

ALBION PROCESS™ SIMPLICITY IN LEACHING

INTRODUCTION TO THE ALBION PROCESS



ALBION PROCESS™



xstrata
technology

1 General Albion Process™ Description

The Albion Process™ is a combination of ultrafine grinding and oxidative leaching at atmospheric pressure. The feed to the Albion Process™ is a 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 Albion Process™ technology was developed in 1994 by Xstrata PLC and is patented worldwide. There are three Albion Process™ plants currently in operation. Two plants treat a zinc sulphide concentrate and are located in Spain (4,000 tpa zinc metal) and Germany (18,000 tpa zinc metal). A third Albion Process™ plant is operating in the Dominican Republic treating a refractory gold/silver concentrate, producing 80,000 ounces of gold annually. A photograph of the Las Lagunas IsaMill™ and oxidative leaching circuit is shown in Figure 1. Xstrata Technology is currently completing the design and supply of an Albion Process™ plant for the GPM Gold Project in Armenia. Procurement has begun for this project, with civil works on site advanced. The GPM Gold Project will commission in September, 2013.



Figure 1
Las Lagunas Albion Plant

The first stage of the Albion Process™ is fine grinding of the concentrate. Most sulphide minerals cannot be leached under normal atmospheric pressure conditions. The process of ultrafine grinding results in a high degree of strain being introduced 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. The 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 increased mineral surface area.

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.

Fine grinding also prevents passivation of the leaching mineral by products of the leach reaction.

Passivation is normally complete once the 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. This is illustrated in Figure 2.

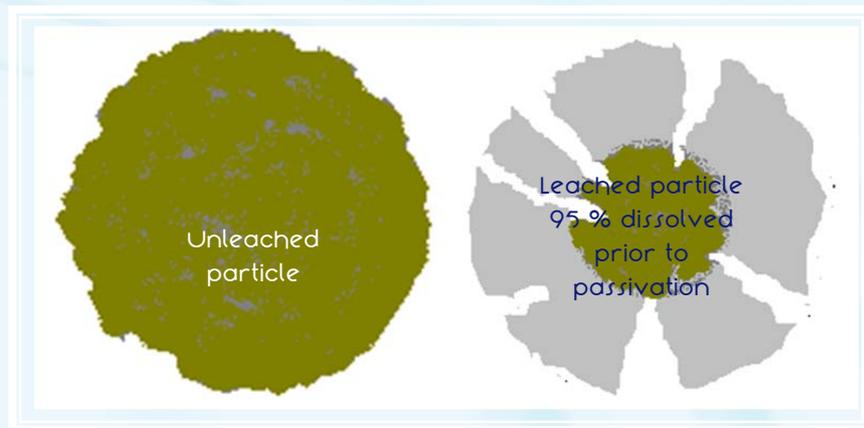


Figure 2
Mechanism of Passivation of Sulphide Minerals

After the concentrate has been finely ground, the slurry is then leached in agitated vessels, and oxygen is introduced to the leach slurry to oxidise the sulphide minerals. The agitated leaching vessels are designed by Xstrata and are known as the Albion Leach Reactor. The Albion Leach Reactor is agitated using dual hydrofoil impellers and oxygen is introduced to the leach slurry at supersonic velocity to improve mass transfer efficiency and ensure efficient oxidation of the sulphides. 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.

2 Ultrafine Grinding and the IsaMill™ Technology

Ultrafine grinding requires a different milling action than found in a conventional ball mill, due to the fine nature of the grinding media required. In most ultrafine grinding mills, an impeller is used to impart momentum to the media charge. Media is agitated through stirring, and the resulting turbulent mixing overcomes the tendency of fine media to centrifuge. Abrasion is the major breakage mechanism in a stirred mill. The common aspects of a stirred mill are a central shaft and a series of impellers attached to the shaft. These impellers can be pins, spirals, or discs. In stirred mills, two configurations are common. In the first, the mill shaft and grinding elements are set up vertically within the mill. This type of configuration is limited in size to typically 750 kW of installed power or less. This limitation is brought about by the large break out torque imposed on the impeller located at the base of the media charge, due to the compressive load of media sitting vertically on the impeller.

In the second configuration the mill shaft is aligned horizontally within the mill chamber. This configuration, which is used in Xstrata's IsaMill™, is more cost efficient at motor sizes in excess of 500 kW. There is very little break out torque required to begin to agitate the media charge, which limits the motor size to that required for grinding only.

