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Detailed engineering for the implementation of filtered tailings in Peruvian underground mining

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Abstract

This study focuses on the operation of an underground mining unit located in the central highlands of Peru, at an altitude exceeding 4,000 m above sea level. The metallurgical process includes primary crushing, fine grinding, gravity concentration, and tank cyanidation to produce a gold-rich and silver-rich solution. This solution is subsequently treated in a Merrill–Crowe plant (zinc precipitation). The resulting precipitate is dried and smelted to produce doré bars containing gold and silver.

The tailings generated from the cyanidation process are directed to the flotation circuit, where lead–silver and zinc–silver concentrates are recovered. Due to the very limited area available for tailings disposal, the use of a filtered tailings storage facility was evaluated, as filtered tailings allow higher density placement and improved storage efficiency in constrained topographies (Fourie & Blight 2017). This approach offers significant advantages, including improved water recovery – which is critical for mineral concentration processes in Peru, where water resources are scarce – enhanced mine closure conditions, and safer storage facility operation, as filtered tailings exhibit very low moisture content.

For the design of the tailings filtration plant, a detailed engineering study was performed to produce filtered tailings based on their physical characteristics. The study also considered the challenges posed by the project location, including high rainfall and extreme cold temperatures. The scope included evaluating the area required for the filtration plant (selecting filter press technology), assessing the filtration rate through laboratory testing, and determining the moisture content required for efficient transport and disposal of the filtered tailings.

This document outlines the benefits associated with filtered tailings, describes the key design considerations for the filtration plant, and identifies the main estimated costs associated with the engineering development.

Keywords: *tailings filtration, filter presses, high altitude*

1 Introduction

The use of filtered tailings has gained significant traction in the mining industry in recent years, driven both by its operational advantages and by increasingly stringent regulatory requirements for surface tailings facilities. As mining companies seek more robust and sustainable tailings management solutions, filtered tailings have emerged as a viable alternative to conventional disposal methods. This paper presents the overall benefits of filtered tailings for surface deposition, along with key design considerations and the final implementation approach adopted for a gold mining operation in southern Peru.

The project encompasses the engineering design of a thickened and detoxified tailings filtration plant, including its auxiliary systems – water supply, compressed air, and power distribution – as well as the civil and structural infrastructure required to support continuous plant operation.

The filtration plant will be installed on a dedicated platform located at an elevation of 4,790 m above sea level, positioned east of the processing plant's tailings thickener. The facility incorporates the main filtration

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equipment – vertical plate filter presses – along with air compressors, buffer tanks, agitated slurry tanks, sedimentation tanks, ponds, and the associated pumping systems required for fluid transport.

The filtration plant is composed of the following systems:

- tailings filtration system
- seal water system
- fabric washing water system
- recovered filtration water system
- turbid filter washing water system
- truck tire cleaning system.

2 Benefits: filtered tailings

Among the various benefits of applying filtered tailings disposal are:

- water recovery
- stability/safety
- greater tailings dam storage capacity.

The implementation of filtered tailings disposal provides a suite of critical advantages that collectively enhance the performance, safety, and long-term sustainability of modern mining operations. One of the most significant benefits is the substantial improvement in water recovery, which directly reduces the need for freshwater intake and strengthens operational resilience in regions where water scarcity poses a technical, regulatory, or social constraint (Szymanski & Davies 2004). By extracting a greater proportion of water during the filtration stage, the process not only supports more efficient recirculation within the plant but also contributes to a reduced environmental footprint and improved compliance with water-use standards. Equally important is the enhanced geotechnical stability and overall safety associated with filtered tailings, whose low moisture content dramatically lowers the potential for liquefaction, slope failure, and uncontrolled deformation – risks that have historically challenged conventional slurry-based deposition methods (Fourie & Blight 2017). This improvement translates into a more predictable, robust, and inherently safer storage configuration capable of withstanding seismic loading, extreme climatic conditions, and long-term closure scenarios. Furthermore, the higher density and compactability of filtered tailings enable more efficient stacking, maximising the usable storage volume within the existing footprint of the tailings facility. This is particularly advantageous for operations facing physical constraints, permitting limitations, or complex topographies, as it extends the operational life of the storage facility without requiring additional land disturbance. Taken together, these benefits position filtered tailings disposal as a high-performance, future-ready solution that aligns with evolving industry expectations for environmental stewardship, risk reduction, and optimised resource utilisation.

