

Tailings disposal facilities project for a Brazilian niobium mine: innovation and sustainability in tailings management

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Abstract

Companhia Brasileira de Metalurgia e Mineração (CBMM) is implementing a new tailings disposal facility. The Tailings Storage Facilities 9 (TSF9) project incorporates innovative technologies and engineering practices to optimise safety and efficiency in the management of tailings generated by niobium production. TSF9 includes three main facilities: main dam, with a capacity of 92.8 million cubic metres, and two dry stacking piles with capacities of 16.8 million and 43.5 million cubic metres. The project utilises specific dewatering methods, minimising operational and environmental risks. The tailings were categorised into magnetite, coarse flotation, fine flotation and ultrafine flotation, allowing for more efficient disposal. The physical, chemical and mineralogical characterisation of the tailings was conducted to ensure the best dewatering and disposal solutions for each type of tailings. The magnetic tailings exhibit large, compact grains that drain more easily. In contrast, the flotation tailings, due to their fine granulometry, present challenges in achieving optimal moisture content for compaction, while the coarse fraction of these tailings showed good filtration results. Complementary geotechnical studies, such as compaction and permeability analyses, reinforced the safest techniques for each type of tailings. The solution for the magnetite tailings involves dewatering with hydrocyclones and placement in a specific compacted pile, increasing the potential for re-use as iron ore. Coarse flotation tailings are filtered and placed in compacted piles, while the finer flotation tailings undergo thickening before being disposed of as high-density slurry in the main dam reservoir. The facilities were designed with efficient drainage systems and geomembrane liners to ensure long-term safety. The project also promotes sustainability by re-using materials as byproducts, such as the production of iron ore concentrate.

Keywords: tailings, TSF9, dam, dry stacking piles, magnetite, coarse flotation, sustainability, management

1 Introduction

Companhia Brasileira de Metalurgia e Mineração (CBMM) was founded in the 1950s with the purpose of transforming niobium ore, obtained through metallurgical processes, into high-value-added products as well as developing applications for this element. Niobium value proposition, which enhances material properties to make them more efficient, is widely recognised and applied across sectors such as mobility and infrastructure, and in systems for the generation and distribution of transitional and renewable energy.

The Minero-Industrial Complex is located in Araxá, in the state of Minas Gerais, Brazil. The niobium ore at this site is currently mined by COMIPA (Companhia Mineradora do Pirocloro de Araxá), a joint venture between CBMM and Companhia de Desenvolvimento Econômico de Minas Gerais (CODEMIG). The Mosaic Company (Mosaic Fertilizantes) mines the phosphate ore in the western half of the Complex (Figure 1).

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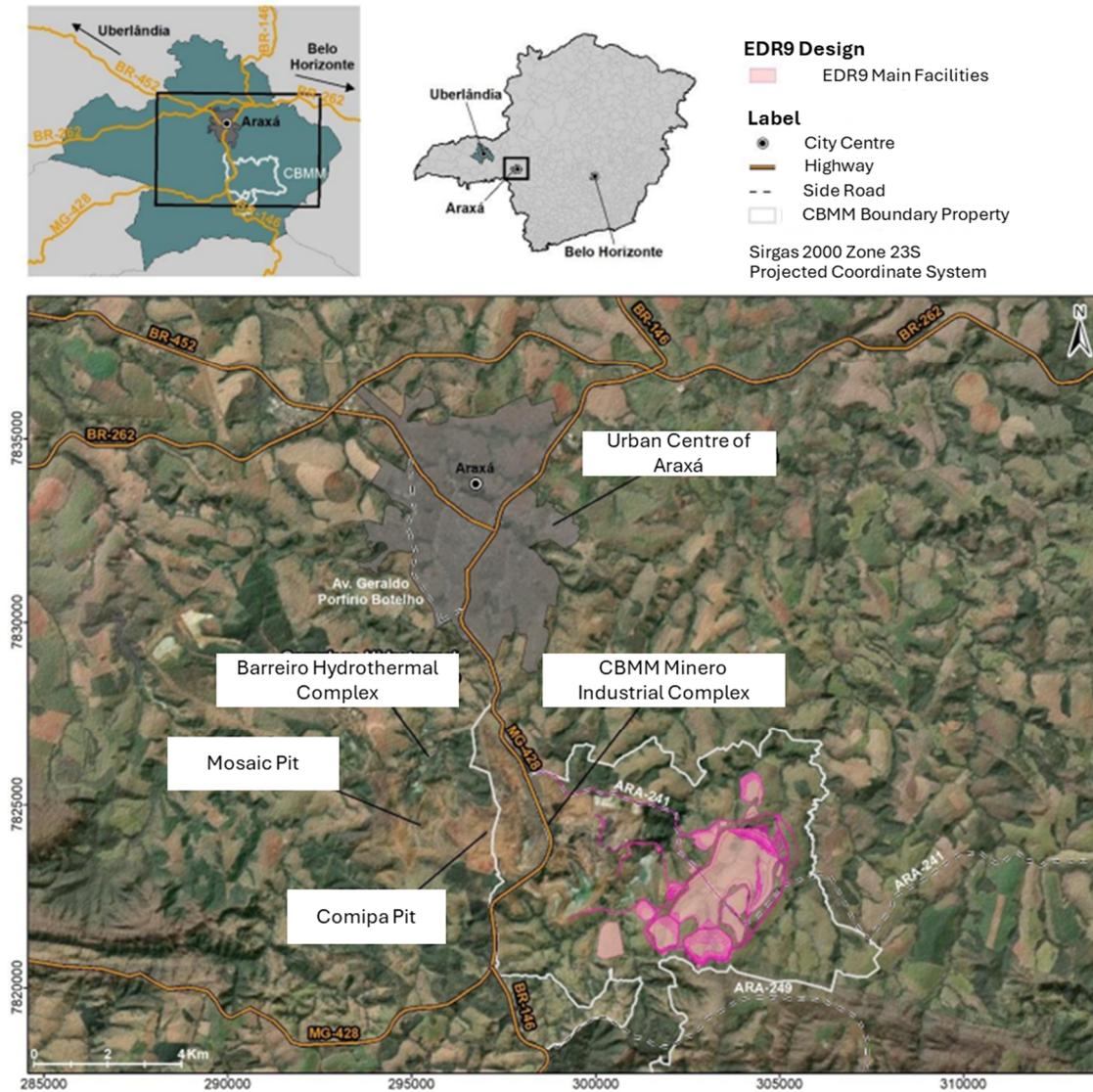


