Ramp-up and long-term performance of the Albion Process™ plant at GeoProMining Gold Armenia

P Voigt[1], D Walker[2], O Kloiber-Deane[3] and A Tsvetkov[4]

1. Manager - Hydrometallurgy, Glencore Technology, Brisbane Queensland 4000. Email: paul.voigt@glencore.com.au
2. General Manager – Integrated Solutions, Core Resources, Brisbane Queensland 4010. Email: dwalker@coreresources.com.au
3. Principal Process Engineer, Core Resources, Brisbane Queensland 4010. Email: okloiber-deane@coreresources.com.au
4. CEO Deputy – Processing and Metallurgy, GeoProMining Gold LLC, Yerevan, Armenia. Email: atsvetkov@geopromining.com

ABSTRACT

The GPM Gold Operation has been employing an Albion Process™ plant at its Sotk (Zod) gold mine in Armenia since 2014. Long term data from the operation is now being published for the first time. The data presented includes concentrate throughput, as feed to the Albion Process™ plant (tonnes per day), sulphur grade in concentrate (% S), total sulphide sulphur oxidation in the Albion Process™ plant (% SOx) and gold recovery from Albion Process™ plant residues (%). The data provides a basis for evaluation of the effectiveness of the commissioning, ramp up and operation of the Albion Process™ plant. Notwithstanding the impact of a slower concentrator commissioning than expected, the plant demonstrates Series 1 behaviour on McNulty ramp up curves, indicating successful commissioning and fast ramp up. Interrogation of the data and operational experience indicates that this successful operation is a result of a process that is flexible, robust and stable, one that was designed well based on solid testwork results and pilot plant trials during the study phase undertaken by Glencore Technology and Core Resources, and where the local operators were provided with appropriate training in operation of the plant.

BACKGROUND

The GPM Gold Project

GeoProMining Gold LLC (GPM) owns and operates the Sotk (Zod) gold mine and Ararat processing facility in Armenia ("GPM Gold"). The open cut mine is located near the border with Azerbaijan, and gold bearing ore is transported via a state-owned rail link to the process plant at Ararat, near the Turkish border.

Reserves at the Sotk mine (as at an August 2011 estimate) were 14.2 Mt at 4.3 g/t Au. Indicated resources were estimated to contain 28 Mt of ore at 4.2 g/t Au, and inferred resources were estimated to contain 16 Mt at 4.2 g/t Au. The gold-bearing mineralogy is dominated by arsenopyrite and pyrite. Gold is preferentially associated with arsenopyrite and to a lesser extent pyrite. Gold occurs as free milling and finely dispersed through arsenical sulphides and tellurides. The geology of the deposit has been discussed separately (Voigt, Hourn, Mallah and Turner 2014).

The project has been in operation for several decades, originally mining weathered oxide ores overlaying sulphides. GPM acquired the project in 2007 and began initially treating gabbro and low sulphide ores. Testwork performed on samples obtained from exploration drilling into the underlying sulphide zones showed gold recoveries of around 20-30 per cent when treated through the conventional carbon in leach (CIL) process. Further testwork was performed to evaluate oxidation of the sulphide material prior to cyanidation. Oxidation of arsenopyrite and pyrite before cyanidation of the resulting residue was successful, with gold recoveries lifting from 20-30 per cent to over 90 per cent.

GPM evaluated four oxidation technologies, namely roasting, pressure oxidation (POX), biological oxidation (BiOX) and the Albion Process™, an atmospheric oxidative leaching process. An environmental-technical-economic evaluation was performed, with the Albion Process™ prevailing as the most suitable technology. The main driver was a lower capital cost and reduced implementation time.

Development testwork for the project began in 2009. Four sulphide ore samples (600 kg each) from across the ore body were tested, culminating in a continuous pilot plant oxidative leaching program. The final flowsheet consisted of milling and sulphide flotation to generate a sulphide concentrate, which was then treated through an Albion Process™ oxidative leach plant. Residue from the Albion Process™ plant is combined with flotation tails and fed to the existing CIL circuit.

Nameplate design for the plant is 100,000 tpa concentrate, generating on average ~100,000 ozpa gold as doré. The Albion Process™ plant was delivered to GPM as a lump sum technology package linked to performance guarantees by Glencore Technology. Mechanical design was completed in December 2012. Construction of the operation was completed in April 2014, and commissioning completed in July 2014.

The Albion Process™

The Albion Process™ is an established atmospheric oxidation technology for treatment of refractory sulphide concentrates. It is currently installed in six operations globally, with two Albion Process™ plants applied to the leaching of gold hosted with refractory sulphides. The chemistry of the Albion Process™ has been widely reported (Voigt, Mallah and Hourn, 2017).

