Original Article

Recovery of fine cassiterite from jigging tailing in Colniza/MT using shaking tables

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Abstract

Traditionally, cassiterite processing in the Brazilian Amazon is carried out by spirals and jigs, efficient equipment for recovering dense minerals. This study technically evaluated the implementation of a Wilfley-type shaking table plant for the concentration of cassiterite, fed with tailings from the jig plant of São Francisco Mining, located in Colniza, MT, Brazil. These tables are recognized worldwide for their high precision in the separation of fine particles (-3 mm). The proposed circuit consisted of six vibrating tables operating in parallel (rougher) followed by a cleaner table, which significantly increased the daily tin production to an average of 262.7 kg/day, reducing the amount of tin sent to the tailings dam. The average tin content in the final concentrate was 63.21%, increasing the overall tin recovery. This study highlights the importance of the synergistic combination of gravimetric techniques in the optimization of mineral processing.

Keywords: Cassiterite; Gravity concentration; Tin recovery; Shaking tables.

1 Introduction

Mining has been a central activity in the economic and technological evolution of societies, providing indispensable resources for industrial development and job creation, especially in regions rich in natural resources such as Brazil [1]. Cassiterite stands out among the minerals of great national importance, as the main tin (Sn) ore, an essential element for several industries, including the production of metallic alloys and electronic components [2]. Historically, cassiterite exploration in Brazil has played a strategic role in the country's economic development, with emphasis on alluvial production in the North region [1]. São Francisco Mining is located in the city of Colniza/MT, in the Center-West region of Brazil, is an important player of this mineral production. Operating in a former artisanal mining area, the mining company processes the old tailings deposits from the previous activities. This historical context, combined with the geographical location of the mining operation, close to the Amazon rainforest, poses environmental and logistical challenges that require innovative practices to concentrate cassiterite (see Figure 1). Despite the challenges, São Francisco Mining operation stands out for its ability to recover Sn from tailings, adopting sustainable approaches that reduce the need to expand extraction areas and impact the ecosystem.

Cassiterite processing involves concentration operations to enhance the Sn grade. Given the cassiterite high specific gravity (ranging from 6.86 to 7.03 g/cm^3), gravity concentration methods became particularly suitable for its processing [3]. This technique is widely used and is based on the separation of particles based on their specific gravity through gravitational or centrifugal forces [1]. Jigs use a pulsating water flow to expand the mineral bed and separate the denser materials (sinks) from the lighter ones (floats). Shaking tables, on the other hand, apply an asymmetric movement on an inclined surface with rifling to perform a more refined separation, being especially effective for fine particles [1,4,5]. The conventional gravity equipment can be used with a particle size ranging from 60 to 1,000 µm. Equipment such as jigs, spirals and shaking tables operates efficiently with different particle size distributions. Jigs are

