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Paste plant feed optimisation using a piston diaphragm pump

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Abstract

In the mining backfill industry, significant focus is placed on the use and optimisation of paste plants, which prepare the paste recipe essential for achieving an efficient, safe, and cost-effective backfilling process, particularly in minimising cement consumption. However, when optimising the entire paste preparation process, the material received by the paste plant itself is not always duly considered.

This paper presents the work undertaken to optimise the operation of the Magdalena (MGD) paste plant at Sandfire MATSA mining operation through an improved tailings feed with a solids content of up to 73% by weight. This was made possible by replacing the existing deep-cone thickener pump system in the mineral processing plant with an ABEL piston diaphragm pump. Before this modification, the limitations of the previous pumping system and the tailings pipeline feeding the MGD paste plant imposed restrictions on feed tonnage, negatively impacting the facility's backfill capacity.

Located in southwest Spain, Sandfire MATSA is at the forefront of innovation in mining processes and equipment, driving efficiency and environmental sustainability. A testament to this commitment is its adoption of piston diaphragm pumping technology, making it the first facility in the world to pioneer this innovation for cemented paste fill at the Aguas Teñidas (ATE) paste plant.

Keywords: *paste plant feed optimisation, piston diaphragm pump, high-density tailings*

1 Introduction

Sandfire MATSA currently operates 3 underground mines: Aguas Teñidas (ATE), Magdalena (MGD), and Sotiel (SOT), from which copper, zinc, and lead concentrates are extracted and processed. Collectively, these operations yield approximately 4.7 million tonnes per annum (Mtpa) of ore, which are treated at the central processing facility located directly above the ATE orebody. This processing generates around 4.1 Mtpa of tailings, which must be carefully managed to ensure environmental and operational sustainability.

Tailings disposal is primarily conducted through a tailings storage facility (TSF) located near the processing plant. Approximately 2.1 Mtpa of tailings – just over 51% of the total generated – are deposited in the TSF. The remaining tailings are utilised in underground backfilling operations.

All 3 mines employ a cut-and-fill mining method. Due to the spatial distribution of the operations, different backfill technologies are used. At Sotiel, a cemented rockfill (CRF) system is utilised. In contrast, both ATE and MGD employ cemented paste fill (CPF), facilitated by their relative proximity to the plant – 200 and 7,000 m respectively. These paste backfill plants consume nearly 49% of the tailings produced, delivering paste at rates of up to 150 m³/h with a solids content of 75–78% w/w.

Tailings are transported from the central paste distribution point to a buffer tank located near the ATE paste plant. From this tank, flow is diverted either to the ATE or the MGD CPF facilities. While both paste plants

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share a similar downstream design, the MGD facility – being over 7 km away – requires a dedicated pumping system comprising of 8 centrifugal pumps arranged in series to achieve the necessary head for tailings delivery. Figure 1 presents a conceptual overview of the tailings transfer infrastructure across the operation.

