Extending Paste Pumping Envelopes at Minera San Rafael's Escobal Mine Using Admixtures and Pressure Spike Dampening

Maureen McGuinness and Rob Brown
Paterson & Cooke Canada Inc.

Craig Barich
Tahoe Resources Inc.

ABSTRACT

Expanding the existing pastefill distribution system to the East Zone of Minera San Rafael's Escobal Mine posed a challenge due to long pumping distances and high discharge elevations. Several options were considered for delivering pastefill to the new area which included procuring a replacement higher pressure surface pump, installing an underground booster pump station and increasing the efficiency of existing site infrastructure with a pressure damper and admixtures. Hydraulic modelling inputs were refined after a series of field trials and the final decision was made to use admixtures and to install a pressure dampener to reduce peak pressure spikes and increase the average operating pressures with existing site infrastructure. This paper outlines the steps taken to reach this decision including testing, modeling and an economic evaluation. It presents how the pressure dampener and admixtures are used to extend pumping distances while maintaining targeted paste quality.

INTRODUCTION

The Escobal Mine is a 4500 tonne per day underground silver-gold-lead-zinc mine located in the Santa Rosa Department of Guatemala. The Escobal Mine is owned by Tahoe Resources Inc. and operated by Tahoe's wholly owned subsidiary, Minera San Rafael. Cemented paste backfill has been routinely placed in the Central Zone of the Escobal Mine since November 2013. With the anticipated demands of supplying quality paste to the East Zone, the site upgraded its existing infrastructure and commissioned a new paste plant in January 2016. Supplying paste to the Upper East Zone is challenging due to a long reticulation length (845m) and with parts of the orebody higher than the elevation of the paste plant.

Pumping to this location could be achieved using different methods including procuring a higher pressure surface pump, installing an underground booster pump station and/or through the use of admixtures to modify paste rheology. This paper reviews the aforementioned options, field trials, modeling and an economic evaluation to support the decision process.

BACKGROUND

Pressure filtered tailings are supplied from the mill using an 850 m enclosed belt conveyor to the paste plant's live bottom feeder. Water is then added to the tailings at the first paddle-mixer where it then discharged into one of two holding hoppers. The tailings-water mixture is transferred into a second (batch) paddle-mixer for cement addition. The paste backfill is discharged through one of two 80 Bar positive displacement (PD) pumps to either the Central- or East Zone reticulation lines.

All paste boreholes are steel cased whenever possible. Permanent horizontal reticulations lines are steel pipe, with HDPE pipe used for short term infrastructure where pressures allow.

Escobal's mining method is an overhand primary-secondary sequence separated by crown pillar levels. The target paste recipe is 70%m solids with a static yield stress (YS) of approximately 350 Pa. Varying binder dosages between 4 to 12% are used to accommodate different strength requirements.

Figure 1 is a long section of the life of mine reserve at Escobal. To facilitate plans of increased East Zone haulage in coming years, the site needs to be able to readily backfill all stopes to achieve 100% ore extraction.

The area of interest for this paper is the part of the Upper East Zone located above the 1500 elevation within the East Zone orebody (Figure 1). Modelling suggests once the paste is pumped to the 1500 Level, stopes located below this level (i.e., within the Lower East Zone) will be able to be filled using a traditional gravity system.