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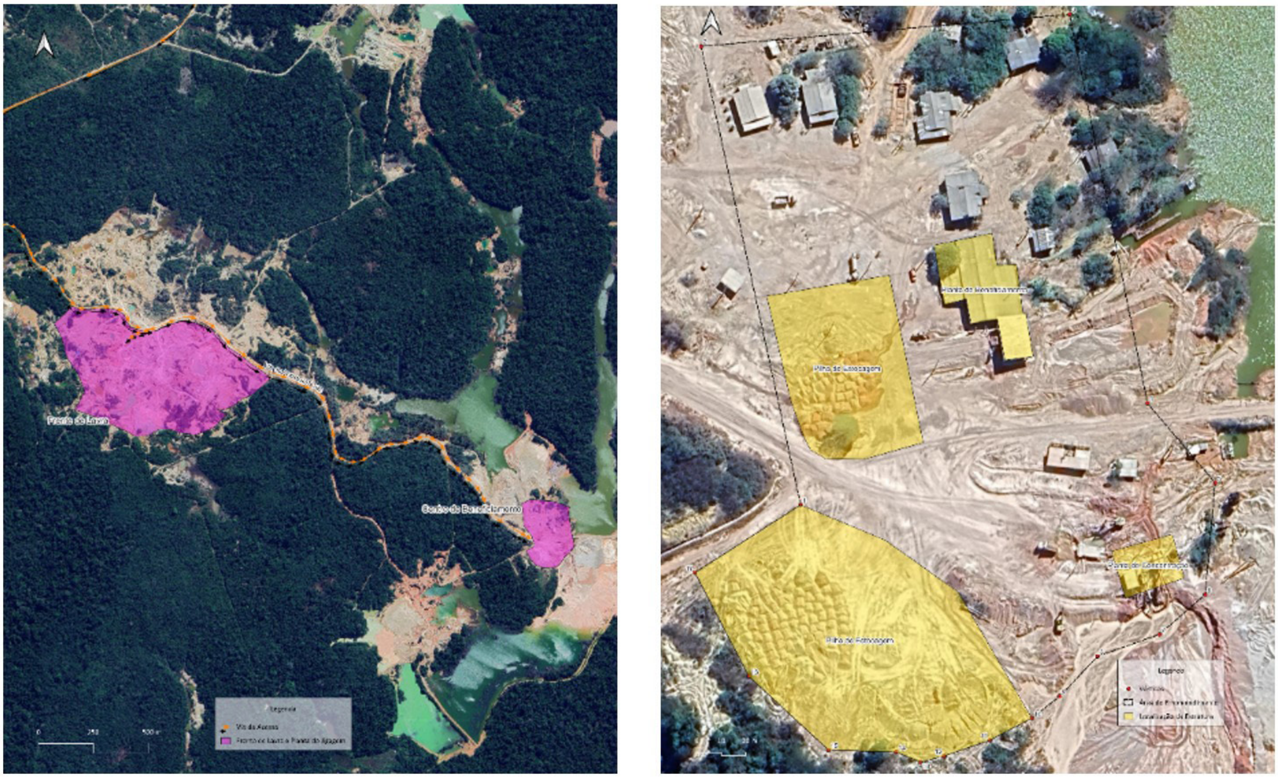

(a) (b)

Figure 1. Location of São Francisco Mining's cassiterite mine (a) and mineral processing plant (b).

normally used to concentrate relatively coarse material and, if the feed is fairly close-sized (e.g., 3 to 10 mm), although they can achieve good recovery down to 150 µm and acceptable recoveries often down to 75 µm. Tables operating on feed sizes in the range 3 mm to 100 µm are sometimes referred to as sand tables, and the hydrosizer overflow, consisting primarily of particles finer than 100 µm, is usually thickened and then distributed to tables whose decks have a series of planes, rather than riffles, and are designated slime tables [6].

The efficiency in Sn processing from tailings in São Francisco Mining is mainly due to the use of jigs. The choice of this equipment is justified by its effectiveness in the selective recovery of heavy minerals [7]. Figure 2 presents the company's original flowsheet. It is possible to notice that the concentration was carried out in two rougher stages and two cleaner stages, all then using twin cell Pan-American jigs (see Figure 3). This equipment is designed for high-efficiency gravity concentration and is equipped with two cells (hence the name twin cells), which operate in an interconnected manner, allowing continuous separation of heavy minerals, consuming less water and space, without losing production capacity [8].

Despite the results already obtained by jigs, the company was interested in recovering tin from the tailings. However, the low grade in this flow required the adoption of more advanced concentration strategies. In this sense, São Francisco Mining introduced shaking tables fed with jig tailings. Although the initial investment (CAPEX) with shaking tables is higher, this equipment is widely recognized as one of the most accurate gravity methods for fine particles, an essential feature for the efficient treatment of cassiterite [2,5,7].

The shaking tables implemented were Wilfley tables, following the configuration developed and patented by Arthur Wilfley in the United States in 1895 [2], consisting of a slightly inclined deck that combines hydraulic and mechanical action to separate particles based on their density and size. Water is fed into the upper end of the table, creating a flow that transports the particles along the rifled surface, while an asymmetrical oscillatory movement, perpendicular to the flow, promotes differential transportation of the particles.

The dense particles settle behind the rifles, gradually advancing with the oscillatory movement and are discharged at the opposite end of the driving mechanism, where an adjustable diverter separates them into high and low-grade concentrate [9]. Light particles and slimes, which remain suspended in the water flow, go to the opposite side of the feed or to the end of the smooth part of the deck [10]. This combination of hydraulic and mechanical forces allows differential transport and results in a partial overlap of the concentrate and tailings bands.

