

ALBION PROCESS™ SIMPLICITY IN LEACHING

COPPER APPLICATIONS



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.

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 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.

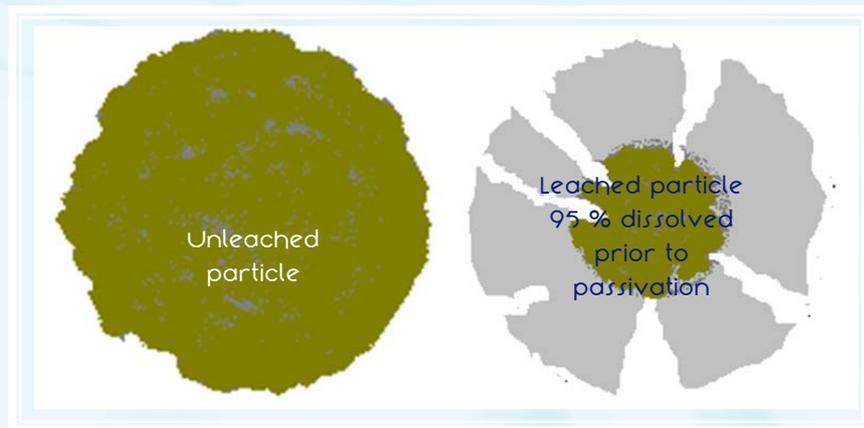


Figure 2
Mechanism of Passivation of Sulphide Minerals

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.

