ALBION PROCESS™

SIMPLICITY IN LEACHING

REFRACTORY GOLD 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.

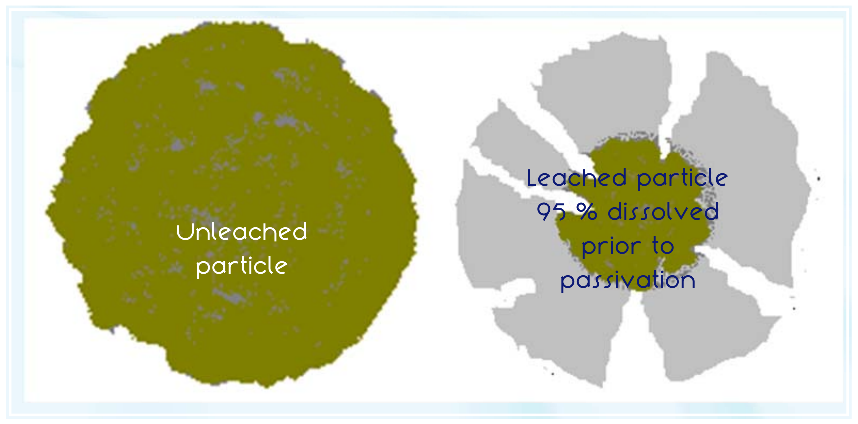


Figure 2
Mechanism of Passivation of Sulphide Minerals

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/m^3 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.

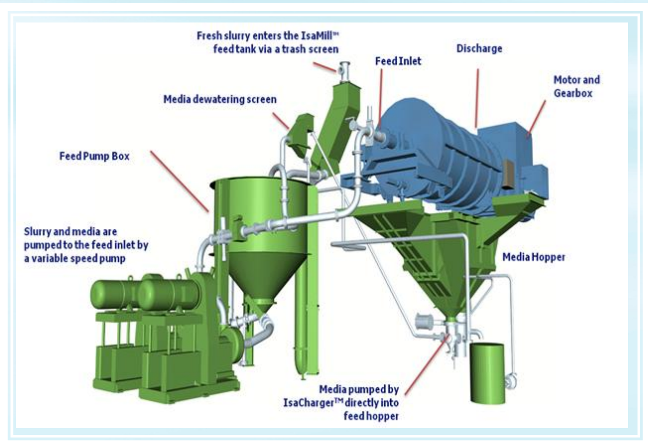


Figure 3
IsaMill™ Feed and Media Systems

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 % 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/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.