The study of this gravity concentration configuration aims to evaluate the performance of concentrator tables in

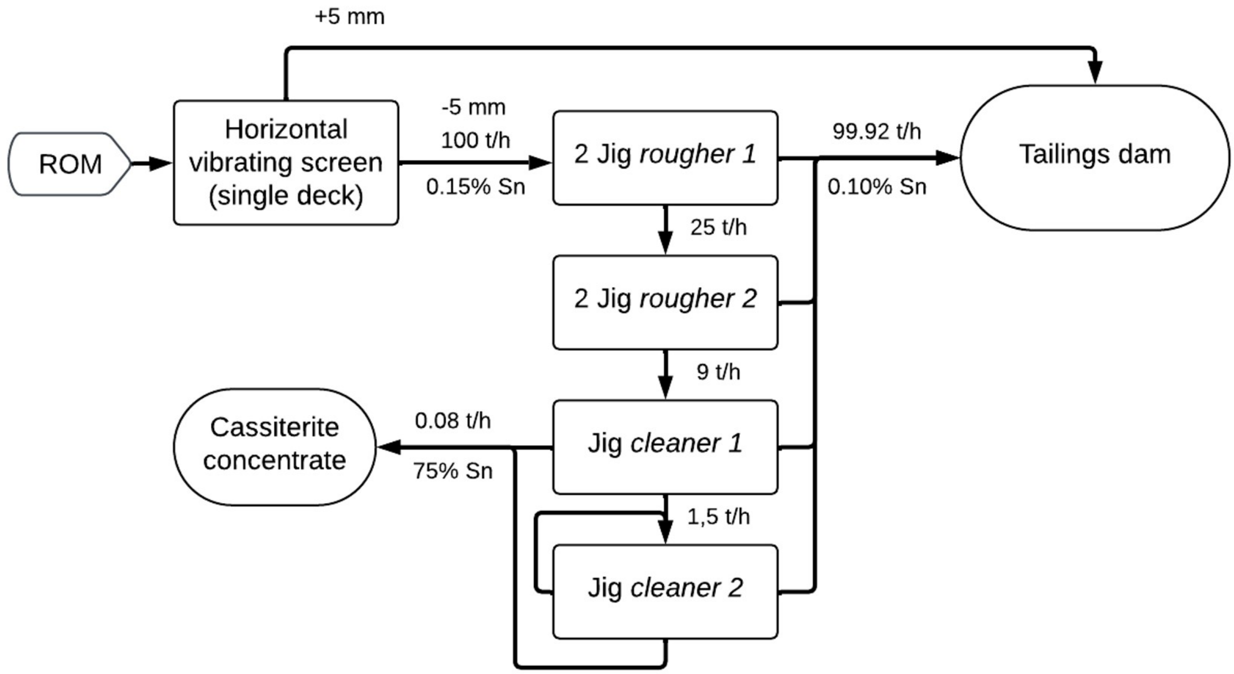

Figure 2. Cassiterite processing flowsheet before the shaking tables commissioning.

Figure 3. Twin cell Pan-American jig operating at São Francisco Mining.

the recovery of cassiterite from jig tailings at São Francisco Mining, through a detailed analysis of the feed and production data. The relevance of this research lies in the scientific contribution to the field of mineral processing, offering technical subsidies that can optimize operations and serve as a reference for other mining companies seeking to improve the efficiency and sustainability of their processes. In the context of growing demand for tin in the global market, the study stands out for its potential to provide technological solutions for more sustainable and effective processing of cassiterite, with positive impacts on economic and environmental issues [11].

2 Methodology

The study was conducted at São Francisco Mining (Colniza, MT), with the aim of evaluating the efficiency of cassiterite recovery from the reject from the cleaner stage of the jigging plant, implementing shaking tables. To attest to the efficiency of this process, yield and recovery were used. The implementation of Wilfley-type shaking tables at São Francisco Mining began in April 2023, with the installation of a table to assess the efficiency of cassiterite recovery from the jig cleaner stage tailings. After the initial results, six shaking tables were added to the circuit operating in parallel in June 2024. This new arrangement allowed the material to be distributed simultaneously between the tables, increasing the system's throughput. Each table had their inclination and solid percentage adjusted to maximize recovery according to the density and granulometry of the material, reducing cassiterite losses throughout the process.

