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Availability of piston-diaphragm pump in paste fill: cement savings

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Abstract

It is well known that cement is the most representative cost in the operation of a paste plant (Granlund 2020). It plays a crucial role in preparing the recipe for paste to be poured into the different underground chambers to ensure sufficient strength on exposure, depending on the mining method.

In this paper, we aim to evaluate how the use of an available paste pump using piston–membrane technology has a significant positive impact without incurring additional operating costs due to using too much cement. This will significantly improve the availability of the conventional cement pump systems that have been used for decades in the application of paste fill.

The design and filling standards of the Aguas Teñidas filling plant and the data obtained will be used as an example in this paper. The client is Sandfire MATSA who use a cut-and-fill exploitation method, which has been using two ABEL® piston–membrane pumps since 2020 for pumping cement paste into the Castillejitos body.

Sandfire MATSA is located in southwest Spain and is at the forefront of innovation for processes and equipment to develop efficient and environmentally sustainable mining. Proof of this can be seen in its commitment to piston–membrane pumping equipment when it became the first facility in the world to develop this innovation.

Keywords: *paste fill, piston-diaphragm availability, cement savings*

1 Introduction, paste plant layout

Sandfire MATSA currently has two paste filling plants: Aguas Teñidas and Magdalena, whose design and operation are very similar. Their objective is to conduct efficient, safe and uniform cement filling in both mining operations, which are also called Aguas Teñidas and Magdalena mines.

In the Aguas Teñidas backfilling plant, both gravitational and pumped filling can be used via ABEL® piston–membrane technology pumps. Figure 1 shows the general layout and operation of the plant, which is described as follows:

- The thickened tailings from three deep cone thickeners are received at the paste plant at a concentration of 55–70% of solids by weight.
- The two disc filters are fed from the slurry reception tank, through a centrifugal pump, and produce up to 150 m^3/h of filter cake under the design conditions.
- The discharge of both filters occurs on a belt conveyor with a solids concentration of 80–84%. This is where the tonnage of disc cake produced is measured.
- The following flows are discharged into the continuous mixer:
    - Disc filter cakes.
    - Binder from the silo located in the paste plant.
    - Tailing bypass for the operator to control the targeted paste recipe.

  - Fluidiser, which was commissioned at the same time as the piston–membrane pumps.
  - Water, as required or for emergency situations. When the synchronisation of the different flow rates that make up the final paste recipe are inadequate, the plant has a water supply to remedy this situation immediately in emergency situations and return the recipe to the intended working point.

- The final paste recipe is discharged by overflow into the paste hopper located on the lower level of the paste plant. At this point, depending on the filling needs, the Aguas Teñidas mine can be filled by gravity or the paste can be diverted to the pumping system responsible for filling the Castillejitos orebody.
- Immediately below the hopper, a centrifugal pump is installed which produces two positive effects for charging the ABEL piston–membrane pump: firstly, it positively charges the pump and secondly, it ensures maximum filling and therefore pumping efficiency.
- The piston–membrane pump moves the paste 1,250 m along the surface to the borehole at Castillejitos under operating conditions of 130 m^3/h and 60 bar. One pump is in operation, with a second pump on standby for emergency situations. These pumps have been operational since 28 February 2020, when they were installed for the first time in the world in a large-scale paste fill plant; replacing conventional technology in the pre-feasibility design.

