

Technical Solution for Beneficiation Plant Operational Continuity During Tailings Thickener Overhaul

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Abstract

Mineração Paragominas carries out different stages of process, including bauxite extraction on the mine, beneficiation and transfer to the Alunorte alumina refinery through a long-distance pipeline. To meet pipeline and refinery's requirements, there are strict particle size distribution and chemical composition specifications to the beneficiation process. The beneficiation plant consists of two production lines operating in parallel, with SAG and ball mills, for bauxite comminution and particle size adjustment for transport on the pipeline, vibrating screens and hydrocyclones for clay removal, and thickeners for water recovery and slurry density adjustment for next process steps. The present study objective was to develop a process solution to allow beneficiation plant operational continuity without one of the four installed thickeners, due to the need for complex maintenance for approximately 20 days. Potential solutions were raised and evaluated conceptually, then simulated using Nageswararao model for hydrocyclones to bring a quantitative understating on their effect over plant productivity, water balance and product particle size distribution. Prioritized solutions for the temporary condition included bottlenecks evaluation and process flows redirection, replacing water by low density bauxite slurry for cyclone feed density control and changes on cyclone geometry to meet product specification. As a result, product specification and water balance requirements were achieved and production loss during tailings thickener maintenance was reduced from 40 %, expected without the present work, to 2 %.

Keywords: Bauxite processing, Optimization, Thickener.

1. Introduction

Mineração Paragominas (MPSA), located approximately 70 km from the municipality of Paragominas, in northeastern Pará - Brazil, plays a strategic role in the aluminium production chain in the country. The company is involved in activities such as bauxite extraction, ore pre-processing, tailings disposal and site rehabilitation. Bauxite is transported through a 244 km pipeline, to the city of Barcarena-PA, where it is refined into alumina by Alunorte. To meet the operational requirements of the pipeline and ensure the quality of the product, the beneficiation process follows strict specifications, for particle size distribution and chemical composition [1].

The beneficiation plant consists of two parallel production lines, which include SAG and ball mills for bauxite comminution, vibrating screens, and hydrocyclones used for the removal of clay fractions. These fractions, predominantly composed of kaolinite, are considered contaminants as they react with sodium hydroxide in the Bayer process, increasing caustic soda consumption [2]. The plant also has product and tailings thickeners, that plays a critical role in managing the process water balance by promoting efficient water recovery and adjusting slurry densities to downstream

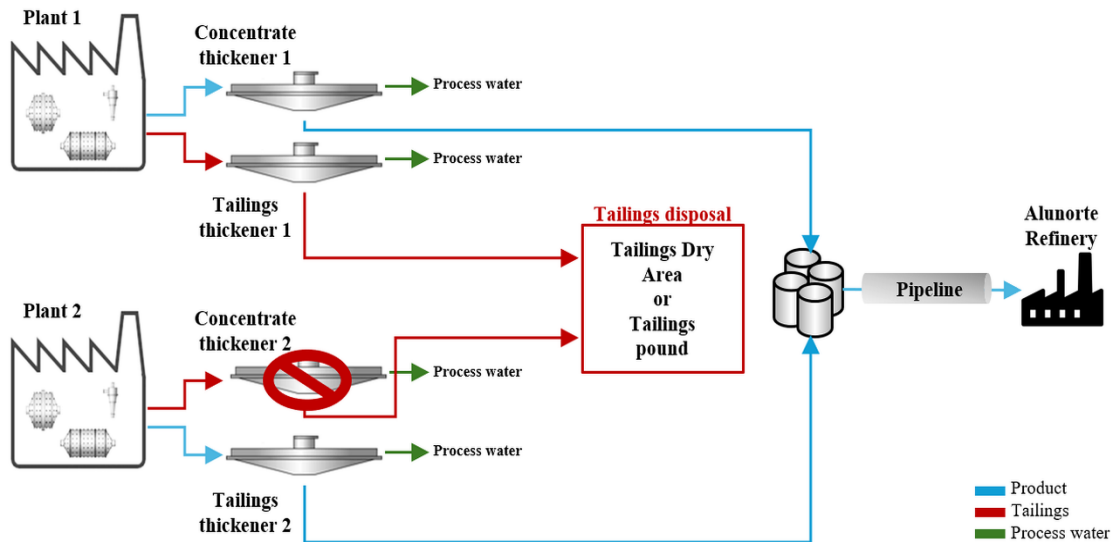


Figure 2. Bauxite beneficiation process flow overview.

