
THE NEW CESL GOLD PROCESS

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1 SUMMARY

CESL has developed an efficient new process for recovering gold and silver from copper sulphide concentrates, using cyanide to leach residue from the existing CESL Copper Process.

The challenge has been to make the process economic, in comparison with conventional smelting and refining, which recovers gold and silver effectively at very low cost. Hydrometallurgical processes for gold and silver recovery from leach residues have a fundamental disadvantage that the precious metals are never concentrated as in smelting/refining but are contained in roughly the same mass as the original concentrate. Furthermore, a conventional cyanide process suffers due to the unusual characteristics of the residues compared to naturally occurring gold and silver ores.

The residue from the CESL copper process contains virtually all of the gold and silver in the original concentrate, in about 80 % of the mass. Gold and silver recovery by simple cyanidation of this residue is unsatisfactory as it consumes very large amounts of cyanide, due to formation of both thiocyanate and also copper cyanides, typically consuming >30 kg NaCN/tonne residue.

Cyanide consumption, however, can be reduced to tolerable levels by a combination of process innovations: These include pressure cyanidation for short retention times to minimize thiocyanate, partial suppression of copper cyanide formation, and finally by recovering cyanide as efficiently as possible from the (reduced) copper cyanide complexes.

Total cyanide consumption with the new process is now about 2 kg NaCN/tonne concentrate, net of cyanide recovery. Gold and silver recovery is consistently 90%.

The new process for both copper and gold/silver recovery has been successfully tested on a continuous pilot plant scale for several thousand hours, on five different Cu concentrates; this is over three years work in total. Careful accounting of cyanide consumption during the various campaigns has shown that the cyanide consumption due to thiocyanate is between 0.5 – 1.3 kg NaCN/tonne residue, accounting for about half of the known consumption.

This low cyanide consumption now enables the CESL Copper Process to efficiently process copper-gold-silver concentrates in competition with conventional smelters.

Preliminary operating costs are presented in summary form for a hypothetical CESL refinery producing 154,000 tpy Cu from 550,000 tpy concentrate, at 29% Cu and containing 9 g/t Au. In this case study, the operating costs for the gold/silver process are estimated to add about US\$ 0.024/lb Cu to the existing CESL copper process, for a total of US\$ 0.20/lb Cu.

The net cash flow is improved by approximately US\$ 74 Million per year, compared to the alternative of selling the concentrate to a smelter and paying realization costs. This is equivalent to US\$ 0.22/lb Cu increased cash flow, before amortization costs.

2 CESL COPPER PROCESS

The CESL Copper Process was developed for copper sulphide concentrates as a hydrometallurgical alternative to smelting and refining. This process has been described previously and consists of five main process steps, (Figure 1):

- Pressure oxidation of concentrate at 'medium temperature', i.e. above the melting point of sulphur, but below phase transition point of sulphur
- Copper leaching of the solid oxidation product with raffinate at atmospheric conditions to produce a PLS
- Solvent extraction of PLS to produce a high purity electrolyte and regenerate raffinate
- Partial neutralization of raffinate to remove any excess sulphate
- Electrowinning to recover copper in commercial product form, (full cathodes).

The concentrate slurry and a recycled acidic chloride solution are pumped separately into an autoclave operating at about 150°C and 1,400 kPag total pressure. High purity oxygen is added to achieve almost quantitative oxidation of the copper minerals within a retention time of about 1 hour. Operating pH varies from about pH 1 to about pH 3, depending on minerals in the feed concentrate and the other operating conditions.

Under these conditions, copper sulphide minerals are efficiently converted to an acid-soluble sulphate salt, *basic copper sulphate*, which reports to the PO filter cake, or to the PO product solution, depending on operating pH of the autoclave. Iron present in the copper minerals is oxidized to hematite-type minerals, and sulphur is converted mostly to elemental sulphur. Very little sulphur to sulphate oxidation occurs, and therefore acid generation from sulphur oxidation is minimal.

The autoclave discharge slurry is thickened and filtered. Copper may be removed from the autoclave leach liquor by solvent extraction if necessary, before it is recycled to become feed to the autoclave.

The pressure oxidation filter cake is then leached at atmospheric pressure with recycled raffinate at about pH 1 – 2, and the resultant residue separated from the solution by a CCD circuit and final filtration. Wash liquor for the CCD is supplied internally from the process, as a secondary raffinate. The copper-containing pregnant leach solution (PLS) is processed in a conventional solvent extraction circuit, producing a raffinate which is recycled back to leaching.

In the final process step, copper is recovered from the copper rich electrolyte solution produced by the solvent extraction process by conventional electrowinning. The cathode production meets LME Grade-A standards.

The waste streams from the plant include the final washed leach residue and the combined gypsum product from neutralization. The leach residue contains the elemental sulphur,

hematite and any precious metals present in the concentrate. Copper recovery is generally 95 – 98%, roughly the same as a smelter.

