The Garpenberg Paste Backfill Reticulation System—A Case Study

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ABSTRACT

The Garpenberg Mine in Sweden is owned and operated by Boliden, producing lead and zinc concentrate. The mine has been operated by Boliden since 1953, and has recently (2014) undertaken a major operational and production upgrade with the construction of a new processing plant operating at 2.5 Mtpa of ore production. The revitalisation being driven primarily by the discovery of increased mineral reserves and resources offering a production life past 2030.

A backfill system has been operating at the mine since 2007, producing a paste backfill from de-slimed mill tailings. Between 2015 and 2016 Boliden, with support from Paterson & Cooke's Backfill Group undertook a program of work to improve the operational performance of the system, focusing on increasing system availability and throughput, as well as enabling reticulation into the new Kvanberget ore body.

This paper is presented as a case study to describe an approach to overcome commonly encountered paste reticulation system problems, notably expansion to new mining areas, system availability and excessive system wear. Specifically, the case study describes how, through the introduction of diversion valving, level loops and hydraulic modelling, the system availability has been increased. The hydraulic modelling including completion of a rheological loop testing to better quantify the paste characteristics so that, through hydraulic modelling the consistency of the backfill could be adapted to ensure full flow operating conditions, accounting for inclusion of the new level loops.

INTRODUCTION

Primary ore extraction at Garpenberg is by long hole open stoping with paste backfill in and overhand sequence. The backfill is consequently required to provide stable vertical exposure faces as well as a stable working floor.

The paste backfill is developed from live mill tailings produced by the new lead / zinc concentrator located adjacent to the backfill plant. The tailings are first cycloned to remove the ultra-fines which results in improved dewatering and higher ultimate backfill strength. The cyclone underflow then reports to a high density thickener producing a nominal 40 %m underflow material before being pumped to a pair of vacuum disk filters. The filtration rate is such that the current backfill plant throughput can be maintained by a single filter with the second installed for potential future production increases. The filter cake is then transferred via an inclined conveyor to the mixing area. A plenary batch mixer receives pre-weighed feeds of the dewatered tailings, cement, slag and water, before discharging each batch to a paste hopper above one of two hydraulic piston pumps.

Within the existing paste plant system, the batch mixer represents the current production bottleneck which caps the throughout at approximately 60 m^3/hr. Future plans may include replacement of the mixer with a continuous system to further increase throughput.

The discovery of the Kvarnberget orebody in 2009 presented the mine with a new lease on life and an opportunity to increase the overall mine production rate. The backfill system has similarly had to respond to this increasing demand, and notwithstanding the current production limitation of the mixer, Boliden has looked to maximise the availability and utilisation of the existing backfill system. It is this demand for increased annual throughput and utilisation that has driven the investment in the reticulation system described within this case study. Key to improving the availability of the underground reticulation system has been:

- Reduced downtime associated with rerouting of backfill pipelines with the installation of diversion valves;
- Adoption of continuous filling of stopes with the introduction of suitable instrumentation and system safeguarding; and
- Reduction in maintenance and wear-related downtime by improvement in the reticulation system stability and elimination of free-fall.

Figure 1 schematically illustrates the current underground reticulation system.

