Demonstration of the CESL Gold Process

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ABSTRACT

Teck Resources Ltd. has developed a suite of hydrometallurgical technologies, collectively known as the CESL Processes, to recover base and precious metals from sulphide concentrates. The CESL Gold Process is fed leach residue produced from the CESL Copper Process and uses pressure cyanidation to increase the kinetics of gold and silver leaching, as well as cyanide recovery to recover copper and reduce cyanide consumption, allowing for economic recovery of precious metals. In partnership with Aurubis AG, the CESL Gold Process was demonstrated at a design basis of 1.5 t/d leach residue over a six month trial utilizing commercial scale equipment, during which extensive metallurgical and engineering data was collected. Results confirmed previous bench and pilot gold extractions in excess of 90%. Acidification volatilization re-neutralization technology was used, resulting in the recovery of 93% of the cyanide and 93% of the copper sent to the circuit. The net reagent operating costs were US$2.75/g of gold recovered. Plant availability was 96%. Maintenance requirements were minimal.

Keywords: Hydrometallurgy; Oxidation; Cyanidation; Precious metals ores; Sulphide ores

1   BACKGROUND

Teck Resources Ltd. (Teck) is Canada's largest diversified resource company committed to responsible mining and mineral development with major business units focused on copper, metallurgical coal, zinc and energy (Teck). Within the Technology division, Teck has developed a broad range of proprietary hydrometallurgical processes over the last 15 years and process know-how for the extraction of copper, nickel and precious metals from copper and nickel

concentrates, including significant experience related to processing concentrates with elevated impurity content (arsenic, fluorine, mercury).

Aurubis AG (Aurubis) is a leading integrated copper company and the world's largest copper recycler. The company produces approximately 1.1 million tonnes of copper cathode and more than 1.2 million tonnes of copper products each year (Aur). They also have expertise in several hydrometallurgical processes in the production of copper including: the production of precious metals, treatment of intermediate products, and recycling of scrap materials. Based on a concentrate and mine supply market analysis, Aurubis anticipates increasing arsenic content in their future concentrates feed stocks and increased regulatory pressure on arsenic disposal practices. As a result, Aurubis has set, as a strategic goal, the development of a solution to arsenic issues coinciding with the exploitation of copper business growth opportunities (Mayhew, et al., 2011).

Recognizing the potential value in arsenic-challenged copper deposits, Aurubis and Teck agreed in 2009 to jointly evaluate CESL hydrometallurgical technology to treat arsenic-rich concentrates at a mine site, hence facilitating development of arsenic-challenged copper and copper-gold resources.

Aurubis and Teck engaged in a multi-stage work program. One aspect of this work was to operate the CESL Gold Process at a larger scale than had been previously tested, in order to evaluate the process using commercial scale equipment and address any scale-up issues. Although the work program focused on arsenic bearing copper concentrates, the evaluation of the scale-up of the Gold Process used residue produced from a non-arsenic bearing copper concentrate.

The gold demonstration plant was commissioned and operated between March and August of 2011. This paper discusses the metallurgical and engineering data captured during the campaign, as it relates to scale-up and commercialization of the CESL Gold Process.

2   PROCESS AND EQUIPMENT DESCRIPTION

The recovery of copper and precious metals from concentrate using the CESL Process occurs in two sequential phases. The copper is initially recovered from the concentrate using the CESL Copper Process (Robinson, Mayhew, Jones, & Murray, 2011). The gold and silver remain in the leach residue, which is subsequently treated using the CESL Gold Process. The CESL Gold Process consists of the following main steps as illustrated in the figure below.
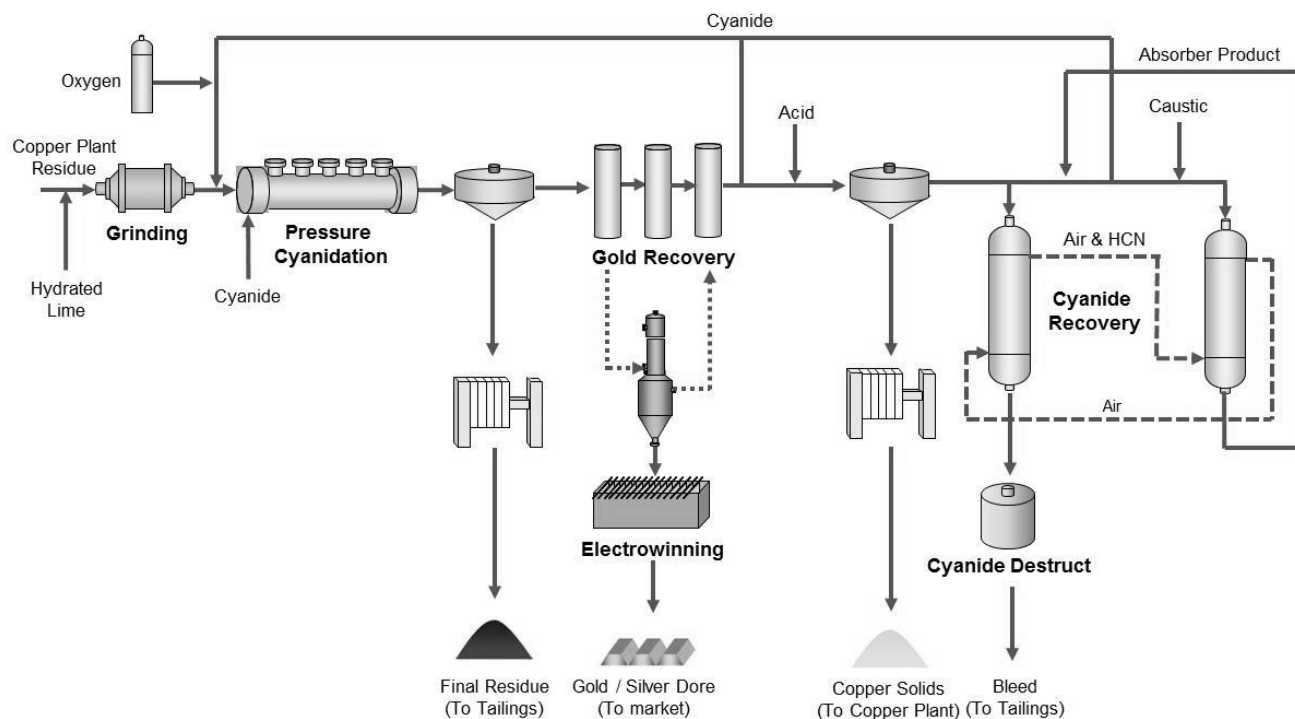
Figure 1 - CESL Gold Process flowsheet