The IsaMill™ is a large-scale energy efficient continuous grinding technology specifically developed for rugged metalliferrous applications. Xstrata supplies the IsaMill™ technology 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/m³ in the grinding chamber, resulting in a small footprint and simple installation. The IsaMill™ can be scaled up directly from small scale laboratory tests. Xstrata's IsaMill™, is installed in more than two-thirds of the world's metalliferrous ultrafine grinding applications. The grinding media size for the IsaMill™ is within the size 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.

Xstrata will provide the IsaMill™ as a packaged Grinding Plant, consisting of the mill, slurry feed and discharge systems, media handling system, all instrumentation and control and all structural steel and platforms. Some of the IsaMill™ Grinding Plant components are shown in Figure 3 and 4. The IsaMill™ Grinding Plant incorporates all of Xstrata's operational and design experience gained from over 100 IsaMill™ installations, ensuring a trouble free commissioning.

The IsaMill™ will contain up to eight discs on the shaft, with each disc acting as a separate grinding element. The operating mechanism for the IsaMill™ is shown in Figure 5. This allows the IsaMill™ to be operated in open circuit without the need for cyclones. 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.

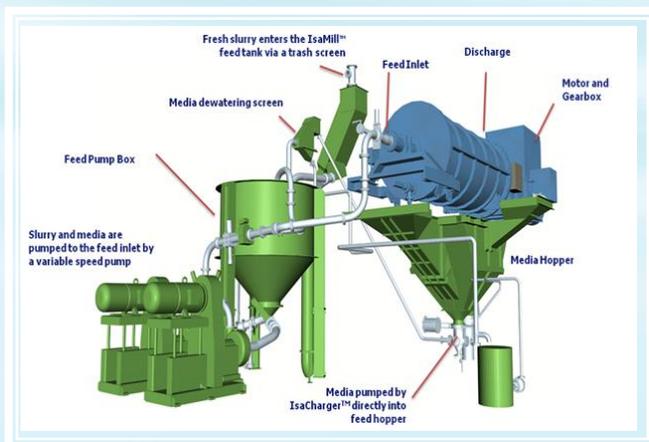


Figure 3
IsaMill™ Feed and Media Systems

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.

The IsaMill™ is the highest intensity grinding technology available (>300kW/m³), 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 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. The 98 %

