



Intec Ltd

*Engineering for Superior and
Sustainable Metals Production*

Intec Gold Process

March 2009

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Printed in Australia

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1 Introduction

The major proportion of the world’s gold reserves are gold-bearing refractory ores, which are dominated by iron sulphides such as arsenopyrite and pyrite. There are a number of factors that can render a gold-bearing ore refractory, as shown in Table 1.

Table 1. Causes of Refractory Characteristics

Type	Causes of Refractory Characteristics
Locked	Physical locking or substitution in silicates, sulphides, carbon, etc.
Passivation	Passivation due to formation of a chemical layer.
Chemical	Formation of auriferous compounds e.g. gold tellurides and aurostibnite.
Adsorption	Adsorption of dissolved gold by ‘active’ carbonaceous material in the ore pulp.

Current conventional technologies require an oxidative pre-treatment step such as pressure oxidation or biological oxidation to liberate gold from the concentrates. The oxidised residue is then leached using an alkaline cyanide solution, followed by purification and gold recovery.

In contrast, the Intec Gold Process (Intec Gold Process) uses a mixed halide lixiviant (chloride, bromide and/or iodide), permitting gold dissolution to occur concurrently with sulphide mineral oxidation. Once the gold is solubilised, it can be extracted from the solution onto activated carbon or ion-exchange resins, either in the leach pulp (carbon-in-pulp/resin-in-pulp), or separately in columns (carbon-in-column/resin-in-column). Gold is typically eluted using appropriate complexing agents, and then either electrowon as gold metal or cemented using reductants (e.g. zinc powder).

Therefore, the Intec Gold Process differs from all current commercial practices for treatment of refractory gold concentrates, where gold is extracted from the oxidation residue using cyanide. Cyanide systems require a separate dedicated leach circuit and costly measures for residual cyanide destruction. Importantly, however, the Intec Gold Process can be retrofitted to existing operations where a cyanide strip is employed to recover gold from activated carbon, prior to an electrowinning circuit (Zadra (Zadra 1951) or Anglo processes).

The Intec Gold Process has successfully treated concentrates containing the full range of minerals associated with gold (Table 2). However, highly carbonaceous feeds that contain “active” carbon may be unsuitable for direct treatment using the Intec Gold Process due to excessive preg-robbing behaviour during leaching. In these cases, concentrate pre-treatment or leach residue treatment techniques are recommended to attain high gold recovery.

Table 2. Minerals Suitable for Treatment Using the Intec Gold Process

Class of Mineral	Typical Minerals	Chemical Formula
Arsenides	Arsenopyrite Enargite Tennantite	FeAsS Cu ₃ AsS ₄ (Cu,Fe) ₁₂ As ₄ S ₁₃
Sulphides	Pyrite Pyrrhotite Chalcopyrite Stibnite	FeS ₂ FeS CuFeS ₂ Sb ₂ S ₃
Tellurides	Krennerite Hessite	AuTe ₂ Ag ₂ Te
Elemental	Electrum Native gold and silver	Au _x Ag _y Au and Ag
Antimonides	Aurostibnite Tetrahedrite	AuSb ₂ (Cu,Fe) ₁₂ Sb ₄ S ₁₃

2 Intec Gold Process Flowsheet

A generic Intec Gold Process flowsheet for refractory gold concentrates (Figure 1) consists of three main sections: leach, gold recovery using packed columns, and impurity bleed. The flowsheet can be easily modified to recover specific trace metals such as silver, selenium, tellurium, indium, platinum, etc, and/or base metals such as copper.