2.1 Repulp and Grinding

The copper plant residue, contained in one tonne bulk bags, was placed in the hopper where it was transferred into the repulp tank via excavator. The slurry density was maintained at 600 g/L solids. Hydrated lime was added to the repulp tank to achieve a slurry pH of 10.5. The slurry was processed through a grinding mill to liberate the precious metals encapsulated in elemental sulphur. Once the desired particle size was reached, it was pumped to the slurry feed tank for processing.

2.2 Pressure Cyanidation

The PCN vessel was constructed of stainless steel 316, had five agitated compartments and a total volume of 700 L. Slurry and liquor feed were fed separately into the first compartment. Oxygen was supplied from a pressurized T-cylinder to maintain an overpressure of 1700 kpag. Dilution from the liquor feed decreased the solids density of the slurry from 600 g/L solids to 250 g/L solids inside the vessel. Stock cyanide solution was pumped into the first four vessel compartments via metering pumps. The vessel was operated at a capacity of 1.5 t/d copper plant residue with a 90 min retention time.

The slurry from the pressure vessel was letdown in a single stage. The pressure letdown vessel was lined with jasper rock and vented to the atmosphere. Leach slurry was pumped to a thickener designed to produce a high density underflow of 50% by weight solids with less than 200 mg/L solids in the overflow liquor. The thickener underflow was filtered and washed on a belt filter with a three stage wash to minimize soluble gold, silver and cyanide losses. The washed residue was bagged for disposal. The overflow solution was further processed in the gold recovery circuit.
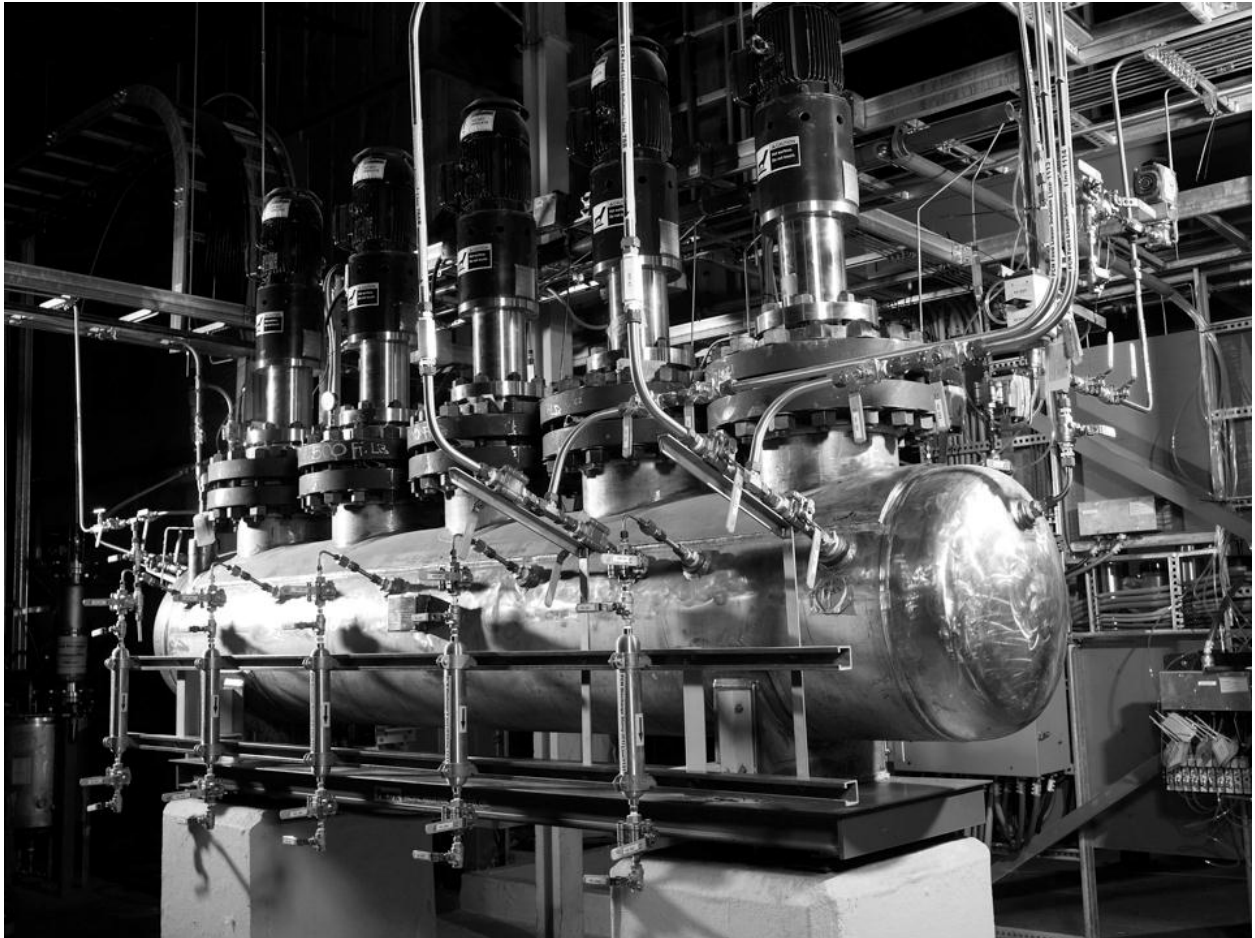
Figure 2 – CESL demo plant pressure cyanidation vessel

2.3   Adsorption Desorption Regeneration

Precious metals in the pregnant leach liquor from PCN circuit were fed counter currently through a series of six carbon columns containing 50 kg of activated carbon in each. Gold and silver cyano-complexes were selectively adsorbed onto the carbon. The six columns were designed to operate at ambient temperature. The carbon-in-column circuit adsorbed more than 98% of the gold and 96% of the silver from the leach solution.

