CONVERSION OF AN EXISTING INDUSTRIAL FACILITY OF PELLET FEED FILTRATION TO TAILINGS FILTRATION*

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Abstract

Since 2019, a new Brazilian directive has prohibited in the country the use of dams constructed by the upstream method and limited the use of those by the downstream method. From that, some iron ore wet processing plants that used to dispose their tailings into upstream constructions had to be redesigned to filter their own tailings using their existing process and equipment. This was the situation for at least one plant in the Iron Quadrangle Region, which will be analysed in this article. First, laboratory tests were carried out to provide process parameters to support a sizing assessment of the existing equipment for the new type of material. Next, an industrial test was executed, where a deactivated auxiliary dewatering plant received the total tailings from one operational plant for a two-month period. The total tailings filtration rate obtained was 1.46 t/h.m². The average moisture content of the filtered tailings was 11.8%, while the average iron content was around 17%. The apparent bulk density of the filtered tailings was 1.80 t/m³. At the end, the operational plant was successfully redesigned to filter its total tailings. The work showed that it is feasible to adapt a plant to filter its own tailings.

Keywords: Filtration; Tailings; Geotechnical; Iron ore

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1 INTRODUCTION

In recent decades, the unavailability of high-grade iron ore supplies and satisfactory liberation of its minerals, associated with the increase in world demand for high-quality products, has required increasing use of concentration processes for iron ore. In addition to the generated product, a large volume of tailings is inevitably generated, which was previously disposed of in dams. These mining dams are geotechnical structures designed with the purpose of containing the tailings as well as providing an environment for solid-liquid separation for later water reuse in the process.

In Brazil, after the registered accidents involving the failure of dams built by the upstream method, the inspection bodies, together with society, began to request that mining companies develop other ways to dispose of their tailings. In this context, on August 8, 2019, the Brazilian National Mining Agency (ANM) published Resolution No. 13, which prohibited the construction or raising of new upstream dams and provided regulations for the closure of existing structures built by this method. This regulation also established short deadlines for these changes to be implemented [1]. Later, on September 30, 2020, Federal Law No. 14,066 was enacted, which confirmed the provisions of Resolution 13 [2].

Faced with this challenge, Brazilian operations that used to use upstream dams to dispose of their tailings needed to study alternative methods for their disposal, as in the instance of the plant discussed in this case study, which is located in the Iron Quadrangle Region of Brazil, in the state of Minas Gerais.

Mining tailings are residues of the beneficiation of iron ore plants. As most ore beneficiation processes are carried out using a wet process, the tailings are generally presented in the form of a pulp, that is, an aqueous flow containing different mineral particles in suspension and/or dissolved ions [3].

There are two main forms of tailing materials that are collectively referred to as iron ore tailings: a coarse (or sandy) tailing produced during the flotation stage and an ultra-fine tailing that, most often, is produced during the desliming process, which comes right before flotation [4].

The management of tailings has been a significant issue for the sector in the last few years. Due to process water loss and the possibility of dam failures, dry storage (dry stacked tailings) has been progressively replacing tailings pond storage. The water content of the tailings can be reduced mechanically by utilizing thickeners to increase dewatering, followed by filtering to recover most of the process water and enable dry stacking [5].

Many authors have already discussed the influence of particle size distribution on the filtration process, more specifically for iron ore, where, for example, Fränkle *et al*. [5] claimed that the ultra-fine tailings create a compressible filter cake and have a significant impact on the filtration process. Araujo Júnior *et al*. [6] also observed a decrease in the filtration rate per unit area as the specific surface area of a sample increased, which occurs when there is a higher proportion of ultra-fines in comparison to sandy tailings.

In addition to the impact on filtration performance, Torquato *et al.* [7] observed that the increase in the proportion of ultra-fines in the total filtered tailings led to an increase in their residual moisture, which would make their dry stacking difficult and may even become impossible. Because ultra-fine tailings have a considerable negative impact on the productivity of the dewatering stages, investigations and projects that diminish the generation of tailings are crucial.