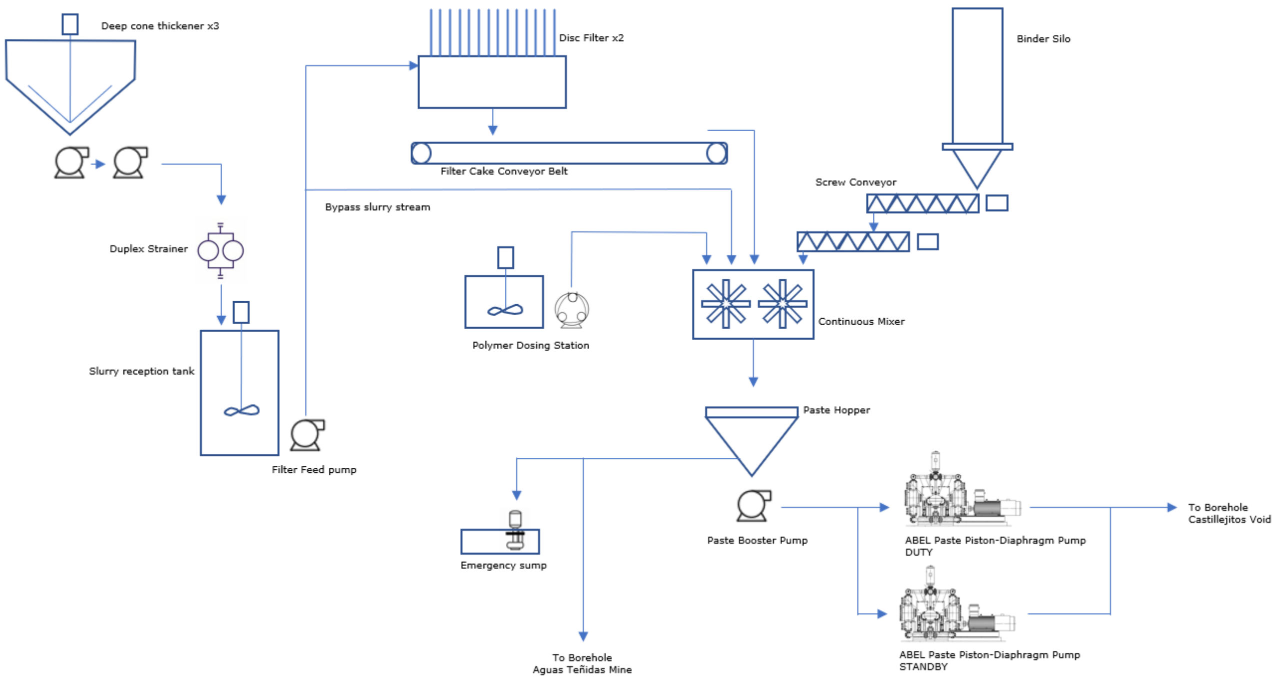


Figure 1 Basic operating design of the Aguas Teñidas filling plant

2 Paste recipe description

Sandfire MATSA has a very advanced fill management and control system which establishes the optimal paste recipe for each filling stope in advance depending on the mining cycle and the need for early exposure of the stope being filled. Of course, this recipe varies with the safety standards required for a task, as mine filling must always be done under safe conditions.

Therefore, the data provided below will be considered as typical under normal filling conditions. Table 1 shows the working range of the different parameters that make up the paste recipe.

Table 1 Paste recipe parameters

Parameter	Range
Stope unconfined compressive strength (kPa)	200–1,000
Stope bottom unconfined compressive strength (kPa)	200–400
Curing time stope (days)	14–28
Curing time stope bottom (days)	5–7 to 14–28
Solid concentration by weight (%)	75– 79
Paste density (tonnes/m^3)	2.1–2.4
100 mm measured slump test (mm)	60–30
100 mm measured yield stress (Pa)	136–156
	344–393

The data in the table varies greatly with:

- The origin of the mineral in the mine from which the tailing comes
- The time for which the specific stope will be exposed
- Percentage solids
- Percentage cement applied.

Figure 2 shows the relationship between the yield stress (Pa) and pumped paste density (tn/m^3), covering 100% of the filling plant operational spectrum.