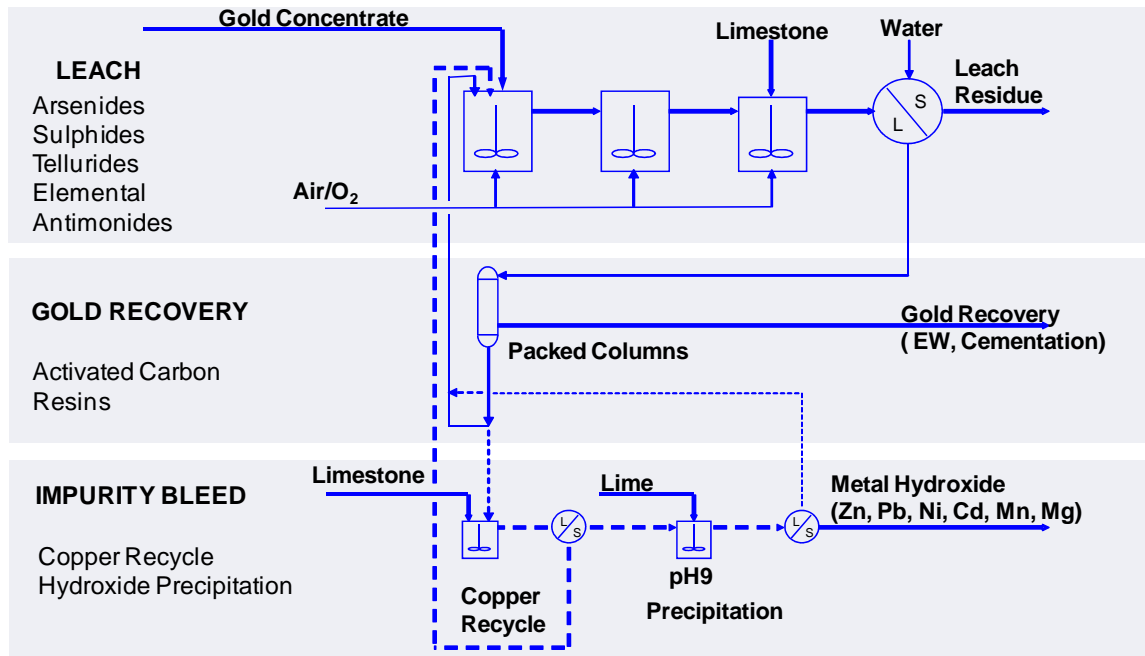


Figure 1. Generic simplified Intec Gold Process flowsheet for the treatment of refractory gold concentrates

Concentrate is fed to a leach train where the refractory sulphides are oxidised along with the liberated gold by oxygen from direct air injection. For most concentrates, sulphide oxidation is carried out at a temperature of 85-95°C in a 6-8M chloride/bromide electrolyte containing 20-60g/l Cu²⁺. The residence time is generally 3-4 hours, but can be up to 10 hours depending on overall leach kinetics and mineral composition of the concentrate. Copper is used as a catalyst to assist the transfer of oxygen from air. Soluble iron is controlled by the addition of limestone into the last leach reactor.

The slurry is then sent to the solid/liquid separation stage, where the leach residue is washed and discharged. Gold in the clear liquor is adsorbed onto activated carbon or resin packed fixed-bed columns. Gold can then be eluted using an appropriate complexing agent (thiourea, thiosulphate, cyanide, etc), and is subsequently recovered as a metal by electrowinning or cementation. The metal is then ready for refining and casting into bullion.

Gold-depleted liquor is sent to the purification circuit where by-products are precipitated with slaked lime. The precipitated solids are separated by filtration where they are washed, and the filtrate is recycled to leaching operations.

3 Intec Gold Process

3.1 Concentrate Grind Size

During conventional flotation and concentration processing, particles of ore are typically ground to a size range of $p_{80} = 70\text{-}100\ \mu\text{m}$. In most cases leach kinetics are significantly enhanced when concentrates are re-ground to a finer particle size. Where arsenopyrite is the sole gold-bearing mineral, a size of $p_{80} = 30\text{-}40\ \mu\text{m}$ has proven adequate to achieve good gold extraction and an acceptable leach retention time. Where gold is locked in pyrite, the grind size will principally depend on the reactivity of the pyrite. For a highly active pyrite, the grind employed for arsenopyrite is used, but more refractory pyrite examples commonly require finer grinding. This may extend to an ultra-fine grind ($<10\ \mu\text{m}$) in rare cases.