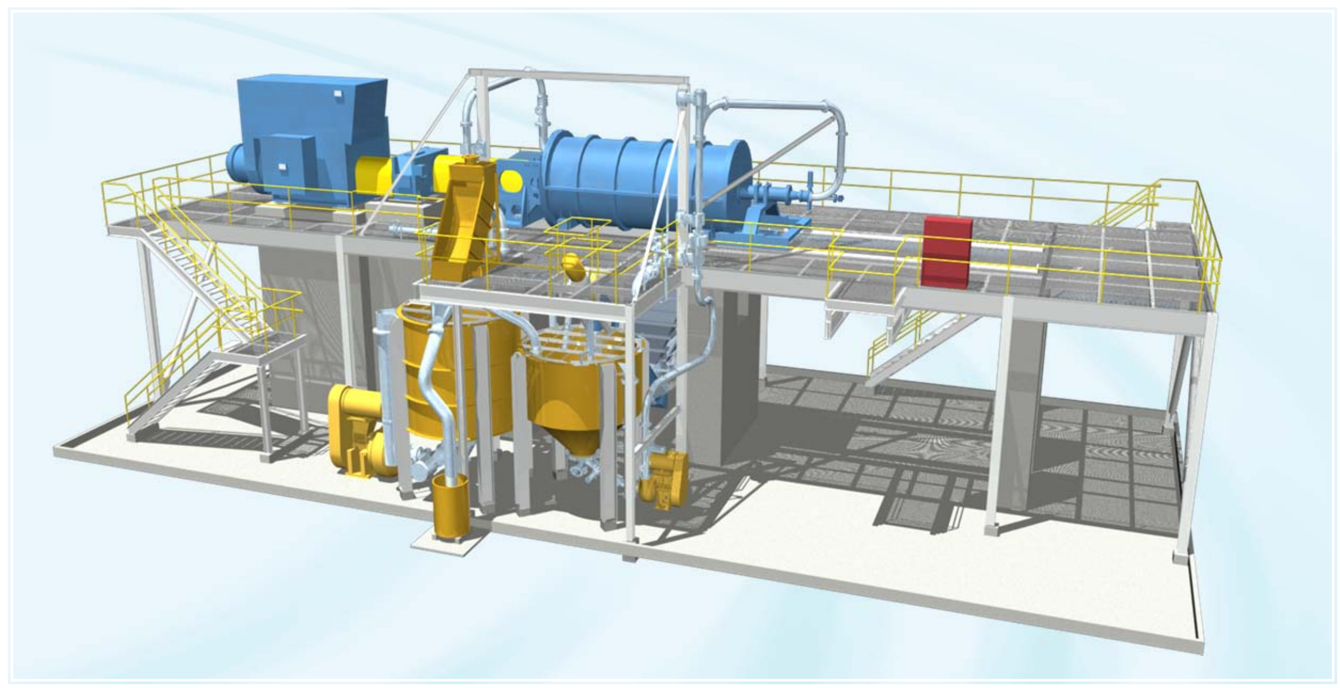


Figure 4
IsaMill™ Grinding Plant Layout

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

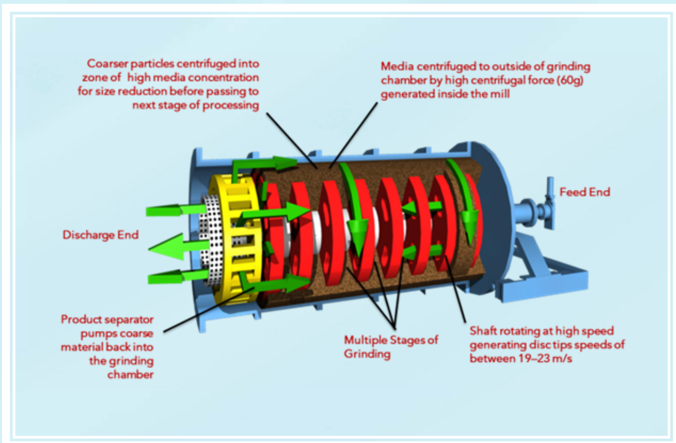


Figure 5
IsaMill™ Operating Mechanism

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.

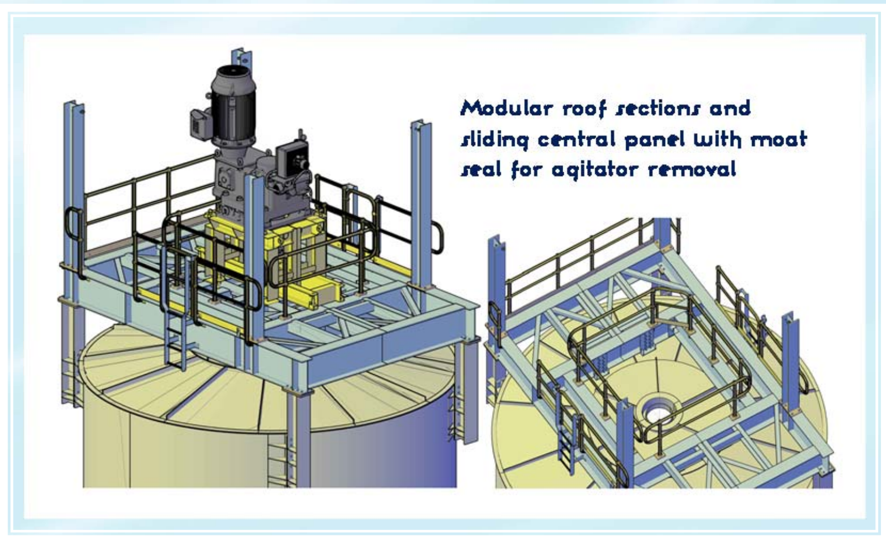


Figure 8
Albion Leach Reactor Roof Section

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 it 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.

