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Original Article

Iron ore tailings dry stacking in Pau Branco mine, Brazil



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ABSTRACT

The mining industry has seen several significant dam failures in recent years. Dam failures are associated with errors in design, implementation, operation, and monitoring (Azam, 2014, [2]). Dewatered stockpiling (dry stacking) is a safer alternative to tailings dams (Rico et al., 2008, [3]) for tailings disposal; however, this method has not yet been used in iron ore mines in Brazil, where geotechnical conditions and abundance of water are favorable for the use of tailings dams. This paper describes the results of the study that supported the implementation of an innovative dewatering plant for iron ore tailings in Pau Branco mine, Quadrilatero Ferrifero, Brazil, contributing to improve its sustainability (Gomes et al., 2015, [6]). Magnetic concentration rejects ($>45\text{ }\mu\text{m}$) were feasibly dewatered through high-frequency screenings, and slimes ($<45\text{ }\mu\text{m}$) were effectively filtered in a horizontal filter press, enabling dry stacking of tailings. A comparison with the current tailings dam structure is presented, demonstrating that Capital Expenditure (CAPEX) for the solution proposed here is significantly lower.

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1. Introduction

The mining industry has experienced several significant dam failures in recent history. Prior works interpreting the history of tailings storage facility failures have concluded that a lower number of failures and incidents in the two most recent decades evidence the success of modern mining regulation, improved industry practices, and modern technology. Contrariwise, since 1960, a clear trend toward failures of ever-greater environmental consequence has been noted [1].

Tailings dams are often built using the coarse fraction of tailings from mineral processing installations with steep slopes, thereby, saving on cost. To maintain the stability of these structures is one of the most complex activities in the management of mine wastes [2]. Generally, the following reasons are responsible for failures in these structures: (i) use of residual materials from mining operations to construct the embankment; (ii) sequential dam raisings; and (iii) high maintenance costs [3].

A good option for ensuring safe tailings management is dried disposal rather than slurry disposal. Dry stacking is being

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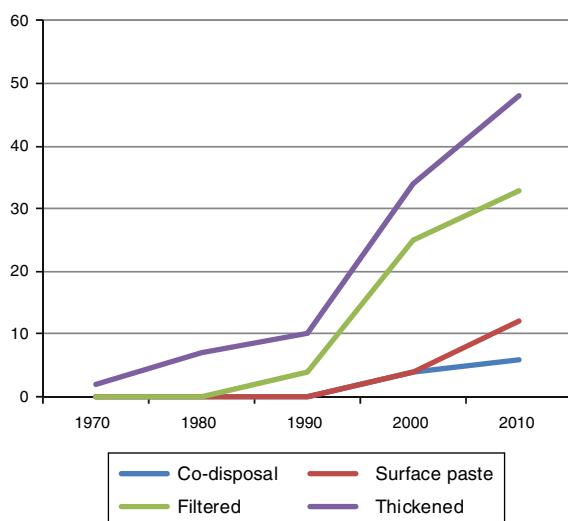


Fig. 1 – Trends in use of dewatered tailings in mining: filtered tailings disposal represents approximately 35% of the method utilized in tailings facilities [5].

applied to areas that have limited space and water resources, and in areas in which topographic and geotechnical conditions contraindicate conventional impoundments [4]. This is shown in Fig. 1, which provides a summary of the relative number of dewatered facilities on a global scale.

Although projects have demonstrated the technical feasibility of iron ore tailings filtering [5], it has not been yet implemented in iron ore mines in Brazil. Some of the reasons include high cost of acquisition and operation, availability of water, and topographical and geotechnical conditions favorable to dam installations. Bibliographic references to studies evaluating dewatering screening for tailings were not found during the development of this study.

This paper describes the tests performed to define the most cost-effective manner of obtaining a dried product to be stacked in a co-disposition structure in Pau Branco mine, Quadrilatero Ferrifero (QF), Minas Gerais, Brazil. The solutions tested include filters, dewatering cyclones and screening for fines ($>45\text{ }\mu\text{m}$) and slime ($<45\text{ }\mu\text{m}$). The results from dewatering, compaction, and stability tests support the implementation of a dewatering plant for tailings dry stacking, eliminating the need of a tailings dam, which is currently in use at the mine.

