

Technical Proposal for the Recovery of Iron Tailings in Dams in the Context of a Circular Economy

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Abstract

The objective of this study is to present a tailings recovery project in a dam located in northern Brazil; the tailings in this dam have high concentrations of iron. The sustainable recovery of mineral resources can be achieved using the dredging method. The methodology used was based on two drilling projects conducted in 2001 and 2010; these projects contained samples with information on the chemical composition and particle size fractions. The dredging system was designed to operate with four cutter suction dredgers. For operation, factors such as productivity, pumping distance and material flow were considered. The material contained in the dam was estimated using the natural neighborhood interpolation method; this resulted in approximately 192 million tons of tailings, with an average iron content of 63.37%. Based on these data, a 13-year mining plan was prepared, with the potential to maximize the use of the tailings and reduce the environmental impacts, thus contributing to a circular economy.

Keywords

Tailings, Dredging, Iron Content, Circular Economy

1. Introduction

Tailings dams are engineering structures used to store materials from the ore beneficiation process. Typically, the associated material is the material that cannot be recovered during the physical-chemical concentration process and is discarded.

Given the large number of tailings dams worldwide and the increasingly low quality of the resources in mineral deposits, the reuse of tailings disposed of in

dams will substantially increase. In addition, in many dams, the metallic content of the deposited material is high because mineral processing is not performed at the time of deposition (Wates et al., 2010; Ferrante, 2014; Franks et al., 2021).

Mineral extraction in aquatic environments, particularly in dams, has attracted increasing interest for its potential as an efficient and sustainable method. Løvik et al. (2018) emphasized that the reuse of tailings from dams has two main purposes: to reprocess the sediments to recover metals and valuable elements and to reintegrate the product into the industrial chain.

Engels et al. (2004) noted that the characteristics of the deposit, the composition and storage conditions of the deposited sediments, and the possibilities of transport and handling of the tailings need to be determined to select the appropriate method for the extraction of tailings from dams. Muir et al. (2005) and Sousa (2020) noted that other characteristics needed to be determined to aid in the extraction method selection of the tailings; these other characteristics included topography, water flow, climatic conditions, density and homogeneity of the sediments since these characteristics directly impact the costs of the mining projects and the use of tailings.

Three main methods are used to mine tailings in dams: 1) hydraulic blasting, the use of water jets with high-pressure cannons; 2) mechanical excavation, the use of conventional equipment such as excavators, bulldozers and trucks; and 3) dredging, the use of hydraulic or mechanical dredges. Alves (2015) highlighted the importance of evaluating the sediment deposition characteristics, the area available for performing the method and the alternatives for transporting the material to identify the best mining alternative since each method has its own unique characteristics.

The use of dredges as a mining tool for dams has emerged as a viable alternative; dredging promotes not only the maximization of the recovery of mineral resources but also the minimization of environmental impacts. Therefore, the aims of this study are to present a dredging project of an iron tailings dam and provide the operating procedures that meet the needs of the ore treatment plant.

2. Dredging

Dredging is defined as the excavation or removal of soil at the bottom of rivers, lakes or other bodies of water and is performed using a dredger. Generally, a dredger is a floating vessel or platform equipped with the mechanisms that are able to remove the soil.

Historically, dredging has been considered a very old activity, with data dating back thousands of years. In ancient Greece, artificial canals were built for irrigation purposes, as well as to unite water bodies, such as the connection of the Nile River with the Red Sea. Historical data also revealed the construction of the Babylonian Canal, which joined the Tigris and Euphrates rivers (Bray et al., 1997).

The longest and oldest canal that still exists today is the Grand Canal of China; this canal is more than 1600 km long and took approximately 2000 years to build

(its work began in the 7th century BC and ended approximately 1280 AD). In Europe, the pioneers in the construction of canals were the Italians; however, the French valued the quantity and extension of their canals. Currently, the Dutch contributes the most in technology for the construction of channels for the drainage of their territory. All major water systems of northern Europe are interconnected by artificial channels.