However, despite these substantial operational and environmental advantages, the adoption of filtered tailings technology also introduces a notable economic challenge: the significantly higher capital and operating costs associated with filter press systems. Vertical plate filter presses require considerable investment not only in specialised equipment but also in auxiliary systems such as high-capacity air compressors, slurry conditioning tanks, and robust structural platforms designed to support heavy mechanical loads. Operating costs are likewise elevated due to intensive energy consumption, frequent maintenance associated with filter cloth replacement, and the need for skilled personnel to operate and troubleshoot the equipment. In comparison with conventional thickened or slurry-based tailings disposal, filtered systems present a materially higher unit cost per tonne of processed tailings. As a result, the financial implications of implementing filtration technology must be carefully weighed against its long-term benefits

(Martin & McRoberts 1999), ensuring that the selected approach provides a favourable balance between cost, environmental performance, and operational risk reduction.

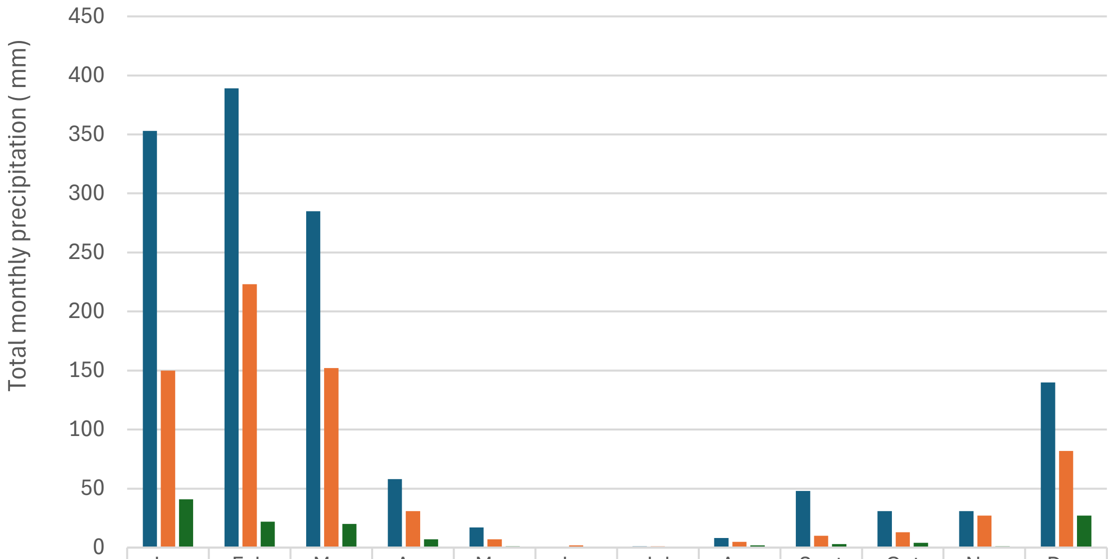
3 Design bases

3.1 Site conditions

Based on records from 19 meteorological stations between 1963 and 2012, all located in the vicinity of the project, the main meteorological variables are summarised below:

- The average annual precipitation (average year) is 1,023 mm, and the average annual evaporation is 1,337 mm. The months with the highest precipitation, exceeding 50 mm per month, are December to April. From May to November, precipitation is less than 50 mm per month.
- The average annual wind speed is 17 km/h (4.7 m/s), occurring in August, with a minimum average speed of 7 km/h (1.9 m/s) occurring in June. The prevailing wind direction is from the west-southwest, accounting for 29.8% of the recorded data.
- The average annual temperature is 2°C, the average annual maximum temperature is 12.5°C, and the average annual minimum temperature is −4.2°C.
- The average annual relative humidity is 69.6%. In wet years, the average annual maximum humidity reaches 86.2%, and in dry years, the average annual minimum humidity is 60.3%.