The system's performance was evaluated considering the three phases of development of the concentration process: initial operation with jigs only, the addition of a table and, finally, the expansion with the installation of six additional shaking tables in parallel. At each phase, it is possible to gradually observe the improvement in cassiterite recovery efficiency.

The comparative analysis between these stages considered the total recovery rate and the cassiterite grade in the final concentrate.

Samples were collected during the tests and the chemical analysis was performed by sampling the concentrates (stored in big bags) to produce samples of 10 kg, which were quartered into two samples of 100 g. The cassiterite samples were pulverized in a ring and puck mill and sieved to be 100% passing in 200#. A 0.2 g sample was sent to wet chemical analysis. The sample was melted at 1000 °C with NaOH, producing a soluble, orange-colored compound called sodium stannite (Na_2SnO_2). After cooling, the bead was dissolved in a solution of HCl and distilled water, transferred to an Erlenmeyer flask, where the tin is reduced with acid and aluminum wire. A titration was performed using an automatic burette and a starch-iodine solution as an indicator (1 ml of 0.1 N iodine + 5 ml of 5% starch solution diluted to 100 ml), allowing the precise quantification of the tin grade, with the end point indicated by the color change [12]. Minitab 21.4.2 was used to plot the graphics.

3 Results and discussion

The concentration process using the jig circuit was analyzed to assess its efficiency. From the feed rates, production and concentrate grade, it was possible to plot frequency histograms, as illustrated in Figure 4, representing the daily yield and Sn recovery from the jig circuit. The analysis of the histograms reveals that, despite the daily concentrate production at São Francisco Mining, which varies from 175 to 225 tons, the yield does not exceed 5%, reflecting the limited process tin low grade in the feed, approximately 0.15% of Sn, since the deposit had already been partially explored in the past by another company.

However, the jig plant has proven to be capable of producing high-grade concentrate, as shown in Figure 5, which presents a control chart of the Sn grade in the final concentrate. The average Sn grade in the concentrate was 68.50%, with lower control limit (LCL) 66.21% and upper control limit (UCL) of 70.80%, classically known as sigma limits. These values, although presenting outliers, are within the expected range for a tin processing plant, whose concentrate production should reach grades between 70.0% and 76.5% [13]. The found outliers were responsible for a high production or a low Sn grade and are directly connected to the fact that the mine is an anthropogenic deposit. Therefore, the ore variability is too high.

The Sn grade in the tailings suggested the need for improvements in the process, especially regarding its recovery. In this context, the implementation of shaking tables, specifically Wilfley-type ones, appeared as a promising

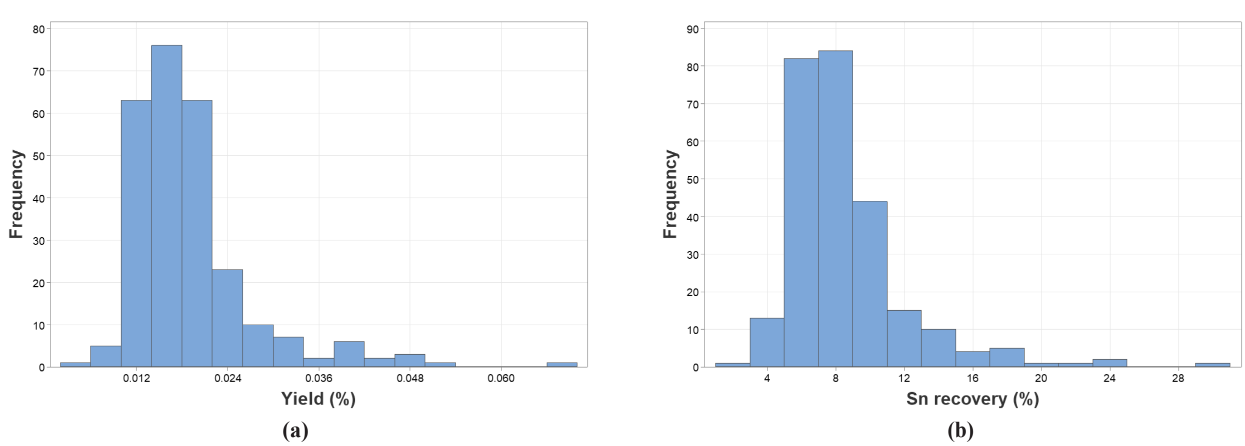

Figure 4. Frequency histogram of the daily yield (a) and Sn recovery (b) by jigs.

alternative. The performance of this alternative was evaluated, and the results are presented in Figure 6.