Figure 3 – CESL demo plant carbon in columns

Each batch of loaded carbon was removed from the first column in series, and washed with dilute hydrochloric acid to remove base metal impurities and inorganic fouling, primarily in the form of calcium carbonate scale. The acid washed carbon was neutralized using dilute caustic solution before transferring to the strip vessel. The carbon acid wash was operated on a batch basis and ventilated to a scrubber to remove any volatilized cyanide.

The gold and silver on the acid washed loaded carbon was desorbed into solution by a caustic cyanide elution in a mild steel strip vessel at 135°C. Desorption continued until the gold in the strip solution exiting the vessel decreased below 10 mg/L. Stripped electrolyte from the

electrowinning circuit was used as strip solution and heated using steam to attain target temperature. The resulting solution contained concentrated precious metals in a low impurity solution suitable for electrowinning.

The stripped carbon was regenerated in a kiln, and recycled back to the sixth (last) column in series in the carbon-in-column circuit. The carbon regeneration kiln was gas heated to $650^{\circ}C$ and quenched in water as it exited the kiln.

Gold electrowinning used stainless steel anodes and stainless steel wool cathodes. The precious metals in the pregnant electrolyte were plated onto stainless steel cathodes as sludge in two cells situated in series. The electrolyte was cooled before exiting the stripping circuit to limit ammonia formation. The cells were ventilated to scrubbers to remove residual hydrogen cyanide (HCN) and ammonia.

To harvest the cathodes, the sludge was removed by pressure washing with fresh water within the cells. The resulting slurry was sent through a filter press to collect the sludge. This dried gold-silver sludge was the final product and was further refined in an induction furnace to produce a bullion product off site. The resulting spent electrolyte, containing less than 5 mg/L gold, was recycled to the gold recovery circuit to be used for carbon stripping. A small bleed of the stripped electrolyte was sent to the pregnant leach liquor tank to control the chloride concentration introduced through carryover from the acid wash circuit.

Figure 4 – CESL demo plant gold electrowinning

2.4 Acidification Volatilization Re-neutralization

Entrained copper in the residue and copper leached during PCN must be removed from the gold process. In order to limit the copper concentrations in the leach solution, copper precipitation was accomplished by acidification.

Sulphuric acid was added to barren solution to precipitate copper thiocyanate (CuSCN) solids at an acidic pH in an inline static mixer. The copper precipitate was separated in a thickener for

removal. The acidified solution in the overflow was divided into two portions, with approximately half being sent to the volatilization stage and the remainder to the re-neutralization stage.

Volatile HCN from the acidified barren solution was stripped from the low pH bleed stream by air circulated counter-currently through the stripper column. The 5 m tall packed stripper column was a constructed out of reinforced fiber glass. Stripper product was sent to the CND circuit for residual cyanide destruct.

A portion of the barren from the acidification stage was used in the re-neutralization stage to recover the HCN. This barren portion was first neutralized with absorber product and caustic to reach a high pH in static inline mixers. The re-neutralization product was used in a 4 m tall reinforced fiber glass packed absorber column to capture the HCN released from the stripper column. The absorber product and acidified barren solution was recycled to the leaching step.

An air bleed from the absorber outlet was processed through a caustic scrubber to remove residual HCN prior to air discharge to the atmosphere. The air bleed maintained a slightly negative draft within the columns ensuring leaks would not result in any releases of HCN.
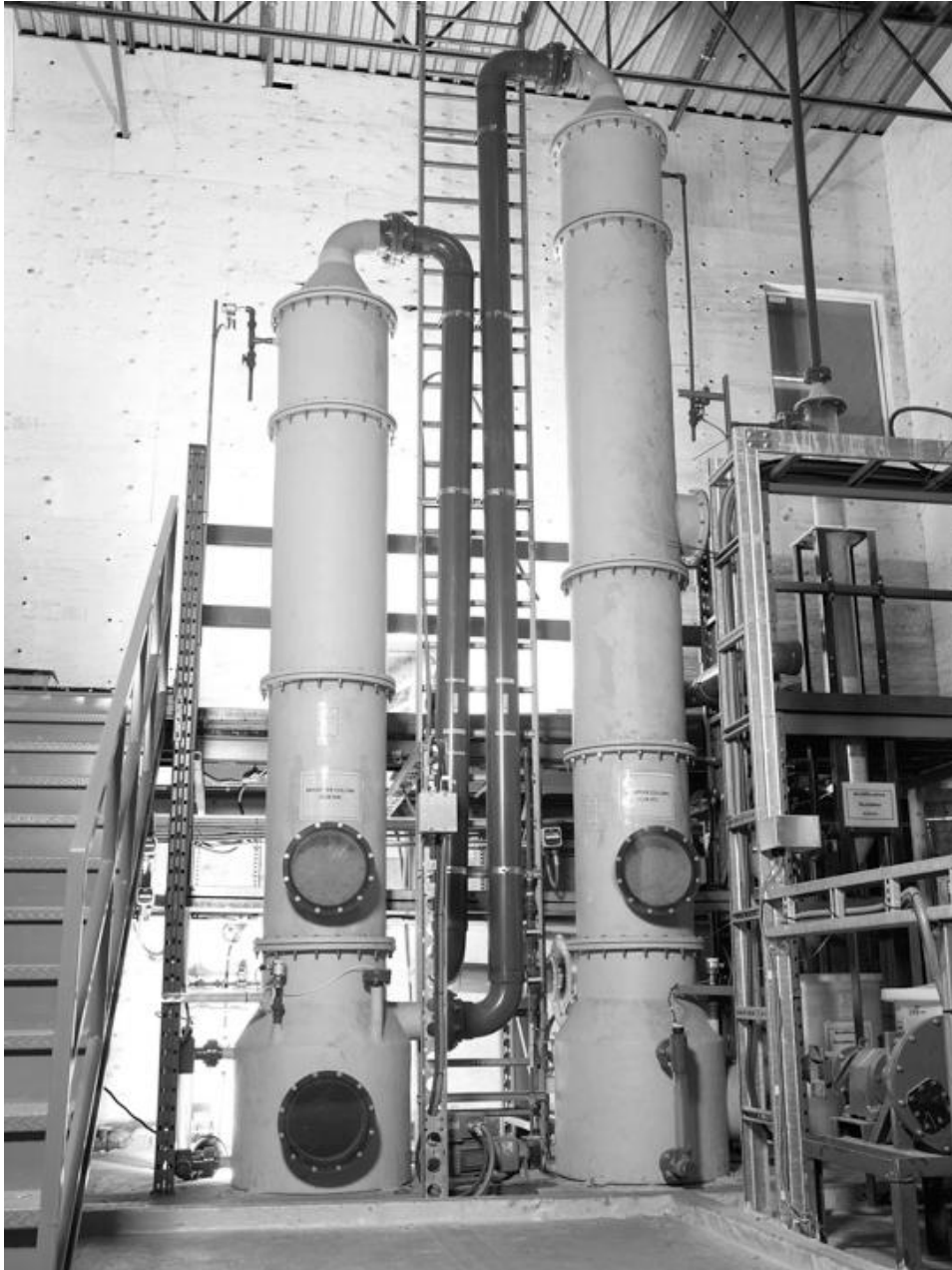
Figure 5 – CESL demo plant stripper and absorber columns for cyanide recovery