In applications for gold, the Albion Process™ consists of fine grinding of the sulphide concentrate, followed by oxidation in tanks operating at atmospheric pressure with gaseous oxygen injected at supersonic velocities to maximise oxygen mass transfer and facilitate the oxidation reactions. Oxidised residue from the Albion Process™ is then treated with a standard cyanide leach circuit for gold recovery.

The oxidation reaction is carried out under a mildly acidic pH (5.5), and is maintained by the addition of limestone. The reactors are auto-thermal and typically operate in the range 85-98°C. Oxygen utilisations of 80-90 per cent are typical. The Albion Process™ for gold does not solubilise any base metals and does not produce any elemental sulphur or jarosites, meaning discharge slurry does not require washing and cyanide consumption remains low in the leaching circuit. Residues typically have good filtration characteristics, and materials of construction requirements are typically lower than for acidic POX or BiOX circuits.

THE GPM ALBION PROCESS™ PLANT FLOWSHEET DEVELOPMENT AND DESIGN

The overall GPM plant flowsheet is shown in Figure 1.

Before the implementation of Albion Process™ the GPM plant comprised the existing milling, CIL and gold recovery plants to treat ore directly from the Sotk mine. A flotation plant was existing at the site but was no longer used. The implementation of the Albion Process™ required the refurbishment of the flotation plant and installation of the new Albion Process™ plant equipment.

The flowsheet components for an Albion Process™ plant treating refractory concentrate for gold recovery comprises more or less the same unit operations between different projects; fine grinding followed by oxidative leaching and in some installations thickening. The GPM plant comprises an M3,000 IsaMill™ fine grinding plant and nine (9) 270 m^3 Albion Process™ leach reactors followed by a 10m high rate thickener where leach residue is directed to the CIL at a target 42 per cent solids. The process plant has been described in detail elsewhere (Voigt, Hourn, Mallah and Turner, 2015).

Key design criteria for the GPM project are provided in Table 1.

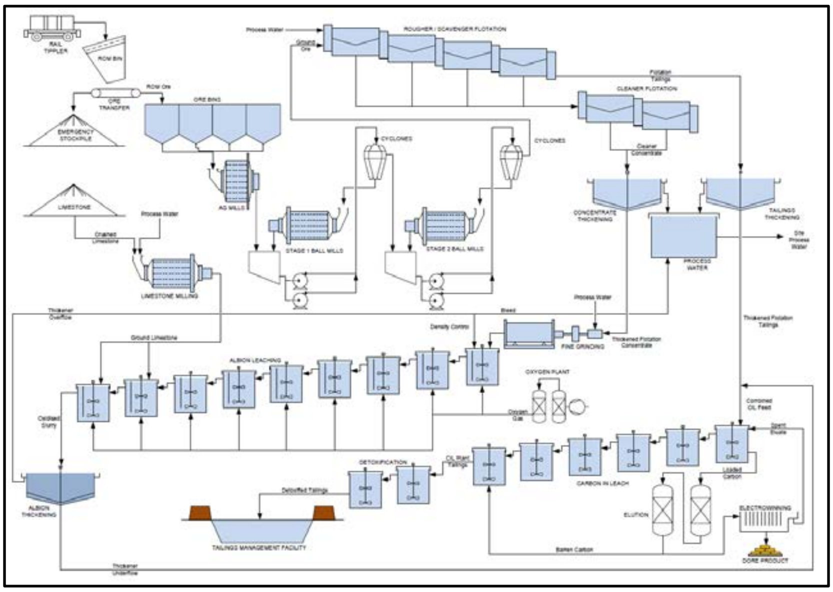

Figure 1: GPM flowsheet.

GPM OPERATIONAL PROCESS DATA

This paper presents process data from 2014 to 2017, supplied by GPM, with a view to evaluating the ramp up and the performance of the Albion Process™. This set reflects the largest series of operational data from an Albion Process™ plant made publicly available to date. It demonstrates the performance of the Albion Process™ under a number of conditions, some of which are normally adverse for hydrometallurgical sulphide processing circuits.

Key process data has been collected over the duration of plant operation and analysed. Key process data includes:

1. Concentrate throughput, as feed to the Albion Process™ plant (tonnes per day);
2. Sulphur grade in concentrate (% S^{2-});
3. Total Sulphide sulphur oxidation in the Albion Process™ plant (%); and
4. Gold recovery from Albion Process™ plant residues (%).