3.2 Leach Reactions

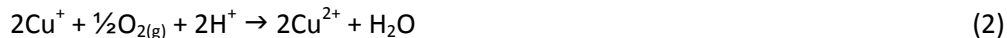
The principal leach reactions are described using arsenopyrite and pyrite as these are the dominant iron minerals that are associated with gold. Similar mechanisms are employed for leaching other minerals, albeit oxide materials require acid leaching instead of oxidation.

3.2.1 Leach reactions for arsenopyrite

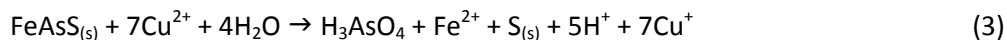
Gold is typically “locked” in arsenopyrite as a lattice-bound species, often referred to as solid solution. As a consequence, complete destruction of the arsenopyrite lattice is required to liberate gold. This is achieved in the Intec Gold Process by chemical oxidation according to the following overall reaction:



The oxygen does not oxidise the arsenopyrite directly, but acts through several intermediate steps, as its solubility in the process liquor is exceedingly low. Oxygen, supplied directly from air sparged into the leach at atmospheric pressure, is initially used to generate a soluble oxidant in the form of cupric ion (Cu^{2+}) according to the following reaction:



This reaction takes place at the interface between air bubbles and the process liquor. The cupric ion then oxidises the arsenopyrite according to the following reaction:



The ferrous and cuprous reaction products are subsequently oxidised by further air sparging according to reaction (2) and the following reaction:



The oxidative action of the $\text{Cu}^{2+}/\text{Cu}^+$ couple is supplemented by the $\text{Fe}^{3+}/\text{Fe}^{2+}$ couple, since a background concentration of iron is always present in the process liquor. The potential achieved under the influence of the Cu^{2+} and Fe^{3+} is $\sim 850\text{mV}$ (versus SHE) in the presence of oxygen.

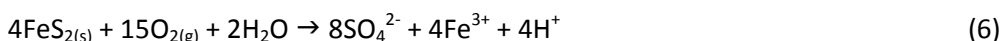
In the presence of ferric ion, the arsenic acid readily forms insoluble ferric arsenate according to the following reaction:



Ferric arsenate (scorodite) formed in the high chloride electrolyte, and under the operating conditions used in the Intec Gold Process, is typically crystalline and stable in the natural environment.

3.2.2 Leach reactions for pyrite

The oxidation of pyrite (FeS_2) in the Intec Gold Process is achieved via the same series of intermediate reactions as employed for arsenopyrite oxidation according to the following overall reaction:



It should be noted that the pyritic sulphur is oxidised all the way to sulphate in contrast to the arsenopyritic sulphur that is only oxidised to the elemental state. Thus higher amounts of oxygen are consumed in leaching pyrite compared to arsenopyrite.

Pyrite is more refractory than arsenopyrite, typically requiring a finer grind size to achieve acceptable reaction kinetics. However, individual pyrite samples exhibit variable reactivity that is thought to be influenced by arsenic substitution for a portion of the sulphur in the crystal lattice. Such pyrite is often termed arsenical pyrite, and the higher the arsenic contamination the more the pyrite reactivity approaches that of true arsenopyrite with an As/S ratio of one. For particularly refractory (low As) examples of pyrite, a higher oxidation potential than is achievable with air may be needed, and pure oxygen can be used.

To maintain a stable background iron tenor in the process liquor, ferric is precipitated as hematite by the addition of limestone at a pH of approximately 1-1.5 according to the following reaction:



The sulphate precipitates as calcium sulphate (crystalline anhydrite) due to the presence of calcium chloride in the brine matrix, according to the following reaction:



3.2.3 Gold stability in the Intec Gold Process leach circuit

Leaching gold into an acidic solution requires highly oxidising conditions, otherwise the gold remains as an insoluble metal. Active sulphides (e.g. pyrite) or inorganic carbonaceous materials make leaching difficult as the unleached matter can reduce solubilised gold back to the metallic state. The term coined for this phenomena is 'preg-robbing'. As a consequence, historically gold operations have employed

alkali cyanide treatments for recovery of gold from leach residues. While the gold-cyanide complex is extremely stable across a range of conditions, cyanide is a highly toxic substance and its use is being restricted world-wide.