Figure 1 CBMM Industrial Complex and Tailings Storage Facilities 9 design

The Tailings Storage Facilities 9 (TSF9) project was designed through extensive technical studies and active engagement with the community, enabling the creation of the safest, most advanced, and sustainable solution for the continued operation of CBMM’s industrial complex. It is important to mention that the design currently follows the good practices recommended in Global Industry Standard on Tailings Management (GISTM).

The TSF9 project is focused on the safety of its structures and consideration of the Araxá region’s climate, which has a well-defined rainy season between November and March. Additionally, regarding climate considerations, all TSF9 surface drainage structures were designed to meet reference standards and best engineering practices for rainwater drainage.

TSF9 is being implemented near the CBMM Minero-Industrial Complex with the aim of maintaining the company’s operational continuity. The expected operational period for TSF9 spans from 2028 to 2048 (20 years), and considers the disposal of approximately 153 Mm³ to meet the anticipated demand for niobium products in the coming years.

This article presents the TSF9 project, which involves implementing tailings disposal structures (EDRs) using the latest disposal technologies and practices while incorporating a dewatering process for all generated tailings to minimise water presence within an EDR and, consequently, its associated risks.

2 Tailings Storage Facilities 9 project design

The TSF9 project was designed to handle the tailings generated during the niobium ore processing. In the CBMM Industrial Complex there are two ore processing plants where the primary operations include grinding, magnetic separation, classification and flotation. This process produces four types of tailings: magnetic, coarse flotation, fine flotation and ultrafine flotation. Each of these materials has specific characteristics, especially particle size distribution.

For the new structure, alternative solutions to using diluted-form tailings dams were evaluated, applying the concept of Best Available Technology and Best Available Practices to ensure the safety of the constructed structures. Several hypotheses on how to dewater and dispose the tailings were tested.

To support this evaluation, all tailings flows were characterised, and their physical, chemical and geotechnical properties were measured. Magnetic tailings were segregated from flotation tailings due to their potential for marketing as iron ore concentrate. Dewatering tests using different techniques were carried out with flotation tailings, and filtration tests indicated that achieving optimal moisture levels for the overall tailings was not possible. The tests were conducted considering all flotation tailings (coarse, fine and ultrafine). As optimal moisture contents were not achieved, new tests were performed: initially without ultrafine tailings (coarse and fine), and subsequently with only coarse tailings. The filtration test for coarse tailings achieved optimum moisture, as presented in Table 1. As a result, filtering only coarse flotation tailings was considered. Portions that could not be filtered were dewatered through thickening, achieving a high-density pulp.

Table 1 Best results of tailings filtration tests

Parameter	Coarse, fine and ultrafine flotation tailings	Coarse and fine flotation tailings	Coarse flotation tailings
Optimal moisture content (%)	13.8	13.2	11.0
Lowest moisture obtained in dewatering process (%)	18.0 (filter press)	17.0 (filter press)	8.2 (filter press) 10.9 (vacuum filter)

The study results showed that the best option was to segregate the tailings (magnetic, coarse flotation, fine and ultrafine flotation) and process them separately (Figure 2).

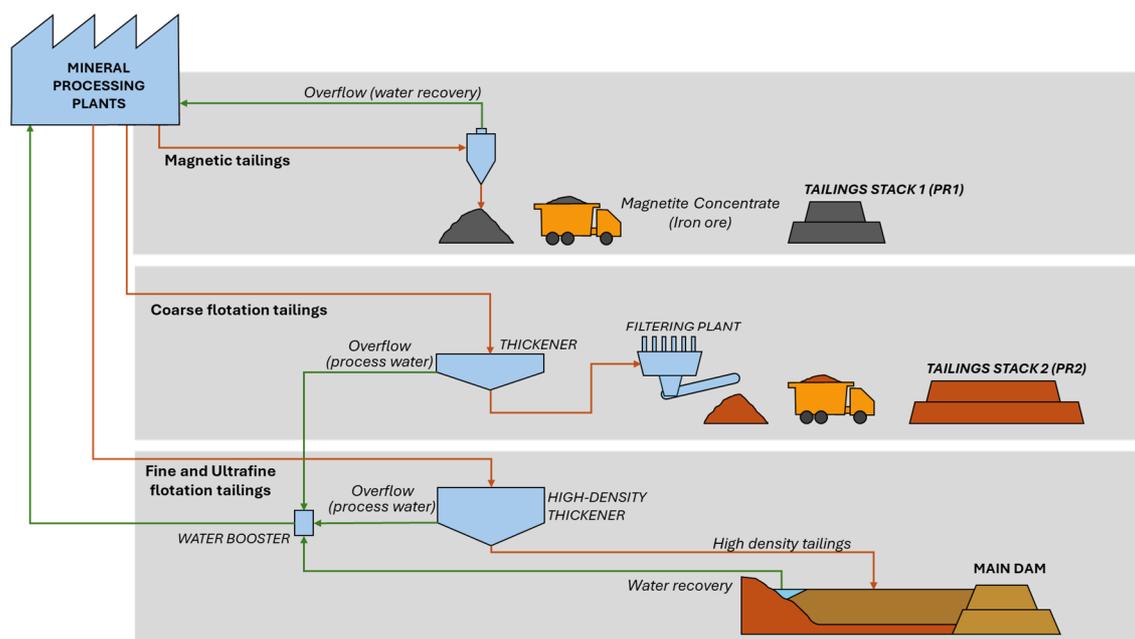


Figure 2 General flow sheet of Tailings Storage Facilities 9

2.1 Tailings characteristics

Tailings generated by niobium ore processing have characteristics that were considered in developing tailings processing and design disposal facilities. Table 2 summarises the main aspects of typical tailings.