The average production of a shaking table is lower than a jig, given that shaking tables operate with a feed < 2 t/h, therefore restricting their use mainly to the cleaning stages [1], which can be seen in Figure 6A, with an average daily production around 93.8 kg of Sn, which represents a substantial increase to the total concentrate produced by the plant.

The concentrate had an average Sn content of 55.81%. This value, although lower than that obtained by jigging, was expected, since the table was operating with low-grade tailings, making it difficult to obtain higher enrichment values. The found results were higher that obtained by Youssef et al. [14]. The authors obtained a concentrate with 13.2% of Sn working with samples from Igla placer ore. Arief [15] worked with tin ore samples from PT TimahTbk, one from the Bantam B122 plant and the other from Jangkang Washing Plant, obtained optimal recoveries of 75.03%, and 70.15%, respectively. The authors conclude that the optimum operational condition was achieved at a deck slope of 8° and water flow rate of 15 lpm. The yield and tin grades in the concentrate by shaking table are shown in Figure 7.

The optimization of this process route was achieved by combining shaking tables operating in a rougher/cleaner circuit [6,11]. In this sense, a new arrangement of shaking tables operating in two stages (six shaking tables operating in parallel in the rougher stage followed by one in the cleaner stage) was proposed, with the aim of increasing the final concentrate grades, as illustrated in Figure 8. This configuration increased the total capacity of the plant, allowing the processing of up to 6.2 t/h of material, distributed evenly between the tables by a screw feeder. The pre-concentrated is classified by hydrocyclone, which sent the fine particles to the tailings and promoted a sludge dewatering and fed the cleaner table. The concentrated daily production and tin grades in the concentrate are shown in Figures 9 and 10.

The found results suggest that the new route with shaking tables operating in two stages can provide a significant increase in Sn daily production (average production in the considered period of 262.7 kg/day). Although the tin content registered an average of 63.21%, the increase in the amount of concentrated recovered from the jigging tailings represented a substantial gain for the mine company.

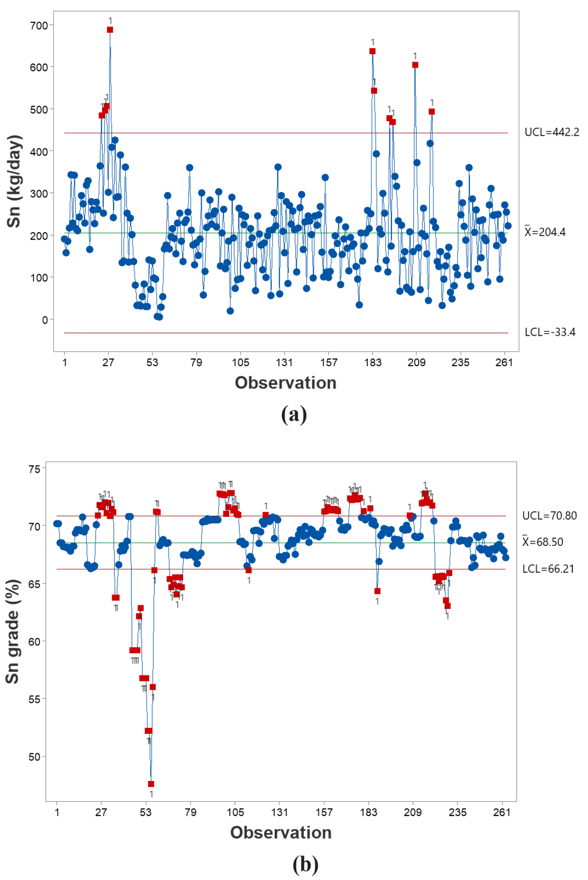

Figure 5. Control chart of the daily Sn production (a) and Sn grade (b) in the final concentrate produced by jigs.