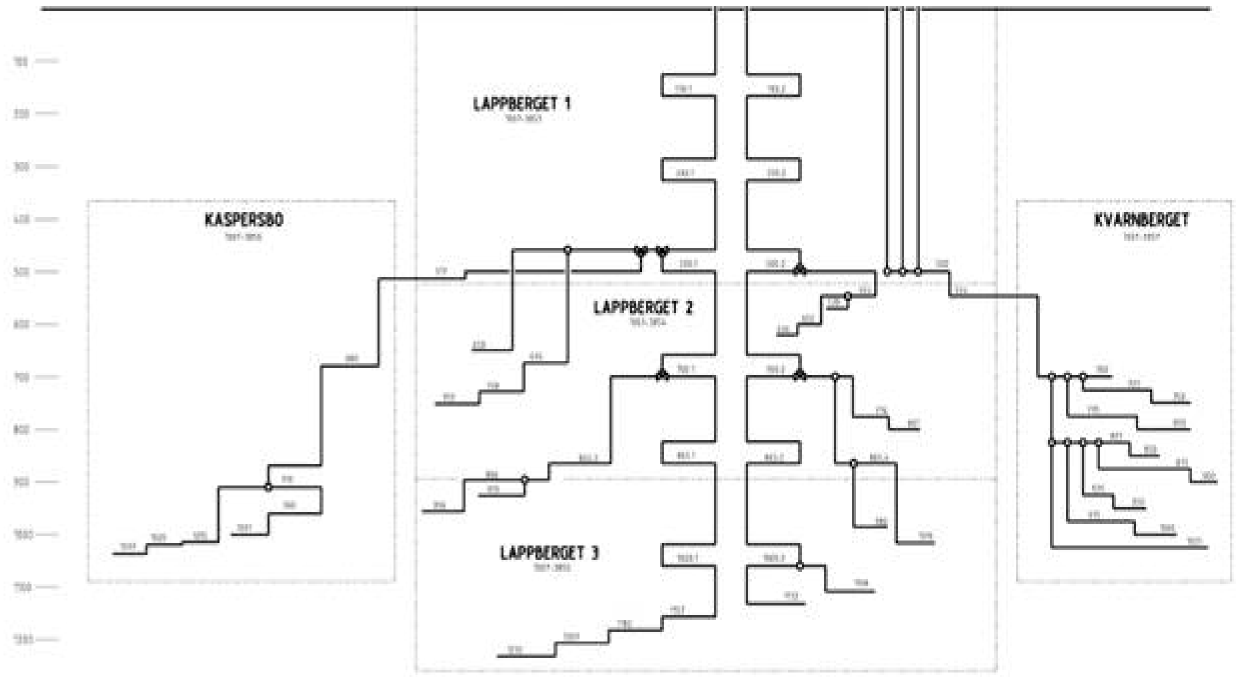

Figure 1. Schematic of Garpenberg Mine underground reticulation system

Two primary boreholes are located close to the existing backfill plant and provide reticulation of paste into Kaspersbo and Lappberget. Reticulation to the Kvarnberget ore body is via three new near vertical boreholes located remotely from the paste plant, however provision is included (although not shown) for a connection between the two systems on the 500 Level.

PIPELINE DIVERSION

Two types of diversion valves are installed within the system, namely

- A Putzmeister hydraulically actuated swing tube valve; and
- Multiple electrically actuated Victaulic diversion valves.

On the surface, the Putzmeister valve is installed immediately downstream of the two paste pumps and was originally installed with the pumps, enabling either pump to discharge into one of the two original borehole systems. This avoids the downtime associated with manual relocation of the piping. Further to the system expansion to Kvarnberget, and installation of the flow loop (described further below) a need was identified for an additional diversion arrangement on surface and this has been achieved with the installation of a Victaulic diversion valve. This valving arrangement is illustrated in Figure 2 below.

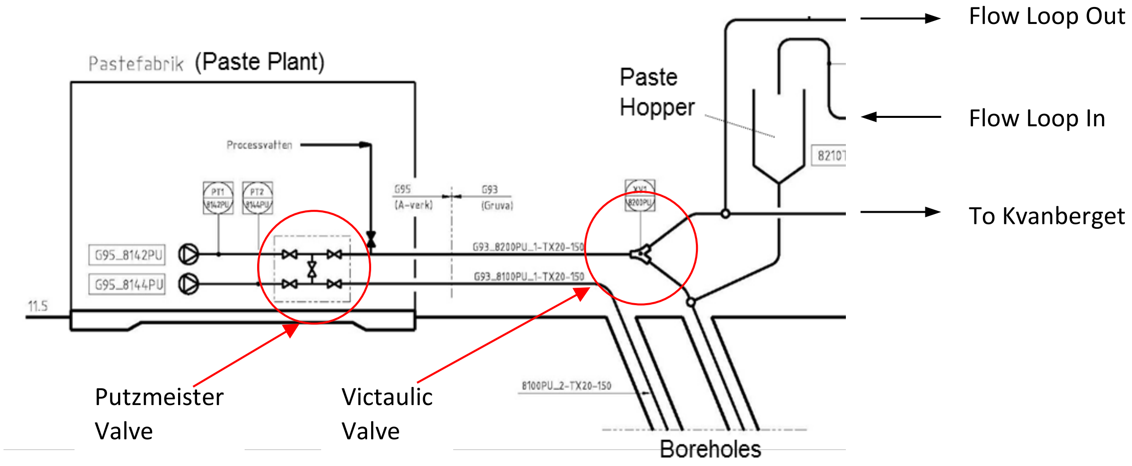

Figure 2. Surface diversion valving

This arrangement enables the plant operator to control the discharge of either pump to either of the three borehole systems. Selection of operating through the flow loop remains manual given the reduced frequency of this selection.