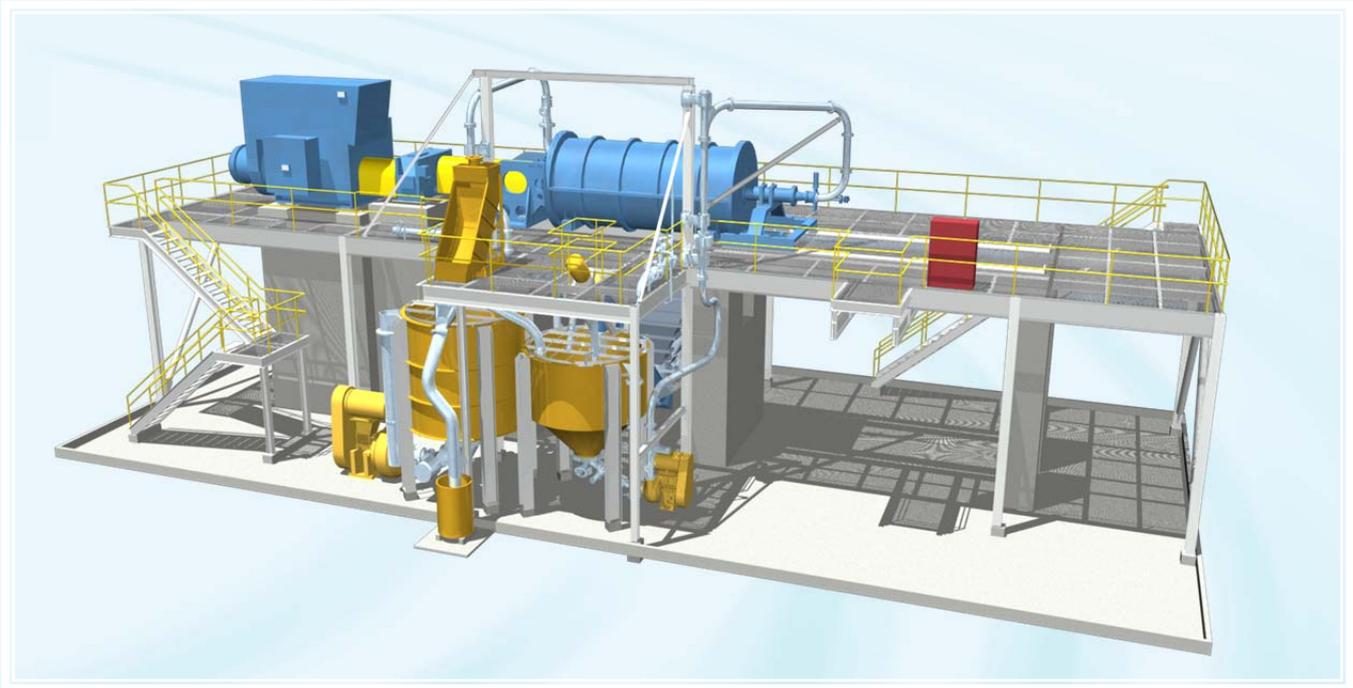


Figure 4
IsaMill™ Grinding Plant Layout

The internal rotating shaft in the IsaMill™ 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.

The IsaMill™ is available in the following models:

- M500 (300 kW), capable of throughputs in the range 2 – 6 tonnes per hour
- M1000 (500 kW), capable of throughputs in the range 10 – 16 tonnes per hour
- M5000 (1200 and 1500kW), capable of throughputs in the range 20 – 60 tonnes per hour
- M10000 (3000kW), capable of throughputs in the range 60 – 100 tonnes per hour

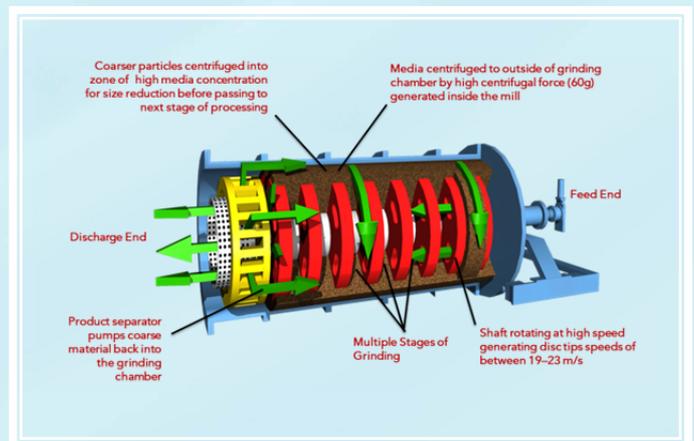


Figure 5
IsaMill™ Operating Mechanism

3 Oxidative Leaching

After the sulphide concentrate has been finely ground, it is then leached under atmospheric conditions in an oxidative leach consisting of interconnected Albion Leach Reactors. The Albion Leach Reactor is an atmospheric leaching vessel that has been designed by Xstrata Technology to achieve the oxygen mass transfer required for oxidation of the sulphide minerals at low capital and operating cost.

Oxygen is injected into the base of the Albion Leach Reactors using Xstrata's 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 impeller tip speed is chosen in combination with the HyperSparge™ injection velocity to provide the required mass transfer rates.

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 6.



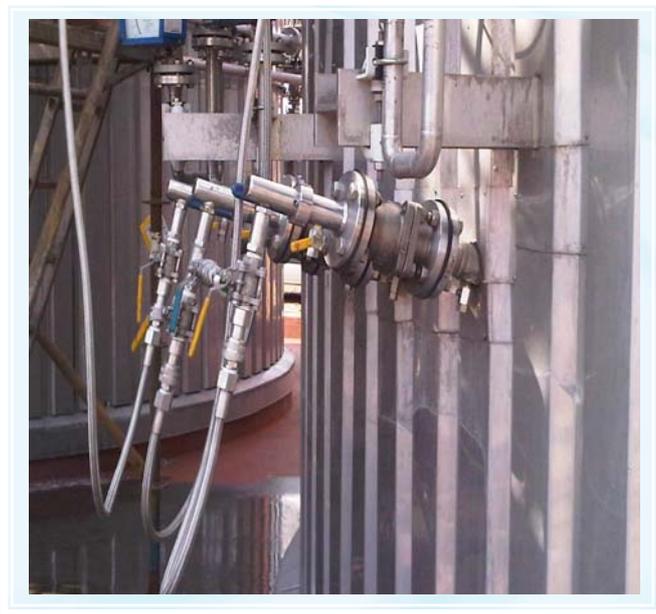
Figure 6
Albion Leach Reactor

sealing assemblies. This design ensures that no downtime is incurred for maintenance of the oxygen delivery system, as all HyperSparge™ units can be removed live for inspection.