2. Materials and methods

Vallourec's beneficiation plant produces concentrated iron ore lumps and fines in Pau Branco mine [6]. Tailings are composed of both fines ($>45\text{ }\mu\text{m}$) and ultra-fines ($<45\text{ }\mu\text{m}$). Ultra-fines are generated from the de-sliming cycloning of the magnetic concentration process, and fines are the rejects of this process. Both fines and ultra-fines are disposed in a tailings dam inside the mine operation area. Thickening, filtering, and dewatering screening tests were performed to demonstrate the feasibility of tailings dry stockpiling and eliminate the need of a tailings dam.

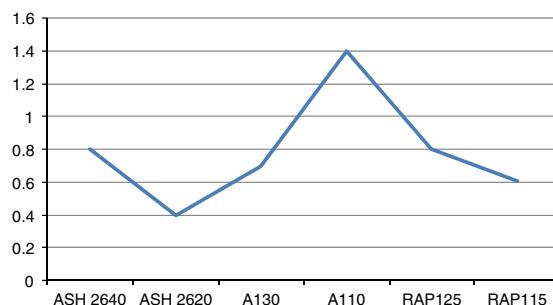


Fig. 2 – Solids flow rate for flocculant type.

2.1. Thickening tests

Thickening tests were performed using laboratory scale thickeners. These tests aimed to define the need of chemical conditioning, maximum overflow rate, and maximum solids percentage.

To evaluate the filtering performance for slimes, a leaf test apparatus was used [7]. Cake thickness versus moisture, and filtering rate per unit area were defined. Dewatering of magnetic concentration rejects was evaluated in a high frequency screening, to define the moisture versus time per unit of screening area.

Natural sliming samples, collected from the industrial plant process, indicated 9.8% solids, 7.5 pH, 130 tph dried solids flow rate, and solids density of 3.9 g/cm^3 . Magnetic concentration samples indicated 65% solids, 7.5 pH, 250 tph dried solids rate, and solids density $\sim 3.0\text{ g/cm}^3$. A Beckman PHI 12 PH/ISE meter was used to measure pH.

Initially, to define the most effective flocculant, samples with 5% solids, and 7.5 pH, were collected from the Pau Branco mine industrial plant, representing typical industrial tailings. Anionic flocculant ASH 2620 (Praestol), ASH 2640 (Praestol), A130 (Kemira), A110 (Kemira), RAP115 (Kemira), and RAP125 (Kemira) were tested. A flocculant dosage of 40 g/t was used. Fig. 2 illustrates these results.

It can be seen from Fig. 2 that flocculant A110 showed the best performance for the evaluated flow rate, but its water clearness was not satisfactory. Accordingly, flocculant RAP 125 was chosen, because of its adequate solids rate and excellent water clearness, which was less than 3 mg/l.

Subsequently, different dosages of flocculants, from 30 to 70 g/t were tried. Fig. 3 shows the results.

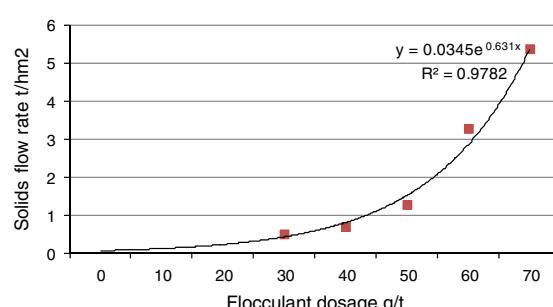


Fig. 3 – Solids flow rate versus flocculant dosage.