2.2 Conceptual Analysis

Operational alternatives were identified based on field experience, technical literature and preliminary analysis of process bottlenecks. The strategies considered included:

- Optimization of mining sequencing;
- Redirecting flows in the desliming circuit;
- Partial replacement of process water by low-density bauxite slurry;
- Optimization of water management in rain water reservoirs;
- Modifications to the cyclone geometry (Apex and Vortex diameter);
- Evaluation of the operating capacity of the remaining thickeners and an increase in flocculant dosing capacity.

The feasible alternatives were modelled for simulation, with the aim of predicting the effects on the mass and water balance, as well as on the granulometric distribution of the product.

2.3 Process Simulations

For the classification stage, the Nageswararao model was utilized, which is based on empirical equations derived from the operational behaviour of hydrocyclones. This model allows for the accurate estimation of parameters such as separation efficiency, product particle size distribution, and the system's water balance, based on the cyclone's geometric variables and operating conditions (pressure, solids concentration, and flow rate) [4].

Initially, a “Base Case” was conducted, representing the current operation of the circuit through a mass balance. Experimental plant data, obtained through routine sampling and installed instrumentation systems, were used for model fit after balancing:

- Feeding and discharging flows from the mills and hydrocyclones;
- Solids content in the process streams;
- Particle size distributions at strategic points in the circuit;
- Hydrocyclone geometry and pulp flow characteristics.

The models were calibrated using iterative adjustments to minimize deviations between the simulated results and the balanced data. After calibration, different operating scenarios were simulated to identify the optimal conditions during the maintenance period, as follows:

- Base Case 1, 2, and 3: The traditional operational settings of the hydrocyclone clusters were maintained, and the plant feed rate was varied in three cases. The first being the critical minimum feed to meet production requirements (882 t/h), the second an intermediate feed (986 t/h), and the third the maximum productivity without compromising asset integrity (1042 t/h).
- Optimized Scenarios 1, 2, and 3: Optimized scenarios were simulated after conceptual analysis, flow redirection, and reconfiguration of the hydrocyclone clusters. The plant feed was varied under the same conditions as the Base Case (882 t/h, 986 t/h, and 1042 t/h).
- Simulated results: To validate the method employed, after the operating period with the three thickeners, a simulation was executed using the average feed rate recorded during the period (994 t/h).

3. Results and Discussion

3.1 Base Case Evaluation

Initially, the circuit was simulated with all four thickeners in operation to establish a baseline. The simulation confirmed that the plant met the requirements of the pipeline and the refinery, particularly in terms of particle size distribution (within specification limits) and slurry density. Subsequently, a simulation was conducted under the same conditions, but with the tailings thickener from plant 2 removed. This led to a noticeable impact in the water balance making it not possible to keep plant 2 operation.

3.2 Simulation of Operational Alternatives

The key findings from the simulations are presented in Table 1.

Table 1. The key findings from the simulations.

Scenario	Plant feed 2 (bs) t/h	Hydrocyclone clusters							
		1 st Fines		2 nd Fines		1 st Ultrafines		2 nd Ultrafines	
		N° HC	Pressure	N° HC	Pressure	N° HC	Pressure	N° HC	Pressure
Base Case 1	882	4	0.75	4	0.75	30	3.00	7	3.00
Base Case 2	986								
Base Case 3	1042								
Optimized 1	882	4	0.55	3	0.55	19	2.60	7	2.60
Optimized 2	986								
Optimized 3	1041								
Actual	994	4	0.55	3	0.55	19	2.60	7	2.60

Table 1. The key findings from the simulations (continuation).

Scenario	Mass recovery (%)	Alumina (%)	Silica (%)	10 µm (%)	Feed rate to tailings thickener 1 (m ³ /h)	Feed rate to tailings thickener 2 (m ³ /h)
Base Case 1	66.6	47.6	5.0	25.0	3805	3787
Base Case 2	66.5	47.5	5.0	25.0	3796	3768
Base Case 3	66.4	47.5	5.0	25.1	3785	3758
Optimized 1	67.9	47.0	5.3	26.0	4392	1753
Optimized 2	67.6	47.0	5.3	26.2	4383	1740
Optimized 3	67.5	47.0	5.3	26.2	4372	1733
Actual	64.0	47.3	5.3	24.9	4488	1700
Simulated results	67.6	47.0	5.3	26.2	4378	1739

3.2.1 Redirecting Flows

Redirecting a portion of the feed material from one thickening line to another has proven to be an effective contribution. Production line #1 tailings thickener operates below its capacity, what allowed a direct transfer of 9.5 % of line #2 tailings to line #1 thickener, without exceeding equipment capacity.

