Process Optimization: from Software Sensor to New Control Strategy and Applicability of Artificial Intelligence

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Abstract

Mineração Paragominas' operations involve the extraction, beneficiation, and hydraulic transport of bauxite to the Hydro Alunorte alumina refinery. This study focuses on the beneficiation stage, which comprises two parallel processing plants that treat homogenized ore independently. Through various unit operations, including cycloning, high-frequency screening, milling, crushing, and thickening, the desired mineral is separated and concentrated. The final product is composed of three streams: the underflow from the secondary cycloning of superfines, undeflow from the thickening cycloning, and underlow from the concentrate thickening. The latter, which contains the finest ore fractions, represents approximately 30% of the total output. These streams are stored in slurry tanks and pumped through a 244 km pipeline from the beneficiation plant to the alumina refinery.

Occasionally, fluctuations in the physical quality of the slurry batches impact the final product quality. In response, a set of control engineering strategies was developed to improve process stability and product consistency. The main initiatives included:

1. Development of a software-based density sensor enabling closed-loop control in the cycloning stage.
2. Implementation of an override control strategy to enhance process responsiveness and reliability.
3. Application of artificial intelligence (AI) techniques – specifically, fuzzy logic control – to optimize slurry tank composition by dynamically adjusting the mass flow rate of the Concentrate Thickening underflow.

The density software sensor leverages mass balance principles to overcome instrumentation limitations, effectively closing the control loop. The AI-driven system predicts the physical quality of the slurry in real time and adjusts the setpoints to ensure consistent blending within quality limits. These innovations have resulted in improved product quality, increased productivity, enhanced thickener performance, and overall gains in process efficiency at the refinery – delivering value across the entire production chain.

Keywords: Regulatory Control, Advanced Control, Fuzzy Logic, Process Optimization, Bauxite processing.

1. Introduction

Mineração Paragominas S.A. (MPSA), a bauxite beneficiation facility located in Pará state, Brazil, is currently in full operation. The bauxite is processed in two parallel plants that operate independently, undergoing comminution, classification, and thickening stages, which are the main unit operations in mineral processing. The product is transported via a 244 km long slurry pipeline to the Hydro Alunorte alumina refinery, located in the municipality of Barcarena, Pará.

Mining constantly faces challenges related to process variability and the need to produce materials with increasingly strict granulometric and chemical specifications, especially due to its integration into a production chain for slurry transport and feeding the Bayer process.

The product from the bauxite beneficiation plants is composed of three main streams: secondary hydrocycloning of superfines, thickening hydrocycloning, and concentrate thickening, as shown in the flow diagram in Figure 1. Approximately 70% of the product corresponds to the alumina-rich particle size fraction composed of coarser particles above 37 µm, obtained through classification operations using hydrocyclones. These devices separate particles based on differences in their behavior in a fluid medium (water), featuring an inlet, an upper outlet (vortex finder), and a lower outlet (apex). The concentrate thickening stream consists of the finer fractions of the ore, between 45 µm and 10 µm, which significantly impact the final quality of the material sent to the refinery. This fraction is directed to concentrate thickeners, which are responsible for increasing the solids content of the slurry through sedimentation. The underflow mass from these thickeners represents about 30 % of the total product.

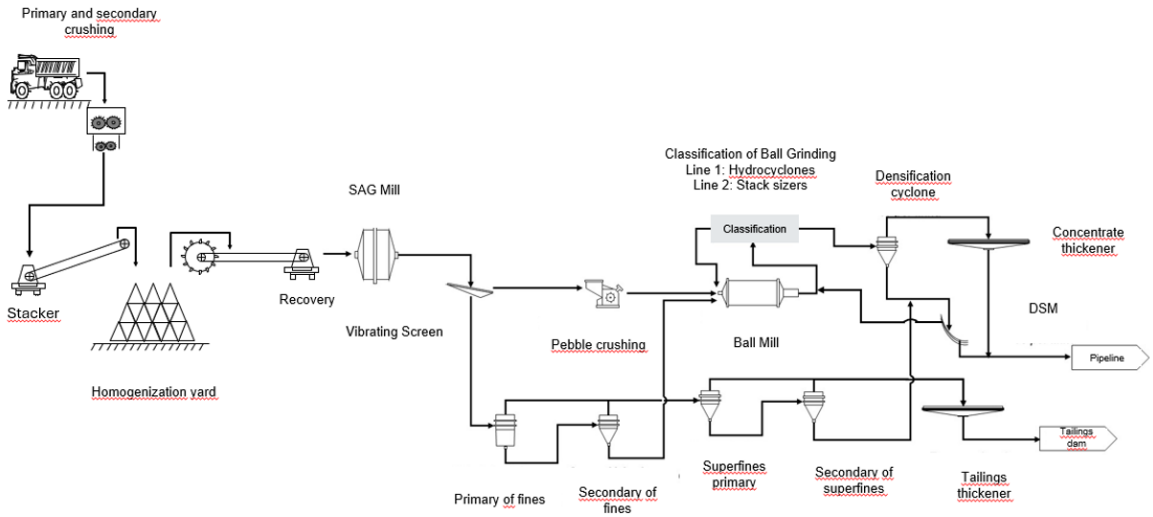

Figure 1. Simplified flowchart of the product formation streams at MPSA.

However, variability in the physical properties of the slurry batches pumped to Hydro Alunorte can compromise the performance of the refining process, affecting, for example, the efficiency of the digestion stage, and posing risks to the integrity of the slurry pipeline, such as accelerated wear, which occurs due to larger particles, as they promote more intense impacts on the internal wall of the pipeline, in addition to causing abrasion by scraping when in contact with the bottom of the pipe, significantly reducing the useful life of the pipeline.

Similar results were observed in the granulometric fractions:

- **45 µm**: standard deviation reduced from 1.55 to 1.00; Ppk increased by 0.27; Cpk increased by 0.44.
- **10 µm**: standard deviation reduced from 1.24 to 0.75; Ppk increased by 0.17; Cpk increased by 0.13.

These results demonstrate that the Fuzzy controller contributed significantly to homogenizing the quality of the final concentrate, mitigating the impact of fine fractions originating from the thickener underflow.

Furthermore, the hypothesis tests (t-test) with 95 % confidence confirmed the accuracy between predicted and actual data, validating the fuzzy logic model.

Overall, these results highlight the effectiveness of Fuzzy logic as a complementary tool to traditional control systems, delivering tangible improvements in quality, operational stability, and beneficiation process efficiency.

4. Conclusion

The integrated adoption of technologies such as virtual sensors, advanced regulatory control strategies (such as override control or similar), and intelligent advanced control systems like fuzzy logic, represents a significant advancement in the management of industrial beneficiation processes. When applied in a complementary manner, these solutions enable greater operational stability, improved control of critical variables, and increased adaptability to the inherent fluctuations of mineral operations.

Virtual sensors make it possible to obtain reliable information even in environments with instrumental limitations, allowing the applicability of loop controls, reducing the usage of open control loops. The override control strategy provides robustness in systems with multiple control variables and limited actuation options, ensuring safer and more effective automatic decisions across various operational scenarios. Finally, the use of artificial intelligence with fuzzy logic enables predictive and real-time adjusted actions, reducing variability and ensuring greater compliance with established quality standards.

Together, these approaches contribute to a more efficient, safer, and standardized operation throughout the beneficiation process. Their outcomes point to consistent gains in productivity, product quality, asset preservation, and readiness for future advancements in automation and digitalization paving a promising path toward intelligent mining.

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