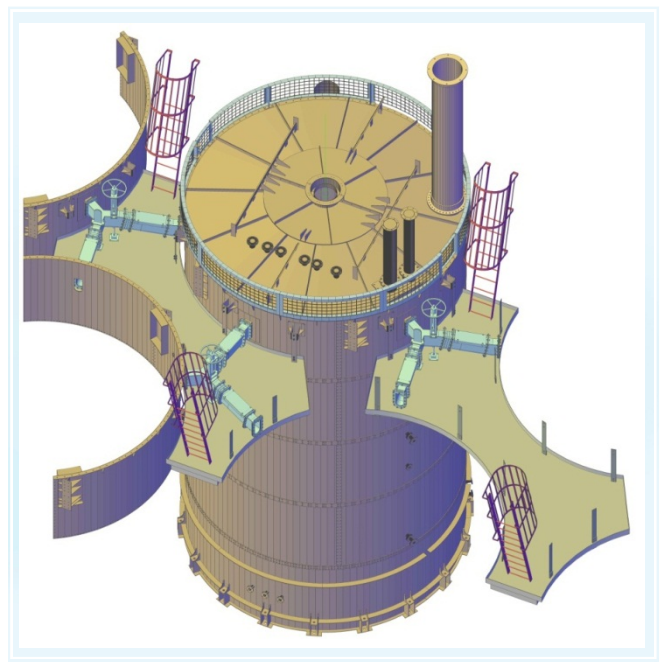


Figure 9
Launder System

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.

The Albion Process™ 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.

Step 1 $$MS + H_2SO_4 + \tfrac{1}{2} O_2 = MSO_4 + S^o + H_2O \qquad (A)$$

In the second step, the elemental sulphur is then oxidised to form sulphuric acid.

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

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 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 setpoints varied within the range 1 – 6.

For the processing of a refractory gold/silver concentrate, the pH of the oxidative leach is held at 5.5 by the continual addition of limestone slurry to ensure complete oxidation of the sulphur to sulphate. This results in complete breakdown of the sulphide lattice, and ensures no cyanide consumption by elemental sulphur.
The principle gold bearing mineral in most refractory gold concentrates is pyrite. During the oxidative leaching of pyrite, the sulphide matrix is broken down to release ferric iron and sulphuric acid, according to the reaction:

$$FeS_2 + 15/4O_2 + 1/2H_2O = 1/2Fe_2(SO_4)_3 + 1/2H_2SO_4$$

Oxidation of the pyrite matrix liberates precious metals for recovery by cyanidation and the precious metals remain in the oxidised residue. In conventional refractory gold treatment circuits, the oxidised residue is separated from the acidic leach solution prior to cyanidation. This results in a high capital cost solid/liquid separation circuit. The acidic liquor is then neutralised in a dedicated neutralisation circuit, involving additional capital cost.

In the Albion Process leach, the liberated ferric and acid are neutralised in-situ by the continual addition of limestone slurry. The neutralised iron oxides and gypsum are then sent to the CIL circuit along with the liberated gold and silver, resulting in a single tailings stream and a single tailings impoundment.

In-situ neutralisation in the oxidative leach eliminates the need for dedicated solid/liquid separation circuits and neutralisation plant, resulting in substantial capital cost savings. Limestone is dosed into all Albion Leach Reactors off a central ring main, to maintain the leach pH within the range 5 – 5.5.

Low cost materials, such as 304 stainless steel, or LDX 2101, are suitable for construction of the Albion Leach Reactor.

The Albion leach is carried out at close to neutral pH, and at the temperature in the range 90 – 98 °C. Under these conditions goethite will be the major iron precipitate formed on neutralisation with limestone, and the overall pyrite leach reaction becomes:

$$FeS_2 + 15/4O_2 + 9/2H_2O + 2CaCO_3 = FeO.OH + 2CaSO_4.2H_2O + 2CO_2$$

Operation of the oxidative leach under conditions of neutral pH is only possible due to the finely ground nature of the concentrate. Without fine grinding, the iron oxides and gypsum formed during neutralisation of the leach solution would passivate the sulphide, and prevent further leaching.

The neutral operating pH in the Albion leach results in very low background salt levels in the leach solution. This prevents formation of scale in the Albion leach, simplifying operation. The low dissolved salt level also enhances the oxygen mass transfer rates in the Albion Leach Reactor, reducing the agitator installed power requirement.

No elemental sulphur is formed under the neutral leaching conditions, and so the oxidised residue has a very low cyanide consumption relative to bacterial or pressure leach circuits. The final oxidised residue is also inert, with no residual acid generating components.

Arsenopyrite is common gold bearing mineral in most refractory gold concentrates, and is also broken down in the neutral oxidative leach according to the following reaction:

$$FeAsS + 7/2\ O_2 + 4H_2O + CaCO_3 = FeAsO_4.2H_2O + CaSO_4.2H_2O + CO_2$$

Arsenic liberated from the oxidation of arsenopyrite under the neutral leach conditions will form a very stable ferric arsenate with low solubility. The ferric arsenate formed under these conditions is crystalline and environmentally stable.