Additional Victaulic diversion valves are installed on the 500 and 700 levels to enable further dictation of the final discharge location. A typical installation of these valves is shown in Figure 3 below from the 500 Level. The valves are installed in an elevated position and can be operated locally or by the operator in the surface plant. The complete installation on the 500 Level is shown in Figure 4 below.

Figure 3. Diversion valve installation on 500 level

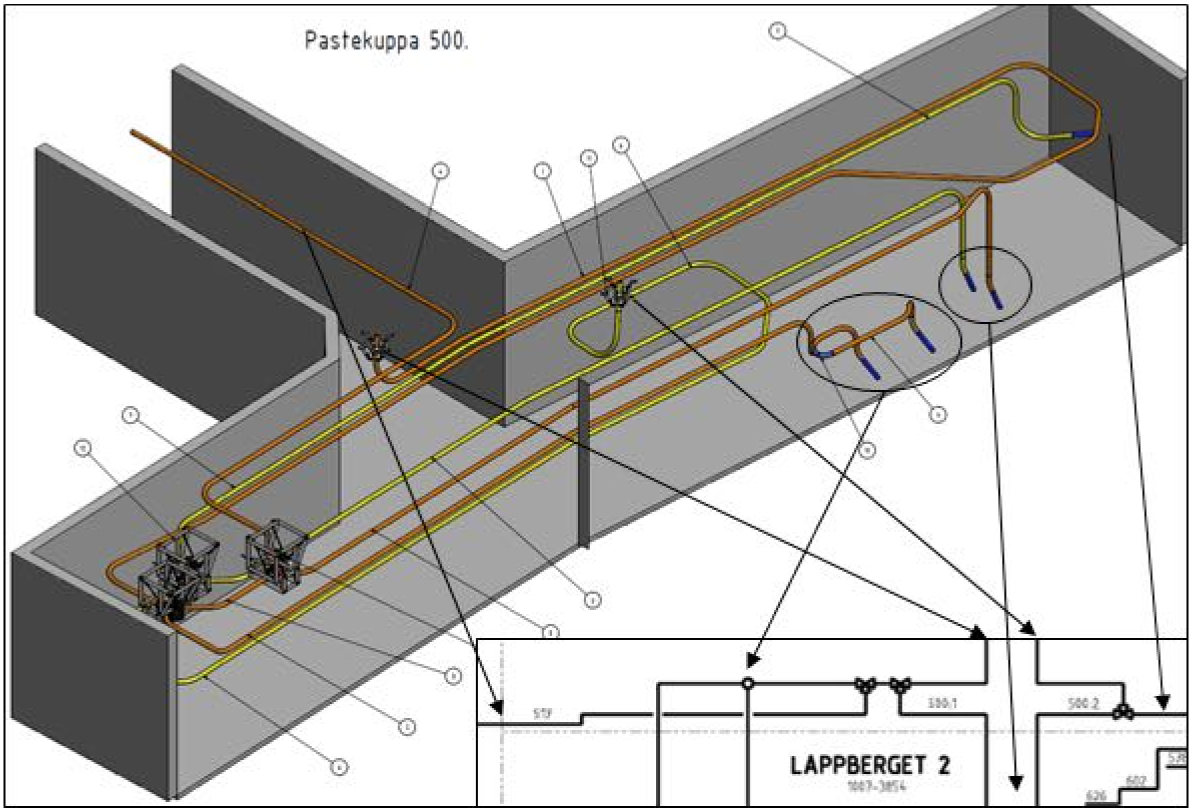

Figure 4. Level 500 diversion valve and loop installation

The inclusion of these valves has notably reduced the time required to achieve underground piping changes, enabling the underground crew to focus on the installation of local piping at each stope, thus enabling the reticulation lines to subsequent stopes to be completed well in advance, and without any suspension of filling to the active stope.

It is noted that the system does still require flushing before operation of the diversion valves, however with the necessary downstream piping of the new route already in place, the flush and relocation operation can be effected by the plant operator, and thus the downtime is minimised and can be completed with a plant 'suspension' rather than complete shut down and restart.

INSTRUMENTATION

The reticulation system includes a comprehensive array of pressure and video monitoring in addition to the diversion valve control systems.