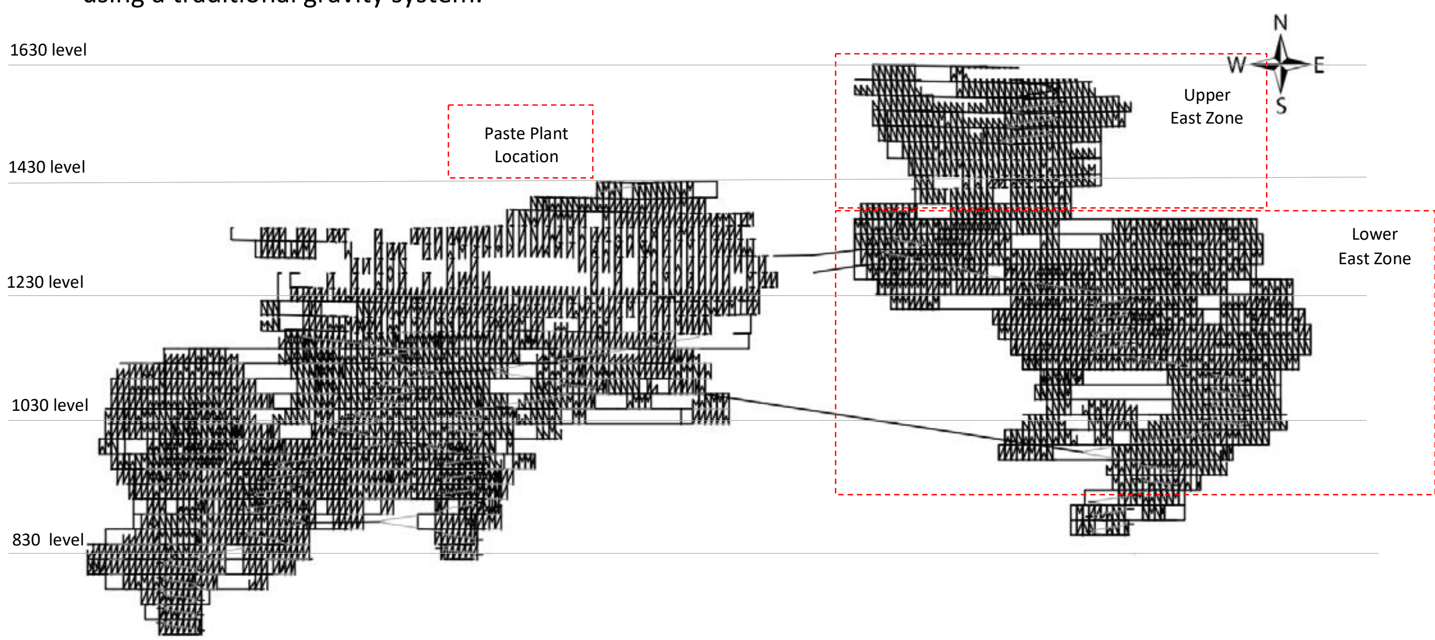

Figure 1. Escobal life of mine reserve

FIELD TRIALS

The first stage of the analysis was to verify the ability of the existing pumping system to supply paste to the Upper East Zone. A hydraulic model was developed to calculate line pressures throughout the distribution pipeline. Friction loss is a key modeling parameter which can be estimated from first principles or measured.

Field trials were conducted in May 2016 to measure line pressures and friction losses under operating conditions. Instrumentation was setup to measure pressure loss in the reticulation system as shown in Figure 2. This data was used in hydraulic modeling to predict if paste could be delivered to the Upper East Zone with current infrastructure. With the current paste recipe design, results indicated that this was not possible and a booster pump would be required.

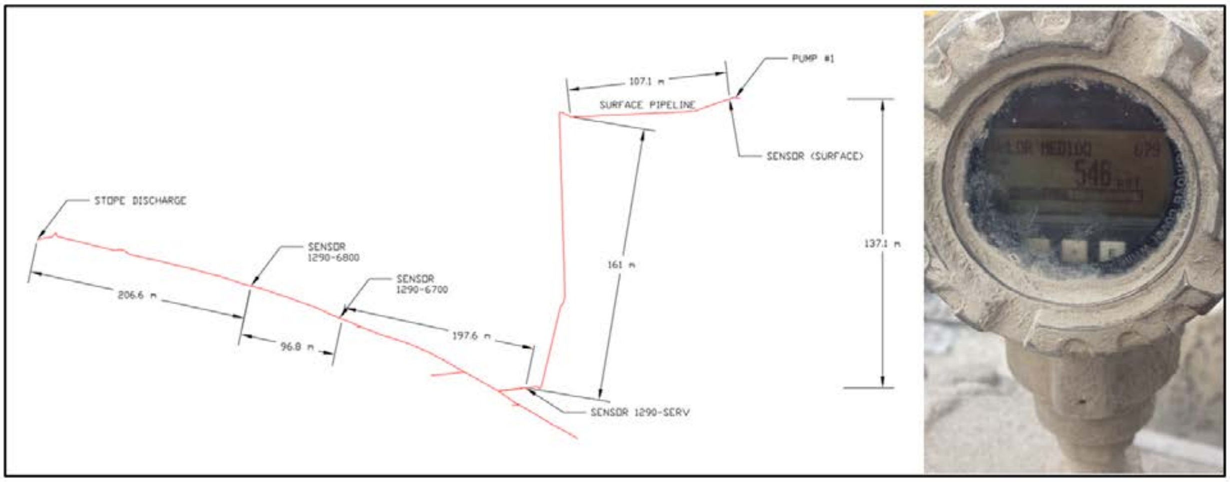

Figure 2. Reticulation schematic and underground data logging locations at Escobal

