

**APPENDIX 4-Y
CYANIDE DETOXIFICATION OF SEABRIDGE GOLD
PLANT WASH WATER**

**An Investigation into
CYANIDE DETOXIFICATION OF
SEABRIDGE GOLD PLANT WASH WATER**

prepared for

SEABRIDGE GOLD INC.

Project 12628-001
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Executive Summary

A solution, representing a product of the KSM two-stage counter-current (CCD) washing of the cyanide leach residue ('Wash Water' sample, approximately 20L), was received for preparation of the feed solutions for testing. The test program had originally been established to evaluate hydrogen peroxide and activated carbon as the treatment methods for producing treated solutions meeting the target of <0.5 mg/L CN_{WAD} and Cu. The program was later modified to include other treatment methods in an attempt to achieve the target level of cyanide and copper in the final discharge solution.

Testing was conducted on the Wash Water sample as received and on three solutions from diluting the Wash Water sample with gypsum saturated water to approximately 90 mg/L (Solution A), 5 mg/L (Solution B), and 2 mg/L (Solution C) copper to simulate polishing treatment of the tailings pond effluent.

Solution A (104 mg/L CN_{WAD} , 88 mg/L Cu) responded reasonably well to treatment using the SO_2 /Air method. Conducting the test at pH 8.5, 1 hour retention time, using 4.8 g SO_2 per gram CN_{WAD} produced treated product containing 1 mg/L CN_{WAD} and 2 mg/L Cu. Contacting the SO_2 /Air solution product with 15 g/L fresh activated carbon reduced the residual CN_{WAD} and Cu to <0.5 mg/L. Treating the SO_2 /Air solution product with ferrous sulphate, at approximately 11 moles Fe per mole Cu, also successful in attaining the target <0.5 mg/L residual CN_{WAD} and Cu. However, treating the SO_2 /Air solution product with NaSH, at pH 3 and 120% of the stoichiometric requirement of NaSH, was unsuccessful in reducing the Cu concentration in solution to below 0.5 mg/L.

Cyanide destruction testwork using hydrogen peroxide was conducted on Solution B (5.4 mg/L CN_{WAD} , 4.9 mg/L Cu) to evaluate the use of this reagent for polishing treatment of solutions containing low levels of cyanide and copper. The results indicated that treating Solution B with approximately 10 times the stoichiometric required of H_2O_2 was successful in reducing the concentrations of CN_{WAD} and Cu in solution to < 0.5 mg/L.

The possibility of polishing treatment of Solution B with NaSH was investigated using 120% the stoichiometric requirement of NaSH for the precipitation of Cu, and at two pH levels of 3 and 8. However, both tests were unsuccessful in attaining the target <0.5 mg/L residual CN_{WAD} and Cu.

The use of fresh activated carbon for polishing treatment of solutions containing very low levels of CN_{WAD} and Cu was investigated using Solution C (2 mg/L CN_{WAD} , 2.1 mg/L Cu). Treating Solution C in a fluidized bed column, at a solution flowrate of 10 carbon bed volume per minute and a solution to carbon mass ratio of 1988, reduced the Cu concentration from 2 mg/L to <0.5 mg/L. However, the effluent still contained 0.79 mg/L CN_{WAD} . Passing the solution through the same carbon bed a second time reduced the CN_{WAD} to <0.5 mg/L.

Direct treatment of the Wash Water (176 mg/L CN_{WAD}, 145 mg/L Cu) was evaluated using a combination of SART (Sulphidization, Acidification, Recycling of precipitate, and Thickening of precipitate) precipitation of copper sulphide and AVR (Acidification, Volatilization of HCN gas, and RENEUTRALIZATION) recovery of cyanide, followed by polishing treatment of the AVR barren solution. Conducting the SART treatment at pH 3 using 120% of the stoichiometric requirement of NaSH followed by AVR of the SART solution product produced an AVR barren solution containing 14 mg/L CN_{WAD} and 0.5 mg/L Cu. Selenium appeared to precipitate during AVR processing of the SART solution product. This finding should be confirmed in future testwork for possible use in controlling the selenium level in plant solutions.