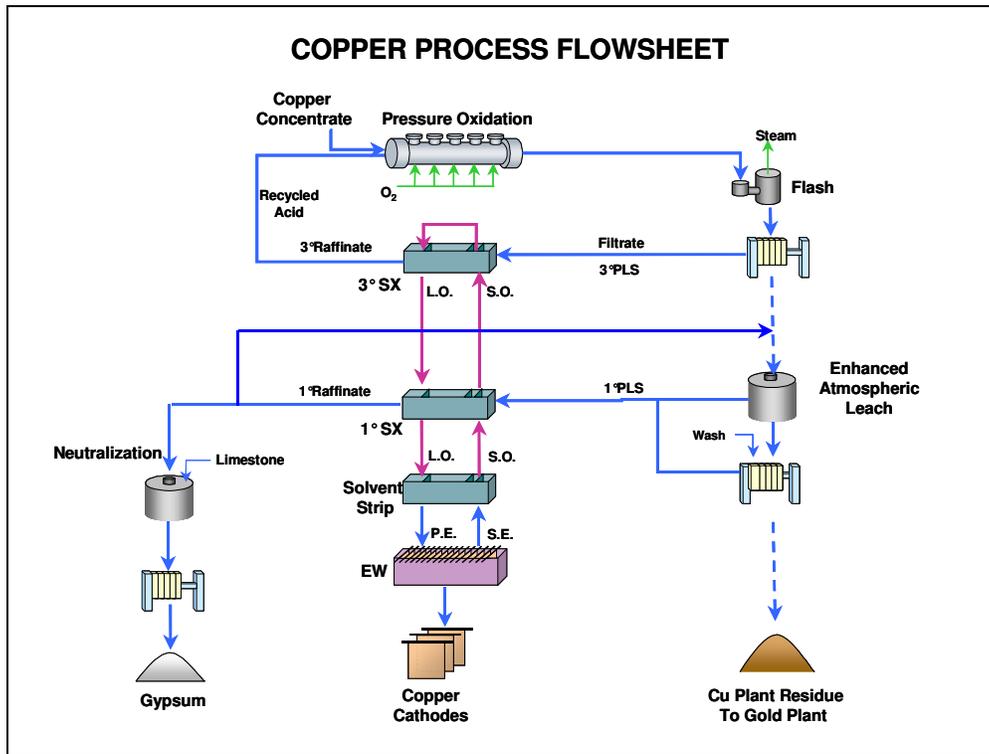


Figure 1: CESL Copper Process Flowsheet

This paper is concerned with the efficient recovery of gold and silver as an important adjunct to the above CESL Copper Process. It is significantly different from a previously disclosed CESL process for gold and silver recovery, and has the advantage of being much simpler than the previous process.

3 GOLD AND SILVER IN COPPER CONCENTRATES

3.1 Value of Gold and Silver in Copper Concentrates

Gold and silver occurring in copper sulphide ores generally follow the copper into the flotation concentrate in fairly high yield, and frequently there is enough gold and silver present to be economically significant.

A survey of copper concentrates (Figure 2) shows that the average concentrate contains the equivalent of about US\$0.04 - 0.15 /lb Cu in gold and silver, using 2004 gold and silver prices. More importantly, about 95% of the copper concentrates in the world have a payable gold and silver value above 2 ¢/lb copper in the concentrate. In order for a

hydrometallurgical process to be a competitive alternative to smelting, precious metals recovery must be economical and efficient in this concentration range of gold and silver.