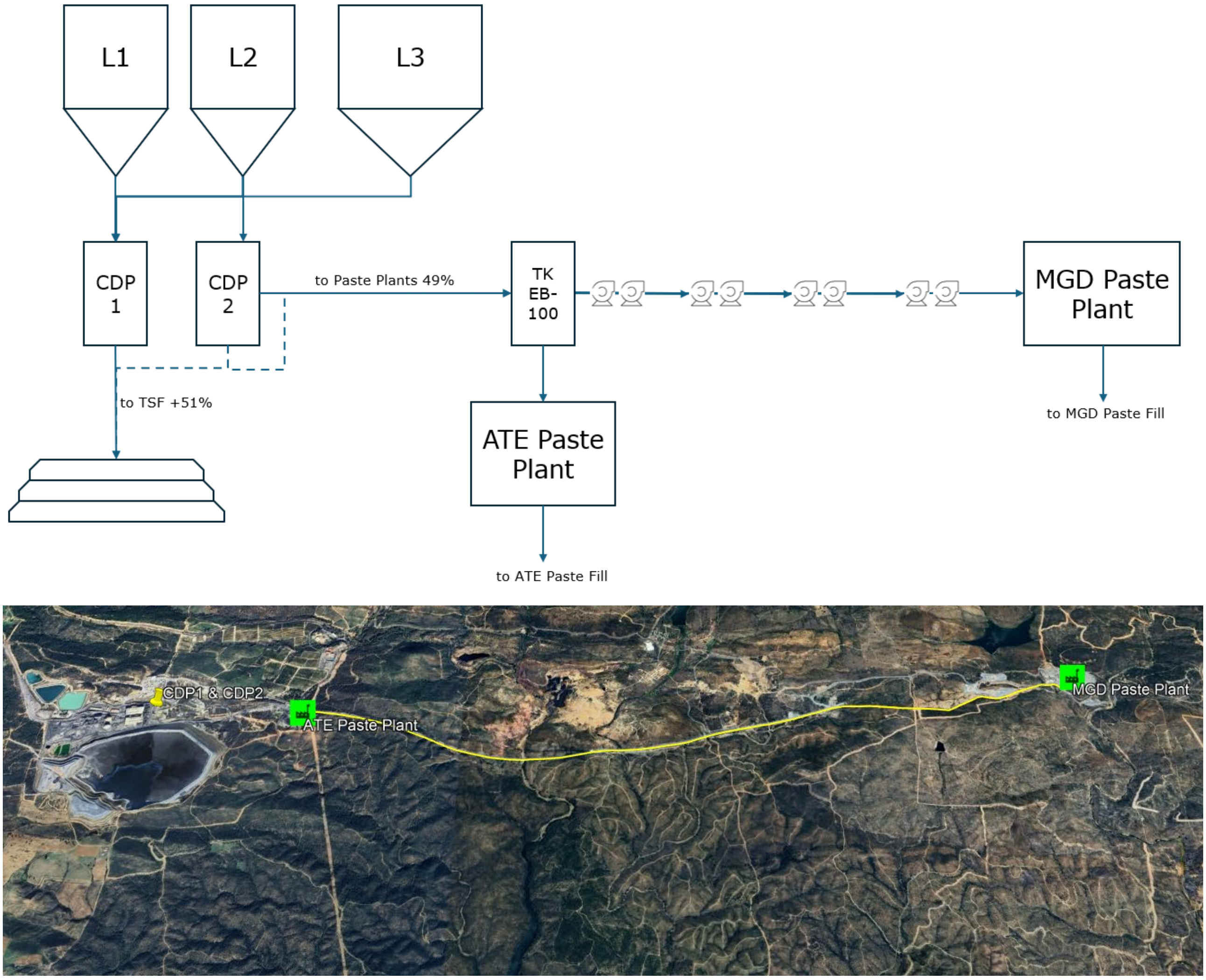


Figure 1 Surface distribution of tailings in Sandfire MATSA until April 2025. ATE = Aguas Teñidas, MGD = Magdalena, L = line

Figure 1 distinguishes the 3 deep-cone thickeners from different processing lines, as this is critical for both operational control and tailings management feeding the paste plants.

Sandfire MATSA operates 3 mines, processing a range of ore types with variable copper, zinc, and lead contents and grades. To maintain a consistent feed across the processing circuits, 5 ore blends are prepared, resulting in 5 distinct tailings streams.

- Line 1 (L1) treats copper-rich ore (ATE cobrizo [COB] ore, ATE STW COB ore and MGD COB ore).
- Line 2 (L2) processes copper and polymetallic ore (including SOT polimetalic [POL] ore and SOT COB ore in addition to the previous sources).
- Line 3 (L3) handles polymetallic ore (ATE POL ore, MGD POL ore and CST POL ore).

This variability in tailings composition introduces significant differences in rheological behaviour during transport and in paste recipe mixes, resulting in different unconfined compressive strength (UCS) performance during the backfill process (Gamboa & Castilla 2024). Consequently, the design and operational flexibility of the downstream paste backfill system must accommodate these variations. Detailed empirical data illustrating these effects within the transport system will be presented in Section 3. As per the existing tailings distribution system and paste plant capacity, there is a requirement to increase the paste plant production to meet the targets of the mining sequence while reducing the power consumption and disc filters maintenance tasks.

2 Background

The original design for tailings transport between the slurry tank EB-100 and the MGD paste plant – separated by 7,000 m above – considered installing 3 pairs of centrifugal pump trains arranged in series (EB-100, EB-200, and EB-300). However, due to high pressure at one of the stations (EB-200), an additional intermediate pumping station was installed approximately 4,000 m from the first station (EB-250). This fourth pair of centrifugal pumps was installed to reduce the excessive head requirement at EB-200 and ensure stable operation across the system.

Over several years of operation, the system has relied on 8 centrifugal pumps, which have been subjected to demanding operating conditions. At times, these conditions exceeded the pumps' design capacity, driven by variations in solids concentration and the rheology of the tailings slurry. These factors often necessitated discharge pressures beyond the pumps' rated limits, as well as beyond those of the gland seal water (GSW) system specified in the initial design.

From an operational standpoint, controlling the long-distance tailings transport system required implementing a lined packing arrangement, ensuring that each pump received feed on the low-pressure side with a minimum suction flange pressure of 2 bar. This procedure was critical to prevent cavitation failures on a long-distance pipeline. Figure 2 illustrates the hydraulic grade line (HGL) and the associated pressure values at key points throughout the centrifugal train pumping system.