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 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.

HyperSparge™ supersonic oxygen injection lances 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



The HyperSparge™ injects oxygen at supersonic velocities 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 7. The high jet velocities at the tip of the HyperSparge™ keep the nozzle clean and eliminate blockages.

The HyperSparge™ is incorporated in an overall oxygen addition and control system developed by Xstrata, 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.

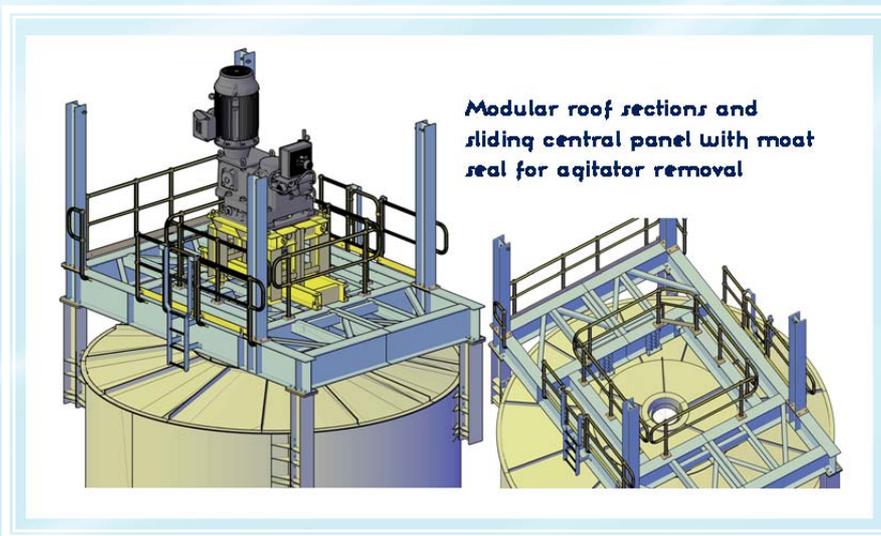


Figure 8
Albion Leach Reactor Roof Section

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 is typically vented, however condensers can be fitted if required to recover the

evaporated water. The Albion Leach Reactor has a modular lid assembly, incorporating an agitator moat seal and sliding roof section to allow easy removal of the agitation mechanism for maintenance. This is shown in Figure 8.

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 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 oxidative leach train is 99%. Xstrata Technology's launder design accommodates froth, preventing a build-up of foam in the leach train. The Launder Assembly is shown in Figure 9.

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 – 95 °C. 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.

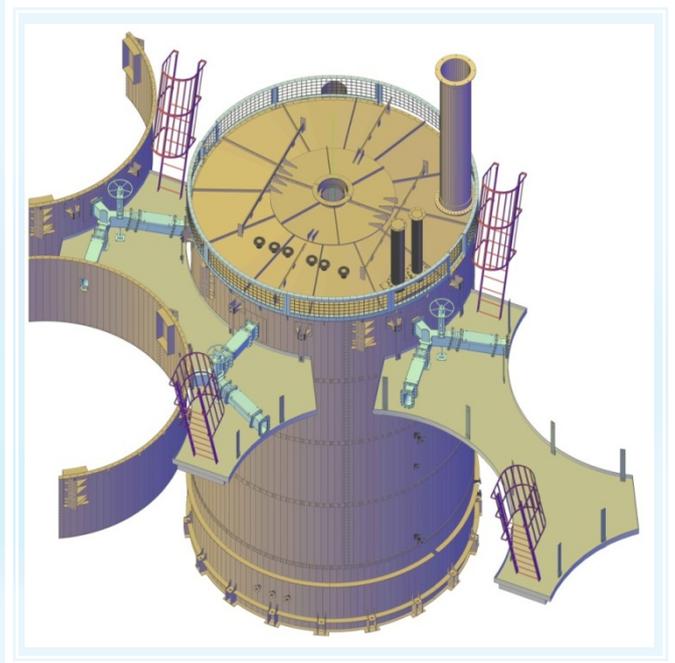


Figure 9
Launder System

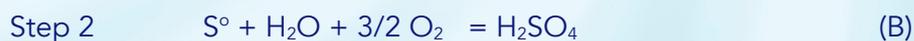
4 Oxidative Leach Chemistry

The Albion Process™ oxidative leach circuit 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. Operating temperatures are in the range 93 – 98 °C.