An alternative system to cyanide is to use halides. The stability of gold-halide complexes is given below, and clearly the gold complexes become more stable as the halide changes from chloride to bromide to iodide:



Gold recovery processes using only a single halide are difficult, and no commercial processes are available (Marsden and House 2006). This is due to chloride complexes being insufficiently stable to prevent preg-robbing, and circuits using just bromide or iodide struggle to limit the loss of the expensive halide. In contrast, Intec has developed and patented the use of mixed halide systems for the recovery of base and precious metals from sulphide and oxide feedstock. The key advantage of a mixed system is that the major halide can be chloride, and only trace amounts of the gold-stabiliser halide (bromide or iodide) need to be used. In this manner, the circuit is economically viable and achieves excellent recovery of gold.

3.3 Gold Recovery

Extraction of gold from the mixed halide liquor can be achieved using activated carbon or ion-exchange resins. Both techniques have been successfully tested by Intec and third-parties.

3.3.1 Activated Carbon

Activated carbon is the most widely used adsorbent for the recovery of gold from cyanide leach solutions. Either the Zadra (Zadra 1951) or Anglo processes are used, and are known to be reliable, simple and cost effective. In these systems, gold-cyanide complexes are loaded onto activated carbon, and then stripped using a combination of temperature, pressure and alkali cyanide solutions.

The gold-halide complexes used in the Intec Gold Process are also readily loaded onto activated carbon. Extensive testing by Intec and the AJ Parker Centre for Hydrometallurgy, Australia, has demonstrated the full life cycle performance of activated carbon. Repeated loading of gold-halides and stripping tests using cyanide solutions were successfully completed.

Retention time for gold adsorption was 10-15 minutes, which is similar to conventional practice for cyanide systems. Gold loading onto the carbon was typically 2-5% w/w due to the relatively high gold concentrations in solutions - typically 10-100mg/l. The testing concluded that gold could be recovered

by conventional elution or by burning of the carbon, with the choice depending on the economics of the individual situation.

However, there are two major limitations to carbon systems. The first is that activated carbon is non-selective for gold, with co-loading of copper and the formation of iron precipitates observed. A strong hydrochloric rinse of the carbon is sufficient to remove copper and iron prior to gold stripping, but this clearly adds cost and complexity to the operation. The second limitation is that activated carbon is a reductant and can reduce solution potentials to the extent that elemental/colloidal gold can be directly cemented onto the carbon. This can lead to deposition of gold along surfaces of equipment, reducing the overall “efficiency” of the system.

Nevertheless, direct integration of the Intec Gold Process with existing carbon treatment circuits is viable.

3.3.2 Resins

In recent years, ion-exchange resins have been widely used across all metal industries. However, industrial use of resins for recovery of gold has predominantly been confined to Eastern European countries, where gold thiosulfate chemistry has prevailed instead of gold cyanide chemistry. Resins have been developed due to the well documented inability of gold-thiosulfates to load onto carbon (Gallagher et al. 1990; Navarro et al. 2006).

In Intec process liquors, resins have been shown to be more selective for gold loading than activated carbon. Also, unlike carbons, resins do not need to be regenerated via a thermal process, which means the initial capital and the subsequent operating costs are substantially lower than the activated carbon technology. Loaded resins have been successfully stripped with thiosulfate and/or thiourea solutions, which can be readily forwarded directly to electrowinning or zinc cementation circuits.

3.4 By-Product Recovery

3.4.1 Silver

Silver is commonly associated with gold concentrates. However, high cyanide concentrations (>0.5 g/L) are often required to enable silver solubilisation, and recovery is generally limited to zinc cementation circuits instead of activated carbon circuits due to poor silver loading characteristics.

Silver is readily solubilised in the Intec Gold Process due to the mixed halide brine. If the silver content in the concentrate is high compared to the gold content, then selective recovery onto resins or solvent extraction is preferred. High purity silver chloride is precipitated from the hydrochloric acid strip solutions, and then melted to yield silver metal.