After the 2019 dam disaster that had happened, the company’s guideline was to interrupt the disposal of tailings in all types of dams in the operational site of this case study. It was necessary to develop a provisional alternative to allow for filtering the total tailings of the site’s processing plants and avoid their shutdown.

The operational plant of this case study was originally designed to send its total tailings, that is, the combined sandy and ultra-fine tailings, to a tailings dam. Then, with the tailings dam’s interdiction, the idea was to reduce the operational plant's feed rate to dedicate one of the vertical filtering lines to filter the total tailings and the other vertical filtration line would continue filtering pellet feed as usual.

The existing operational facility consisted of 8 vertical disc filters with an area of 40 m² each and 8 vertical disc filters with 120 m² each and, prior to the filtering stage, two conventional thickeners of 100 m and 60 m in diameter. Those thickeners would be utilised for the compaction of the ultra-fine tailings. Two batteries of 30 hydrocyclones of 10-inch in diameter and a 31 m in diameter thickener also were in place and would be utilised for the consolidation of the sandy tailings. The consolidation step is required to adjust the solids percentage in the flows that feeds the filtration operation.

The process flowsheet of the operational plant can be seen in Figure 1.

Aiming to redesign the operational plant to filter its own tailings, laboratory scale tests were performed as well as an industrial scale test, which used an auxiliary dewatering plant. That facility was shut down and a two-month industrial test was carried out in it to confirm the design parameters for the operational plant. With the laboratory and industrial results, the operational plant was then successfully redesigned and was able to filter its own tailings.

This article will go over both the laboratory and industrial scale tests that were carried out and will set out the methodology used for the plant redesign.