2.5 Cyanide Destruct

The CND circuit consisted of three agitated reactors in series containing 400 L of solution in each. The first two reactors were used for cyanide oxidation utilizing the sulphur dioxide and air (SO_2/Air) Process on the stripper product and the third reactor was to remove metals as hydroxides such as copper and zinc. Sodium metabisulphite was added as an oxidizing agent

and copper sulphate was added as a catalyst into the first two reactors to oxidize cyanide and thiocyanate (Marsden & House, 2006) in the bleed stream. Air was sparged into all three reactors to provide oxygen. The SO_2/Air Process has an optimal operating pH of 9, and used inter-stage lime addition to neutralize the acid generated during oxidation. The last reactor operated at a pH of 10 in order to precipitate metal hydroxides. The solids were filtered for disposal. The filtrate, meeting discharge limits, was discharged to sewer.


Figure 6 – CESL demo plant cyanide destruct reactors


3 PROCESS CHEMISTRY

The main reactions occurring in the individual circuits are described below.

3.1 Pressure Cyanidation

In the PCN process, oxygen serves as an oxidant and cyanide as a complexing agent. The cyanide gold dissolution reaction is described by Elsner's Eq. (Marsden & House, 2006):

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN)_2^- + 4OH^- \tag{1}$$
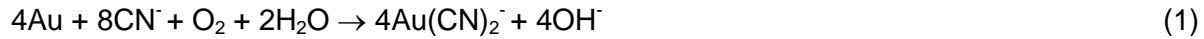
In addition to gold and silver leaching, a small portion of the copper and sulphur present also leach. Cyanide consuming side reactions in the cyanidation process are deleterious to the process economics. Elemental sulphur reacts with cyanide to form thiocyanate through the Eq.:

$$S° + CN^- \rightarrow SCN^- \tag{2}$$
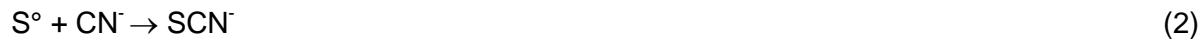
Copper sulphide and oxidized copper (II) species react with cyanide to form copper cyano complexes.

Understanding the behavior of copper in cyanide bearing solutions is important to the CESL Gold Process as copper is present in significant concentrations (~600 mg/L). Copper can form cyano complexes as shown in the Eqs:

$$Cu^+ + 2CN^- \rightarrow Cu(CN)_2^- \tag{3}$$

$$Cu(CN)_2^- + CN^- \rightarrow Cu(CN)_3^{2-} \tag{4}$$

$$Cu(CN)_3^- + CN^- \rightarrow Cu(CN)_4^{3-} \tag{5}$$

In the presence of significant concentrations of copper and with high cyanide-to-copper ratios, the tetracyano complex dominates. The tetracyano complex is assumed to be the predominant species in the CESL Gold Process as a weight ratio >4:1 of cyanide to Cu is maintained

(Marsden & House, 2006). In order to ensure there is sufficient free cyanide present for gold and silver leaching, an active sodium cyanide concentration of 1 g/L is maintained in the leach solution as defined by the Eq. below.

Active sodium cyanide (g/L) = Total sodium cyanide (g/L) – 3.1*[Copper] (g/L)   (6)

PCN is used, as opposed to typical atmospheric cyanidation, to increase the gold and silver leaching rate relative to the cyanide consuming elemental sulphur leaching rate. With the elevated leaching rates, the leach time can be reduced to 90 min. The reduced leaching time minimizes cyanide consuming thiocyanate formation which is not an oxygen dependent reaction.

3.2   Adsorption Desorption Regeneration

In the ADR process, activated carbon is used to adsorb the precious metal cyanide complexes from the high impurity leach solution. The activated carbon undergoes an acid wash where hydrochloric acid (HCl) is used to dissolve principally accumulated calcium carbonate ($CaCO_3$) as shown in the Eq. below (Marsden & House, 2006).

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O \tag{7}$$

Precious metals are stripped from the carbon at an elevated temperature of 135°C into a caustic and cyanide based low impurity solution. The precious metals in the pregnant electrolyte are recovered in electrowinning.

The stripped carbon is regenerated in a kiln at a temperature of 650°C where organic fouling volatilizes. The carbon is then recycled to the adsorption circuit.