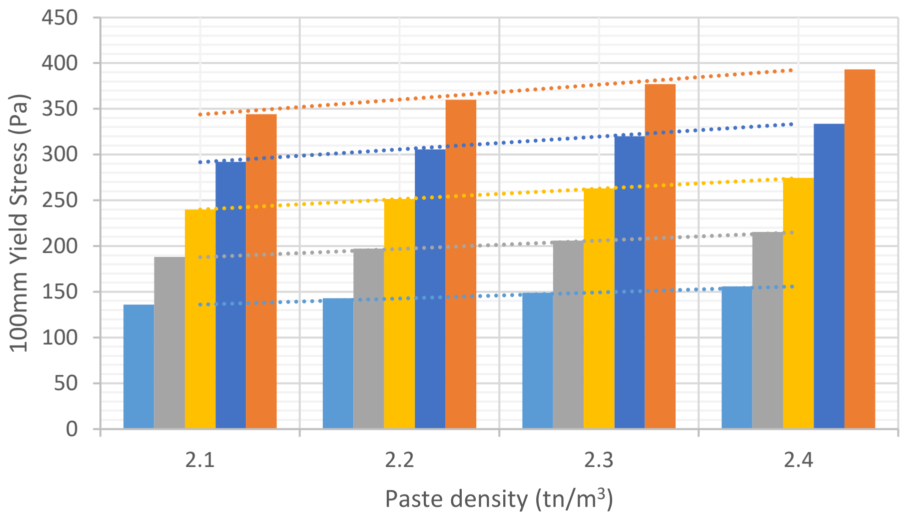


Figure 2 100 mm yield stress (Pa) values measured at different paste densities (tn/m^3)

3 Paste pumping system description

The plant has a Warman® centrifugal pump assembly and two ABEL piston–membrane pumps.

3.1 ABEL paste pumps

There are two ABEL HMQ-F-250-2000-U pumps installed, each designed to achieve the duty point described in the following paragraphs.

These two pumps worked from February 2020 to February 2023 for a total of 5,722 hours filling different chambers in the Castillejitos orebody.

ABEL has developed a duplex double acting piston–diaphragm pump for the application of adapting to two critical requirements in the pumping of cemented paste; the complex rheology and a cementitious material to be pumped. Two double acting cylinders mechanically and hydraulically operate two respective pre-moulded membranes, each of which has two conical valves (one for suction and the other for discharge). For cement paste, a special design of several internal components of the pump has been developed so they occasionally admit larger particles, mainly from the dry dispensing of cement, into the system. Figure 3 shows the three-dimensional design of the two pumps in the paste plant.

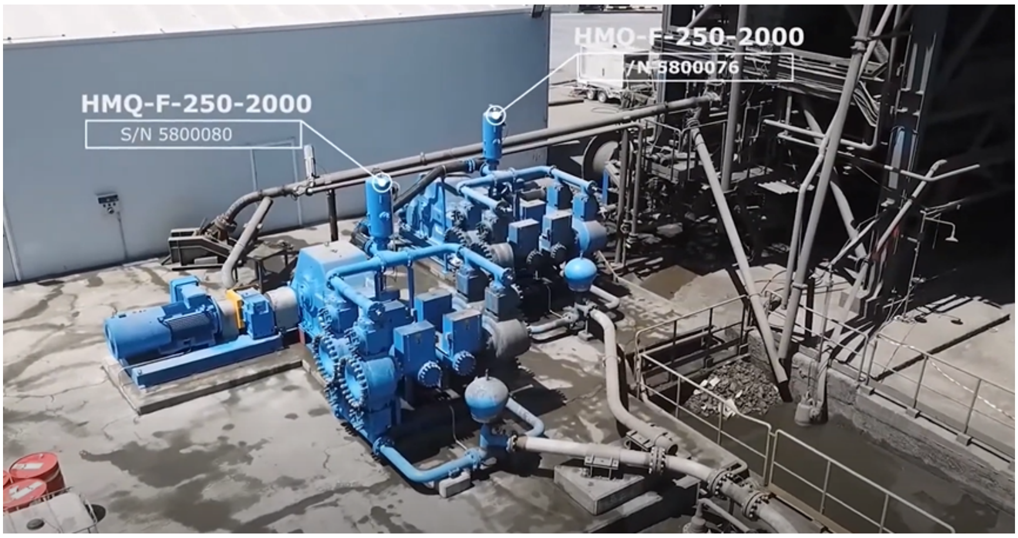
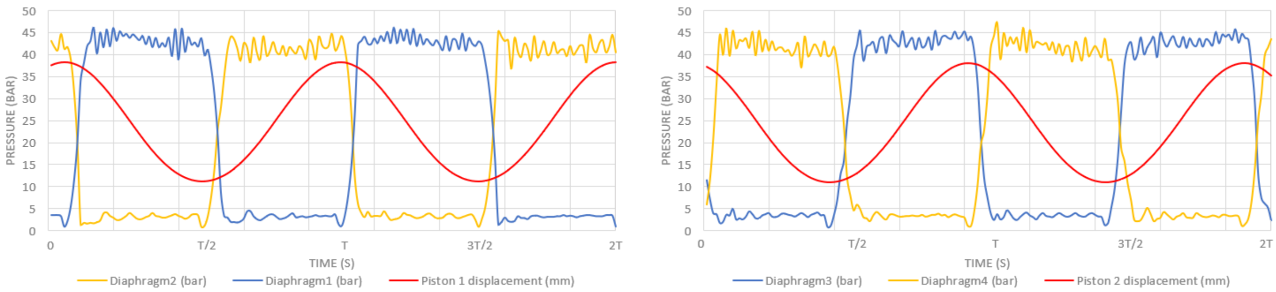