Although dredging is popular in engineering structures for desanding, cleaning, unclogging, widening, and deepening in rivers, lakes, seas, bays and channels, it has also been used for the exploration of mineral deposits. Several studies address dredging as a mining method, especially in placer-type alluvial deposits, for the extraction of gold and tin in various territories of the world (Nelson, 1976; Hearn & Hargreaves, 1985; Kaur & Diehl, 1996; Spence, 1996; Morse, 2003; Phillips et al., 2003; Hillman, 2005; Lloyd, 2006; Wegner, 2009; Waterhouse, 2010; Ross, 2014; Spence, 2016; Lawrence et al., 2021).

In terms of dredging tailings dams, technical-scientific publications are limited. On the other hand, as highlighted by Aquino et al. (2024), the companies that supply dredgers show various projects around the world in their catalogs. Dredging projects for uranium, copper and gold, coal, iron, gold and silver tailings dams have been performed.

Several types of dredgers exist and can be classified by the type of material movement (hydraulic or mechanical) and by the way the material is fragmented (centrifugal, pneumatic or aerial) (Granato, 2005). The most common mechanical dredgers are the dipper, backhoe, bucket ladder and grab dredgers. The most common hydraulic dredgers are the cutter suction, tailing suction hopper, and dust-pan.

3. Case Study

The mineral deposit is located in northern Brazil, and the project is developed in an iron tailings dam (Figure 1); in this dam, the deposition of the material in the dam has been performed since the 1980 s. Due to the lack of technological development at the time and market concerns, much of the pellet feed was not recovered in the iron ore beneficiation operation. Therefore, iron with a potential high concentration was deposited in the dam.

Over the years, several studies have been conducted, and a project for the recovery of the tailings was developed. Thus, the project for reprocessing the tailings from the dam was started and was characterized by the recovery of the tailings with respect to economic use and includes the desanding of the dam.

The tailings deposited in the dam are recovered using four cutter suction drums and are pumped through floating water pipelines to surface treatment facilities. In these facilities, the material is initially sieved to remove organic material and any coarse material. The retained material is then sent to the pulp thickener. Then, this material is pumped via a pipeline toward the existing structures and/or adapted to the treatment plant currently implemented; in this plant, the magnetic

concentration, thickening and filtering are performed.



Figure 1. Iron tailings dam.

4. Methodology

The methodology consists of determining the type of dredger to be used in the project and analyzing the required production demands and operating parameters. In addition, the proposed mine plans for dredging are provided.

4.1. Database

Two drilling projects were conducted in 2001 and 2010. For both projects, the standard penetration test (SPT) method was used. The samples obtained have records of the contents of the main chemical components linked to the iron ore and of particle size fractions in certain ranges of interest. No record of material density samples; therefore, for the purposes of the model, an average density of 2.50 t/m^3 was used.

In the 2001 project, 153 holes were drilled, and 272 samples were recorded. The average distance between the drillholes was 70 m, with a maximum distance of 149 m and a minimum distance of 49 m. The database consisted of 3 types of files: a) collar involves the identification of each hole, the coordinates of the hole mouth and the depth of the drilling holes; b) assay involves the identification of each hole, the identification of each sample per hole, the initial and final depths of each sample per hole, the total length of the sample, the percentage of the chemical components of each sample, such as Fe (iron), SiO_2 (silica), P (phosphorus), Al_2O_3 (alumina) and Mn (manganese) and the percentage of the particle size fractions between -0.045 mm and -0.020 mm ; and c) survey involves the identification of each hole, the depth of each hole, the azimuth and dip of each hole.

In the 2010 project, 153 holes were drilled, and 569 samples were recorded. Compared to the 2001 project, the 2010 project differed with respect to the

characterization of the material, with 529 samples of ore and 40 samples of waste rock. The average distance between the drillholes was 100 m, with a maximum distance of 215 m and a minimum distance of 3 m. The database was composed of the same 3 types of files from the 2001 project. In the assay file, the percentages of the chemical components of each sample refer to Fe (iron), SiO₂ (silica), P (phosphorus), Al₂O₃ (alumina), Mn (manganese), CaO (calcium oxide), MgO (magnesium oxide), TiO₂ (titanium dioxide) and PPC (loss on calcination). The percentages of particle size fractions refer to the following sizes: +0.250 mm, +0.150 mm, +0.106 mm, +0.075 mm, +0.045 mm and -0.045 mm.