Table 2 Niobium ore tailings characteristics

Parameter	Magnetic tailings	Coarse flotation tailings	Fine flotation tailings	Ultrafine flotation tailings
Mass distribution (%)	15	34	26	25
Mass distribution (t/h)*	183	418	317	302
D80 (µm)	500	70	65	6.5
D50 (µm)	200	40	32	2.5
D10 (µm)	60	12	0.8	0.3
SG (g/cm ³)	5.0	4.2	4.0	3.9
Liquid limit	NL	NL	NL	29
Plastic limit	NP	NP	NP	18
Optimal moisture content (%)	9.01	10.95	15.18	16.11
XRF, chemical composition	91.7% Fe ₂ O ₃	43.6% Fe ₂ O ₃	42.1% Fe ₂ O ₃	54.3% Fe ₂ O ₃
	3.5% BaO	29.5% BaO	17.6% BaO	10.3% BaO
	3.5% TiO ₂	5.7% SiO ₂	10.8% SiO ₂	8.1% REO
	1.3% other elements**	5.7% TiO ₂	5.1% REO	3.7% MnO
		4.2% S	3.3 TiO ₂	3.2% SiO ₂
		11.3% other elements**	2.6% MnO	2.7% TiO ₂
		2.2% S	17.7% other elements**	
		16.3% other elements**		
XRD, mineralogical composition	57% hematite	36% barite	44% goethite	52% goethite
	29% magnetite	35% hematite	23% barite	16% barite
	6% goethite	15% goethite	14% hematite	14% hematite
	4% barite	4% anatase	8% monazite	10% monazite
	3% anatase	3% gorceixite	4% gorceixite	2% gorceixite
	1% other	3% quartz	4% quartz	2% anatase
		2% magnetite	2% anatase	2% quartz
		2% monazite	1% other	2% other
	< 1% other			

* Considering the first years of operation

** Other elements, including H, O and C, that are not analysed

Particle size distributions of reference samples are presented in Figure 3. The values were measured by laser diffraction equipment (Bettersizer) for flotation tailings and sieves for magnetic tailings.

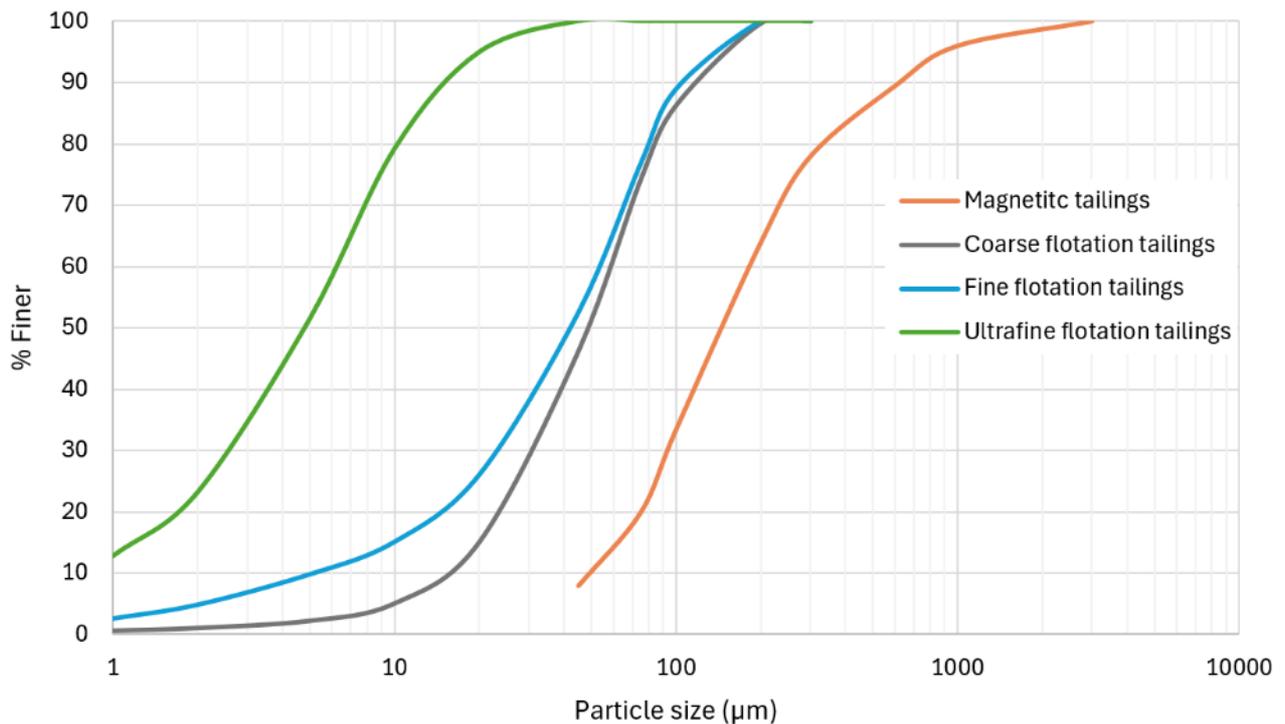


Figure 3 Tailings particle size distributions

2.2 Dewatering system

2.2.1 Magnetic tailings dewatering

In niobium ore processing, the removal of magnetic minerals occurs through low intensity magnetic separators installed in the concentration plants before the niobium flotation process. The magnetic separation operation is performed in a wet environment, generating magnetic tailings with 20% solids.

