22nd Annual Event

Proceedings

Gold-PM Conference

Including

Cyanide Alternatives/Alleviation Forum

8th Annual Gold Event

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NEW DEVELOPMENTS IN GOLD PROCESSING TECHNOLOGY

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ABSTRACT

Factors driving new developments in gold technology include increasing environmental concern over the use of cyanide, the trend towards refractory, complex, and lower grade resources, and the pressure to reduce operating cost and increase plant performance efficiency.

New developments reviewed in this presentation include non-cyanide lixiviants, preoxidation processes for sulphide ores and concentrates, application of ion exchange, in-situ/in-place leaching, and analytical, control and monitoring systems.

*Keywords: G*old processing, new developments, non-cyanide lixiviants, process control and monitoring

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Introduction

Factors driving new developments in gold technology include:

- Increasing environmental concern over use of cyanide.
- Trend towards refractory, complex and lower grade resources.
- Need to reduce capital and operation costs.
- Pressure to improve plant performance efficiency.

Resulting New Developments

- Cyanide alternatives and alleviation.
- Developments in preoxidation of refractory ores.
- Investigation of in-situ leaching.
- Application of IX technologies.
- On-line analytical, control and monitoring systems.

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Cyanide Alternatives

Processes at various stages of development include:

- Thiosulphate leaching – Barrick Process
- Chloride leaching – KellGold Process, Neomet Process
- Chloride-Bromide leaching – INTEC Process, Dundee DST Process, Outotec Process
- Bromide leaching – ICL AuBrLSX Process, Albemarle Stabilised Bromine Process
- Glycine leaching - GlyLeach™ Process

Cyanide Alternatives – Barrick Process

- Developed by Barrick Gold Corp, Canada.
- More environmentally favourable alternative to roasting/cyanidation for highly preg-robbing, double refractory, sulphide ores with high content of carbonaceous material.
- Consists of pressure oxidation of whole ore followed by resin-in-leach using calcium thiosulphate, elution of the resin with a mixture of trithionate and sulphite (developed at CSIRO, Australia), then EW.
- Includes an innovative approach to reduce reagent consumption comprising RO and thiosulfate regeneration, with CaTS manufacturing on site.
- Demonstration plant operated at Goldstrike, USA, 2010-2011.
- Commercial plant came on stream in late 2014 to treat 13,400 tpd ore.

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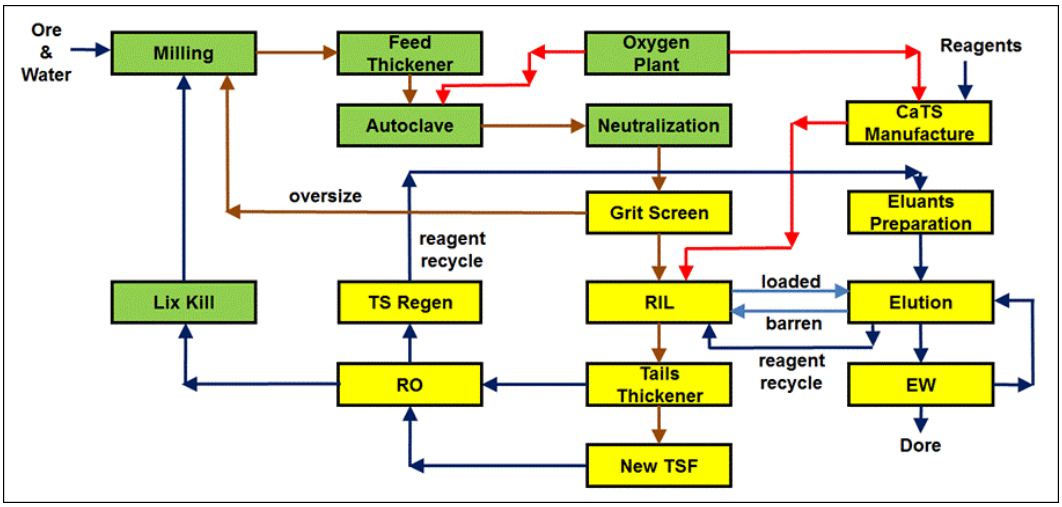
Barrick Process Flowsheet



(Ref: Barrick Gold Corp presentation, ALTA 2013)

Cyanide Alleviation – RECYN™ Process

- Developed by Green Gold Technologies (GGT), Indonesia.
- Recovers and recycles cyanide, and recovers base metals, using IX from slurries or solutions.
- Uses a functionalized resin bead, pretreated to allow the dual duty of recovering free and complexed cyanide ions from solution.
- Flowsheet includes countercurrent IX adsorption, separate elution of cyanide and metals at ambient temperature, cyanide recovery by volatilization and scrubbing to form a concentrated cyanide solution for recycle to leaching, EW for gold recovery, and precipitation for copper and other metals recovery.
- Improved version of previous Vitrokele Process.