At these operating temperatures, mineral leaching 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.



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 via reaction B. The extent of elemental sulphur oxidation can be varied from a few percent to full oxidation by control of the leach pH. This is the main control loop employed in the oxidative leach, with pH set points varied within 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™ oxidative leach at acidities below 10 gpl, and slows significantly as the acidity approaches 15 gpl. In this way the acidic oxidative leach is self-regulating, oxidising elemental sulphur to maintain the required acidity.

Oxidative leaching under acidic conditions 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 filtration and recovery of the economic metals from the neutralised filtrate. Metal recovery can be via conventional processes.

Oxidative leaching at near neutral pH is used to oxidise pyritic concentrates containing precious metals. Pyritic concentrates generate acid, and so continual neutralisation of the oxidative leach to remove the acid from solution accelerates the pyrite oxidation reaction.

The near neutral oxidative leach is carried out at a pH in the range 5 – 6, with the continuous addition of an alkali to neutralise acid and iron sulphates generated by oxidation of the sulphide minerals. 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.

4.1 Acidic Oxidative Leaching

Oxidative leaching under acidic conditions is suitable for sulphide concentrates containing copper, zinc, nickel and cobalt minerals. The recovery of copper, zinc, nickel and cobalt will be in the range 98 – 99 %. Some of the common leach reactions are outlined below. Oxidative leaching under acidic conditions operates as a ferric leach, however the leach reactions are presented as the oxygen equivalent to provide a better indication of reagent usage.

Oxidative leaching under acidic conditions is operated at acid levels in the range 5 – 15 grams per litre, with oxygen injected into the leach slurry to facilitate oxidation. The leach is operated as a ferric leach, with iron liberated by the leaching sulphides.

4.1.1 Pyrite

Pyrite is one of the major minerals present in many sulphide concentrates. The pyrite leach reaction will be:

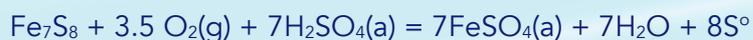


Pyrite will not form elemental sulphur at leach acidities below 25 gpl, and so little elemental sulphur formation is expected from pyrite within the oxidative leach circuit. Where base metal sulphides are present in the concentrate, significant pyrite leaching will not occur until most of the base metal sulphides have leached to completion, due to the galvanic effects.

When oxidised under near neutral pH conditions, the oxidation of the ferrous sulphate is instant, and the resultant ferric sulphate and acid liberated in the oxidation of pyrite are immediately neutralised and precipitated to accelerate pyrite oxidation.

4.1.2 Pyrrhotite

Pyrrhotite is also a common iron bearing mineral in sulphide concentrates. Pyrrhotite will oxidise readily under the conditions found in the oxidative leach, with the formation of elemental sulphur predominating. The leach reaction for Pyrrhotite is outlined below.



4.13 Pentlandite series

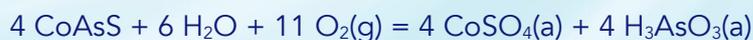
Nickel and cobalt recovery using the Albion Process™ is normally carried out in combination with an intermediate nickel-cobalt precipitation circuit for metal recovery with sale of the intermediate product to a refinery. The most common of the cobalt and nickel bearing minerals are the pentlandite series. Nickeliferous and cobaltiferous pentlandite will leach according to the following general reactions:



In addition to the pentlandite series, other cobalt and nickel sulphides, such as millerite, voliarite and linneite can be readily leached in the Albion leach.