3.3 Acidification Volatilization Re-neutralization

In the AVR process, copper is precipitated as CuSCN at an acidic pH in the presence of thiocyanate and sulphuric acid as shown in the Eq. below:

$$Cu(CN)_4^{3-} + 4H^+ + SCN^- \rightarrow CuSCN + 4HCN \tag{8}$$

The cyanide from the bleed stream is recovered through volatilization prior to feeding to the CND circuit.

Once formed in the presence of acid, HCN readily volatilizes from solution. The HCN formation reaction is shown in the Eq. below.

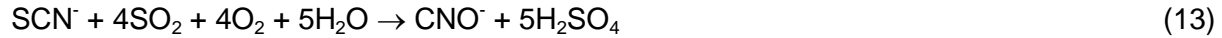$$2CN^- + H_2SO_4 \rightarrow 2HCN + SO_4^{2-} \tag{9}$$

Cyanide is recovered in the re-neutralization stage where the HCN produced is converted to soluble sodium cyanide in the presence of caustic as shown in the Eq. below:

$$HCN + NaOH \rightarrow NaCN + H_2O \tag{10}$$

3.4 Cyanide Destruct

In the CND process, sodium metabisulphite ($Na_2S_2O_5$) is added and forms sulphur dioxide (SO_2) that subsequently oxidizes cyanide and thiocyanate in the presence of catalytic cupric ions as shown in the following Eqs. (Marsden & House, 2006):

$$Na_2S_2O_5 + H_2O \rightarrow 2SO_2 + 2NaOH \tag{11}$$

$$CN^- + SO_2 + O_2 + H_2O \rightarrow CNO^- + H_2SO_4 \tag{12}$$

$$SCN^- + 4SO_2 + 4O_2 + 5H_2O \rightarrow CNO^- + 5H_2SO_4 \tag{13}$$

Cyanate can then hydrolyze to form ammonium and carbonate ions through the Eq. (Marsden & House, 2006):

$$2CNO^- + 4H_2O \rightarrow 2NH_4^+ + 2CO_3^{2-} \tag{14}$$

In addition to free cyanide oxidation, weak acid dissociable cyanide complexes (e.g. copper, nickel and zinc) can also be oxidized to cyanate and the corresponding metal hydroxide by the following Eq. (Marsden & House, 2006):

$$Cu(CN)_2^- + SO_2 + O_2 + 2OH^- + H_2O \rightarrow 2CNO^- + Cu(OH)_2 + H_2SO_4 \tag{15}$$
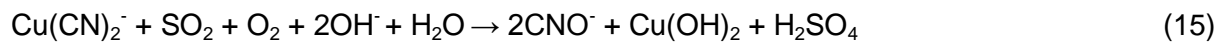
Iron, which forms a strong acid dissociable cyanide complex, is not present in the CND circuit, because iron is precipitated in the acidification circuit prior to CND where it deports to the copper slurry.

4   OPERATIONS

Commissioning commenced on March 10, 2011 and operations ran until August 19, 2011. During this time, a total of 157 tonnes of dry copper plant residue was processed producing approximately 1680 grams of gold and 1648 grams of silver to electrowinning sludge. The campaign was divided into three periods as shown below.

- Commissioning: March 10 – May 2 (52 days)

- Optimization: May 3 – July 20 (79 days)

- Demonstration: July 21 – August 19 (30 days)

During commissioning, all circuits were water tested, followed by reagent introduction. Circuits were operated at target capacity to identify and address any deficiencies or issues observed. During optimization, key parameters were varied in order to observe the sensitivity of the process to these changes, and to determine optimal operating conditions. During the demonstration phase, operating parameters were set to those conditions deemed optimal in earlier operations.

The gold demonstration plant operated fully integrated on a 24 hours per day, 7 days per week schedule. Each shift had a shift supervisor, seven operation staff, two assay technicians, one instrumentation personnel and one maintenance personnel.

5   RESULTS

5.1   Environment Health & Safety

The primary objective for CESL during the Gold Demonstration Campaign was the health and safety of employees. There were no incidents of medical aids or lost time incidents for the duration of the entire campaign.

Measurements were taken throughout the campaign to assess the air quality. A focus was put on metal exposure including copper, iron, nickel and lead. In all cases, exposure was less than 15% of the WorkSafeBC limits.

In addition to air quality monitoring, health and safety precautions focused on safe handling of cyanide. The AVR process is potentially hazardous due to the acidification and volatilization steps, where HCN gas evolution occurs. Engineering controls such as equipment interlocks, sealed negative-pressure reactors, HCN monitoring, HCN scrubbing, high flow ventilation and

preventative maintenance were implemented to run this process safely and minimize the risk of cyanide exposure.

In addition to the engineering controls, safety measures included extensive training, creation of standard operating procedures for higher risk tasks, and job aids for minimal risk tasks as well as an emergency preparedness and response plan.

During the campaign, the AVR circuit operated for a total of 2672 hours without any health or safety incidents.

5.2 Key Process Indicators

The key process indicators (KPI's) were used to measure the success of demonstrating the CESL Gold Process. Average KPI results displayed below reflect the demonstration period of the campaign when operating parameters were held constant at conditions deemed optimal.

Table 1 – Overall gold plant KPIs during the demonstration period

KPI	Unit	Data
Gold Extraction	%	91
Silver Extraction	%	73
Overall NaCN Recovery	%	93
Copper Leaching	kg/t concentrate	2.2
Thiocyanate Formation	kg/t concentrate	5.7
Copper Removal	%	93
Stripper Product NaCN	mg/L	27
CND Effluent Discharge [$NaCN_T$]	mg/L	1.0

Gold and silver extractions were chosen as KPI's because they drive the economics of the process. Feed residue was collected during operations for comparative bench scale testing.