Good results were achieved for dewatering the magnetic tailings using cyclones, which not only recover water but also help the removal of ultrafine particles, especially aluminium-phosphate minerals, which are contaminants. This removal enhances the appeal of magnetite for sale as iron ore, and this product is currently being marketed.

Studies on magnetite began with computer simulations and laboratory tests. Following positive results, the testing advanced to a pilot plant (Figure 4) with the construction of a dewatering system (which currently processes magnetite from Concentration Plant 2 for sale) and an experimental magnetic tailings pile to evaluate geotechnical parameters.



Figure 4 View of the magnetite tailings dewatering plant

The industrial plant for magnetic tailings dewatering will consist of 12 hydrocyclones, each with a diameter of 15 inches (0.381 m). The underflow contains 76% solids, with 91% achieved through natural drainage. The overflow from the hydrocyclones and the drained water will return to the mineral processing plant, allowing for water recovery (Figure 5). To accommodate future production increases, a space will be allocated for expansion.

The magnetic underflow, with low moisture content and the removal of fines, achieves over 60% of Fe and can be marketed as iron ore concentrate. If it is not commercialised it will be dry stacked in Tailings Pile 1.

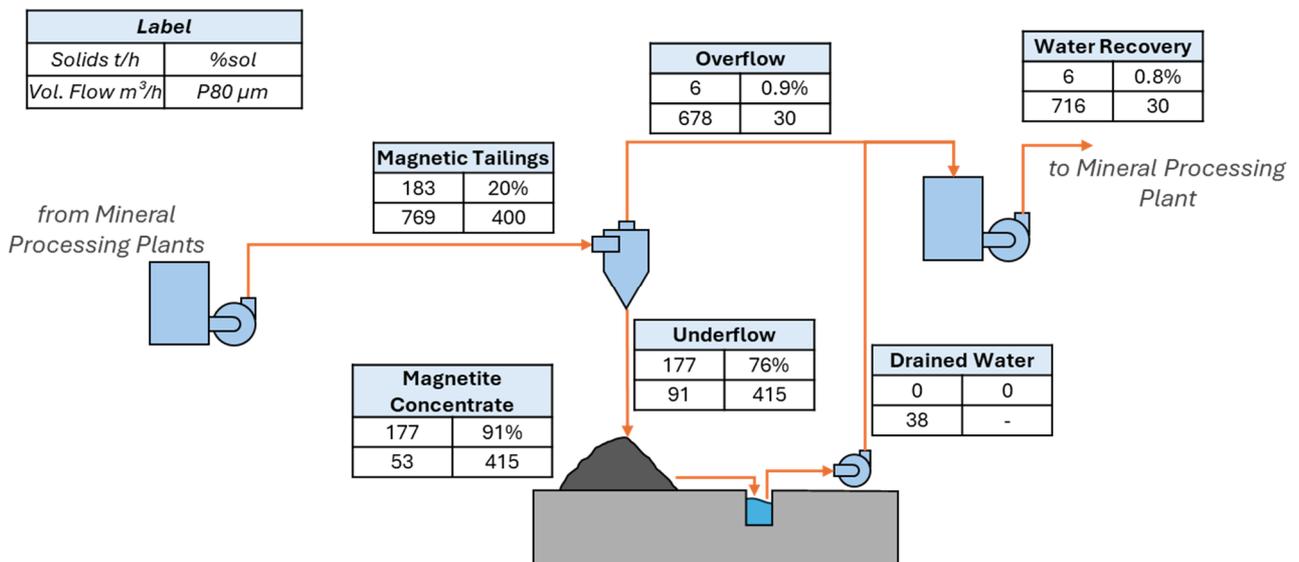


Figure 5 Magnetic tailings dewatering flow sheet

2.2.2 Coarse tailings filtration

Various solid–liquid separation techniques were tested for the flotation tailings. Filtration results for the overall flotation tailings did not reach the optimal compaction moisture as they remained slightly too wet. Therefore, it was decided to maintain the segregation of tailings as done in the ore processing plant. When only the coarse fraction of tailings, which accounts for 35% of the total generated tailings, was filtered, adequate moisture levels were achieved using various types of filters. The selected filter for dewatering coarse tailings was a vacuum disc filter.

The dewatering process for coarse flotation tailings begins by directing tailings from the concentration plants to a conventional thickener to remove most of the water; in this stage, around 80% of the water is already removed. Pumps at the thickener’s base transfer the high-solid-concentration slurry to a set of vacuum disc filters.

The industrial project includes the installation of 12 vacuum disc filters, 10 in operation, with tests indicating that the cake will achieve optimal compaction moisture (Figure 6). A stockpile with two days of capacity will be formed to be loaded and transported.