On the other hand, if the silver content is low or similar to the gold content, simultaneous recovery through to electrowinning a mixed silver/gold product is also a viable option.

3.4.2 Copper

Many copper concentrates contain gold. Depending on the size of the project, the Intec Gold Process flowsheet can be modified to recovery copper as metal via electrowinning, copper sulphate pentahydrate crystals via solvent extraction and crystallisation, or copper oxychloride via precipitation.

3.4.3 Elemental sulphur (selenium and tellurium)

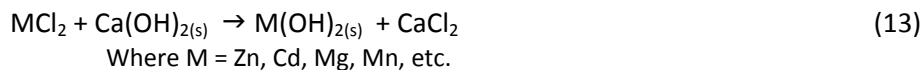
The leach residue from the Intec Gold Process contains elemental sulphur. Intec has successfully recovered the sulphur by differential flotation from the residue, as the other components are iron oxides (hematite), calcium sulphate, and any unreacted minerals. Given appropriate markets, sulphur can be sold, or burnt for energy and sulphuric acid production.

The crystal structure of elemental sulphur is an eight-member ring (S₈). Selenium and tellurium are well known to substitute into these rings, and this is the case when the Intec Gold Process treats concentrates rich in either metal. The Se/Te-rich sulphur can be separated from the leach residue by flotation and re-processed by third-parties for recovery of these important and valuable trace metals.

3.4.4 Minor metals (zinc, cadmium, magnesium, manganese, etc)

The presence of impurities in the feed concentrate (e.g. zinc, cadmium, manganese, magnesium, etc) has no detrimental effect on either the leaching or arsenic precipitation operations. Nevertheless, a method for the management of impurities is required.

Firstly, limestone is added to the gold-depleted bleed to precipitate residual iron and copper at pH 3.5. The solids are removed by filtration and recycled to the leach. Impurities are then removed via slaked lime addition at pH 9 to form insoluble hydroxides that are recovered by filtration for disposal, according to the following reaction:



4 Intec Gold Process Advantages

4.1 Environmental Advantages of the Intec Gold Process

The inherent environmental advantage of the Intec Gold Process are summarised as such:

- No cyanide is used in the leaching process, and when using resins no cyanide is required for the gold recovery circuit.
- Arsenic is converted into a stable and benign ferric arsenate (FeAsO_4 – scorodite), enabling successful treatment of concentrates containing > 10% arsenic. This compares favourably with roasting technologies which create toxic arsenic trioxide (As_2O_3), which must be carefully stored and eventually disposed of at considerable expense.
- No liquid effluents
- No noxious gaseous emissions
- Low carbon-foot print due to low energy consumption relative to other minerals processing technologies (POX, roaster, etc)
- Under appropriate project conditions, a zero-waste process can be implemented
- High overall metal extraction from feedstock (typically > 98%), resulting in stable iron oxide (hematite)/elemental sulphur/calcium sulphate leach residues with little trace/toxic metals present.

4.2 Economic Advantages of the Intec Gold Process

In addition to having significant environmental benefits when compared to alternative technologies, the Intec Gold Process also has superior economics. A comparison of the Intec Gold Process to a range of existing process technologies with respect to plant capital and operating costs is provided. The data is based upon comparative cost analysis commissioned by Intec in 2004 and compiled by J.R. Goode (Goode 2005) and HG Engineering (HG Engineering 2005). Further costing data is referenced from Marsden and House 2005 (Marsden and House 2006).

The following assumptions were used for the comparison;

- Plant located in North America
- Costs exclude tailings disposal, effluent treatment and ore mining costs
- Costs include flotation and grinding circuits where necessary
- Gold concentrate throughput of approximately 50,000 tpa (at 60 g/t gold)
- Intec Gold Process oxidation circuit assumes the use of air as a source of oxygen
- Costs have been inflated to 2009 levels using a Marshall & Swift/ Mine & Mill cost escalation index

The comparisons are only indicative, as variations in ore mineralogy and specific project conditions and requirements may render some processes unsuitable. Sixteen process options were included in the cost comparison as summarised in Table 3;

