Improved Safety and Efficiency Realized by automated diverter valves at Agnico Eagle - A Review of Fosterville Gold Mine

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Summary
Traditional manual approaches to managing backfill systems are being replaced with improved and more efficient methods that are faster and safer. Automated diverter valves are among the technologies being used to effect efficiency and safety gains. Using diverter valves eliminates time-consuming manual operations that require special equipment and put workers in harm's way. A case study that assesses automated diverter valve operation and manual diversion at an Australian mine provides a comparison of functionality, time-savings, and safety advantages inherent to the diverter valve.

Key words: backfill diverter valve, risk reduction, efficiency

Introduction

Many mine owners around the world are using manual backfill processes that rely on experienced workers investing considerable time and effort in risk-prone processes. These methods require significant manhours and are dependent upon having skilled laborers on site and expensive, specialized equipment on hand.

As mine owners employ different means of improving economics, many are using backfill systems to dispose of tailings and enhance ore recovery and are looking for safe and efficient ways to manage the backfill process. At Agnico Eagle Mines Fosterville Gold mine in Victoria, Australia, automated diverter valves were installed at distribution switching points to improve this process, directing paste to the intended stopes without the need for underground crews and additional equipment.

Prior to the adoption of diverter valves, making changes in paste distribution was a manual operation that involved long sweep elbows to be disconnected from the piping network and reconnected to a different downstream pipe. This manual operation was time consuming, when the necessary manpower and/or equipment was not available, resulted in considerable downtime and safety risk. The diverter valves address many of the issues encountered during manual operations. The valves function reliably in a broad temperature range, and valve operation does not require specialized equipment or skills. Because the valves can be operated remotely, they improve safety by reducing the risk of injury by removing people from harm's way.

This paper examines the use of automated diverter valves to replace manual diversion of paste in the Fosterville Gold Mine (FGM) reticulation system. Replacing the manual process with a remotely controlled system of valves resulted in dramatic reduction in safety risks and improved uptime by enabling safe and timely switching of the reticulation route.

Traditional Approaches

Most medium and high grade mining operations use backfill. The backfill is comprised of sand, tailings, aggregate and binders and can be abrasive resulting in wear on the system. Traditionally when maintenance is required in the reticulation system or when backfill is required in a different stope the system is shutdown and manual switching of the piping is needed. Each time this is required, multiple workers and equipment are involved and the resulting downtime is significant. In addition, this manual process introduces safety risks for the workers and takes them from more productive activities.

Introducing Innovation

Victaulic designed the Series 725S and 725T Diverter Valves specifically for use in backfill operations. Providing multidirectional service, the valves eliminate the need for manual manipulation of backfill piping systems and come automation-ready. The 725S is a two-outlet valve rated for backfill distribution as well as emergency dump. The 725T adds a third dedicated dump port that features a taper to eliminate dead-heading for either flush water diversion, emergency dump or both. *See figure 6 and 7 below.*

Designed to withstand high pressures of underground systems, the valves used are rated to 100 Bar (1500 psi) with a new generation launching with a rating of 150 Bar (2175 psi). The valves use a 4D bend radius flow path to reduce wear from abrasive slurry and high-flow conditions. All wetted surfaces of the Series 725S/T valves are constructed from martensitic stainless steel, which provides both excellent abrasion resistance and corrosion resistance. Continuous flushing is not necessary because the smooth profile of the plug prevents clogging. These valves are customizable, accommodating electric, hydraulic, or pneumatic actuation - and can be installed vertically, horizontally or in any intermediate position. The valve is offered with either grooved, double grooved or ringed ends, allowing the specifier to choose their preferred mechanical couplings for quick and simple installation and removal. Installing automated diverter valves at switching points on paste piping allows backfill to flow to alternative stopes without requiring manual manipulation of the pipe/pipe fittings to redirect flow.