Oxygen utilisation data is not collected by site and has been reported elsewhere based on plant surveys (Voigt, Mallah and Hourn, 2017). Since the power supply contract is arranged on a take-or-pay basis, excess oxygen that is generated is directed to the CIL.

Monthly data has been compiled in Figures 3 to 6. Charts of plant data are shown based on monthly averages, with bars showing one standard deviation calculated from the individual daily data for each month. The data presented is based on monthly averages of daily data, with no data conditioning – i.e. downtime for plant maintenance etc. has not been removed from the data prior to reporting average monthly figures.

Interrogation of the detailed process data reported along with operational experience indicate that, in addition to achieving the main design parameters of throughput and recovery, the project has enjoyed success because of several key factors:

1. Fast ramp up – the Albion Process™ was commissioned and ramped up within three months of construction;
2. Flexible, robust and stable – the Albion Process™ has been able to effectively treat a feed concentrate with highly variable throughput and quality;
3. Designed right, the first time – the project was designed and executed based on solid testwork and engineering design so that the commercial plant performed better than laboratory tests (Voigt and Walker, 2018); and
4. Technology transfer – the technical know-how about the Albion Process™ was effectively transferred to the client team so they knew how to operate and maintain the plant.

These factors are discussed in greater detail throughout this paper.

Parameter	Units	Value
Albion Nominal Feedrate	tph	12.1
	tpd	290
Albion Design Feedrate	tph	13.5
	tpd	334
Flotation Concentrate S^{2-} Concentration	%	17.6
Degree of S^{2-} Oxidation	%	76
Design Oxygen Utilization	%	80
Design Gold Flotation Recovery	%	88
Design CIL Gold Recovery (Albion residue)	%	92
Design CIL Gold Recovery (flotation tails)	%	40
Design Overall Gold Recovery	%	85.8
Annual gold production	oz	100,000
Annual ore throughput	tpa	1,000,000

Table 1: Key process design criteria.

Fast ramp up

The GPM Albion Process™ Plant commissioning was completed in July 2014. This was approximately four months ahead of the completion of the concentrator commissioning, with the resulting reduction in concentrate supply affecting the Albion Process™ plant ramp up rate. Furthermore one of the two oxygen plant air blowers failed soon after commissioning, however the Albion Process™ plant was not oxygen limited at this time and was able to deal with the concentrate production rate.

The GPM plant gold production data was plotted on a McNulty curve to assess ramp-up performance as shown in Figure 2.

Figure 2 shows that the GPM plant exhibited ramp up behaviour between Series 1 and Series 2 during the first two years with Series 1 performance exceeded after 2 years. Series 1 is indicative of a successful implementation of project, typically representing a higher degree of “care exercised during the project development phase.” (McNulty, 2014). The basis for analysis is the gold production which was taken as the principal measurement of the success of the overall project.

The early stages of the project demonstrated Series 2 behaviour, in part constrained by the slow concentrator commissioning. However, the ramp up characteristics of the project accelerated rapidly, and the plant exceeded Series 1 behaviour within the first 3 years of operation.

This was a major achievement for the technology. McNulty and others have observed that "projects exhibiting Series 1 behaviour generally relied on mature technology" (McNulty 2014) and that the presence of a licensed technology with "few or no predecessors" (McNulty 2014), was one of several risk factors that might contribute to a plant lowering ramp up performance from Series 2 through to 4. The experience at the GPM plant is contrary to this observation, where ramp up constraints in the concentrator were more significant than in the Albion Process™ circuit.

Concentrator ramp up

During 2015, concentrator throughput and recovery were poor due to ramp up problems in the concentrator and treatment of transitional ores with poor flotation response. The second half of 2015 onwards saw primary sulphide ore presented to the flotation plant with a corresponding increase in recovery, grade and throughput. Concentrator performance achieved a significant step-change in performance around the middle of 2016 following a de-bottlenecking project.

Figure 3 shows that concentrator performance has improved significantly since commissioning in terms of absolute grade, recovery and throughput as well as stability. The flotation gold recovery and concentrate production remains below nominal and design levels (88 per cent, 282 tpd and 324 tpd respectively) however the gold grade and sulphur grades are higher than design resulting in design gold units processed through the plant. Gold units that tend not to float are typically non-sulphide and more amenable to direct cyanidation, and these flotation tails are passed direct to the CIL circuit.

Albion Process™ramp up

During the corresponding period since commissioning, the performance of the Albion Process™ has been above design and stable, oxidising any feed that is directed to the process despite significant variation of feed quality and quantity, as discussed in the following section. The Albion Process™ plant is limited by concentrate feed and tends to operate at design rates over an hourly basis until feed is depleted. This is to maintain efficient and steady operation of the IsaMill™.