Polishing treatment of the AVR barren solution was evaluated using the Caro's acid and the hydrogen peroxide methods. Treating the AVR barren solution with 5 times the stoichiometric requirement of Caro's acid resulted in near complete removal of Cu and thiocyanate. However, the test was unsuccessful in reducing the CN_{WAD} level to the target <0.5 mg/L.

The AVR barren solution responded well to polishing treatment using 10 times the stoichiometric requirement of H₂O₂. The CN_{WAD} and Cu concentrations were reduced to <0.5 mg/L.

In summary, the testwork has demonstrated the effectiveness of peroxide polishing treatment by simultaneously reducing the concentrations of both copper and CN_{WAD} in solution to the target <0.5 mg/L. Polishing treatment of SO₂/Air treated solution product with fresh activated carbon and ferrous sulphate were also successful in achieving the target <0.5 mg/L CN_{WAD} and Cu in solution.

Feed/ Treatment Method	pH/ pH Target	NaHS Add. % Stoic.	H ₂ SO ₄ Add. g/L	SO ₂ g/g CN _{WAD}	Ferrous M/M Cu	Fresh Activated Carbon		H ₂ O ₂ % Stoic.	Caro's Acid % Stoic.	Solution Analysis						
						g/L	Sol'n/C g/g			CN _T mg/L	CN _{WAD} mg/L	CNS mg/L	CNO mg/L	Cu mg/L	Fe mg/L	Se mg/L
<i>Wash Water</i>	7.7	-	-	-	-	-	-	-	-	187	176	270	25	145	3.90	0.055
SART 3	3.0	120	0.43	-	-	-	-	-	-	162	156	280	12	0.38	2.20	0.138
AVR on SART Sol'n	3.0	-	0.46	-	-	-	-	-	-	42	14	261	<1	0.50	2.78	<0.001
Caro's Acid on AVR Barren	8.4	-	-	-	-	-	-	-	500	8.8	1.2	<2	94	0.10	1.86	0.051
H ₂ O ₂ on AVR Barren	8.6	-	-	-	-	-	-	1000	-	12.6	0.4	240	9.3	0.10	1.86	0.084
<i>Solution A</i>	8.1	-	-	-	-	-	-	-	-	108	104	160	17	87.8	1.53	0.064
SO ₂ /Air	8.7	-	-	4.6	-	-	-	-	-	4.8	1	120	120	2.04	<0.05	0.084
Carbon on SO ₂ /Air Sol'n	7.7	-	-	-	-	5	200	-	-	0.17	<0.1	44	110	0.45	<0.05	0.096
SART on SO ₂ /Air Sol'n	3.0	120	0.50	-	-	-	-	-	-	<0.1	<0.1	90	24	0.80	-	-
FeSO ₄ on SO ₂ /Air Sol'n	6.0	-	0.012	-	11.2	-	-	-	-	<0.1	<0.1	88	130	0.07	<0.05	-
<i>Solution B</i>	8.1	-	-	-	-	-	-	-	-	6.4	5.4	8.7	0.9	4.89	<0.2	-
Hydrogen Peroxide	8.0	-	-	-	-	-	-	1095	-	<0.1	<0.1	<2	8.5	0.14	<0.05	-
SART	3.0	120	0.028	-	-	-	-	-	-	6.6	6.4	-	-	0.60	-	-
<i>Solution C</i>	7.8	-	-	-	-	-	-	-	-	2.4	2.0	4.2	0.4	2.13	<0.2	-
Carbon in Column CIC 1	-	-	-	-	-	-	1988	-	-	0.78	0.79	2.9	0.4	0.40	<0.05	-
CIC 2 Using CIC 1 Sol'n	-	-	-	-	-	-	896	-	-	-	0.50	-	-	0.20	<0.05	-

Introduction

Laboratory testwork was conducted at SGS Minerals Services Laboratory in Lakefield to investigate various treatment options for detoxification of the KSM plant cyanide leach residue CCD wash water. The goal was to produce a final treated product containing less than 0.5 mg/L of residual Cu and CN_{WAD} .