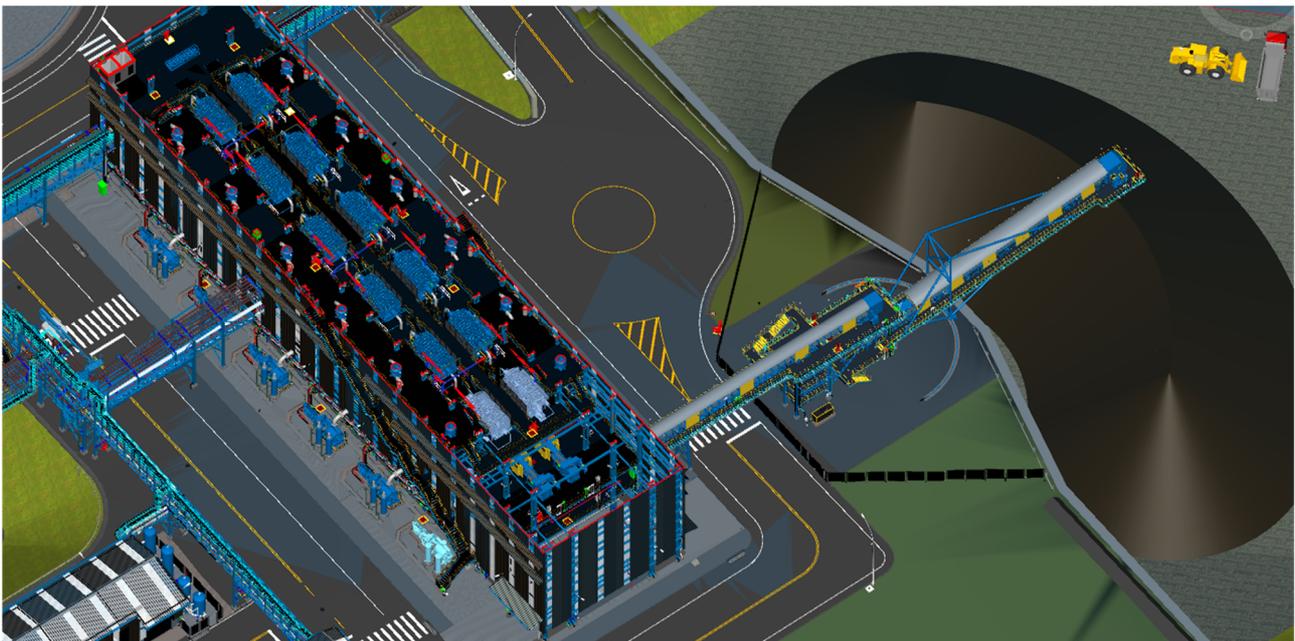


Figure 6 View of the filtration plant 3D model

The filtrate is returned to the preceding thickener for solids removal and water recovery, as presented in the flow sheet of Figure 7.

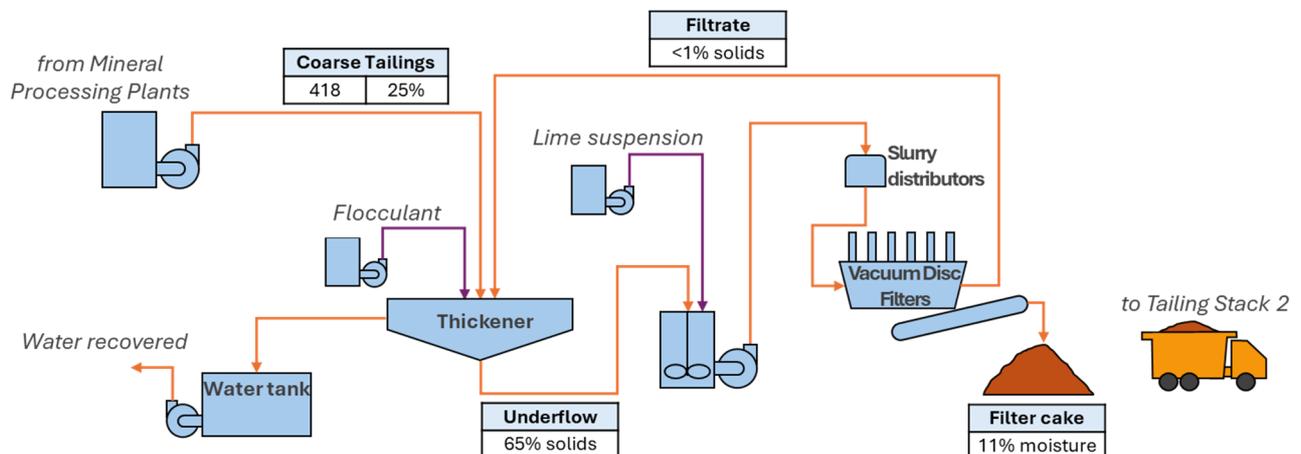


Figure 7 Coarse tailings dewatering flow sheet

Successful implementation of dry stacking is often seen in dry climates (Watson et al. 2010). Rainfall can affect the moisture levels in the filtered tailings. An alternative circuit is installed to pump the thickener underflow to the main dam, to be used during the period between November and March when Araxá has high-intensity rainfall (Figure 8)