TRADE-OFF

A trade-off evaluation was conducted between the underground booster pump against other alternatives to increase pumping energy into the system. Using only the current pastefill infrastructure and operational parameters, hydraulic modeling results indicated paste would have only been able to be supplied to approximately 39% of the East Zone reserve. Table 1 summarizes the alternative solutions considered to increase the percentage of backfill placement while maintaining paste quality. The three alternative solutions are discussed in the sections below.

Table 1. Summary of alternative solutions

Alternative Solution	Comment	Cost Scale
New High Pressure (150 Bar) Positive Displacement Pump	Replace Surface Pump and Line Couplings	High Capital Medium Operating
Underground Booster Pump Station	Automated Paste Booster Station to synchronize with Surface Paste Plant	High Capital High Operating
Use of Admixtures to reduce Paste Rheology	Increase pumping envelope with existing infrastructure	Low Capital Medium Operating

New Pump from Surface

The paste plant is equipped with two 80 Bar positive displacement (PD) pumps – one in operation, one stand-by. As the pumps are independent, paste could not be pumped to the top four levels of the Upper East Zone. To be able to achieve this, operating pressures needed to increase to 150 Bar. Procuring a new high pressure pump and upgrading pipe reticulation was not favored due to the time delay and major capital investment for the site. Another alternative was to retrofit and synchronize both existing pumps in series to achieve the required operating pressure. Due to the plant configuration and capital investment, the retrofit was not deemed a long-term sustainable solution due to:

- higher operating costs for the continuous operation of both pumps;
- reticulation bracing and coupling upgrades; and
- operational contingency in the event of a pump failure.

Booster Pump

The design of the underground booster pump station was performed to a feasibility level and an initial budget estimate established. In this scenario, paste backfill is produced on surface and is pumped to the booster pump via the 1386 Ramp. The booster pump would be of the same type and size as those used in the paste backfill plant to benefit from synergies with spare parts and previous maintenance experience.

A new pipeline from surface would be installed which would supply the East Zone via the 1386 Ramp. The booster pump station would be installed just off this drift near 1450 Level access to pump the paste through the upper East Zone piping system.

The pump would be decoupled from the surface pump system. Paste would leave the booster station via a secondary pipeline to the East Zone distribution system. The pastefill plant could supply paste to either the existing main piping system or the new East Zone, but only one system would be used at a time. A long section of the mine showing the existing and proposed East Zone paste backfill distribution systems is provided in Figure 3.