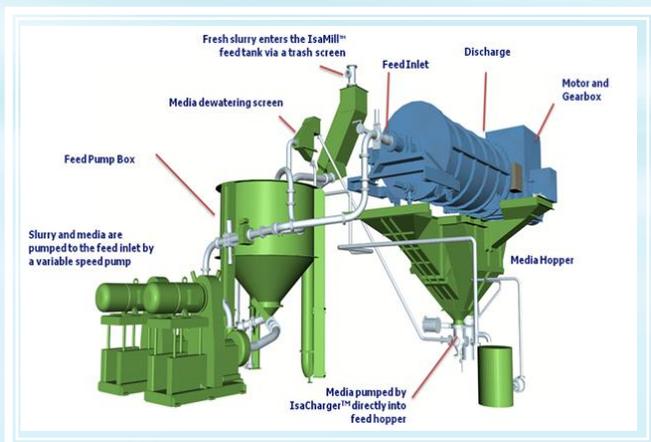


Figure 3
IsaMill™ Feed and Media Systems

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 %

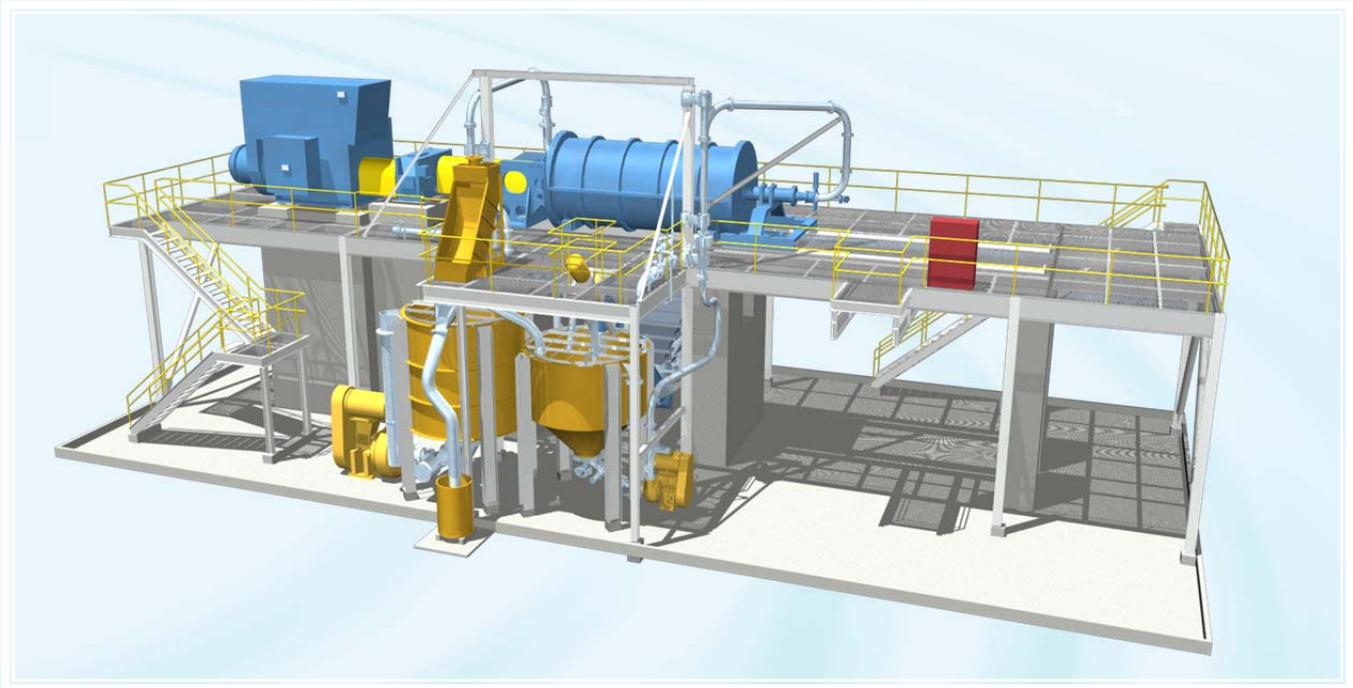


Figure 4
IsaMill™ Grinding Plant Layout

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

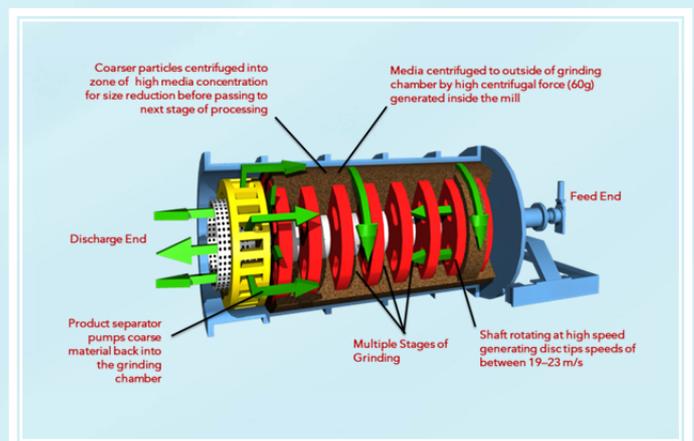


Figure 5
IsaMill™ Operating Mechanism

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.



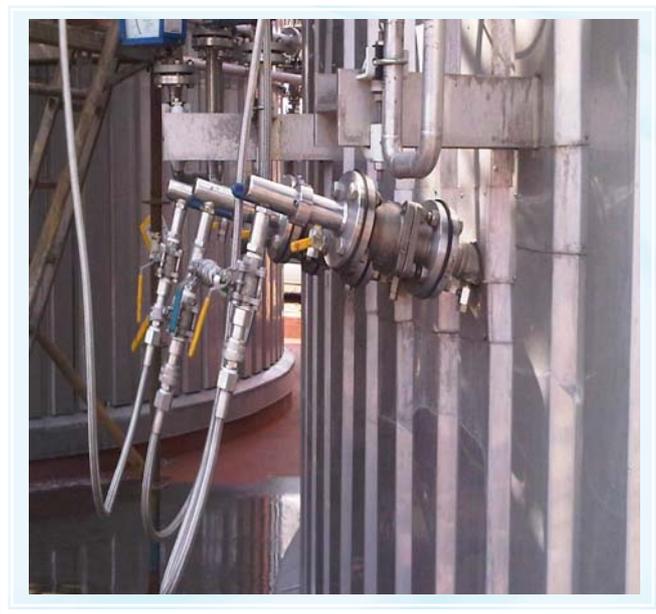
Figure 6
Albion Leach Reactor

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

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 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.

