COMMERCIALISATION OF THE ALBION PROCESS

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ABSTRACT

The Albion Process™ is a combination of ultrafine grinding using Xstrata Technology's IsaMill™, followed by oxidative leaching at atmospheric pressure in a series of reactors designed to achieve high oxygen mass transfer efficiency. The feed to the Albion Process™ is a sulphide concentrate containing base or precious metals, and the Albion Process™ is used to oxidise the sulphide minerals in the concentrate and liberate these metals for recovery by conventional means. The oxidative leach circuit is operated at near neutral pH for treatment of refractory gold and silver concentrates, simplifying plant layout and reducing capital costs. For base metal concentrates, the oxidative leach is operated under acidic conditions.

The Albion Process™ has had a long and varied road from concept to commercialisation. The Albion Process™ technology was originally developed in 1994 by MIM Holdings/Xstrata and is patented worldwide. The idea for the Albion Process™ followed the successful commissioning of the first M3000 IsaMill™ at Mt Isa in 1994. The technology had been seen as strategic by MIM Holdings for the first 12 years of its development and was not offered to clients outside the MIM Holdings group. In 2005, after the Xstrata takeover of MIM Holdings, there was a change in strategic direction, and the technology was offered to external clients, through Xstrata Technology.

Interest in the technology has been very strong, with early licences signed in 2005 for the Las Lagunas Project, and 2006 for the Certej Project. The technology moved into commercial production in 2010 with the commissioning of Xstrata's Albion Process™ plant in Spain (4,000 tpa zinc metal), followed in 2011 by the commissioning by Xstrata of a second Albion Process™ plant in Germany (16,000 tpa zinc metal). The Las Lagunas refractory gold project will be commissioned in 2012, and the GPM Gold refractory gold project will be commissioned in 2013. A fifth Albion Process™ plant for the Certej refractory gold project in Romania is in final Permitting stages.

THE ALBION PROCESS™

The Albion Process™ is a combination of ultrafine grinding and oxidative leaching at atmospheric pressure. The feed to the Albion Process™ is a sulphide concentrate containing base or precious metals, and the Albion Process™ is used to oxidise the sulphide minerals in the concentrate and liberate these metals for recovery by conventional means.

The first stage of the Albion Process™ is fine grinding of the concentrate using Xstrata's IsaMill™ technology. Most sulphide minerals cannot be leached at acceptable rates at atmospheric pressure. The process of ultrafine grinding introduces a high degree of strain into the sulphide mineral lattice. As a result, the number of grain boundary fractures and lattice defects in the mineral increases by several orders of magnitude, relative to un-ground minerals. This introduction of strain lowers the activation energy for the oxidation of the sulphides, and enables leaching under atmospheric conditions. The rate of leaching is also enhanced, due to the increase in mineral surface area.

Fine grinding also prevents passivation of the leaching mineral by products of the leach reaction. Passivation occurs when leach products, such as iron oxides and elemental sulphur, precipitate on the surface of the leaching mineral. These precipitates passivate the mineral by preventing the access of chemicals to the mineral surface. Passivation is normally complete once this precipitated layer is 2 – 3 µm thick. Ultrafine grinding of a mineral to a particle size of 80% passing 10 – 12 µm will prevent passivation, as the leaching mineral will disintegrate prior to the precipitate layer becoming thick enough to passivate the mineral.

After the mineral has been finely ground, the slurry is then leached in agitated tanks specially designed by Xstrata, known as the Albion Leach Reactor. In the Albion Leach Reactor oxygen is introduced to the leach slurry for oxidation at supersonic velocity to improve mass transfer efficiency. The Albion Leach Reactor is designed to operate at close to the boiling point of the slurry, and no cooling is required. Leaching is carried out autothermally, and the temperature of the leach slurry is set by the amount of heat released by the leaching reaction. Heat is not added to the leaching vessel from external sources, and excess heat generated from the oxidation process is removed through humidification of the vessel off gases.

THE ISAMILL™ TECHNOLOGY

The IsaMill™ is a large-scale energy efficient continuous grinding technology specifically developed for rugged metalliferrous applications. Xstrata Technology supplies the IsaMill™ to mining operations around the world, with over 100 mills installed in 9 countries worldwide. The IsaMill™ uses a very high energy intensity of 300kW/m^3 in the grinding chamber, resulting in a small footprint and simple installation. A diagram of the typical components of the IsaMill™ Grinding Plant is shown in Figure 1 and Figure 2.

The grinding media size for the IsaMill™ is within the range 1.5 – 3.5 mm. Media can come from various sources, such as an autogenous media screened from the feed ore, silica sands or ceramic beads.

The IsaMill™ will contain up to eight discs on the shaft, with each disc acting as a separate grinding element. The slurry residence time distribution through the mill approaches perfect plug flow with virtually no short circuiting. This allows the IsaMill™ to be operated in open circuit without the need for cyclones.

The IsaMill™ is available in the following models:

- M1000 (500 kW), capable of throughputs in the range 10 – 16 tonnes per hour
- M3000 (1100 kW), capable of throughputs in the range 20 – 35 tonnes per hour
- M5000 (1500 kW), capable of throughputs in the range 30 – 55 tonnes per hour
- M10000 (3000kW), capable of throughputs in the range 60 – 100 tonnes per hour

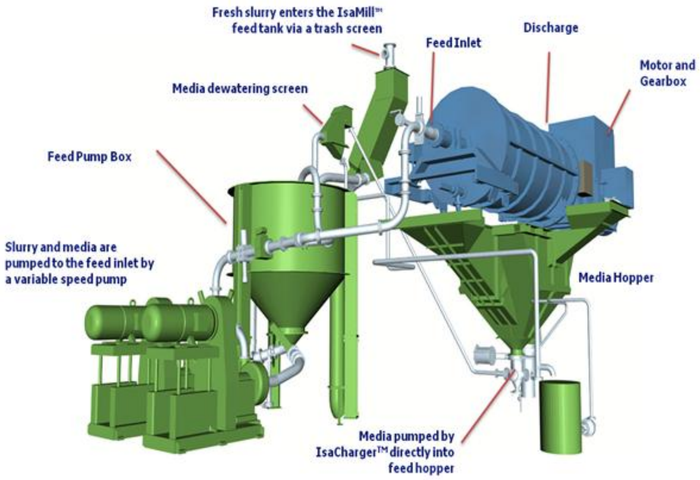

Figure 1
IsaMill™ Key Components

The IsaMill™ produces a sharp size distribution in open circuit, as the feed must pass through multiple distinct grinding zones in series before reaching the Product Separator. This plug flow action ensures no short circuiting, and efficiently directs energy to the coarser feed particles. The Product Separator is a centrifugal separator at the end of the mill shaft that spins at sufficient rpm to generate over 20 "g" forces, and this action is responsible for the sharp classification within the mill. The IsaMill™ can be operated in open circuit at high slurry density, which is a key advantage for the leaching circuit, as the entry of water to the leach is limited, simplifying the water balance.

The IsaMill™ uses inert grinding media that produces clean, polished mineral surfaces resulting in improved leaching kinetics. A steep particle size distribution is produced in the mill, with very little coarse material. The 98 % passing size in the mill is typically less than 2.5 times the 80 % passing size, and very little coarse material enters the leaching circuit, resulting in very high leach recoveries.