A New Approach

Efficiency gains are being achieved by replacing manual backfill systems with methods that are faster and safer. Automated diverter valves are among the technologies being used to effect efficiency and safety gains. Using diverter valves eliminates time-consuming manual operations that require special equipment and introduce risks for workers. Although automated diverter valves are installed at several Agnico Eagle mines globally, this paper will focus on FGM and will illustrate how functionality and safety can be improved, leading to time savings and ultimately better economics.

Mine History

The FGM is approximately 20 km east of the city of Bendigo and 130 km north of Melbourne in the State of Victoria, Australia. The FGM and associated infrastructure are on Mining License 5404, which is 100% owned by Agnico Eagle. Gold was discovered in the area in the mid-1800s, and mining activity was underway by 1894. Exploration activities by various owners of what is now the FMG ensued from 1973, with heap leaching operations from an oxide pit beginning in 1993. By 1998, Perseverance Corp., which operated the mine, was producing 40,000 oz/yr from the oxide ore. In mid-2001, a sulfide resource was developed, and an open pit was initiated in 2004. The first gold pour at the site took place in 2005.

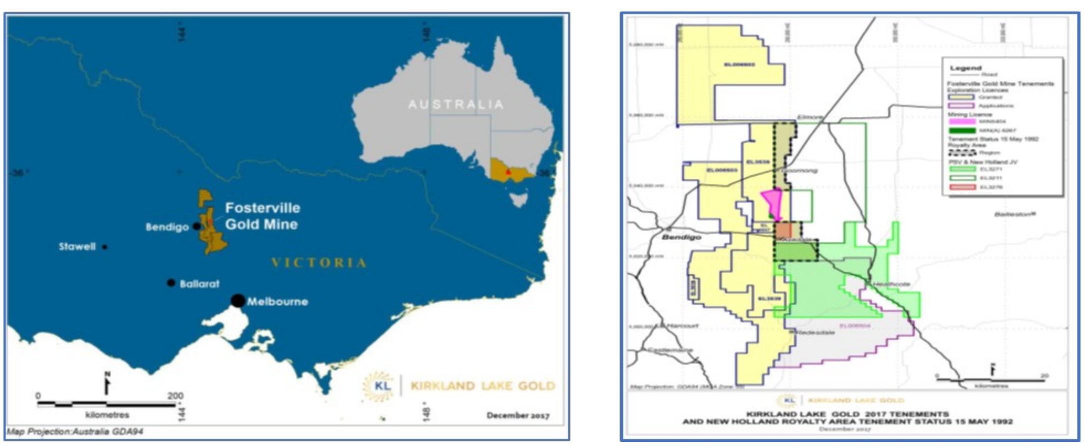

Figure 1. The Agnico Eagle Fosterville Gold Mine is approximately 20 km east of the city of Bendigo and 130 km north of Melbourne in the State of Victoria, Australia, on Mining License 5404; Source: Agnico Eagle, Toronto, Ontario.

The owners started an underground decline in March 2006, and the first underground stope was mined in December 2006. By early 2008, underground ore had become the main mill feed. The 500,000th ounce of gold was produced in March 2011. Over the next seven years, the mine produced gold at a rate of 150,000 oz/year. Kirkland Lake Gold Ltd., headquartered in Canada, purchased the mine in November 2016 and began an aggressive exploration program that yielded impressive results, including the higher grade Swan Zone. Subsequently in early 2022 Kirkland Lake Gold merged with Agnico Eagle Mines Limited also headquartered in Toronto, Canada.

Mining Method

Current mining at FGM is undertaken predominantly as owner-miner. FGM uses an open stoping, retreat mining method with the use of backfill to extract gold ore from the Phoenix decline ore bodies. Figure 2. shows the actual and proposed mining layout at FGM.