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Cyanide Alleviation – RECYN™ Process

- Commercial facility at Mirah gold/silver operation, Indonesia, commissioned in 2015.
- Successful 2+ years operation involving recycle of 1 t/d NaCN.
- Second project under construction for recycling 1.5 t/d NaCN at the Mt Muro gold/silver project, Indonesia.
- Claimed advantages include 50% reduction in cost of cyanide usage, eliminates detox, resistance to poisoning, low resin abrasion losses, stable operation, simple elution, improved metal recovery.
- GGT offer various commercial arrangements, including full tailings treatment service, operating a stand alone on-site treatment plant with responsibility for achieving environmental standards.

Preoxidation – Albion Process

- Developed by Xstrata, and marketed through Core Resources, Australia, for preoxidation of refractory iron/arsenic and base metal sulphide ores.
- Consists of flotation, ultrafine grinding of concentrate to 10-12 micr. using Isamill technology, and agitated oxidative atmospheric leaching reactors with oxygen sparging operating autothermally at 90-95°C.
- Limestone dosing to maintain neutral pH of 5-7 used for pyrite, arsenopyrite, and tellurides. Retention time is about 10-12 hours.

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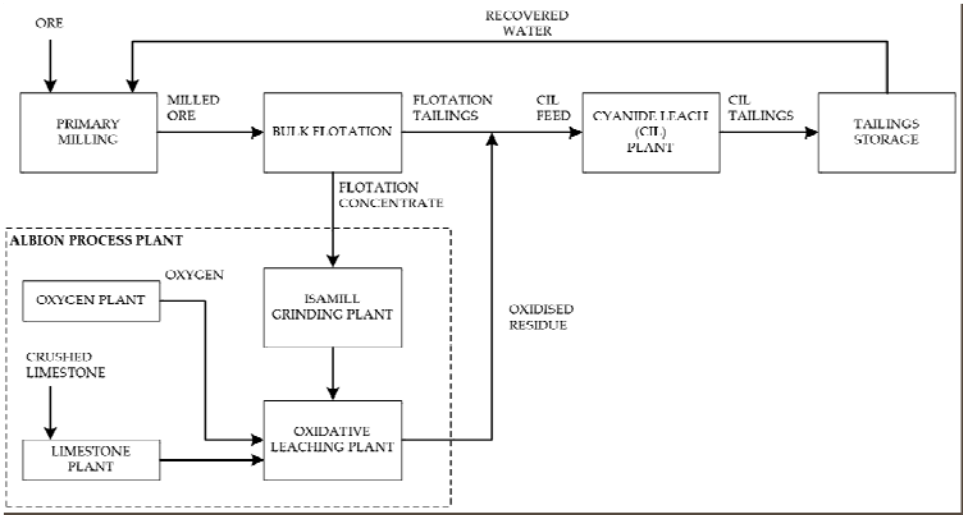
Preoxidation – Albion Process (Cont.)

- Followed by thickening, cooling and gold recovery by CIL.
- Low capex, short duration, alkaline conditions, higher Ag recovery than pressure-ox and bio-ox, slightly lower Au recovery than pressure-ox.
- Second commercial plant, GPM Gold Project, Armenia, rated at 108,108 t/a concentrate, raised gold recovery from 20% to 98%.

GPM Gold Project Flowsheet



(Ref: Glencore/Core paper, ALTA 2015)

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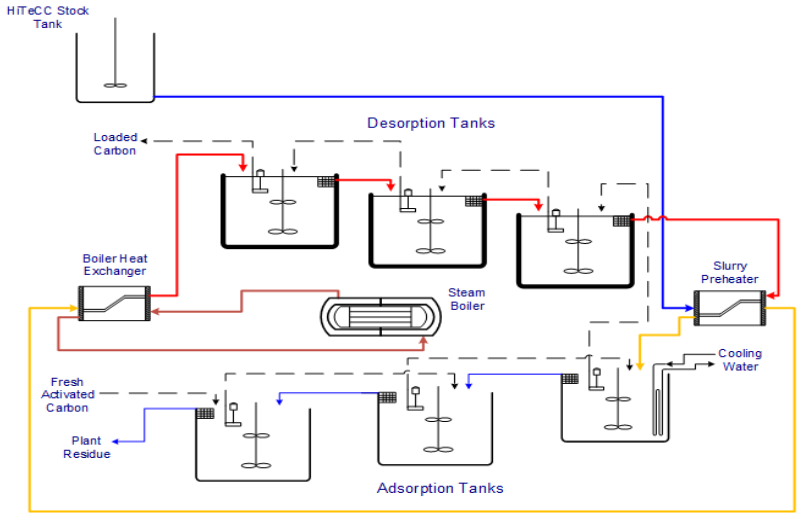
Preoxidation – HiTeCC Process