Figure 2 shows the spatial distribution of the 2001 and 2010 drillholes.



Figure 2. Exploration drilling.

4.2. Sizing of the Dredging System

When a company proposes to acquire a dredger, a market study is usually carried out on the production capacity of the dredger to verify if the production capacity matches the need required by the operation. According to Vlasblom (2016), the productive capacity of a dredger can be expressed in m³/hour or in t/hour. In addition, insight into the expected average cycle time of the dredger and the type of soil to be dredged are needed. The productivity of dredgers depends on two components: a) variability in equipment operation and b) variability in the material flow.

In the case of material flow variability, the productivity depends on variables such as the pumping distance and the geological characteristics of the mining fronts. The relationship between dredger productivity and pumping distance is shown in **Figure 3**.

The flow of the planned process from the dredging of the tailings to the final pellet feed product has several stages and starts with 4 cutter suction dredges. The dredged material is suctioned by booster pumps and travels through pipelines for a distance of 950 m until it reaches the first plant. The pumped material goes through the following sieving process: 4 horizontal vibrating sieves followed by 4 linear sieves. Following the flow, the sieved material passes through a thickener

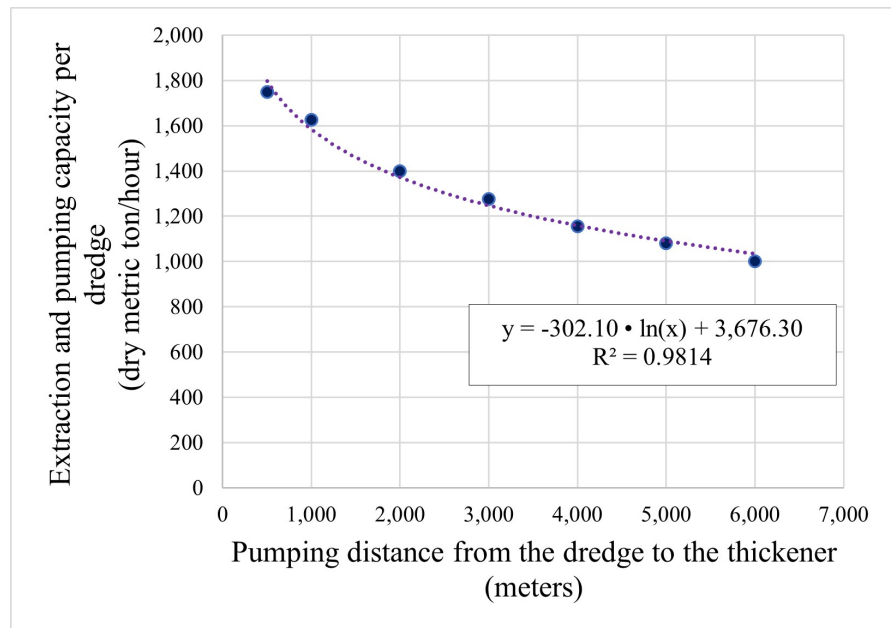


Figure 3. Dredge production sensitivity as a function of the pumping distance.

and is then sent to 4 feed tanks of the ore pipeline. From these tanks, the material is pumped by 2 cargo pumps and 4 positive displacement pumps through an ore pipeline that covers a 7 km path until the terminal station is reached. From this station, the material is sent to the magnetic concentration tank; in this tank, the material passes through 2 protection sieves, 2 distributors and 8 magnetic concentrators. The product from the magnetic concentration passes through filter presses and disc filters and is then ready to be commercialized. The tailings from the magnetic concentration are sent to a tailings thickener and mixed with the tailings from other plants; subsequently, this tailings mixture is sent through a chute back to the dam.