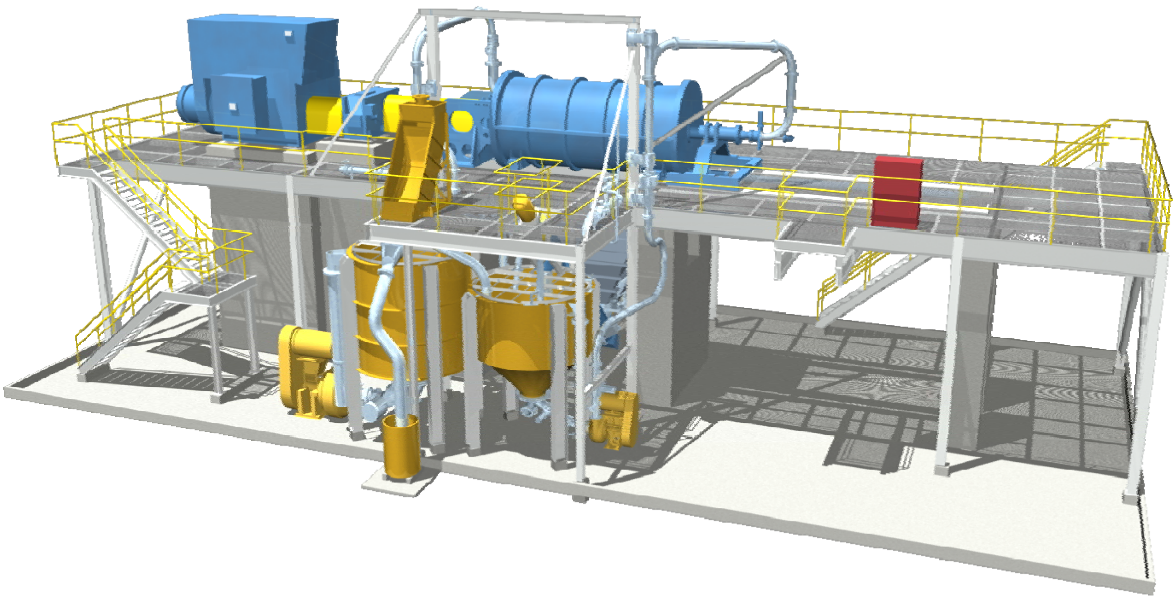

Figure 2
IsaMill™ Grinding Plant Layout

The IsaMill™ is the highest intensity grinding technology available (>300kW/m^3), meaning it is also the most compact, with a small footprint and low profile. The IsaMill™ is oriented horizontally, with the grinding plant accessed by a single platform at an elevation of approximately 3 m. Access to the mill and maintenance is simplified by the low operating aspect of the IsaMill™ and the associated grinding plant. Maintenance of the IsaMill™ is similar to routine maintenance for a slurry pump. The internal rotating shaft is counter-levered at the feed inlet end so the discharge end flange and grinding chamber can be simply unbolted and slid off using hydraulic rams. A shut down for inspection and replacement of internal wear parts takes less than 8 hours. Availability of 99% and utilisation of 96% are typical of the IsaMill™.

Scale-up of the IsaMill™ is straight forward. Laboratory test results are directly scaled to commercial size with 100% accuracy. The IsaMill™ has a proven 1:1 direct scale-up to reduce project risk.

OXIDATIVE LEACHING

After the sulphide mineral has been finely ground, it is then leached under atmospheric conditions in a oxidative leach consisting of interconnected Albion Leach Reactors. The Albion Leach Reactor is an atmospheric leaching tank that has been designed by Xstrata Technology to achieve the required level of oxygen mass transfer to facilitate oxidation of the sulphide feed at low capital and operating cost[1].

The oxidative leaching circuit in an Albion Process™ leach plant is similar to a conventional cyanide leach plant, with the Albion Leach Reactors connected in series with a launder system that allows gravity flow of the slurry through the leach train. All Albion Leach Reactors are fitted with bypass launders to allow any reactor to be removed from service for periodic maintenance. This is a low cost leaching system that is simple and flexible to operate, and the overall availability of the leach train is 99%.

Oxygen is injected into the base of the Albion Leach Reactors using a series of HyperSparge supersonic injection lances. The design of the HyperSparge injection system is carried out in conjunction with the design of the agitation system to ensure high oxygen mass transfer rates are achieved in the reactor. The agitator unit power is moderate, and the reactor is typically designed to achieve a blend time of 1 minute in the tank. The impeller tip speed is chosen in combination with the HyperSparge injection velocity to provide the required mass transfer.

The Albion Leach Reactor has a corrosion resistant alloy steel shell and base, supported on a ring beam or raft foundation. The tank aspect ratio is designed to achieve high oxygen transfer rates and capture efficiencies. Xstrata Technology has developed fully modular tank shell systems, which can be rapidly installed on site in one third the time of a field welded tank and at much lower costs. The Xstrata modular reactor designs require no site welding. The modular Albion Leach Reactor is shown in Figure 3.

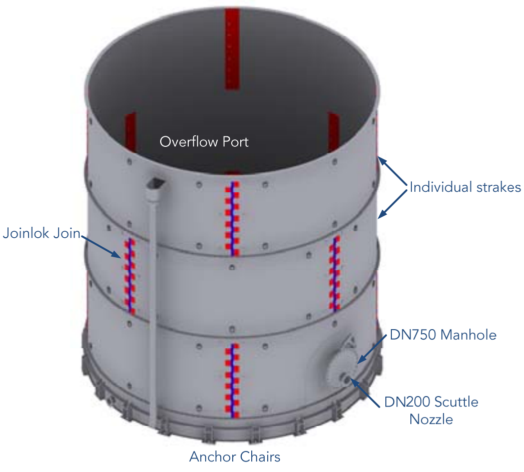

Figure 3
Modular Albion Leach Reactor

The reactor is fitted with a centrally mounted agitator consisting of one or more hydrofoil impellers. The agitator sizing and impeller geometry is chosen by Xstrata Technology using in house design correlations and testwork data to provide sufficient power to meet the oxygen mass transfer requirements in the leach vessel, as well as provide adequate solids suspension and gas dispersal. Impeller arrangements and spacing are also designed to assist in foam control within the vessel. The agitator is mounted off the tank shell, and modular maintenance platforms and structural supports are provided as part of the Albion Leach Reactor. Key design aspects of the agitator, such as the solidity ratio, the impeller diameters and tip speeds and the overall pumping rate are determined in combination with the design of the oxygen delivery system to provide the optimum mass transfer rates in the reactor.

The oxygen delivery system on the Albion Leach Reactor consists of Xstrata's Technology's HyperSparge supersonic oxygen injection lances, which are mounted circumferentially around the reactor, close to the base. The HyperSparge is mounted externally to the tank, and penetrates through the tank wall using a series of sealing assemblies. This novel design means that no downtime is incurred for maintenance of the oxygen delivery system, as all HyperSparge units can be removed live for inspection. The high gas capture efficiencies achieved by the HyperSparge system results in low gas rates entering the Albion Leach Reactor, and so there is little or no correction to the drawn power for the agitator. Aeration numbers are typically less than 0.025.

The HyperSparge injects oxygen at supersonic velocities, typically in the range 450 – 550 m.s^{-1}. The supersonic injection velocities result in a compressed gas jet at the tip of the sparger that incorporates slurry via shear resulting in very high mass transfer rates within the Albion Leach Reactors. The unique design of the HyperSparge means that the agitator power required for the Albion Leach Reactors is much lower than is required in a conventional system. Oxygen capture efficiencies of 85 % or higher are achieved in Albion Plants within the Xstrata group using the HyperSparge system. A typical HyperSparge assembly is shown in Figure 4. The high jet velocities at the tip of the HyperSparge keep the nozzle clean and eliminate blockages.

The HyperSparge can be incorporated in an overall oxygen control system, consisting of in stack off gas monitoring and control of the HyperSparge delivery pressure. The oxygen control system is used to maintain high oxygen capture efficiencies within the Albion Leach Reactor.