Table 3 Gold Processing Options

Leach Process	Process Option	Pre-treatment Step	Recovery
Dump Leach	1	None	Carbon in Column, Electrowinning
ROM Ore	2	Coarse Crushing	Carbon in Column, Electrowinning
	3	Medium Crushing	Carbon in Column, Electrowinning
	4	Medium Crushing	Carbon in Column, Zn Precipitation
	5	Fine Crushing, Agglomeration	Carbon in Column, Electrowinning
Free Au con	6*	Grinding, Flotation	Carbon in Pulp
Ground Ore	7	Grinding, Bio-oxidation	Carbon in Pulp, Electrowinning
	8	Grinding, Roasting	Carbon in Pulp, Electrowinning
	9	Grinding	Carbon in Pulp, Electrowinning
	10 ⁺	Grinding, Flotation	Carbon in Pulp+
	11	Grinding, Pressure Oxidation	Carbon in Pulp, Electrowinning
	12	Grinding	Counter-current decantation Zn Precipitation
Locked Gold Concentrate	13	Grinding, Flotation, Roasting	Carbon in Pulp, Electrowinning
	14	Grinding, Flotation, Bio-Oxidation	Carbon in Pulp, Electrowinning
	15	Grinding, Flotation, Pressure Oxidation	Carbon in Pulp, Electrowinning
	16	Grinding, Flotation	Resin Columns, Electrowinning

* Free gold concentrates only
+Sale of concentrate

Figure 2 highlights the advantage of the Intec Gold Process in terms of capital costs when compared to the 15 other process technologies. While the Intec Gold Process capital cost is significantly lower than process options 5 – 15, it also compares favourably to heap and dump leach operations for treatment of ore. Some feedstocks are unsuitable for heap or dump leaching, and these are particularly suitable for treatment using the Intec Gold Process.

Figure 3 highlights the advantage of the Intec Gold Process in terms of operating costs. As expected, apart from the cheaper heap or dump leach operations, the Intec Gold Process operating cost is the lowest of all other available technologies.

As shown through this indicative cost comparison, the Intec Gold Process has a significant cost advantage in both capital and operating cost to all other standard gold processing technologies.