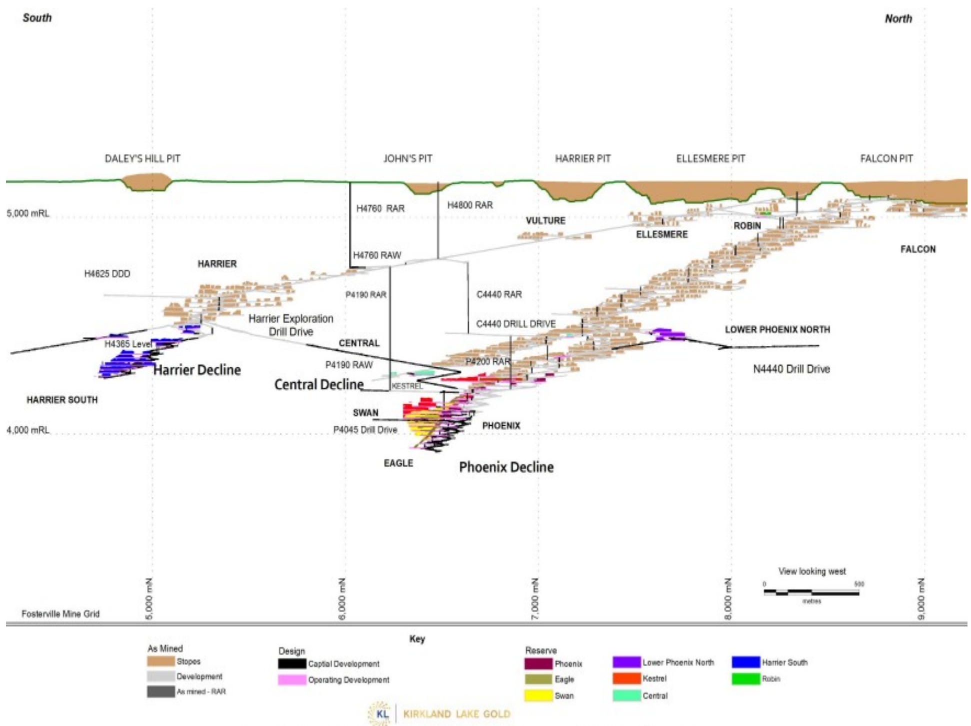

Figure 2. Actual and proposed mining layout at the Agnico Eagle Fosterville Gold Mine.
Source: Agnico Eagle, Toronto, Ontario

Stoping widths vary as dictated by grade distribution in the block model and strike length is determined by rock mass and hanging wall stability assessments. Once a stope has been mined out, the void is generally backfilled to ensure stability in accordance with planned future vertical and horizontal exposures. The open stopes are relatively small, ranging from 500m^3 to 2,700m^3 with an average of 1,500m^3. The current annual backfill requirement is 150,000m^3 to 200,000m^3 per year. The selection of the specific mining method within the open stoping regime is based on previous experience at the Fosterville Mine and expectations of ore zone geometry and geotechnical conditions. A standard level interval of 20 vertical meters is usually applied across all mining areas. However, this can be varied to maximize the extraction of the economic material.

Underground mining is carried out using a conventional fleet, including twin boom development drills, production drills, loaders, trucks and ancillary equipment.

Backfilling
Historically, mining at FGM had been done top down without backfill or with limited quantities of cemented rock fill (CRF) using underground development waste mixed with cement slurry. With the discovery of the high-grade Swan Zone, a decision was made to design and construct a paste backfill system. In the interim, while awaiting the construction of the new paste plant, the stopes would all be filled with CRF. Because of the relatively flat dipping nature of the ore body, the hanging walls required topping up with flowable fill, a mixture of various sands, cement and water. The objective of this process was to reduce hanging wall failure. While it was effective, the backfill method was slow, and operating costs were high.

The decision to switch to paste backfill was based on ensuring that the backfill achieved full confinement of hanging wall voids leading to higher productivity, lower dilution and reduced operating costs. The plant process design combines full plant tailings and binder at a rate of 65m^3 per hour. The paste plant design includes a thickener and two large vacuum disc filters feeding a continuous mixer where binder and water are added to the filter cake to produce paste with the required slump or yield stress. Lime can also be added during this process. The paste plant is located so the paste fill flows by gravity to the Phoenix ore zones. The paste is delivered through a 1040m borehole from the surface paste plant to the P4190L. The 7 5/8" steel casing in the borehole is lined with a 12 mm ceramic epoxy polymer coating. The borehole casing has an ID of 150mm. Figure 3 shows the paste reticulation long section at FGM.