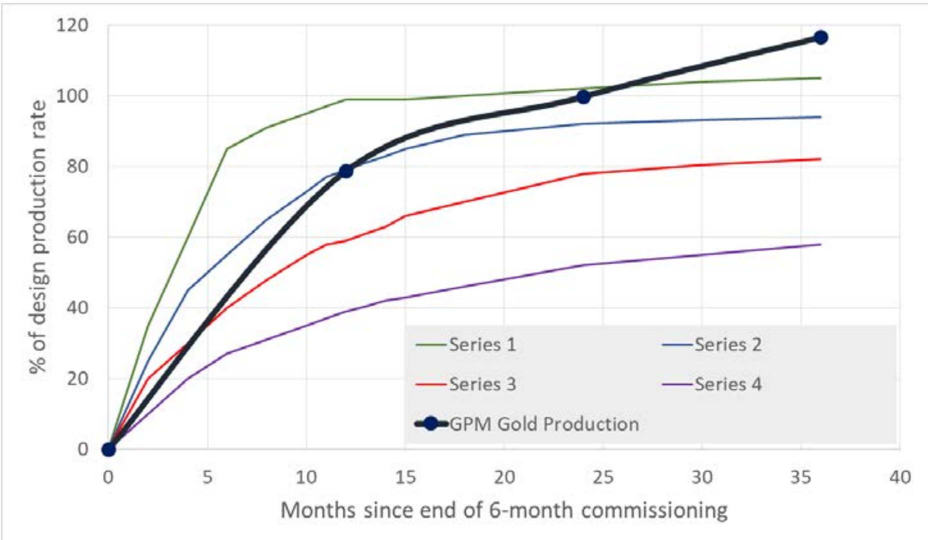

Figure 2 – McNulty curve for GPM process plant.

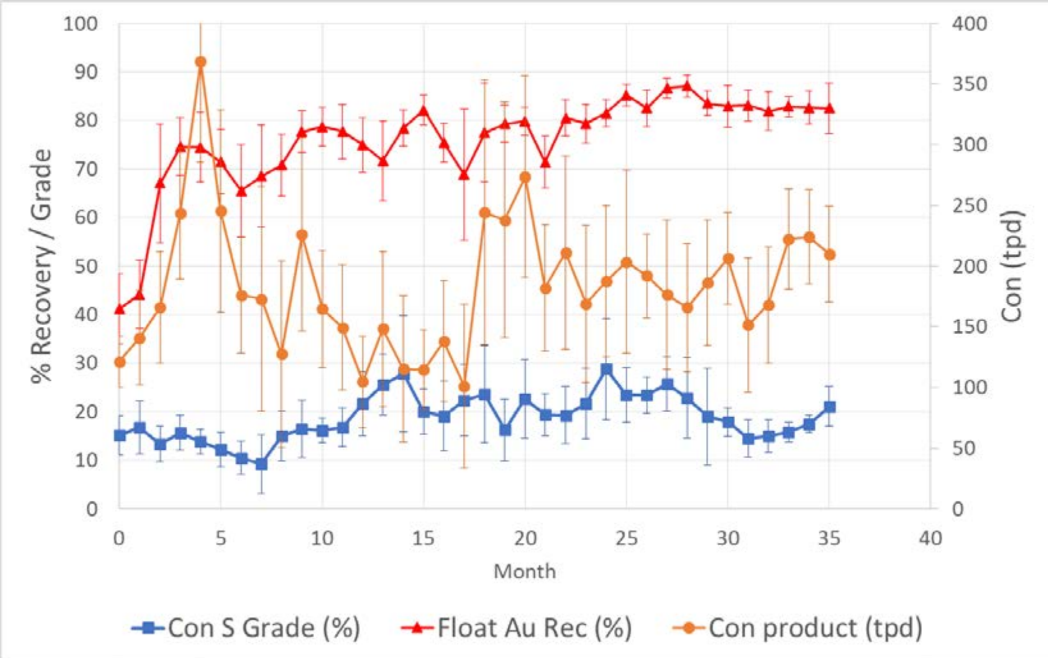

Figure 3: Concentrator performance.