Figure 3 ABEL HMQ piston–diaphragm pumps general arrangement

Both pumps include pulsation dampeners at the suction and discharge side to provide stable suction and discharge flow rates, with less than 7% flow variation. These dampeners are of simple design and charged manually without complex synchronisation and programming systems which allows a stable flow without large fluctuations. Figure 4 shows the pressure oscillation during filling of one of the chambers.



(a) (b)

Figure 4 Discharge pressure value along the piston stroke. (a) Left piston with diaphragms 1 and 2; (b) Right piston with diaphragms 3 and 4

This information was recorded by ABEL's internally developed smart monitoring system during a stope pouring in July 2020. It automatically detects wear and specific failures due to the internal deterioration of components subject to friction against the cement paste itself, as well as detecting specific anomalies in the filling paste production process.

Figure 5 shows a general section drawing with the basic operating design of this piston–diaphragm pump and its main components.

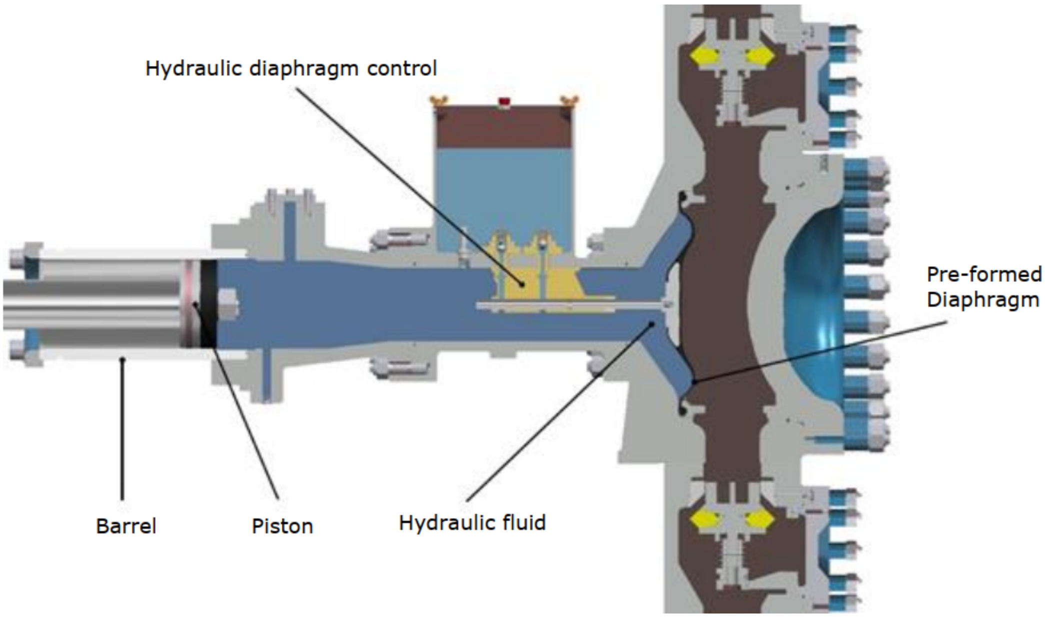


Figure 5 Typical arrangement of the ABEL piston–diaphragm pump cross-section

3.2 Pre-charge centrifugal pumps

Immediately under the lower part of the paste hopper is a Warman 6/4 D-AH pump, whose selection and design was validated by the Sandfire MATSA filling department in conjunction with ABEL. This was based on its good performance in the filling department for pumping thickened tailings to around 70% solids. This pump must be derated to handle high density/viscosity paste, which confers a particular impeller speed that also increases its useful life. Currently, due to its availability and the limited space in the filling plant, there is only one centrifugal pump installed to power either the main ABEL paste pump in operation or the standby ABEL paste pump.

In addition to charging the ABEL pump, one of the main benefits of this pump is that it can be placed out from the location of the paste hopper, which gives the plant greater flexibility in design and height, while enabling the main pump area to be cleaner, due to the larger space for maintenance.

4 Overview of stopes backfilled

4.1 Stopes volume backfilled

As an example of the availability of the pumping system, it was limited to filling work between 26 February 2020 and 28 February 2023 in order to measure it for three full years. At this time, given the need to fill the Aguas Teñidas plant, a large number of chambers were pumped and filled in the Castillejitos orebody, which is the focus of this study.