The test program consisted of performing experiments on direct CCD plant wash water and on solutions prepared by diluting CCD plant wash water with gypsum saturated water to simulate polishing treatment of the tailings pond effluent. The methods used in current program are column and batch adsorption tests using activated carbon, SART and AVR recovery of cyanide, cyanide detoxification using SO_2 /Air, hydrogen peroxide, Caro's acid, and ferrous sulphate.

The program was directed by Mr. J. Smolik and Mr. D. Lindsay of Seabridge Gold. The results were forwarded to them as they became available. The details of the testwork are presented in this report.



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Testwork Summary

1. Feed Sample

The solution, submitted for testing, representing a product of the KSM two-stage counter-current washing of cyanide leach residue (Wash Water) was received at the SGS Lakefield site on June 12, 2012, and given the SGS receipt number 0289-Jun12.

A batch of gypsum saturated water was also prepared in the laboratory by agitating 80 g of industrial grade gypsum in 20L of deionized water overnight followed by filtration to remove the undissolved solids. This solution simulated gypsum saturated recycled stream. Three feed solutions having target copper concentrations of 90 mg/L (Solution A), 5 mg/L (Solution B), and 2 mg/L (Solution C) were prepared by diluting the Wash Water sample with gypsum saturated water. A head sample was taken from each solution and submitted for chemical analysis. The results are presented in Tables 1 (major elements/species) and 2 (multi-element ICP scan).

Table 1: Feed Samples- Quantitative Analysis

Analysis		Wash Water	Test Solution		
			Diluted with Gypsum Saturated Water to Target Cu Conc.		
			90 mg/L Solution A	5 mg/L Solution B	2 mg/L Solution C
CN _T	mg/L	187*	108*	6.4	2.4
CN _{WAD}	mg/L	176	104	5.4	2.0
CNO	mg/L	25	17	0.9	0.4
CNS	mg/L	270	160	8.7	4.2
Cu	mg/L	145	87.8	4.89	2.13
Fe	mg/L	3.9	1.53	<0.2	<0.2
Se	mg/L	0.055	0.064	-	-

*Calculated based on CN_{WAD} assuming that Fe present as ferrocyanide

Table 2: Feed Samples - ICP Scan

Analysis		Wash Water	Test Solution		
			Diluted with Gypsum Saturated Water to Target Cu Conc.		
			90 mg/L Solution A	5 mg/L Solution B	2 mg/L Solution C
Fe	mg/L	3.9	1.53	< 0.2	< 0.2
As	mg/L	<0.3	< 3	<0.3	<0.3
Ca	mg/L	726	610	669	704
Ag	mg/L	< 0.08	< 0.08	< 0.08	< 0.08
Al	mg/L	< 0.2	< 0.2	< 0.2	< 0.2
Ba	mg/L	0.012	0.012	0.008	0.007
Be	mg/L	< 0.002	< 0.002	< 0.002	< 0.002
Bi	mg/L	< 1	< 1	< 1	< 1
Cd	mg/L	< 0.09	< 0.09	< 0.09	< 0.09
Co	mg/L	< 0.3	< 0.3	< 0.3	< 0.3
Cr	mg/L	< 0.1	< 0.1	< 0.1	< 0.1
K	mg/L	9	5	< 1	< 1
Li	mg/L	< 2	< 2	< 2	< 2
Mg	mg/L	3.46	0.08	0.7	0.61
Mn	mg/L	< 0.04	< 0.04	< 0.04	< 0.04
Mo	mg/L	< 0.6	< 0.6	< 0.6	< 0.6
Na	mg/L	499	502	18	7
Ni	mg/L	< 0.6	< 0.6	< 0.6	< 0.6
P	mg/L	< 5	< 8	< 5	< 5
Pb	mg/L	< 2	< 2	< 2	< 2
Sb	mg/L	< 1	< 1	< 1	< 1
Se	mg/L	< 3	< 3	< 3	< 3
Sn	mg/L	< 2	< 2	< 2	< 2
Sr	mg/L	1.18	1.84	3.75	3.7
Ti	mg/L	< 0.02	< 0.02	< 0.02	< 0.02
Tl	mg/L	< 3	< 3	< 3	< 3
U	mg/L	< 1	< 1	< 1	< 1
V	mg/L	< 0.2	< 0.2	< 0.2	< 0.2
W	mg/L	< 2	< 2	< 2	< 2
Y	mg/L	< 0.02	< 0.02	< 0.02	< 0.02
Zn	mg/L	< 2	< 2	< 0.7	< 0.7