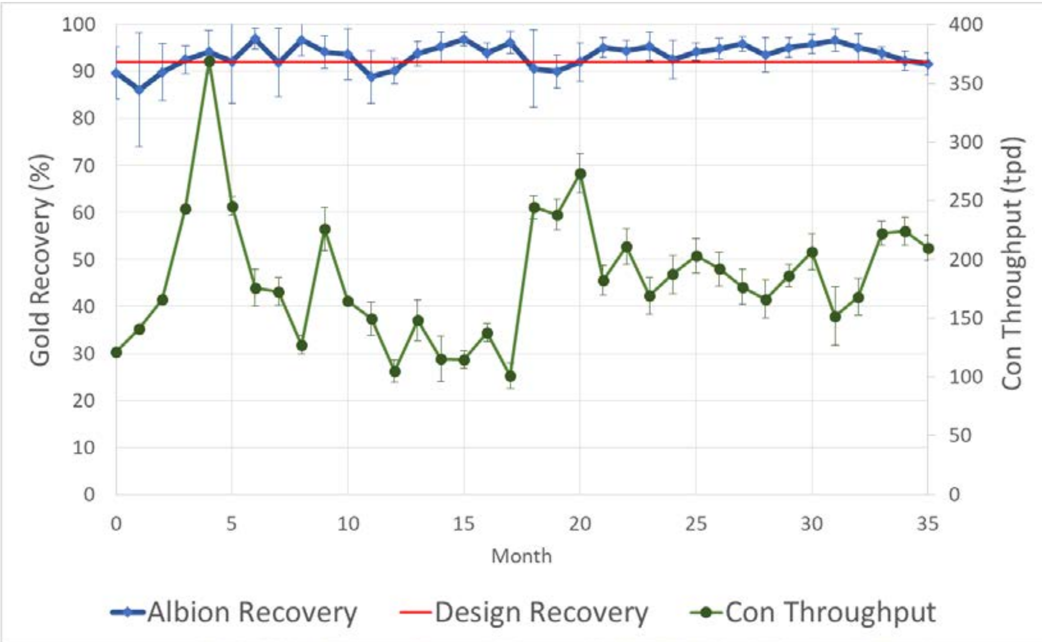

Figure 4 - Gold recovery versus throughput.

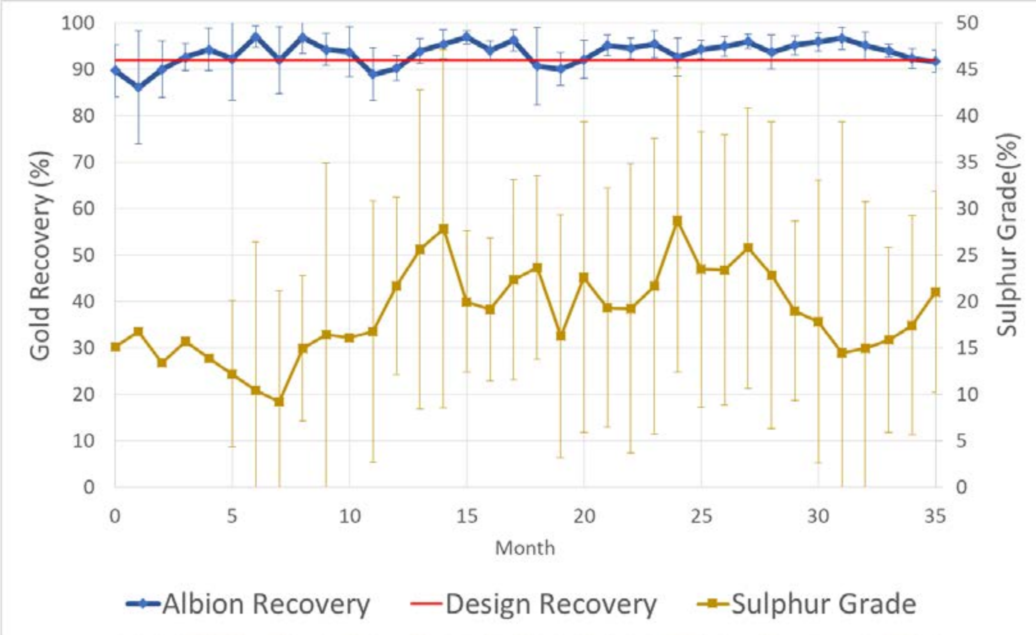

Figure 5 - Gold recovery versus concentrate sulfur grade.

