



Gekko Systems' InLine Leach Reactor

TECHNICAL OVERVIEW



Technical Leadership on intensive cyanidation



Table of contents

Background	3
Theory of operation	4
Batch versus continuous models	5
ILR – Batch	6
ILR – Continuous	7
Safety	8
Benefits	9
Security	9
Leach the Entire Concentrate	9
Superior Oxidant Flexibility	10
Summary performance data: IAMGOLD's Essakane	10
Processes Steel Scats	11
Simple Maintenance	11
Effective Scale Up.....	11
Operating results and applications	12
Free Gold.....	12
Silver.....	12
Sulphide gold.....	13
Sensitive flow sheets	13
The intensive leaching of gold (ILR) online training	14
Summary	15
Offices and agents	16

Background

First developed in 1997, the InLine Leach Reactor (ILR) was a breakthrough technology for the gold sector providing an innovative approach to precious metal concentrate treatment and was the first modern commercialised technology for the application of intensive cyanidation. Based on the principle of the "bottle roll", which has been used for decades as the most reliable test work method for gold and silver leaching, the InLine Leach Reactor (ILR) has provided benefits over traditional physical separation steps, such as using shaking tables. Shaking tables are often inefficient and require high levels of labour. They also create a security risk in handling coarse gold concentration. The ILR's innovative design and efficient mineral leaching chemistry is providing high gold recoveries, cost benefits, production improvements, and improved security to many operations worldwide.

Gekko has installed over 185 commercial ILR units into more than 30 countries, treating concentrate masses ranging from 0.5tph in ILR-B batch units up to 10tph in the new generation ILR-C continuous systems.

The ILR can be easily retrofitted into any gold grinding circuit. The modular, small footprint design requires minimal space for integration. The ILR's chemical dosing is automated and important leach parameters are electronically controlled, maximising efficiency and safety.

Key features and benefits of ILR

- Fully automated PLC controlled system
- Retains 100% of the concentrate in the reaction zone
- Mechanical agitation for superior leach kinetics
- High recoveries and lowest operating costs
- Online gold analysis options and cyanide monitoring options available
- Turnkey cyanide detoxification can be integrated
- Turnkey electrowinning packages can be integrated
- Proven scale up; successful installation from 0.5tph – 150tph
- Multiple Leach Accelerants and oxidants can be utilised



Figure 1: 3D model Gekko ILR

New generation Continuous ILR-C systems demonstrate the scale up capability of Gekko Systems' ILR. Environmental benefits are achieved through significantly reduced cyanide affected tailings, smaller footprint, and greater flexibility around water balance and reagent re-cycle.

Theory of operation

The ILR receives gravity concentrates or flotation concentrates into a fully enclosed rolling drum. Inside the drum, the ore concentrates are mixed typically with a 1-2% sodium cyanide solution and an oxidant, known as intensive leaching. Specialised baffles inside the drum keep the solids in constant contact with the chemical solution providing a high shear environment. The correct combination of chemicals and concentrate, plus the rolling action of the drum, creates a highly efficient leaching reaction. This drives faster kinetics primarily through mixing and attrition which is critical to remove the oxidation layer away from the surface of the gold particles and allow enriched solution containing the required reagents to access fresh. Leach rate can be directly correlated to the attrition energy absorbed.

Lifters inside the ILR drum mechanically agitate the slurry, forming an oxidant rich zone with high solids-liquids mixing for leaching. Gekko has conducted multiple comparisons on the scale- up between bottle rolls and site data, consistently demonstrating that the ILR has performed equal to, or in some cases better, than laboratory bottle rolls.

The automated ILR-B treats up to 24 tonnes per day per unit, of either gravity or flotation concentrates. The concentrates are typically low mass, high grade Au and or Ag concentrates.

The Continuous ILR-C treats concentrate masses between 1-10tph per unit based on the residence time required for economic leaching, with the systems able to be treat low grades and high grades. Both the batch and the continuous systems can be applied to both free and complex sulphide gold concentrates.

The Batch and the Continuous ILRs work to chemically leach metal from ore concentrates using the same leaching principle. The ILR's horizontal "rolling bottle" design keeps the concentrates in suspension and continuously mixes to accelerate the chemical reaction within the solution.