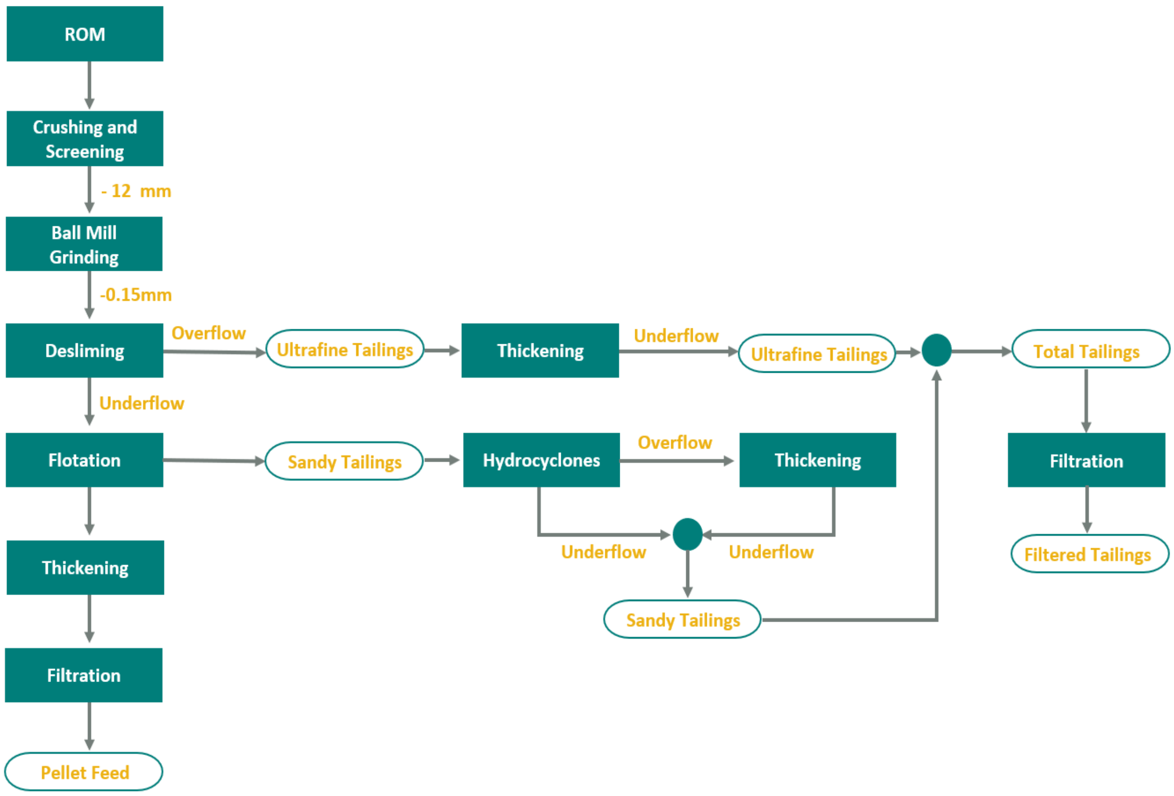

Figure 1 Process flowsheet of the Operational Plant

2 DEVELOPMENT

2.1 Methodology

Material characterization, sedimentation, and bench-scale filtration tests, also known as leaf tests, were carried out to obtain the main process parameters needed (sedimentation unit area and filtration rate) to evaluate the volume of tailings the circuit would be able to process.

The sample was homogenized and divided to obtain aliquots for chemical analysis, performed by X-ray fluorescence and gravimetric methods; particle size analysis, by wet sieving and laser diffraction (Mastersizer Malvern, model 2000); and finally specific surface area determination, by the Blaine method using PC Blaine Star (Wasagchemie®).

Mineralogical analyses were carried out by both automated electron microscope with the QEMSCAN system and a field emission gun (FEG) source by the particle mineral analysis (PMA) method with two-dimensional measurements individualizing each particle and analysing at least 5,000 particles per polished section. The data were subsequently treated using the iExplorer software, from which it was possible to obtain modal quantification, digital images, identification of mineralogical associations, and a liberation spectrum. In liberation analyses, the QEMSCAN performs a stereological conversion, which uses an integral equation to transform the information obtained by analysing two-dimensional images into three-dimensional data.

A sedimentation test for each type of tailings of the operational plant was also carried out. Initially, the percentage of solids and the pH of the pulp were adjusted according to pre-established values. The pulp was transferred to a measuring cylinder and mixed with an appropriate plug. During the cylinder sedimentation test, the displacement of the pulp upper interface with time was recorded. The data was used in the construction of the "Interface Height x Time" graph, which made it possible to determine the rate of pulp sedimentation.

The tests were carried out with the ultra-fine tailings and the classification's overflow of sandy tailings using the corrected Kynch methodology [8] to determine the sedimentation unit area required for sizing the thickeners.

The bench-scale filtration test (leaf test) with the total tailings was carried out using the Dahlstrom and Silverblatt method [9-10], with top-feed tests, using the typical setup arrangement consisting of the standard leaf and a support for the filter element, and connected to a vacuum system. Initially, the pulp was prepared for filtration by adjusting the percentage of solids and the pH in a beaker. When necessary, carbon dioxide (for pH reduction) and sodium hydroxide (for pH increase) were used as pH modulators. For the total tailings stream, tests were carried out with the pre-treatment of the pulp under various conditions and with different types of reagents (coagulants and flocculants). In all cases, the reagents were added to the pulp in the beaker before feeding the leaf. First, coagulant was added, and the pulp was stirred for 30 s. Then, flocculant was added, and the pulp was stirred for another 30 s. Coagulants were used at 100% concentration and flocculants at 0.033%. The pulp was transferred to the leaf with manual agitation, and the vacuum valve was then opened.

The bench-scale filtration test is divided into two stages: cake formation, characterized by the flow of only one fluid (water) through the cake, and drying, characterized by the flow of two fluids (air and water) through the already formed cake. During the test, the "formation stage" ends when the water completely percolates through the cake, disappearing from the surface. The drying time then starts and ends when no more water is being removed.

In the exploratory study, flocculants, coagulants, and cloths were varied, with fixed formation and drying times. Tests were then performed to determine the formation and drying times. Graphs were plotted from the obtained results allowing the dimensioning of the cycle time and the filtration rate per area by the method of Dahlstrom (1997) and Silverblatt (1974) [9-10].

