BX07 - Enhanced Desiccation of Bauxite Tailings by Solar Drying

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Abstract

Tailings management has an ever-increasing importance in the bauxite mining and aluminum industry. Dewatering technologies are being adopted and further developed to reduce environmental impacts and operational risks of tailings storage facilities. In this regard, Hydro combines two steps to desiccate bauxite tailings at Paragominas mine: tailings thickening in a gravity settler and solar drying in a large-perimeter low-height dam. The tailings disposal method used in Paragominas consists of disposal and drying cycles, with tailings being disposed into the Plateau system. The Plateau system was designed for continuous rotation between disposal quadrants, each quadrant receiving a 50-centimeter layer of tailings at each cycle, allowing for solar drying of the layers deposited at the other adjacent quadrants. Parameters such as cycle duration and layer width were initially estimated based on monitoring of disposal test areas and the system was expected to deliver a final solids content of 60 %. This paper shows that, by further developing the tailings disposal process, Hydro has been able to achieve solids content of up to 80 %, a dewatering efficiency like that obtained by filter presses, for instance. Also, a large investigation campaign was undertaken to show that drying is highly homogeneous i.e. no significant changes were found in the spatial distribution of tailings. By increasing tailings solids content, Hydro has been able to increase the geotechnical and rheological performance of the tailings, resulting in a safer and better tailings storage facility. Lastly, future uses of tailings as made easier by the decreased moisture of tailings.

Keywords: Bauxite tailings, tailings disposal, dewatering.

1. Introduction

Hydro currently owns and controls one major mining operation in Brazil: the Paragominas bauxite mine. Paragominas is located in the municipality of Paragominas, state of Pará, Northern Brazil. The mine production capacity is approximately 16 Mtpy of run-of-mine, producing about 11.5 Mtpy of bauxite and generating approximately 4.5 Mtpy of tailings. The mine started operations in 2006 and was acquired by Hydro in 2012.

For the disposal of tailings and water recovery, two different tailings systems have been implemented in Paragominas – the Valley System and the Plateau System. Both systems were designed for the final and permanent disposal of desiccated tailings in dams. Figure 1 shows the two tailings disposal systems in Paragominas.

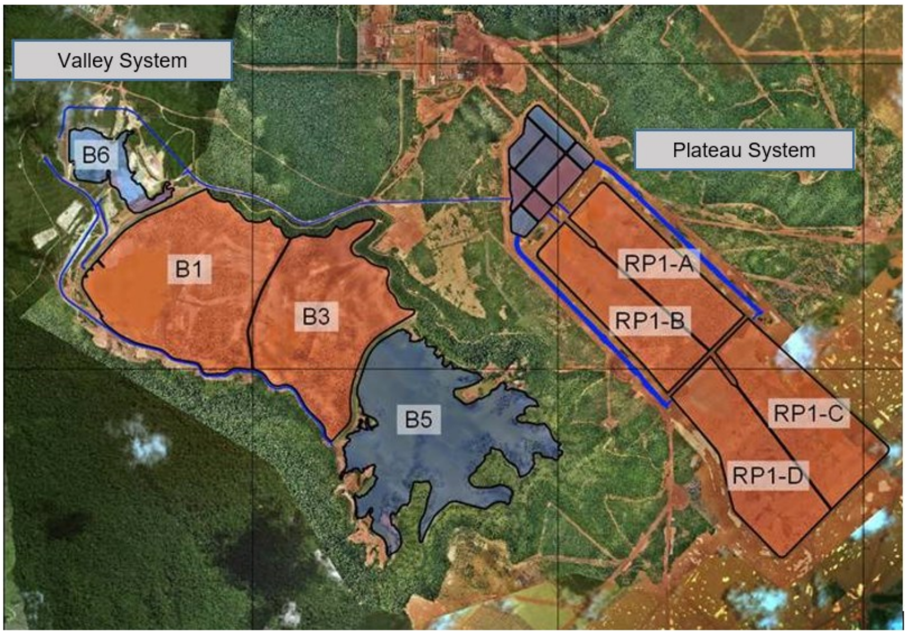

Figure 1. Valley and Plateau tailings systems in Paragominas.