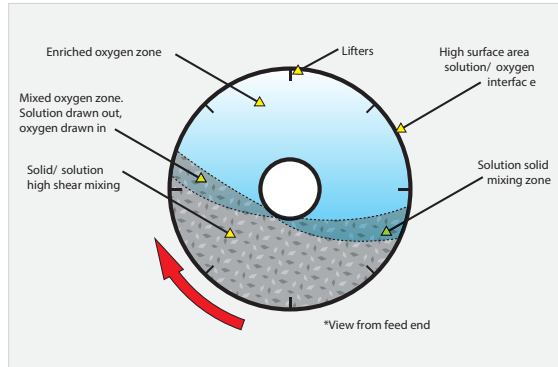
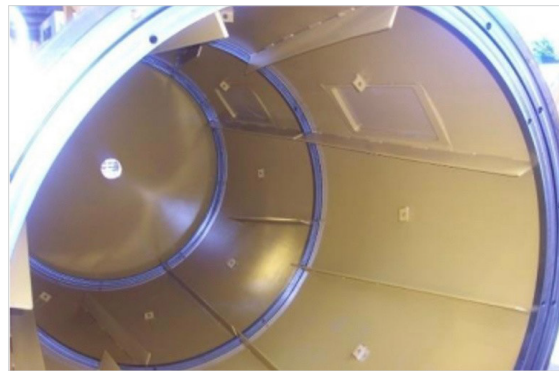


Figure 2:
The rolling bottle



The rolling bottle provides a pure mixing zone, preventing the risk of the solution short circuiting.

When leaching in the batch units is complete, the pregnant 'metal rich' solution is clarified and transferred to an electrowinning circuit. With the continuous units, there is an additional process route. The options include the pregnant solution reporting to carbon columns, resin columns, Merrill Crowe circuits and in some cases direct electrowinning can still be applied. The barren residual solution can report back to the circuit, detoxification process, recycled or in some cases a combination is applied.

Performance guarantees for the ILR are available and can be provided subject to testwork undertaken in approved laboratories.

Batch versus continuous models



Figure 3: Batch ILR at Peak Gold Mines in NSW.



Figure 4: Continuous ILR at Ballarat Goldfields. This unit has been in operation for 15 years.

The ILR-Batch models have been developed to treat higher-grade, lower volume, gold bearing concentrates, typically from centrifugal concentrators, while the ILR-Continuous reactors have been developed to treat lower grade, higher volume, gold and silver bearing concentrate streams from continuous gravity devices and flotation.

If the concentrate grades are too low, then the intensive cyanide process may be uneconomical and other options may need to be considered. [Talk to Gekko](#) about options for your low-grade concentrates.