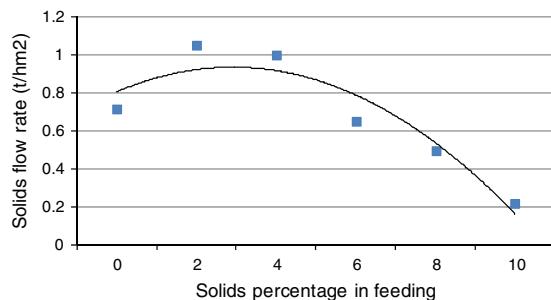


Fig. 4 – Solids flow rate versus solids percentage in feeding.

The optimal flocculant dosage was found to be 50 g/t, as higher dosages formed big flakes that could affect the effectiveness of pumping installations.

Accordingly, considering the optimal dosage, the samples obtained from diluting the original sample with different solids percentage (from 2% to 10% solids) were submitted to thickening tests, to define the optimal solids flow. Fig. 4 shows that the best solids percentage is 3%, offering the highest solids underflow.

After defining the best flocculant, dosage, and pulp dilution, batch settling experiments (BSE) were performed to determine the overflow rate and the settling curve, which is presented in Fig. 5. BSEs were conducted using a 2000 ml graduated beaker, where the original sample with 9.8% solids was fed and diluted to 3% solids. Afterwards, flocculant RAP 125 (Kemira) was added at a dosage of 50 g/t. The slurry was then mixed by three times inversion, turning the beaker upside down, and the initial mudline height was visually measured every 20 s, till 10 min after the initial measurement, where the pulp achieved the point of compression [8]. After that, a new measurement was taken at 60 min.

The unit area requirements [8,9] are given by:

$$\text{Unit Area (m}^2 \text{ tpd}^{-1}) = 0.0694 \times t_u/C_0 \times h_0$$

where,

t_u : time to meet compression point (min)

C_0 : initial pulp concentrates (g/cm^3)

h_0 : height of the pulp from beaker base (cm)

Results from the field tests showed that for a solids rate of 130 tph, and unit area of $0.1 \text{ m}^2/\text{tpd}$, a tank with an area of 312 m^2 , equivalent to a thickener with 20 m diameter would be needed.

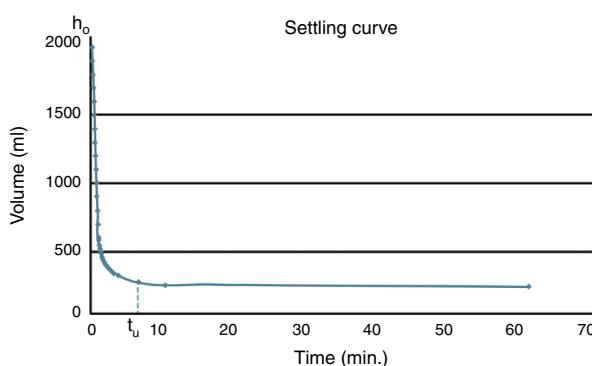


Fig. 5 – Settling curve obtained from the BSEs.

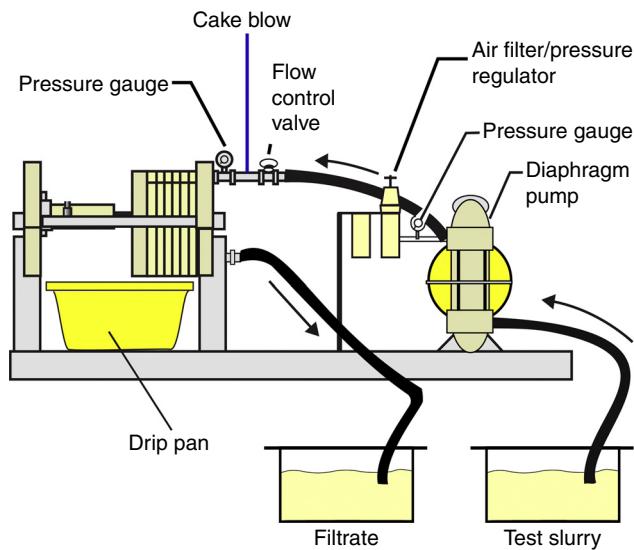


Fig. 6 – Pilot filter press schematic, as proposed by Dahlstrom and Silverblatt [7].