In addition to sulphide minerals, refractory gold concentrates can also 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 neutral to 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 reaction:

$$AgAuTe + 2O_2 = TeO_2 + AuO + AgO$$

A very high degree of telluride oxidation is expected at the operating pH in the neutral 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 neutral leaching conditions do not activate carbonaceous preg robbing phases in the ore and will also not solubilise chlorides that may otherwise result in gold losses to solution. Mercury bearing minerals are not oxidised under the neutral leaching conditions. Base metal sulphides of copper, nickel or zinc will also not oxidise under the neutral leaching conditions, and will not result in unwanted reagent consumption.

The neutral leach conditions ensure soluble iron and sulphate levels are very low throughout the leach, preventing the formation of mixed iron hydroxide/sulphate phases and jarosites. Silver recoveries from the oxidised residue are very high, and the lack of iron sulphate phases in the oxidised residue results in low cyanide demand in the cyanide leach.

5 Process Flowsheet

A process flowsheet for a typical refractory gold/silver concentrate is shown in Figure 10. The feed to the circuit will be a bulk sulphide concentrate. A high grade concentrate is not required for the leach circuit, and so it is recommended that rougher flotation only be used to produce the bulk concentrate.

The bulk concentrate is fed to the Albion Process™ circuit as thickened slurry prior to grinding in the IsaMill™. The thickened slurry is ground to 80 % passing 10 - 12 microns and then stored ahead of the oxidative leach circuit. A feed slurry density of 40 – 45 % solids is preferred as feed to the IsaMill™.

Finely ground slurry is added to the head of the oxidative leach train and oxygen is injected into the base of each Albion Leach Reactor using the HyperSparge system. Limestone slurry is dosed into each Albion Leach Reactor off a ring main to maintain the pH in each vessel at 5 – 5.5. No cooling is required in the Albion Leach Reactor, and the leach temperature will operate in the range 90 – 98 °C.

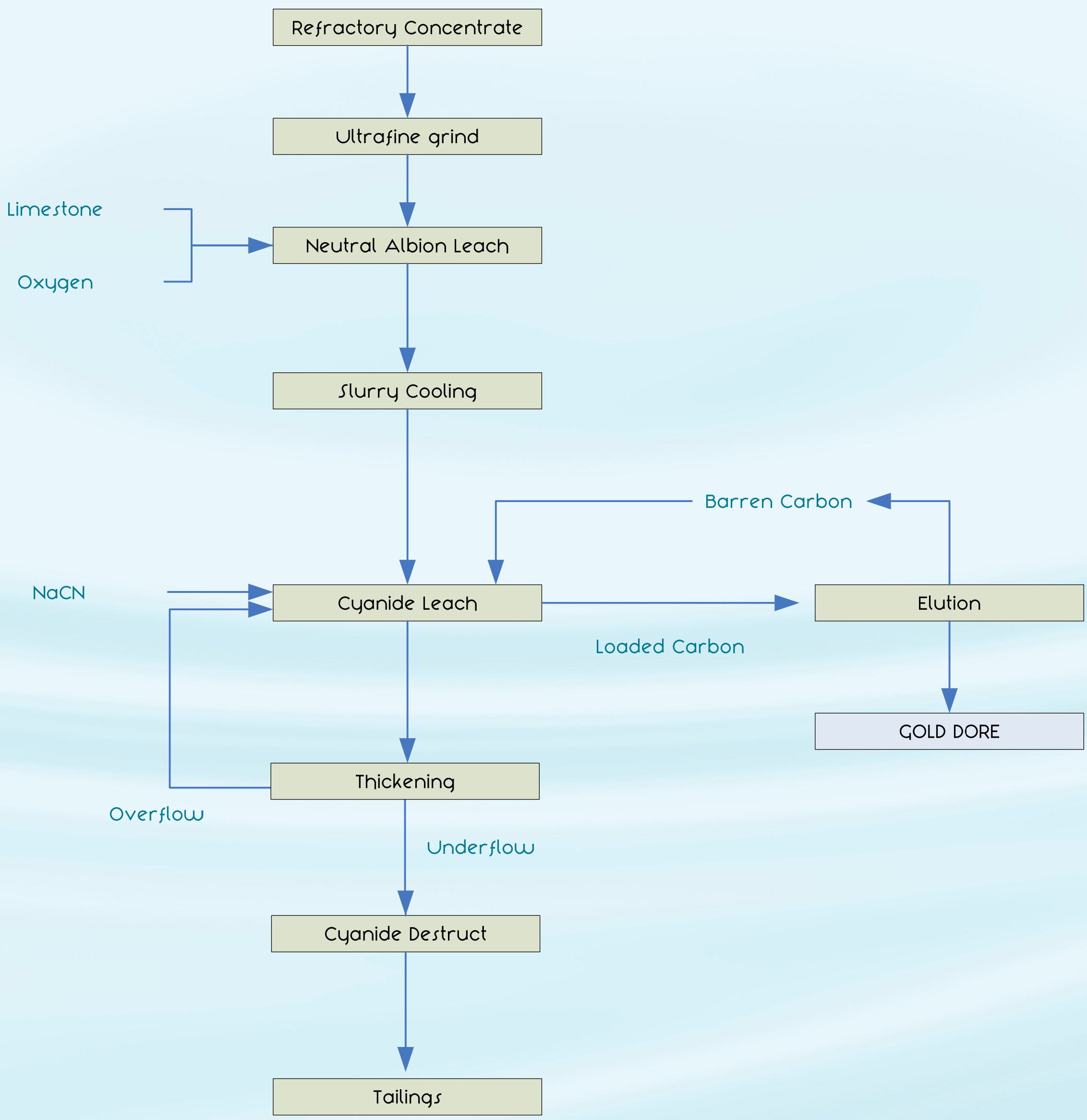
On completion of the oxidative leach, the oxidised slurry is thickened to 45 – 55 % solids prior to transfer to the CIL circuit. The thickener overflow is returned to the oxidative leach as makeup water, with a component bled from the circuit to control build-up of impurities.