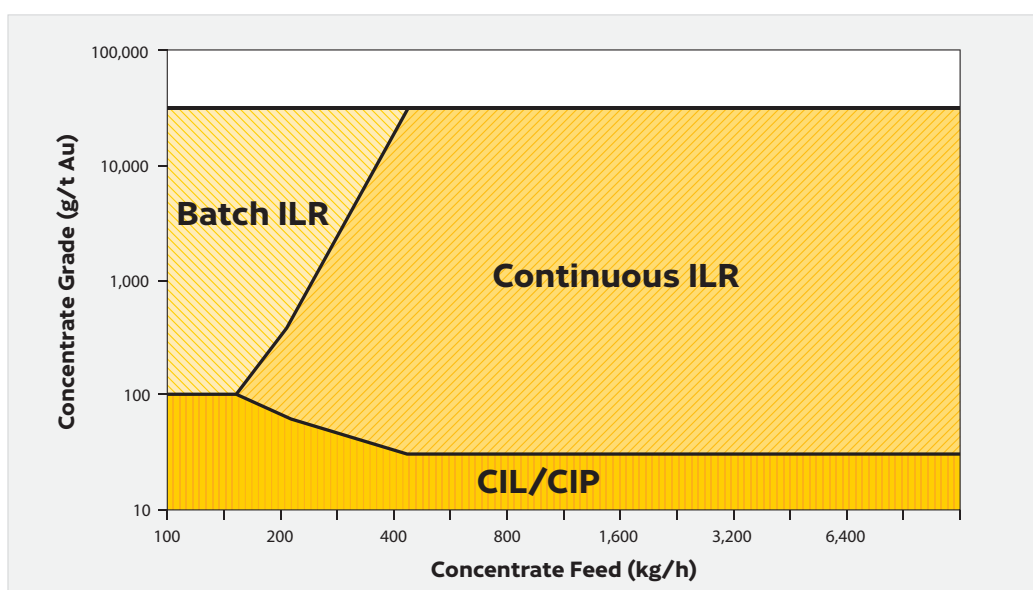


Figure 5: This is a guide to ILR model required, contact Gekko for sizing

Batch versus continuous models

ILR – Batch

- Multiple models and sizes available
- Different models treat between 1-24tpday
- Designed to treat lower mass higher grade concentrates
- Automated process – PLC controlled
- Less people – better security
- Well established – more than 155 units globally
- Standard option in gold room design – replaced tables
- Leading experts in the world – having pioneered the technology