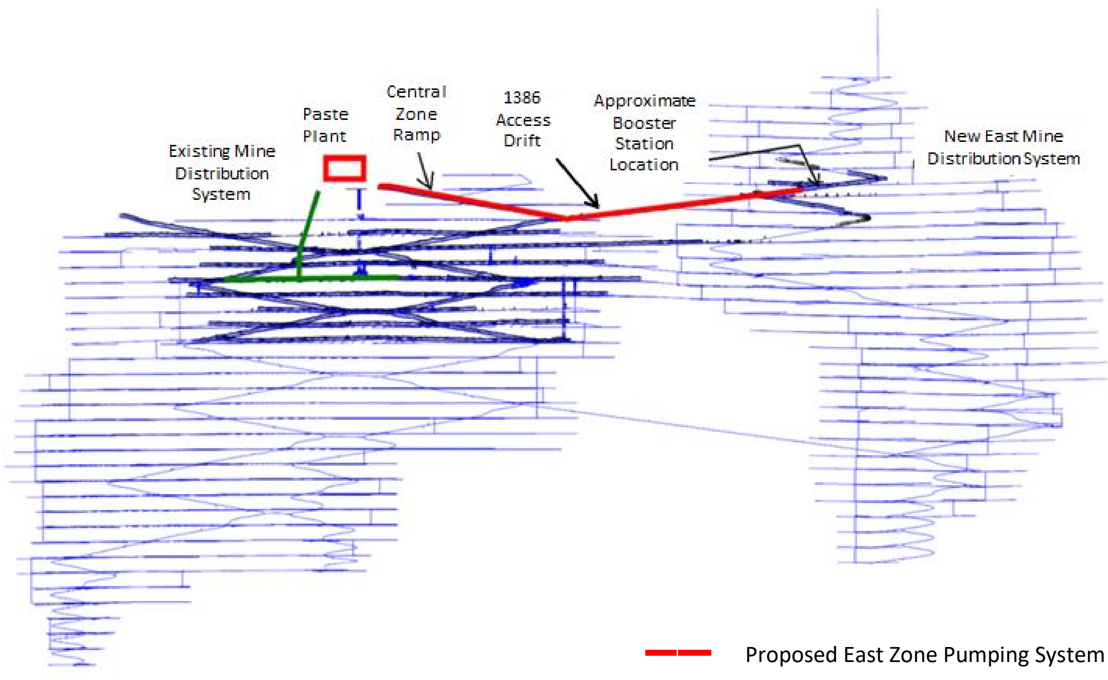

Figure 3. Existing and proposed paste distribution systems

The booster pump system comprises of three main components:

- the pump and associated equipment;
- material containment from pipeline drainage; and the
- breakthrough point of the borehole on level 1450.

The booster pump station design is illustrated in Figure 4. In addition, two flow releases are accommodated into the design for the surface pipeline and the Upper East Zone borehole drainage. Both pipelines must be emptied of water after every planned shutdown, and more importantly emptied of paste and water during emergency shutdowns. Discharge is captured in drive-in sumps where the water will be pumped to the mine water system and the solids removed by scoop to a disposal location.

Location selection

Hydraulic analysis was performed for multiple pump locations along the East Zone ramp to determine the optimum location for the booster pump. A key consideration for choosing this location was to ensure the surface pump operates at its maximum capacity. This reduces the capacity required by the booster pump to deliver paste to the farthest East Zone extents, and is achieved by locating the booster pump as far up the East Zone ramp as possible. If it were located lower, it increases effort required by the booster and does not fully utilize the capacity of the surface pump.

Hydraulics

1625 Level is the highest production level in the mine and inherently is the most challenging in terms of pumping requirements. Pumping pressure required from the booster to fill 1625 Level exceeds the pump's maximum pressure rating at the nominal slump. Decreasing the mass % solids (thereby increasing the slump, lowering the yield stress) will reduce the pressure required to pump the pastefill up to the level, but increases the amount of binder required to achieve the target paste strengths. The maximum yield stress that can be delivered to the 1625 Level stopes is 205 Pa corresponding to a solids concentration of 71.5 %m. The hydraulic grade line plot for the booster pump option is provided in Figure 4.

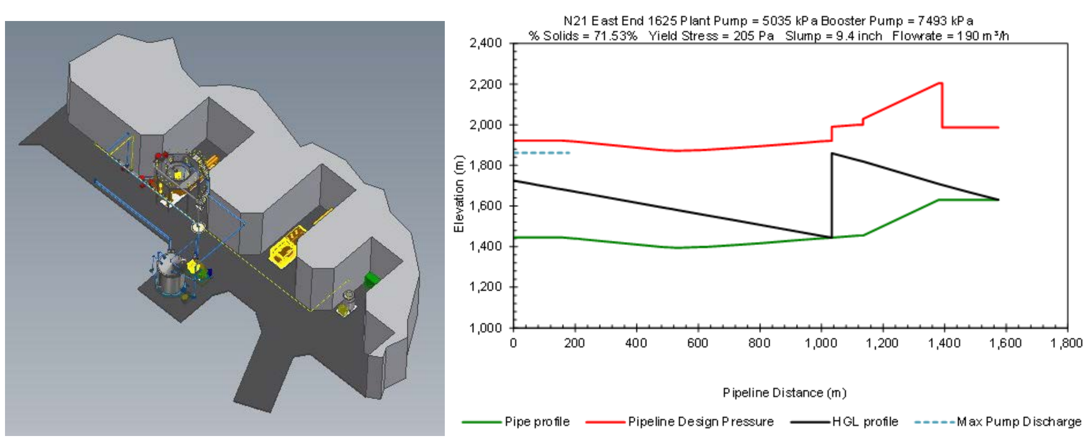

Figure 4. Underground booster pump station layout for Escobal and hydraulic grade line for 1625 level

Responding to the variable hydraulic requirements for varying reticulation routes, paste recipes will vary in mass solids concentration to deliver pastefill to far-reaching levels without exceeding the surface and booster pump maximum operating pressures. As paste is delivered to higher levels, the mass % solids value has to decrease to maintain a delivery pressure below the maximum pump pressure. This reduction in % solids results in an increase of water which reduces the effectiveness of the binder, and negatively effects paste strength.