The pressure monitoring is installed at each level breakthrough and provides the operator with real-time confirmation of the system operation. Pre-set trigger alarms offer an early indication of out of tolerance operation which may be an indication of a process upset, either in the backfill plant or the reticulation system. In the event of a system blockage, interrogation of the pressure data can assist the underground team in identification of the plug location.

Video monitoring is included on all primary level areas, the discharge into the stope and the stope barricade, with the data feeds reporting to the paste backfill plant.

Both the pressure and video monitoring enables Garpenberg to mitigate the risk of operating the backfill system during periods when the mine is evacuated for blasting or for shift changes. Furthermore, the entire backfill control system and the monitoring data is repeated to the main process plant control centre, mean shift changes in the backfill plant can be supported by the process plant crew, ensuring there is no downtime during shift changes on surface either.

LEVEL LOOPS

In tandem with the installation of the underground diversion valves, level loops have been installed, along with updated reticulation modelling. Level loops have been introduced into the main borehole system feeding the Lappberget and Kaspersbo ore bodies as illustrated in Figure 4. The prevalence of free fall in the system had been identified and consequently there was a need to dissipate the energy to achieve a full flow condition in the borehole system. Level loops were therefore developed on the 180, 330, 500, 700, 850 and 1050 Levels to the extent possible as reported in Table 1.

Table 1. Level loop installations

Level	**Borehole System 1**	**Borehole System #2**
180	146 m	146 m
330	75 m	89 m
500	126 m	85 m
700	75 m	60 m
850 / 1050	90 m	45 m

RHEOLOGY

In parallel with the installation of the level loops an investigation was undertaken to determine the necessary changes required to the backfill consistency to ensure the system would run in a full condition. Hydraulic modelling of the system, inclusive of the loops, confirmed that free-fall and slack flow would still occur with the previously developed backfill consistency. Figure 5 illustrates this.

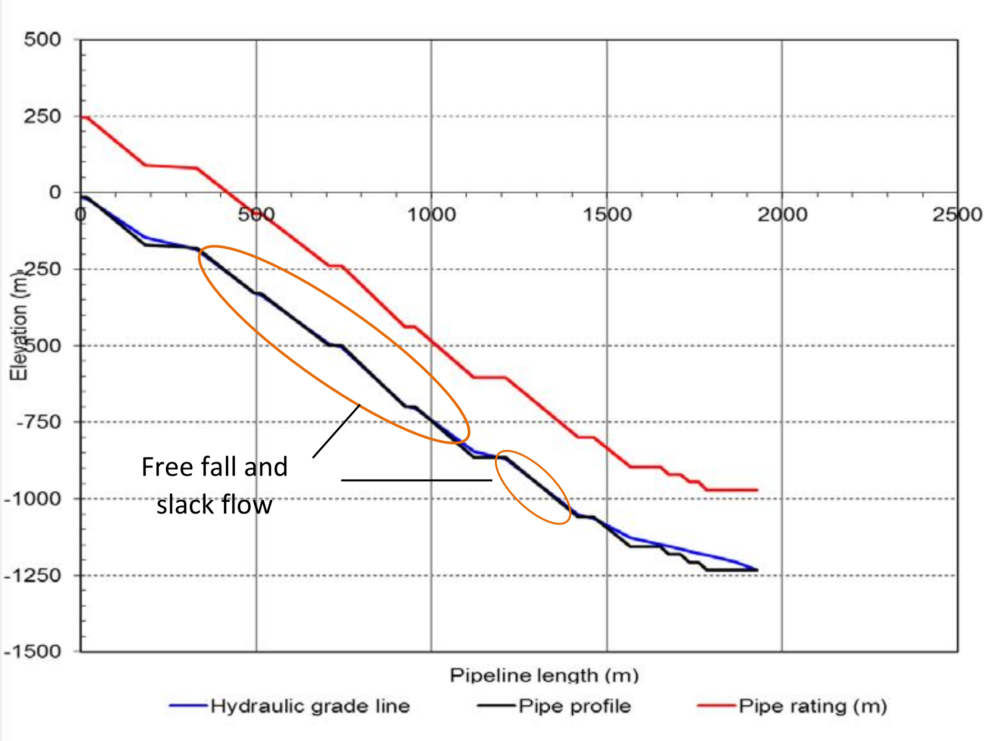

Figure 5. Hydraulic grade line indicating free fall and slack flow

The hydraulic grade line indicates the pressure within the pipeline as metres of head of slurry plotted against the gradient of the pipeline routing. In occasions where the hydraulic grade line collapses onto the pipeline profile, the pipe is not operating fully filled and negative pressure exists in the line. Free-fall would therefore be expected in the boreholes.