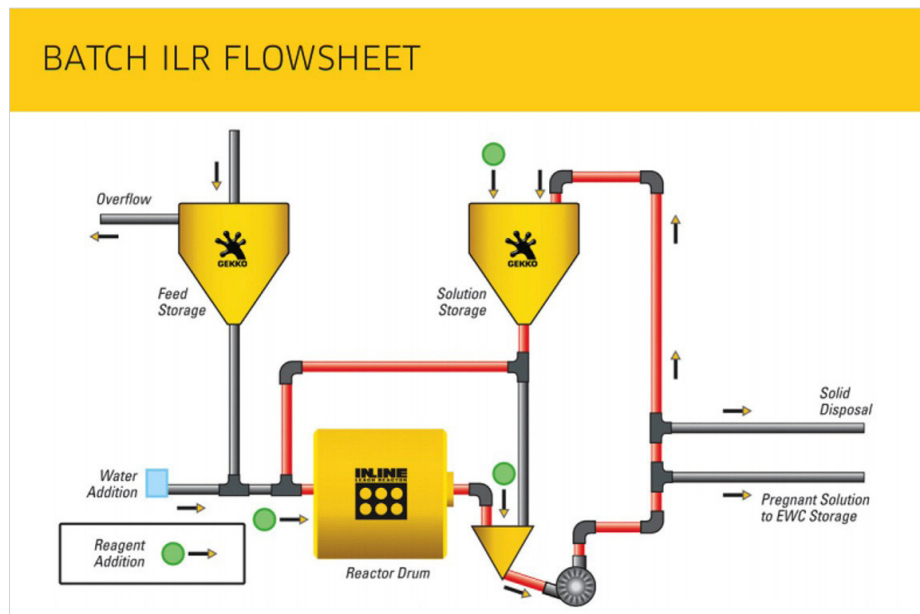


Figure 6: Batch ILR flowsheet

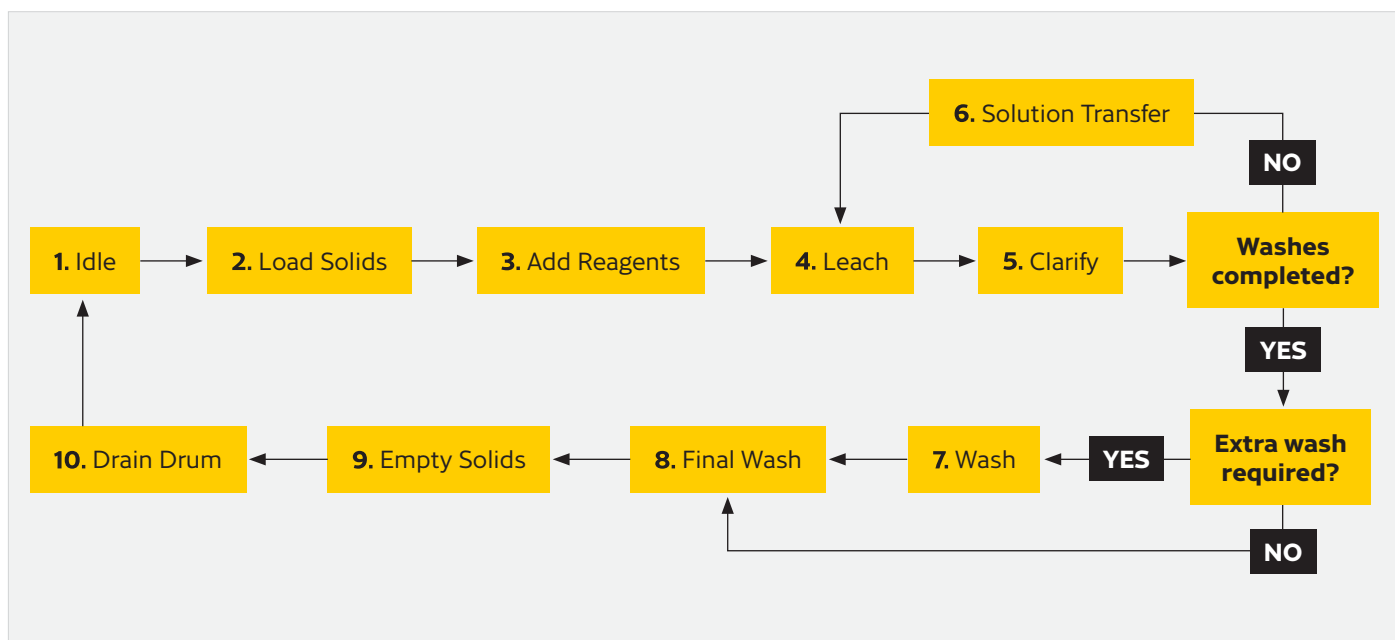


Figure 7: ILR Batch steps of operation

Batch versus continuous models

ILR – Continuous

- Sized on required leaching retention time
- Treats up to 10tph of gravity or flotation concentrate depending on required residence
- Designed as a low-medium grade, high mass machine for circuits with downstream upgrade
- Designed as high grade (ie; Ag flotation concentrates) high mass machine for direct electrowinning applications
- Automated process – PLC controlled
- Secure, high availability unit
- Well established – more than 32 units globally
- Providing a genuine option to CIL on complex low tonnage sulphide concentrates and silver concentrates

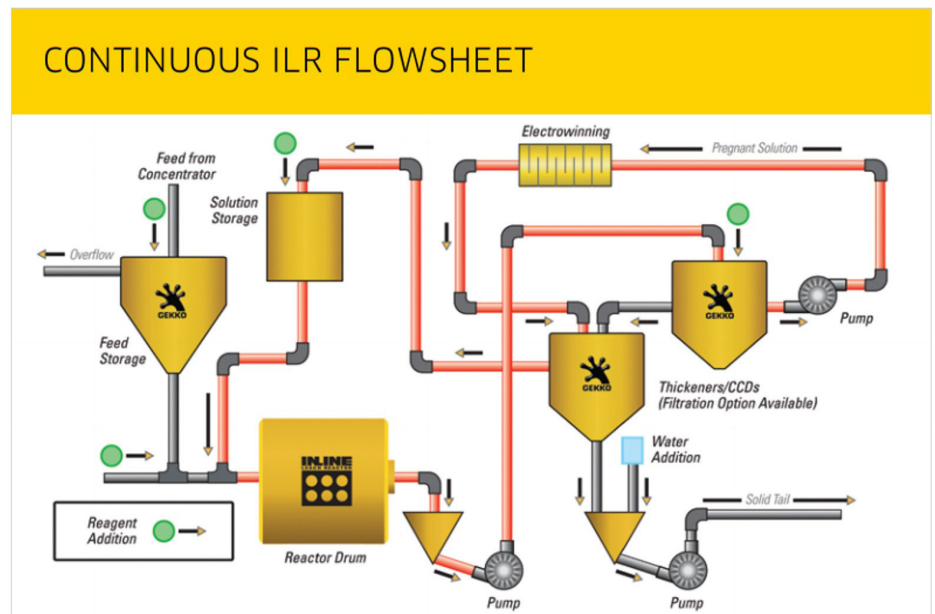


Figure 8: Continuous ILR flowsheet



Figure 9: The ILR1000 Batch at Stawell Gold Mine. The ILR unit achieves +98 per cent recovery and is currently contributing 40 per cent of total gold production.

Safety



Figure 10: InLine Leach Reactor in the production shed in Ballarat, Victoria. All units are fully tested before shipped.

