. A direct causticization of Palmital water is also being studied.

4.2. Organic carbon and inorganic impurities

The two main concerns about organics are sodium oxalate co-precipitation and high molecular compounds build up. A negative impact on the alumina quality and a decrease in the aluminum hydroxide precipitation yield are the expected impacts of these compounds [2]. Barro Alto bauxite presents very low impurity content (Table 2).

Table 2. Barro Alto bauxite quality.

Parameter	%
Available Alumina	> 50
Reactive Silica	< 2,5
Organic Carbon	< 0.06

By introducing this bauxite into the plant, the input of organics will decrease significantly, compensating for the organics purge reduction caused by press filter installation.

Oxalate Critical Concentration, that is the level where oxalate starts to precipitate, was measured in different pregnant liquor conditions. Figures 19 and 20 present the value obtained.

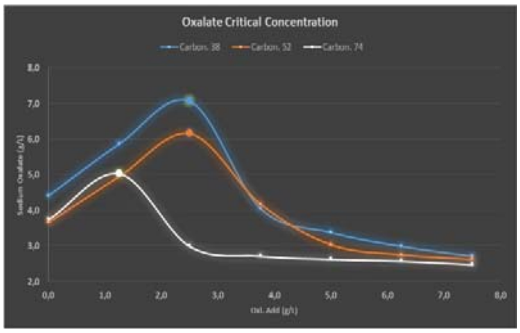


Figure 19. Oxalate critical concentration.

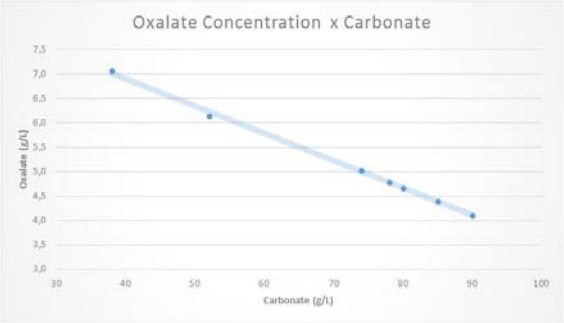


Figure 20. Correlation between oxalate and carbonate concentration.

Currently the pregnant liquor oxalate concentration has a safety margin from the oxalate critical concentration. By decreasing the sodium carbonate concentration by causticisation, no oxalate co-precipitation is expected [2].

Inorganic impurities can affect the efficiency of the plant, specially the pregnant liquor properties [2]. However, inorganic impurities are not expected to be significantly affected in the process by using this new bauxite source.

5. Bauxite residue as raw material

Votorantim Cimentos (VC) is one of the largest cement producers worldwide. The company has a research center in Curitiba Brazil. Two cements plants are located within 30 km of the Votorantim Metais alumina refinery. The total production capacity of these plants is 6 million tons per year of OPC (Ordinary Portland Cement). Currently, no pozzolan is used in those plants. This presents a very good opportunity to convert bauxite residue into a pozzolanic raw material, reducing the cement cash cost.

5.1. Converting bauxite residue into pozzolan

The process for producing artificial pozzolan (calcined clay) normally uses large amounts of calcined kaolin clays. Some bauxite residues may contain residual amounts of kaolin that when calcined can produce material with these same pozzolanic properties.

However, CBA bauxite residue does not contain kaolin and has a relative high content of sodium, which prevents it of being transformed into a pozzolan simply by heating. To enable the residue to be used, its chemical composition needs to be adjusted and a high temperature is required to transform the mineralogy [1]. This forms new compounds with pozzolanic properties and acceptable color.

The pozzolanic reaction is described generically by the equations in the Figure 21 [1].

Calcium Silicate + Water → Hydrate Calcium Silicate + Calcium Hydroxide

Calcium Hydroxide + Pozzolan → Hydrate Calcium Silicate

Figure 21. Pozzolanic reaction.

5.2. CBA Bauxite residue characterization

VM/CBA bauxite residue characterization was obtained by X-ray diffraction (Figure 29) and X-ray fluorescence analysis (Tables 3 and 4).

Table 3. Residue mineral composition.

CBA Bauxite Residue DRX Analyse		
Parameter	Scale Factor	Chemical Formula
Quartz	3,3	SiO_2
Gibbisite	25,3	$Al(OH)_3$
Cristobalite	19,3	SiO_2
Hematite	23,3	Fe_2O_3
Sodalite	0,21	$Na_8(AlSiO_4)6(CO_3)2(H_2O)4$

Table 4. Residue chemical Composition.

CBA Bauxite Residue FRX Analysis			
Parameter	%	Parameter	%
CaO	3,3	K_2O	0,42
Fe_2O_3	25,3	Na_2O	8,0
SiO_2	19,3	SO_3	0,53
Al_2O_3	23,3	TiO_2	3,4
MgO	0,21	Moisture	25,0
P_2O_5	0,61	LOI	15,8

5.3. Pozzolan and cement production

In a pilot plant CBA bauxite residue was blended with limestone and aluminous clay to adjust the chemical composition and the mixture was calcined at 1150 °C to produce the pozzolanic material. Figure 22 shows a photograph of the pilot kiln. The process flowchart is showed in Figure 23. This process can be run in a regular clinker line production.