The Figure 1 shows the total monthly precipitation. This is an important factor since the filtered tailings and the operating philosophy depend on climatic conditions.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Wet year	353	389	285	58	17	0	1	8	48	31	31	140
Average year	150	223	152	31	7	2	1	5	10	13	27	82
Dry year (Tr100)	41	22	20	7	1	0	0	2	3	4	1	27

Figure 1 Total monthly precipitation

3.2 Physical characterisation of tailings

The main characteristics of the tailings studied are presented in Table 1.

Table 1 General characteristics

Description	Units	Value
D_{80}	Microns	24.8
D_{50}	Microns	10.4
%solids	%	50.0
Specific gravity	–	2.77
pH	–	11.0
Filtration rate	$kg/h/m^2$	86.0
Metallurgical moisture	%	15.0
Thickness	mm	25
Cycle time	min	13.0
Bulk density (pulp)	t/m^3	1.901
Bulk density (dry)	t/m^3	1.557
Feed press	Bar	6
Press	Bar	12
Blow	Bar	8

The Figure 2 shows the particle size distribution of the tailings representative of the process.

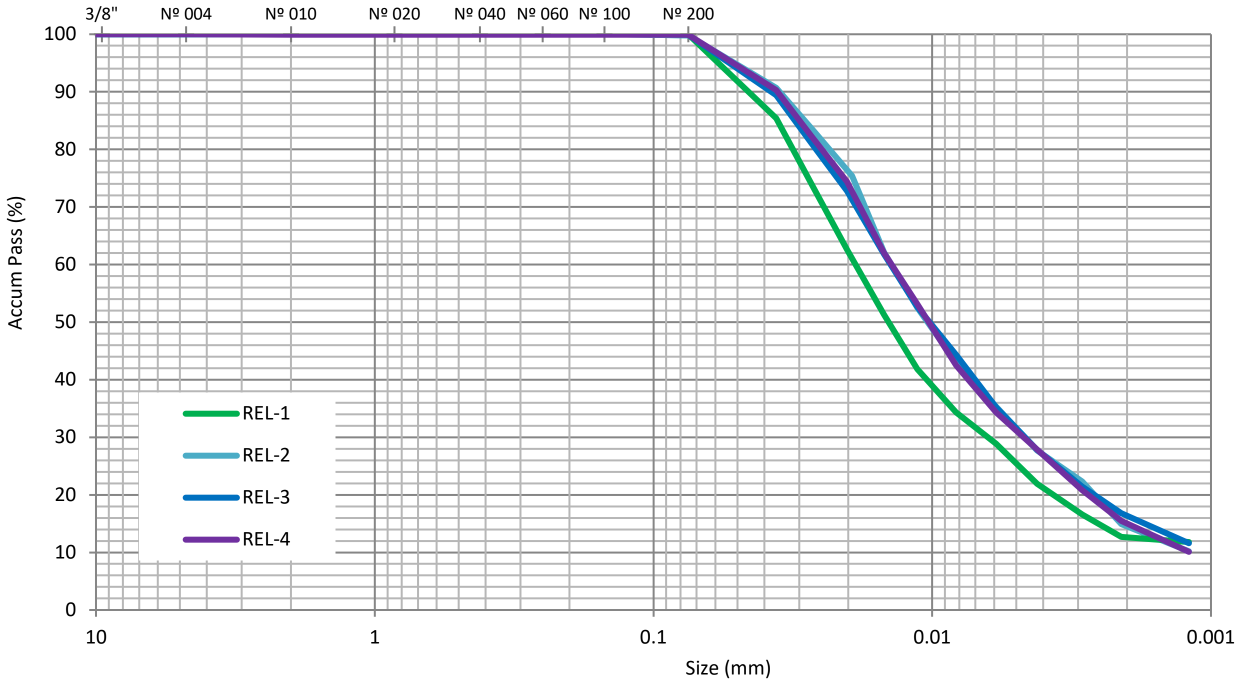


Figure 2 Size distribution: tailings

Figure 3 presents the results of the filter press tests, considering the physical characteristics of the tailings. These estimates allowed us to determine the required filtration area and, therefore, the number of filter presses needed.