4.14 Cobaltite

Cobaltite is often present as a combination of rimming on pyrite and intimately housed within the pyrite lattice. Cobaltite will leach according to the following reaction:



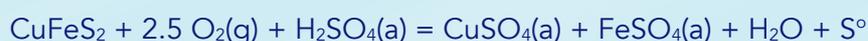
In the reaction above, the arsenic liberated on oxidation of the cobaltite is shown reporting to solution as Arsenic(3⁺). Liberated arsenic can then be oxidised in the leach circuit to Arsenic(5⁺) according to the reaction:



This reaction is favoured by the presence of pyrite, as pyrite surfaces have a catalytic effect on arsenic oxidation. The extent of oxidation of Arsenic(3⁺) to Arsenic(5⁺) will depend on the leach conditions, however over 70 % of the arsenic would be expected to be present in the oxidative leach as Arsenic(5⁺).

4.15 Chalcopyrite

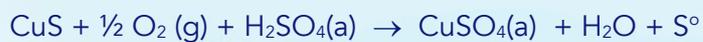
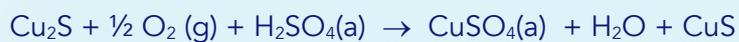
Copper recovery using the Albion Process™ is normally carried out in combination with solvent extraction and electrowinning for copper recovery. Chalcopyrite is the most common of the copper sulphide minerals, and will leach according to the reaction:



The presence of ferrous iron and copper in the return raffinate to the copper leaching circuit is important in maintaining ideal chalcopyrite leaching conditions.

4.16 Chalcocite and Covellite

Chalcocite and Covellite are the most common secondary copper minerals found in copper sulphide concentrates, and will leach according to the reactions below.



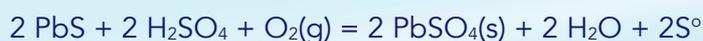
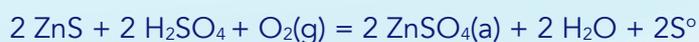
4.17 Enargite

Enargite and tennantite are the most common arsenic bearing copper minerals present in sulphide concentrates. Enargite is normally the most refractory of the minerals in a copper concentrate, and will be the slowest to leach. The leach reaction for enargite will be:



4.18 Sphalerite and Galena

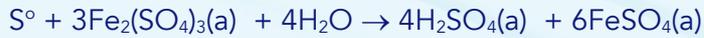
Zinc recovery using the Albion Process™ is normally carried out in combination with either a direct electrowinning circuit or a solvent extraction and electrowinning circuit for zinc recovery. Lead and silver are concentrated in the oxidised residue for sale to a smelter. Sphalerite is the most common of the zinc sulphide minerals, and often occurs in zinc and lead concentrates in the presence of Galena. These minerals will leach according to the reaction below.



In addition to the sulphide leach reactions listed above, ferric iron will be continually re-oxidised in the leach by the injection of gaseous oxygen, according to the reaction:



Elemental sulphur will also be progressively oxidised in the leach, according to the reaction:



The acid demand for the leach will be met by the oxidation of pyrite and elemental sulphur within the leach train. Sulphuric acid will also be added to the leach to neutralise gangue acid consumers, in the form of raffinate or spent electrolyte from the downstream solvent extraction or electrowinning operations.

The residence time in the oxidative leach circuit will be in the range 24 – 30 hours, depending on concentrate mineralogy. The leach will operate autothermally, without external heating or cooling. The major control loops within the oxidative leach train will be pH, slurry density and oxygen addition.

4.2 Neutralisation

Both iron and sulphur, in the form of sulphates and acid will be liberated in the acidic leach, along with minor levels of other deleterious elements such as arsenic, aluminium and silicon. On completion of the leach, the oxidised slurry will be neutralised to precipitate iron, acid and deleterious elements. Two iron precipitation circuits are commonly employed in mineral sulphide leaching circuits – goethite and jarosite.

Goethite is formed by neutralisation of the oxidative leach slurry with limestone or lime to elevate the slurry pH. Goethite has the general form $FeO.OH$, however will occur as a range of crystal forms, as well as related products such as ferrihydrite. Goethite has a large surface area, and can entrain economic metals at higher pH, leading to metal losses. Goethite precipitates encapsulate arsenic as a ferric arsenate phase, and provide an inert and stable arsenic residue.