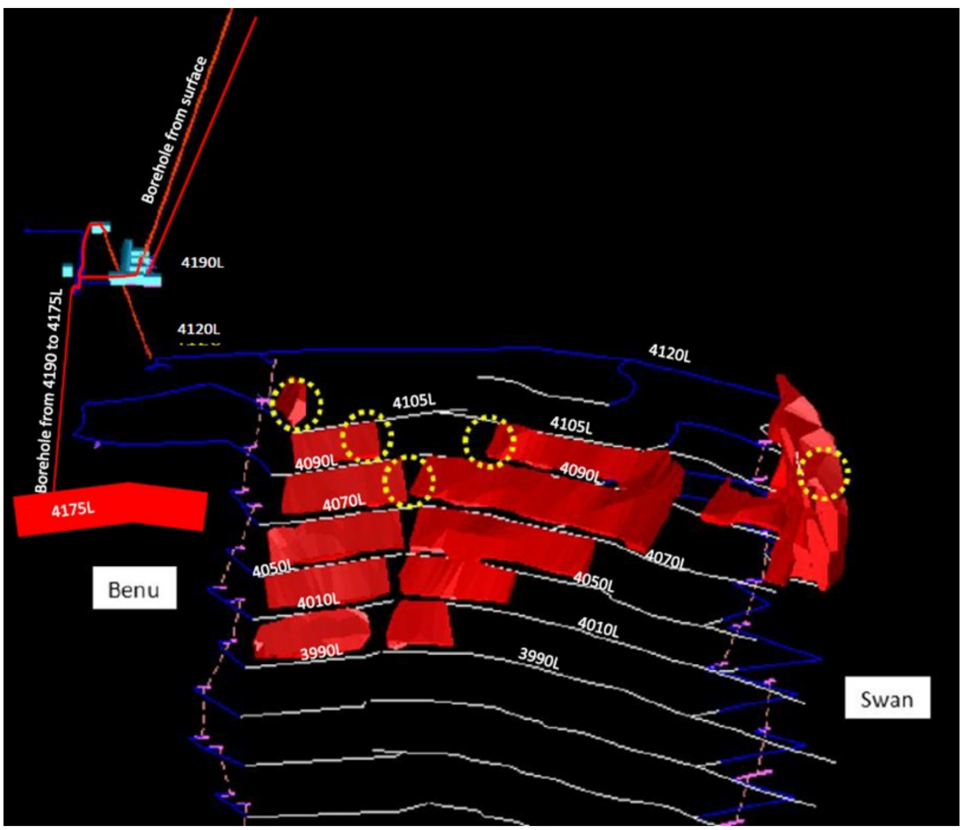

Fig 3. The Paste Reticulation Long Section at Fosterville Gold Mine.
Source: Agnico Eagle Gold Mines, Toronto, Ontario

Implementing Automation

The current paste reticulation system is made up of 100NB & 150NB Sch80 A106B SMLS pipe connected with Victaulic HP70ES couplings. The pipe lengths include exact 6, 3, and 1 m, 300 mm straight lengths, as well as Victaulic Sch80 cast 3D bends of 90, 45, 22.5 and 11.25 degrees. The hanging and thrust support is galvanised steel. The reticulation system instrumentation includes pressure sensors and flow meters as well as a dump valve at the bottom of the main borehole and pressure relief spools on each level. There are permanent closed circuit television (CCTV) cameras at two location on the P4190L. Portable CCTV cameras are positioned at the pour point for each stope and at the fibrecrete bulkheads on the undercut of each stope. Total earth pressure cells and piezometers were installed inside some bulkheads in the early stages. Workers monitor the instrumentation and CCTV cameras in real time from the control room at the paste plant.