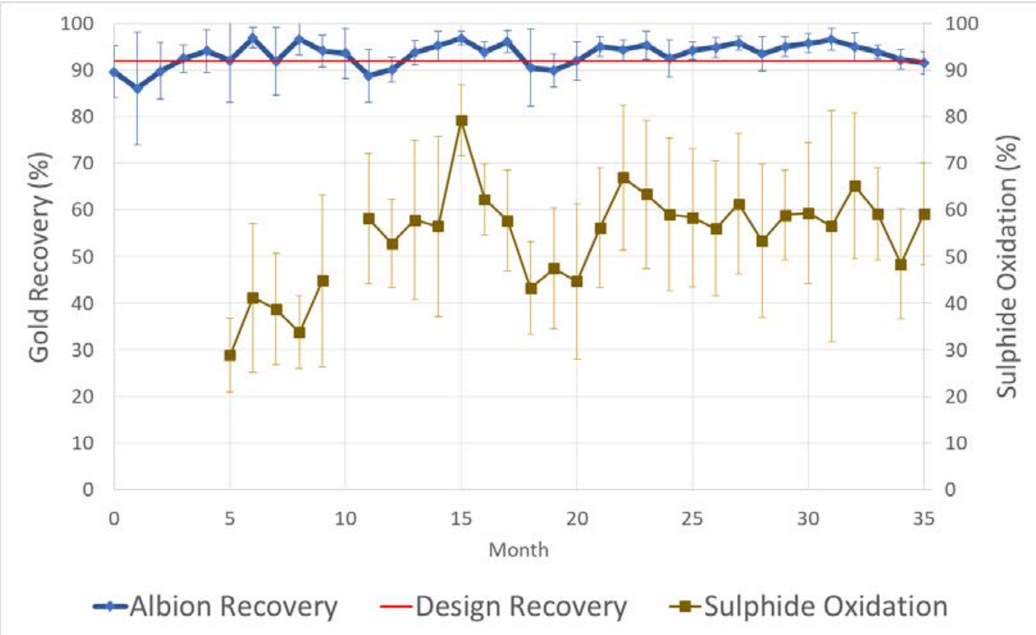

Figure 6 – Gold recovery versus degree of sulfide oxidation.

FLEXIBLE, ROBUST AND STABLE

A key feature of the data is the stable performance of the Albion Process™ when treating a range of throughput rates and a range of quality of feed in terms of sulphur grade and gold grade. Gold recoveries have remained consistent since commissioning and have predominantly been above design levels.

Consistent gold recoveries above design have been maintained in spite of unexpected variability in the throughput rate to the Albion Process™ plant, and significant variability in the sulphur grade being fed to the plant. The figures below represent graphically the consistency of the Albion Process™ plant gold recoveries against the variability of these parameters:

Throughput variability has reduced over time as the operation matures. Nevertheless gold recoveries were consistent early in the life of the operation, a significant advantage for the operator of the plant as it works from that early base towards better process control.

The ability of the Albion Process™ to process variable sulphur grades at GPM is due to the auto-thermal nature of the Albion reactors. Once a minimum sulphide-sulphur throughput is met, the reactors operate in the range 85-98°C. If the plant encounters lower sulphide levels it can usually operate for several hours due to the large thermal inertia in the process and has no material impact.

By that time, the issues causing the low sulphur grade in the concentrator have usually been resolved. If the low sulphur condition persists and temperature drops in the first few reactors, the first reactor can be partially scuttled with slurry draining to the bunded area below the thickener and recycled to the process via spillage pumps. This allows the reactors to be re-filled with higher grade material with the temperature increasing again for regular operation. The reactors at GPM are open to atmosphere, so when the sulphide feed rate increases the additional exothermic heat released by oxidation of these units immediately raises the vapour pressure of the slurry, which in turn drives a greater evaporation rate that removes the additional heat. The reactors at GPM operate near the boiling point of water.

This contrasts with Pressure Oxidation circuits which are typically sensitive to variations in sulphur grade due to the requirement to manage heat of reaction in an autoclave. During an environmental-technical-economic evaluation phase of the project, a more stable throughput and sulphur grade was assumed as a basis for comparison of the POX and Albion Process™ options. The Albion Process™ was selected in part for its ability to handle any unexpected variability in feed arising from the ore body or from operation of the concentrator; selection of an autoclave circuit may have resulted in significant reduction in throughput in order to manage the ore variability seen as the project has operated.

Additionally, during project development, different ore bodies required different levels of sulphide sulphur oxidation. Selection of VPSA type oxygen plant allows turn-down of oxygen generation to match the required oxidation level and subsequent oxygen requirements for the system. Due to the lower oxidation level requirement than design, the leach reactions are normally completed in Albion Leach Reactor 6, and the full 9 reactors are not required.

Oxidation capacity

It is also noted that to achieve and exceed the design recovery, the extent of sulphide sulphur oxidation required has varied and typically is around 55 per cent, well below the design value of 76 per cent. The Albion Process™ plant generally allows more control of oxidation levels than in an autoclave circuit. There is a reduction in oxygen operating costs associated with lower oxygen requirements.