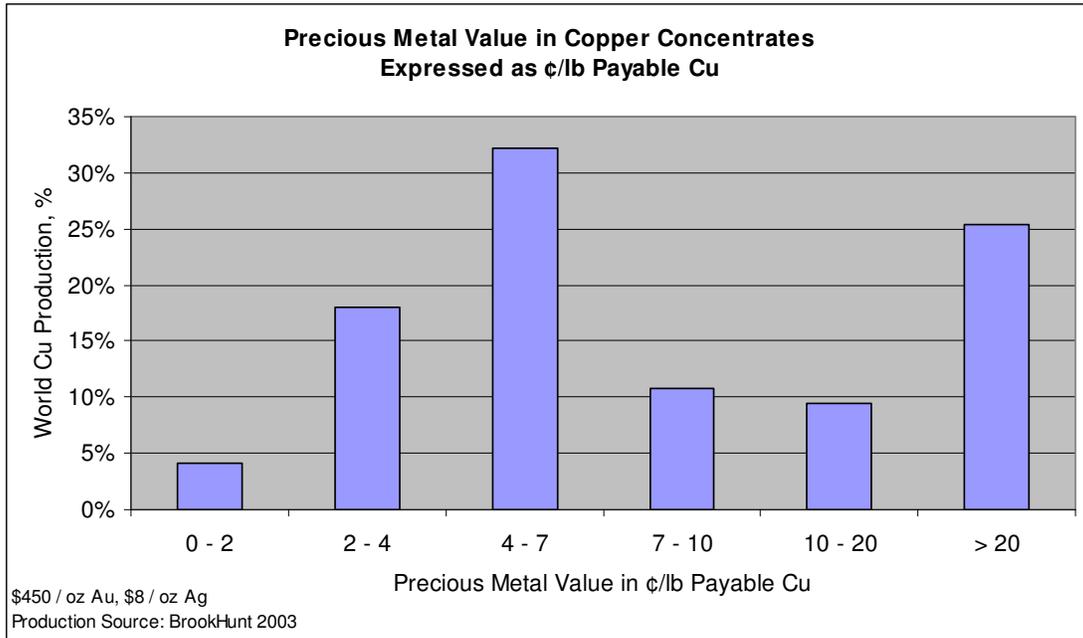


Figure 2: Precious Metals Value in Copper Concentrates

3.2 Gold and Silver Recovered in the Copper Smelting Process

When copper concentrates are processed by smelting and refining, the precious metals are generally recovered in high yield (about 90 - 98%). The extra cost to the copper smelter/refinery of such precious metal recovery is quite low. The precious metals follow the copper through the various steps of matte smelting and converting to blister copper; the blister copper is then usually refined by electrolysis to remove impurities and during this refining process precious metals report almost quantitatively to the (refinery) anode slime, which has a low mass (typically only a few kg per tonne of copper metal). The anode slime therefore has a high concentration of said metals relative to the original copper concentrate fed to the smelter, e.g. 1000X more concentrated. Such low mass and high concentrations of gold and silver in the slime lead to low processing costs for final recovery and refining.

The monetary returns from such precious metals in concentrate processed in a smelter are economically significant, and any alternative process for sulphide concentrates must take this into consideration. Smelters will generally pay at least 90% of the value of the gold if there is at least 1 g Au per tonne concentrate; for silver the minimum for payment is usually 15 g/t. Probably over 85% of copper concentrates traded worldwide have at least this much gold and/or silver, so there is a significant credit for such values when the concentrate payment terms are negotiated between seller and buyer. Typically this credit

amounts to about 5 - 10% of the value of the concentrate, and generally the gold value is about 80 - 90% of this, with silver making up the remainder.

If gold and silver are not recovered efficiently along with copper, then the overall economics of the process would be adversely affected in comparison smelting, and would render some concentrates which are particularly rich in gold and silver, uneconomic to process.

3.3 Gold and Silver Department in CESL Copper Process

Gold and silver generally do not leach in the CESL Copper Process, and are therefore left almost quantitatively in the residue after recovery of base metals. Thus any recovery process for gold and silver must be an additional or subsequent step(s) processing such residue, which still has a mass of about 80% of the original concentrate. Concentrations of gold and silver in such residue are only slightly higher in this residue, and still quite low.

3.4 Economic Considerations for Gold and Silver Recovery from CESL Copper Residues by Cyanide Leaching

The residue generated by the CESL Copper Process has unusual characteristics in regard to cyanidation which can greatly increase the cost of the process, even to the point of making it uneconomic.

The copper residue contains two components in particular which tend to consume very large amounts of cyanide, when the residue is leached under "standard" conditions, i.e. leaching with low concentration cyanide solution in atmospheric conditions for 1 – 3 days.

Firstly the residue from the CESL Copper Process still has a significant copper content, despite the fact that it has already been processed specifically for copper extraction. The CESL Copper Process is about 95 – 98% efficient for Cu extraction, and thus the residue typically contains 1.0 – 1.5% Cu. This small Cu content unfortunately is partly (15 – 25%) soluble in standard cyanide leach conditions, leading to the formation of soluble copper cyanide compounds, as well as other cyanide compounds such as cyanate.

Also present in the copper residue is elemental sulphur that typically constitutes 25 – 35% of the residue. A minor amount of elemental sulphur also reacts with cyanide solutions leading to the formation of thiocyanate compounds.

Both of these phenomena lead to very high cyanide consumption when the CESL copper residue is treated in a standard cyanide leach, e.g. 30 kg NaCN consumed per tonne of copper residue, or more than 100X the consumption typically experienced in leaching gold ores. Such levels of cyanide consumption render the process far too expensive in view of the modest value of gold and silver to be extracted.

Worse still, the gold and silver themselves cannot easily be extracted from the Cu process residue by cyanide leach solutions, and extractions of gold and silver from leach residue are generally incomplete.

In summary, with standard cyanide leaching of the copper residue, costs are high, gold and silver recoveries are poor, and the costs of the process tend to outweigh the value of the recovered metals.