In the above example, it can be seen that this occurs through the majority of the boreholes and this was confirmed in reality by the system operating noisily as paste freely cascaded down the boreholes and before striking the filled section of pipe or elbow at the bottom of the borehole. This is also the mechanism by which accelerated pipe wear occurs, the increased velocities in the free fall section lead to greater wear on the pipe. In addition to accelerated wear, a second mechanism of failure occurs whereby a transient event (shockwave) is created when the freefalling paste re-joins the fully filled pipeline, typically at the bottom of the borehole. This shockwave has the effect of increased system fatigue in fittings and instrumentation.

Rheological Loop Testing

In order to alleviate slack flow in the system, the characteristics of the paste at varying binder concentrations needed to be understood. To gather this information, rheological loop testing was undertaken on site. The concept of a rheology loop is to pump a paste of known composition through a known length of piping to evaluate the pressure drop at varying flow rates and consistencies.

The Garpenberg flow loop was developed as a permanent installation, thus enabling future trialling as part of a robust quality control and quality assurance process being implemented. Further, the ability of the loop to receive paste produced during the normal operation of the plant improves the validity of the data obtained and avoids the need to recirculate the same material through the loop, which may lead to variations in material characteristics.

The loop used piping to match the two primary types of piping installed in the underground system, namely:

- 150 mm NB Grade B Steel Pipe; and
- 150 mm NB Grade B Castolin Pipe.

The Castolin piping includes a high wear resistance internal face of TeroMatec® 4666 alloy which has proven successful at Garpenberg.

The paste was pumped through the loop using the existing paste pumps. After passing through the flow loop, the paste discharges into an open-topped hopper which flows freely down a borehole and is discharged into a suitable stope. Figure 6 below illustrates the flow loop and the instrumentation installed on it.