2.2. Slimes filtration tests

Using the thickened sample from the previous test, laboratory leaf filtering tests [7] were performed. The equipment consists of two plates, with an area of $300 \times 300 \text{ mm}^2$, double faced, chamber thickness of 35 mm, and solids concentration of 34% (underflow of the proposed thickener). The tests are aimed to optimize the cake thickness versus the filtration rate. A premeasured amount of slurry is taken from a recipient through a diaphragm pump into the filter press. Pressure filtration begins and the amount of filtrate versus time is recorded. Fig. 6 shows a schematic of the laboratory filter press experiment, and images of the cake obtained from the test are shown in Fig. 7. The results from these tests are summarized in Table 1.



Fig. 7 – Images of actual cake obtained from the laboratory filter. The best cake moisture was obtained for a cake thickness of 35 mm.

Table 1 – Filter press sizing from laboratory experiment results.

% Solids	34%
Cake thickness	35 mm
Cake moisture	15%
Filtration cycle	20 min
Pump	9.83 min
Core blow	0.34 min
Air blowing after cake washing	1.36 min
Closing/opening	3.05 min
Discharge	5.42 min
Fabric	Andritz 211
Feeding pressure	7 kgf/cm ²
Necessary filter area	1306 m ²
Cake discharge clog	No
Need of washing	Every 24 h

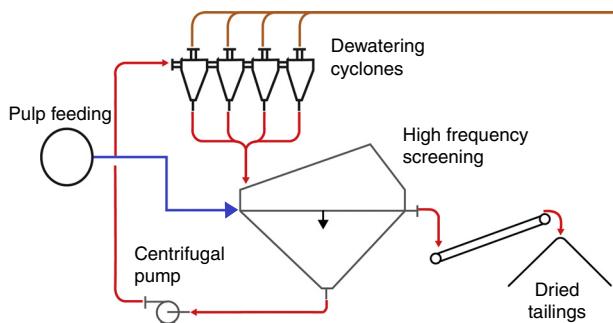


Fig. 8 – Schematics of dewatering high-frequency screening.

2.3. Dewatering screening tests on magnetic concentration rejects

Magnetic concentration rejects were tested in a pilot plant: 25 tph pulp, 30% solids feeding a dewatering high-frequency screening with 0.15 mm aperture, and 3 m² of useful area. The underflow feeds a battery of four cyclones with a diameter of 254 mm. The underflow of the cyclones retro-feeds the screening. Screening overflow is stockpiled. The final moisture obtained was 15%, which is appropriate for dry stacking. Fig. 8 shows schematics and Fig. 9 shows a picture of the dewatering plant, used in the magnetic concentration rejects dewatering.

3. Discussion

Test results demonstrated the feasibility of dewatering for iron ore tailings from Pau Branco mine, as dried cakes with final moisture content of about 15% for natural slimes (ultrafines, <45 µm) and 15% for magnetic concentration rejects (granulometry between 150 and 45 µm) were obtained. These results are convenient for dry stacking, for which the maximum recommended moisture is 20–25% [4].

A comparison of the results reported for tests with slimes from other mines in the QF [5] with those obtained in this work is shown in Fig. 10; it can be seen that slimes from Pau Branco mine are coarser. This may explain the higher efficiency, both in terms of final moisture (20% against 15%) and unitary filtering rate (100 kg/h m² against 128 kg/h m²).

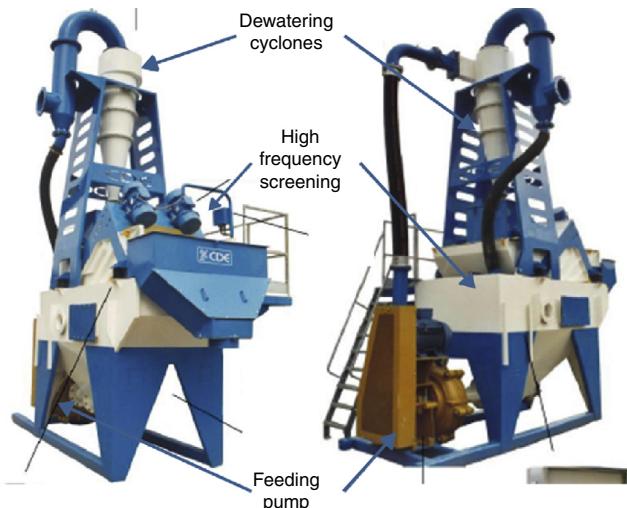


Fig. 9 – Front and rear view of the pilot dewatering plant.