2. Metallurgical Test Program

The objective of the test program was to investigate various treatment options to produce a final treated product containing less than 0.5 mg/L of residual Cu and CN_{WAD} . Testwork was performed on the CCD plant Wash Water sample and on solutions prepared by diluting the CCD plant wash water with gypsum saturated water to target copper concentrations of 90 mg/L (Solution A), 5 mg/L (Solution B), and 2 mg/L (Solution C). The overall test program is presented in Figure 1.

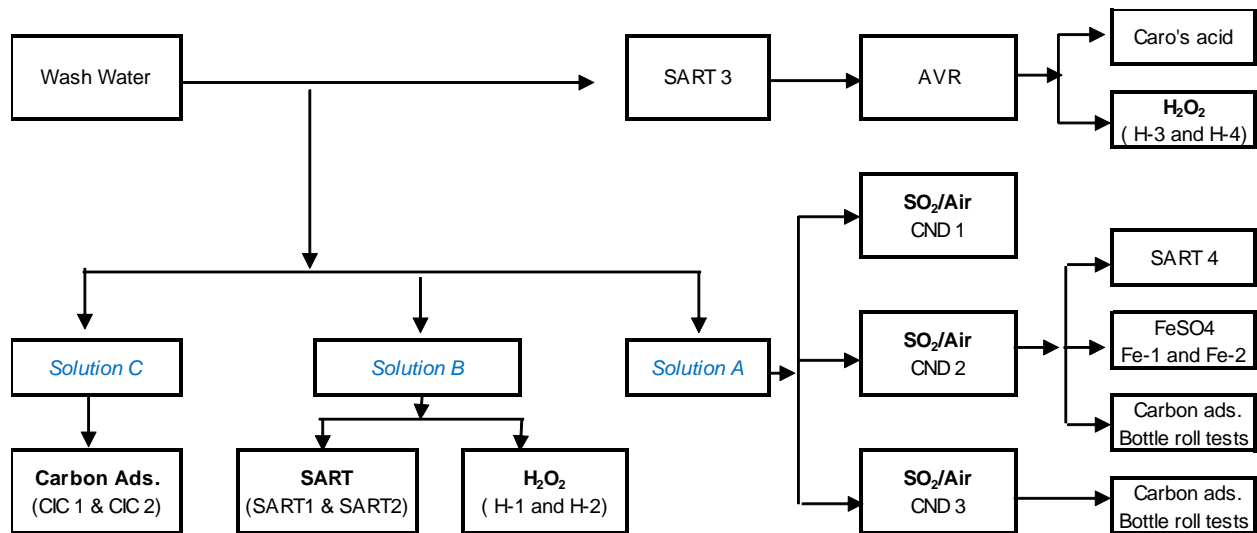


Figure 1: Program Flowsheet

2.1. Cyanide Recovery by SART and AVR Followed by Polishing Tests on Wash Water

2.1.1. SART Precipitation of Copper

The recovery of cyanide and copper from the Wash Water sample was investigated using the SART method in Test SART 3. The test was conducted in a 3 litre glass kettle using 2 litres of feed solution. The copper was precipitated at pH 3 using 120% of the stoichiometric requirement of NaSH. The results are presented in Table 3.