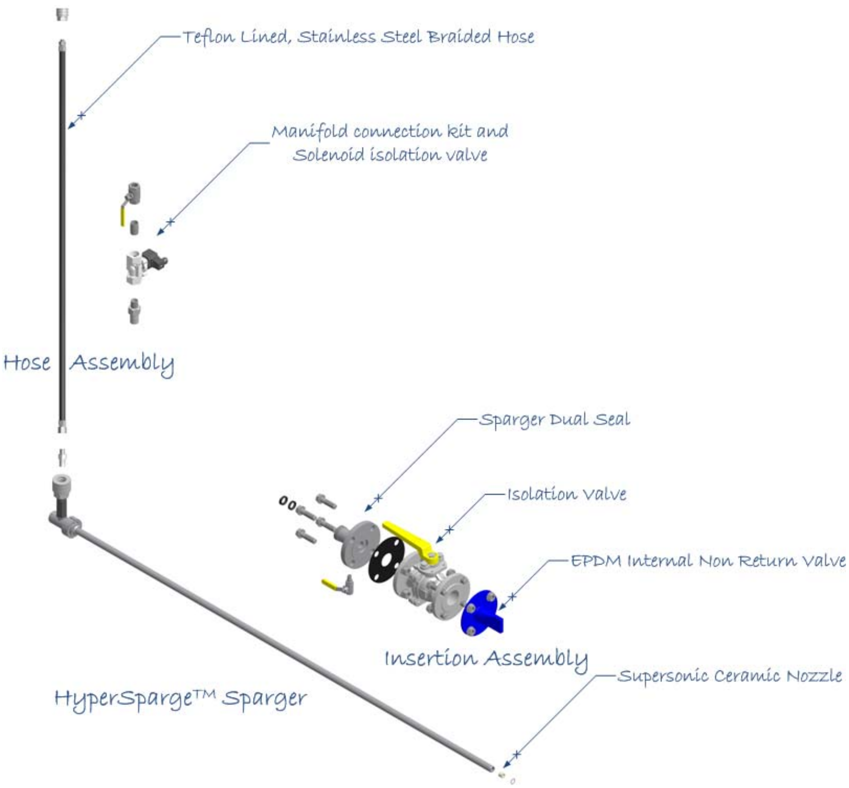

Figure 4
HyperSparge System

Exhaust gas from the oxidative leach is inert, and so the Albion Leach Reactor is fitted with sectional lids and an off gas stack to vent steam from the vessel to a safe working height. As the Albion Leach Reactors operate at close to the boiling point of the slurry, significant water vapour is released from the vessel with the exhaust gas, which assists in overall process water balance. The off gas stack is designed as a natural chimney to vent this exhaust gas to a safe working height. The exhaust gas it typically vented, however condensers can be fitted if required to recover the evaporated water.

Each Albion Leach Reactor has modular Internal baffles to assist mixing and prevent slurry vortexing, as well as a modular slurry riser to prevent slurry short-circuiting and assist in transport of coarser material through the leaching train.

The Albion Leach Reactors are connected to each adjacent reactor via a launder system to transport slurry between the reactors. The launders are designed according to sound hydraulic principles and accomodate both slurry and foam transport. Xstrata Technology's launder design accommodates froth, preventing a build up of foam in the leach train.

No internal heating or cooling systems are required in the Albion Leach Reactors. The vessel is allowed to operate at its equilibrium temperature, which is typically in the range 90 – 98 ^{o}C, depending on site elevation. Heat is provided by the oxidation of the sulphide minerals, with heat lost from the vessel by humidification of off gas. No direct or indirect temperature control is required, simplifying tank construction and maintenance. No external cooling towers or flash vessels are required.

The Albion Process^{TM} oxidative leach has three primary control loops. The major control loop is the leach pH, with either acid or limestone dosed into the reactor to maintain pH to a set point. The pH set point is determined in testwork, and is set by the desired extent of oxidation of sulphide sulphur in the leach. For refractory gold circuits, full oxidation of sulphide to sulphate is desired, and the pH is held at near neutral with the addition of limestone slurry. Limestone is dosed off a ring main.

The slurry density in the reactor is maintained at the optimum level for viscosity and mass transfer control by the addition of process water. Oxygen addition is the third primary control loop, with oxygen gas addition rates through the HyperSparge oxygen delivery system varied based on off gas composition and flow rate. Temperature monitoring is provided, however no temperature control is necessary in the Albion Leach Reactor, and the leach operates autothermally.

Reagent dosing ports are located in the lid of the Albion Leach Reactor with all dosing valves and instruments located in easily accessible positions on the leach tank top platform.

OXIDATIVE LEACH CHEMISTRY FOR REFRACTORY GOLD

The Albion Process^{TM} oxidative leach oxidises sulphide minerals to either elemental sulphur or sulphate. This process liberates significant heat, and the oxidative leach is allowed to operate at a temperature close to the boiling point of the slurry. Typical operating temperatures are in the range 93 – 98 ^{o}C. At these operating temperatures, mineral leaching in the Albion Process^{TM} will occur in two steps. In the first step, the mineral sulphide is oxidised to a soluble sulphate and elemental sulphur. In the second step, the elemental sulphur is then oxidised to form sulphuric acid:

Step 1 $MS + H_2SO_4 + ½\ O_2 = MSO_4 + S^o + H_2O$ (A)

Step 2 $S^o + H_2O + 3/2\ O_2 = H_2SO_4$ (B)

These reactions can be catalysed by the action of ferric iron under acidic conditions.

The oxidative leach can be operated under a range of pH conditions, varying from acidic to neutral. The control pH will set the amount of elemental sulphur oxidation desired via reaction B. The extent of elemental sulphur oxidation can be varied from virtually nil to 100 % by control of the leach pH in the range 1 – 6.

When the oxidative leach is operated under acidic conditions, employed for copper, zinc or nickel leaching, some elemental sulphur oxidation is required to provide acid for the leach. In these systems, the background acidity is held in the range 5 – 15 gpl, and the leach acidity is maintained by either the addition of raffinate, or by allowing Reaction (B), the oxidation of elemental sulphur, to proceed. Elemental sulphur oxidation will proceed readily under the conditions found in the Albion Process^{TM} oxidative leach at acidities below 10 gpl, and slows significantly as the acidity approaches 15 gpl. In this way the Albion acidic leach is self regulating, oxidising elemental sulphur as required to maintain the required acidity.

The acidic leach is a two stage process, where economic metals are first leached in oxygenated acidic solution, with the acidic leach slurry then neutralised to precipitate iron and other deleterious elements such as arsenic, prior to separation of the leached solids and recovery of the economic metals from the neutralised leach solution. Metal recovery can be via conventional processes. Iron removal by goethite precipitation is the preferred neutralisation circuit for Albion Process^{TM} acid leach circuits.

Neutral leaching is used to oxidise pyrite and arsenopyrite concentrates, as well as concentrates containing tellurides and sellenides. The neutral leach is carried out at a pH in the range 5 – 7, with the continuous addition of an alkali to neutralise acid and iron sulphates generated by oxidation of the sulphide metals. All elemental sulphur is converted to sulphate, ultimately in the form of gypsum in the neutral leach. The neutral leach product is suitable for direct feed to a cyanide leach plant, without any filtration, counter current decantation or neutralisation stage, resulting in substantial capital savings relative to an acidic oxidation process.

Under the neutral pH operating conditions, the overall pyrite leach reaction is:

$$FeS_2 + 15/4O_2(g) + 9/2H_2O + 2CaCO_3 = FeO.OH + 2CaSO_4.2H_2O + 2CO_2 \qquad (C)$$

The iron precipitate, goethite, is very stable and has no solubility in cyanide. Albion Process™ oxidative leach residues do not generate ferro or ferri cyanide species in the cyanide leach, simplifying cyanide destruction.

Arsenopyrite is a common gold carrier in many refractory gold concentrates. Depending on the level of arsenopyrite present in the concentrate, arsenopyrite is readily oxidised under the neutral leaching conditions, to form a stable ferric arsenate product.

The overall arsenopyrite leach reaction is:

$$FeAsS + 7/2O_2(g) + 4\ H_2O + CaCO_3 = FeAsO_4.2H_2O + CaSO_4.2H_2O + CO_2 \qquad (D)$$

Some refractory gold concentrates can contain a range of telluride bearing phases, such as AgAuTe, AgTe, PbTe, Pb(Bi)Te, PbAu(Sb)Te. All of these telluride phases contain high levels of gold and silver. Telluride leaching in an oxidative system is enhanced by ultrafine grinding, and is also accelerated under alkaline conditions. Tellurides break down quickly at elevated pH, with oxidation of telluride to $HTeO^{3+}$ and Au^+. The gold and tellurium then precipitate as oxides.