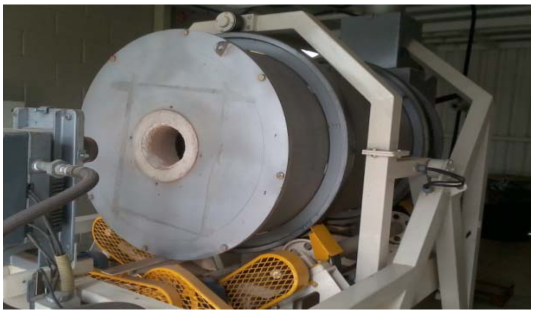


Figure 22. Pilot Kiln.

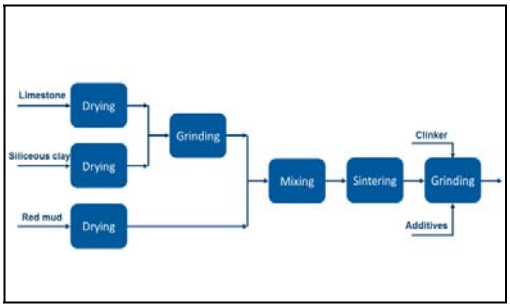


Figure 23. Pozzolan process flowchart.

Mixtures of standard cement and the produced pozzolanic material in the proportions of 15 % and 30 % of pozzolan was prepared to produce CPIV-32 ENV197 (CP IV/A) and CP II-Z-32 (CP II/A-Q) cements, respectively.

Figures 24 and 25 show the pozzolan raw material, pozzolan and produced cement.

Figure 24. Materials, Pozzolan & cement.

Figure 25. Cement with bauxite residue and regular reference cement'

5.4 Cement quality

Strength tests were performed in standard cement (reference material), CPIV-32 ENV197 (CP IV/A) cement (30 % pozzolan) and CP II-Z-32 (CP II/A-Q) cement (15 % pozzolan). The results (Figure 26) met the specifications for the respective cements. The strength value meets a similar strength to the reference value after 60 days.

Strength testing was also performed on the concrete produced with the pozzolanic cements and the results met the respective specifications (Figure 27). As in the cement test, the strength value meets a similar strength to the reference value after 60 days.

The color of pozzolan ia also important. Red colored pozzolan cannot be used in the OPC production. The pozzolan produced with this technology has the same clinker color.

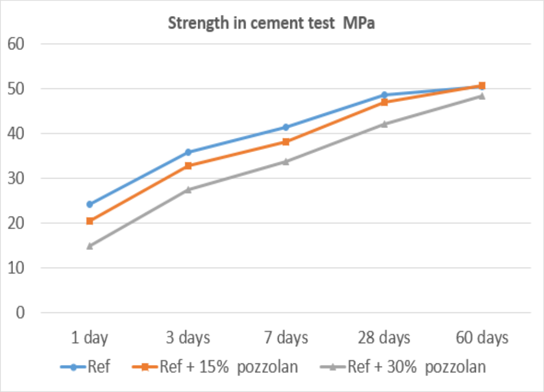


Figure 26. Cement strength test.

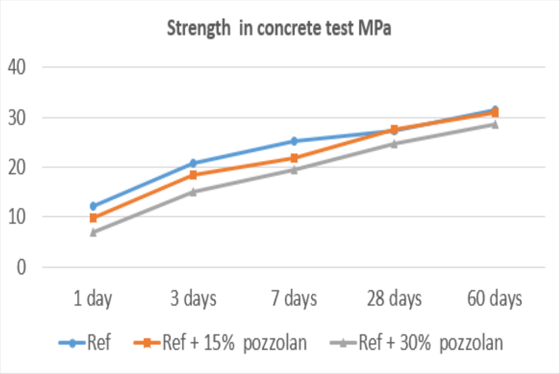


Figure 27. Concrete strength test.

Pozzolan produced with bauxite residue has additional advantage of lower energy consumption and lower CO_2 emission (carbonate content and fuel) when compared to clinker production.

A Brazilian green patent was requested for the developed technology (Patent number BR 10 2013 024226-8) as well as its international extension over 30 countries (PCT/BR2014/000208). Votorantim Metais and Votorantim Cimentos share the patent ownership.

6. Conclusions

Using dry disposal technology with a press filter it is possible to increase the life of the existing disposal area, reduce the residue soda content and store the residue in a more secure and environmentally sound manner.

The new bauxite source, with very low impurities content, and the causticization process will allow use Palmital water with no problems to the refinery.

Adjusting the chemical composition of the bauxite residue is possible to transform it, using a traditional clinker production line, to produce a good quality pozzolanic material. This can be used to replace up to 30 % of the clinker in OPC while maintaining the quality of cement and concrete. When compared to clinker production, the use of bauxite residue to produce pozzolanic material can reduce CO_2 emission as well as decrease fuel consumption. This is due to lower carbonate content in the bauxite residue.

7. References

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