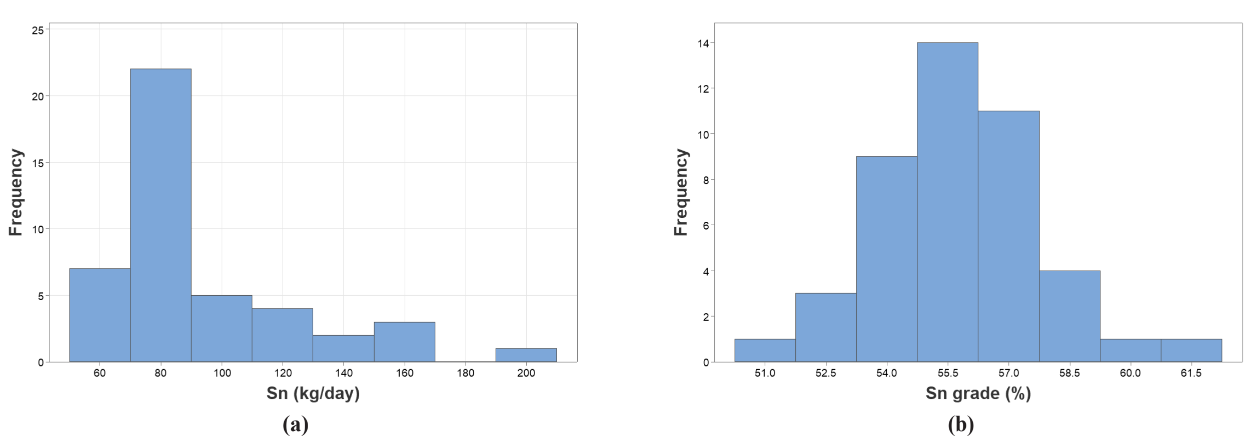

Figure 6. Frequency histogram of the daily Sn production (a) and grade (b) for one shaking table.

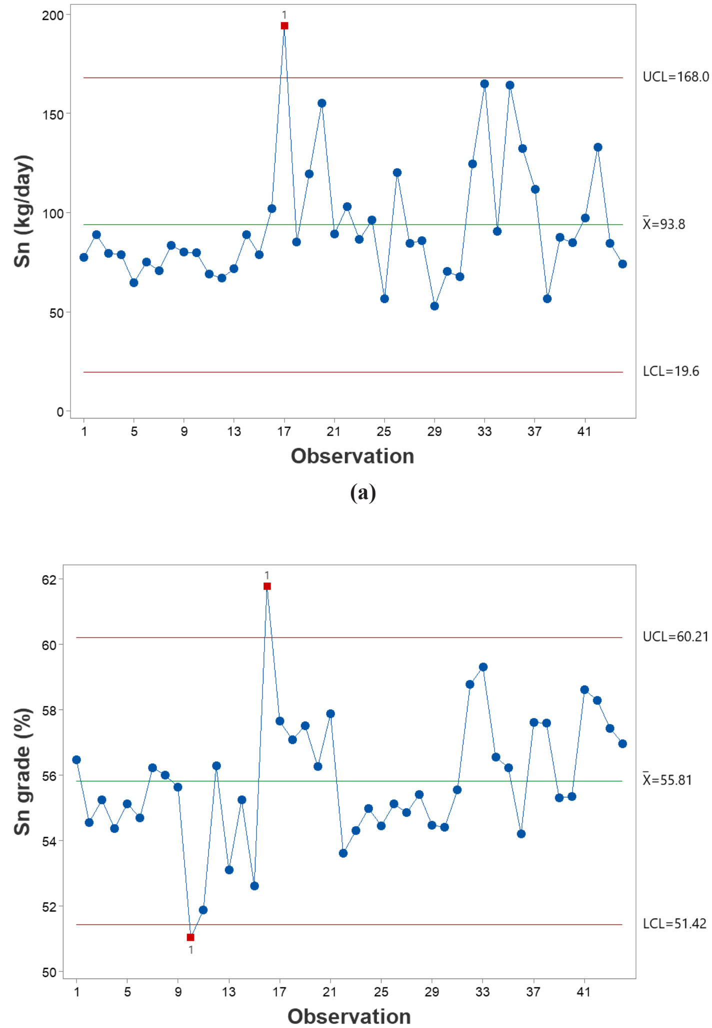

Figure 7. Control chart of the daily Sn production (a) and grade (b) for one shaking table.