Admixture Use

The necessity to modify paste rheology provided an opportunity to use admixtures to increase flowability without compromising strength.

Laboratory tests conducted by BASF indicated that admixtures could reduce paste rheology and allow paste to be placed at a higher solids concentration. Three combinations of BASF's MF 506 and MM33 were used during the April 2016 trial on-site. Their corresponding line pressures were recorded, while solids concentration and flowrate were held constant at 68%m and 209 m^3/h respectively. Two pressure gauges were installed near the pipe discharge location to calculate the pressure losses in the system. The average ASTM slump of paste with no admixture was 8 inches, whereas the average ASTM slump increased to 10 inches with MF506 and MM33.

These results were used to calibrate the hydraulic model. Line pressures were calculated based on the paste properties (yield stress, % solids, viscosity, tonnage) and the reticulation configuration. The model was customised to reflect Escobal's reticulation design, % solids and tonnage used during the trial. Viscosity relationship used in the model was conservatively estimated at 0.6 Pa·s, as it could not be measured during the test, nor had it been measured in the laboratory work. The yield stress for the trial was determined by varying the yield stress input in the model until the pressure losses calculated in the model equalled the pressure losses measured in the field. The yield stresses for the three admixtures were calculated and are summarised in Table 1 along with the corresponding measured pressure losses and ASTM slumps.

Table 1. In-situ pressure monitoring data

	Unit	April 6, Control	April 7, Trial 1	April 7, Trial 2	April 7, Trial 3
Mass Concentration	%m	68	68	68	68
Flowrate	m3/h	203	209	209	209
BASF MF506 Dosage	mL/m3	0	1800	1200	0
BASF MF33 Dosage	mL/m3	0	300	300	300
Slump - Surface	Inch	8.5	10	10	9.5
Slump - Underground	Inch	8.75	10	10	not taken
Pressure Loss Average	kPa/m	6.05*	5.76	3.53	5.38
YS Calculated from modelling	Pa	295	279	158	258

*estimated

Unfortunately, due to logistical issues, line pressures during the control trial run with paste at 68% solids without admixture could not be measured, however, ASTM slumps taken measured 8.5 inches. Based on manual recording of the trial, the pressure losses for the paste without any admixture were estimated at 6.0 kPa/m.

Together with the rheology data from BASF's laboratory, pressure monitoring data collected during the trial and the on-site rheology work performed by Escobal, rheology curves were developed and illustrate the influence of admixture and likely dosages required to be used in the operation. The relationship with ASTM slump was also established as a method of quality control during operation as shown in Table 2.

Table 2. Calculated mass % solids and yield stress values

No Admixture			With Admixture		
Slump	Mass % solids	Yield Stress (Pa)	Slump	Mass % solids	Yield Stress (Pa)
7 inch	69.0	425	7 inch	72.0	570
8 inch	68.0	330	8 inch	70.7	376
9 inch	67.3	275	9 inch	69.3	246
10 inch	66.4	220	10 inch	68.0	160

Pumping Envelope

The new rheology relationships were used to model friction loss through the underground reticulation system. In order to create paste pumping envelopes, each yield stress was related to a mass % solids and slump.

Each envelop was created by determining the distance along each level at which the surface pump reached its maximum operating pressure at each concentration. Figure 6 and Figure 5 illustrate pumping envelopes for paste without and with admixture.

Modeling results indicate paste with admixture can be supplied to the extremities of the East Zone which was previously not possible without a unacceptably high water:cement ratio. A low yield stress material is still needed to reach these extremities but with the addition of admixture, paste of similar slumps and yield stresses can be delivered at lower water:cement ratio which favors strength gain.

Pump Dampener

During the pumping trials it was seen that the pump was operationally constrained due to the peak pressure spikes created on each stroke of the piston pump. To maintain pumping pressures below alarm thresholds, the actual average operating pressure was lower to keep the peak pressures within the acceptable operating range. From this observation, it was determined that overall capacity the pump could be used more effectively if these peaks could be lowered and thereby increasing the overall average operating pressure.