Telluride breakdown occurs rapidly in the neutral leach, according to the following general reaction:

$$AgAuTe + 2O_2(g) = TeO_2 + AuO + AgO \qquad (E)$$

No elemental sulphur is formed under the neutral leaching conditions, and the oxidised residue will have a low cyanide consumption, as thiocyanate formation is avoided.
At high levels of oxidation, the final oxidised residue may be inert, with no residual acid generating components. The neutral pH operating conditions prevent the formation of jarosite, and so silver recoveries from the oxidised residue are high.

The neutral operating pH in the oxidative leach also results in very low background salt levels in the leach solutions. This improves oxygen solubility and significantly reduces the formation of scale in the Albion leach, simplifying operation. Gypsum scale formation is a major concern for neutralisation circuits where the initial tanks operate under acidic conditions. At the operating pH of 5 - 6 the stability of the HCO_3^- ion in solution is very low relative to acidic neutralisation circuits. When neutralising acid, limestone reacts according to the following general reaction:

$$CaCO_3 + H^+ = HCO_3^- + Ca^{2+} \qquad (F)$$

Calcium will precipitate liberated sulphate to form gypsum. High bicarbonate activities seen under more acidic conditions will lower the calcium solubility and push the system closer to super-saturation with respect to gypsum. Bicarbonate activity follows the acidity level inversely, and so the higher the pH, the lower the bicarbonate activity, and hence the lower its effect on gypsum solubility. Ideally, the operating pH for the oxidative leach would be as high as the limestone quality will allow, to minimise scale, however limestone utilisation then ultimately becomes limiting. For this reason, a control set point in the range pH 5.5 – 6.5 is used for the oxidative leach circuit.

DEVELOPMENT HISTORY

As is the case with all new technologies, the Albion Process™ has had a long and varied road from concept to commercialisation. The Albion Process™ technology was originally developed in 1994 by MIM Holdings (MIM) and is patented worldwide [2]. The idea for the Albion Process™ followed the successful commissioning of the first M3000 IsaMill™ at Mt Isa in 1994. The IsaMill™ was developed to provide efficient grinding down to 80 % passing sizes of 5 – 7 microns prior to flotation for Xstrata's complex M^{c}Arthur River and George Fisher lead-zinc deposits.

At that time, MIM were studying options for the development of the large Frieda River/Nena project in PNG through its subsidiary Highlands Pacific. The Nena ores were not amenable to smelting, due to the elevated arsenic content, and several hydrometallurgical options were examined. The option chosen originally was pressure oxidation, as MIM had experience in this operation through its holding in the Porgera joint venture, also in PNG. Feasibility studies indicated that the cost of the pressure oxidation circuit was prohibitive, and so lower cost options were examined. MIM had experience in atmospheric leaching through its joint venture zinc operations in Germany, and the atmospheric leach was seen as a low cost option that was also robust and simple to operate.

Initial batch testwork examining the combination of fine grinding and oxygenated atmospheric leaching began in early 1994, and the testwork was very successful with copper recoveries in excess of 98 % from the chalcopyrite, covellite, enargite mineralogy. Techno-economic studies were carried out with Davy John Brown in late 1994, and the economics of the process compared very favourably with pressure oxidation. The original patents were then filed in 1995

MIM decided to divest its interests in Highlands Pacific in 1996/7 and sold out of the Frieda River joint venture. MIM made a strategic decision at the time to focus future development of the Albion Process™ on refractory gold. The major project targeted was the large Pueblo Viejo project in the Dominican Republic. MIM Holdings evaluated the Pueblo Viejo project between 1997 and 2002, during which time they constructed a 1 tonne per day Albion Process™ demonstration plant in Brisbane that operated continuously for 18 months. This led to the development of a new variation of the Albion Process™, which involved oxidation of pyrite under near neutral pH conditions. Patents for this new process were lodged in 1999.

MIM Holdings competed in the tender process for the Pueblo Viejo project in 2001, however were not successful, with the project being awarded to Placer Pacific, later Barrick GoldCorp, who are now developing this project.

Following the unsuccessful bid for the Peublo Viejo Project, MIM then turned its focus for the Albion Process™ to zinc, and started to develop a project around the large M^{c}Arthur River mine in the Northern Territory. The M^{c}Arthur River mine produces a low grade zinc concentrate containing elevated levels of lead, copper and iron. The deposit is complex, with lead and iron present as fine, sub 3 micron intergrowths within the sphalerite lattice. The IsaMill™ had been instrumental in allowing MIM Holdings to develop the M^{c}Arthur River project, however the ongoing closures of imperial smelting furnaces in the late nineties caused concern about long term placement of the concentrate.

MIM began pilot testing of an Albion Process™ circuit to recover zinc as cathode from the M^{c}Arthur River concentrate in 2001. In the flowsheet developed, zinc was leached in the Albion Process and recovered as cathode using a conventional purification/electrowinning circuit, with lead and silver reporting to a residue that could be sent to a smelter for lead recovery. Development of this project was continued by Xstrata following the takeover of MIM Holdings in 2003, and this has now led to the construction of two Albion Process™ plants in Zinc and Germany. These plants will be discussed in the next section of this paper.

In the period from 1994 until 2004, the Albion Process^{TM} was seen as strategic to the MIM/Xstrata group, and was not marketed externally. In 2005, a decision was made within Xstrata to offer the technology to external clients under licence, and Xstrata appointed a marketing agent – Core Resources, to market the technology globally. Interest in the technology has been very strong in the subsequent period, with early licences signed in 2005 for the Las Lagunas Project, and 2006 for the Certej Project. The technology moved into commercial production in 2010 with the commissioning of Xstrata's Albion Process^{TM} plant in Spain (4,000 tpa zinc metal), followed in 2011 by the commissioning by Xstrata of a second plant in Germany (16,000 tpa zinc metal).

The Las Lagunas refractory gold project will be commissioned in 2012, and the GPM Gold refractory gold project will be commissioned in 2013. A fifth Albion Process^{TM} plant for the Certej Project in Romania is in final Permitting stages. These projects will be reviewed briefly.

XSTRATA ZINC PROJECTS – SAN JUAN DE NEIVA AND NORDENHAM

An Albion Process^{TM} plant was constructed at the San Juan de Neiva zinc refinery in July 2010. San Juan de Neiva is the world's largest zinc refinery, with an annual production of over 450,000 tonnes of zinc. The refinery is owned by Xstrata, and the feed to the Albion Process^{TM} plant is finely ground lead/zinc concentrate from the McArthur River mine in the Northern Territory. The Albion Process circuits employed by Xstrata Zinc are unique, in that the fine grinding stage is located at a different site to the oxidative leach, with the finely ground concentrate transported by sea freight.

Figure 5
Albion Leach Reactor at San Juan de Neiva

The San Juan de Neiva Albion Process^{TM} plant has a throughput of 9000 tonnes per annum of concentrate, ground to a size of 80 % passing 7 microns. The plant produces 4,000 tonnes per annum of cathode zinc from the concentrate, at a recovery of 98.6 % w/w. The leach is an oxygenated sulphuric acid leach, using spent electrolyte from the electrowinning plant.

The McArthur River Lead-zinc concentrate is first re-slurried in spent electrolyte from the electrowinning cellhouse, and the slurry pumped to the oxidative leaching circuit. The oxidative leach consists of 280 m^3 Albion Leach Reactors, with a live height of 9.5 m and a diameter of 6 m.

One of the Albion Leach Reactors, showing the HyperSparge insertion points, is shown in Figure 5.