In terms of implementation of this modification, an effort was made to do this smartly with minimum CAPEX, which was achieved as follows:

- To redirect the feed from the super fines primary of Plant 2 to the fines secondary feed of Plant 1, we used approximately 50% new piping and 50% existing piping from the underflow system of the fines primary.
- To connect the overflow, we used a new 18" pipe that was available in the warehouse, left over from previous projects.

3.2.2 Replacing Water with Low-density Bauxite Slurry

Replacing process water with low-density bauxite slurry (< 3%w/w) in the hydrocyclone feeds can be a solution to reduce process water consumption in mineral processing [5]. Simulations on the present work have shown two positive effects:

- Ensuring control of the feed density of the 2nd step of classification of mid-size particles;
- Reduction in freshwater consumption, contributing to the water sustainability of the process.

Viscosity is one of the most important parameters in bauxite transport since it is primarily affected by particle sedimentation, which influences the formation of agglomerates that, in turn, hinder pumping [6].

However, simulations have shown that slurry recirculation would result in a reduction in hydrocyclone separation efficiency, increasing the presence of fine (< 45 µm) clay particles in the product.

To mitigate this effect, a maximum solid concentration of 3 %w/w was established for the recirculated slurry. This limit was defined to prevent an increase in fines content, as values exceeding 47 % of < 45 µm particles in the product directly impact the flow resistance –Yield Stress – surpassing the safe pumping specification for the pipeline system (70 Dyn/cm²). The control of the fine fraction and Yield Stress is detailed in Table 3.

3.2.3 Adjustments to Hydrocyclone Geometry

Among the hydrocyclone operating and project variables that can be adjusted to increase classification efficiency, apex and vortex diameter can be changed in short-term bringing relevant improvements [7]. Aiming to offset the effects of low-density bauxite slurry recirculation over hydrocyclone classification efficiency, a set of simulations have been done evaluating different apex and vortex diameters. Simulated mass fraction of particles finer than 10 µm on the product reduced from 31 % on the scenario with slurry recirculation with standard apex and vortex diameters, to 26.2 % on the scenario with adjusted cyclone geometry.

The simulated modifications were reduction of apex diameter of secondary step of classification on mid-size particles circuit from 150 mm to 125 mm, reduction of apex diameter on both steps of classification at fine particles circuit from 50 mm to 38 mm and increase of vortex diameter on the primary step of classification on fine particles classification circuit from 76 mm to 101 mm.

Table 2. Adjustments to hydrocyclone geometry.

Modifications	Apex			Vortex
	2 nd Finos	1 st Ultrafines	2 nd Ultrafines	1 st Ultrafines
Before (mm)	150	50	50	76
After(mm)	125	38	38	101

The simulated results of changing the referred apex and vortex diameters was evaluated as an effective solution to offset the impacts of slurry recirculation over classification efficiency, as the simulated mass fraction of particles finer than 10 μm on the product is similar to the observed on the base case scenario, with all thickeners under operation: 25.0 % on the base case versus 26.2 % on the scenario with adjusted apex and vortex diameters.

3.2.4 Managing the Water Balance

Simulations have shown that the water balance would be the limiting factor for operating the beneficiation plant without one of the tailings thickeners. In this scenario, the simulations indicated that process water consumption could increase by 32 % compared to the base case with all thickeners in operation, exceeding the capacity of Mineração Paragominas' water sources. This increase in water consumption occurs due to the diversion of 1 700 m^3/h of tailings slurry, originally intended for the tailings thickener of line #2, to the tailings disposal system.

The simulations also demonstrated that, during this period, the total specific water consumption (process + freshwater) to produce 1 tonne of dewatered bauxite would reach 2.09 m^3/t , while under normal operating conditions this figure would be 1.39 m^3/t . At the end of the maintenance period, the actual specific consumption was 2.03 m^3/t .

To achieve the water efficiency projected in the simulations, a comprehensive assessment of the water system was carried out, resulting in two main definitions were set:

- Line #2 tailings thickener maintenance must be carried out during the rainy season, when water availability is higher due to the contribution of rainwater to Mineração Paragominas' water reservoirs;
- On the weeks before tailings thickener maintenance, the strategy should be to maximize water supply from the river (keeping it within the granted limits) contributing to a lower consumption and thus, higher water storage on the reservoirs. Water from the reservoirs would be key to keep operations with the higher water consumption during maintenance activities.