A dampener reduces the pressure peaks by reducing the pressure dips in the line during the piston switch overs. Figure 7 shows the decrease in pressure between strokes when the HMC-S valve and dampener is installed.

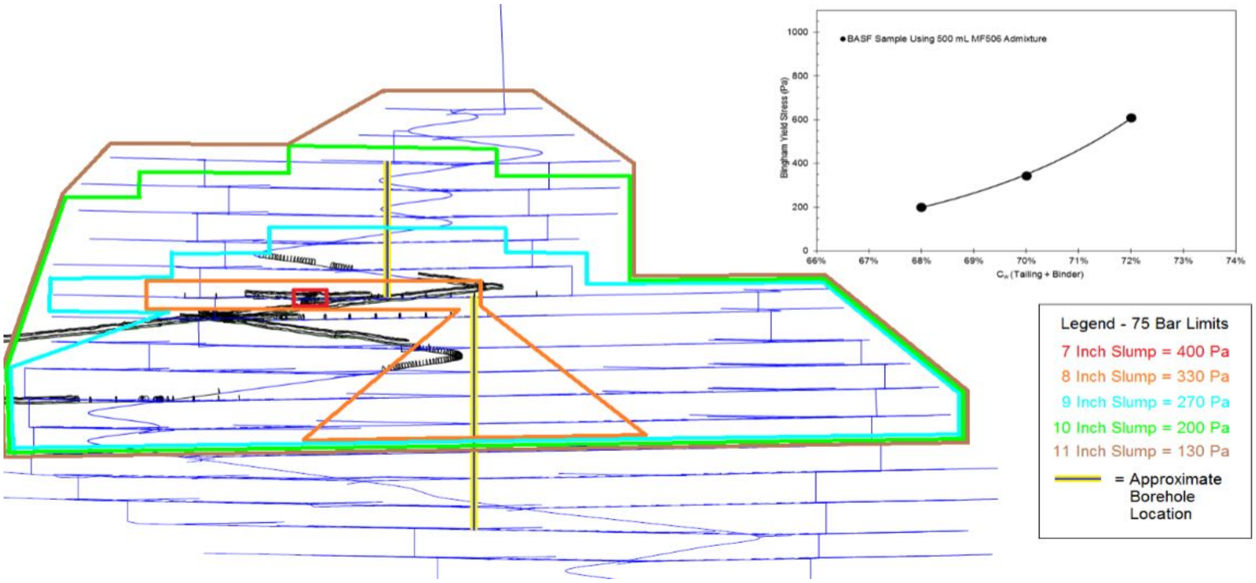

Figure 5. Pumping envelopes for Upper East Zone - with admixture

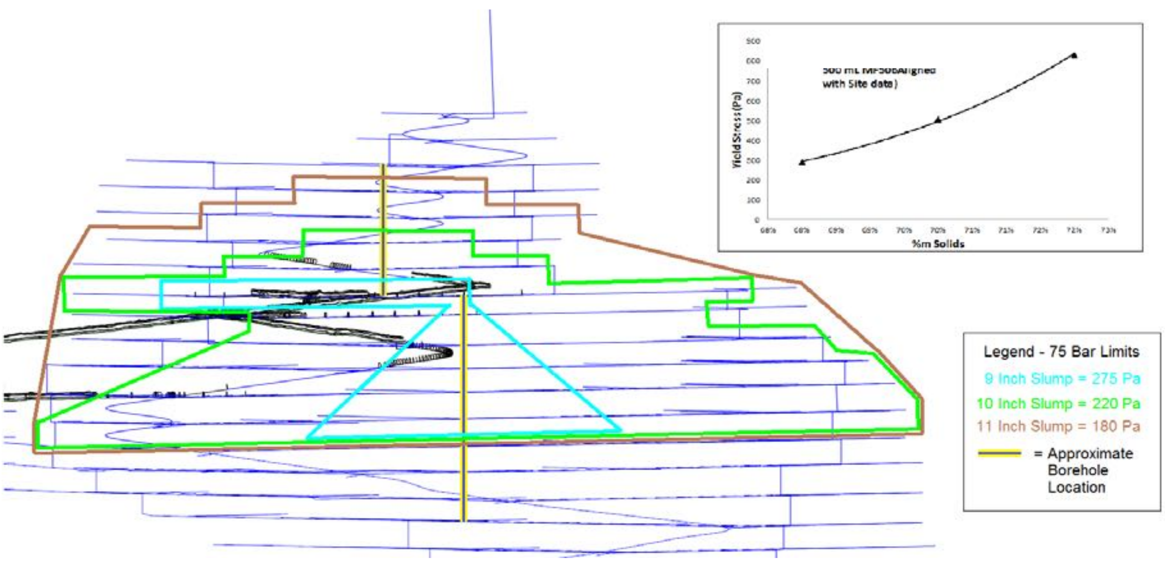

Figure 6. Pumping envelopes for Upper East Zone - no admixture

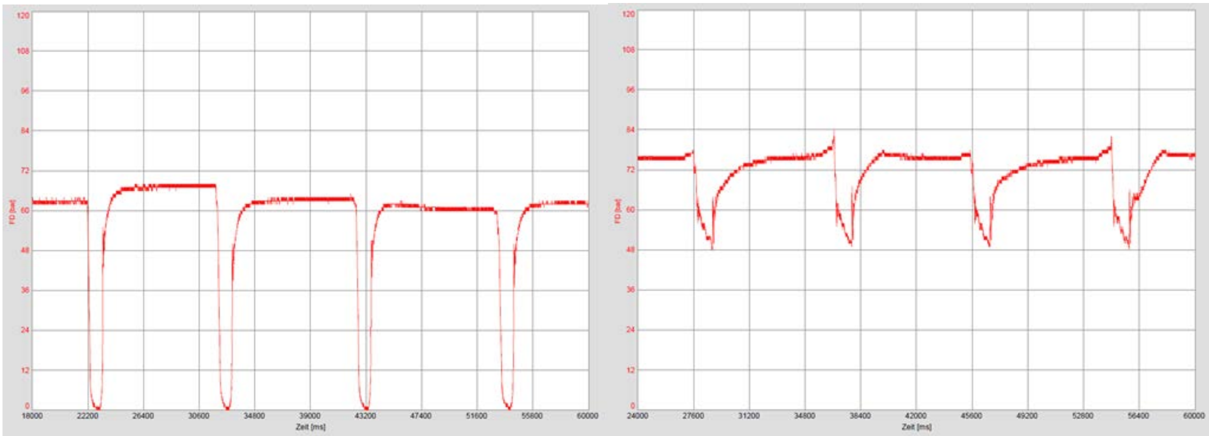

Figure Provided by Putzmeister

Figure 7. Schematic of pressure dip during piston switch over; left – without dampener, right – with dampener

Recent installation at another site showed the effect of a dampener on a similar pump system to that used at Escobal. The magnitude of pressure fluctuations in the line was reduced by 6 times – a change of over 1500 kPa (225 psi). With this information, it was conservative to assume a 500 kPa (73 psi) increase in average operating pressure capability for the Escobal system is achievable if a dampener was installed. The extra pressure capacity allows thicker paste to be sent to the extremities of the upper levels of the East zone, improving the water:cement ratio thus reducing the binder requirements.

ECONOMIC EVALUATION

The final step was to evaluate the viability of the Hydraulic Pulsation Dampening (HPD) system and use of admixtures compared to the booster pump station option. An economic evaluation, conducted internally by Escobal, compares capital expenditure, operating costs and ore reserves in the Upper East Zone.

Cost Model

Rheology and solids concentration can be linked to a monetary cost as they effect the binder requirements for producing a target paste strength. Rheology modeling results provided an estimation of achievable solids concentration, whereby equivalent cement dosages could be calculated and captured in the evaluation. A regression analysis was conducted for Unconfined Compressive Strength (UCS) to determine strength sensitivity of varying binder addition rates and water:cement ratios. Output from this analysis included the following relationships:

- percentage increase in strength (kPa) per unit increase in % solids; and
- percentage increase in strength (kPa) per unit increase in cement addition rate.

The paste recipe designs to achieve 100% fill placement using the HPD and admixture option were modelled with the following assumptions:

- Lower East Zone placed at an average 66% solids with a 10 inch slump (220 Pa YS) using a 6.6% binder.

- Upper East Zone placed at an average 68% solids with a 10 inch slump (160 Pa YS) using a 6.0% binder rate with admixture.