The ILR's operational and control protocols make it a safe, highly operable and world leading technical solution for the global gold industry. For over 25 years, Gekko have continually developed the ILR as a safe unit operation. With any cyanide based technology there are inherent risks that are managed with initial design and installation, maintenance, robust procedures and operator training.

The Gekko ILR technology is designed and manufactured to Australian or the required country standards, with built in safety measures. Gekko recognises the risk of cyanide and has documented the associated hazards and control measures in our operating manuals.

Gekko has a focus on continuous improvement, and we are proud of our long history of successful technical collaboration and technology installations within the gold industry globally. Risk assessment of both in-principal design and on-site installation are carried out internally and in collaboration with the client on site.

In conjunction with the control mechanisms that are in place for potential hazard management, instrumentation, alarms and watchdog systems are utilised. The enclosed drum system isolates potential HCN emissions to the well-ventilated discharge end, whilst mechanically all pinch points are fully guarded.

Benefits

The ILR is the most sophisticated and flexible, precious metals, Intensive Leach system in the world whilst having the lowest maintenance requirement. This allows for high leach rates and high overall recovery. The ILR has many advantages over competitive technologies as described below.

Security

No manual handling of the gravity gold concentrates is required, due to the unit being a completely automatic process. The enclosed drum design provides the highest level of security even with installation external to gold rooms, in open access environments.

Concentrates are not accessible at all during the leaching process.

Leach the Entire Concentrate

The ILR provides increased contact between particles and solution through a mechanically agitated bed, allowing all solid size fractions to be leached. By comparison, fluidised bed type reactors remove the fine material prior to leaching. These fines can typically contain up to 15% of the gold, significantly reducing overall gravity recovery. An example of a gravity concentrates grade-by-size curve (Figure 11), indicates that when the minus 38 micron (yellow section) is removed in a de-slime step, within a fluidised bed type reactor, approximately 13% of the gold in concentrate reports to the solid tailings stream.

The ILR treats 100% of the concentrate mass

To obtain equivalent gold recoveries to an ILR in a fluidised bed type reactor, often a supplementary 'slimes recovery module' is required, adding further capital and operating costs, as well as operating complexity.

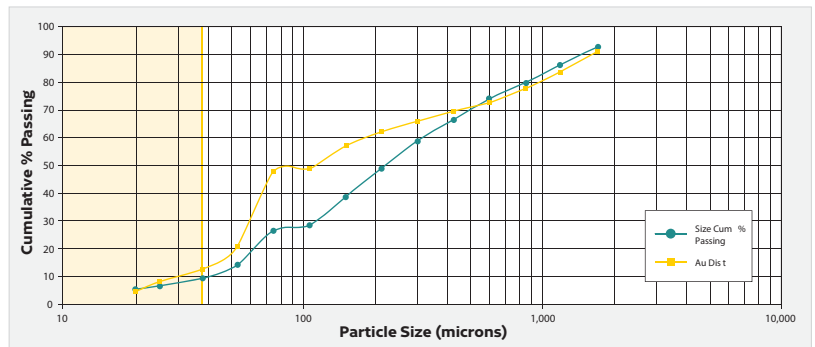


Figure 11: Grade-by-Size Curve for Gravity Concentrate, Existing Site with ILR installed

The ILR maximises the recovery of the very fine gold recovered by high 'G' centrifugal concentrators

Fines Handling by Simple Clarification

Gekko make a conscious technical decision to retain all fine gold within the drum's reaction zone in nearly all installations. This increases total gravity gold recovery and reduces the load on the downstream carbon adsorption circuit. Clarification of the pregnant solution is achieved by using a simple flocculation clarification step in its sequence to produce a clear pregnant leach solution suitable for direct electrowinning. The flocculant doses used in the ILR to achieve clarity have no effect on electrowinning performance. The heavy gravity and or flotation concentrates clarify very easily with correctly specified flocculants, optimized during commissioning.