In a strenuous effort to overcome these difficulties a previous process was devised several years ago (to reduce cyanide consumption and boost metal recovery). This process was fairly complex, involving a number of steps. The general strategy of this process was to remove the components of the residue that consume cyanide in a series of pre-treatment steps prior to the actual Cyanidation. After considerable testwork and development over several years, a successful flowsheet was developed which achieved the aim of reducing cyanide consumption and recovering gold and silver. Subsequently an engineering study was carried out on this process which estimated the operating and capital costs of a commercial plant; the conclusion was that the costs were too high to be a competitor for existing smelters.

Now a new simpler process for gold and silver recovery from copper concentrates has been discovered which overcomes these economic challenges.

4 NEW PROCESS FOR GOLD AND SILVER

4.1 Gold Recovery Options Considered

Recovery of gold and silver from copper concentrate leach residue has been investigated previously. The list below provides a quick overview of the various routes that were considered during the development of the CESL Gold Process.

4.1.1 Direct Cyanidation

The simplest route conceivable, the Copper Plant residue is subjected to a cyanide leach. Perceived disadvantages:

- Very high cyanide consumption due to:
 - thiocyanate production
 - copper cyanide production
- Poor recovery of gold due to:
 - occlusion of gold in sulphur
 - insufficient cyanide present

4.1.2 Roast / Cyanidation

The Copper Plant residue is first roasted to remove elemental sulphur and residual sulphides. The calcine is then subjected to a cyanide leach. Perceived disadvantages:

- Novel roaster technology (unusual feed material)
- Efficient gas cleaning required (to avoid losses of gold and silver)
- Large amount of acid production, roughly equal to smelter acid plant
- Environmental issues with tail gas emissions
- High capital costs

4.1.3 Total Oxidative Leach / Cyanidation

The Copper Plant residue is processed through a high temperature, high pressure autoclave, which oxidizes elemental sulphur and residual sulphides. Leach residue subjected to a cyanide leach. Perceived disadvantages:

- Large volume of dilute acid produced in TOL (hence must be used onsite or neutralized with high reagent costs, large gypsum production)
- Very high oxygen consumption
- Large autoclave, leading to high capital and operating costs
- High impurity load introduced by TOL liquor into process solutions (gangue elements)
- Large wash circuit to remove cyanide consuming copper
- Difficult silver recovery

4.1.4 Sulphur Leach / TOL / Cyanidation (previous CESL process)

The Copper Plant residue is first leached with an organic solvent to remove elemental sulphur. The loaded solvent is processed by evaporation cycle to recover sulphur and recycle the solvent. The sulphur crystals and the sulphur leach residue are both cleaned to remove residual solvent; The residue is subjected to TOL to remove residual sulphur and copper and then finally leached with cyanide. Perceived disadvantages:

- Sulphur leach technology (new technology)
- Filtration issues with sulphur leach residue (very fine)
- High costs of solvent
- Solvent recovery issues and novel drying technology required
- TOL costs...see above, but with a low S feed, leading to heat balance issues
- High capital and operating costs

4.2 Gold Flowsheet Description

This CESL Gold Process consists of five main process steps, (Figure 3):

- Pressure cyanidation of repulped residue with high pressure oxygen to leach gold and silver into solution, followed by filtration of cyanidation slurry, to produce preg and washed residue
- Carbon absorption of preg (CIC), and a conventional adsorption-desorption-recovery process for treatment of loaded carbon. The major portion of barren is recycled to Pressure Cyanidation directly after CIC
- Copper removal from remaining barren by acidification, precipitation as CuSCN , and filtration
- HCN volatilization and absorption to reconstitute NaCN for recycling to front end of process and also generate a bleed stream

- Cyanide destruction by conventional means on the bleed stream from volatilization

In addition to the five steps listed above, there is an optional flotation step.