- Developed and commercialized in 2009 at Fosterville Gold Mine, Australia, for recovery of preg-robbed gold from CIL tailings after BIOX® treatment of double refractory concentrate; now marketed by Outotec.
- The slurry is passed countercurrent to activated carbon through a six stage HiTeCC circuit (High Temperature Caustic Conditioning).
- Gold is desorbed from the carbonaceous material in the first three stages at up to 70°C, then is adsorbed by the activated carbon in the final three stages after cooling. Resulted in recovery of approximately 40% of preg-robbed gold and 10% gain in total gold recovery.
- Second commercial facility commissioned in 2016 at Nordgold's Sudzal Mine in Kazakhstan to treat CIL tailings from a BIOX® operation.

HiTeCC Process Flowsheet



(Ref: BIOMIN paper, ALTA 2014)

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Preoxidation - Sand Farming Process

- Biooxidation process for sand sized whole ore for refractory gold ores.
- Developed by JRKelso&Associates, Henderson, Nevada.
- Comprises HPGR crushing (or grinding) to 80% passing 650 microns, agglomeration, biooxidation in aerated vat or pond reactors for typically 60 days, washing to remove residual sulphates, hydraulic or mechanical unloading, followed by cyanidation in heaps, vats, tanks or combinations.

Preoxidation - Sand Farming Process (Cont.)

- Carried out in plastic lined reactors typically loaded with agglomerated ore to 5 m depth; recirculated bio-oxidation solution is added to the top of the ore bed with drip emitters, and air is blown into the bottom of the ore bed.
- Lab scale testwork for variety of ores has achieved 85+% gold extraction.
- Prefeasibility studies indicate 30-50% capex and opex savings versus tank bio-ox and pressure-ox.

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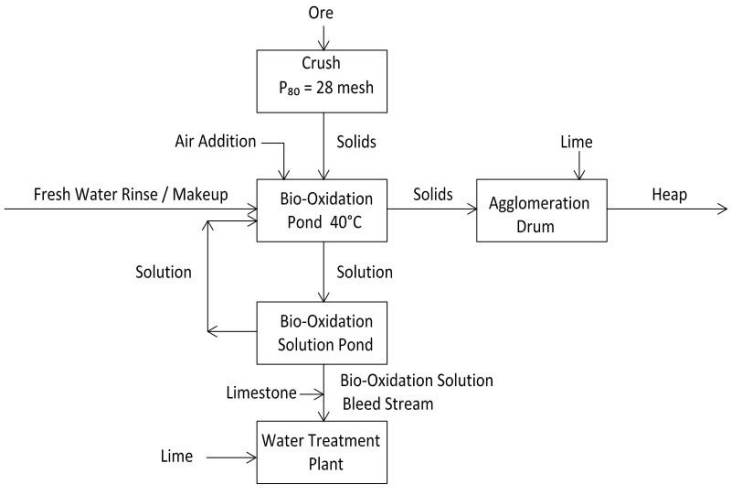
Sand Farming Process Flow Diagram



(Ref: JRKelso&Associates presentation, ALTA 2014)

In-Situ/In-Place Leaching

- Non-Cyanide leaching systems at various stages of development:
- Thiosulphate – CSIRO, Australia, utilizing IX with elution technology developed at CSIRO and commercially applied in Barrick's thiosulphate leaching operation at Goldstrike, USA.
- GlyMine™ - Mining & Process Solutions, Australia, using glycine leaching technology licensed from Curtin University, Australia.

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In-Situ/In-Place Leaching

- Pintails Systems, USA - have developed and commercialized bio-processes for heap leach closure compliance and enhanced gold and silver recovery utilizing naturally occurring microbes.
  - Proposed for non-cyanide in-situ gold recovery applications.
  - Uses site-specific and ore specific development, isolation, and bioaugmentation of naturally occurring microbes.
  - Testwork reported to show technology is effective for liberating gold from silicates and iron minerals, and accelerated bio-leaching of coarse gold.
  - Proposed by Coomooroo Explorations Coy for in-situ treatment of refractory cemented gravel gold ore, at Guildford, Victoria, Australia, where coarse gold is locked in oxidized iron minerals.