Benefits

Superior Oxidant Flexibility

The ILR is the only reactor which allows the use of oxygen, peroxide, solid oxidant (GoldiLOX), or a combination to provide the optimal leach conditions for your concentrate. Different oxidants can often provide better overall gold recovery, thus having this flexibility allows the ILR to reach the optimal leach configuration for different concentrate recoveries. The air gap inside the drum maintains an oxygen rich environment whilst a thin film of solution on the inner periphery of the drum absorbs oxygen creating ideal leach conditions. In addition, the type of oxidant used can be easily modified to adapt to different orebodies that may have a better response to different oxidants. It should be noted that peroxide is only used when oxygen or solid oxidants are not available. In comparison, open top fluidised bed reactors are only able to use solid oxidants, which can give suboptimal leach conditions compared to oxygen on certain orebodies.

There has been considerable debate around heating solutions for better recovery and higher leach rates. The ILR can easily be converted to run at elevated temperatures with the addition of an electric immersion heater in the solution vessel. To date, there has never been a need to elevate the temperature of the solution in an ILR installation. Elevating temperature, in most cases, adds unnecessary complexity and is a high energy consumer.

Gekko's ILR's have also been implemented in a number of cyanide sensitive plants. Both Runruno and Obuasi BIOX plants utilise the ILR's within their circuits, the automated solids wash steps dilute cyanide levels and allow the solid residues to return to the milling circuit.

The ILR has also been successfully applied to concentrates with high arsenic content, by including a lime precipitation step, allowing the

Summary performance data: IAMGOLD's Essakane

Commissioned July 2016

Gold recovery from gravity concentrates

- 75-80% using shaking tables
- 99.3% on average with ILR - systematically above 98.5%



Arsenic content in gold bars

- Well below the limit of 0.5% when ILR is used

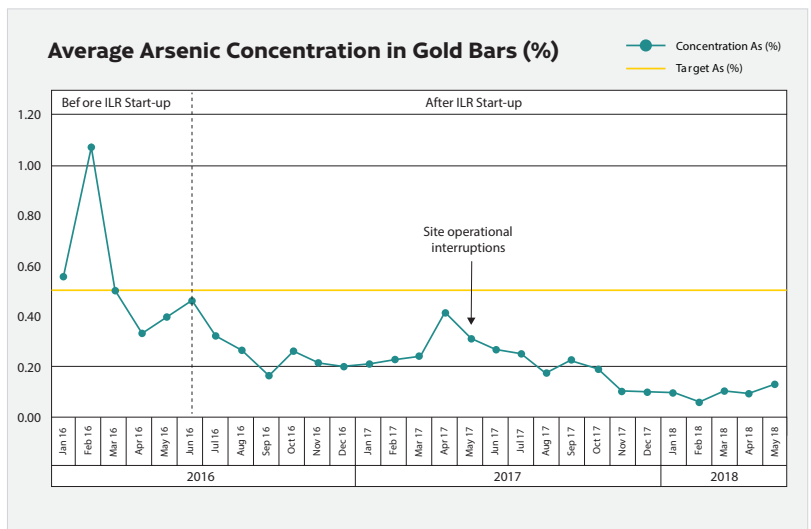


Figure 12: Key results: ILR IAMGold's Essakane operations.

site to produce gold bars well under arsenic limits. An ILR was installed at IAMGold's Essakane operations in July 2016. Figure 12 outlines some of the key results achieved on site.

One of the key drivers for adoption of the ILR in favour of tabling of concentrates was the critical reduction in arsenic levels in the smelting of the gold bars.

Benefits



Figure 13: ILR ready for shipment to Mexico. All units fully tested and quality control has been done before shipment.

Processes Steel Scats

The ILR performs well in cases with high steel content in the concentrate. The ILR's rolling drum provides a true mixing environment preventing any low oxygen zones from occurring. Low oxygen zones are often associated with poor fluidisation or dead zones with agitated leaching systems. This causes gold to plate out on the steel scats reducing recoveries.

Leaching of steel scats can be important as free gold can tend to smear onto the clean steel faces of the scats. Removal of the scats from the milling system can also prove beneficial to grinding.

Simple Maintenance

The ILR has a very simple maintenance requirement. A brief daily check-over is always recommended to ensure the unit is operating optimally. Auto lubrication systems are recommended for regular greasing points on the drum caster wheels and the pump glands, and as with any critical piece of plant equipment.

An example of the ILR longevity is the fact that in over 25 years no ILR has ever worn a hole in its drum.