3.3 Impact on Productivity and Product Quality

Potential solutions to allow the operation without one tailings thickener were evaluated, prioritized and then implemented on beneficiation plant. Tailings thicker maintenance was carried out and had the following results:

- A reduction in estimated production loss from 40 % to just 2 %. This was validated by tonnage processed, projections. Without operational adjustments, it would have been infeasible to operate Plant 2 during the maintenance period;
- Maintenance of the product's particle size specification and rheology within specification limits. Product mass fraction passing 45 μm and 10 μm was respectively 1.5 % and 2.1 % higher during the operation without one thickener, when compared to the regular operating conditions, meeting the specifications for transportation through the long-distance pipeline, as illustrated in Table 2 and Figure 3.

- Stability of the water balance, maintaining optimum operating slurry densities at all critical points in the circuit.

Table 3. Viscosity and particle size distribution data before and after operation with 3 thickeners (using Bingham Model).

	% Solids	Plastic Viscosity (mPa)	Yield Stress (Dyn/cm ²)	45 μm	10 μm
Before	51.4	8.1	45.4	42.8	25.0
After	51.2	8.6	53.3	43.4	25.5

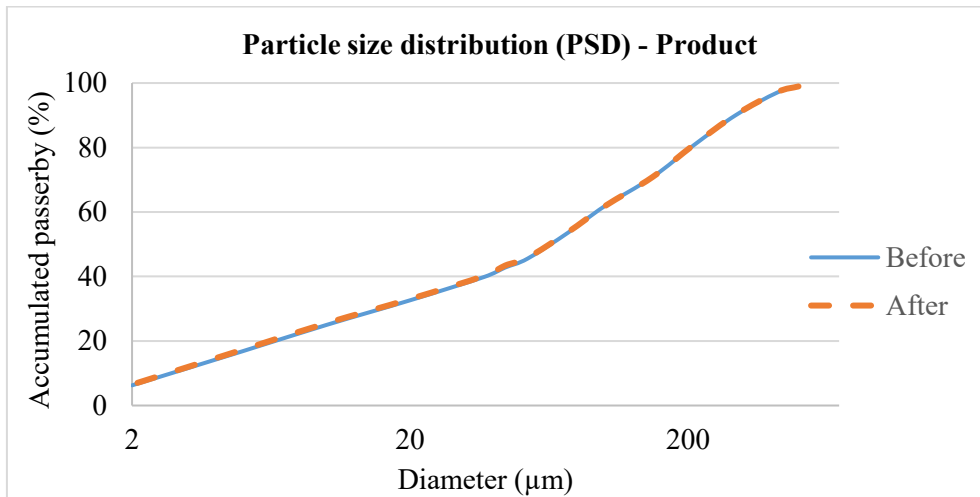


Figure 3. Comparative graph of particle size distribution before and after operation with only 3 thickeners.

3.4 Operational Validation

During the 20 days of maintenance on line 2’s tailings thickener, the operation with adjusted process flows was successfully implemented. The process data collected confirmed the accuracy of the predictions obtained in simulations, with good adherence between the simulated and real results. Average plant 1 tailings thickener flowrate during the maintenance activities was 4 448 m³/h, 1.6 % higher when compared to the output from simulations. Regarding to plant 2, tailings generation flowrate during the maintenance activities was 1 700 m³/h, 2.25 % lower when compared to the output from simulations, validating the effectiveness of the methodology and the Nageswararao model for classification. Figures 4 and 5 display the results of the daily flow averages compared to the simulation.

The accuracy of the model was assessed using the MAPE (Mean Absolute Percentage Error), which represents the average of the percentage errors - the lower the MAPE, the better the fit of the model [8]. For the thickener feed flow from Plant 1, a MAPE of 8.1 % was obtained, indicating excellent accuracy, and an MAE (Mean Absolute Error) of 369 m³/h, within the acceptable operating variation range to guarantee the integrity of the asset. These results reinforce the reliability of the simulations, and the decision-making based on the model.