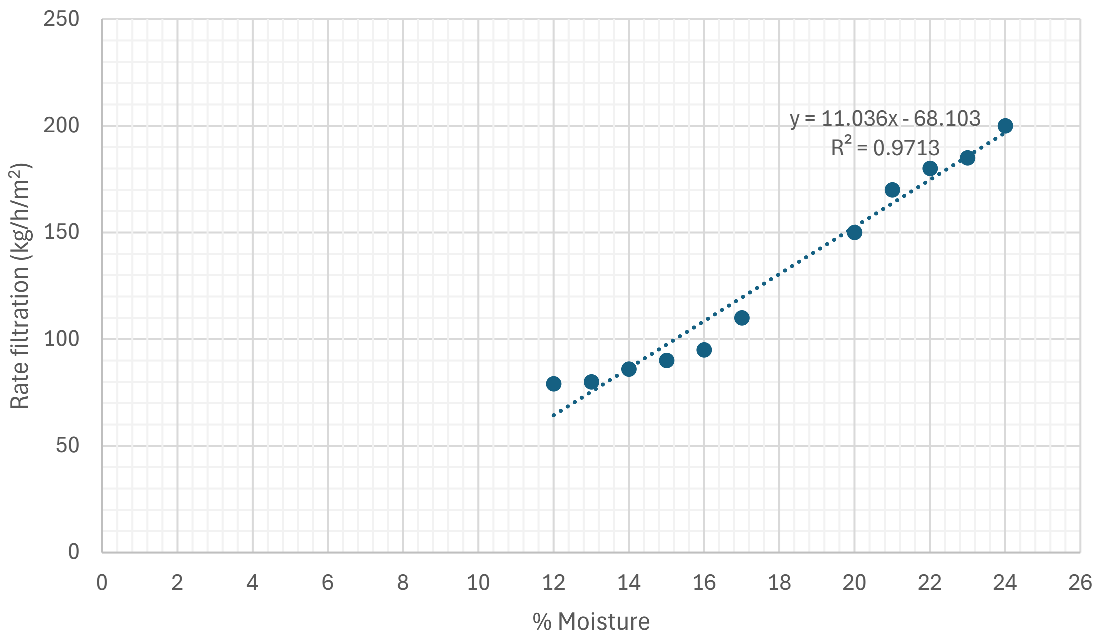


Figure 3 Rate filtration versus per cent moisture

3.3 Production

The processing plant's production will be developed in 2 stages. The first stage will last 5 years, with a concentrator plant capacity of 1,500 t/d. Production will then double to 3,000 t/d over the next 15 years. The production for the filtration plant is shown in Table 2.

Table 2 Production for the filtration plant

Description	Units	Value
Nominal tailings production: production stage I	t/d	1,500
Nominal tailings production: production stage II	t/d	3,000
Scheduled operating days per year	Days	360
Scheduled operating hours for the filtration plant	Hours	24
Effective hours for the filtration plant	Hours/day	22.0
	Hours/year	8,035
Filtration plant availability	%	93.0
Design factor	–	1.15

3.4 Description of filtration plant

As part of the engineering study developed by WSP, a summary of the main components of the tailings filtration plant is presented.

The tailings filtration plant designed for surface disposal incorporates a complete filtration system equipped with filter presses processing tailings at 50% feed solids. Once filtered, the tailings reach a metallurgical moisture content of 15% and are discharged onto the loading platform where they form stockpiles suitable for handling. These filtered tailings are then loaded by front-end loaders and transported by 40-tonne haul trucks for final deposition.

The 4 filter presses have plate dimensions of 2 × 2 m and will have 90 chambers per filter, with a nominal treatment capacity of 750 t/d and a design capacity of 900 t/d. The filter presses include a cloth washing system, cake washing system, and compression system as auxiliary systems. Figure 4 presents the flow diagram corresponding to the tailings filtration plant, showing the scenario to produce 3,000 t/d.