2.2 Results

2.2.1 Laboratory Tests

2.2.1.1 Characterization

The chemical analyses, specific surface area and particle size distribution of the samples are presented in Table 1 and in Figure 1. Contaminants are found in greater proportion in the ultra-fine tailings. For the total tailings, the particle size lower than 0.010 mm was 17%, with a specific surface area of 1,659 cm²/g.

Table 1 Chemical Analysis and Specific Surface per Area

Sample	Fe (%)	SiO_2 (%)	P (%)	Al_2O_3 (%)	Mn (%)	TiO_2 (%)	CaO (%)	MgO (%)	LOI (%)	Specific Surface (cm^2/g)
Flotation Tailings	9.8	84.9	0.017	0.26	0.002	0.010	0.022	0.089	0.17	650.0
Ultra-fine Tailings	35.2	42.5	0.079	4.33	0.243	0.085	0.090	0.305	2.14	7,214.0
Total Tailings	15.1	75.8	0.025	1.09	0.055	0.026	0.032	0.132	0.61	1,659.0

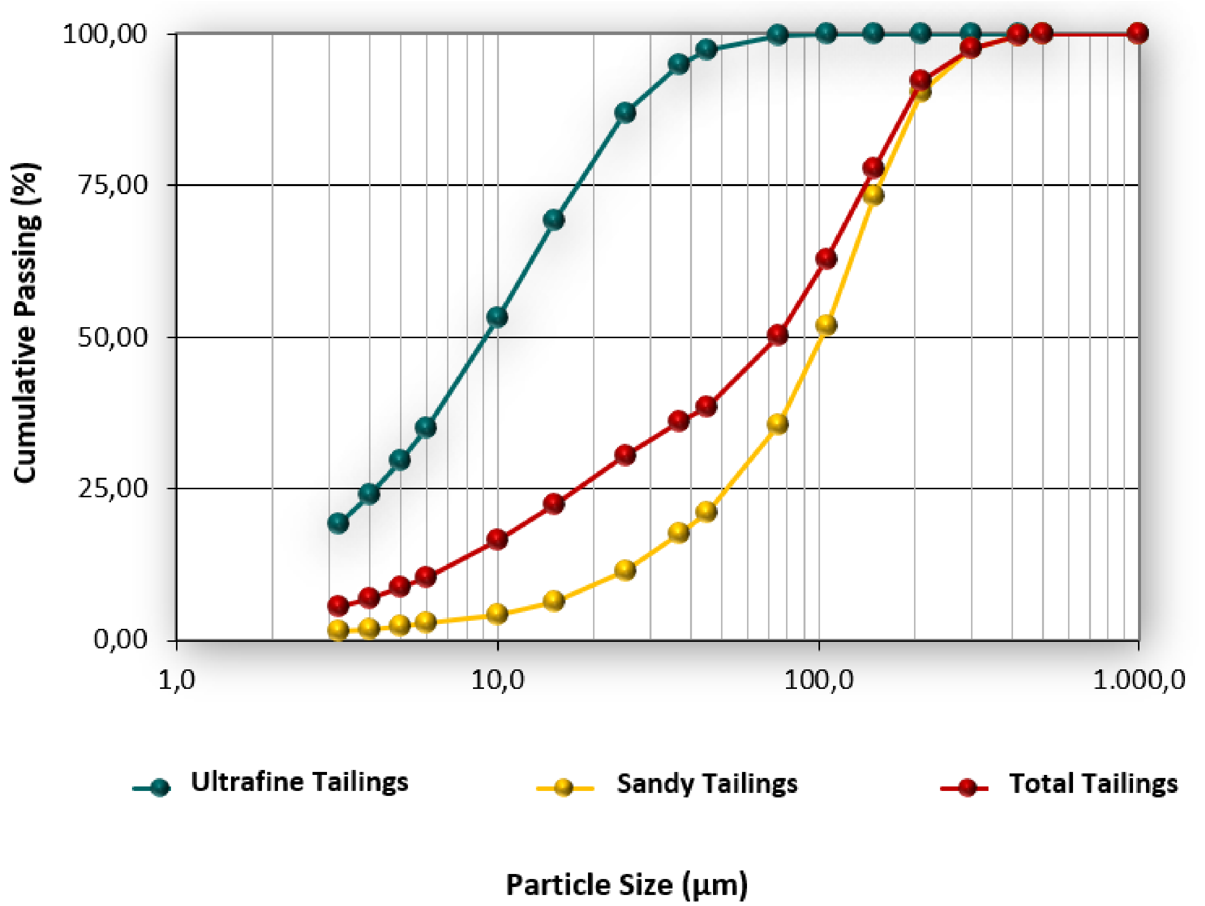

Figure 2 Particle size distribution of the tailings

The mineralogical characterization was carried out via QEMSCAN and the results are presented in Table 2. It was confirmed that the samples were predominantly composed of quartz and iron oxides.

Table 2 Mineralogical quantification via QEMSCAN (%)

Sample	Quartz	Iron Oxides	Biotite	Gibbsite	Kaolinite	Feldspars	Talc	Other Silicates	Mn Oxides	Other Phases
Flotation Tailings	81.11	18.28	0.01	0.00	0.31	0.02	0.05	0.05	0.00	0.07
Ultra-fine Tailings	41.33	52.90	0.25	0.01	4.27	0.12	0.10	0.08	1.01	0.06
Total Tailings	76.29	21.26	0.06	0.00	1.90	0.04	0.02	0.06	0.01	0.05

2.2.1.2 Sedimentation of the Sandy Tailings

The results are presented in Table 3 below. The pH was 7.0. The flocculant used was of an anionic and high molecular weight. A flocculant dosage of 40 g/t resulted in the fastest sedimentation rate and consequently the lowest sedimentation unit area, which was equal to 0.245 m²/t.day. All assays resulted in high turbidity in the supernatant.

Table 3 Sedimentation results of the sandy tailings