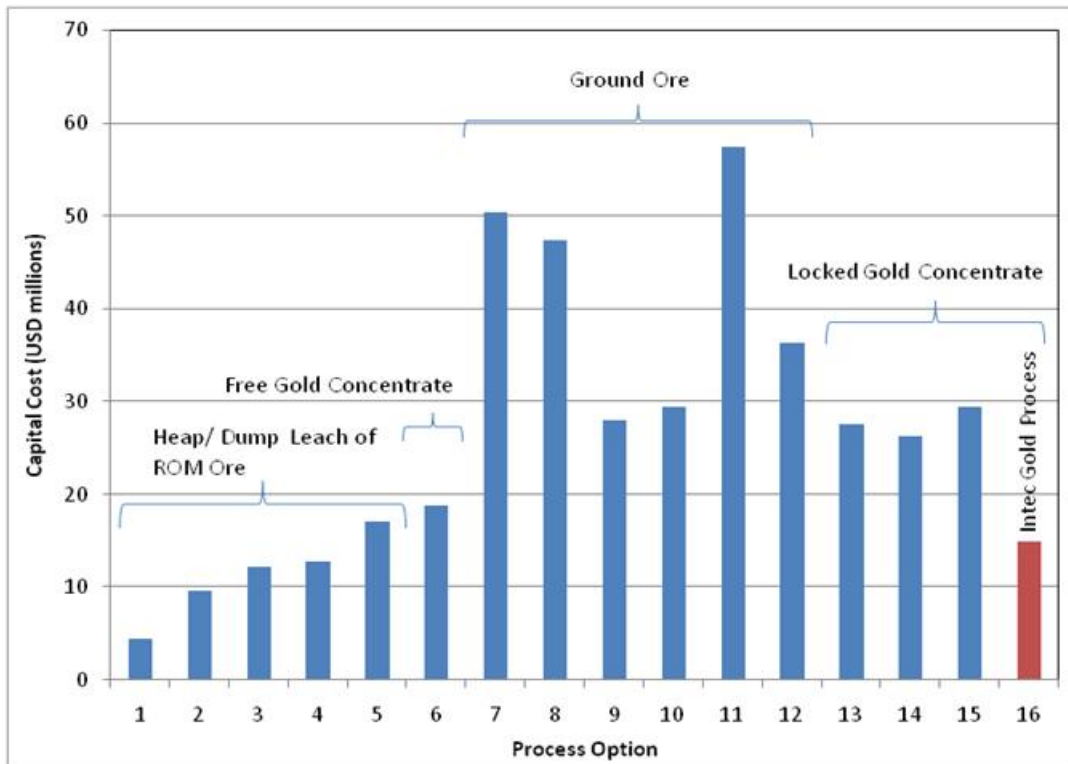


Figure 2 Comparison of Plant Capital Costs (USD millions)

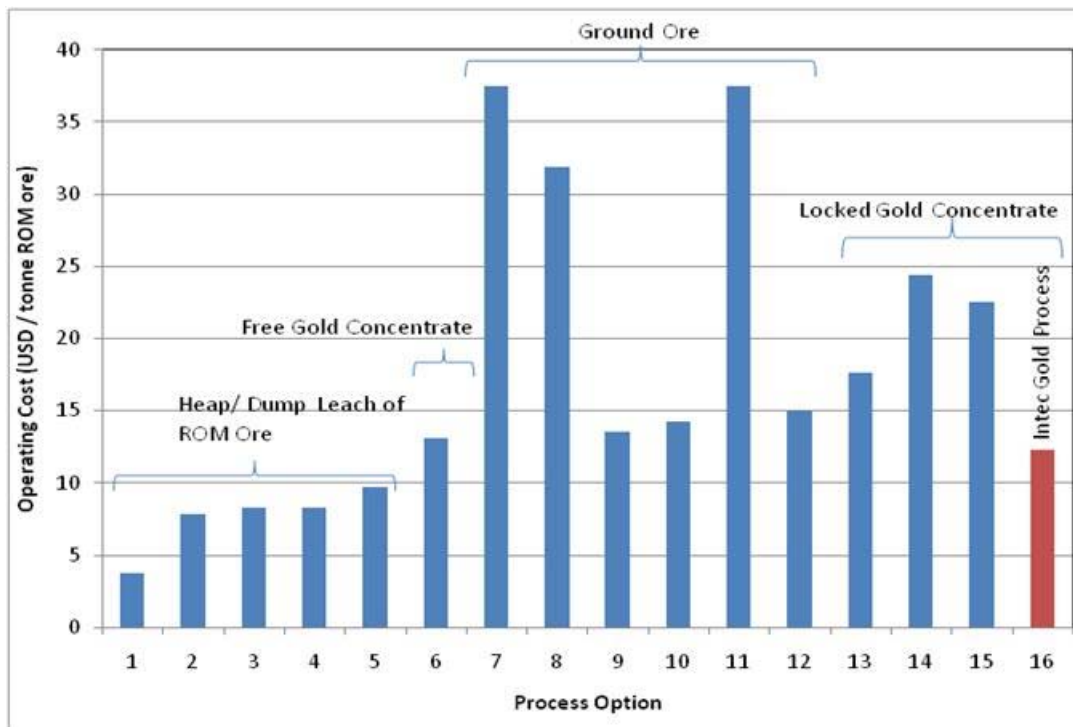


Figure 3 Comparison of Plant Operating Costs (USD per tonne ROM ore)

5 Intec Experience

Over the last 10 years Intec has successfully carried out test work for external clients to evaluate and prove the Intec Gold Process technical feasibility, economic and environmental advantages. Testwork has ranged from proof of concept studies to pilot plant campaigns. It has also verified the process at a demonstration plant scale in Burnie, Tasmania. Examples of testwork are provided in Table 4:

Table 4. Examples of successful application of Intec Gold Process to refractory gold concentrates