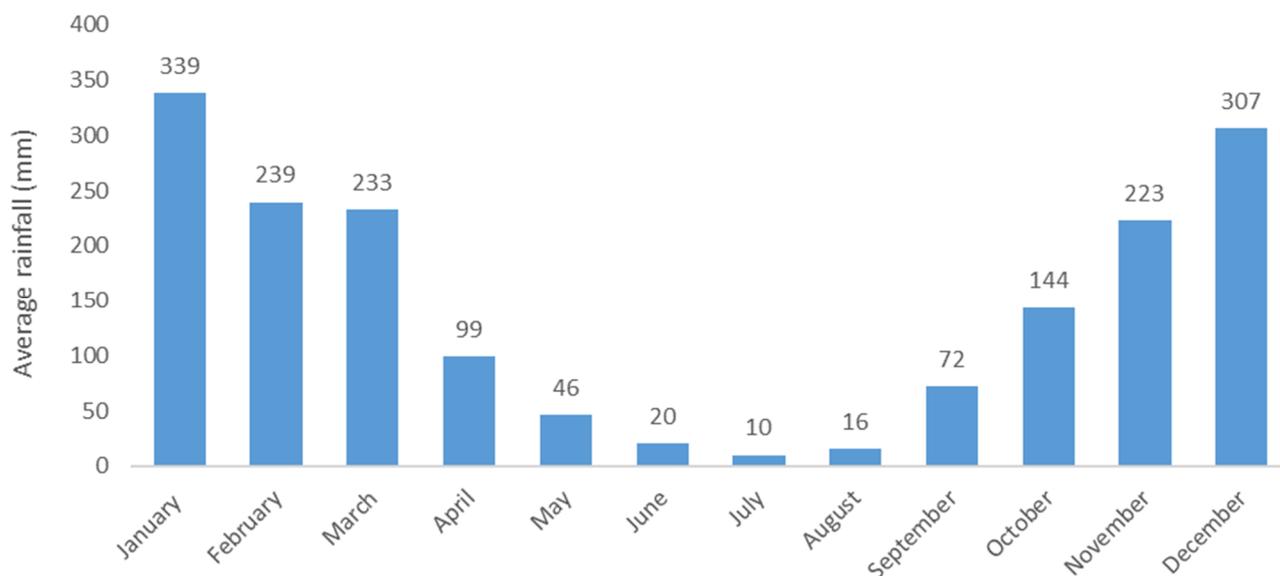


Figure 8 Average rainfall in Araxá (1979–2023)

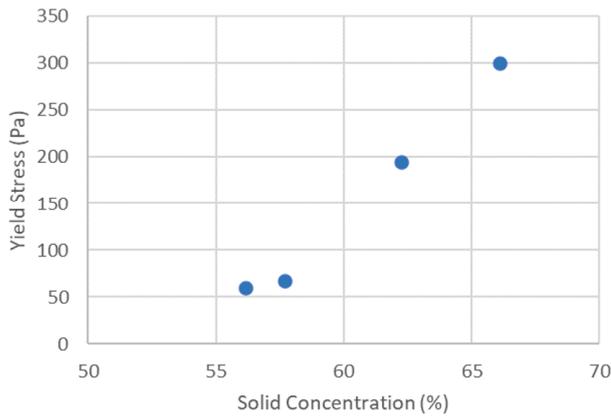
2.2.3 Thickening of fine and ultrafine tailings

Fine and ultrafine flotation tailings will be disposed in a dam but as ‘high-density slurry’, which means it has a high solids concentration (around 60%) with a yield stress between 50 to 80 Pa, representing the force required to make the material flow.

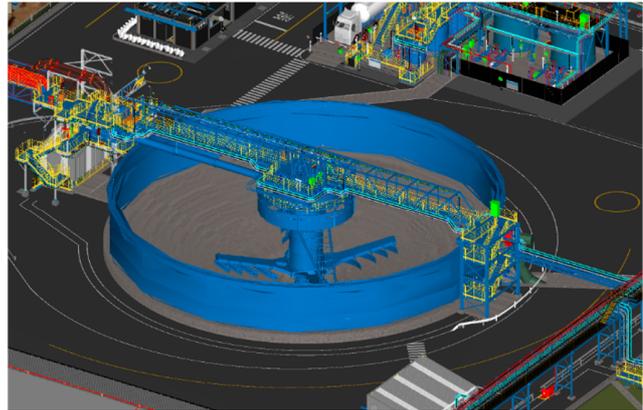
Disposing of tailings as high-density slurry offers several benefits (Fourie 2012; Testa et al. 2023), including:

- enables faster water recovery
- prevents segregation of coarse and fine particles, increasing dam reservoir capacity
- reduces water inflow to the dam
- decreases the mobility of tailings in the event of a dam break
- prevents rainwater from mixing with the tailings, allowing rainwater to flow over the disposal tailings
- takes advantage of natural evaporation to dry and compact the tailings, forming cracks that provide additional space for further tailings disposal.

The solids concentration needs to be above 55% to achieve 50 Pa, as shown in Figure 9 from tests conducted with the RheolabQC rheometer from Anton Paar, to achieve a high-density slurry. A 45-metre high-density thickener with flocculant addition was designed (Furtado et al. 2023a). Positive displacement pumps were required to transport the slurry to the main dam reservoir (Figure 9).



(a)



(b)

Figure 9 (a) Effect of the solids concentration of fine and ultrafine slurry in yield stress; (b) View of the fine and ultrafine high-density thickener project

2.3 Geotechnical structures

The main dam is a tailings disposal structure (EDR) that will receive flotation and thickened total tailings during periods when it is not possible to operate the tailings piles. The main dam has a projected disposal capacity of approximately 92.8 Mm³. Tailings Pile 1 (PR1) is a EDR that will receive dewatered magnetite tailings, which will be dewatered by hydrocyclones, dried in a bay and subsequently compacted. This structure may also receive coarse flotation tailings, which will be filtered and then compacted depending on the future feasibility of using magnetite as a byproduct of the process, thus reducing the disposal of this material as waste. The PR1 has a projected disposal capacity of 16.8 Mm³. Tailings Pile 2 (PR2) is a disposal structure that will receive coarse flotation tailings, which will be filtered and subsequently compacted. The PR2 has a projected disposal capacity of 43.5 Mm³ (Figure 10).