Treating the Wash Water sample with SART was successful in reducing the copper concentration from 145 mg/L to 0.38 mg/L. The sulphuric acid consumption was 0.42 g/L feed solution.

Table 3: SART Treatment on Wash Water Sample

Test	pH		NaHS Add. 120% Basis g/L	H ₂ SO ₄ Add. g/L	Solution Analysis						
	Target	Final			CN _T mg/L	CN _{WAD} mg/L	CNS mg/L	CNO mg/L	Cu mg/L	Fe mg/L	Se mg/L
Feed (Wash Water)	7.7	-	-	-	187	176	270	25	145	3.9	0.055
SART 3	3.0	3.0	0.5	0.43	162*	156	280	12	0.38	2.2	0.138

*Calculated based on CN_{WAD} assuming that Fe present as ferrocyanide

2.1.2. AVR Recovery of Cyanide

A 2 litre portion of the solution product from Test SART 3 was placed in a 2 litre airtight glass kettle. Air was drawn through the solution at a flowrate of 2 L/min for 6 hours to purge the HCN into a glass scrubber containing a sodium hydroxide solution. The solution was maintained at pH 3 using a dilute

sulphuric acid solution. The cyanide concentration in the scrubber solution was monitored during the test. The results are summarized in Table 4 and the details of the test are included in Appendix A.

Since the AVR feed contained very little Cu, the concentration of CN_{WAD} was essentially the same as CN_F , and was present as dissolved HCN in solution. The residual CN_{WAD} in the final AVR barren was 14 mg/L. The slow rate of volatilization of cyanide is attributed to the nature of laboratory batch testing. Large scale continuous AVR testing using stripper and adsorber columns would be required for the design of the AVR plant. The amount of cyanide collected in the scrubber was equivalent to 64% of the CN_{WAD} in the feed solution. The low CN recovery in the scrubber was likely due to the loss of HCN during filtration of the acidic SART product to obtain filtrate for use as AVR feed. The AVR feed contained 0.138 mg/L Se while the AVR barren had <0.001 mg/L Se. The final scrubber solution assayed only 0.003 mg/L Se, which was likely from the small amount of mist carried over to the scrubber during the 6 hour test. These findings suggest that Se might have precipitated during AVR. This should be confirmed in future testwork as this process could potentially be used for control of Se level in plant solutions.

The AVR sulphuric acid consumption was 0.46 g/L, and the amount of hydrated lime required for reneutralization of the AVR barren was 145 g/m³ solution.

Table 4: AVR Test on SART Solution Product

Test	pH	H ₂ SO ₄ Added Cumulative g/L	Lime for Neutr. g/L	Reactor Solution Composition									Scrubber (1.5 L)	
				Vol. mL	CN _T mg/L	CN _{WAD} CN _{Picric} mg/L	CNS mg/L	CNO mg/L	Cu mg/L	Fe mg/L	NH ₃ +NH ₄ as N mg/L	Se mg/L	CN mg	% of Feed CN _{WAD}
<i>SART 3 Solution</i>	3.3	...	...	2000	162*	156	280	12	0.38	2.2	15.5	0.138	...	...
15 min	2.6	...	...	...	...	...	...	...	...	...	...	...	14	5
30 min	2.6	...	...	...	...	...	...	...	...	...	...	...	24	8
60 min	2.6	...	...	...	...	...	...	...	...	...	...	...	43	14
120 min	2.6	...	...	...	...	...	...	...	...	...	...	...	76	24
180 min	2.5	...	...	...	...	...	...	...	...	...	...	...	111	36
240 min	2.5	...	...	...	...	...	...	...	...	...	...	...	142	46
300 min	2.5	...	...	...	...	...	...	...	...	...	...	...	165	53
360 min	2.5	...	...	...	...	...	...	...	...	...	...	...	184	59
420 min	2.5	...	...	...	...	...	...	...	...	...	...	...	194	62
480 min	2.6	0.46	...	2000	42	14	261	<1	0.50	2.8	16.9	<0.001	200	64
Reneutralization	9.2	...	0.145	...	...	...	...	...	...	...	...	...	...	...