Effective Scale Up

The ILR utilizes a directly scalable mixed drum reactor design. The ILR design is based around ideal solid liquid contact data through efficient mixing, based on both theoretical modeling and practical application, resulting in the optimisation of the ideal solution recirculation rates. An ILR system treating 50 kg per day, or 150 tonnes per day, will have the same solid- solution interaction, the same contact rates, and the same performance. This has been proven in large (+20 tonne) batch systems, and continuous systems operating at +6 tonnes per hour. Solution grades can be engineered to suit existing systems but will typically be managed to ensure an optimised system is delivered to the client.

Operating results and applications

Free Gold

Free gold applications make up the majority of ILR installations globally with over 155 units globally. The ILR-B is installed in the majority of the world's top 20 major gold companies. Batch sizes are typically between 0.5 and 20t of concentrate, with recoveries of >97% reported. Evidence of the ILR's efficiency has been proven; Gold Fields – Granny Smith re-leach tests have highlighted the technologies efficiency with only 0.4 - 0.5% additional recoveries achieved by retreating the residues.

	ILR Batch 156	ILR Batch 168
Leach Recovery (%)	99.5	99.3
Re-leach Recovery (%)	99.9	99.8

Figure 14: Test Results Granny Smith Re-leach Trials



Figure 15: ILR Batch in the production shed

Silver

Silver applications including free silver, as well as silver sulphide, silver arsenic sulphide and silver lead sulphide complexes can also be batch or continuous and highlight the benefits of the Gekko ILR's aggressive leach kinetics. Gekko has built a strong technical reputation in the treatment of high-grade silver flotation concentrates which have changed the life of mine economics for our customers and provides operating cost benefits over bulk silver concentrate smelting. The ILR installation at the Ares Mine in Peru is designed to treat up to 40tpday tonnes per day in 5 x ILR batch units with feed grades up to 30,000ppm silver achieving recoveries of + 98%.

The San Jose mine in Argentina utilizes an ILR 5000 Continuous units to treat silver concentrates at +30,000ppm silver achieving + 95% recoveries.



Figure 16: The ILR at the Ares Silver Mine in Peru

Perfecting cyanide leaching chemistry is easy with the ILR. The ILR's automated and adjustable intensive conditions, including cyanide and oxidant addition and adjustable leaching times and easily tuned to optimise silver metal recovery.

Operating results and applications

Sulphide gold

Sulphide gold applications are often treated in continuous applications. There have been multiple successful applications around the world including Ballarat Goldfields, Hope Bay, Penjom, and Kloof. Ballarat Goldfields treats a high mass yield of reground gravity and flotation concentrates at a rate of ~3tph in an ILR10000 Continuous for >95% recovery and Hope Bay treats +6tph of sulphide concentrate in 6 x ILR5000 Continuous units.



Figure 17: ILR at Ballarat Goldfields

Sensitive flow sheets

The ILR is proven option to use in cyanide sensitive flow sheets such as BIOX circuits and in flotation environments. It is the ILR's ability to thoroughly wash residual cyanide from the residual solids that makes this possible. The automated solution balance and optimization ensures that the ILR can add value in the treatment of concentrates in the most sensitive of environments. The AngloGold Ashanti Obuasi mine in Ghana has long realised the benefits of ILR at the front of a BIOX plant whilst the Runruno BIOX operation in the Philippines also benefits from ILR's efficiency, both direct leaching and thorough solids washing phase capability. Many flotation circuits around the world have utilised the ILR's automated solids washing capability to reduce cyanide concentrations in the feed to below the level which may interfere with recoveries.

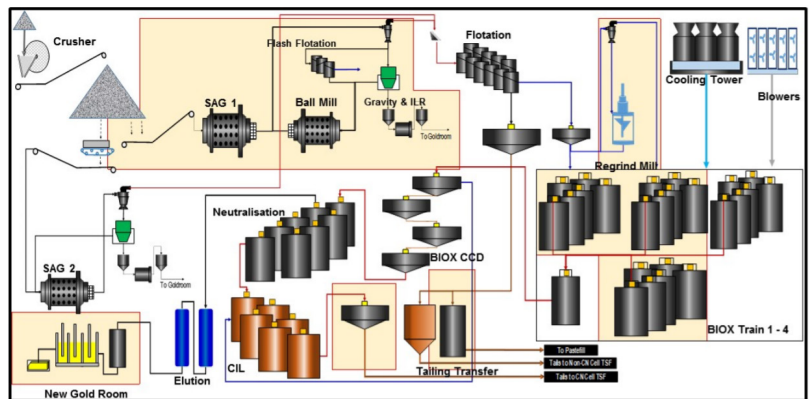


Figure 18: AngloGold Ashanti Ghana - Obuasi Process Flow Diagram. Sensitive flow sheet including multiple ILR's