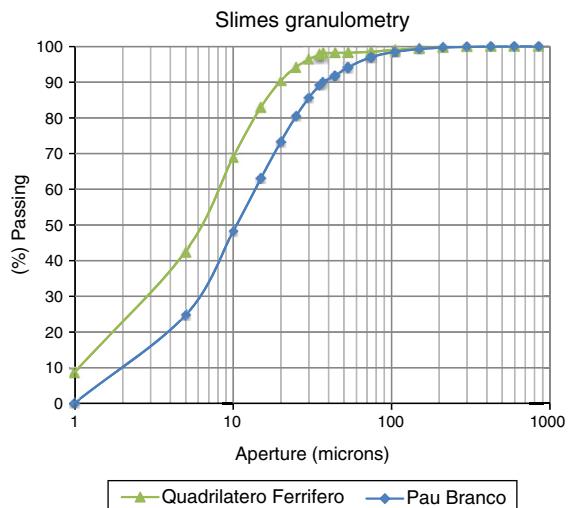


Fig. 10 – Comparison between slimes from Pau Branco and other QF mines [6]. For Pau Branco slimes, 50% of the grains are retained in a 10 µm' aperture.

Based on the tests results, the following flowsheet was proposed: tailings generated from the industrial plant are classified in a cyclone in 45 µm. Coarse tailings are then treated in dewatering screening, 100 tph, and fine tailings are treated in a thickener to feed a horizontal filter press, 200 tph. Both processes generate a final dried reject with 15% moisture.

On comparing the current cost of acquisition of the equipments, filter press, and high frequency screening dewatering, against the ones proposed in a previous study [5], a considerable decrease in CAPEX over production capacity ratio can be observed. Such savings can be explained by: (1) a decrease in the filtering unit area cost (USD/m²), probably because of the development of technology and the number of suppliers and unities sold, (2) lower dewatering screening unit area cost (USD/m²), compared with a filter press, and (3) higher unit area rate (kg/h m²) of both filter press and dewatering screening of Pau Branco mine materials compared with other QF mines [5].

Table 2 – Economic evaluation of Pau Branco tailings dewatering against other QF slimes [6].

Slimes QF (Guimarães et al., 2011)	Pau Branco			Total tailings
	Slimes filter press	Magnetic concentration rejects dewatering screening	Total tailings	
Capacity (tph)	440	200	100	300
CAPEX M USD	21	4	1.2	5.2
Ratio (M USD/tph)	0.05	0.02	0.01	0.02

A comparison between these indexes is presented in **Table 2**.