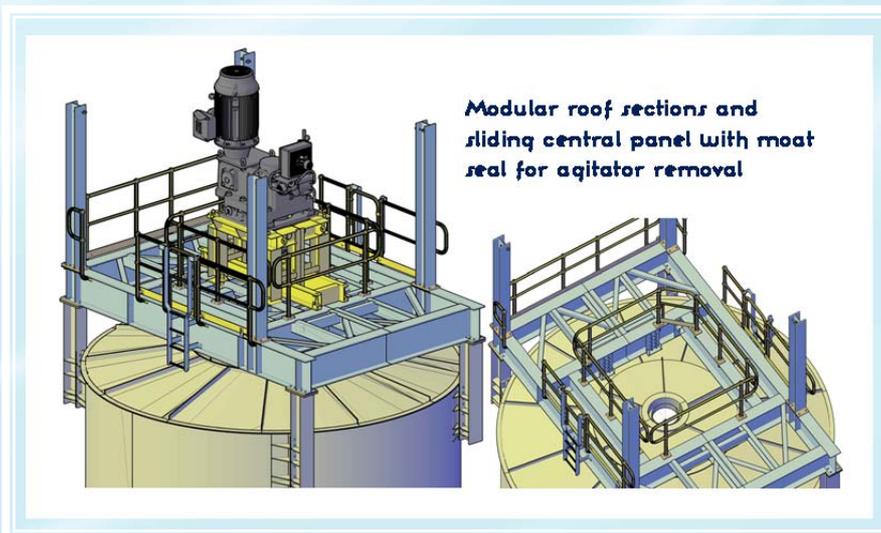


Figure 8
Albion Leach Reactor Roof Section

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.

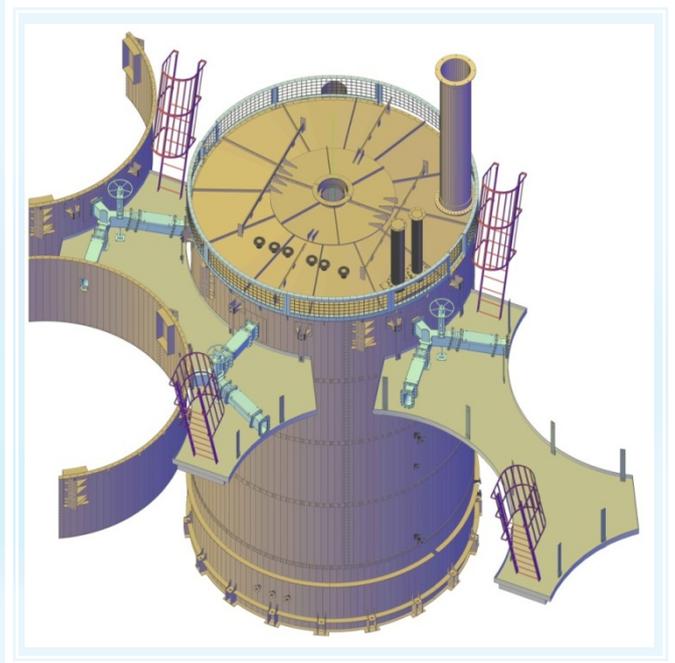


Figure 9
Launder System

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.

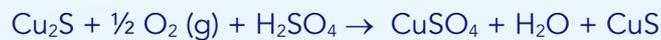


These reactions can be catalysed by the action of ferric iron under acidic conditions. The oxidative leach can be operated under a range of pH conditions, varying from acidic to neutral. The control pH will set the amount of elemental sulphur oxidation via reaction B. The extent of elemental sulphur 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, as employed for copper concentrate 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 oxidative leach is self-regulating, oxidising elemental sulphur as required to maintain 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™ oxidative leach circuits.