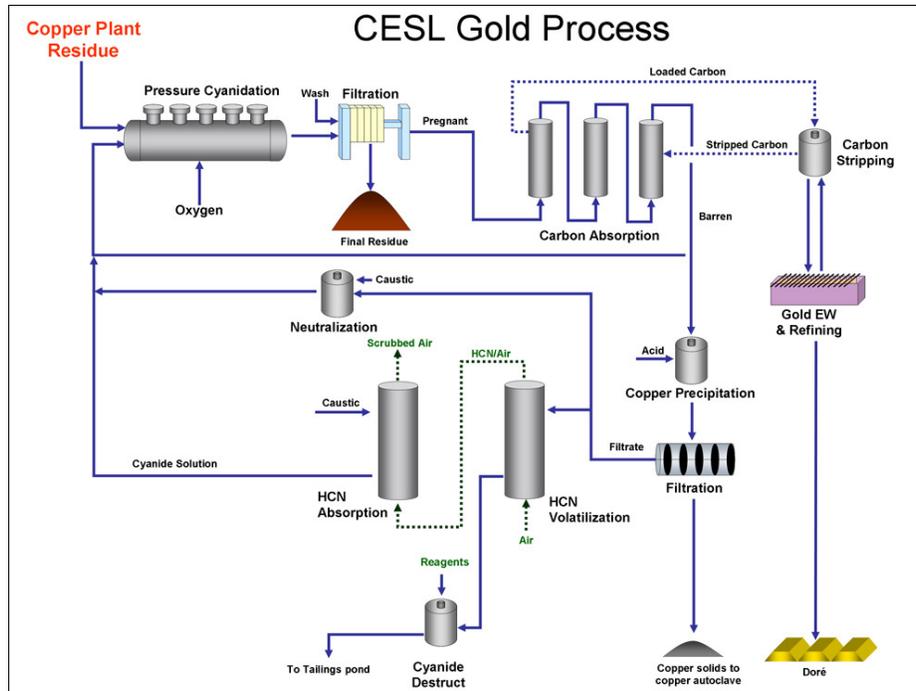


Figure 3: CESL Gold Process Flowsheet

4.2.1 Flotation of Copper Plant Residue (Optional)

Copper residue may be floated to increase the residue gold and silver grade which reduces the solids throughput and hence reagent consumption in the Gold Plant.

Flotation is carried out if gold content (or silver equivalent) drops below the total processing cost including amortization. In our estimation this would be worthwhile if the gold content is below about 4 - 5 g/t in the Copper Plant residue. However, the decision depends on the individual concentrate characteristics including cyanide consumption, flotation response, etc.

Flotation is carried out at natural pH with modest additions of collector and frother. Generally, mass reduction is about 50% depending on elemental sulphur grade of the copper residue. The gold/silver recovery is about 95%.

4.2.2 Pressure Cyanidation

Copper Plant residue is sent to Pressure Cyanidation where it is mixed with recycled barren solution to form slurry at about 600 g/l solids. Simultaneously slaked lime is added to neutralize any remaining acid components in the residue and increase the pH to about pH 10.5, in preparation for cyanidation.

The repulped and neutralized residue is then leached with cyanide solution, under high pressure oxygen, at about 3500 kpag, (500 psig). This process may be carried out in a gently agitated autoclave or in a pipeline reactor.

The retention time is comparatively short (compared to conventional atmospheric cyanidation), about 60 to 90 minutes, as surprisingly this has been found sufficient to obtain excellent gold and silver recovery from the residue under these conditions.

Pressure Cyanidation has been found to have a very important benefit: the short retention time minimizes the formation of thiocyanate during cyanidation. Thiocyanate production can thus be drastically reduced, compared to atmospheric cyanidation using the typical long retention times.

The major by-products of cyanidation of the Copper Process residue are copper cyanides, as well as some thiocyanate and cyanate.

4.2.3 Gold and Silver Recovery

The resultant slurry from Pressure Cyanidation is filtered and the solids well washed. The preg is then treated first for precious metal recovery, typically by carbon absorption, and then the barren solution is treated for cyanide recovery, before recycling back to the pressure cyanidation vessel. The loaded carbon is then treated to recover the gold and silver.

4.2.4 Copper Removal – Acidification and Precipitation

The copper removal process is designed to remove the two byproducts listed above, Cu and SCN.

Copper cyanides are treated primarily by a variation of the AVR (Acid-Volatilization-Reneutralization) process, in which most of the cyanide in the copper cyanide complex is recovered as NaCN, and recycled back for more gold and silver leaching. The copper is precipitated as solid CuSCN with minor solid CuCN, with the solids recycled back to pressure oxidation for Cu recovery.

The acidified slurry is filtered by an inline filter to remove the CuSCN solids and other solids precipitated, leaving both gaseous and aqueous phases together in the filtrate. This mixture is then passed to the next part of the flowsheet, but is first split into two streams. One stream goes to Neutralization and the other to HCN Stripping and Absorption.

The split is determined partly by the need for water balance (the stream sent to Stripping is sent to Cyanide Destruction), and partly by the need to limit the overall cyanide tenor in the recycled barren (to limit HCN vapour losses throughout the circuit).

4.2.5 Cyanide Recovery – HCN Stripping and Absorption

The acidification product is stripped of its HCN gas phase by air stream contact in a packed tower. At the pH 2-4, HCN is stripped and effectively quantitative HCN recovery is observed.

The gas product now containing HCN is then recovered in an absorption tower using caustic solution at pH 11, and is recycled as cyanide liquor to Pressure Cyanidation.

4.2.6 Cyanide Destruction

Cyanide Destruction is used to treat the bleed stream from the process in order to maintain a water balance and bleed out minor impurities from the process.