2.1.3. Polishing Test Using Caro's Acid

The use of Caro's acid for polishing treatment of the AVR barren solution was evaluated using 5 times the stoichiometric requirement of H₂SO₅ based on CN_{WAD} . The Caro's acid reagent was prepared in advance using a procedure provided by INTEROX (Appendix D). The required amount of Caro's acid was added to 500 mL of the AVR barren solution while stirring. The solution was maintained at pH 8.8.5 with hydrated lime for 30 minutes before taking sample for analysis. The results are shown in Table 5.

Treating the AVR barren solution with 5 times the stoichiometric requirement of Caro's acid resulted in near complete removal of Cu and thiocyanate. However, the test was unsuccessful in reducing the CN_{WAD} level to the target <0.5 mg/L.

Table 5: Polishing Test on AVR Barren Using Caro's Acid

Test	Lapsed Time min	H ₂ SO ₅ 25%		pH	Lime g/L	EMF AgCl mV	Solution Composition						
		Added g/L	Stoich. %				CN _T mg/L	CN _{WAD} mg/L	Cu mg/L	Fe mg/L	CNO mg/L	CNS mg/L	Se mg/L
<i>Feed (AVR Barren)</i>				2.4	...	180	42.1	14.3	0.50	2.78	<1	261	<0.001
Caro's acid	30	11.19	500	8.4	27.3	239	8.8	1.2	<0.05	1.54	94	<2	0.05

2.1.4. Polishing Tests Using Hydrogen Peroxide

The polishing treatment of the AVR barren solution with hydrogen peroxide was investigated in two tests using 10 times the stoichiometric requirement of H₂O₂. In the first test (Test H-3), 20 mg/L Cu (as copper sulphate) was added followed by the addition hydrogen peroxide. The solution was maintained at approximately pH 8.5 with hydrated lime for 60 minutes. A solution sample was submitted for analysis of CN and species of interest. The second test (Test H-4) was carried out using the same procedure except copper catalyst was not used. The comparative results are presented in Table 6.

Treating the AVR barren with 10 times the stoichiometric requirement of H₂O₂ was successful in reducing the CN_{WAD} and Cu to the target <0.5 mg/L. Adding a copper catalyst was not beneficial as high CN and Cu were present in the test product.

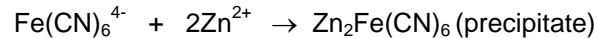
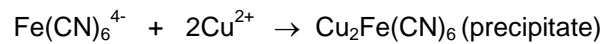
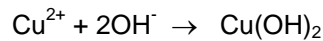
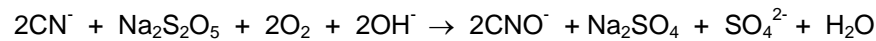
Table 6: Polishing Test on AVR Barren Using Hydrogen Peroxide

Test	Method	Lapsed Time min	H ₂ O ₂ 100% Basis		pH	Lime g/L	Cu ²⁺ Added mg/L	EMF AgCl mV	Solution Composition						
			Added g/L	Stoich %					CN _T mg/L	CN _{WAD} mg/L	Cu mg/L	Fe mg/L	CNO mg/L	CNS mg/L	Se mg/L
<i>Feed (AVR Barren)</i>					2.5			214	42	14	0.50	2.78	<1	261	<0.001
Test H-3	Batch	60	0.19	1000	8.9	0.50	20	141	8.4	5.4	15.2	<0.05	30.0	270	0.087
Test H-4	Batch	60	0.19	1000	8.6	0.38	...	169	12.6	0.4	0.10	1.86	9.30	240	0.084