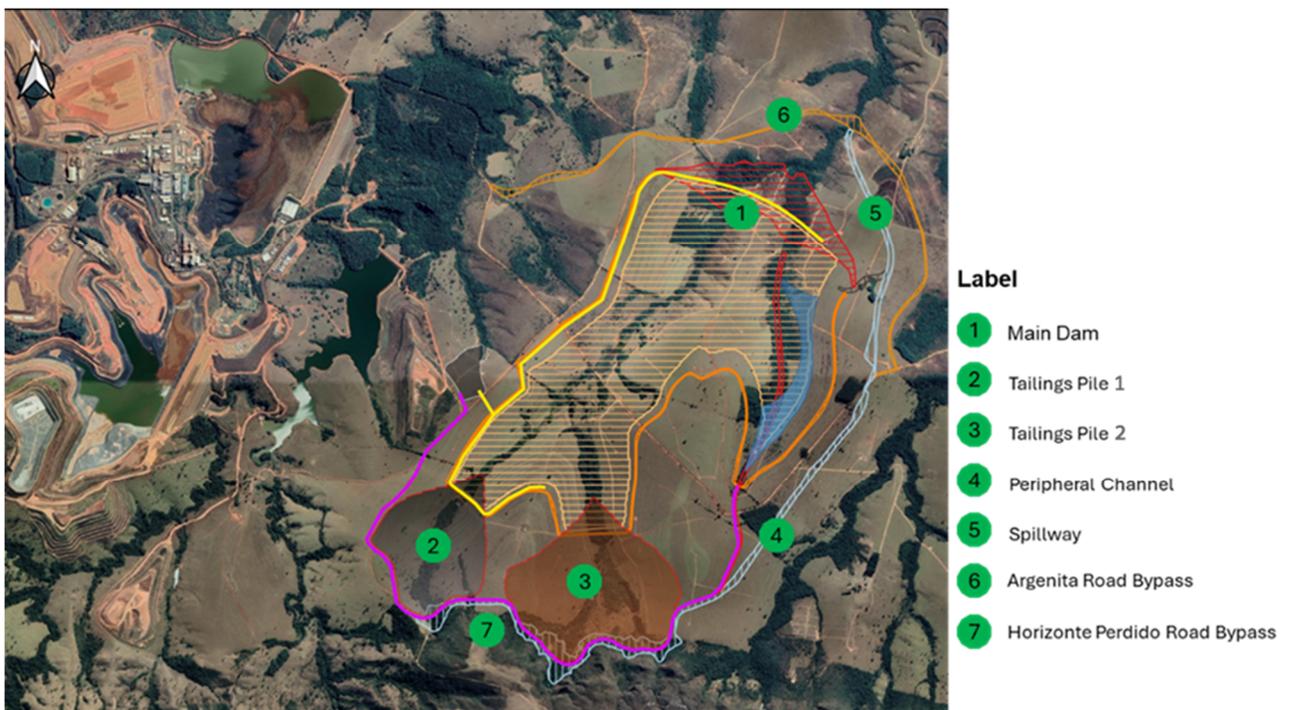


Figure 10 Tailings Storage Facilities 9 main facilities

Compared to the international landscape of dam construction using tailings, the company practice stands out in the following ways:

- Tailings are not used as construction material. The compacted embankment of the dam, which forms the structural zone, is built with compacted clay soil in layers as specified in the project, with strict field compaction control. This factor is essential as it eliminates liquefaction as a critical failure mode.
- The compacted soil dam is raised downstream.
- The dams are designed and built with drainage systems that include transitions sized to considerably mitigate the risk of piping (one of the causes of dam failure).
- The reservoir is fully lined with a high-density polyethylene (HDPE) geomembrane. The lining system controls hydrogeological impacts on groundwater and considerably mitigates the risk of piping and/or the rise of the phreatic level in the downstream embankment.
- The dam is designed not to overflow. This is achieved through a water collection system that recirculates water back to the processing plant, ensuring operational continuity. In case of an extreme event, the emergency spillway is designed to accommodate flows associated with the return time of the structure's operation and/or closure, aligning with international best practices to mitigate the risk of overtopping (one of the causes of dam failures). It is important to highlight that the flow took into account a rain event with probable maximum precipitation (PMP).
- Water inflow from the catchment basin is diverted from the dam reservoir through a peripheral channel, further reducing the risk of overtopping. The design flow took into account a rain event with return times of 1,000 and 10,000 years.

3 Geotechnical design of Tailings Storage Facilities 9 structures

The main dam will consist of a homogeneous compacted soil embankment with downstream slopes at a global gradient of 4.0H:1.0 V, with local slopes varying from 2.5H:1.0 V and 3.5H:1.0 V. Upstream slopes will have a 1.5H:1 V gradient, with an internal drainage system comprising a vertical filter, drainage blanket and bottom drain. Note that the concept developed for the main dam envisions the embankment being progressively raised downstream, in parallel with the dam's operation (Figure 11).

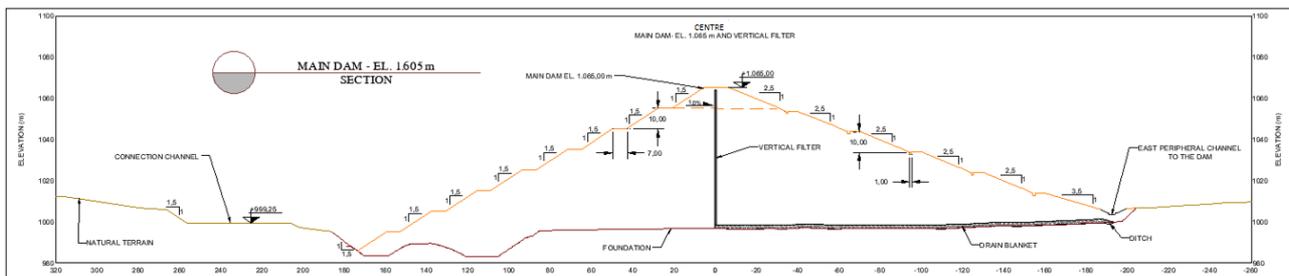


Figure 11 Main dam – typical section

PR1 (Figure 12) features a pile of dewatered magnetite through hydrocyclones and dried in bays, while PR2 (Figure 13) consists of a pile of C1 flotation tailings, filtered and compacted. Both structures will be constructed with compacted tailings, with slopes at a global gradient of 4.5H:1.0 V. The entire projected area of the tailings piles will be lined with a layer of geomembrane beneath another layer of protective material that allows for traffic to deposit the tailings. A drainage system will also be built to manage any percolated flow-through the structures.