As can be seen in Table 2, the volume of the stopes and the tonnes of cement used in each varies. This was managed in accordance with the mining cycle required by the underground mining operation. Volume of the stopes, and paste recipe varies significantly. To consider a representative average value, it will be considered that the stope plug is filled with 5% cement (although sometimes 8% is needed), while the main body of the stope will be considered with a cement dosage of 4% (although this value ranges from 3–5% in certain circumstances). The average stope volume will be considered as 20,000 m^3.

Table 2 Stopes backfilled in three year timeline

Stope name	Paste volume (m^3)	Binder dosing (tn)
MLBR 990 144 a+b	48,570	4,365
MLR 990 140 b (S)	15,166	1,286
MLR 1020 142 a + 139 d	11,564	1,057
MLR 1020 139 e	2,825	230
MLR 1020 143 e	5,111	468
MLR 990 140 a	11,240	1,013
MLB 940 161 a	14,930	1,475
MLB 960 161 b+c	37,438	3,587
MLR 990 156 a	9,264	867
MLR 990 147 a	34,412	1,964
MLR 990 132 a + 136 c	15,768	1,211
MLR 990 142 a	26,611	1,957
MLR 1020 143 v	13,159	1,289
MLBR 930 166 a	26,699	2,832
MLBR 940 159 a+b	54,085	6,083
MLR 1020 141 c	5,800	490
MLR 990 147 b	9,784	696
MLB 166 b	16,615	1,760
MLBR 960 154 b+b	47,100	4,955
MLR 990 159 c	4,469	389
CAM 990 149 A	5,712	584
CAM 990 154 A	15,647	1,262
CAM 930 176 A	40,452	4,737
CAM 940 149 A	8,251	885
CAM 940 156 A	16,826	1,204
CAM 900 171 B	17,169	1,579
CAM 960 176 A	8,186	965
CAM 940 151 A	8,053	703
CAM 900 171 A	3,307	344
CAM 930 179 A	19,684	1,380
CAM 960 156 A	19,336	1,449
CAM 990 151 A	14,546	1,224
CAM 900 163 A	7,312	745

4.2 Time dedicated to backfill

The stopes listed in Table 2 were backfilled in a very short time due to availability in the plant of 97.2%, and availability of the pumping system at a value of 97.3%. Figure 6 shows the number of working hours per month since the pumping system was started. Sandfire MATSA alternated the operation of one ABEL paste pump with the other to maintain the availability of the system in case of failure. Only during October 2022 and February 2023 did the backfill department need to change from one pump to the other due to unavailability caused by an estimated repair time exceeding the time to change the suction and delivery pipes. This task is currently carried out manually and takes the maintenance team less than two hours to do.