The principal duty of the Albion Process™ plant is the oxidation of sulphur, to release gold finely disseminated in the sulphide matrix for recovery in the downstream cyanide leach circuit. The oxidation capacity of the Albion Process™ plant is constrained either by the residence time in the circuit, or by the available oxygen, and was a major consideration in the design and engineering of the plant during the design phase. The nominal and design oxidising capacities are 1.56 and 1.80 tonnes sulphide sulphur per hour respectively assuming an 80 per cent oxygen utilisation.

The design for the GPM Albion Process™ plant is to achieve 76 per cent sulphide sulphur oxidation, with a nominal and design sulphur oxidation of 37.6 and 43.2 tonnes oxidised per day. The design oxygen consumption was 336 kg / t concentrate assuming 80 per cent utilisation. Actual consumptions are around 215 kg / t concentrate based on plant experience due to higher than design oxygen utilisation and lower oxidation rates (Voigt, Hourn, Mallah and Turner, 2015). The reported plant data indicates the oxidation extent has been controlled and adjusted in order to maintain gold recoveries, demonstrating the flexibility of the process.

Periods of oxidation that exceeded the design maximum were demonstrated in 2016 and 2017. The spare oxidation capacity evident in the Albion Process™ plant is demonstration of the contingency applied in design, and is to the superior performance of the HyperSparge™ supersonic gas injection lance. Supersonic gas injection maximises the shear imparted to the slurry resulting in the resistance to gas to liquid oxygen mass transfer being reduced and in turn maximising oxygen mass transfer rate. The actual plant oxygen utilisation was found to be around 90 per cent or higher based on plant surveys and has been reported by Voigt, Mallah and Hourn (2017).

DESIGNED RIGHT – THE FIRST TIME

A pillar of fast ramp up and achievement of design throughput and recovery is a successful design process from the laboratory to the full-scale production plant. The GPM plant was designed and supplied by Glencore Technology based on results from batch and continuous testwork campaigns conducted as part of the BFS managed by Core Resources during 2011 and 2012. The purpose of the testwork was to obtain the following key design parameters which culminated in the mass and energy balance and process design criteria:

- optimise the grind size to minimise the IsaMill™ energy input,

- IsaMill™ Signature Plot to determine the grind energy required to achieve a certain particle size in order to size the IsaMill™ (The design specific energy to achieve 80 per cent passing 10µm was 59.0 kWh/t and recent plant data shows 59.7 kWh/t although not always required to run at 10µm),
- sulfide oxidation against gold recovery to optimise gold recovery and minimise oxidation requirements,
- measurement of slurry oxygen up-take rate under various conditions for designing the oxygen mass transfer system,
- rheological measurements for sizing of the pumps,
- determine the sensitivity of sulphide leach kinetics to key parameters such as operating temperature and slurry density,
- dettling data for sizing of the thickener, and
- test the process performance against samples that represent potential variance in the feed material during the life of the plant.

Testwork was structured around defining metallurgical performance of ore types and composites based on the life of mine schedule. During the testwork it was found that different ore types gave a different flotation response and required different levels of oxidation to achieve greater than 90 per cent gold recovery in cyanidation.

The design approach was to select a conservative sulphide sulphur oxidation target of 76 per cent to ensure that different combinations of ore types could be treated and still achieve the design target of greater than 90 per cent gold recovery in the CIL. The oxidation target largely drove the tank volume required and the oxygen plant size. Since oxygen is recognised as a large portion of the operating costs, two Vacuum Pressure Swing Adsorption (VPSA) type oxygen plants were selected for oxygen generating duty to allow oxygen output to be turned down when not required for the process and save on operating costs (as illustrated in Figure 6). VPSA technology was selected over PSA due to the lower power cost per unit of oxygen produced. The oxygen purity generated is 93 v/v %.

The important part of oxidation design is oxygen mass transfer to the slurry system. The scale up of oxygen mass transfer process is critical to the process success and is well understood and proven through the use of the HyperSparge™ supersonic gas injection technology (Voigt, 2017). A conservative oxygen utilisation was assumed at 80 per cent although plant measurements have shown this to be closer to 90 per cent (Voigt, 2015).