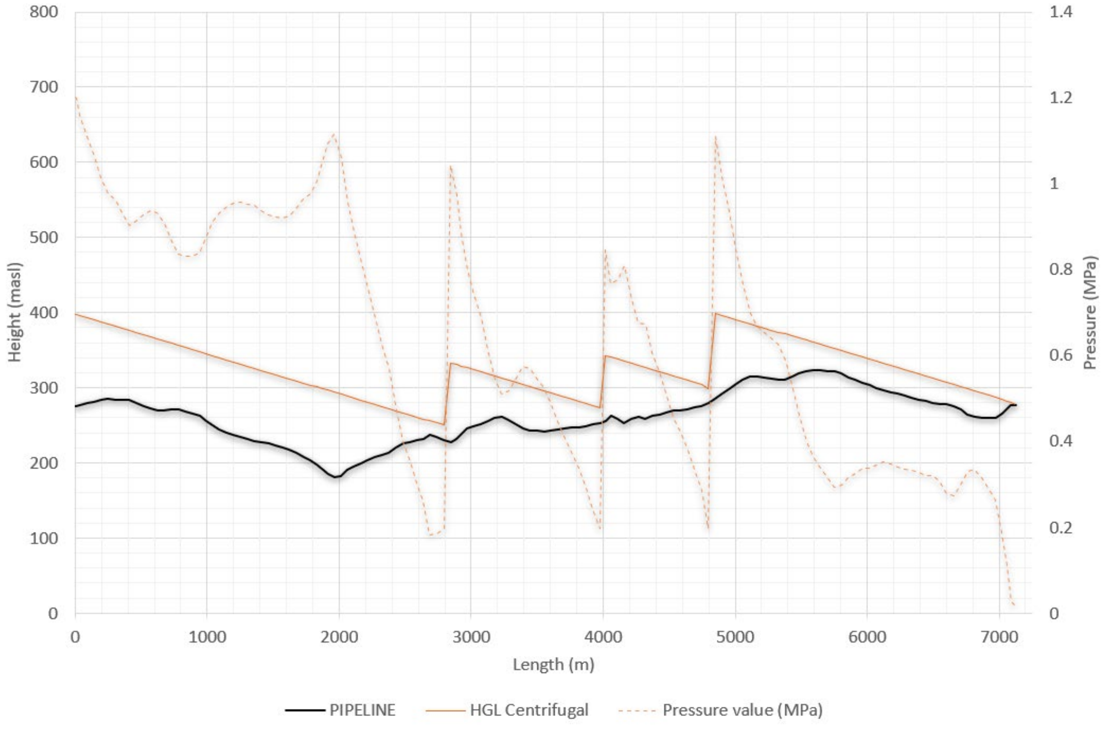


Figure 2 Hydraulic grade line (HGL) and pressure values in the transport line built from values in the field

As shown in Figure 2, the system includes a critical point located approximately 2,000 m downstream of the first pumping station, called the bridge, where the operator must never exceed the pipeline's design pressure rating of PN16, built in high-density polyethene (HDPE) material. This limitation arises from the tight-packed arrangement and the absence of intermediate storage tanks serving as hydraulic breaks between the series-connected pumping stations.

Both the pumps' operating pressure and GSW limits, as well as the critical pressure threshold at this point, constrain the system to operate with a head loss of 0.486 kPa/m.

As will be further explain in detailed in Section 3, the MGD paste plant cannot be fed at rates exceeding 170 t/h of dry solids at a slurry density of approximately 66–69% w/w due to limitations of the pumping system. This throughput is further reduced if the slurry needs to be diluted, negatively impacting energy consumption and the efficiency of the paste plant.

As previously discussed in the context of mineral processing at Sandfire MATSA, the material transported to the MGD paste plant exhibits significant variability. This variability results in substantial fluctuations in system operating pressures for a given tonnage and solids concentration. Therefore, operators must anticipate the material type and slurry solids content in advance to adjust system controls and adjust pumping flow rates, thereby avoiding overpressure at critical system points.

In recent years, the operation has aligned with the industry trend towards finer milling (D_{80} = 38–50 µm), producing a particle size distribution (PSD) similar to that shown in Figure 3. This PSD aligns with findings by Salvoldi & Gerhardi (2025), which report that ultrafine materials exhibit 15–30% of particles below 20 µm, compared to those typically used in paste fill applications (Grice et al. 2009).

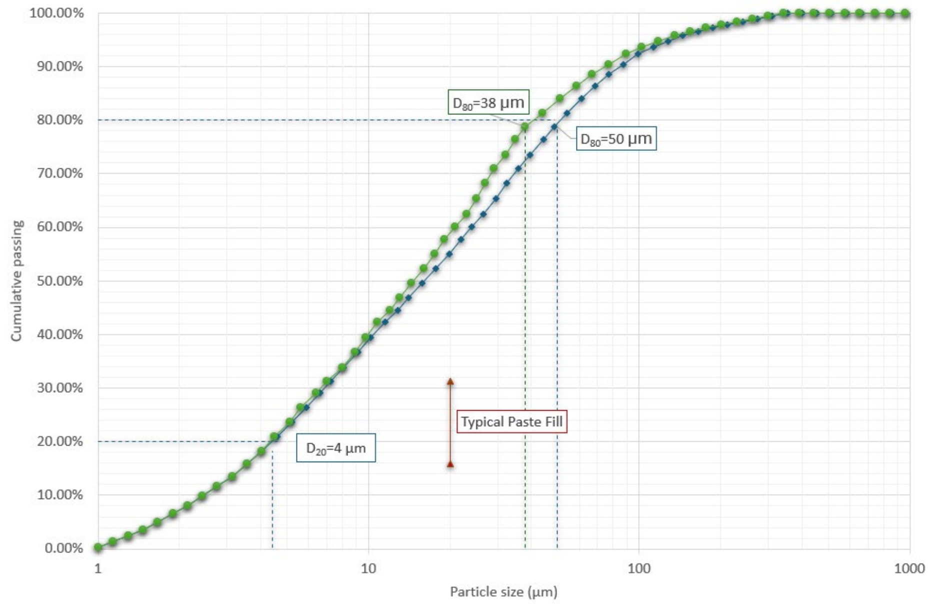


Figure 3 Particle size distribution trend observed since 2022

2.1 Operational challenges with the original system

The PSD and variability of processed ore blends result in significant differences in slurry rheology, which become more pronounced as solids concentration approaches the thickening capacity of the deep-cone thickeners. As per design, these thickeners can achieve a maximum solids content of 72% w/w. The range between 66 and 72% w/w is particularly challenging, as rheological differences – especially in viscoplastic viscosity – are most evident in this operating range.