The Valley System was built when the mine first started its operations and consists of three dams: B5 dam, located upstream of the valley, is intended for the protection of springs; B1 dam has the purpose of receiving bauxite tailings and B6 dam, located further downstream, is a sediment containment facility and is also important for the plant water balance. As the Valley System – the legacy system that was in place when Hydro took over Paragominas operations – approached the end of its useful life, the Plateau System was built.

2. The Plateau System

In operation since the end of 2017, the Plateau System was built in a mined-out area. It consists of RP1 dam, a large-perimeter low-height dam, divided in four quadrants for the disposal of tailings (RP1-A, RP1-B, RP1-C and RP1- D), as well as eight effluent clarification basins. RP1 dam total storage capacity is 10.7 Mm³ of tailings. Figure 2 shows a photo of the Plateau System.

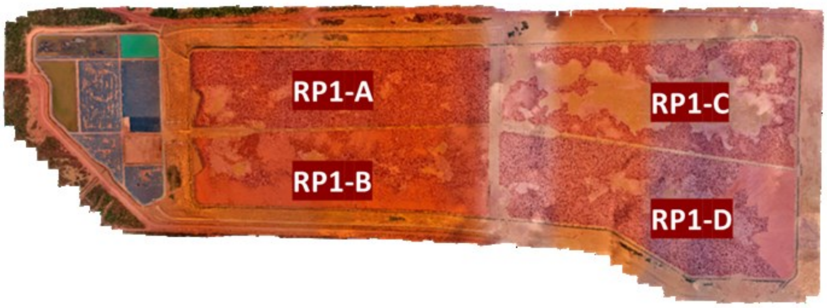

Figure 2. Plateau system.

RP1 dam was designed so that the geometry of the quadrants, the positioning of their decant systems and the spacing between spigots allow for the adequate drying of the tailings. RP1 total area is approximately 300 ha and it contains 142 spigots spaced between 75 to 100 meters from one another.

RP1 dam decant system is composed of 4 spillways, which have the purpose of driving out rainfall water and water released from the tailings thus helping in the drying of the tailings. The spillways are connected to transfer channels, which in turn flows to the clarification basins.

RP1 dam was designed based on the following geotechnical characteristics of the tailings:

- Specific gravity (Gs) = 2.68
- Average solids content at disposal (by weight) = 35 %
- Final solids content (by weight) = 60 %
- Density at disposal = 1.27 t/m^3
- Density after desiccation = 1.60 t/m^3

Originally, the disposal method used in RP1 consisted of the disposal of thickened tailings, with average solids content of 35 wt. %, in layers of approximately 50 cm that are later exposed to solar drying, allowing tailings to reach the design assumption of 60 wt. % solids contents. Disposal alternates between the four quadrants to allow enough sun exposure time for the tailings to desiccate. It is estimated that drying takes 30 and 60 days during the Amazon drying and wet season, respectively. Figure 3 shows tailings desiccation process.

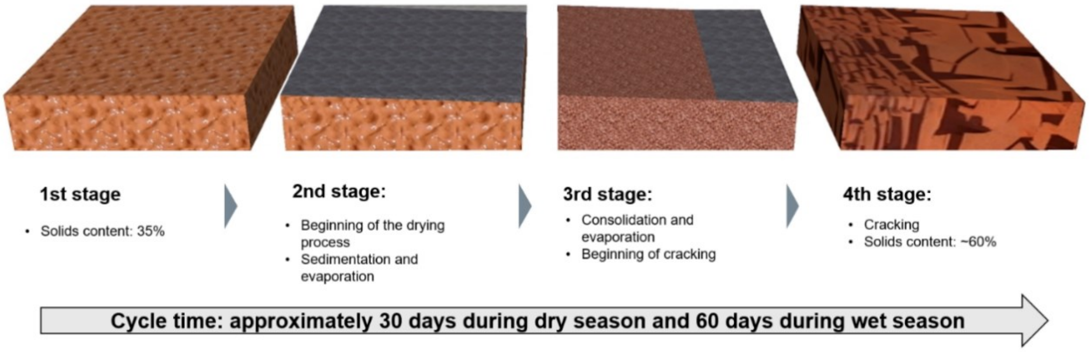

Figure 3. Tailings desiccation process.