Sample	Dosage (g/t)	pH	Solids (%)			Sedimentation Rate (m/h)	Sedimentation Unit Area (m²/t.day)	Turbidity (FTU)
			Initial	Final Calculated	Final Measured			
No Flocculant	0	7	9.1	40.2	40.3	0.39	1.250	22,467.0
Anionic Flocculant	20	7	9.1	38.8	39.4	1.71	0.682	12,867.0
Anionic Flocculant	40	7	9.2	38.2	38.1	10.66	0.245	5,833.0

2.2.1.2 Sedimentation of the Ultrafine Tailings

The conventional sedimentation tests for the ultra-fine tailings were carried out with a pH of 7.0, a feed concentration of 10%, and with an anionic and high molecular weight flocculant. This resulted in a sedimentation unit area of 0.471 m²/t.day with a flocculant dosage of 20 g/t and a percentage of solids of 49.4% after compaction. It should be noted that the ultra-fine tailings have higher iron content than the overflow of the sandy tailings previously tested.

2.2.1.3 Exploratory Leaf Tests

Initially, an exploratory study evaluating cloths filter media, reagents, and dosages with a flow of total tailings was carried out. The cloth filter media test showed that optimum performance was obtained with a monofilament fabric. The optimum flocculant results were obtained with a non-ionic, high molecular weight flocculant with a dosage of 50 g/t.

For the coagulants evaluated, the only improvement shown was in relation to the solids concentration in the filtrate which was below 1.2 g/L, within the acceptable limit of 15 g/L. The optimum results were obtained with an inorganic coagulant.

2.2.1.4 Design Leaf Tests

Based on the series of exploratory tests carried out, the optimum conditions in terms of moisture content and filtration rate were selected to conduct the design leaf test with the objective of sizing the cycle time and obtaining the filtration rate per area.

By applying the optimized conditions found in the exploratory tests, it was possible to obtain a cake with a moisture content of 14.7% with a filtration rate per unit area of 1.5 t/h.m².