PCN leaching testwork was conducted in a batch 1 L pressure vessel at similar operating conditions to those in the demonstration plant. The bench and demonstration plant gold extraction results are shown in the figure below.
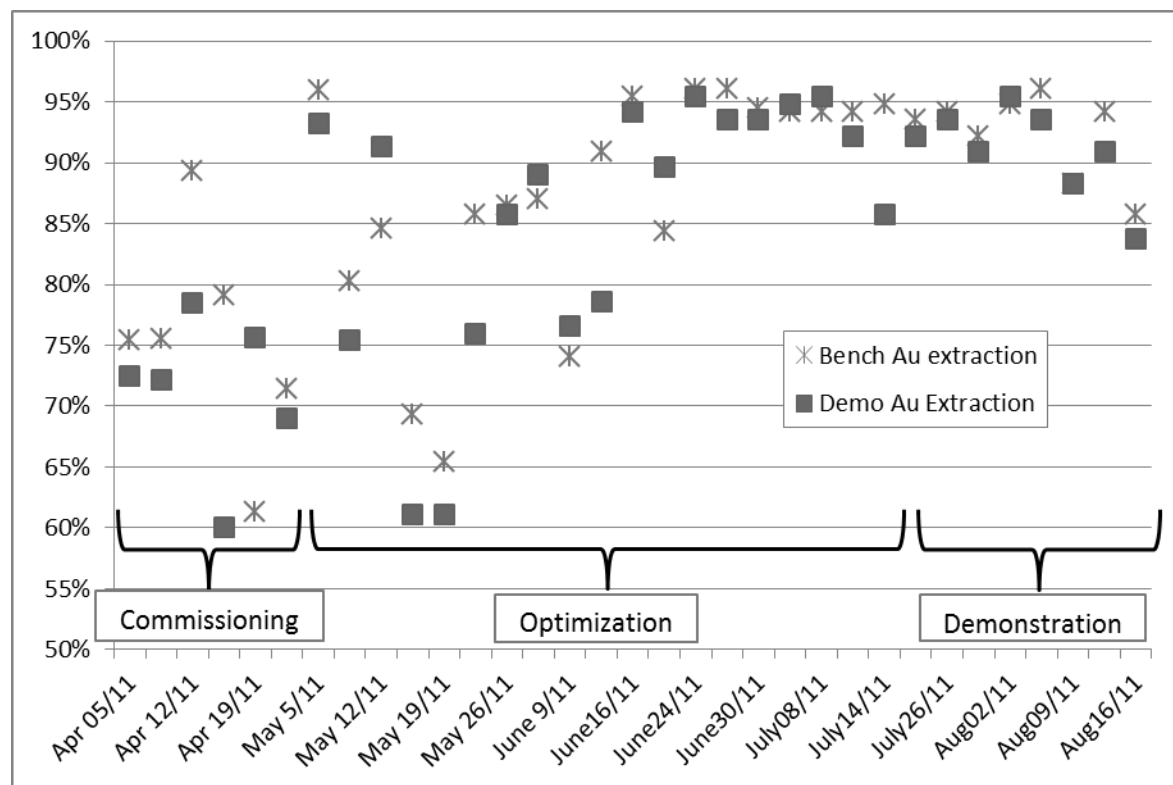

Figure 7 - Bench vs. demonstration test gold extraction results

The bench gold extraction results closely reflected the demonstration plant extractions, confirming the successful scale-up of the process. The lower extractions experienced during the commissioning and optimization phase represented variation in the operating conditions in order to assess the process sensitivity and determine optimal operating conditions. A noticeable increase in extraction, as well as in the consistency of the results, can be seen in the later portion of the optimization phase as optimal conditions were defined.

SCN formation and copper leaching were chosen as KPI's because they were the main factors affecting cyanide consumption, which represented the main operating cost from a reagent consumption perspective. Copper leaching determined the total cyanide concentration in the leach solution because cyanide was added until an excess above that complexed with the copper was present. The total cyanide in solution directly affected volatile losses. In addition, copper leaching determined the amount of solution fed to the acidification circuit for copper removal and consequently affected cyanide consumption. SCN formation resulted in cyanide losses. Copper removal was chosen as a KPI because it impacted the circulating copper load and, therefore, affected the total cyanide concentration and cyanide consumption.

The cyanide in the stripper product was monitored because it determined the losses to the CND circuit, as well as dictated the CND reagent consumptions. The cyanide concentration in the final effluent was chosen as a KPI because it was a permitted value that it was necessary to satisfy in order to dispose of the effluent.

With the mass loss across the copper process, the average gold and silver grades in the copper plant residue feeding the gold plant was 15.4 g/t and 22.1 g/t respectively. The gold demonstration campaign showed an economically beneficial increase in gold extraction through grinding of the feed residue despite increased thiocyanate leaching. It achieved high precious metal extraction and confirmed scale-up of the process. The gold and silver extraction results were 91% and 73% respectively.

5.3 Mineralogy

The concentrate was studied using combined x-ray diffraction (XRD), polarized light microscopy (PLM) and mineral liberation analysis (MLA) techniques. Mineralogy analysis identified native gold and electrum as the main gold bearing minerals. Silver in the concentrate occurred as

sulphides, antimonides, and tellurides. MLA scans revealed the presence of acanthite (Ag_2S), hessite (Ag_2Te), and pyrargyrite (Ag_3SbS_3).

5.4 Availability

The simplicity of the CESL Gold Process allowed for the high availability of the plant. The individual circuit availability was defined as the total runtime divided by the sum of the total runtime and internal downtime. Because the PCN circuit operational time drives the throughput of the process, it was taken to represent the overall plant availability. Circuit availability during the demonstration phase for all circuits ranged from 95% to 100% as shown in the table below.

Table 2 – Process availability from demonstration phase

Process Area	Availability
Repulp Grinding	99%
PCN	96%
ADR	95%
AVR	98%
CND	100%

The majority of downtime experienced in PCN was a result of plugging in the PCN vessel discharge valve and slurry feed pumps.

The ADR circuit was a semi-continuous operation that required shutdown in order to transfer loaded carbon into and out of the recovery circuit. These transfers occurred every two to three days and did not impact the operability of the other circuits due to built-in surge capacity. This scheduled downtime was excluded from the availability value. The majority of downtime experienced in the ADR circuit was a result of carbon fines plugging the solution flow through the carbon columns due to failure of the carbon screens.