Inconsistent paste feed rates, both in terms of dry tonnes and homogeneity, complicate the formulation of an optimal paste mix recipe in terms of quality and quantity. It is widely recognised in the mining backfill industry that such variability negatively impacts paste plant operability, particularly the disc filters and the mixer downstream of the described pumping system.

In addition to these challenges, operators responsible for pumping tailings to the MGD paste plant must maintain a low level in the tailings reception tank, which has a total capacity of 500 m³. This precaution is necessary because in the event of a pumping system shutdown – whether due to the aforementioned factors or equipment wear caused by slurry abrasiveness – the entire pipeline must be flushed with water.

This flushing operation requires displacing 150 m³ of slurry contained within the pipeline into the reception tank. Furthermore, an additional 150 m³ batch of water is needed to prevent pipeline sedimentation following maintenance activities, effectively reducing the available buffer capacity at the MGD paste plant.

3 Methodology

As described by Robitaille et al. (2025), pumping tailings to feed a paste plant located at a certain distance from the processing facility is the transport technique with the lowest environmental impact, energy consumption, and susceptibility to climatic variations – when compared to filtration followed by road haulage or railveyor systems.

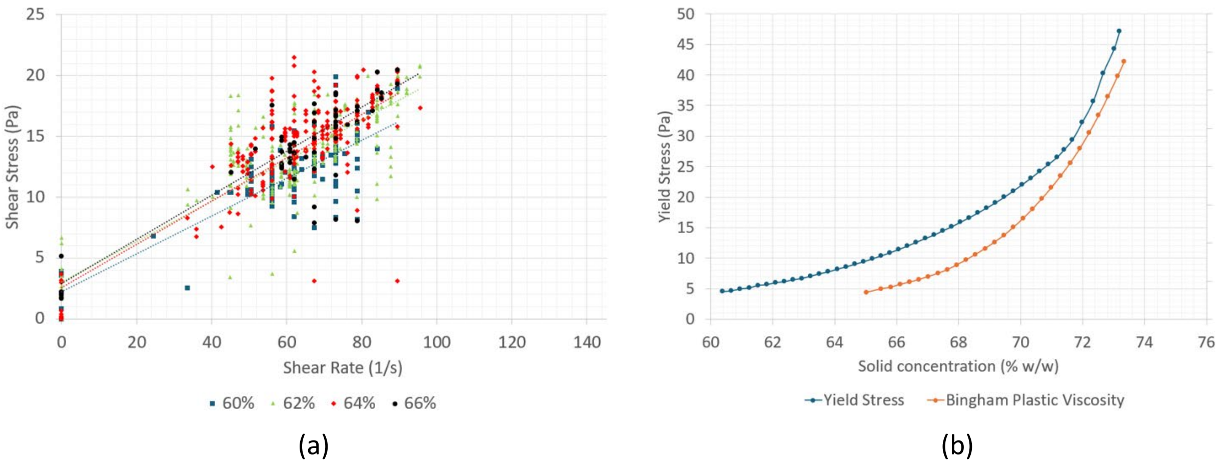
To mitigate the operational challenges associated with the current arrangement of 8 centrifugal pumps in series, the proposed solution is to implement a positive-displacement piston diaphragm pump. Given the specific characteristics of this installation, the system would require a priming pump to ensure optimal filling of the diaphragm housings and achieve the maximum filling efficiency of the main pump.

For pump sizing and selection, operational data collected throughout the life of the original tailings transport system were utilised in a large-scale flow loop test facility.

The original pipeline consisted of an HDPE DN200 route with an internal diameter of 163 mm. To accommodate a single high-pressure pumping unit, an upgrade to the discharge pipeline was required from the outset of the pumping section. This upgrade involved replacing the original line with a DN200 Schedule 80 steel pipe internally coated with polyurethane. The material selection was based on operational experience with the material's performance under abrasive and corrosive conditions, as well as its electrochemical compatibility with carbon steel. The new arrangement provides a distribution system with an internal diameter of 174 mm.

The hydraulic model must be recalculated using empirically derived data. For clarity and ease of interpretation, only boundary conditions at the system's extremities have been considered in this paper.

As illustrated in Figure 4, data variability is significant, and at certain solids concentrations and transport flow rates (shear rate), notable fluctuations in shear stress occur. These variations are attributed to the high heterogeneity of the ore materials being pumped and become increasingly pronounced as the solids content rises. The fact that the trend is increasing while the solid concentration is growing also suggests that the values are being appropriately collected in the field.



(a) (b)

Figure 4 (a) Data collected from the field to evaluate the original hydraulic model; (b) Yield stress and Bingham plastic viscosity correlation at maximum solids concentration

This trend results in higher pressure requirements, and a new operating pressure has been calculated for the worst-case scenario: maximum flow rate, maximum solids concentration, and the most challenging material characteristics. These values have been used in lab testing shown in Figure 4b. Under these conditions, the selected pump must operate at pressures of up to 52 bar. Figure 5 presents the revised HGL for the positive-displacement pump under these design conditions.