Concentrate slurry and spent electrolyte are transferred to the Albion Leach Reactors along with residue slurry from the Neutral Leach circuit, which introduces ferrite residues from the Neutral Leach into the Albion leach circuit for oxidation. This allows the Albion Process^{TM} leach circuit to act as a traditional Hot Acid Leach for the recovery of zinc from ferrite residues.

Oxygen is injected into the base of the reactors using 8 HyperSparge supersonic oxygen injection lances, and the slurry is agitated by a centrally mounted dual hydrofoil impeller. Residence time in the oxidative leach circuit is approximately 28 hours.

Sphalerite is the main zinc mineral in the McArthur River concentrate, and is oxidised to form soluble zinc sulphate and elemental sulphur. The reaction consumes acid and oxygen:

$$2\ ZnS + O_2(g) + 2\ H_2SO_4(a) = 2\ ZnSO_4(a) + 2\ S^o + 2\ H_2O \qquad (G)$$

Lead is present in the concentrate as Galena, and is oxidised almost exclusively to lead sulphate, which remains in the leach residue:

$$2\ PbS + O_2(g) + 2\ H_2SO_4(a) = 2\ PbSO_4(s) + 2\ S^o + 2\ H_2O \qquad (H)$$

Some plumbojarosite is formed in the early stages of the leach, however this is converted to lead sulphate as the leach progresses.

The McArthur River concentrate is a relatively low grade zinc concentrate, and contains elevated levels of iron, present as pyrite. Pyrite is slow to leach at the acid levels in the oxidative leach, and will not start to oxidise at a significant rate until over 90 % of the sphalerite is oxidised, due to galvanic effects. The leach reaction for pyrite under the acidic conditions in the oxidative leach is:

$$2\ FeS_2 + O_2(g) + 2\ H_2SO_4(a) = 2\ FeSO_4(a) + 4\ S^o + H_2SO_4(a) \qquad \text{(I)}$$

The elemental sulphur is slow to react under the 40 – 160 gpl acid concentrations in the leach, and less than 5 % oxidation is typical:

$$S^o + 3/2\ O_2(g) + H_2O = H_2SO_4(a) \qquad \text{(J)}$$

The oxidative leach circuit is also used to recover zinc from ferrite phases that do not leach in the existing calcine leaching circuit. The high operating temperature of the leach circuit results in rapid breakdown of the ferrites, according to the reaction:

$$ZnFe_2O_4 + 4\ H_2SO_4(a) = ZnSO_4(a) + Fe_2(SO_4)_3(a) + 4\ H_2O \qquad \text{(K)}$$

The oxidised slurry from the oxidative leach plant processed to recover both the elemental sulphur and the lead as separate products. The slurry is first thickened, and the thickener underflow then treated to recover elemental sulphur in a series of 10 m^3 flotation cells. The flotation concentrate, containing up to 70 % w/w elemental sulphur, is filtered in a plate and frame filter assembly, and the filtrate returned to the thickener circuit. The sulphur concentrate is transferred to the roasting plant and burnt to produce sulphuric acid.

The flotation circuit tailings are filtered in a horizontal belt filter, with the high grade residue then sold to secondary lead recyclers. The filtrate and wash from the horizontal belt filter is returned to the thickener. Thickener overflow reports to the existing jarosite precipitation circuit for iron removal ahead of the zinc dust precipitation circuit and the cellhouse.

Figure 6
Albion Leach Reactor at Nordenham

Following the success of the first Albion Process™ plant at San Juan de Neiva, Xstrata then constructed a second Albion Process plant at the Nordenham zinc refinery. This plant was commissioned in March 2011. The feed to the plant is also finely ground lead/zinc concentrate from the McArthur River mine, and the process flowsheet is similar to that employed at San Juan de Neiva.

The Nordenham Albion Process™ plant has a throughput of 36,000 tpa of concentrate, and the plant produces 16,000 tpa of cathode zinc from the concentrate, at a recovery of 98.8 % w/w.

The oxidative leach consists of an 800 m^3 and a 280 m^3 reactor in series. The 280 m^3 reactor is similar in geometry to the San Juan de Neiva leach reactor, and the 800 m^3 has a height of 13.6 m and a diameter of 9 m. Oxygen is injected into the base of the both reactors using HyperSparge supersonic oxygen injection lances, and the slurry is again agitated by a centrally mounted dual hydrofoil impeller. A picture of the Nordenham Albion Process™ oxidative leach is shown in Figure 6.

The lead residue from the Nordenham Albion Process™ plant is also sold locally to secondary lead producers.

A summary of the key operating data for the two Xstrata Zinc Albion Process^{TM} plants is presented in Table 1.

Table 1
Summary Data for the Xstrata Zinc Albion Process^{TM} Plants

Parameter	**San Juan de Neiva**	**Nordenham**
Feed Rate - tph		
MRM Concentrate	1	4
Neutral Leach Residue	0.25	1
Concentrate Composition		
Zinc - %	47.2%	47.2%
Lead - %	8.17%	8.17%
Iron - %	5.4%	5.4%
SiO_2 - %	4.3%	4.3%
Copper - %	0.8%	0.8%
Sulphur - %	47.2%	47.2%
Tank Size – m^3	280	800, 280
Leach Recovery - % w/w	98.6	98.8
Conversion to elemental sulphur	<5	<5
Leach acid demand – kg/tonne	488	470
Leach oxygen demand – kg/tonne	209	214
Residue Composition		
Sulphur - %	43	42
Zinc - %	1.3	0.8
Lead - %	15.5	16.2
Iron - %	8.4	8.1
SiO_2 - %	7.5	7.1
Copper - %	0.20	0.20

PANTERRA GOLD – LAS LAGUNAS

The Las Lagunas project is a refractory gold and silver project owned by Panterra Gold Limited. The project involves the reprocessing of high grade gold/silver pyritic CIL tailings from prior operation of the Rosario mine in the Dominican Republic. The Project is 15 km west of the provincial capital of Cotui and approximately 100 km northwest of the national capital of Santo Domingo. The lease is adjacent Barrick Gold Corp’s Pueblo Viejo gold mine.

The tailings dam was constructed in 1991, and was filled with sulphide tailings from open pit operations at the Rosario mine between 1992 and 1999. The Rosario mine was operated by Rosario Dominicana S.A, a mining corporation owned and operated by the Dominican government. Oxide reserves at the mine were depleted in the late eighties, with the feed to the plant containing increasing levels of sulphides, present primarily as pyrite, with minor enargite. The host rock was predominantly lithic tuff, with minor carbonaceous shales.

Operations at the Rosario mine were put on care and maintenance in 1999 due to the increasingly refractory nature of the ore. At the time of closure of the mine, gold and silver recoveries in the carbon in leach plant had fallen to below 30 %, with the unrecovered gold present as sub-microscopic inclusions in pyrite. Treatment of these increasingly refractory ores in the early nineties resulted in significant tonnages of tailings with +3.5g/t gold being stored in the Las Lagunas dam.

PanTerra Gold's subsidiary, EnviroGold (Las Lagunas) Limited, won an international tender and signed a Contract with the Dominican State in 2004 giving it the right to reprocess the tailings under a profit sharing agreement with the Government. The project has a JORC Indicated Resource of 5.137mt of ore grading 3.8g/t gold and 38.6g/t silver.

Annual production from the project will be 65,000 ounces per annum of gold and 600,000 ounces per annum of silver. The project contains significant silver revenue, and the neutral Albion Process^{TM} oxidative leach was chosen for the project, due to the high gold and silver recoveries from the oxidised residue. The process flowsheet was developed by Xstrata Technology with testwork carried out Xstrata's research facilities in Brisbane in 2004 – 2006.

Construction at the project was completed in the first quarter of 2012, and the project is currently being commissioned. Capital costs for the project were approximately $US 82.7 million, and the operating cost is projected at $US 30.68 /tonne, resulting in a cash cost of about $US 307 per ounce of gold equivalent produced.