2.2.2 Industrial Test at an Auxiliary Dewatering Plant

For the industrial test, part of the operational plant's total tailings was pumped to the auxiliary dewatering plant's existing thickeners. Then, the underflow was sent to the existing auxiliary plant's filtration facility for testing. The product yard was used for stacking the filtered tailings. From there, they were transported to a waste pile by trucks to be subsequently subjected to geotechnical tests of tailings disposal in piles. Figure 3 shows the process flowsheet.

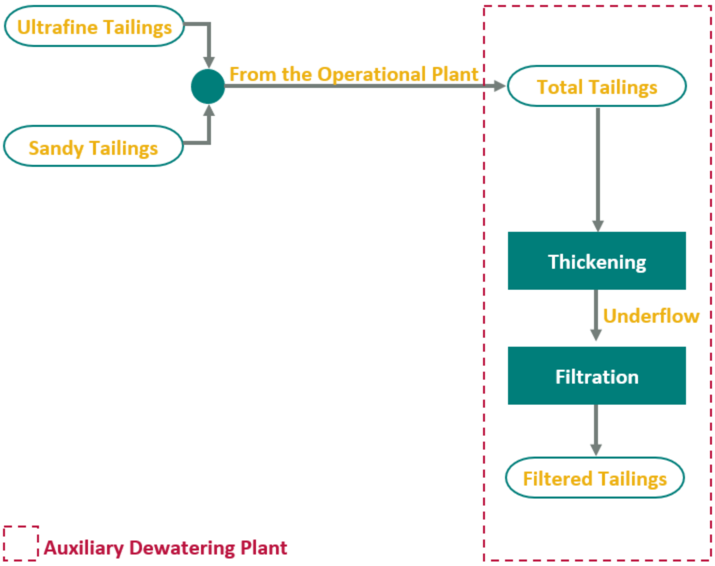

Figure 3 Process flowsheet of the Auxiliary Dewatering Plant

The tailings volume that the existing process equipment could manage was first estimated. Disc vacuum filters require constant cleaning and maintenance, so it was assumed that two filters should always be unavailable, one for electrical and mechanical maintenance and another for cloth cleaning. Thus, it was assumed that only six out of eight existing filters would be operational at one time. Each filter of this plant has an available area of 120 m². Considering the total available area of 720 m² and the expected filtration unit rate of 1.5 t/h.m² (from the laboratory tests results), the filtration capacity would be 1,080 t/h.

The industrial test was carried out for a period of two months, during which it was possible to survey the main process parameters through an extensive and reliable database.

The average filtration feed density was around 1.54 t/m³. It was not possible to achieve higher densities due to the increase in the thickener torque, which caused shutdowns in the entire circuit to protect the equipment. It should be highlighted that the thickener was receiving the total tailings flow. One of the main variables in the filtration process is the pulp density, which directly impacts the productivity and moisture content of the filtration product. Feed density values greater than 1.70 t/m³ had been expected. As that could not be achieved, the average filtration feed rate was reduced to 700 t/h. This result demonstrated the importance of combining hydrocyclone consolidation with thickening consolidation before the filtering stage.

With the reduced mass flow rate of 700 t/h, it was necessary to use only 4 out of the 8 available filters. Then, the average filtration rate per unit area (a variable that expresses the filtration productivity) observed was around 1.46 t/h.m², very close to the expected filtration rate per unit area of 1.50 t/h.m² obtained in the laboratory tests. The measured cake moisture contents were better than expected compared to the laboratory tests, reaching an average of 11.8%.

The quality of the filtrate was also within the expected range resulting in less than 0.5% solids. However, this was only obtained with the use of a coagulant to reduce the percentage of solids of the filtrate flow. The result was better than expected, because the presence of ultra-fine particles in the tailings slurry tend to cause the solids percentage in this flow to be greater than 1.0%.
The iron content of the total filtered tailings during the period of the industrial test was, on average, 17%.