2.2. SO₂/Air Cyanide Destruction Followed by Polishing Tests on Solution A

2.2.1. SO₂/Air Cyanide Destruction

Cyanide destruction testwork using sodium metabisulphite (as the source of SO₂) and air was conducted on Solution A to generate product for polishing testwork. In this process, the weak acid dissociable cyanide is oxidized to cyanate and copper precipitates as copper hydroxide. Ferrocyanide is not oxidized in the process and instead is precipitated as mixed metal ferrocyanide precipitate:



Testing was carried out using a 1L reactor and hydrated lime slurry was used to maintain the solution at the desired pH level. A batch test (CND 1) was conducted to produce a solution product with low residual cyanide for use as the starting solution for the first continuous test (Test CND 2). The treated product in the reactor from one test was used as the starting material for the next test.

The results are presented in Table 7. The details of the experimental procedure and results are appended (Appendix B).

Table 7: Cyanide Destruction Tests on Solution A Using SO₂/Air

Test	Mode	Reactor Vol. L	Reten. Time min	Composition (Solution Phase)								Product Vol. L	Cumulative Reagent Addition ⁽¹⁾			
				pH	CN _T mg/L	CN _{WAD} mg/L (2)	CNO mg/L	CNS mg/L	Cu mg/L	Fe mg/L	Se mg/L		g/g CN _{WAD}			
													SO ₂ Equiv.	Lime	Fe ⁽³⁾ mg/L Feed	
<i>Feed (Solution A)</i>																
CND 1	Batch	1.0	60	8.5	...	<0.1	87.8	1.53	0.064	...	4.75	3.66
CND 2	Continuous	1.0	57	8.7	4.8	1	120	120	2.04	<0.05	0.084	3.4	4.61	2.60
CND 3	Continuous	1.0	52	8.6	10.3	...	120	130	1.52	<0.05	0.059	0.9	5.14	5.04	0.004	0.4

⁽¹⁾SO₂ added as Na₂S₂O₅

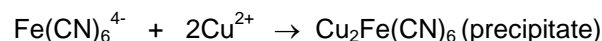
⁽³⁾Fe added as FeSO₄

⁽²⁾by the Picric acid method

...not analyzed or added

Conducting the SO₂/Air test at approximately pH 8.5, 1 hour retention time, 4.8 g SO₂ per gram CN_{WAD} in the feed (Test CND 2) reduced the concentration of CN_{WAD} from 104 mg/L to 1 mg/L and copper from 87.8 mg/L to 2 mg/L.

Test CND 3 was carried out in an attempt to further reduce the residual copper in the SO₂/Air product by adding a small amount of ferrous during the test to convert some of the residual CN_{WAD} to ferrocyanide for precipitation of the residual copper as copper ferrocyanide:



The results are included in Table 7. Adding 0.004 g ferrous per gram CN_{WAD} of the feed (0.4 mg/L Fe²⁺) during SO₂/Air treatment appeared to have a positive effect in reducing the residual copper in the test product. The residual Cu concentration in solution decreased slightly from approximately 2 mg/L (Test CND 2) to 1.5 mg/L. However, the residual cyanide in the SO₂/Air treated product increased with the

addition of ferrous to approximately 10 mg/L CN_T . Owing to the exhaustion of feed, Test CND 3 only operated for 1 reactor displacement (52 minutes) instead of the typical 3 reactor displacements for a standard SO_2 /Air test. Therefore, these findings should be confirmed and the effect of higher dosages of ferrous should also be evaluated in future testwork.

The two products from Tests CND 2 and 3 were used as feeds for polishing testwork using activated carbon, NaHS, and ferrous sulfate.