The majority of downtime that occurred in the AVR circuit was due to scaling of the re-neutralization circuit with calcium carbonate solids leading to plugging. A descaling method was implemented to increase the cyanide recovery circuit's availability.

There was no internal downtime in the CND circuit.

5.5   Mass Balance

The copper, gold and silver mass balances were tracked from March 18th to August 19th, and their mass balances closures were 104%, 100%, and 100% respectively. It is important to note that the mass balance was performed over the entire duration of the campaign and not just during the demonstration period. The reported values reflect commissioning and optimization operations, during which extractions were not optimized.

The bulk (88%) of the copper fed to the gold plant was insoluble in a cyanide matrix and therefore deported to the residue solids. A minor proportion of the copper within the copper plant residue deported to the aqueous phase through either entrainment or leaching of cyanide soluble copper in the PCN circuit. Of the copper that reported to the solution phase, 97% was precipitated across the AVR circuit for recycling to the copper plant to recover the metal value. As well as increasing the overall copper recovery of the combined CESL Copper Process and Gold Process by 0.5%, the copper credit received offsets a significant portion of the operating cost of the Gold Process as is discussed in the economics section.

Gold and silver remained in the solids throughout the copper plant and are subsequently leached with cyanide in the gold plant. The two major gold and silver outputs from the process are the electrowinning product sludge and the final leach residue. The mass balance showed

that 83% of the gold deported to the carbon and the remaining 17% deported to the gold plant residue as either unleached gold or as entrainments in the final residue. The silver balance during the campaign was excellent at an overall closure of 100%. Similar to gold, the bulk of the silver deported to either the EW sludge or the final residue. The silver deportment to carbon and residue was 63% and 33% respectively.

6   ECONOMICS

In order to evaluate the performance of the gold process, estimated operational and capital expenditures were developed. The estimations were based upon a CESL gold refinery sized to process residue, of similar composition to that processed during the demonstration gold campaign (15.4 g/t gold and 22.1 g/t silver), produced from a CESL copper refinery consuming 580,000 dry t/y copper concentrate.

There were two main sources of information used to generate the operating and capital costs. The first source was the metallurgical results obtained from the gold demonstration campaign and the second was a pre-feasibility report completed in 2008 for a CESL gold refinery sized to process 511,600 t/y copper plant residue. The gold campaign metallurgical performance was used to estimate the majority of the reagent and consumable costs. The pre-feasibility report was used to estimate the remaining operational costs as well as the capital cost estimates. Because the repulp, grinding, PCN, AVR and CND circuit sizes were based on residue throughput, the capital cost estimates were scaled on this basis, while the gold recovery circuit capital cost estimate was scaled based on the gold and silver throughput.

Costs have been updated from the 2007 United States dollars (USD) used in the pre-feasibility study to reflect 2011 USD using The Chemical Engineering Plant Cost Index factor (Chemical Engineering). The table below summarizes the factors used.

Table 3 - Cost estimate factors used in the economic analysis

Conversion	Multiplier
Updating Capital/Operating Cost Estimates from 2007 to 2011 dollars	1.115 (Chemical Engineering)
Scaling plant from 511,600 t/y throughput to 500,000 t/y	0.986*
Scaling the gold recovery circuit from 7003 kg/y gold to 7013 kg/y	1.001*

*Applying an exponential factor of 3/5

6.1 Operational Expenditure

The table below presents the reagent costs with respect to concentrate, residue and copper. This is based on the 14% concentrate mass loss observed across the Copper Process and with an average grade of 30% copper in the concentrate. Reagent pricing was obtained by procuring scoping level cost estimates from multiple distributors in 2011. Cyanide, caustic and lime are the main cost drivers for the CESL Gold Process.

Table 4 – Reagent costs and distribution

Consumable	$/t reagent	$/t concentrate	$/t residue	% Distribution
Sodium Cyanide	1,720	13.9	16.2	43
Caustic	629	7.7	9.0	24
Lime	150	5.1	5.9	16
93% Sulphuric Acid	130	2.5	2.9	8
Carbon	2,650	1.8	2.1	6
35% Hydrochloric Acid	280	0.5	0.6	2
Sodium Metabisulphite	620	0.4	0.4	1
Oxygen (@ $0.07/ kWh)	31.5	0.3	0.4	1
Flocculant	4,500	0.2	0.2	0.6
Borax	1925	0.02	0.02	0.1
Coagulant	5,000	0.00	0.00	0.0
Copper Sulphate	1,825	0.01	0.01	0.0
Silica	800	0.00	0.01	0.0
Soda Ash	690	0.01	0.01	0.0
Sodium Nitrate	1345	0.00	0.00	0.0
Total	**-**	**32**	**38**	**100**

Although hydrated lime was used in the plant, this reagent was priced as lime and the cost of an appropriately sized lime slaking unit operation was included in the capital cost estimate.

The demonstration campaign produced an electrowon sludge as the final product. Further refining to produce a doré was performed offsite. Doré production reagent costs and consumption rates were estimated from the pre-feasibility study.

The copper leached during cyanidation was precipitated in the AVR process as CuSCN and, in a commercial application, would be recycled back to the copper refinery for recovery. Testwork has shown more than 90% of the copper in the CuSCN was recovered to cathode when recycled to the CESL Copper Process. Copper recovery to the AVR solids was 2.42 kg/t of

residue processed. At a copper price of $6000/t and a recovery to cathode of 90%, the copper credit obtained from the AVR solids offsets approximately 35% of the gold plant reagent operating cost as shown in the table below.

Table 5 – Total reagent and consumable cost of the gold demo plant

Reagent Cost	Cost ($/t concentrate)	Cost ($/t residue)
Gross	32.40	37.68
Copper Credit	11.24	13.07
Net	21.16	24.61

The following table displays the total operating costs of the plant including labour, utilities, maintenance supplies, and general and administration in addition to a 10% contingency.