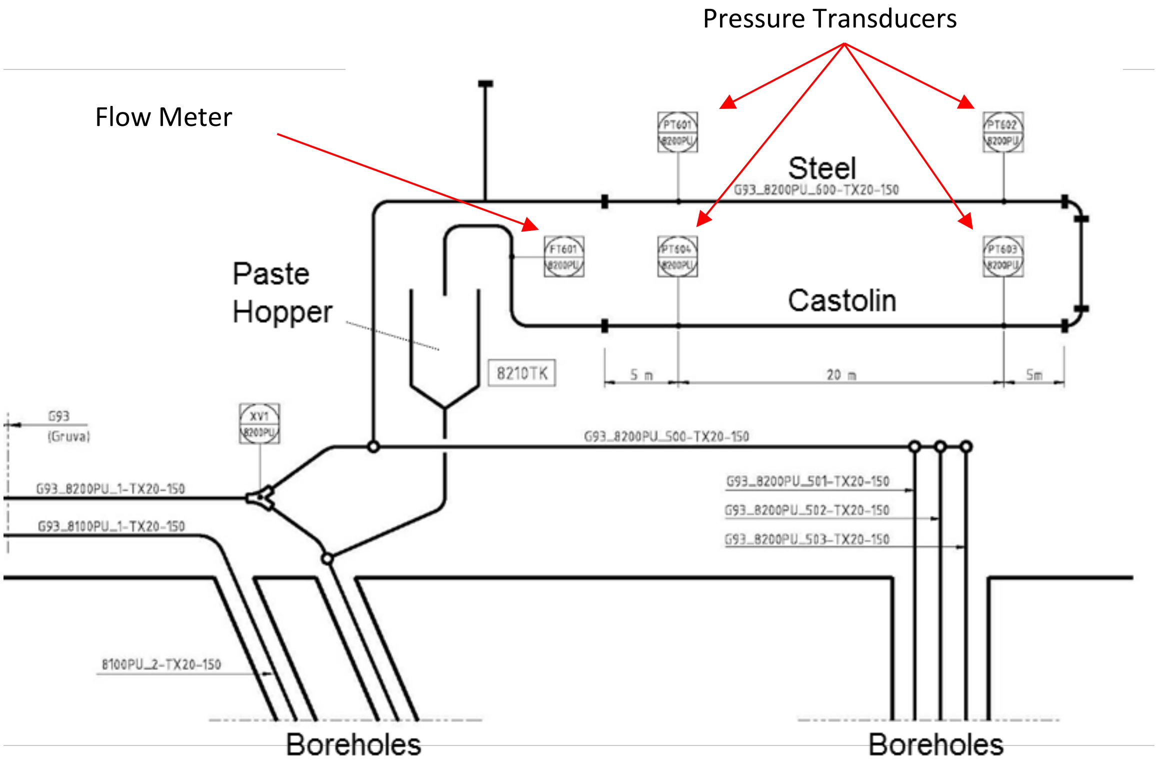

Figure 6. Schematic of the flow loop at Garpenberg

To monitor the pressure in the loop, four Endress and Hauser Cerabar PMP75 S pressure transmitters, rated to 40 MPa were installed and linked to the existing Supervisory Control and Data Acquisition (SCADA) system. The data logging frequency was sufficiently high to enable identification of pressure values attributable to surges from the stroking action of the paste pump, thus differentiating this from “normal” flow conditions. A Krone Optiflux 4000 flowmeter was installed on the vertical leg to the paste hopper to record the quantity of paste flowing through the loop.

Images of the rheology loop test are shown in Figure 7.

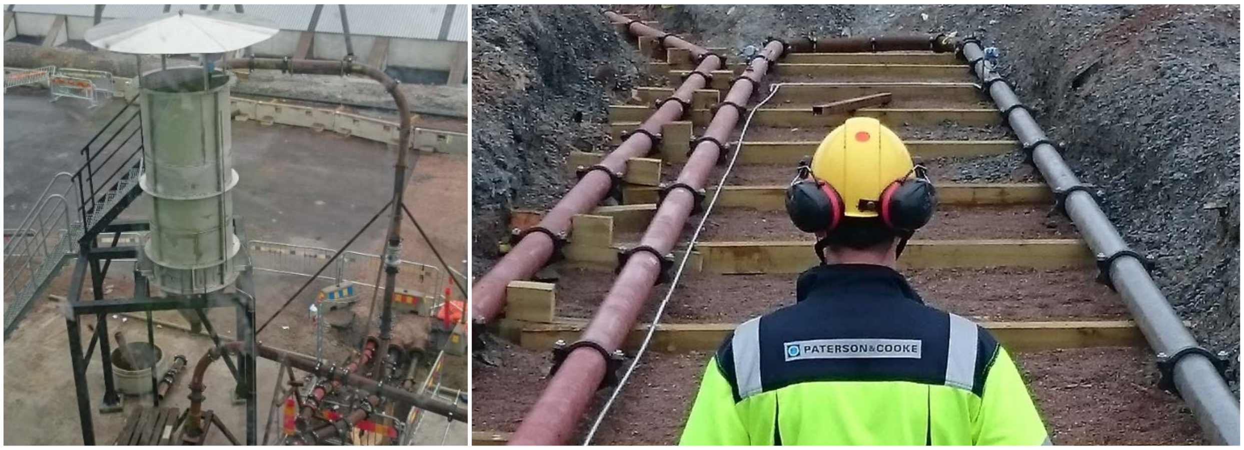

Figure 7. Rheology loop images

Data from the flow loop testing was used to develop relationships between yield stress, viscosity and mass concentration, further to which updated hydraulic modelling could be undertaken. An example of this correlation is given in Figure 8.