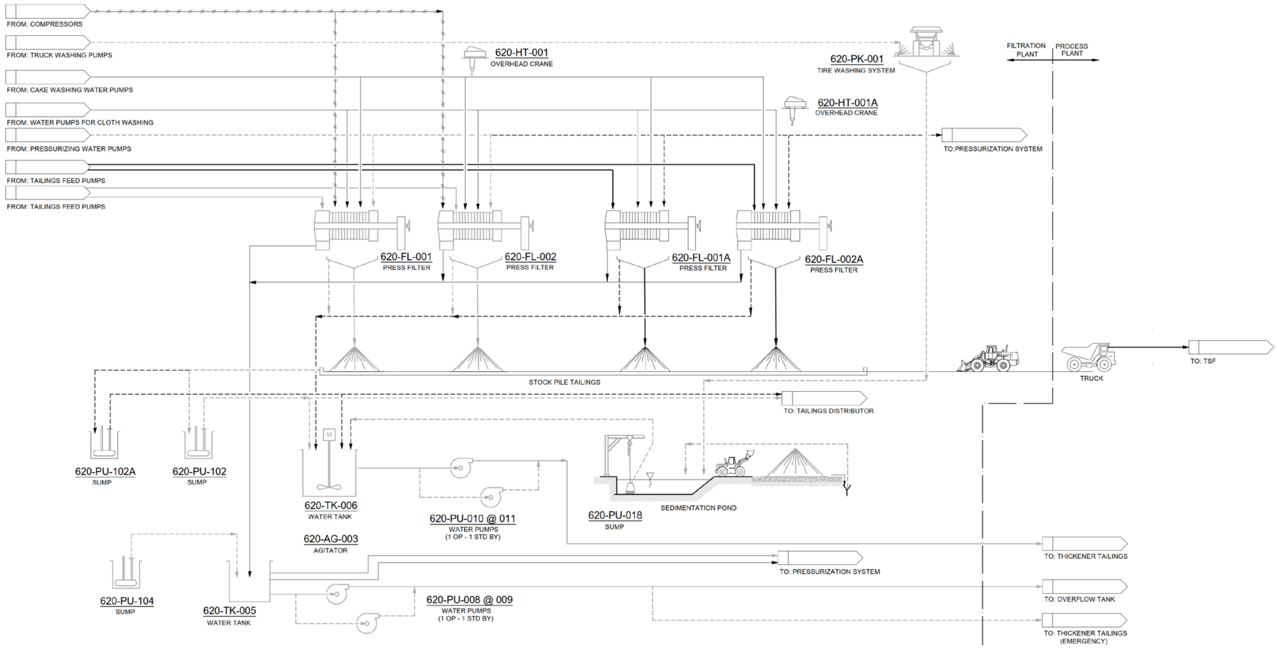


Figure 4 Flow diagram: filtration plant

It should be noted that the transport of the filtered tailings is done by trucks, which implies a continuous movement around the filtration plant and the tailings deposit, for which reason a tyre washing system was planned.

After the filtration process, which yields a filter cake with 85% solids content and 15% metallurgical moisture (equivalent to 17.6% geotechnical moisture), the filter cloths are washed twice a week for 90 minutes at a nominal flow rate of 18 m^3/h per filter. The system generates cloth wash water, which is channelled to the recovered turbid water tank (620-TK-006). From there, the pumping system, consisting of one operating sludge pump and one standby pump (620-PU-010@011), transports the water to the tailings thickener.

The filtered water is conveyed to the cake washing and filtered water recovery tank (620-TK-005). This tank has 2 pumps, one operating and one on standby (620-PU-008@009), which discharge the recovered water into the thickener's overflow tank or the tailings thickener inlet, depending on the process requirements.

The filtration product is discharged directly onto the filtration plant platform, where the filtered tailings stockpile is handled by front-end loaders for loading onto tailings transport trucks.