Another important measure was the bulk density which was measured via a drone. The volume of the stored filtered tailings pile and the mass of the processed filtered tailings on the belt conveyor was, respectively, 4,024 m³ and 7,245 tons, thus reaching an apparent density of 1.80 t/m³. This measure is important for determining the size of the handling systems and loading equipment.

2.2.3 Assessment for the Use of an Existing Filtration Unit

Based on the results of the laboratory and industrial tests, the maximum tailings filtration capacity for the operational plant was calculated.

Industrial tests confirmed the necessity of a hydrocyclone stage to increase the density of the total tailings since the industrial test at the auxiliary plant presented difficulty to achieve the solids concentration target using only a thickener.

Thus, in the operational plant, two existing hydrocyclone batteries from the circuit were used to receive the flow of sandy tailings, each with 30 hydrocyclones of 10 inches in diameter. The separation between the underflow and overflow of the hydrocyclones, according to the mass balance simulated in the Usim Pac software, was 76% and 24%, respectively. The overflow of the hydrocyclones would be directed to the sandy tailings thickener and, after the density increase, would again be mixed with the underflow of the hydrocyclones to form the sandy tailings flow. The ultra-fine tailings flow would be consolidated in the ultra-fine thickener and, together with the sandy tailings flow, would compose the total tailings flow.

When adding up the tailings, the proportion between the sandy and ultra-fine fractions is, in mass, around 81% and 19%, respectively. The percentage of the fraction smaller than 0.010 mm is approximately 17%. When talking only about the sandy tailings, the percentage passing lower than 0.010 mm is approximately 5%.

The total operational area available for filtering the total tailings was 640 m² (4 filters of 120 m² and 4 filters of 40 m²), for a filtration rate of 1.5 t/h.m² in the vertical disc filter. The maximum nominal rate that could be filtered for the total tailings would be 960 t/h.
The nominal plant feed rate was 2700 t/h, but the design calculations showed that the capacity of the operational plant would need to be reduced to 66%, or about 1,800 t/h, to make it possible to filter its own tailings using only the already existing equipment. The total tailings generation would be around 885 t/h. The 31 m diameter thickener had to be used to process the sandy tailings nominal feed rate of 140 t/h since the laboratory tests achieved a sedimentation unit area of 0.245 m²/t.day.

Additionally, two existing thickeners, one with a 100 m diameter and one with a 60 m diameter, had to be used to process the ultra-fine tailings nominal feed rate of 302 t/h generated in the desliming stage since the laboratory tests achieved a sedimentation unit area of 0.471 m²/t.day.

2.2.4 Operational Plant Industrial Results

The total tailings filtration operation began at the redesigned plant in March 2020. Sampling and monitoring the operational variables at the plant showed that the hydrocyclone stage increased the density of the flotation tailings achieving a separation, in mass, of 80% to the underflow and 20% to the overflow.

The ultra-fine tailings thickening stage made it possible to increase the solids concentration to 28%. It was not possible to achieve higher solids concentrations in the thickener underflow due to mechanical restrictions of the machine. With the obtained results, the filtration was fed with a flow of around 50% solids concentration, resulting in a productivity of around 1.6 t/h.m² for this unit operation.

Due to the highly abrasive tailings, the need to use polyurethane filtration collector tubes and to coat the filter basins, separator vessels, and vacuum filtration tubes with a ceramic coating was identified for future tailings filtration projects.

3 CONCLUSION

Laboratory and industrial tests validated the plant redesign to temporarily filter its tailings by reducing the plant feed rate and splitting the existing filter capacity between tailings and pellet feed duties. This was necessitated due to dam's interdiction. Operation of the redesigned plant commenced in March 2020.

It was possible to operate the plant with a reduced nominal feed rate while guaranteeing its operational continuity until the entry of a new total tailings filtration facility, as a greenfield project, in June 2023.

This work also had the additional purpose of confirming that the filtration of the total tailings (blend of sandy and ultra-fine tailings) on an industrial scale in disc filters is technically possible.

The importance of further studies and projects that reduce the generation of tailings is necessary, especially for ultra-fine tailings, which significantly impact the productivity of the dewatering stages.

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