The thickened slurry will be hot, and may require cooling to below 40 degrees prior to transfer to the cyanide leaching plant. An open void cooling tower would be used to cool the slurry. Cooled slurry would then be transferred to the CIL circuit for gold and silver recovery by conventional means.

The oxidised slurry exiting the Albion circuit will consist of goethite, gypsum and gangue minerals. The cyanide demand for the slurry will low, and the leach kinetics in the cyanide leach will be rapid, with full dissolution of the precious metals expected within 8 – 12 hours.

The oxidised product will be alkaline in nature, and the solution phase will not contain any components that will be harmful to the cyanide leach circuit. The oxidised residue can be transferred directly to the cyanide leach, and no solid/liquid separation or additional neutralisation stage is required. This results in significant capital and operating cost savings relative to acidic leaching technologies such as pressure or bacterial leaching.

Figure 10
Flowsheet – Refractory Gold Concentrates



6 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.

For more information on the Albion Process™, please refer all enquiries to:

Duncan W. Turner PhD
General Manager- Technology
Albion Process P/L
44 Corunna Street Albion, QLD 4010
Ph +61 7 3637 8105
Fax +61 7 3637 8199
Email: dturner@coreresources.com.au

Mike Hourn
Manager Hydrometallurgy
Xstrata Technology
Level 10, 160 Ann St, Brisbane, QLD 4001
Ph +61 7 3833 8539
Fax +61 7 3833 8555
Email: mhourn@xstratatech.com.au

Website www.albionprocess.com

Xstrata operates mines throughout the world.

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

Xstrata Technology
Australia

Level 10, 160 Ann St
Brisbane QLD 4000,
Australia

Tel +61 7 3833 8500
Fax +61 7 3833 8555
xstratatech@xstrata.com

Xstrata Technology
Chile

Alcántara 200, Of. 1202
Las Condes, Santiago
CP7550159 Chile

Tel +56 2 478 22 11
Fax +56 2 478 22 30
xstratatech@xstrata.com

Xstrata Technology
Canada

10th floor, 700 West Pender St,
Vancouver, British Columbia V6C
1G8 Canada

Tel +1 604 699 6400
Fax +1 604 689 4719
xstratatech@xstrata.com

Xstrata Technology
South Africa

Suite 19, Private Bag X1,
Melrose Arch 2076, South
Africa

Tel +27 82 441 7482
Fax +27 86 627 3099
xstratatech@xstrata.com

Xstrata Technology
European Representative
United Kingdom

Tel +44 (0) 207 746 2721
Mb +44 (0) 771 356 3353
xstratatech@xstrata.com

www.xstratatechnology.com

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