The filtered tailings are handled by the front-end loader and deposited into 40-tonne capacity transport trucks, which travel approximately 8.7 km to the filtered tailings storage facility.

The tailings filtration plant will require a 2,000 kW electrical substation to supply the power needed for operation at a capacity of 1,500 t/d.

For the first stage of production, which will last 5 years, the tailings filtration plant has been designed for a nominal capacity of 1,500 t/d (dry metric tonnes per day). For subsequent years of operation, the nominal capacity of the tailings filtration plant will be increased to 3,000 t/d.

At the filtered tailings storage facility, the trucks will unload the filtered tailings in mounds, which will then be spread using a D6R tractor or similar to form layers with an average thickness of 0.30 m. The filtered tailings will then be aerated and dried using a ploughing technique (at least twice a day) for a period of

7–10 days. This will be done using a D6R tractor or similar equipped with a disc plough system, until a geotechnical moisture content of 15% is achieved. The tailings will then be compacted to reach 95% of the maximum dry density (MDD) of the test. Considering a desiccation rate of 0.4%/day, according to laboratory results, the filtered tailings with a geotechnical moisture content of 17.6% at the outlet of the filtration plant will undergo a desiccation cycle of approximately 7–10 days in the tailings storage area to reach a geotechnical moisture content of 15% before compaction. Therefore, in the tailings storage area, it will be necessary to prepare sufficiently large desiccating areas to ensure a continuous work cycle in the field (3 hectares for a daily production of 1,500 t/d), which includes the placement of the filtered tailings, the waiting period for drying, and finally, the compaction of the tailings.

The maximum capacity for filtered tailings stored in the tailings pond will be 12.6 Mm^3 (20 million tonnes), which will be reached over a 21-year operating period.

The key parameters to be controlled during operation and permissible levels are as follows:

- Minimum solids content at the tailings filtration plant outlet: 85%.
- Average compacted layer thickness: 0.30 m.
- Minimum compaction density from the Standard Proctor test: 95%.
- Maximum geotechnical moisture content for compaction: 15.0%.

In the tailings deposit area, the trucks will unload the filtered tailings in the form of mounds onto the previously enabled drying platform, as shown in Figure 5.

Figure 5 Filtered tailings on the drying platform

After the tailings have been unloaded, the filtered tailings will be spread using a D6R bulldozer/tractor mechanical equipment, until a layer of 0.30 m nominal thickness (0.35 m maximum thickness) is formed, as shown in Figure 6.

Figure 6 Filtered tailings material spread in layers 0.30 m thick

After the filtered tailings have been spread, they will be ploughed (at least twice a day) for a period of 7–10 days (depending on the moisture readings), using the D6R crawler tractor, which will be fitted with a system of plough discs, in order to reduce the moisture of the tailings by aerating and drying until a geotechnical moisture content of 15% is achieved (Figures 7 and 8).

Figure 7 Tractor

Figure 8 Ploughing process of filtered tailings

After achieving a reduction of the geotechnical moisture content of the tailings to 15% (verified by moisture readings), the filtered tailings will be compacted using a 10 t load smooth roller, with a minimum of 4 passes, until achieving 95% of the MDD of the standard Proctor test of the compacted layer (Figure 9).

Figure 9 Compaction of filtered tailings

The process of placing, spreading, ploughing-drying and compacting the filtered tailings is a continuous cycle to be carried out throughout the dry season and when the wet season allows (Figure 10).

Figure 10 Compacted filtered tailings disposal cycle

3.5 Electrical energy

The following are the installed capacities considered for the first and second phases:

- 100% tailings filtration for 1,500 t/d, with an absorbed power of 1,562 kW and an installed capacity of 2,872 kW
- 100% tailings filtration for 3,000 t/d, with an absorbed power of 3,208 kW and an installed capacity of 4,506 kW.

The tailings filtration plant is estimated to have an average energy consumption of 17.56 kW-h/t. Electrical power will be supplied from a 10 kV transmission line, operated by a third party, to the 4,000 kVA substation and electrical room in the first production stage. The plant will operate with natural air ventilation, and will be expanded to 5,000 kVA in the second production stage, with forced air ventilation.