A tradeoff study was done to evaluate the benefits of using actuated diverter valves versus manually changing the direction of pipe spools when switching the pour locations. The relatively small stope volumes averaging only 1500m^3 of paste was one of the factors that contributed to the decision to implement the use of diverter valves. Based on the stope volumes and the production rate of 65m^3 per hour, reticulation changes would be required at least once per day and possibly two times per day.

The decision was made to use remotely actuated diverter valves based on:

a. Improved safety
b. Higher productivity
c. Lower operating costs.

The Victaulic 725S diverter valve was selected from among the various diverter valves available on the market based on design, footprint and price.

Table 1 Remote switchover process results in hours of labour savings

Time study	
Manual switchover	**Remote actuated diverter valves**
Travel to lockout location and perform lockout	Paste engineer directs plant operator (PO) to switch diverter valve(s) to specified reticulation line number(s)
Travel to switching location	PO locates diverter valves on underground HMI screen
Access hoist, crane or other heavy lifting equipment	PO selects valve – actuates it to the direction specified
Perform the manual switching operation	PO confirms correct position – indicated by limit switch
Travel back to the lockout location and remove locks	PO advises paste engineer that the switchover is complete
Number of labourers: 2–3	Paste engineer confirms on his HMI screen
Estimated time to complete: 2–5 hours	Estimated time to complete: 3–5 minutes

Fosterville Diverter Valve Installation Detail

The Victaulic 725S diverter valves at FGM are equipped with 415 V electric actuators, limit switches and Auma remote control units. Pneumatic actuators and 240 V electric actuators were considered, but although pneumatic actuators could have reduced the capital cost, electric actuators were selected because electric power is required at the valve for the limit switches and solenoids and on each level for pressure sensors, flow meters and CCTV cameras. Underground power at FGM is 1,000V. The underground instrumentation and diverter valves are controlled with a separate dedicated PLC and communications system. Rockwell Automation equipment was selected as this was the current standard at FGM. The surface Paste Reticulation Control Panel includes an Allen-Bradley ControlLogix 5571 PLC, FLEX I/O module and a Managed Ethernet switch. This panel receives the inputs from the underground instrumentation and CCTV cameras and controls the diverter valves. This control panel communicates with the main Paste Plant PLC via ethernet which then enables the Paste Plant Operator to see the data from the instrumentation and control the diverter valves.

On each level underground there is a Form-4 Paste Board. These boards contain a 1000V to 415V transformer, a 1000V to 240V transformer, RT1100 Power Shield UPS and 24VDC power. These boards also contain FLEX I/O modules and ethernet switches. The communication between the surface and underground control panels is through fiber optic cable. The fiber optic cable is connected to the ethernet switches in each panel and the FLEX I/O then connects the instruments and valves to the PLC. Each diverter has a unique valve number in the PLC control logic, and each discrete paste line has a number. The inlet line and the A and B outlet lines from the diverter are numbered, with the numbers displayed on the valve as well as the underground pipes.

Diverter Valve Operation

The Paste Fill Note includes instruction for the setup of each diverter valve for each pour (Figure 4). The instructions indicate the required direction for each diverter using the diverter valve number and identifies the specified direction of flow to either the A or B outlet, including the paste line number for the outlet.