Dredging operations require hydraulic transport of iron ore tailings, and the design parameters were set as follows:

- Dredge model: cutter suction;
- Deadweight: 115.93 t;
- Total length: 46.92 m;
- Length between perpendiculars: 3 m;
- Width: 8.86 m;
- Maximum dredging depth: 16 m;
- Level of the dam: 219.45 m;
- Unloading point elevation: 279.50 m;
- Geometric unevenness: 60.05 m;
- Duty cycle: 24 hours/day, 365 days/year;
- Physical availability (FA): 75%;
- Physical use (FU): 72.20%;
- Operating Income (OI): 54.15%.
- Operating cycle: 4,745 hours/year;
- Type of dredger drive: electric;

- Dredge pump power: 1000 kW;
- Dredge productivity: 750 t/h per dredger (3,000 t/h total);
- Production scale: 3,558,750 t/year per dredger (14,235,000 t/year total);
- Nominal pulp flow rate at 34% solids by weight: 1617.6 m³/h;
- Variation in the percentage of solids: 10 to 55%.

5. Results and Discussion

5.1. Estimated Dam Material

Based on the samples from the 2001 and 2010 drillholes, the thickness of each hole was subdivided into 5 m benches. The iron contents contained in the samples are represented by their arithmetic means on each bench.

The digital surface models were generated using the natural neighbor interpolation method because of its conservative nature. In this method, the set of points (x, y, z) is processed to generate a regular grid with predetermined spacing. In this case, the spacing used was 20 m. This technique has advantages over simpler methods, such as the nearest neighbor method, because it creates a smoothed approximation of the underlying function to the real surface.

The volume of tailings contained in the sampling region of the dam was calculated by multiplying the flat projections of the areas by the height of the benches of 5 m. The sum of the various levels of iron contents of the 5 m-thick benches resulted in a total volume of tailings of 76,913,267 m³. Considering the average density of 2.50 t/m³, the tonnage corresponds to 192,283,168 t. The average iron content is 63.37%, and the main contaminants are silica and alumina. In addition, approximately 82% of the material is contained in the fraction below 45 µm (0.045 mm), and no data are available on the sludge fraction ($-10\ \mu\text{m}$).

5.2. Mining Plan

A mining plan was developed for an operation scheduled to last 13 years. As a



Figure 4. Dredging planning and schedule.

premise, the annual production of dredging was defined as 14.235 Mt; this value was estimated considering the capacity of the plant. Dredging in the entire estimated region was not possible because of operational issues.

In addition, some operating assumptions needed to be made, as follows:

- Distance between the anchorage points of the dredgers;
- Space between the discharge pipes and electrical cables;
- Distance and height of the discharge point of the dredged material;
- Desired time for mining execution.

Figure 4 shows the distribution of the sequenced areas of the mine plan for each dredging year. **Table 1** shows the amount of dredged material used, as well as the average iron content in each year.

Table 1. Production scheduling.

Year	Tonnage (t)	Fe (%)
2021	14,110,586	62.34
2022	14,139,350	62.03
2023	14,175,121	62.27
2024	14,160,136	62.24
2025	14,250,966	62.37
2026	14,163,410	64.11
2027	14,223,641	62.49
2028	14,222,234	62.38
2029	14,129,761	63.08
2030	14,193,974	62.03
2031	14,153,616	62.45
2032	14,165,645	62.33
2033	14,143,201	62.13
Total	184,231,639	62.48

6. Conclusion and Recommendations

The recovery of iron tailings in dams using the dredging method has proven to be a promising alternative for the economic recovery of mineral resources and for the mitigation of the environmental impacts associated with the storage of tailings. The application of modern techniques, such as the use of cutter suction dredgers and efficient beneficiation processes, has enabled the extraction of materials with high iron contents and reinforced the importance of the reuse of tailings in dams.

In addition, as part of a broader strategy of environmental and economic management in the mining sector, this study contributes to the circular economy since reusing previously discarded resources adds value to the mining chain. The methodology discussed enables sustainable operational planning, integrating engineering

practices with technological innovation.

Further research is still needed, especially with respect to the distribution of tailings along the dam. More robust geostatistical studies need to be conducted to obtain a more accurate estimate of resources using techniques such as ordinary kriging or sequential Gaussian simulation. Thus, with a better estimated model, an even more reliable dredging plan can be developed.

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Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this paper.

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