Jarosite is formed by the addition of sodium, ammonium or potassium salts to the oxidised slurry. The sodium, ammonium or potassium cations precipitate an iron sulphate salt of the general form $NaFe_3(SO_4)_2(OH)_6$. Jarosite will precipitate at acidities up to 20 gpl, and as a result does not incorporate as much co-precipitated base metal compounds as goethite precipitates do. Jarosite precipitates, however, are generally less acceptable environmentally, as they can release acidic sulphate to groundwater, and do not form as stable an arsenic precipitate as goethite circuits.

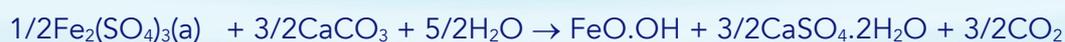
The neutralisation circuit will be operated using the same Albion Leach Reactors as used in the oxidative leaching circuit, to ensure commonality of spares and simpler maintenance. The intertank launder system will be the same as employed in the oxidative leach, and all reagent mains will have dosing points extending through the interface between the leach and neutralisation stages. This will allow several tanks to be operated as either leach or neutralisation vessels, providing flexibility for differing concentrate compositions.

A goethite based circuit will be described below, however Xstrata has operational experience in both goethite and jarosite circuits. When the neutralisation stage is operated as a goethite circuit, the following control parameters are maintained:

- Ferric levels in all tanks are maintained at less than 1 g/L at all times and the temperature is maintained at over 85 degrees. This ensures that iron precipitates as goethite, and any arsenic as a stable ferric arsenate.
- The circuit is operated with precipitated solids recycle to partially neutralise acid exiting the leach train and provide seed to the neutralisation circuit. This enhances precipitation through the process of crystal growth rather than nucleation, and improves the settling and filtration properties of the precipitate.
- The pH profile across the neutralisation circuit is progressively increased in discrete stages to minimise super saturation of both iron and sulphate. This ensures a stable precipitate and minimises scale formation.

The oxidative leach discharge slurry is initially neutralised to a pH of 1 – 1.2 in the first neutralisation reactor, by adding recycled neutralised product. The pH is then increased in the subsequent neutralisation vessels to precipitate the required metals, with oxygen added to assist ferrous oxidation to ferric. The terminal pH will depend on the metals to be recovered from the neutralised solution. Any residual ferrous iron present in the leach discharge are oxidised at the more neutral pH to ferric iron.

Ferric iron is then precipitated as goethite at the elevated pH:



Goethite and the analogous phase, ferrihydrite, will be the favoured iron precipitates in the neutralisation stage, due to the operating temperature of approximately 85-95°C. Minor hematite formation will also occur. Arsenic will be fixed in the residue as a stable ferric arsenate.

Iron will co-precipitate with arsenic in the neutralisation stage according to the reaction:



To ensure a stable ferric arsenate, the neutralisation circuit design needs to be such that growth of a crystalline ferric arsenate is favoured over nucleation and precipitation of amorphous iron arsenic phases. These considerations are taken into account in the design of the neutralisation circuit, and some of these key principles were outlined earlier.

Either oxygen or air can be used as the oxygen source in the neutralisation stage. Oxygen is recommended to promote the iron and arsenic oxidation kinetics and to prevent excess heat loss due to humidification of off-gas. High temperatures in the neutralisation circuit are important in forming a stable arsenic precipitate.

The neutralised product from the oxidative leach circuit has excellent settling and filtration properties, despite the fine size of the feed to the oxidative leach. Goethite tends to grow on other particles, and provides a coarser discharge particle size distribution. The neutralised slurry responds well to flocculant in a high rate thickener, with settling fluxes of 250 – 350 kg.m⁻².h⁻¹. The thickened slurry is readily filtered on a horizontal belt filter, with filtration rates, inclusive of wash, in the range 350 – 550 kg.m⁻².h⁻¹.

The residence time in the neutralisation circuit will be in the range 6 – 10 hours, depending on the iron level to be precipitated. The neutralisation circuit will operate autothermally, without external heating or cooling. The major control loops within the neutralisation circuit will also be pH, slurry density and oxygen addition. The Albion Leach Reactor will be used for both oxidative leach and neutralisation duties, in a continuous train of identically sized vessels.

4.3 Neutral Oxidative Leaching

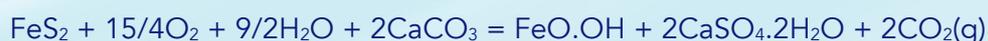
Recovery of gold and silver from refractory concentrates is carried out using a near neutral oxidative leach coupled directly with a cyanide leach plant. The near neutral conditions in the oxidative leach provide a neutralised slurry that does not require any further processing prior to the cyanide leach, and has low levels of any species that is harmful to the cyanide leach.