The most commonly occurring copper sulphide minerals are chalcopyrite, chalcocite, covellite and bornite. These minerals will be oxidised through the catalytic action of the ferric/ferrous couple in the leach, with the ferric iron continually regenerated by the addition of oxygen and sulphuric acid. The reactions outlined in this section are shown without the ferrous/ferric catalytic couple to provide a better indication of the oxygen and acid demand for each reaction.

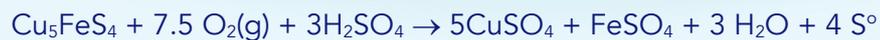
The following overall reactions are expected for chalcocite and covellite leaching.



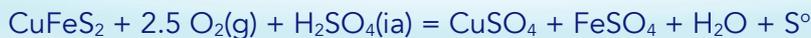
The initial oxidation of chalcocite to covellite will be rapid, with the oxidation of covellite then slowing due to the build-up of elemental sulphur on the surface of the leaching covellite.

As covellite leaching generates elemental sulphur, both minerals will require ultrafine grinding to ensure that the layer of elemental sulphur does not passivate the leaching surface. The grind size required to achieve copper recoveries in excess of 99 % is in the range 80 % passing 18 – 24 microns.

Bornite is slightly more refractory than chalcocite. Bornite leaching will follow the general reaction:



Chalcopyrite is one of the most refractory of the sulphide minerals, and is also the most important commercial copper mineral. The overall leach reaction will be:



The leaching rate of chalcopyrite is enhanced considerably by ultrafine grinding to prevent passivation of chalcopyrite by elemental sulphur. The grind size required to achieve copper recoveries in excess of 99 % is generally in the range 80 % passing 12 – 14 microns.

The exact mechanism for chalcopyrite leaching is not proven, however the following mechanism is proposed by Hiroyoshi in *Hydrometallurgy*, Vol 60, 2001, p 185 – 197. In this mechanism, ferrous iron and the cupric ion play a key role in the initial breakdown of chalcopyrite:



The mechanism is a two stage process, where chalcopyrite is first reduced to covellite, by ferrous iron in solution. The resulting chalcocite is then oxidised by ferric iron to copper sulphate, with the formation of elemental sulphur. Ferrous iron and copper in solution are therefore critical to the successful leaching of chalcopyrite. The design of the overall leach/solvent extraction circuit must take into account the need to recycle ferrous iron and copper in raffinate to the leach circuit to assist in the leaching of chalcopyrite.

Enargite and Tennantite are common arsenic bearing minerals in copper orebodies. The presence of these minerals in significant quantities will result in a concentrate that will attract substantial smelter penalties due to the arsenic content, and these minerals often require a hydrometallurgical process.

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:



Enargite leaching requires a finer grind than chalcopyrite or covellite – typically 80 % passing 8 - 10 microns.

Pyrite, present in the copper concentrate, will also oxidise in the leach, and pyrite oxidation is catalysed by the presence of copper in solution. Pyrite oxidation does not form elemental sulphur at the acidity maintained in the oxidative leach. The major pyrite leach reaction will be:



Pyrite leaching will not occur until most of the copper minerals have leached to completion, due to the galvanic effects.

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



In addition to the reactions outlined above, elemental sulphur will also be partially oxidised in the leach, according to the reaction:



In the Albion Process copper leach circuit, the level of oxidation of elemental sulphur can be varied in the range 5 – 80 %, with control of key operating conditions such as the pH.

The acid demand for the leach is met largely by the acid in raffinate returned to the leach from the copper solvent extraction circuit, through oxidation of elemental sulphur within the leach train, and by acid liberated by the leaching of pyrite.

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.

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 inter tank 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 key control parameters are set:

- Ferric levels in all tanks are maintained at less than 1 g/L and the temperature is maintained at over 85 degrees. This will ensure that iron precipitates as goethite, and any arsenic as a stable ferric arsenate.
- The circuit will be operated with precipitated solids recycle to partially neutralise acid exiting the leach train and provide seed to the neutralisation circuit. This will enhance crystal growth at the expense of nucleation, and improve the settling and filtration properties of the precipitate.
- The pH profile across the neutralisation circuit will be staged to minimise super saturation of both iron and sulphate, to ensure a stable precipitate and minimise scale formation.