IX - Molecularly Imprinted Polymer (MIP) Beads

- 6th Wave Innovations, Salt Lake City – have introduced new range of Molecularly Imprinted Polymer (MIP) IX beads, IXOS®, as potential replacement for carbon in CIP, CIL and CIS. Laboratory and field trials are reported to have shown significant advantages over carbon and conventional IX resins.
- Negotiating full operational tests. Aiming for implementation by end of 2017
- Advantages versus carbon claimed to include: potential saving >$100/oz, higher recovery (no losses to fines or solution), higher mechanical strength, higher capacity, higher selectivity, smaller plant, lower capex and opex, one step elution at atmos. conditions, shorter elution time, no regeneration/reactivation, long life, predictable performance, effective with preg-robbing ores.
- Advantages vs conventional resins claimed to be higher selectivity, faster kinetics, better adsorption and elution, higher strength, lower gold loss, and longer, life.

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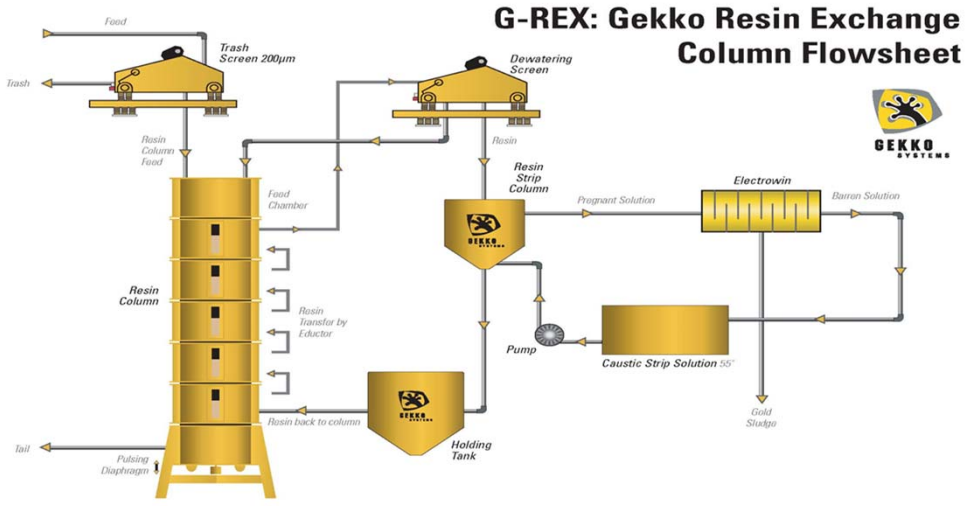
IX – G-Rex CIX Column

- Developed by Gekko Systems, Australia. Commercially applied at Bong Mieu Vietnam; Ballarat Goldfields, Australia; and Hoschilds, Argentina.
- Multistage countercurrent, pulsed, column contactor, with stages separated by internal screens. Feed solution flows down the column and the column pulsed to fluidize the resin.
- Resin is transferred upwards between compartments using an external educator, and loaded resin is transferred to an upflow batch elution column.
- Designed to minimize resin wear, and is reported to handle unclarified solutions with up to 2% solids at < 200 microns.
- Uses Purolite AuRIX® 100 resin licensed exclusively to Gekko.

G-Rex Column Flowsheet



(Ref: Gekko presentation, ALTA 2016)

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On-Line Analysis, Modelling and Process Control

- Curtin Carbon Meter: Developed at Curtin University, Australia, to automatically measure carbon concentration in each tank. Can provide improved carbon management in CIP/CIL, thus reducing gold solution loss, and optimising carbon inventory, particularly when coupled with Curtin University's proprietary SIMCIL process software. Gekko Systems have licensed the technology and will be responsible for the marketing, manufacture and sales of the technology as "Carbon Scout". (Ref: Curtin University presentation, ALTA 2015)

On-Line Analysis, Modelling and Process Control

- Orica LeachIT Cyanidation Model: Real world gold leaching and reagent consumption model to optimize CIP/CIL profitability. Inputs are principally data commonly collected on gold processing plants. Once calibrated, the model can be used to predict effects of throughput, particle size, residence time, cyanide addition, pH, DO, carbon concentration and by-passing ratios. (Ref: Orica presentation, ALTA 2016)
- Outotec On-line Analyser: New slurry analyser technique based on laser-induced breakdown spectroscopy able to measure carbon and sulphur in the slurry. Opens new process control options for sulphide flotation ahead of pretreatment processes such as pressure-ox.
  (Ref: Outotec presentation, ALTA 2016)

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