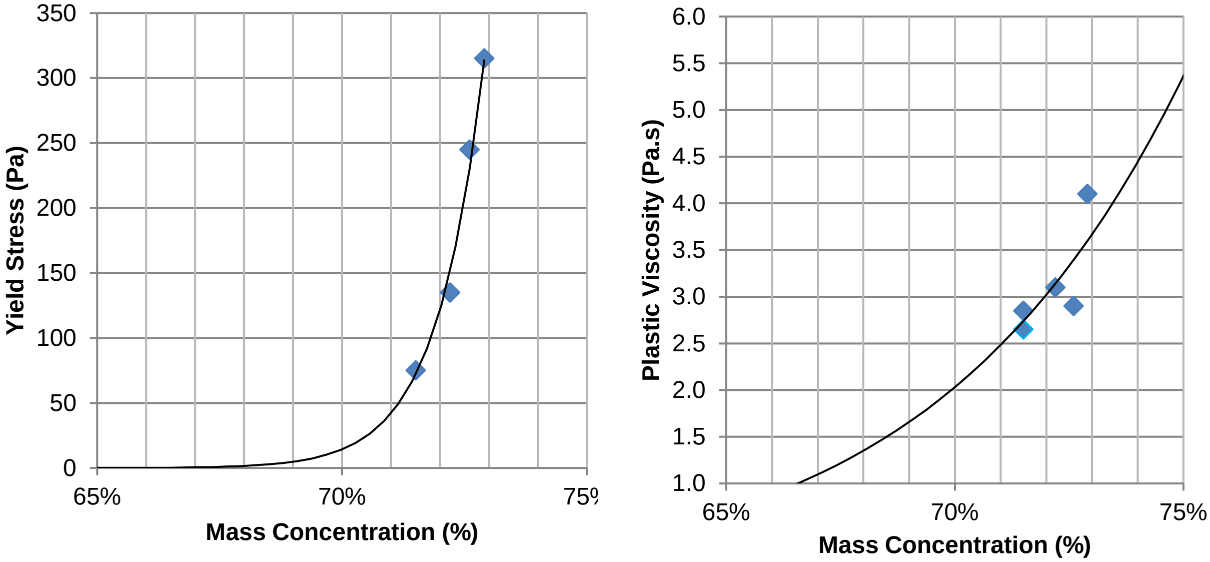

Figure 8. The relationship between mass concentration and yield stress measured in the loop

Rheology Modification

Using the calculated parameters for yield stress and plastic viscosity, the pipeline pressure at loss for a range of paste consistencies was determined.

Given the previously described limitations in the volumetric throughout capacity of the mixer, an increase in pressure loss was not feasible through modification of flow rate. As a consequence, the consistency of the paste, here represented by yield stress, could be varied by changing the solids content of the paste. In so doing it is possible to adjust the consistency of the paste to suit the reticulation to each stope by modelling the system hydraulics based on the derived relationships from the flow loop. Examples of this are provided in Figure 9 for stopes in the Lappberget and Kaspersbo, with the pipeline design parameters shown in Table 2. In both examples, full flow conditions are maintained throughout the reticulation system.