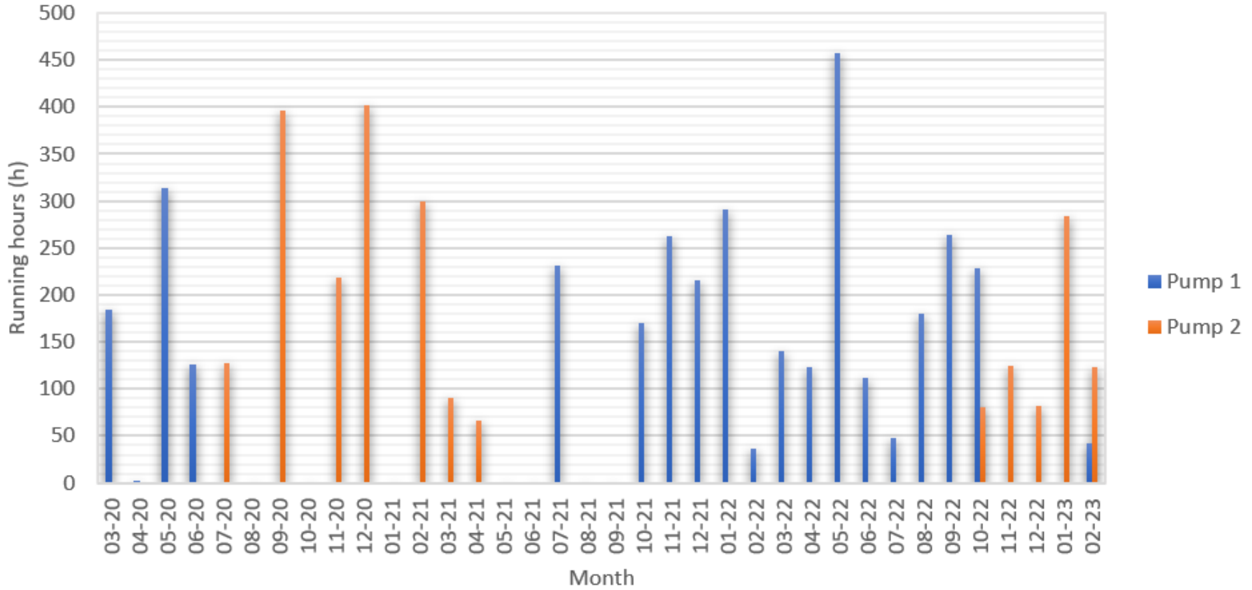


Figure 6 Paste pumping system running hours between February 2020 and February 2023

5 Pumping system unavailability: action required

Based on the data in Section 4, a 20,000 m^3 void backfilled under conditions of 5% dispensed cement will be taken as an example to calculate the plug located in the base. For the main stope body, a 4% dispensed cement will be taken as a reference point.

Under conditions of 100% availability, this filling work must be carried out in six days, nine hours and 50 minutes, taking into account the system pumping capacity. As an example for this calculation, considers a curing time for the plug of five to seven days , plus the chamber curing time of 14–28 days depending on the mining cycle. Table 3 shows the total time of pumping and curing time.

Table 3 Backfilling time at an average size stope

Parameter	Value (days)
Time dedicated to allow the plug to cure	7
Time dedicated to backfill with 100% availability	6.41
Time dedicated to allow the stope to cure	28
Total	**41.41**

In these circumstances, given the need to continue with the mining cycle, Sandfire MATSA applies a general rule in case there is a pumping system failure. In such a situation, the pipe has to be washed with water until clean water can be seen coming out of the pipe via the CCTV cameras. Once this has happened, the equipment is stopped and the repair carried out. The paste fill plant is then put back into operation with the desired paste recipe and paste production is continued. Furthermore, as a preventive measure to maintain the stability and strength of the stope, and considering safety, Sandfire MATSA adds an excess amount of cement during the next two hours, increasing it by 1% over the original agreed recipe for finalising filling that particular void.