It can be observed from Figures 2 to 6 that there are no large drops in production rate over a monthly period. This stability of the production is a result of a well-designed plant. Specific factors which have contributed to high-availability of the plant include:

1. No major works or process modifications were required following commissioning, with most activity focussed on bringing the grinding and flotation concentrator up to full production;
2. The concentrator has two lines of operation and one line can be kept going while a mill re-line occurs; The Albion Process™ has been designed to avoid major downtime, through:
    - the surge capacity around the IsaMill,™
    - the ability to remove, inspect and insert HyperSparge™ without stopping the process or emptying a leaching tank,
    - the capability to by-pass the leaching section, and
    - the process comprises well known and understood equipment (tanks, pumps, thickeners, agitators).

As a result of this design, the process operates with very high availability (more than 95 per cent) and stable throughputs.

TECHNOLOGY TRANSFER

The Albion Process™ is an established technology but had not been previously deployed into Armenia or the wider CIS. This meant that training of operations and maintenance personnel was required to ensure safe and timely ramp up of the process. Training was performed in a class room environment during the final stages of construction and then on the plant during pre-commissioning checks and commissioning. Training was performed by Glencore Technology experts as well as representatives from sub-suppliers.

The training performed prior to commissioning meant that Glencore Technology (GT) was positioned to take the role as commissioning manager with minimal site presence (three personnel) while GPM personnel operated the plant. This ensured that a high level of ownership of the plant process management was taken on by the project owner at the very beginning of the project.

Following commissioning and ramp up, bi-annual visits from Core Resources and Glencore Technology personnel ensured that regular communication on technical issues occurred.

As a testament to the technology transfer process and ownership of the process, GPM have arrived at a number of process modifications and improvements:

1. By-passing the thickener

   The Albion Process™ leach residue is directed to a thickener to increase the solids content from 30-42 per cent suitable for feeding to the CIL process. Since the Albion Process™ residue is mixed with flotation tailings and sent to CIL, the Albion Process™ thickener has been by-passed and CIL feed density specification met by slightly increasing the flotation tailings thickener underflow density.

2. Reduced reagents and Closed overflow lines on tanks

   The Albion Process™ leach reactor design comprises inter-connecting launders for slurry transfer and each tank is fitted with an overflow arrangement that works with a weir to keep the head space sealed so only gases exit the ventilation stack. In the event of high carbonates in the feed or excessive flotation reagent accumulation in the process water, the tanks can overflow due to excessive foam production which is designed to be transported between tanks through the launders but often finds the path of least resistance through the reactor overflow pipes. Although this material is recovered back to the process with the bund and spillage system, it sometimes results in the oxygen flowrate to be reduced in the offending reactor and then increased in another causing gas surging and further foaming issues. The recycle of the spillage material also causes process surges.

   Site personnel undertook an improvement project to gradually reduce flotation chemicals (mainly frother) and to close up the overflow weirs. Froth generation has been significantly reduced through reduced reagent additions in the concentrator. The overflow weirs were also welded shut which directs all foam through the interconnecting tank launders. These two measures have eliminated froth overflow.

3. Control system

   The Albion Process™ was supplied with a distributed control system (DCS) with the plant operated from a centralised control room. The existing milling and CIL plant was controlled with minimal instrumentation and field control panels so transition to a centralised control system was a new concept. During the implementation of the Albion Process™ the milling and flotation plants were integrated into the DCS for fully centralised control from ore feeding to Albion Process™ discharge.

4. Tellurides

   The presence of gold hosted in tellurides was identified during the initial testwork phases and based on drilling would be encountered after a few years of mining primary sulphides. As such, GT designed the Albion Process™ plant to be able to raise the pH to around 9.0 in the last leach reactor allowing oxidation to occur at elevated pH with the aim of oxidising and liberating gold hosted in tellurides. This had the added benefit of conditioning before the CIL which is operated around 10.5. Since the Albion Process™ runs around pH 5.5 this is a simple process transition to make. The lime ring main from the CIL was extended to Albion Process™ leach reactor 9 allowing elevated pH operation and recovery of gold and silver from tellurides. Tellurides have been observed in the feed concentrate ranging from 80 ppm to 1200 ppm. Initially the plant suffered notable reductions in gold recoveries (around 2 to 3 per cent) and was mitigated through the implementation of the elevated pH in the last leach reactor.

COLLABORATION AGREEMENT

During 2017, GPM and Glencore Technology signed a collaboration agreement for the marketing of the Albion Process™ in Russia. This is a significant milestone for the two companies because it allows new companies installing an Albion Process™ plant to leverage off the experience of the collaboration for the implementation of the Albion Process™ plant at GPM. The details of the agreement allow new project personnel to visit the GPM plant to learn more about the Albion Process™ and allows access to the GPM site for training of personnel in operations and maintenance.

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