The paste recipe design requirements to achieve 100% fill placement using the Booster Pump Station in both Lower and Upper East Zone was:

- paste placed at an average of 68% solids, 8 inch slump (349 Pa YS) using a 5.8% binder addition.

The evaluation also considers the following:

- cost variance on underground and surface tailing disposal rates;
- operating costs for both the HPD and Booster Pump Station. Operating costs for the HPD was estimated to be 19% of the proposed Booster Station;
- admixture dosage rates were determined from the on-site trial in February 2016;
- target paste design strength is 300 KPa representing a typical backfill scenario.

Capital expenditure for the Booster Pump Station is significant, requiring dedicated underground infrastructure and systems. In contrast, the HPD is relatively simple and can be partially absorbed into the existing infrastructure for approximately 10% of the cost.

Results

Using the HPD and admixtures increases the unit cost of pastefill by 1 to 11% per m^3. Figure 8 illustrates the relative cost variation and forecast paste tonnes for the East Zone reserve. The highest unit cost will occur at an 11% premium over the booster station operating costs option as ore demand reaches its peak from the Upper East Zone in 2025.

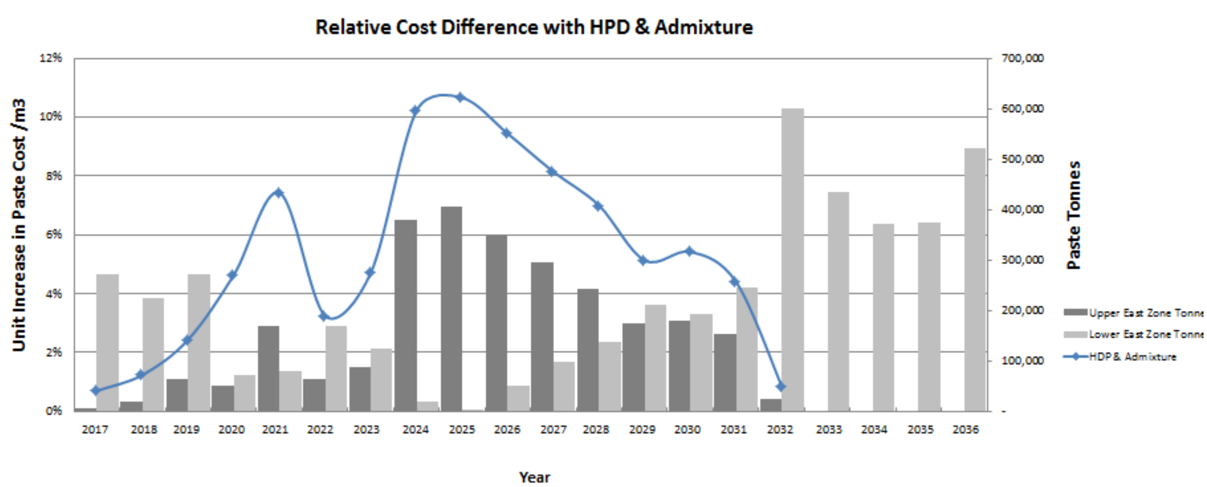

Figure 8. Cost evaluation using the HPD & admixtures

The variation in cost is driven by the following factors:

- additional cost for the use of admixtures;
- the ratio of paste being delivered between to the Lower- or Upper East Zone (i.e., paste delivered to Lower East Zone does not have admixture); and
- increased cement rates due to higher water:cement ratio required to meet target strengths.

The evaluation showed that the higher operating costs using admixture in the Upper East Zones are offset by the savings in CAPEX associated with the booster pump. The payback period is 3.4 years with an internal rate of return of 40%.

CONCLUSION

Through the use of on-site data and proven hydraulic modeling, a desktop comparison between three options to extend the paste delivery envelope at Escobal was possible.

The brute force method of adding pumping power was capital intensive and not conducive to the schedule. The addition of admixtures to modify the rheology, coupled with an investment in a new dampening system, allowed the mine to handle the challenge through incremental increases in the backfill operating costs. The decision making process was strategic and logical and followed a series of due diligence through to completion.

In this case, the mine was able to avoid interruption to their operation, shifted capital to operating cost in a way that still provided a favorable return, and got more out of their existing pump and pipeline infrastructure.