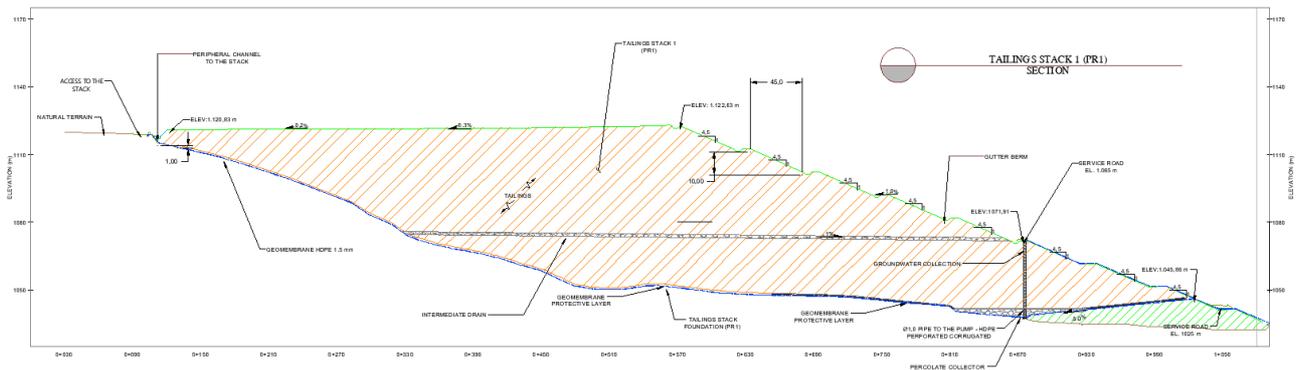


Figure 12 Tailings Pile 1 — typical section

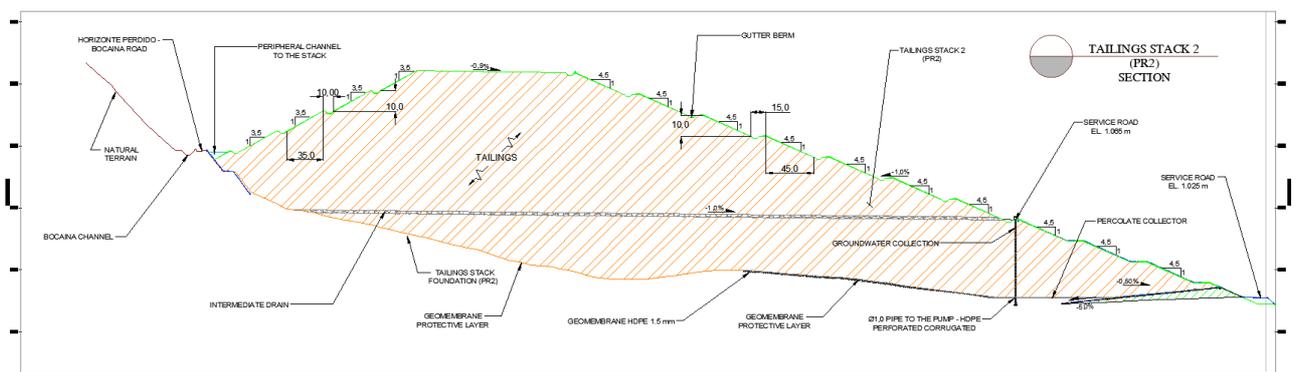


Figure 13 Tailings Pile 2 – typical section

Some key design criteria for the structures are summarised below:

- an impermeable system lined with a 1.5 mm-thick HDPE geomembrane throughout the reservoir
- a bottom drainage system installed beneath the impermeable layer and consisting of spring drains to collect and channel spring water downstream of the dam and safety drains positioned between the HDPE geomembrane lining and the spring drainage system to collect any inflows, ensuring the flow integrity of the watercourses in the area projected for the structures. Downstream of the main dam, a collection and pumping system will be installed for any effluent collected in the safety drains. A total of approximately 22 km of drains (safety and spring) will be installed
- deployment of a peripheral channel to divert water from the catchment basin, reducing water input to the reservoir. It is important to highlight that the design flow took into account a rain event with return times of 1,000 and 10,000 years
- deployment of a spillway system on the right abutment of the embankment, designed for the operational stage and closure stage for flood events associated with the PMP event.

4 Deployment

To begin deploying the structures, two environmental licences are required: the preliminary licence (LP) and the installation licence (LI). The LP is granted during the preliminary planning phase, before the detailed design phase, and certifies the project's socio-environmental feasibility. In this phase, multidisciplinary teams carry out studies to thoroughly assess the vegetation, fauna, water resources, air quality, population and cultural heritage in the project's region, resulting in a socio-environmental assessment. Based on these studies, an evaluation is conducted on the potential environmental impacts of the project's implementation, operation, and closure. TSF9 received its LP in 2021, showing that the project is socio-environmentally

feasible and that all impacts will be controlled and/or maximised through the execution of environmental programs. TSF9 obtained its LI in 2023, subject to the performance of socio-environmental programs.

Immediately after the LI was granted, construction on TSF9 began with activities including: vegetation clearing; procurement, receipt and storage of aggregates for construction of the internal drainage system; relocation of a section of the local road (ARA-241); and preliminary earthworks.

5 Conclusion

In summary, the design complied with the guidelines of current legislation and the GISTM, prioritising tailings dewatering techniques to minimise the volume to be disposed of in the dam. Through continuous innovation in project development and use of the best technologies available, the deployment of the project aims – above all – to ensure the company's operational continuity in a safe and sustainable manner that is aligned with socio-environmental compliance. Having obtained environmental licences, the construction of the geotechnical structures and industrial plants are underway.

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