The product slurry from the cyanide destruct reactors is then filtered to produce a filtrate and a filter cake; the filtrate may be recycled to the Copper Plant or discharged to an effluent or the tailings pond. The filter cake consists largely of gypsum (>95%) with trace amounts of Cu and Fe. This cake is sent to tailings.

5 PILOT PLANT OPERATIONS

5.1 Equipment Description

The main equipment in the Pressure Cyanidation circuit was: a feed solids repulp tank, a slurry feed tank, a four-compartment vessel pressurized with oxygen, and a filtration washing circuit. The pilot plant Pressure Cyanidation vessel was designed in-house, and was a 40" long horizontal autoclave constructed of 8" schedule 40 stainless steel pipe with four compartments. The discharge system operated semi-continuously, and was connected to a filtration circuit. The filtrate fed a four-stage CIC circuit.

The acidification circuit consisted of a closed reactor, filter, and packed columns for stripping and absorption. The Cyanide Destruction circuit consisted of a two-stage reactor train, designed with the ability to add reagents into one of both reactors.

5.2 Feed Materials and Operating Hours

The new process was tested in the pilot plant on five different copper residues, for a total of nearly 2500 hours of operation. Details for four of these campaigns are shown below.

Each concentrate was first treated through the copper pilot plant. Concentrate I exhibited high sulphur oxidation and as a result all the copper leached within the autoclave, (Process 4), whereas Concentrates II, III and IV required a separate step to leach the copper from the oxidized solids (Process 2).

Recovery of Cu was 95.0% for concentrate I, 95.8% for concentrate II, 95.8% for concentrate III and 96.5% for concentrate IV.

Compositions of the feed residues to Pressure Cyanidation are shown in Table 1.

Table 1: Pressure Cyanidation Feed Composition

Concentrate	Copper	Iron	Elemental Sulphur	total Sulphur	Gold (g/t)	Silver (g/t)
I	1.20%	31%	23%	29%	13.7	81
II	1.30%	28%	38%	44%	18.5	68
III	1.11%	35%	26%	29%	9.7	34
IV	1.05%	25%	50%	53%	11.1	16

For concentrates II and IV, and a portion of concentrate III, the Copper Plant residue was subjected to flotation prior to cyanidation realizing a gold recovery of 95%. This allowed for a much smaller amount of solids passed through the Gold Plant with minimal losses of gold to the flotation tails.

5.3 Cyanidation Conditions

The cyanidation target operating parameters outlined in this section were deduced for each concentrate tested at both bench and pilot scale. When processing concentrate II, both atmospheric and pressure cyanidation tests were performed.

Table 2: Cyanidation Conditions for Pilot Plant Campaigns

Leach Condition	Units	Conc II	Conc II	Conc III	Conc IV
Operating Pressure	psig	0	450	450	500
Retention Time	hr	36	1.0	1.5	1.5
Active Cyanide	mg/L	350	500	1000	1000
Total Cyanide	mg/L	8300	2000	3000	2500
pH	-	10.5	10.5	10.5	10.5

Details of the operating conditions are listed below:

- **Active Cyanide**

Active cyanide refers to the non-complexed sodium cyanide in solution, assuming that all copper is present as $\text{Na}_3\text{Cu}(\text{CN})_4$. The active cyanide target for operations was 500 to 1000 mg/L. The initial test results supported using high active cyanide concentrations as gold extraction improved.

- **Total Cyanide Concentration**

The measure of total cyanide includes the sum of various forms of cyanide. In order to maintain an active cyanide target of 500 to 1000 ppm, the total cyanide concentration was maintained at a range of 2000 to 3000 ppm.

- **Slurry Feed pH**

Hydrated Lime (calcium hydroxide) was added to the repulp tank to target a pH of ~10.5.

5.4 Metal Extraction and Recovery

Gold and silver extraction from the feed to cyanidation averaged approximately 90%. It should be noted that this is extraction from the feed to cyanidation and does not take into account any losses through flotation (for concentrates II and IV). Loss of gold through the flotation circuit was approximately 5%; however, overall reagent consumption was higher with no flotation due to treating a larger quantity of solids. Copper extraction was 5 to 15% of the copper in the feed to the Gold Plant (equivalent to ~0.3% of the copper in concentrate).

A summary of the key extraction and recovery data for each concentrate can be found in the table below.