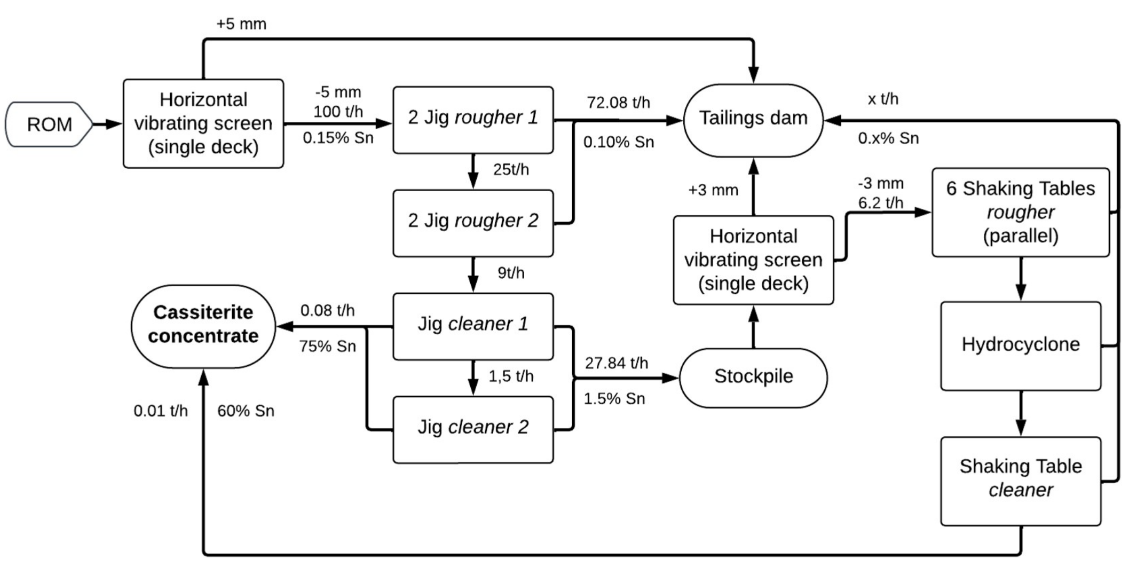

Figure 8. Optimized cassiterite processing flowsheet with the shaking tables plant.

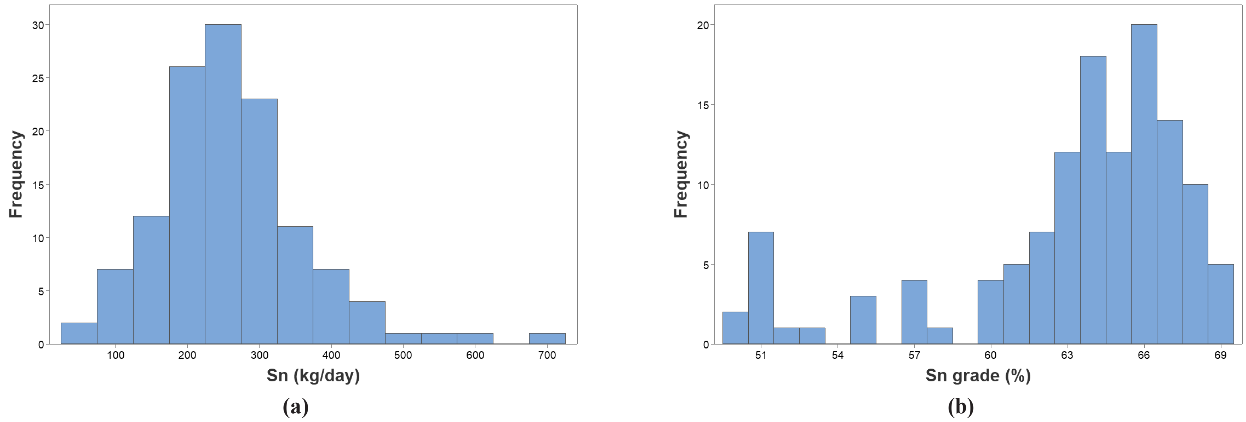

Figure 9. Frequency histogram of the daily Sn production (a) and grade (b) for the jigs and shaking tables combined plants.