The process flowsheet consists of an electric dredge to recover 100 tph of tailings from the dam. The dam is also used to re-deposit treated tailings and is mined in cells. Slurry from the dredge is stored in a 223 m^3 stock tank prior to being pumped to a 700 kW ball mill to freshen the mineral surfaces prior to flotation. The slurry is then processed through a series of flotation cells to recover a sulphide concentrate grading on average 14 g/t gold and 125 g/t silver, with 16 % w/w sulphide sulphur. A single bulk rougher stage is used, consisting of five flotation cells with a volume of 40m^3 each.

Figure 7
Las Lagunas IsaMill Grinding Plant

The flotation concentrate is produced at a rate of 28 tph and is thickened in a high rate thickener prior to being fed to the Albion Process^{TM} Plant. The Albion Process^{TM} plant consists of an M3000 IsaMill^{TM}, with an installed power of 1.5MW and a series of five 600 m^3 stainless steel Albion Leach Reactors. Each Albion Leach Reactor is fitted with 12 HyperSparge supersonic oxygen injection lances, and operates at a pH of 5.5 with continual dosing of limestone slurry. Limestone is dosed into each Albion Leach Reactor off a central ring main. Limestone for the Albion Process^{TM} circuit is quarried from an historic limestone quarry.

The Albion Process Plant operates under near neutral pH conditions, with the pyrite oxidised to goethite, and all sulphide reporting as gypsum. Gold recoveries from the oxidised residue will be above 90 %, and as no jarosites are formed in the leach circuit, silver recoveries are also above 90 %. The leach operates autothermally at a temperature of 98 ^{o}C, and exhaust gas is vented from the reactors via exhaust stacks.

Figure 8
Las Lagunas Oxidative Leaching Plant

The oxidative leach plant was sized to oxidise 80 - 85 tonnes per day of sulphide to sulphate. Oxygen is supplied to the Albion Process^{TM} Plant from a 220 tpd VPSA oxygen plant owned and operated by Panterra Gold. A photograph of the M3000 IsaMill Grinding Plant for the Las Lagunas project is shown in Figure 7. A photograph of the Albion Leach Reactors, showing the reactor shell, HyperSparge insertion nozzles and the off gas vent stacks is shown in Figure 8.

Oxidised residue from the Albion Process^{TM} Plant is thickened to approximately 45 % w/w and the thickener underflow cooled in a slurry cooling tower from 80 ^{o}C to 45 ^{o}C prior to the cyanide leach. The cooled underflow is transferred to a conventional Cyanide Leach circuit. The CIL circuit consists of one 496 m^3 neutralization tank and 6 x 441 m^3 Carbon-in-Leach (CIL) tanks and an AARL elution circuit. Tailings from the CIL circuit are returned to a sectioned cell within the tailings dam.

GPM GOLD PROJECT

The GPM Gold Project is owned by GeoProMining Gold LLC (GPM) and is located in Armenia. The Project consists of an open cut mine at Zod, near the Azerbaijan border, and a processing plant at Ararat near the Turkish border. The gold bearing ore, mined at the Zod Mine, is transported to the Ararat Process Plant via a state owned rail link.

The metallurgical facility at Ararat was originally constructed by the Soviets in 1973 and acted as a central processing facility to treat pyritic gold ores, with flotation concentrates produced at the site and sent to Russia for gold recovery. The project was purchased by First Dynasty Mines in the early 1990's and a CIL plant was constructed and commissioned in 1997 to recover gold from the concentrator tailings. All plant and equipment are still operating at the Ararat site, and will undergo refurbishment as part of the project. The project was briefly owned by Sterlite Gold in the early 2000's and was taken over by GPM in late 2007. GPM have been treating low sulphide ores and gabbro from the Zod mine in the intervening period.

The Zod deposit originally consisted of free milling weathered oxide ores overlying deeper sulphides. Historical mining has depleted the oxide ores, and the Ararat Process Plant now treats sulphide ore with declining gold recoveries. To improve the gold recovery from sulphide ores, GPM will install an Albion Process™ Plant at the Ararat Process Plant.

The remaining deposit has an average sulphur grade of 1.4 % w/w, with an average gold grade of 4.54 g/t and silver grade of 4.65 g/t. Of the remaining minable reserves, less than 30 % of the gold is free milling, with the remainder housed within the sulphides and telluride phases. Within the sulphide phases, gold is preferentially associated with arsenopyrite, and to a lesser extent pyrite. The arsenic grade across the deposit is 0.3 % w/w.

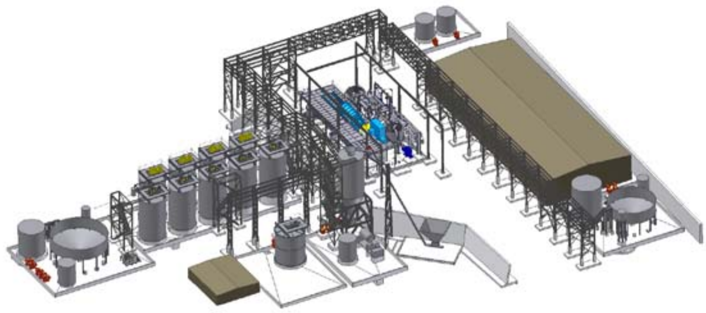

Figure 9
GPM Gold Albion Process™ Plant

Run of mine ore will be ground through parallel milling lines consisting of one AG and two ball mills, with the ground slurry then processed through a flotation circuit to recover a sulphide concentrate. The flotation circuit will consist of a bulk rougher/scavenger float followed by a cleaner stage. Cleaner Concentrate will then be transferred to the Albion Process™ Plant for oxidation ahead of the CIL circuit.

Mill tailings will also report to the CIL plant, and be blended with the oxidised residue prior to processing. The comminution circuit already exists at the project site, having been initially installed in 1976, and will undergo modernisation as part of the project. Components of the flotation circuit exist at the site, and will be refurbished as part of the project as well. Xstrata Technology is providing the detailed design services for the refurbishment of the flotation circuit. The CIL circuit will also undergo partial modernisation as part of the project.

The average throughput for the Albion Process™ Plant will be 94,007 tpa of Cleaner Concentrate, with a design factor of 15 % applied to the nominal rate to achieve a design rate of 108,108 tpa. The cleaner concentrate will grade 20 % w/w iron, 18 - 20 % w/w sulphide and 2.5 – 3.5 % w/w arsenic. The concentrate will grade approximately 40 g/t gold and 35 g/t silver. An Isometric of the Albion Plant for the GPM Gold Project is shown in Figure 9.

Cleaner Concentrate will be ground to an 80 % passing size of 11.1 µm in an M3000 IsaMill™, with an installed power of 1,120 kW. Ground concentrate will be transferred to the oxidative leaching circuit. The oxidative leach circuit volume will be based on a residence time of thirty (30) hours and the Leach circuit will consist of nine Albion Leach Reactors with a volume of 225 m^3 each.

Each Albion Leach Reactor will be fabricated from LDX 2101 alloy and will be agitated by a centrally mounted agitator fitted with dual hydrofoil impellers. The impeller assembly will be designed to provide the required gas hold up and solution pumping rate to ensure efficient reaction within the tank. The Albion Leach Reactors will be identical, and will all be supplied by Xstrata Technology using the ZipaTank™ modular construction system. The ZipaTank™ will be supplied in fully fabricated modular sections for assembly on site. Skilled artisans are rare in Armenia, and so modular construction techniques will be widely used across the plant.

Oxygen will be added to each leach tank via banks of 9 HyperSparge™ oxygen spargers from dual 60 tpd VPSA oxygen plants. The pH in each Albion Leach Reactor will be maintained by dosing of limestone slurry into the reactor. Limestone will be dosed into the Albion Leach Reactors off a central ring main. The project will have a 6 tph limestone milling and distribution circuit that will mill minus 20 mm limestone to 80 % passing 75 microns for dosing into the oxidative leach. Coarse limestone will be sourced from a cement plant located 3 km to the east of the plant site.