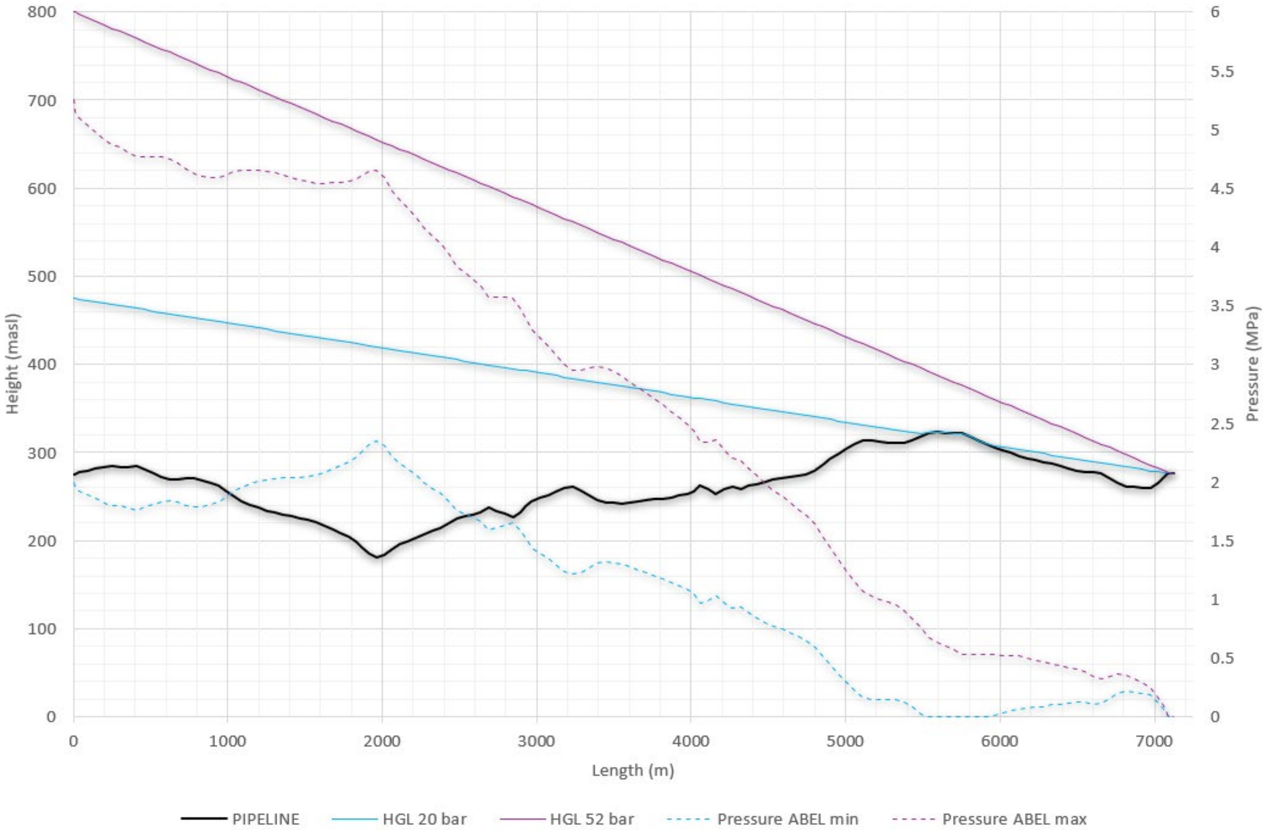


Figure 5 Hydraulic grade line (HGL) and pressure values in the new transport line

With the upgrade from the original HDPE pipeline to Schedule 80 steel pipe with polyurethane lining, combined with the replacement of the pumping system, the following fundamental parameters of the long-distance tailings transport system have been modified (Table 1).

Table 1 Parameters depending on the solids concentration and pipeline used

	High-density polyethene pipeline using centrifugal pumps	Schedule 80 steel with polyurethane lining pipeline using a piston diaphragm pump
Pipe internal diameter (mm)	163	173.5
Flow rates (m^3/h)	90–150	90–200
Dry tonnage (t/h)	100–170	100–240
Slurry speed (m/s)	1.19–1.99	1.05–2.33
Shear rates (1/s)	58–98	51–114
Solid concentration %w/w	54–66–69	60–69–72
Yield stress (Pa)	3–18	5–30
Viscoplastic viscosity (mPas)	10–40	10–90

Figure 6 illustrates the operating envelope as a function of throughput and tailings flow rate for the range of solids concentrations achievable by the deep-cone thickening system located at the mineral processing plant.