4 Cost estimates

4.1 Capex

The estimated costs have been established based on budget quotes for major equipment and estimates and references for minor equipment from similar projects carried out in Peru with known budgets. For this study, the costs have an accuracy of ±15%.

4.1.1 Direct costs

Direct costs include the costs of equipment, labour, machinery, and construction materials for the various works comprising the tailings filtration plant. For each of the aforementioned facilities, the structural, mechanical, electrical, and instrumentation civil works have been considered.

4.1.2 Indirect costs

Indirect costs include the following:

- Owner's costs:
  - engineering and basic studies (2.5% of direct costs)
  - construction management and quality assurance (5% of direct costs)
  - spare parts for the first year of operation (6% of mechanical equipment costs)

- freight costs (2.5% of mechanical equipment costs)
- owner's cost (2% of mechanical equipment cost).

- Contractor's costs:
  - temporary construction facilities (4% of direct contractor cost)
  - pre-commissioning, commissioning, and start-up (4% of direct contractor cost)
  - Contractor's overhead and profit (25% of direct contractor cost).

Table 3 presents the costs associated with the 2 production phases (1,500 and 3,000 t/d).

Table 3 Capex

Description	For 1,500 t/d (USD million)	For 3,000 t/d (USD million)
Total investment cost (capex)	20.79	7.57
Direct costs	16.41	6.02
Indirect costs	4.38	1.55
Total operating cost (opex) to present value	15.06	35.30
Total cost (to PV) capex + opex	35.85	40.0

The capex for tailings filtration for surface tailings disposal (dry stacking) will be USD 20.8 million in the first production stage of 1,500 t/d and for the second production stage of 3,000 t/d, an additional investment of USD 7.6 million will be made.

4.2 Opex

The operating requirements are based on the following:

- A 360 day annual operation has been assumed.
- The electricity cost is USD 0.072/kWh.
- Labour corresponds to the salary database for operators, supervisors, and operation and maintenance engineers, and an additional cost has been considered to cover social benefits.
- Maintenance, as maintenance consumables typically include repair parts (mechanical, electrical, instruments, piping, and accessories).
- To establish tailings loading and transportation costs, a truck travel distance of 8.6 km has been considered.

The opex of the tailings filtration plant for surface tailings disposal (dry-stacking) at each production stage of 1,500 and 3,000 t/d, excluding tailings transportation and loading costs, would be USD 1.35 million and USD 2.34 million annually, respectively. For production levels of 1,500 and 3,000 t/d, the following comparisons are made:

- In the first production stage: 1,500 t/d, filtering 100% of the tailings for surface disposal, excluding transportation and loading costs, the cost is USD 2.51/t.
- In the first production stage: 1,500 t/d, filtering 100% of the tailings for surface disposal, including transportation and loading costs, the cost is USD 7.26/t.
- In the second production stage: 3,000 t/d, filtering 100% of the tailings for surface disposal, excluding transportation and loading costs, the cost is USD 2.17/t.

- In the second production stage: 3,000 t/d, filtering 100% of the tailings for surface disposal, including transportation and loading costs, the cost is USD 6.92/t.

5 Conclusion

Tailings filtration offers the advantage of providing tailings in the tailings storage facility (TSF) with low water content, thereby compacting the material and optimising storage capacity. While tailings filtration is a more expensive operation compared to other dewatering technologies, this technology should be evaluated in conjunction with project closure and the advantages it offers during concentrator plant operation. Furthermore, with tailings of lower water content, a robust reclaimed water system from the TSF to the concentrator plant is not required.

Specifically for this project, the disposal of filtered tailings is linked to climatic conditions, which implies taking into account dry and wet seasons for the consideration of compaction or not of the filtered tailings. Having a tailings disposal area with higher moisture content is essential for continuous operation. Similarly, having a contingency pond for thickened tailings in case of emergency is useful to prevent plant shutdowns.

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