The oxidative leach discharge slurry will initially be neutralised to a pH of 1 – 1.2 in the first neutralisation reactor, by adding recycled neutralised product. The pH will then be increased to 2.2 – 2.5 in the subsequent neutralisation vessels with oxygen added to assist ferrous oxidation to ferric. Copper will not precipitate from solution at this terminal pH, however ferric iron will precipitate readily. Any residual ferrous iron present in the leach discharge will be oxidised at the more neutral pH to ferric iron.



Ferric iron will then be precipitated as goethite:



Goethite and ferrihydrite will be the favoured iron precipitates in the neutralisation stage, due to the operating temperatures of approximately 85-95°C. Minor hematite formation will also occur. One of the objectives of the neutralisation stage may be to separate arsenic and iron from copper by precipitation of the arsenic in an environmentally stable form. In order to ensure the maximum long-term stability of the precipitated arsenic compounds, As⁵⁺ is the preferred oxidation state.

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



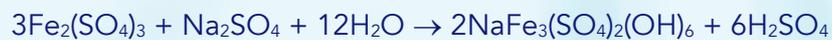
Arsenic will be removed from the leach solution by co-precipitation with iron, as ferric arsenate. While the arsenic precipitate is shown in the above equation as FeAsO₄, the actual species will be a mixture of crystalline ferric arsenate and arsenic absorbed onto the goethite ferrihydrite matrix. These are both very stable arsenic precipitates.

Arsenic absorbed onto ferrihydrite and goethite is recognised as one of the most stable arsenic compounds that can be precipitated in an acid sulphate system across a broad range of pH values. It has very low solubility, typically less than 10⁻⁴⁷, with the solubility decreasing rapidly as the ratio of

iron to arsenic increases in the solution. A generally accepted minimum ratio of iron and arsenic in solution for a stable ferric arsenate precipitate is 3.5:1. At these ratios, less than 10 ppm arsenic should remain in the neutralised solution. The residual arsenic level in solution will decrease further at higher pH, and at a pH of 3.5 or above, will be less than 0.5 ppm.

Either oxygen or air can be used as the oxygen source in the neutralisation stage. Oxygen is normally recommended in the early stages of the neutralisation circuit to promote the iron oxidation kinetics, however air is used at the end of the neutralisation stage to remove heat from the slurry prior to thickening and filtration.

As an alternative to goethite formation, and to reduce the limestone demand of the neutralisation stage, sodium can be added to the leach solution to facilitate precipitation of iron as jarosite:



Jarosite formation will occur at higher acidities than goethite, and will result in a significant reduction in limestone demand, and a reduction in operating costs for the neutralisation stage. The stability of the arsenic precipitate, however, can be lower than for a goethite precipitate, and a jarosite precipitate may have higher cyanide consumption in a subsequent cyanide leach than a goethite precipitate. Jarosite formation will occur in the oxidative leach due to the release of sodium and potassium ions from acid consuming gangue minerals such as albite.

5 Process Flowsheet – Copper Concentrates

A flowsheet for the Albion Process™ for copper concentrates is shown in Figure 10. A bulk sulphide concentrate would be delivered as slurry to the Albion Process™ Plant. The slurry would be thickened prior to delivery, to 45 % w/w solids. A high grade concentrate is not required for the Albion Process™, and a rougher concentrate would be suitable.

Slurry would be milled in an IsaMill™ circuit to an 80 % passing size of 10 – 12 microns prior to transfer to the oxidative leaching circuit. The IsaMill™ would operate in open circuit.

The finely ground slurry would then be oxidised in the oxidative leaching circuit in a series of Albion Leach Reactors. The reactors would operate at a temperature in the range 90 – 96 °C, with a residence time of 24 hours. Copper recovery to the leach solution would be over 98 %. The level of oxidation will be sufficient to liberate the copper and any precious metals. The leach would be acidic, with the acidity in the range 5 – 8 grams per litre on completion of the leach. Raffinate from the copper solvent extraction plant would be added to the oxidative leach as the primary acid source.