5.1 Paste pump availability ABEL SPA

As previously mentioned, the measured availability of the set of paste pumps is 97.3% due to three particular circumstances:

1. Skilled and deep process knowledge of the operators.
2. Piston–membrane technology pump with low wear, and operational and maintenance simplicity.
3. The online monitoring system allows ABEL SPA to predict premature wear; that is, it is neither corrective nor preventive. It anticipates a major failure which would have resulted in the equipment being unavailable during filling; or the failure would have required a prolonged repair that affected the void pouring time.

This online monitoring system is also capable of detecting significant, homogeneous wear from the pump due to being in constant contact with the fine, abrasive cement paste. It is also capable of detecting specific failures or blockages in the valve/seat set sealing system for components in both suction and discharge. This has allowed Sandfire MATSA to operate as follows:

- When a specific blockage is detected by the information collected in the ABEL SPA system, the exact point and nature of the failure is known. The paste plant operator then flushes with water for five minutes.
- After completing this flush, the corresponding maintenance task is started and lasts no more than 20 minutes of operating time (0.33 h) as per the records taken from the plant operation and ABEL SPA.

After the pump is returned to normal operation, it is refilled according to the original paste recipe. This way, Sandfire MATSA no longer has to dispense an extra 1% cement for two hours after start-up of the pumping system.

For more accurate information, the average pump availability values – mean time between failures (MTBF) and mean time to repair (MTTR) – are discussed in the following sections.

5.1.1 Mean time between failures

This is described as the time between both specific failures associated with the use and wear of the pump itself and those due to a foreign material in the paste recipe (e.g. screws, stones, sticks and pieces of rubber). It is understood as the average time taken to require a pump stop and repairment, and is calculated based on the operation records at site.

5.1.2 Mean time to repair

This is described as the time to repair failures both specifically associated with the use and wear of the pump itself and those due to a foreign material in the paste recipe (e.g. screws, stones, sticks and pieces of rubber). It is understood as the average time to completely repair the root cause of the failure that made the pump stop and is calculated based on the maintenance records at site.

This data is shown in Table 4, considering both wear and foreign material root causes of the failure to be addressed.

Table 4 Mean time between failures and mean time to repair

Parameter	Value (hours)
Mean time between failures (wear)	>4,000 h
Mean time between failures (foreign material)	>500 h
Mean time to repair (wear)	0.0833 (flushing) + 0.33 (repair)
Mean time to repair (foreign material)	0.0833 (flushing) + 1 (repair)
Mean time to repair (without ABEL SPA)	**1 (flushing) + 4 (repair)**

The absence of the ABEL SPA smart system is considered in the last row of Table 4. Here, it would have been necessary to flush the pipe for one hour as the exact point of failure is unknown, with an average repair time of four hours due to the nature of the failure being unknown before dismantling the pump.

Comparing the aforementioned data with 97.3% availability, it is calculated that on average, it is not necessary to carry out any unforeseen repairs during the filling of a medium-sized stope void in the mine. This equates to an average pouring and curing time of 41.41 days.

However, to evaluate this situation with or without the ABEL SPA, or compared with other conventional technology pumping systems, the existence of one specific failure during filling will be assessed in the following section.

6 Excess dispensed cement calculation

This example is based on the hypothesis of a pumping system failure using the average operating data of positive displacement pumps with piston–membrane technology. Using ABEL SPA, MTBF is significantly higher than the corresponding value without the usage of the ABEL SPA. Meanwhile MTTR is considerably reduced while using the ABEL SPA.