Project Title	Ore Type	Au head grade (g/t)	Extraction	Recovery from solution	Other Metals in Concentrate
Laboratory Bench Scale Tests:					
Furtei gold project, Sardinia	Enargite, Cu_3AsS_4 Pyrite, FeS_2	38.7	85%	>98% using resins from 0.3 ppm solution	10% As, 28% Cu, 190 g/t Ag, 1860 g/t Te, 750 g/t Hg
Sample from Polyus, Russia	Arsenopyrite, FeAsS Pyrrhotite, FeS Antimonite, Chalcopyrite, CuFeS_2 Pyrite, FeS_2	91.8	90%	>95% using carbon from 10 ppm solution	6% As, 4% Sb, 3% C
Sample from Barrick, South America	Enargite, Cu_3AsS_4 Arsenopyrite, FeAsS Pyrite, FeS_2	48.1	87%	>98% using resin from 2ppm solution	4.4% As, 11.2% Cu, 1.4% C, 175 g/t Te, 705 g/t Ag
Sample from GoldCorp	Arsenopyrite, FeAsS Pyrite, FeS_2	170	95%	not completed	15% As, 9.8% Si, 1.5 % C
Pilot-plant Scale Test: (closed loop continuous operation)					
Sample from Barrick, Australia	Arsenopyrite, FeAsS Pyrite, FeS_2	58.6	>95%	>98% using carbon from 10 ppm solution	0.5% As

In 2004, Intec successfully operated a pilot plant using the Intec Gold Process to treat 30kg/day of refractory gold concentrate provided by Barrick, Australia. Gold leach extraction obtained was up to 96.5% using a single leach circuit and mild grinding (70 μm). Gold recovery onto carbon was very high, as was plant availability at 99%. Intec Gold Process gold recovery was higher than that obtained by using ultra fine grinding (10 μm) followed by cyanide leaching (90-92%) in a conventional circuit. The full-scale ultra-fine grinding option was chosen by Barrick in early 2001 as the most cost effective alternative to roasting when compared to an acid plant, pressure oxidation, and bacterial oxidation. However, this option still involves very high costs associated with energy consumption levels to achieve the required particle size, up to 120kWh/t of concentrate for a grind size of 10 μm (Ellis and Gao 2002). Intec Gold Process performance for this sample concentrate suggests that the Intec Gold Process is a more economic and environmental option than ultra-fine grinding in conjunction with cyanide leaching for this particular case.

6 Capabilities of Intec

The process and design engineering team at Intec is able to provide process flowsheet development, flowsheet modelling, in-house process evaluation testwork (laboratory, piloting and demonstration scale), scoping/feasibility studies, and financial modelling for hydrometallurgical minerals processing projects. In many cases, a combination of common base and precious metal hydrometallurgical circuits can be integrated with proprietary Intec technology circuits, e.g. the production of zinc sulphate crystals would involve an Intec halide leach, solvent extraction, and then crystallisation from sulphuric acid brine.

The Intec team has gathered significant experience in testing and developing over 50 projects in the past 10 years, for extraction and recovery of gold, copper, silver, lead, zinc, nickel, cobalt, indium, and platinum. The testing has focused on agitated leaching circuits, purification techniques (cementation, solvent extraction, ion exchange resins, and precipitation), and product recovery (electrowinning, sulphidisation, and precipitation). Two continuous closed-loop demonstration plants have been designed, built, and operated, with the \$10M (AUD) Burnie Research Facility available for testwork and project demonstration in Tasmania, Australia.

The Intec technology is now commercially available. Intec pursues a flexible client-per-client approach to licensing, royalties, equity participation, or other forms of investment. Exclusive access rights to the technology are available on a geographical basis.

7 Conclusion

The Intec Gold Process represents a new approach to the recovery of gold from refractory sulphide deposits. The process has been proven to deliver high gold extractions and recoveries, which compare favourably against other technologies. The capital costs and operating costs are relatively low, making the Intec Gold Process attractive to new operations. Expansion projects should also consider employing the Intec Gold Process, as it can easily be combined with existing carbon or resin gold recovery circuits.

The environmental benefits of the process are unparalleled, with the elimination of cyanide from the leach circuit and conversion of arsenic into stable ferric arsenate being critical points of differentiation with all other technologies for gold processing.

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