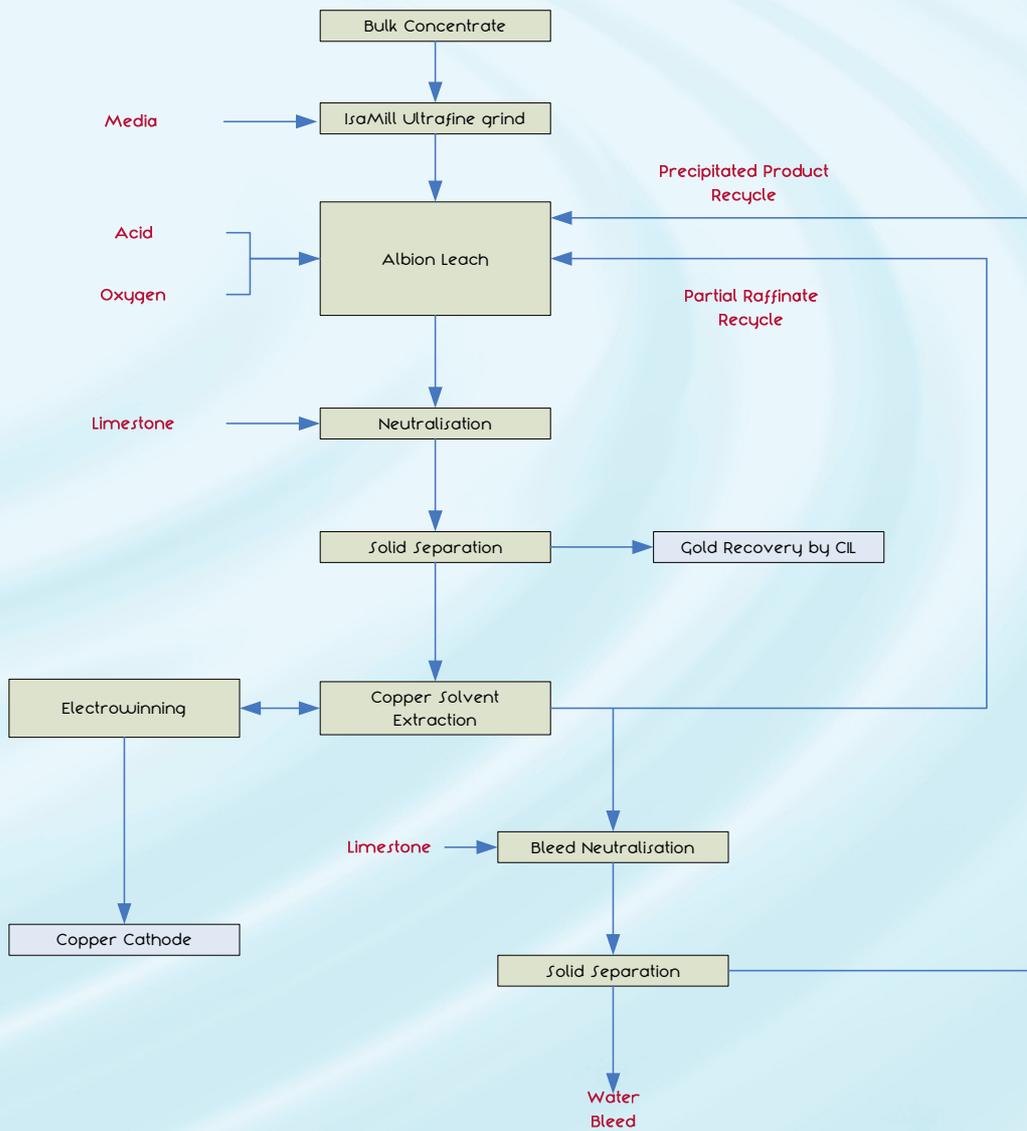
The oxidised slurry would then be partially neutralised to a pH of 1.8 – 2.2 with limestone slurry prior to copper recovery by solvent extraction and electrowinning. Neutralisation would precipitate iron as goethite and acid as gypsum. The neutralised slurry would be filtered, and the filtrate directed to the copper solvent extraction circuit.