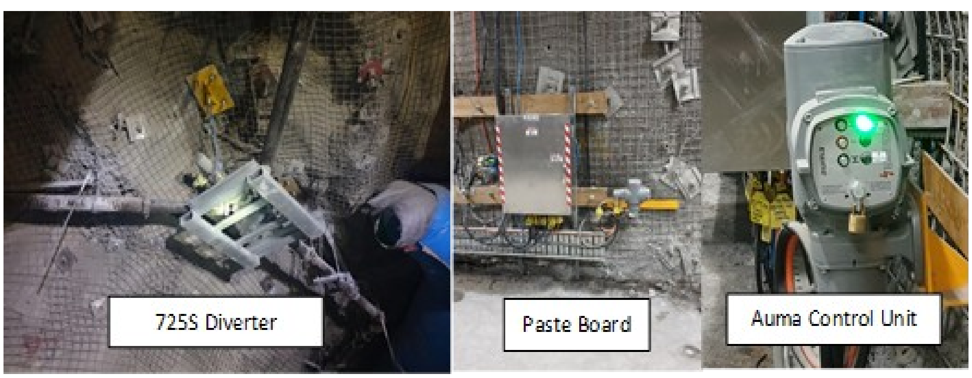

Figure 4. The Paste Fill Note includes instruction for setting up each diverter valve for each pour. Source: Agnico Eagle Gold Mines, Toronto, Ontario

The Paste Fill Note is delivered to both the surface paste plant operator and the underground paste operator. The surface paste plant operator switches the valves to the required positions on the human machine interface (HMI) and advises the underground paste operator that the valves are in the correct position. The plant operator can see the route of the piping highlighted in blue on the HMI display. Once there is pressure or flow in the line, the colour changes from blue to red (Figure 5). Using the Paste Fill Note, the underground paste operator checks all the pipes along the route to the stope, including the diverters. By consulting the diverter valve instruction in the note, the underground paste operator ensures that the yellow indicator on the valve is pointing towards the correct line number indicated in the note. Once that has been confirmed, the underground operator switches the diverter control panel to the local mode so the direction of the valve cannot be changed during pouring.

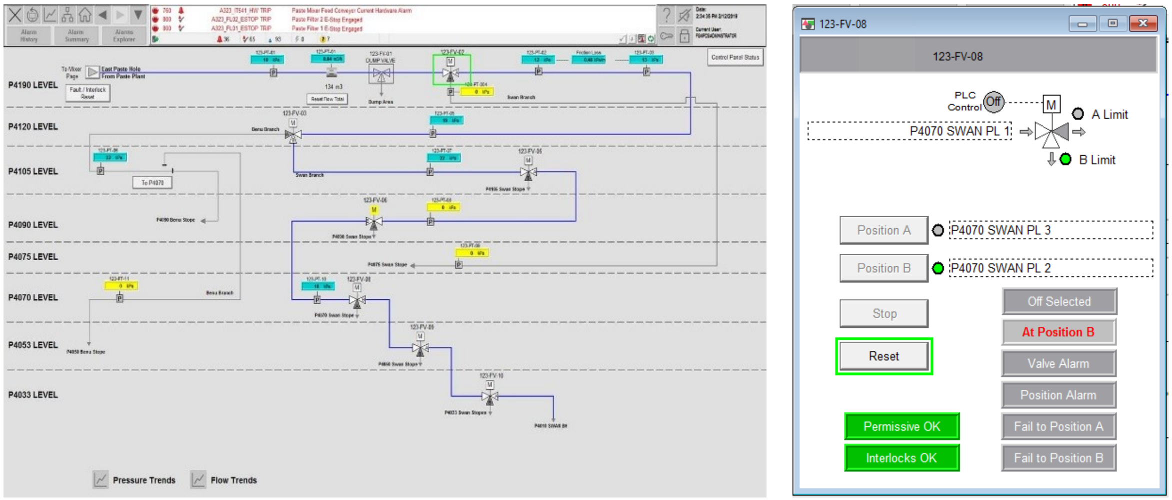

Fig. 5. The plant operator can see the route of the piping highlighted in blue on the HMI display. Source: Agnico Eagle Gold, Toronto, Ontario

Results

Replacing the traditional manual approach to backfilling at FGM has enabled more streamlined operations, increased productivity, and reduced safety risks. The improved process is allowing the mine to produce more ounces per day and has increased profitability.