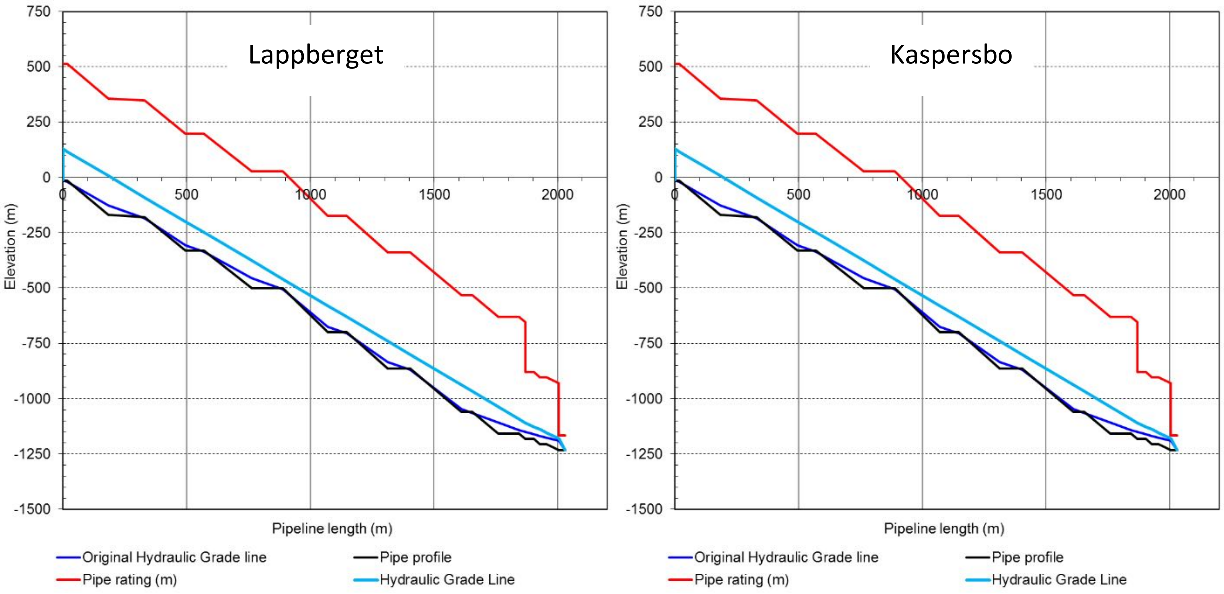

Figure 9. Hydraulic models for stopes in Lappberget and Kaspersbo

Table 2. Pipeline design parameters

Parameter	**Steel Pipe**	**Castolin Pipe**	**Alvenius Pipe**	**HDPE 100 Pipe**
Material	Grade B	Grade B	Alvenius	PE100
OD (m)	0.168	0.168	0.168	0.125
Wall Thickness (m)	0.011	0.008	0.003	0.0114
Lining Thickness (mm)	n/a	3.0	0.5	0
Wear Allowance (mm)	4	4	0.5	2
Pressure rating (MPa) New (B31.3)	15.70	15.80	6.99	1.51
Pressure rating (MPa) Worn (B31.3)	9.98	10.04	5.74	1.22
Location	Boreholes. level and loop piping	New boreholes, elbows	Permanent level piping	Temporary stope piping

The paste plant mixes paste backfill in a batch process controlled by the power draw on the mixer. Therefore, modifying the batch recipe to give differing paste thicknesses can be readily achieved by modification of the power draw process set point. A relationship (Figure 10) was therefore developed between paste mixer power draw and observed yield stress, from which the paste engineer can provide set point targets to the plant operator for each stope. Examples of this are provided in Table 3 below.

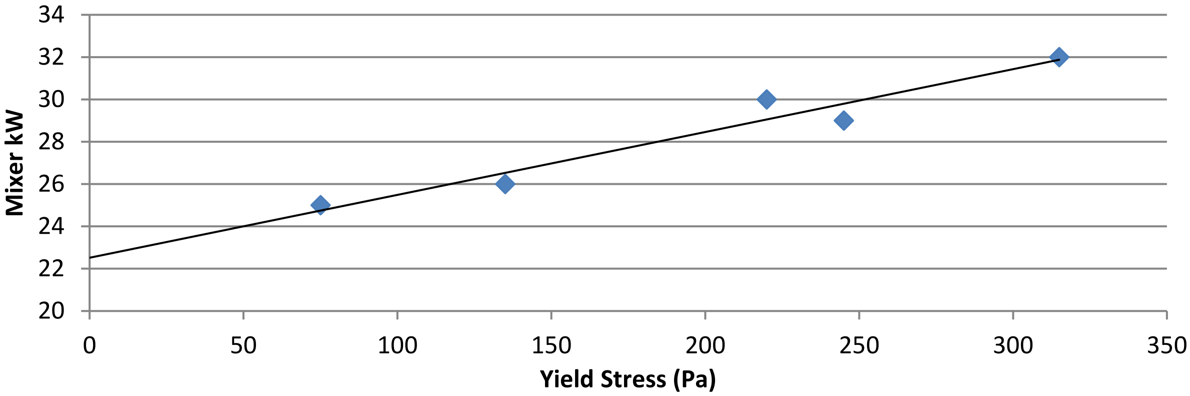

Figure 10. Mixer power draw relationship with yield stress

Table 3. Recommended power draw targets - Lappberget

Stope Level	**Yield Stress (Pa)**	**Pump Pressure (Mpa)**	**Power Draw (kW)**
524	40	2.7	24
752	180	2.6	28
801	90	2.6	25
956	180	2.8	28
1132	180	2.8	28

As can be seen, the yield stress and mixer power draw both vary for each stoping level which results in a near consistent pump discharge pressure. The Garpenberg paste pumps are both rated to 6 Mpa and thus the proposed discharge pressures are well within this capacity.

CONCLUSIONS

The Garpenberg paste backfill system has operated successfully since 2007, however in recent years and in future there has and will continue to be pressure to maximise annual throughput to meet an increasing mining rate. Boliden has therefore invested in improvements in the underground reticulation system to maximise availability and with it, utilisation of its system. As a consequence, the current system utilisation rate at 86.7% (2016 YTD) is high relative to any comparable system type.

The adoption of modern instrumentation and control had minimised avoidable downtime as much as is reasonably possible with the system and mine layout. Furthermore, the efforts to improve the operation of the system, by minimising freefall and slack flow, will further improve the longevity of the infrastructure, reducing unforeseen downtime. The development of rheological models and their use in tailoring the backfill for each stope through adjustments in the mixer power draw set point enables this refinement to be implemented by the operators using the existing paste plant control systems.

It is anticipated that through further flow loop trialling, made possible by the permanent installation of a loop at the paste plant, the correlations between solids content, yield stress and mixer power draw can be further refined, and adjusted as the mineralogy and or processing of the ore changes with time.