The disposal technique is based on tailings disposal into large disposal areas, in a discontinuous manner, in order to guarantee the evolution of the sedimentation and desiccation processes of the tailings under their own weight and the bottom drainage, as well as the formation of a layer of supernatant water, before disposing the next layer. With the continued elimination of surface water, the process of unidimensional and three-dimensional contraction begins and the consequent formation of desiccation cracks [1]

Desiccation of soils usually involves a reduction in the moisture content of the soil induced by evaporation of water from the soil surface to the atmosphere. The phenomenon of desiccation cracking is very complex [2]. For instance, during the drying process the pores are progressively filled with air, inducing negative pore water pressures (or suction). This results in surface tension that affects the mechanical behavior of the soil. Thus, evolution of desiccation cracks which is largely a hydraulic phenomenon has ramifications on the mechanical behavior of the soil as well. Apart from that, initial moisture content, compaction, temperature, drying and wetting cycles also affect desiccation cracking [3].

3. Thickening of Tailings

An important stage of the tailings' disposal solution in Paragominas is the thickening of tailings in a gravity settler. After processing the bauxite, the tailings generated are thickened. Thickening consists in the separation of a solid-liquid suspension, in order to obtain a denser mixture and a more clarified and liquid mixture.

The sedimentation operation is based on the phenomenon of transporting the particle to the bottom of an equipment, where the solid particle in suspension undergoes the action of the following forces: gravity, buoyancy and resistance to movement [4].

Gravity settlers are sedimentation tanks whose function is to receive a more diluted tailing pulp and to generate tailings (underflow) with solids content between 33 to 35 %. A second product, the overflow, will present solids concentration much lower than the feed. This recovered water is then reused on the process.

The efficiency of a gravity settler is assessed by the capacity in terms of volume of the feed and the quality of products, that is, by solids content in the underflow and in the overflow [5].

In Paragominas, tailings are fed into the settler with a concentration of solids between 4 and 6 % and is mixed with flocculant, which flocculates and separates from most of the water. At the bottom of the thickener it is densified to 33 to 35 % solids. The clarified water is sent by gravity to a water tank, from where it is pumped back into the process. Most part of the water is reused in the beneficiation plant. Tailings thickened between 33 to 35 % solids are sent to RP1 dam to start the desiccation process.

4. Statistical Analysis

The consolidation and evaporative drying behavior of hydraulically transported fill materials has been extensively studied. After being discharged from spigots, tailings will undergo three phases of volume change: 1) initial self-weight consolidation; 2) desiccation; and 3) further consolidation during subsequent deposit cycles [6]. This study addresses the volume change during the first two phases with the goal of better understanding and optimizing the drying process of tailings at RP1 dam in Paragominas.

The tailings disposal method used by Mineração Paragominas consists of disposal and drying cycles, with tailings being disposed into RP1 dam in 50-centimeter layers. Cycle duration, tailings solids content and desiccation were initially estimated based on monitoring of disposal test areas.

From the results of the aforementioned studies, and based on monitoring performed during the operation of the RP1 starter dike, it was defined that for the so-called rainy season (between December and May), each drying cycle would take 60 days and for the so-called dry season (between June and November) each cycle would take 30 days, amounting to 09 cycles per year. The average solids content at disposal is 35 % and at the end of the drying cycle the original goal was to reach 60 wt. % solids content.

Data collected in the monitoring during tailings disposal tests has been analyzed statistically, by using canonical correlation analysis (CCA), in order to better understand which variables, controllable or not, influence the tailings desiccation process.