Higher Productivity, Reduced Operating Costs

Once a stope is filled, the time required to change the piping location to the next stope is critical. In reticulation systems where there are no diverter valves, the steps required include:

a. traveling to the lockout location
b. performing the lockout (sometimes this takes place on the surface)
c. traveling to the switching location
d. manually switching the pipe
e. and finally traveling back to the lockout location and removing the locks.

This can take a team of three paste operators anywhere from two to five hours, depending on the layout of the mine and the lockout procedure in place. Using diverter valves eliminates these two- to five-hour delays, allowing paste filling to commence quickly. With the paste filling process expedited, mining can resume more rapidly, and ultimately, more ounces of gold can be mined each year. Another benefit of this tremendous time savings is the substantial reduction of non-productive time. Adopting an automated process means the diverters can be used during shift changes when there is no access to the underground. Automation also frees the paste operators to perform other work during time that otherwise would have been spent manually managing the paste fill process. The cumulative effect is reduced operating costs. In a typical lower cost mine such as FGM, *the total cost to purchase and install a single diverter valve can be repaid in less than one month through increased ore production.*

Improved Safety

In addition to improving profitability, automated diverter valves improve safety. An inherent safety feature of the Victaulic 725S/T Diverter Valves is that all moving components and primary seals are contained within the valve body *(Figures 6&7)*. Other diverter valves that rely on exposed compression seals between the body and sliding plates or rotating discs, expose operations personnel to high pressure media spray and seal leakage if there is a failure during operation. In the unlikely event of seal wear on the Victaulic valve, all media remains contained within the valve body.

Figure 6. Series 725S cross section. Source: Victaulic Co, Easton, Pennsylvania.

Fig. 7. Series 725T cross section. Source: Victaulic Co, Easton, Pennsylvania

Because these valves can be actuated locally or from the surface control room, there is no need for a paste crew to travel to the valve location and work manually from the IT basket. Using these valves reduces the interaction of personnel and equipment and eliminates the risk of personal injury that is introduced every time a pipe switch is performed manually.

The local actuation feature on the Victaulic diverter valve is beneficial when work is required on the reticulation system. Every time paste operators need to work on the paste line, some form of lockout is required. The operator can travel to the level where the work is to be performed, change the diverter control unit to local actuation, switch the valve away from the line to be worked on and lock out the actuator to isolate the line. This functionality provides the highest level of safety for the paste operators working on the line because they can manage the process without relying on other personnel to ensure isolation, further reducing risk.

Additional Benefits

The FGM reticulation system includes a dedicated dump valve on the P4190L so the contents of the surface borehole can be dumped into a dedicated sump in case of emergency. The Victaulic 725S diverter valve is rated for use as a dump valve under full pressure, so installing these valves on each level provides the additional benefit of being able to use the diverters for an emergency dump.

The cost of production delays caused by borehole blockages in mines varies depending on the production rate and the All-In Sustaining Costs (AISC) of the mine versus the current gold price. In broad terms, a month of lost production amounts to a few million dollars at most mines. Also, there are additional costs for clearing borehole blockages, (or in extreme cases total borehole replacement), which can exceed $1 million. Therefore, a strategy of a reliable borehole dumping system and a backup surface borehole is used at most mines.

Conclusions

Replacing the traditional manual approach to backfilling at FGM has enabled more streamlined operations, increased productivity, and reduced safety risks. The improved process is allowing the mine to produce more ounces per day and is increasing profitability.

The outlook for the FGM is positive, with continuing exploration success in the Harrier Zone and downdip in the Phoenix Zone. Expansion of the underground paste reticulation system to new areas will continue. If the stope geometries are similar to those in the Swan Zone, the current diverter valve usage model will be implemented on these levels based on successes to date.

As backfill technology continues to develop and evolve, so will diverter valves. To meet the evolving needs of mine operators, valves containing multiple outlets for paste diversion, paste evacuation and flush water diversion, valves of higher-pressure ratings, valves of larger diameters, valves of more abrasion resistant materials, and valves capable of full automation and integration into intelligent systems are all conceived or being developed.