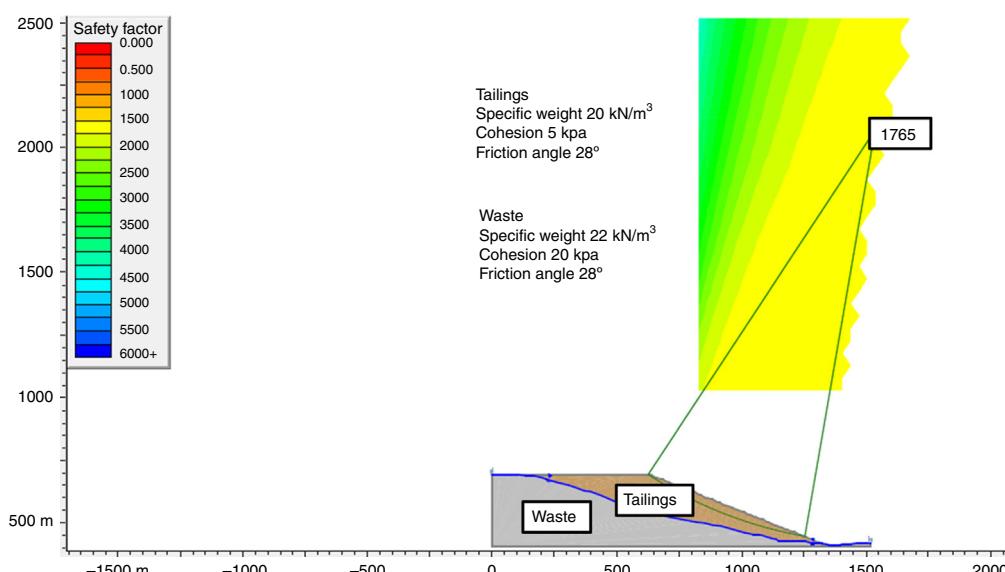
The moisture obtained from the process guarantees the dry stacking of the tailings, eliminating the need of the currently used tailings dam. This was confirmed by compaction and stability simulations. The method of obtaining the stability factor for earth structures, from materials analysis, is explained in the literatures [10–14]. Co-disposal of dried tailings and mine waste will follow the project primarily developed for thickened tailings of Pau Branco mine. Deterministic and probabilistic stability analysis demonstrate a friction angle of 28°, cohesion of 5 kPa, specific weight of 20 kN/m³, average stability factor of 1.765, with 0.0000% probability of failure. This is shown in **Fig. 11**.

CAPEX for the dewatering plant project is estimated at a total of USD 5 million, with USD 1 million for dewatering high-frequency screening and USD 4 million for the filter press. Compared with the preliminary project of tailings co-disposal, where a tailings dam would be required, this method represents a safer solution, with the benefits of water recycling capability, lower monitoring and maintenance costs, besides lower environmental and social impact risks.

Pau Branco mine tailings dam has an area of 200,000 m² [400 m (width) × 500 m (length)], and its beneficiation plant generates an annual volume of 1,000,000 m³ of tailings. Considering the current reserve and processes, the expected

**Fig. 12 – Filter press plant installed at Pau Branco mine.**

lifetime of the system is about 20 years. Consequently, at the end of useful life, it will have generated 20,000,000 m³ of tailings, implying the need for 100 m heightening of the dam (10 heightening of 10 m each). For an average dam width of 10 m, a slope angle of 30°, and 400 m in length, the corresponding volume of this heightening will be about 3,500,000 m³. Considering an average cost of heightening of 10 USD/m³, the total CAPEX for the necessary heightening would be USD 35 million, seven times the CAPEX of the proposed dry stacking plant. The Project was installed and started operation in November/2015, **Fig. 12**.

**Fig. 11 – Stability factor calculation model for Pau Branco mine co-disposal structure.**

4. Conclusion

Tailings dam are the conventional solution for tailings disposal in most Brazilian iron ore mines. In the Quadrilatero Ferrifero region, abundance of water, and geotechnical features are favorable for the installation of iron ore tailings dams. However, these structures have a high risk of collapse, resulting from errors in their project, operation, monitoring, and maintenance.

An innovative dewatering process for Pau Branco mine was evaluated, demonstrating the technical and economic feasibility of its implementation. Tailings from mineral processing classified in 45 µm are treated in a thickener and horizontal filter press (200 tph, < 45 µm), followed by dewatering screening (100 tph, >45 µm), and obtaining a final moisture of 15%, which is adequate for dried stockpiling.

The solution proposed in this study presents economic, environmental, and social advantages, compared with the tailings dam currently in operation in Pau Branco. Considering the expected lifetime of the project, a total of 35 million USD would be required to maintain the capacity of the dam, with 10 consecutive dam raisings, which amounts to seven times the CAPEX of 5 million USD required to the installation of the dewatering plant proposed in this study.

Conflict of interest

The authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.jmrt.2016.03.008](https://doi.org/10.1016/j.jmrt.2016.03.008).

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