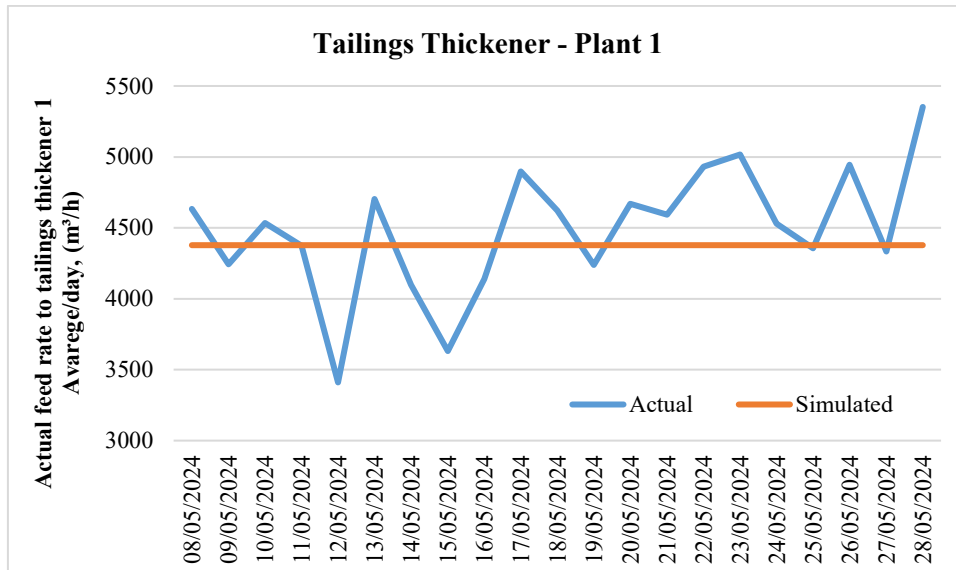


Figure 4. Comparative graph between the average daily flow rates per hour of the tailings thickener feed at Plant 1.

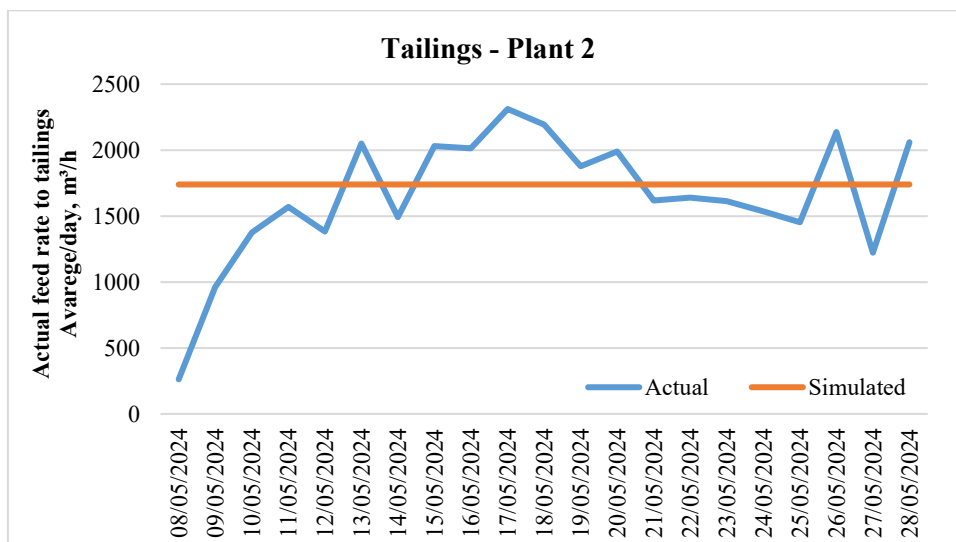


Figure 5. Comparative graph of the average daily flows per hour of the tailings generation at Plant 2.

In the case of the thickener at Plant 2, responsible for the material directed to the tailings, the first two days of operation were dedicated to stabilizing the process and adjusting the setpoints. After this period, the simulation began to more faithfully reflect real behaviour, resulting in an MAPE of 16.8 %, considered satisfactory for mineral processing simulations. The MAE of 290 m³/h represents a variation that could be absorbed by the pumping system without any negative impact on process performance.

4. Conclusion

Maintaining operational continuity at Mineração Paragominas' beneficiation plant, even when one of the four thickeners was shut down, was made possible thanks to the application of a systematic approach, including process simulation and risk management actions. By utilizing the Nageswararao classification model, several operational scenarios were simulated and analysed. This allowed a broad evaluation of alternatives and the development of effective strategies.

Through this methodology, compliance with the product's granulometric specifications and the stability of the plant's water balance, were ensured, ultimately minimizing production impacts during the critical maintenance period.

The main solutions that were implemented - such as redirecting flows, partially replacing water with diluted bauxite slurry, and making changes to the geometry of the cyclones – proved to be effective both in simulation and in real operation. The result was a significant reduction in the estimated production loss, from 40 % to just 2 %, while maintaining product quality within the specification range and operational stability.

This study highlights the relevance of using simulation tools to support decision-making in critical situations. It also emphasizes the value of technical preparation and predictive analysis to anticipate risks, mitigate losses and guarantee the continuity of industrial processes. This ensures the integrity of assets, high levels of productivity and process stability.

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