Canonical correlation analysis (CCA) was proposed by Hotelling [7] and its main objective is to study the linear relationships between two sets of variables. The basic idea is to summarize the information of each set of response variables in linear combinations, and the choice of the coefficients of these combinations is made with the maximization of the correlation between the sets of response variables. The linear combinations that can be constructed are called canonical variables, and the correlation between them is called canonical correlation. This correlation basically measures the degree of association between two sets of variables. Equation 1 shows the correlation calculation:

$$\rho_k^2 = \lambda_k = \left(corr(U_k, V_k)\right)^2 = \frac{(a_k' \Sigma_{XY} b_k)^2}{(a_k' \Sigma_{XX} a_k)(b_k' \Sigma_{YY} b_k)} \tag{1}$$

The monitored variables were divided into process variables and climate variables. Climate variables were monitored mainly through the Pessl RP1 dam weather station, EcoD3 model, which consists of air temperature, rainfall, water level and class A evaporation pan sensors. By better understanding which variables influence tailings desiccation process, one can optimize the tailings disposal process in different times of the year.

A robust data set, containing 175 samples was analyzed. Data included tailings final solids content as the response variable and eight predictive variables: disposal quadrant, desiccation time (in days), rainfall (in mm), evaporation (in mm) and granulometry (20 µm, 10 µm, 5 µm and 2 µm fractions).

Results showed that the Canonical R is substantial (0.70421) and highly significant ($p = 0.0000$). Canonical R refers to the first and most significant canonical root. Thus, this value can be interpreted as the simple correlation between the weighted sum scores in each set, with the weights belonging to the first and most significant canonical root.

The total redundancy calculation can be interpreted in such a way that, based on all canonical roots, given the independent variable (% Solids), one can explain, on average, 84.95 % of the variance in the dependent variables. Similarly, one can represent 27.61 % of the variance in the independent variable, given the set of dependent variables. These results suggest a rather strong overall relationship between the items in both sets.

Of the eight variables, the most substantial in order of magnitude were found to be:

i. desiccation time;
ii. evaporation; and
iii. rainfall.

That is, they are highly correlated with the response variable. The particle size and disposal quadrant showed no significant correlations. The fact that particle size showed no significant correlation indicates that RP1 dam spigot system is efficient in avoiding grain segregation – a known theory that suggests finer particles will typically be carried farther from the spigots and coarser particles will typically remain closer to the disposal points. As a result, particle size distribution will be more homogeneous throughout the dam. As expected, disposal quadrant showed no significant correlation since larger quadrants also have more spigots, and the resulting tailings layer width is virtually the same across all quadrants.

A model was then obtained to calculate the theoretical desiccation time, in days, needed to allow tailings to reach 60 % solids. Since granulometry was found not to have great influence on the desiccation process, average results from the samples were used for all the runs in the model. Evaporation and rainfall values were set based on historic monthly averages. Model was defined by Equation 2:

$$W_1 = \frac{1.17492W_2 + 0.27967W_3}{2.25573} \tag{2}$$

Wherein W1 is desiccation time (in days), W2 is rainfall (mm) and W3 is evaporation (mm). The resulting theoretical time showed a good fit for the dry season, varying between 24 and 30 days (Table 1).

Table 1. Theoretical desiccation time (days) obtained from the model.

Month	Solids (by weight)	Evaporation (mm)	Rainfall (mm)	20µ	10µ	5µ	2µ	Theoretical desiccation time (days)
Jul	60 %	142.5	26.72	84.74	71.43	51.58	19.78	27.67
Aug	60 %	140.2	19.90	84.74	71.43	51.58	19.78	23.83
Sep	60 %	149.6	19.06	84.74	71.43	51.58	19.78	24.56
Oct	60 %	136.1	32.63	84.74	71.43	51.58	19.78	29.95

Since most of the original database was obtained from monitoring performed during the dry season, it was expected that the model would present a better fit for such period. It is important, however, that the model is appropriately extrapolated to the rainy season – which presents longer desiccation times and, therefore, is more important for the tailings dry backfill project.

Furthermore, it has been shown that layer width exerts an important influence on the desiccation process. At the beginning of the tests, layer width data was not available since this was not an operational record – since then, scales were installed inside the quadrants and layer width data is being collected. These data will be input in the model for fine tuning.

Also, since it was shown that desiccation time was the single most important variable for increasing tailings solids content, a trial was carried out to see whether greater solids content could be achieved by simply allowing tailings extra time to desiccate.

5. Field Results

Prior to the analyses, tailings solids content was expected to be at an approximate 60 % solids. After performing statistical analyses, tailings were allowed extra time to desiccate in quadrants RP1-A and RP1-B and tests were performed to verify how tailings solids content was affected by the extra drying time.