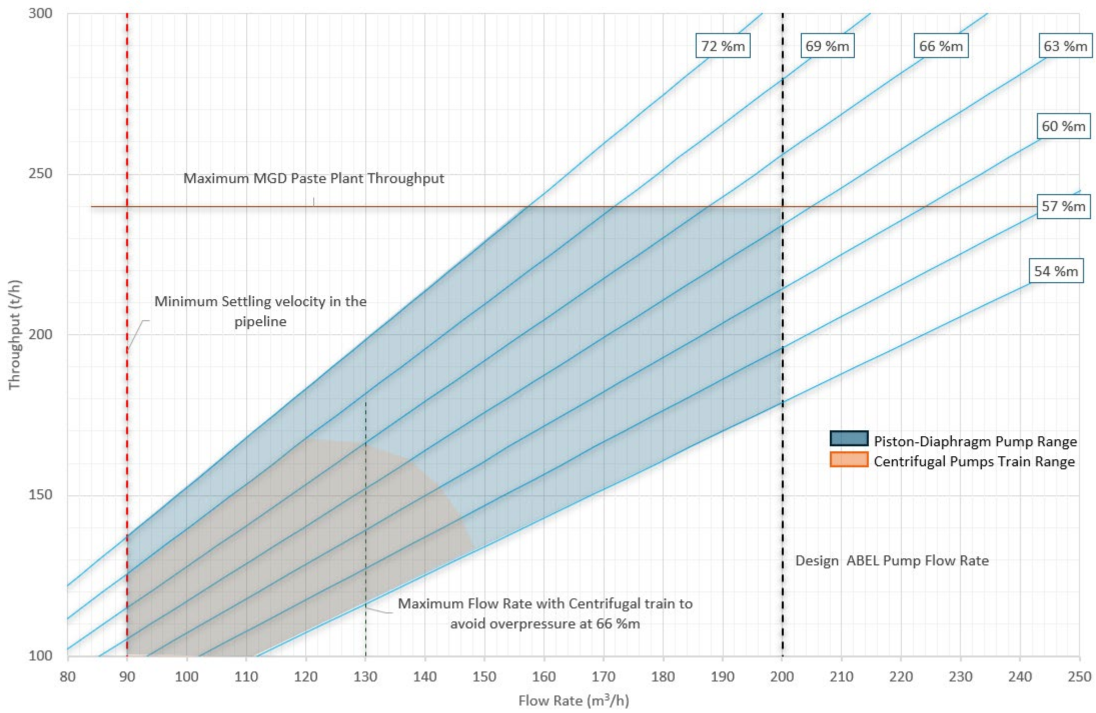


Figure 6 Production envelope: flow rate (m^3/h) and throughput (t/h)

4 Paste plant performance

4.1 Paste plant production and operation improvement

With the implementation of the new pumping system, 2 fundamental improvements have been achieved to enhance the performance and operational efficiency of the MGD paste plant and optimise its operation. The plant layout and process description (Gamboa & Castilla 2024) follow the principles of a conventional paste plant with wet feed, where 2-disc filters produce cakes that are discharged into a mixer. Here, dry cement is added at approximately 4–5%, together with a slurry bypass and an admixture to reduce linear head loss per metre of paste through the reticulation system.

The increase in tonnage and solids concentration delivers 3 operational benefits:

- Enhanced system capacity: the feed rate to the paste plant has been significantly increased, from a previous maximum of 170 t/h of dry solids to 240 t/h, which represents the plant's maximum design capacity. This improvement enables a higher backfill rate downstream of the paste plant, reducing mine fill cycle times at MGD and providing substantial operational flexibility within the mining cycle.
- Improved solids concentration range: solids concentration has been raised from a 60–66% w/w limitation to a new range of 66–72% w/w. This improvement directly enhances the performance and efficiency of the disc filters. For a given production rate, the filters can operate at lower rotational speeds or require less energy from the vacuum pump to achieve the same drying effect. Or, in other words, at a constant operating speed, the filters' loading capacity (kg/m²) increases significantly as the feed solids concentration rises (Wilkinson et al. 2025). This also results in evident savings in filter cloth durability, as the reduced operational demand – combined with higher solids content and lower rotational speed – minimises wear, particularly when handling ultrafine material with a D_{80} of approximately 40 µm.

  In this case study, increasing the feed solids concentration from 60 to 70% w/w has shifted the balance of solids delivery: the amount of dry solids entering the mixer via the bypass line now exceeds the dry solids delivered to the disc filters for dewatering. This shift has a highly positive impact on filter durability, as the reduced load on the filtration system minimises wear and operational stress.

- Finally, with the new configuration, the mixer – where the final paste recipe is prepared at 75–78% w/w solids – receives an increase in solids via the bypass line. This results in a 70–90 t/h improvement in dry solids load at this stage of the process. Consequently, the amount of water and/or cement required to achieve the target UCS in the stopes being backfilled is reduced. In this specific case, similar UCS results can be achieved with slightly different combinations of solids and cement addition.

4.2 Power and water consumption

4.2.1 Electric power

Under the original pumping system design, hydraulic inefficiencies arose from the need to maintain 2 bar suction pressure at the low-pressure side of each centrifugal pump pair. This requirement resulted in an energy loss equivalent to 6 bar across the transport system. Operating within the best efficiency point (BEP), this loss represented approximately 16 kW at a flow rate of 150 m³/h and 170 t/h of dry solids, equating to 0.094 kWh/t in hydraulic inefficiency.

Beyond this design-related issue, it is widely recognised in the mining industry that centrifugal pumps, even operating at BEP, are inherently less efficient than positive-displacement pumps. Under these conditions, each pair of centrifugal pumps consumed between 80 and 110 kW, resulting in a total power demand of 320–440 kW for the entire pumping train. Empirical data collected during operation under the conditions described in Table 1 indicate an average energy consumption per tonne of solids transported of 2.588–3.2 kWh/t.