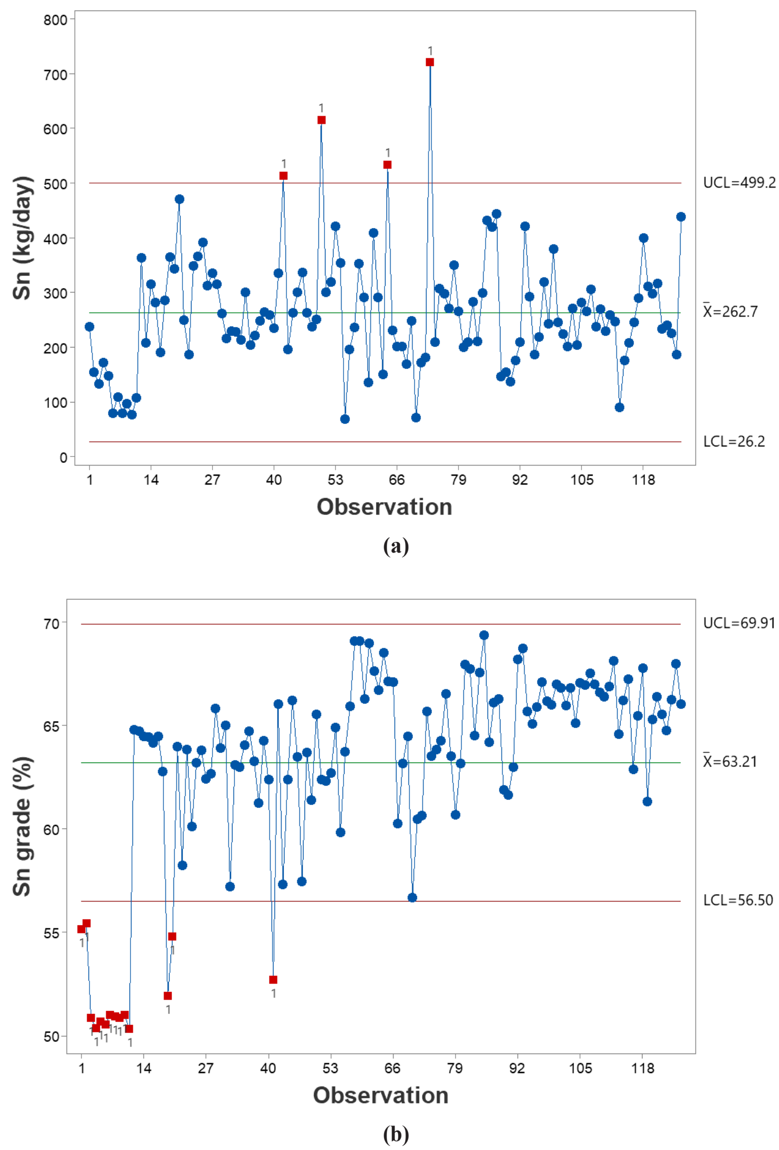

Figure 10. Control chart of the daily Sn production (a) and Sn grade (b) in the final concentrate produced for the jigs and shaking tables combined plants.

4 Conclusions

This study evaluated the efficiency of a new tin concentration plant at São Francisco Mining, using an association of jigs and shaking tables. The results showed that although jigging is traditionally used in mining, its performance was limited. Therefore, the introduction of Wilfley-type shaking tables increased the tin daily production. The proposed processing plant consisted of seven shaking tables, six in the rougher stage followed by one in the cleaner stage. The implementation of this plant not only improved the Sn recovery, but also generated economic gains, a small reduction of the volume of solids sent to the tailings dam, and increased the concentrate production, without expanding the mine exploitation. Therefore, the new plant had positive environmental implications, contributing to the preservation of the Amazon rainforest by reducing deforestation associated with cassiterite mining.

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