For 4 months, more than 230 samples were collected on RP1-A and RP1-B and tested for solids content, with results averaging 82 % solids. Figure 4 shows an example of the samples collection plan on RP1-A.

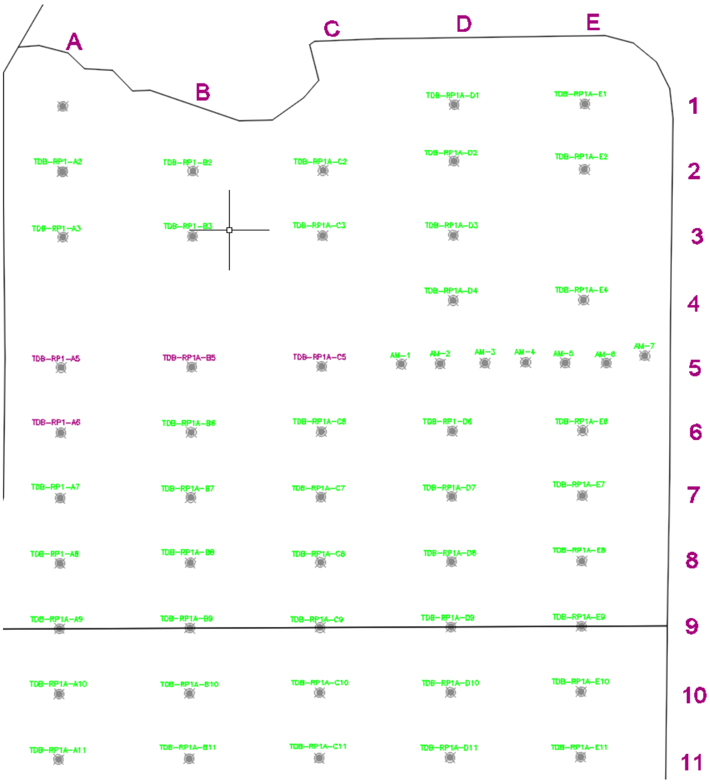

Figure 4. Sample collection plan at RP1-A.

Obtained results were then analyzed to verify whether the spatial position of samples had an influence on solids content i.e. if there was statistical difference between samples as a function of different lanes and strips in the quadrant. Figure 5 shows disposal quadrant RP1-A divided in lanes and strips.

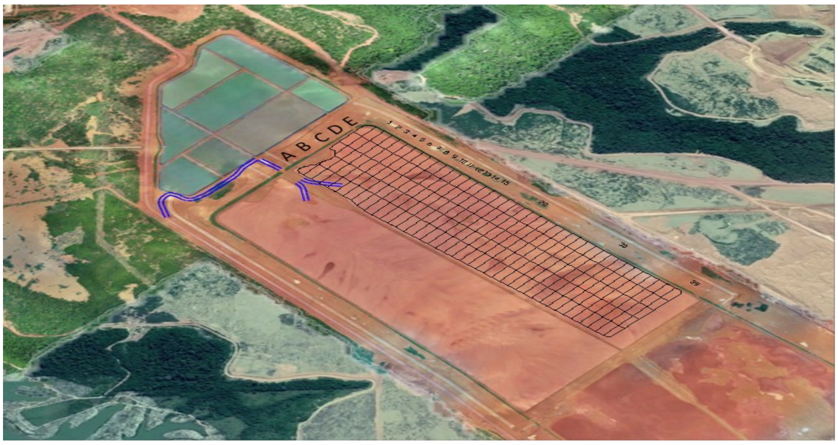

Figure 5. Strips and lanes on RP1-A.

Since some sample sizes, when organized by lanes and strips, were smaller than 15, data normality could be an issue - if the data is not normally distributed, the p-value may be inaccurate for small samples. In addition, atypical data may have a strong influence on test results. Since normality cannot be reliably verified with small samples, laboratory data were probabilistically extrapolated 100 000 times to indicate trends more reliably. Table 2 shows solids content distribution in lanes.

Table 2. Solids content distribution in lanes (%).