The intensive leaching of gold (ILR) online training

The intensive leaching of gold (ILR) training course is a comprehensive, technically focused program developed and designed for metallurgists, engineers and advanced operations personnel. The course has been designed as an online, do at your own pace program providing technical people with the knowledge to get the very best out of the unit process.


Consistency of knowledge and unit operation is the key to best practice and this was recognised by Gold Fields Limited who in collaboration with Gekko, identified the need and the benefits from which the course has been built. The course will provide individuals and organisations throughout the world the knowledge to maximise value from the InLine Leach Reactor.

This course consists of 7 modules, each module includes an explanatory video and a quiz. Modules included in the course are:

- Module 1: Introduction to Intensive Leaching of Gold
- Module 2: Introduction to the Gekko Batch ILR
- Module 3: ILR Sequence overview and its stages
- Module 4: Optimisation of Leach Recovery and Reagents
- Module 5: Optimisation of Gold in Solution Recovery
- Module 6: Gold Leaching Diagnostics
- Module 7: ILR Gold Reconciliation and Auditing

Lastly, there is a final assessment which compels the knowledge transferred from the Course to be applied by using in-field sample data in calculations.

The course can be found on Gekko's online training platform:

 <https://training.gekkos.com/>

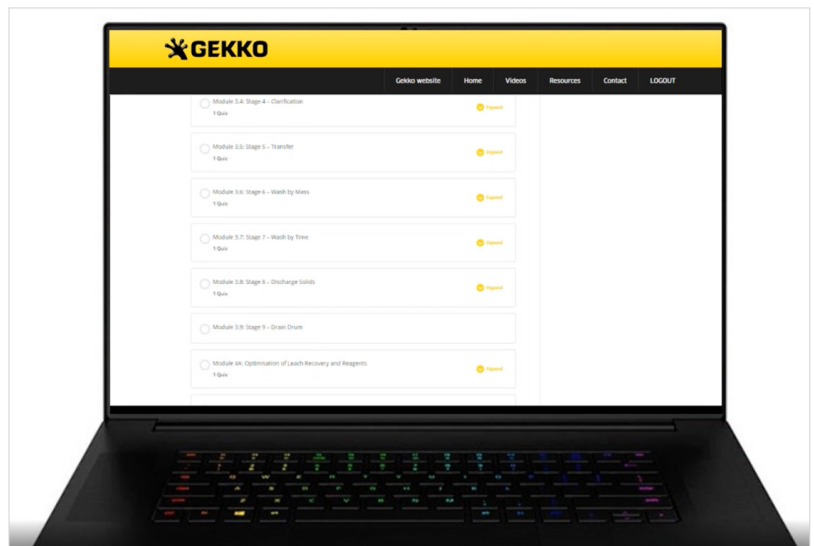


Figure 19: The online course consists out of 7 modules and a final assessment, which can be done at your own pace.

Summary



Figure 20: The ILR Continuous at the Hope Bay gold mine

Gekko's fully automatic ILR-B and ILR-C models offers superior recoveries in a highly efficient, safe and highly secure system. The ILR's innovative rolling drum design and unparalleled flexibility in gold and silver leaching chemistry is providing cost and production benefits to operations across more than 30 countries.

The ILR is available as a completely automated batch model for processing high grade gravity gold concentrates; and, as a continuous model for treating high- throughput gold, silver and complex sulphide concentrates from gravity and flotation circuits.

Contact Gekko today to see if the InLine Leach Reactor is suitable for your operation.

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- Turnkey electrowinning packages can be integrated
- Proven scale up; successful installation from 0.5tpd – 150tpd
- Multiple Leach Accelerants and oxidants can be utilised

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