Neutralised filter cake would be re-pulped and transferred to a separate plant for recovery of the precious metals if required. If the concentrate does not contain precious metals, the residue would be sent to tailings. No precious metals and platinum group metals will be soluble in the acid sulphate leach liquor and would report to the oxidised residue.

The solvent extraction circuit would incorporate the Xstrata Technology MMS side feed mixer settler to provide a low cost and efficient circuit. The electrowinning plant would be a conventional IsaProcess plant using permanent cathode plates and producing LME grade A copper cathode.

Raffinate from the solvent extraction plant would be partially recycled to the leach circuit to recover the acid credit from the cellhouse, with a bleed of raffinate sent to a bleed neutralisation circuit to remove iron, aluminium and other minor sulphates and remove water from the oxidative leach circuit. The precipitate from the bleed neutralisation stage would be thickened and returned to the oxidative leach circuit to recover any copper.

Figure 10
Albion Process Flowsheet - Copper Concentrates



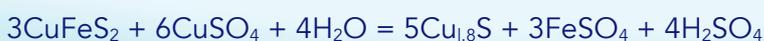
6 Copper Metathesis onto Concentrate

An alternative to SX/EW for copper recovery from low tonnage concentrate streams is metathesis onto smeltable concentrate. Copper ions in solution will undergo an ion exchange reaction with metal sulphides, such as chalcopyrite, bornite, pentlandite and sphalerite, with the copper exchanging for iron or base metals in the metal sulphide lattice. The reaction is the same as chemical activation of minerals prior to flotation. This reaction is known as metathesis, and can provide a very low cost method of copper recovery from leach solutions.

Xstrata Copper uses a copper metathesis step in its copper smelter to recover leached copper from smelter dusts. This circuit has been in operation since 2004.

Metathesis reactions occur best under non aerated conditions and at near neutral pH. The reactions occur quickly at room temperature, however the amount of copper that can be precipitated onto concentrate increases with temperature and so 60 – 70 °C is recommended. Approximately 30 – 60 kg of copper can be precipitated onto a chalcopyrite concentrate, a 10 – 15 % upgrade.

When copper is precipitated onto chalcopyrite, the primary reaction leads to the formation of covellite, CuS, which is followed by an oxidation–reduction couple, ultimately resulting in digenite production. The overall reaction is:



The conversion of covellite to digenite is very slow, requiring fine particles sizes for extensive conversion, and so for practical purposes, the reaction often stops at covellite formation:



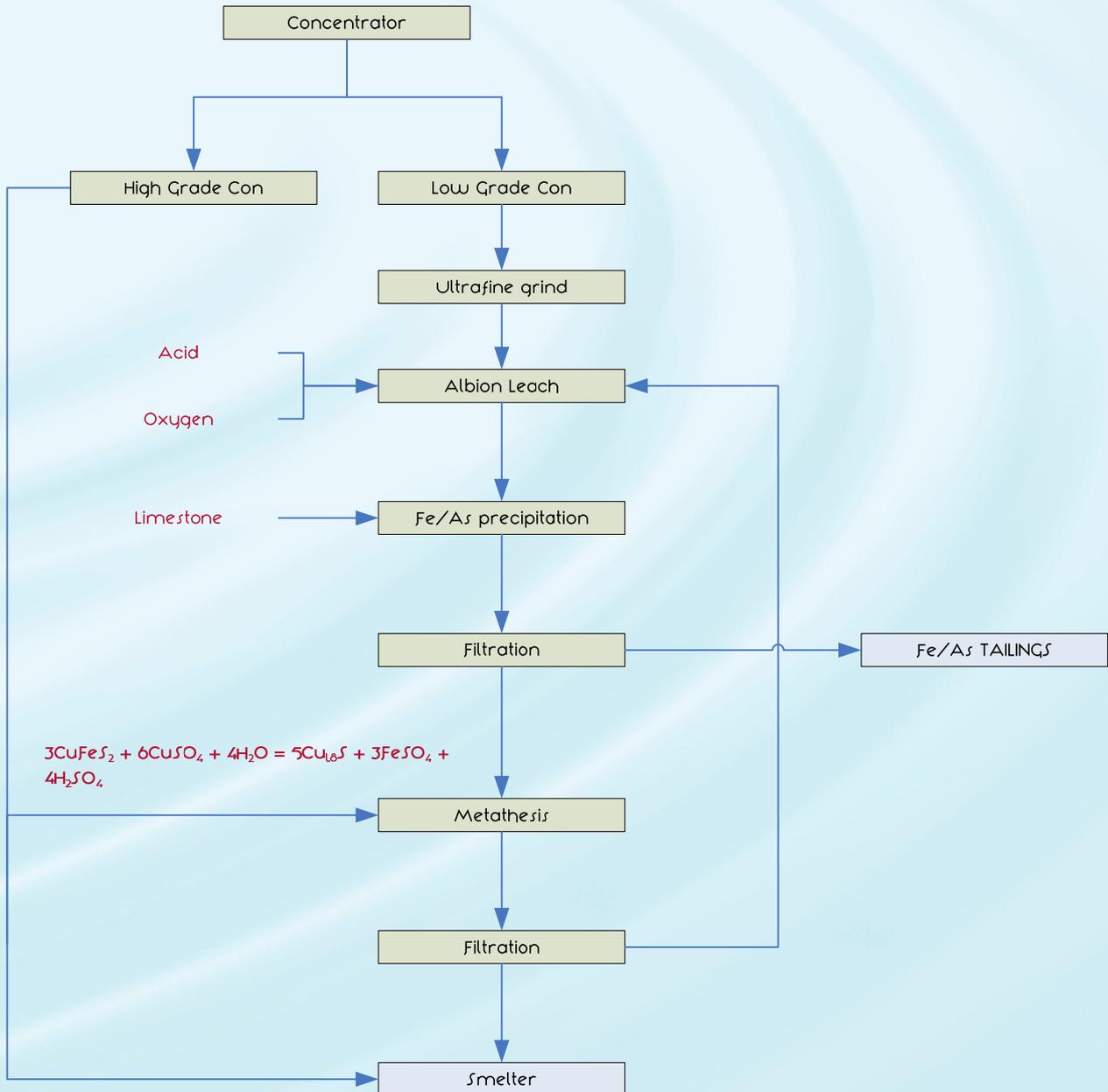
The copper metathesis reaction is not heavily dependent on the copper ion concentrations or on local shear/turbulence. The kinetics are consistent with a two-stage product layer diffusion model, with an apparent activation energy of less than 30 kJ.mol⁻¹. The reaction is surface area dependent.

The first stage conversion of chalcopyrite to covellite is rapid, with up to 30 kg of copper taken up by a tonne of chalcopyrite concentrate within 10 minutes. Subsequent conversion of covellite to digenite is an order of magnitude slower. For both reaction steps diffusion of ferrous ion through the covellite phase (first stage) and covellite and digenite phase (second stage) is rate limiting, and so the reaction is assisted by elevated ferrous levels.

Metathesis reactions are accelerated by ultrafine grinding of the concentrate, as the strain introduced to the mineral lattice provides easy paths for diffusion along dislocation and grain boundaries.

A process flowsheet showing how metathesis may be used in a copper circuit is presented in Figure 11. In this flowsheet, a low grade concentrate that may be high in arsenic or other harmful impurities is produced in the concentrator for processing through the Albion leach and metathesis circuit, with the copper then recovered onto a high grade concentrate for smelting. Arsenic is precipitated in the Albion Process™ circuit as ferric arsenate and reports to tailings.

Figure 11
Albion Process Flowsheet - Copper Metathesis



7 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.

Tough testing grounds that make our process technologies the best on earth.

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