Overflow slurry from the Albion Process™ oxidative leach circuit will gravitate by launder to a 10 m diameter free standing thickener, and thickened slurry, at 41 %w/w solids will be pumped to the CIL plant and blended with mill tailings. Gold recovery from the oxidised residue will be 93 – 96 % w/w, with a silver recovery of 90 - 93 % w/w.

Xstrata Technology is providing the full design and equipment supply for the Albion Process™ plant to the GPM Gold project as a fixed price package. The scope of work also includes the limestone milling and distribution circuit as well as the oxygen plant. Civil and structural works have begun at the plant site, with plant commissioning scheduled to begin in March, 2013.

CERTEJ PROJECT - ROMANIA

The Certej project is located in Western Romania, in the “Golden Quadrilateral” area of the Apuseni Mountains of Transylvania. The project is 12km from the regional town of Deva, and close to the town of Certej. European Goldfields owns 80% of the project through its subsidiary Deva Gold S.A. There is an existing open pit mine at the project site that was operated by the Romanian State mining entity Minvest, until 2006. Ore from the mine was processed in a comminution and flotation facility located at Certej. Deva Gold holds a valid operating permit for the mine.

The Certej deposit is a low to medium sulphidation epithermal deposit. The major sulphide minerals are pyrite with minor levels of arsenical pyrite. Copper and zinc sulphides are present in the ore and report to the flotation concentrate. The gold is present mostly as sub-microscopic inclusions in the pyrite and arsenical pyrite matrix.

The project involves the open cut mining and processing of 3 million tonnes of ore per annum over a project life of eleven and a half years. The project will yield approximately 160,000 oz of gold and 820,000 oz of silver per year in the form of doré, reflecting an average total process recovery of 81% for gold and approximately 75% for silver.

The process flowsheet consists of a comminution circuit and flotation plant to recover the sulphide minerals to a concentrate that is fed to the Albion Process™ Plant. The comminution circuit will consist of a crushing plant and SAG and Ball mills grinding to 80 % passing 106 microns. Ground ore will be floated in a rougher/cleaner flotation circuit producing 28 tph of pyrite concentrate. The concentrate will grade 35 % w/w iron, 43 % w/w sulphide and 0.5 % w/w arsenic. The concentrate will contain approximately 15 - 18 g/t gold and 90 g/t silver.

The Albion Process plant will consist of an M10000 IsaMill™, with 3000 kW of installed power and a series of five 1500 m^3 Albion Leach Reactors. The ground product from the M10000 IsaMill™ will have an 80 % passing size of 11.5 microns. The Albion Process Plant will be sized to oxidise 180 tonnes per day of sulphide to sulphate.

As the feed to the plant is a refractory pyrite concentrate, the Albion Process^{TM} Plant will operate under near neutral pH conditions, with the pH maintained by the addition of limestone slurry to the reactors off a central ring main. Limestone will be quarried locally. Oxygen will be supplied to the Albion Process^{TM} circuit from a 520 tpd Cryogenic oxygen plant owned and operated by European Goldfields, at a purity of 95 % v/v.

Oxidised residue from the Albion Process^{TM} Plant will be thickened and the thickener underflow cooled in an open void slurry cooling tower. The cooled underflow will then be transferred to a conventional Cyanide Leach plant operating with an INCO cyanide destruct circuit to recover the precious metals. Gold recovery from the Albion Process^{TM} oxidised residue will be 93 % w/w.

The level of pyrite oxidation targeted in the Albion Process^{TM} Plant will be 70 - 75 %, with less than 5 % expected oxidation of the copper and zinc sulphides under the near neutral pH operating conditions. The oxygen consumption will be 270 kg/tonne of Cleaner Concentrate, with a limestone consumption of 450 kg/tonne.

Basic engineering for the Certej project was completed in 2008, and the project is currently undergoing final permitting. Detailed design for the project is expected to begin in 2012.

ENGINEERING CHALLENGES ON THE ROAD TO COMMERCIALISATION

THE ISAMILL^{TM}

The IsaMill^{TM} was developed as a joint project between MIM Holdings and Netzsch GmbH of Germany in the early 1990's, with the first commercial mill installed at Mt Isa in 1994. The IsaMill^{TM} was a revolutionary concept in grinding, extending the economic range for grinding down to 80 % passing 5 – 7 microns. The development of the IsaMill^{TM} presented a host of engineering challenges.

The first engineering challenge in the design of the IsaMill^{TM} was how to impart energy to the fine media required for grinding to fine sizes. Media sizes in the range 2 – 5 mm were required to achieve the 80 % passing 5 – 7 micron grind sizes originally targeted in the IsaMill^{TM}, and traditional tumbling mills will begin to centrifuge the ball charge at media sizes of less than 30 – 35 mm.

Agitated mills were originally developed to overcome the tendency for the media charge to centrifuge, and the Tower Mill and Metprotech mill were early variations. These mills extended the range of grinding media down to 10 – 12 mm, however neither mill could agitated a media bed at finer sizes without significant expansion of the media charge or centrifuging.

To overcome the problems associated with bed expansion and centrifuging, the IsaMill^{TM} was developed with an agitator that consisted of a series of flat discs at right angles to a central shaft. This agitation system can be thought of as a zero pumping head impeller, and so all energy is transferred to the media change by shear, rather than by generation of flow. The shaft sits horizontally within a bed of media retained in a cylindrical shell. The discs were designed with holes toward the midline of the disc to allow slurry circulation around the disc. These holes result in a localised circular slurry eddy between each disc. The combination of 7 to 8 of these slurry flow paths in a typical IsaMill^{TM} results in almost perfect plug flow through the mill. For this reason, the IsaMill^{TM} can be operated in open circuit, without the need for cyclones.

The horizontal configuration chosen by the designers of the IsaMill^{TM} also overcame the significant breakout torque typical in the vertically oriented Tower Mill and Metprotech mill. The breakout torque results from the mass of the media charge sitting vertically on the bottom impellers on the shaft. The horizontal mill layout, and the use of the disc style agitators resulted in virtually no breakout torque requirement for starting the mill.

The horizontal alignment of the mill shaft itself introduced several engineering hurdles, with the mill shaft designed as a cantilevered element, with no steady bearing at the end of the shaft and the shaft weight supported by a single bearing assembly. The shaft is immersed in the slurry and so requires sealing. Several sealing options were trailed, with the mill designers settling on a packed gland, similar in design to a centrifugal slurry pump.

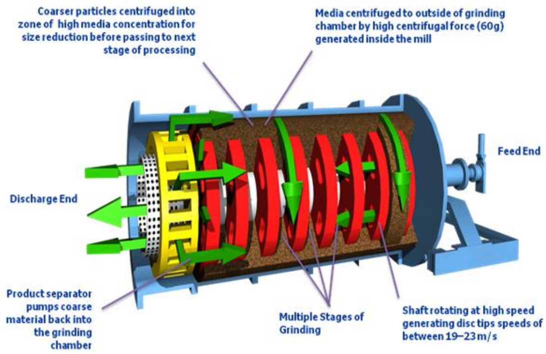

Figure 10
IsaMill^{TM} Operating Mechanism

Media retention within the IsaMill^{TM} was another significant design challenge. Early developments tested screens mounted internally within the mill to retain media and allow the slurry to flow, however these were prone to blockages. The solution to this was elegant, with a change in the final disc geometry and type at the end of the IsaMill^{TM} shaft. The shaft was fitted with an expeller at the end of the shaft, and the distance between the final disc and the expeller was shortened to provide centrifuging of the media bed between the expeller and the final disc. This arrangement is termed the Product Separator. The Product Separator is a very efficient internal classification device, generating up to 20 "g" forces, and provides a very sharp cut size, retaining media within the mill while allowing slurry to flow out of the mill readily. The pressure drop across an IsaMill^{TM} is typically less than 200 kPa. The operating principal for the Product Separator is shown in Figure 10.