Table 6 – Total operating costs

Cost Element	Annual Operating Cost ($000)	Annual Operating Cost ($/g Au equivalent)	Cost Distribution (%)
General and Administration	557	0.08	2
Labour	2,515	0.36	11
Utilities	3,044	0.44	13
Net Reagents and Consumables	12,305	1.78	52
Maintenance Supplies	2,913	0.42	12
Contingency	2,371	0.34	10
Total	**23,705**	**3.43**	**100**

The gold equivalent (including silver) production was determined using the extractions achieved during the demonstration campaign of 91% and 73% gold and silver respectively. In addition, an assumed recovery of 98% gold and 96% silver from carbon to doré was used, resulting in an overall recoveries of 90% and 70% respectively. The total annual operating cost estimated for a CESL gold refinery to process residue from a 580,000 t/y copper concentrate CESL copper

refinery and produce 7,013 kg of gold equivalent was $23.7 million, or $40/t concentrate processed.

6.2   Capital Expenditure

The total capital cost estimates for the gold plant are shown in the table below. Estimates include the cost to design, procure, construct, and commission the gold refinery facilities.

Table 7 – Total capital costs

Description	Total ($000)	Cost Distribution (%)
Plant Site and Preparation	598	1
Process	61,336	53
Utilities	5,317	5
Ancillary Equipment	100	0
Buildings and Facilities	741	1
Indirects	48,362	42
Total	**116,455**	**100**

6.3   Net Present Value

The table below summarizes the metallurgical data collected from the gold demonstration campaign that can be used to calculate the net present value of a CESL gold refinery.

Table 8 – Gold plant economic analysis

Design Parameters	Unit	Value
Copper Refinery Concentrate Consumption	t/y	580,000
Residue Gold Grade	g/t	15.4
Residue Silver Grade	g/t	22.1
Gold Recovery	%	90
Silver Recovery	%	70
Precious Metal Production	gold equivalent kg/y	7,013
Operating Cost	$M/y	23.7
Capital Cost	$M	116.5
Rate of Return	%	10
Gold Price	$/g	32
Silver Price	$/g	0.5

The payback period on the investment is less than a year. For an operational life of 20 years, the net present value (NPV) is $1,595 million.

Alternatively, using the capital and operating costs calculated above, along with the gold and silver recoveries, and setting the silver to gold ratio to 2 in the residue, a minimum gold grade can be calculated in order to achieve a defined payback period. This is shown in the figure below.
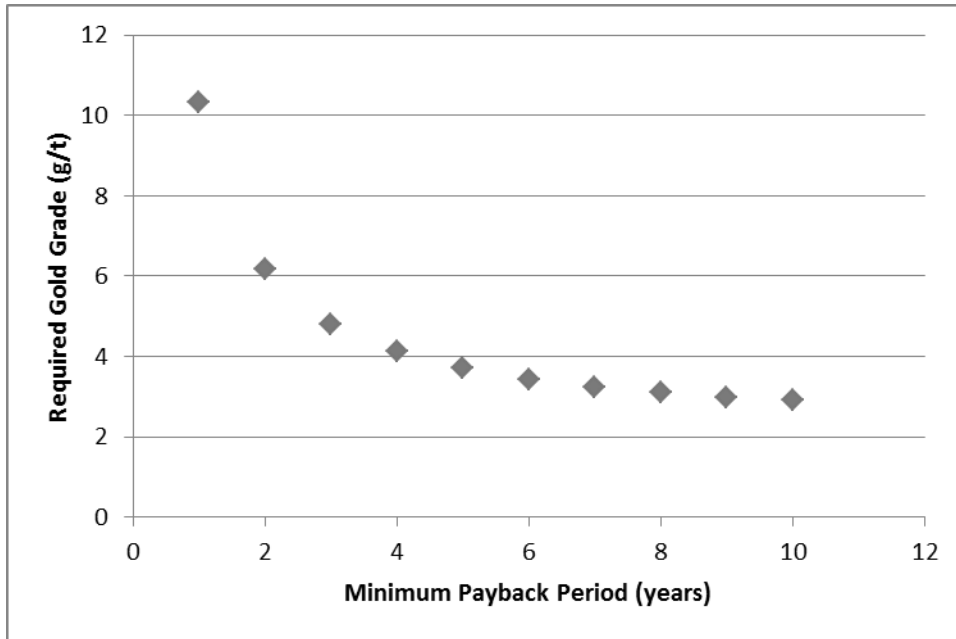
Figure 8 - NPV calculated minimum payback period vs. required residue gold grade

For a defined payback period of 5 years, the required gold grade in the residue is 3.7 g/t which, at the recoveries listed above, works out to recovering 1,700 kg/y of gold equivalent. Because there is a mass loss across the CESL Copper Process, this value becomes a grade of 3.2 g/t gold in the copper concentrate.

7 CONCLUSIONS

The combined CESL Copper and Gold Processes provide the operational flexibility to economically recover metals from high impurity (arsenic, fluorine, mercury) copper concentrates with appreciable gold and silver concentrations. The Processes have been proven to successfully treat concentrates with a wide variety of mineralogies and grades.

The conclusions from the demonstration of the CESL Gold Process are as follows:

- Cyanide recovery, involving volatilization re-neutralization, was operated at a demonstration scale without any environment, health or safety issues.

- The CESL Gold Process has undergone extensive bench and continuous pilot scale (50 kg/d residue) testwork, in which promising metallurgical results were achieved. The recent operation of the process at a larger scale (1.5 t/d residue) confirmed the similar metallurgical results upon scale-up of the process. Average gold and silver extractions of 91% and 73% were achieved respectively.

- The demonstration plant achieved high availability (>95%) for all process areas.

- The analysis showed profitable economics for a CESL gold refinery sized to process residue from a CESL copper refinery with a copper concentrate consumption of 580,000 t/y. A minimum gold equivalent grade was identified to be 3.2 g/t in the copper concentrate in order to achieve a five year payback period on the capital investment of the CESL gold refinery.

8 ACKNOWLEDGEMENTS

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