Sandfire MATSA's average expenditure on cement is as follows:

$$Binder\ Cost = Q_{med} \times P_{ton} = 11.84 \times 100 = 1{,}184\ €/h \tag{1}$$

where:

Qmed = average binder tonnage per hour.

Pton = price of a binder tonne.

Assuming extra cement is dispensed for two hours after the failure, the hourly cost would be:

$$Binder\ Cost = (Q_{med} + Q_{2h}) \times P_{ton} = (11.84 + 2{,}89) \times 100 = 1{,}473\ €/h \tag{2}$$

where Q2h is the binder overdosing cost per hour.

This represents an extra cost of EUR 578 during the two hours following the failure, taking into account that there is no attempt to recover the pump failure time, and the required curing time lost during this time. Depending on the exact time of the repair, this would have a considerable impact on the mining cycle with respect to the curing time required to make up for lack of production, without affecting the original mining cycle required. This data cannot be counted as Sandfire MATSA has never incurred a significant failure of the piston–membrane technology paste pump leading to a failure that delays the expected mining cycle.

Following this principle, another calculation is going to be done, assuming that there is a non-expected failure that leads to a 72-hour maintenance period to solve the failure taken on the paste pump. An event that is unlikely to happen with a piston–diaphragm technology pump in the ABEL SPA is not included, but that could potentially happen with a conventional technology pumping system.

To keep the mining cycle as it was originally planned, in order not to affect the mining activity production, Sandfire MATSA has defined a mitigation risk countermeasure. This countermeasure is a binder overdosing recipe with a +0.5% extra binder increase compared to the originally defined recipe. Following this example, it would represent:

- Binder dosage at 4% on the paste recipe before pumping system failure, with the objective of achieving a 500 kPa strength after 28 days.
- Paste pump failure and stop for 72 hours.
- Binder overdosing at 4.5% after failure, needing to achieve a 500 kPa strength after 14 days as the backfilling department to operate safely while respecting the original mining cycle plan.

Assuming this event happens when the stope has been 50% backfilled, this would represent the following overcost:

$$Binder\ Cost = \left(Q_{med} + Q_{4,5\%}\right) \times P_{ton} = (11.84 + 1.445) \times 100 = 1{,}328.5\,\frac{€}{h} \quad (3)$$

$$Overdosing\ cost = Q_{4.5\%} \times P_{ton} \times t = 1.445 \times 100 \times 76.92 = 11{,}114.94\ € \quad (4)$$

where:

$Q_{4.5\%}$ = binder overdosing cost with 0.5% extra binder.

t = time dedicated to overdose assuming problem happens at 50% of the stope.

Under this event, there is an additional cost of EUR 11,114.94 to the stope backfill to be considered additionally to the pumping system repair.

7 Conclusion

The following conclusions can be drawn from the different sections of the paper:

- The paste recipe required by the operation has not been affected by the introduction of a new centrifugal pump plus positive displacement piston–membrane pump system.
- The 100 mm yield stress (Pa) pumped during operation was in the range 133–393 Pa, depending on the paste density and the recipe required in each chamber.
- The filling forecasts between February 2020 and February 2023 were met satisfactorily due to the high availability of the paste plant and pumping system (both above 97%) and excellent management of the filling operation.
- Stopes volumes are very variable. An average has been considered for cement dosing cost calculation purposes.
- During the pumping operation, a change from the operating pump to the standby pump was required on only two occasions, without the need to alter the original mining cycle or incur extra cement dispensing costs.
- ABEL SPA system has a significant positive impact on the MTTR value which directly affects the pump availability which has been above 97%.
- Binder overdosing calculation cost is a complex value to be considered but has an obvious impact on the backfill operational costs that is mitigated with an available pumping system in Sandfire MATSA.
- The high availability of the piston–membrane pumping system and its use with the online monitoring system prevented extra cement dispensing.

Acknowledgement

We are grateful to Sandfire MATSA for providing the opportunity to present this case. Special thanks are extended to the backfill department for their support, trust and willingness to have a successful and safe operation while using an innovative pumping system in the application.

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