Under the new configuration, comprising the positive-displacement pump and the centrifugal priming pump, power consumption ranges between 125 and 346 kW, reflecting the increased slurry flow and tonnage delivered (170–240 t/h) as previously described. Adding the priming pump's energy demand of 16–22 kW results in a total power requirement of 141–368 kW for tailings transport at this production regime. This corresponds to an average energy consumption per tonne of dry solids transported of 0.829–1.533 kWh/t, representing a significant reduction in energy expenditure per tonne conveyed, as shown in Figure 7.

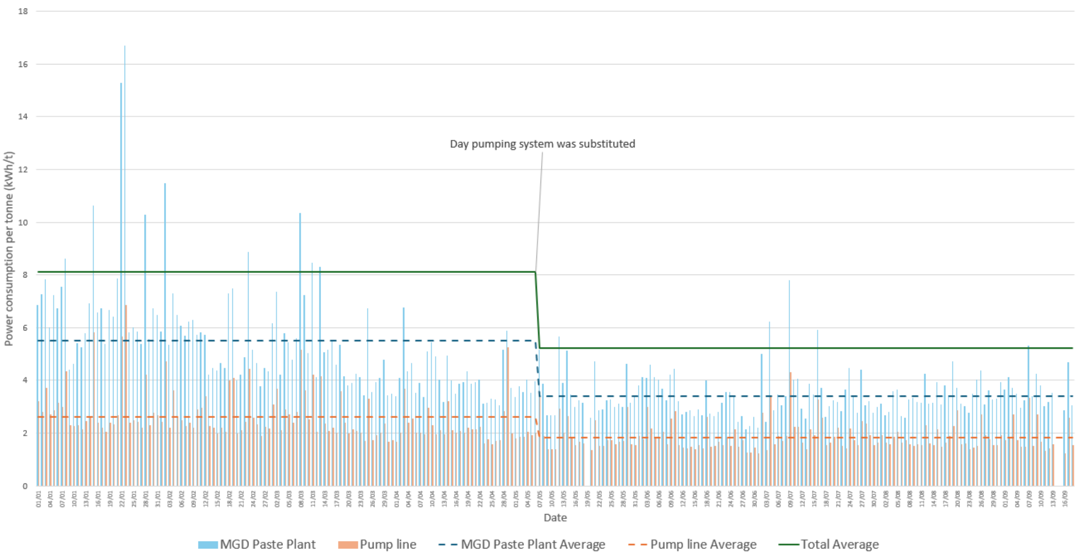


Figure 7 Power consumption per tonne of paste produced at Magdalena (MGD) paste plant and tailings transport line

Furthermore, a comprehensive study has been conducted onsite to evaluate daily power consumption for both the MGD paste plant (including slurry reception tank, feed pump to filters, disc filters and vacuum pump, binder and admixture dosing system, conveyor belt, mixer and paste pump), and the tailings transport line (including active pumping systems and excess-water-return pumping system). Figure 7 presents the breakdown of energy consumption between:

- MGD paste plant (including all equipment)
- tailings transport line (including tailings system and excess water-return system).

As shown in Figure 7 from data gathered from the field in the installation, following the pumping system upgrade and paste plant optimisation, the combined energy consumption of the paste plant (average 3.399 kWh/t) and the tailings transport and water-return line (average 1.828 kWh/t) can now be supplied within the original energy demand of the paste plant alone (average 5.497 kWh/t) before the feed optimisation. This represents a substantial improvement in overall energy efficiency and operational sustainability.

4.2.2 *Water consumption and gland seal water supply*

Under the original design, each centrifugal pump required a continuous seal water supply of 1 m^3/h, regardless of its operating point. For a train of 8 pumps, this amounted to 8 m^3/h of water being introduced into the tailings system, diluting the slurry feeding the MGD paste plant and causing deviations from the thickening level controlled at the processing plant.

The impact of this dilution becomes more pronounced at lower transport tonnages and higher thickening solids concentrations.

Figure 8 illustrates the operating points as a function of solids concentration, highlighting the deviation between the thickener target and the actual solids percentage in the transport system, and comparing the original configuration of 8 centrifugal pumps in series with the new arrangement using a single positive-displacement piston diaphragm pump and a priming centrifugal pump.