The leach chemistry employed in the neutral oxidative leach circuit involves continual addition of limestone or lime slurry to precipitate ferric iron and acid generated by the oxidation of pyrite, with oxygen injected into the leach slurry to facilitate the oxidation. The pH is held in the range 5 – 5.5 to maximise the utilisation of limestone and maintain high rates of oxidation.

4.3.1 Pyrite

Finely ground pyrite will oxidise to liberate ferric sulphate and sulphuric acid in the oxidative leach. Under near neutral conditions, the liberated ferric and acid will be precipitated in-situ by the continual addition of limestone slurry. The oxidative leach slurry will liberate significant heat and will operate in the range 85 – 95 °C. Under these conditions, ferric iron will precipitate as goethite and acid will be precipitated as gypsum with minor anhydrite.

The pyrite leach reaction will be:

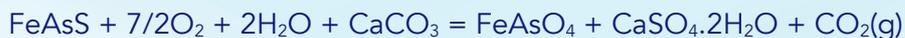


The neutral operating pH in the Albion leach will result in very low background salt levels in the leach solutions. This will prevent formation of gypsum or carbonate scale in the oxidative leach, simplifying operation. The low dissolved salt levels will also enhance the oxygen mass transfer rates in the Albion Leach Reactor, reducing the agitator power requirements.

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

4.3.2 Arsenopyrite

Arsenopyrite is a very common gold carrier in refractory gold concentrates, and often contains the majority of the gold. Arsenopyrite will leach to form a stable ferric arsenate under the near neutral oxidative leach conditions, according to the reaction:



4.3.3 Telluride Minerals

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 can 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 liberated gold and tellurium then precipitate as oxides.

Telluride breakdown will occur in the neutral leach, according to the following general reaction:



A very high degree of telluride oxidation will occur at the operating pH in the near neutral oxidative leach, however, it may be necessary to elevate the pH to 9 with hydrated lime in the final stage of the neutral leach to ensure complete telluride oxidation.

The residence time in the neutral oxidative leach will be in the range 24 - 30 hours, depending on the level of sulphide oxidation required. Most refractory sulphide concentrates require an oxidation of 50 – 75 % to provide the maximum gold and silver recovery. The neutral oxidative leach will operate autothermally, without external heating or cooling. The major control loops within the neutral oxidative leach will be pH through limestone addition, slurry density and oxygen addition. The Albion Leach Reactor will be used for the neutral oxidative leach in a continuous train of identically sized vessels. Low cost alloy steels are suitable for the neutral oxidative leach due to the operating pH and low background dissolved salt levels.

5 Engineering and Project Development Services

Xstrata Technology is the developer and owner of the Albion Process™ technology and offers the technology to clients worldwide.

Xstrata Technology provides lump sum equipment design and supply packages to all Albion Process™ clients. The scope of supply includes the full Albion Process™ plant, inclusive of all structural steel, piping and launders, platforms, stairways and support structures. Full civil and foundation design can be included in the Xstrata Technology scope of work. Construction is supplied by the client, with supervisory labour provided by Xstrata.

The Albion Process plant package provided by Xstrata Technology is low cost and low risk, and incorporates all of Xstrata's knowhow in the 20 year development history of the IsaMill™ and Albion Process™ technologies. Xstrata Technology can work with our client's EPCM contractor to ensure that the Albion Process™ plant interfaces with all other plant areas in an efficient manner.

Xstrata Technology involvement in a project usually begins at the testwork stage, with a testwork and project development program designed for the client by Xstrata and our marketing partner Core Resources. All testwork is carried out at an approved testing facility. Xstrata can provide a range of Engineering Studies in support of the testwork programs to provide capital and operating cost data for the Albion Process™ plant. Xstrata Technology can also provide Feasibility Study services, ultimately leading to a lump sum equipment design and supply package, which is fully guaranteed by Xstrata.

As an introduction to the Albion Process™ technology, Xstrata can provide desktop capital and operating cost estimates for an Albion Process™ plant at no cost to our clients, once provided with a concentrate composition and planned throughput.

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Xstrata operates mines throughout the world.

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