Lane A	Lane B	Lane C	Lane D	Lane E
64.82	65.86	75.55	75.33	73.94
76.21	72.51	75.90	76.32	74.16
80.59	77.88	68.73	74.69	69.09
69.67	83.17	70.65	74.70	7.41
74.38	83.51	80.91	80.15	74.26
79.68	82.95	82.53	7.50	8.28
70.46	7.52	84.34	74.97	80.05
70.66	71.69	81.00	79.33	82.13
66.06	79.79	75.32	83.10	71.70
71.99	79.83	71.56	83.54	65.61
7.24	8.04	73.70	75.04	72.79
75.63	72.53	77.76	77.29	77.25
75.08	-	7.93	78.74	86.08
67.54	-	79.96	85.09	74.44
75.66	-	90.43	8.23	73.63
75.68	-	87.34	77.29	77.16
-	-	-	-	74.81

It was found that average results, for each lane, differ statistically from one another. Outer lanes (i.e. A and E) presented lower solids content than center lanes (i.e. B, C and D). Even though outer lanes are subject to the so-called border effect, wherein desiccation is expected to be greater due to increased infiltration through the borders, tailings solids content was lower probably due to the fact that layers are wider in this region. Also, lane A presented the lowest solids content since this is where the spillway is positioned.

Same tests were carried out to verify difference in solids content as a function of the strips. Table 3 shows solids content distribution in different strips.

Table 3. Solids content distribution in strips (%).

Strip 2	Strip 3	Strip 5	Strip 6	Strip 7	Strip 8	Strip 9	Strip 10	Strip 11	Strip 12	Strip 13	Strip 14	Strip 37
64.81	76.20	80.59	69.67	74.38	79.67	72.37	75.62	75.07	67.53	75.66	75.68	66.06
65.86	72.51	77.87	83.51	83.51	82.94	75.22	71.68	79.79	79.83	80.44	72.53	75.32
68.73	70.65	75.55	84.33	84.33	81.00	73.69	77.75	79.25	79.96	90.42	87.33	72.79
74.96	74.70	75.89	81.10	83.10	83.53	75.03	77.28	78.73	85.09	82.30	77.28	
74.25		80.91	80.04	80.04	82.13	77.24						
		75.32										
		76.31										
		74.68										
		73.94										
		74.15										

As expected, solids content was found to be lower on strips closest to the spillway (i.e. strips 2, 3, 5, 6, 7 and 9).

The difference in solids content as a function of lanes and strips is an important discovery since it will help guide efforts to maximize solids content in RP1 dam. Also, as an indirect result of this study, is the apparent importance of layer width in tailings desiccation. It is important to mention that, even though some strips and lanes presented somewhat lower solids content, results were still better than RP1 dam design assumptions and could be considered homogeneous to some extent.

Samples were also collected in depth to assess whether variation occurred among distinct disposal layers. However, statistical differences were not found among samples collected on different depths. Figure 6 shows an excavated profile of tailings with high solids content.

Figure 6. Excavated profile showing high tailings solids content.

6. Conclusions

By conducting statistical analysis, Hydro was able to establish that desiccation time was the single most important faction influencing tailings final solids content in its RP1 dam – a system that uses solar drying for desiccating bauxite tailings.

It has also been shown that layer width exerts an important influence on the desiccation process. For the tests that were executed, layer width data was not available since this was not an operational record – since then, scales were installed inside the RP1 dam disposal quadrants and layer width data is being collected. These data will be input in the statistical model for fine tuning. The study has also shown factors – such as granulometry - that did not bear great influence on tailings desiccation.

By better understanding the tailings desiccation process and experimentally changing the controllable parameters, Hydro has been able to achieve a much higher overall solids content in its tailings' storage facility. Tailings also presented a significant homogeneity in terms of solids content as a function of spatial distribution.

Tailings solids content was increased from 60 % to over 80 % - a desiccation that will usually be obtained only by filter presses – which results in a volume usage optimization of approximately 60 % thus increasing the lifespan of the facility. Also, there is significant increase in the geotechnical and rheological performance of the tailings, resulting in a safer and better tailings storage facility. Lastly, future uses of tailings are made easier by the decreased moisture of tailings.

7. References

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