Development of the IsaMill^{TM} is ongoing, with Xstrata Technology continually refining aspects of the mill design. Significant work is currently ongoing into new types of wear components to extend disc and liner life within the mill, as well as design of a larger mill, with an installed power of 8 MW.

OXIDATIVE LEACH

The main design challenge of the Albion Leach Reactor is to construct a system capable of achieving the oxygen mass transfer rates required to take advantage of the rapid leach kinetics possible with the finely ground IsaMill^{TM} product. Mass transfer rates in the range 3 – 5 kg.m^{-3}.h^{-1} are required in the oxidative leach. These mass transfer rates correspond to mass transfer coefficients in the range 0.5 – 0.9 s^{-1}.

In conventional atmospheric oxidation systems, such as bacterial leach reactors and fermentation vessels, mass transfer is achieved by shear created by differential acceleration between the gas and slurry phase. The rotational speed of the agitator is used to generate shear. Agitator power is proportional to the agitator tip speed cubed, and so power demand increases as a power law for modest increases in shear and mass transfer requirement.

The power per unit volume required to achieve mass transfer rates in this range is of the order of 2 – 5 kW.m^{-3} of slurry[5]. Agitator tip speeds are in the range 5 – 8 m.s^{-1}, and so the velocity profiles created in the slurry phase are below 10 m.s^{-1} at the tip of the agitator blade, and dissipate as the slurry moves away from the blade. The Albion Leach Reactor is designed to achieve the required oxygen mass transfer rates at a tenth of this power input.

A different approach was taken in the design of the Albion Leach Reactor to lower the power demand. In the Albion Leach Reactor, gas injection at supersonic velocities is used to create the bulk of the shear within the vessel. Gas injection velocities of the order of 500 m.s^{-1} are typical of the HyperSparge oxygen injection lance, compared to the 4 – 8 m.s^{-1} achieved with a typical agitator. Supersonic oxygen injection is a far more efficient method of generating shear than conventional agitation, allowing the total power input into the vessel to be significantly reduced.

The duty requirement for the agitator is reduced, and the agitator tip speed can be decreased, lowering the agitator power draw. Solids suspension in the oxidative leach is not onerous due to the finely ground feed and the slurry is typically homogenous and can be considered non-settling.

Oxygen mass transfer rates are described by the following equation:

$$dO_2/dt = k_L a\ (C_{sat} - C)$$

where:

k_L = liquid film mass transfer coefficient for oxygen into solution ($m.s^{-1}$)
a = the specific gas surface area, which is the ratio of bubble surface area to water volume ($m^2/m^3 = m^{-1}$).
C_{sat} = the solubility of oxygen in the slurry at saturation ($g.m^{-3}$)
C = the steady state oxygen level in the slurry ($g.m^{-3}$)

Typically, the k_L and *a* terms are combined to represent the mass transfer coefficient for the system – the $k_L a$. It is the $k_L a$ term that is most affected by the shear rates in the vessel.

The solubility of oxygen in the slurry at saturation, C_{sat}, is set by the operating temperature of the leach, the hydrostatic pressure in the leach reactor and the leach chemistry. The oxidative leach is designed to maximise the solubility of oxygen in the slurry. The aspect ratio of the leach reactor is increased to provide a higher hydrostatic pressure at the base of the tank to improve the value of the saturated oxygen solubility. The optimum aspect ratio is typically in the range 1.2 – 1.5. Above this range, vessel construction costs tend to increase and outweigh the process benefits achieved with a deeper reactor.

In the Albion Process™ neutral leach, the low dissolved salt background also enhances the saturated oxygen solubility. Total dissolved salt levels are of the order of 25 – 35 $g.l^{-1}$, compared to the 200 – 300 $g.l^{-1}$ typical of acidic leach solutions.

The balance between agitator power and oxygen sparger power is a complex, and is also one of the main testwork outcomes in an Albion Process™ development program. The $k_L a$ value for the Albion Leach Reactor is measured during pilot testwork by measuring the rate of increase of oxygen content in the oxidative leach slurry under a specific set of conditions relating to the impeller and HyperSparge. The testwork considers both the final planned size and aspect ratio of the commercial vessel, as well as the HyperSparge supersonic oxygen injection system. Xstrata Technology has dedicated testwork facilities in Brisbane to collect this essential data prior to reactor design. A range of final slurry chemistries is normally evaluated to provide a robust system that can cope with variations in concentrate composition over the life of the project.

During the Albion Process™ development program, a mass transfer correlation is developed for the leach system of the following form:

$$k_L a = A * [P_{total}/V]^{\alpha} * [U_s]^{\beta}.\ C^{T}$$

where:

$k_L a$ = the mass transfer coefficient for the reactor
V = vessel volume in m^3
U_s = Superficial gas velocity in $m.s^{-1}$
P_{total} = Supersonic sparger input power + impeller power input in $kW.m^{-3}$
C = Temperature constant for the system
T = operating temperature

The balance between the HyperSparge operating conditions and the agitator power and flow requirements is then designed based on this correlation.

The design basis for the Albion Leach Reactor used by Xstrata Technology has been proven to be sound, with above design mass transfer rates achieved with very difficult leach chemistry in both the Spanish and German Albion Process^{TM} plants, at oxygen capture efficiencies of up to 85 %.

Injection of oxygen into a near boiling slurry also presents several design challenges. The time taken to saturate a gas bubble within a near boiling system is less than 1 second[4], and so the injected gas rapidly expands in volume to equilibrate the water vapour pressure at the operating temperature of the reactor. This can lead to ventilated cavities within the tank at high shear zones, such as the impeller and sparger tips. The agitation system needs to be designed for these gas loads, and an impeller must be chosen that can maintain power draw under gassing. Deep downward pumping hollow blade radial flow impellers are preferred. Upward pumping hydrofoils may also be suitable under these gas loads, however this system has not yet been tested commercially. Dual impellers are typically employed due to the aspect ratio of the tank, and so careful consideration must be given to the relative impeller diameters to limit the development of zones of high void fraction within the reactor.

The use of the HyperSparge supersonic injection lance also helps considerably with the injection of oxygen into the near boiling slurry. Oxygen is presented as a coherent jet by the sparger, rather than as individual bubbles, and a significant degree of the oxygen mass transfer occurs prior to the jet resolving into a bubble cloud. This limits the final volume of gas presented to the agitation system.

The heat balance across the Albion Process^{TM} oxidative leach is set by the rate of oxidation of the sulphide minerals. Slurry density is generally allowed to vary down the train to maintain a relatively constant temperature profile across the oxidative leach circuit, and tanks will typically operate in the range 95 – 98 ^{o}C. No cooling is employed within the reactors, with temperature maintained entirely by the evaporation of water from the system through humidification of off gas. No cooling coils or heat exchangers are required.

The vessel temperature will approach boiling, however cannot reach the boiling point in a gas sparged system. Gas bubbles formed in the reactor will consist of a mixture of oxygen, carbon dioxide, nitrogen and steam. The partial pressure of the water vapour will be lower than the pressure at which water would boil due to the un-reacted gases present. A steady state equilibrium will be established in the Albion Leach Reactor at a temperature below the boiling point of water at the plant elevation. This is typically 2 – 3 degrees below boiling for a well insulated tank, or lower for only partially insulated tanks.

The relative number of HyperSparge emplacements in each Albion Leach Reactor is also varied to provide a balanced rate of heat release from each tank in the train. The evaporated water reports to the leach tank exhaust gas, and this is vented from the leach tank via a natural draft chimney. Albion Leach Reactors are covered with a sectioned panel lid to capture the exhaust gas and direct it to the natural draft chimney.

The Albion Process^{TM} oxidative leach circuit can be operated under a range of acidities, and materials of construction are tested during the batch testwork and pilot plant phases. Xstrata Technology has an extensive database of suitable materials for Albion Process^{TM} plant applications.

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