Table 3: Metal Extraction and Recovery in Gold Plant

Conc.	Au Recovery (Flotation only)	Au Extraction (cyanidation only)	Au Recovery (Overall Plant)	Ag Extraction (cyanidation only)	Cu Extraction (cyanidation only)
I	n/a	90%	90%	87%	13%
II	94.3%	91%	86%	70%	9%
III	n/a	92%	92%	87%	5%
IV	95.3%	91%	86%	91%	7%

5.5 Thiocyanate Reduction by Pressure Cyanidation

Sulphur was the primary (net) consumer of cyanide in the cyanidation process, producing thiocyanate. Minimizing thiocyanate production was key to developing an efficient and economical process. Both bench and pilot “atmospheric” cyanidation testwork confirmed that thiocyanate production was directly proportional to leach retention time and cyanide concentration. Two steps were taken to reduce thiocyanate production:

1. Reducing cyanidation leach time. By increasing oxygen pressure in cyanidation, the gold extraction rate increased, allowing the leach retention time to be decreased without losing gold recovery. The decreased retention time decreased thiocyanate production.
2. Reducing cyanide concentration. By reducing the cyanide soluble copper in the feed solids by implementing a copper removal circuit, the total sodium cyanide concentration could be maintained at 2000-3000mg/L while still recycling the barren stream. A benefit of operating at lower cyanide concentrations was to maintain a modest partial pressure of HCN in the slurry, minimizing the volatile losses.

Table 4 compares atmospheric and pressure cyanidation operating conditions and corresponding leach results for the second concentrate tested. Results from pilot plant testing on concentrate II indicate that Pressure Cyanidation operations reduced cyanide

consumption due to SCN production from 7.5 kg/t to 1.3 kg/t, while achieving improved gold extraction.

Table 4: Comparison of Atmospheric and Pressure Cyanidation

Cyanide Leach Results	Units	Atmospheric	Pressure
NaCN to SCN Production	kg NaCN / t Cu conc	7.5	1.3
Gold Extraction	%	86	91

5.6 Copper Removal and Cyanide Regeneration

In order to make the Gold Process feasible, it is imperative to recover the cyanide that complexes with copper. Using a Cyanide Recovery circuit, copper-complexed cyanide was recovered by precipitation of copper as copper (I) thiocyanate and conversion of the cyanide associated with the copper to NaCN. This was accomplished through acidification, filtration, and neutralization of the process liquor. Cyanide was not volatilized during this process.

Recovery of cyanide from copper-cyanide complexes was ~95% effective during the final three phases of operations.

The table below presents the average operating results of the AVR circuit, which includes acidification, volatilization, and regeneration of cyanide from a bleed stream during pilot plant operations.

Table 5: Cyanide Recovery through AVR

Date	Pilot AVR Results	
	NaCN Recovery (%)	NaCN loss (kg/t conc)
Mar – Oct 2004	82	0.5
Feb – Apr 2005	94	0.2
Jul – Aug 2005	95	0.1
Nov 06 – Apr 2007	92	0.2

5.7 Reagent Consumption

5.7.1 Cyanide

The key advancements made to the CESL Gold Process were done with the purpose to minimize reagent consumption (in particular cyanide), while maintaining acceptable gold extraction. As previously described, this was achieved with the incorporation of cyanidation under pressure, by maintaining a maximum total cyanide concentration of 3 g/L NaCN, and through optimization of the copper process to minimize copper transfer into the Gold Plant.

Table 6 shows the actual cyanide consumption during each of the campaigns. Future demonstration plant operations will work on improving cyanide accounting as it proved difficult at pilot scale.

Table 6: Cyanide Losses from Continuous Gold Plant Operations

Conc.	Losses as SCN	Losses as CNO	Losses across CIC, AVR	Losses to samples, inventory additions	Entrained in Residue	Unaccounted losses	Net NaCN Added
I	1.1	0.1	0.8	0.8	0.3	0.9	4.0
II	1.3	0.1	n/a	n/a	0.3	n/a	2.3
III	0.5	<0.1	0.4	0.3	0.5	0.8	2.5
IV	1.3	0.2	0.3	0.2	0.1	0.3	2.4

* Losses are expressed as kg NaCN / t copper concentrate

As is seen in the table above, formation of thiocyanate is the largest single source of cyanide loss. Minimization of the thiocyanate was therefore a key focus during operations. It was imperative to keep the time which cyanide was in contact with the sulphur-rich solids as short as possible before and after the cyanidation pressure vessel. Unaccounted losses were largely volatilization of HCN or due to unknown sources. Cyanide losses due to leaching of copper were minimal, as the copper precipitation step liberates cyanide from the copper-cyanide complex, precipitating the copper as CuSCN and efficiently recycling the cyanide.

5.7.2 Minor Reagents

The CESL Gold Process uses other reagents within the process, although at lesser economic impact than cyanide and lime consumption.

Sufficient lime was added to the Copper Plant residue or flotation concentrate in order to maintain a target pH of 10.5 during Cyanidation operations. Oxygen is used within the Pressure Cyanidation step to ensure oxygen saturation of the slurry. Consumption is approximately 5 kg oxygen / tonne feed material

Caustic is used to neutralize the solution after copper precipitation and is also used within the absorber for solution being bled from the plant. Overall consumption depends on the plant water balance and amount of copper leached during cyanidation.