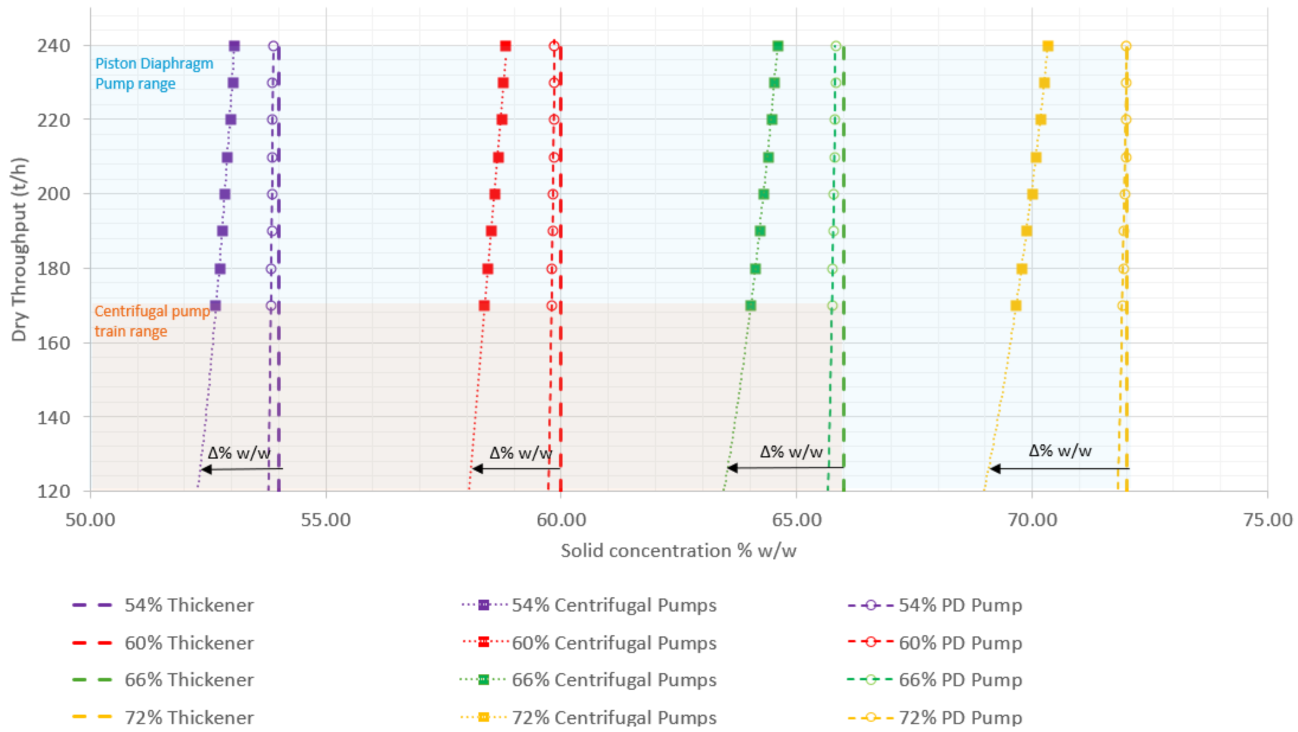


Figure 8 Solids concentration deviation on paste plant feed using different pumping systems.

Within the operating range of the original pumping system, solids concentration deviations ranged from –1.3 to –2.5%, depending on tonnage and thickening performance at the time, due to the use of 8 centrifugal pumps in series.

In contrast, with the positive-displacement pump fed by a single centrifugal priming pump, deviations are reduced to a range of –0.17 to –0.05%, which is negligible for controlling solids concentration and optimising the final paste recipe at the MGD plant. This improvement enhances mixer control and optimises cement usage.

Finally, it is important to note that, due to the long distance between the MGD paste plant and the mineral processing plant, an additional pipeline returns excess water from the paste mix preparation process back to the mineral processing plant. Consequently, the 8 m³/h of seal water injected into the slurry under the original system must also be pumped back, incurring additional energy losses. This return line includes a train of 3 centrifugal pumps in series, which also requires seal water and has associated energy consumption.

The analysis does not cover spare parts consumption due to wear or maintenance hours for this remote pumping system in different stages.

4.3 Future studies and developments

In the short to medium term, further investigation will be required to validate the assumptions and objectives outlined in this study. Key areas for future work include:

- Continuous monitoring of the premises outlined in this paper, including an assessment of spare parts consumption and maintenance hours for the new piston diaphragm pumping system compared to the original centrifugal pump arrangement.
- Evaluation of potential future requirements for the distribution system, considering increased production and potential improvements in paste quality. The current distribution relies on gravity flow supported by a centrifugal pump.
- Investigation into the introduction of a hydrocyclone system to optimise disc filter performance by selectively removing the fine fraction of tailings before filtration.

5 Conclusion

Based on the findings of this case study, the following conclusions have been reached:

- Replacing the pumping system and upgrading the transport pipeline could enable a significant increase in downstream backfill capacity.
- The pumping system is no longer the limiting factor for the solids concentration feeding the MGD paste plant.
- The tonnage handled by the disc filters could be reduced with the new paste plant feed. Consequently, filter performance could be improved, as a greater amount of dry solids can now be delivered directly to the mixer via the bypass line, which is expected to extend filter cloth life – a parameter still under evaluation due to the short operating period of the new system. With more running-time data, this point could be validated.
- Optimisation of the cement content in the MGD paste recipe has been achieved. However, this benefit is also subject to further study, given the limited operational history of the new system.
- Energy consumption for tailings transport to the MGD paste plant has been optimised, decreasing from 2.588–3.2 to 0.829–1.533 kWh/t.
- The average power consumption per tonne of paste produced has been reduced by more than 30%, considering both the MGD paste plant and the tailings transport line feed.
- Storage capacity in the tailings reception tank at the MGD paste plant has been increased, improving plant availability in the event of a pumping system failure.
- Water consumption for GSW in the transport line has been reduced by 7 m³/h, while eliminating the same volume from the return water line to the processing plant. Solids concentration deviation

has been reduced to a minimum, ensuring this is no longer a challenge in MGD paste plant operations.

Acknowledgement

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