Sulphuric acid is added during the copper precipitation step, which operates at a pH of 3.0.

Other minor reagents include sulphur dioxide source for cyanide destruction, copper sulphate as a catalyst for cyanide destruction, gold recovery reagents, and flotation reagents if flotation is used.

6 PROCESS ECONOMICS – A CASE STUDY

The economic advantages of the Gold Process will be reviewed in this section. The base case for this study is a standard chalcopryrite/pyrite concentrate, containing 28% copper, 10 g/t gold, and 65 g/t silver.

6.1 Assumptions

The concentrate considered in this case study is a representative of the Esperanza chalcopryrite concentrate, similar to many lower grade porphyry deposits in the world.

Table 7: Concentrate Composition

Copper %	Gold g/t	Silver g/t	Iron %	Sulphur %
28.0	10	65	30	36

The case study considered treatment of 554,000 tonne per year of concentrate, containing 155,000 tonne per year of copper, 178,000 ounces per year of gold, and 1,158,000 ounces a year of silver.

Table 8: Mill Production Assumptions

Concentrate tpa	Copper tpa	Copper million lbs/a	Gold ounce/a	Silver ounce/a
554,000	155,000	342.0	178,000	1,158,000

This case study employed metal prices indicative of expected long term trends.

Table 9: Case Study Metal Prices

Copper	Gold	Silver
1.40 US\$/lb	475 US\$/oz	8.00 US\$/oz

For concentrate sales, many market terms must be defined in order to complete a comparative analysis. The following table outlines what terms were considered during this evaluation.

Table 10: Concentrate Treatment Terms

Treatment Charge	Cu Refining Charge	Freight Charge	Au Refining Charge	Ag Refining Charge
85 US\$/t	0.085 US\$/lb	75 US\$/wmt	6.0 US\$/oz	0.50 US\$/oz

On top of the treatment, refining, and freight charges, there are other charges which are levied against concentrates during sales.

Table 11: Concentrate Payable Metal Values

Cu Payment	Au Payment	Ag Payment	Cu Price Participation
96.5%	90%	90%	10%, 0.90\$/lb base price, capped at 1.50\$/lb

For the alternative case of selling copper cathode from a CESL Plant, several market details need to be defined.

Table 12: Cathode Market Terms

Cathode Premium	Cathode Freight	Cathode Marketing
70 US\$/t	60 US\$/t	10 US\$/t

6.2 Refinery Operating Cost Estimate

A refinery operating cost estimate was prepared as part of this case study. The case study operating cost estimate assumed a South American location for the refinery. The following table presents a cost element breakdown for the refinery in question. Total operating cost of the gold refinery was calculated to be 3.5 ¢/lb copper cathode for the gold refinery.

Table 13: Copper/Gold Refinery Operating Cost Estimate

	US\$ c/lb Cu Cathode	Copper	Gold	Total
	G & A	0.5	--	0.5
	Labour	2.7	0.4	3.1
CESL	Reagents	2.7	2.5	5.2
Operating	Utilities	5.7	--	5.7
Cost	Maintenance Supplies	4.1	0.4	4.5
	Contingency	1.8	0.2	2.0
	Total	17.5	3.5	21.0

6.3 Comparative Annual Cashflow Analysis Summary

This case study compares two scenarios: in the first, the concentrate follows the traditional route (shipping/smelting); in the second, the concentrate is treated at the mine site through a CESL Copper and Gold Plant. In this comparison, the annual cashflow of each scenario is calculated and compared. The increase in net cashflow is as a result of the CESL Plant advantages. Copper, gold and silver recoveries of the CESL refinery were assumed to be 96.7%, 92% and 87%, respectively.

Table 14: Realization Costs of Both Scenarios

	US\$ million / yr	Selling Concentrate to Smelter	Refining Concentrate
	Treatment / Refining	75.1	--
Realization Costs	CESL Operating Cost	--	69.5
	Price Participation	16.5	--
	Freight / Market	44.9	10.5
	Total	136.5	80.0

Realization costs are dropped from US\$136.5 million per year to US\$80.0 million per year (for a difference of 56.5 million per year) with the addition of a CESL refinery. The final step is to subtract realization costs from gross revenues, to arrive at net revenues.

Table 15: Net Revenue for Both Scenarios

	US\$ million / yr	Selling Concentrate to Smelter	Refining Concentrate
	Copper	462.1	473.6
	Gold	75.2	77.8
	Silver	7.8	8.1
Net Revenue	Gross Revenue	545.1	559.5
	Realization Costs	136.5	80.0
	Net Revenue	408.6	479.5
	Difference		70.9

This comparative analysis indicates that net revenue is increased by US\$71 million per year when the concentrate is treated onsite (equivalent to just over US 22¢/lb copper cathode). This increase in net revenue would need to offset the capital cost of the CESL refinery.