2.2.2. Polishing Treatment Using Activated Carbon

Carbon adsorption polishing tests were conducted on the two solution products from Tests CND 2 and CND 3. The feed solution (approximately 300 mL) was placed in a glass bottle. Fresh preatritioned activated carbon (Calgon GRC-22) was added and the bottle was placed on rolls for 24 hours. Solution samples were taken during the test for copper analysis to determine the kinetics of copper adsorption. Three carbon concentrations of 5, 10 and 15 g/L were evaluated on each feed solution. The results are presented in Tables 8 and 9 and plotted in Figures 2 and 3. The details of the experiments are included in Appendix B.

The results indicated that activated carbon could be used for the successful removal of residual copper and cyanide in SO_2 /Air treated solution products.

Table 8: Carbon Adsorption Polishing Tests on Test CND 2 Solution

Test	Solution Composition, mg/L							
	CN_T	CN_{WAD}	CNO	CNS	$NH_3 + NH_4$ as N	Cu	Fe	Se
<i>Feed - CND 2 Solution</i>	4.8	1	120	120	12.7	2.04	<0.05	0.084
5 g/L Carbon	0.17	<0.1	110	44	15.4	0.45	<0.05	0.096
10 g/L Carbon	0.05	<0.1	90	24	14.7	0.16	<0.05	0.055
15 g/L Carbon	0.02	<0.1	75	12	15.4	<0.05	<0.05	0.056

Table 9: Carbon Adsorption Polishing Tests on Test CND 3 Solution

Test	Solution Composition, mg/L							
	CN_T	CN_{WAD}	CNO	CNS	$NH_3 + NH_4$ as N	Cu	Fe	Se
<i>Feed - CND 3 Solution</i>	10.3	...	120	130	17.2	1.52	<0.05	0.059
5 g/L Carbon	<0.1	<0.1	96	42	43.6	0.42	<0.05	0.067
10 g/L Carbon	<0.1	<0.1	78	21	40.0	0.06	<0.05	0.105
15 g/L Carbon	<0.1	<0.1	65	13	35.5	<0.05	<0.05	0.060

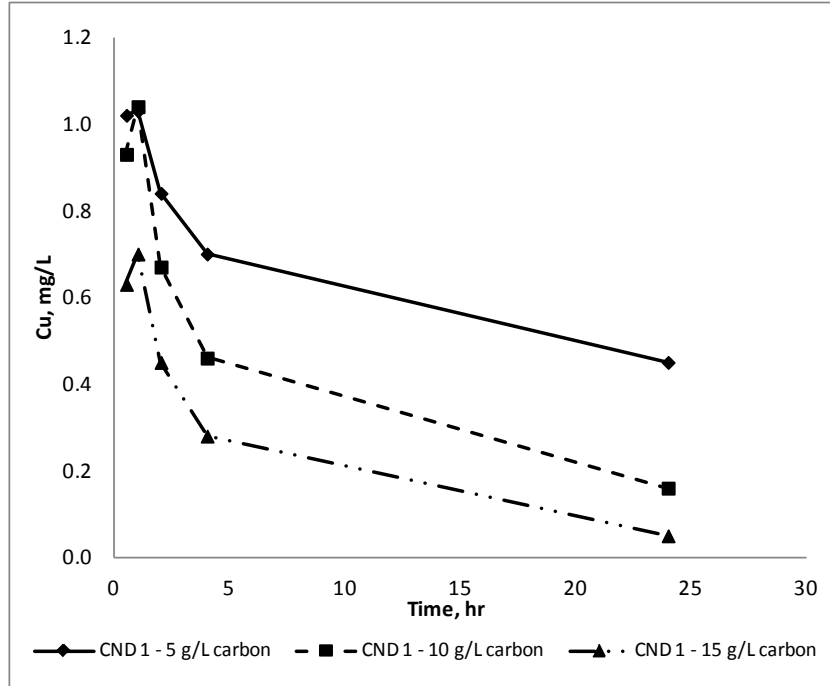


Figure 2: Carbon Adsorption Polishing Tests on CND 2 Solution – Cu in Solution

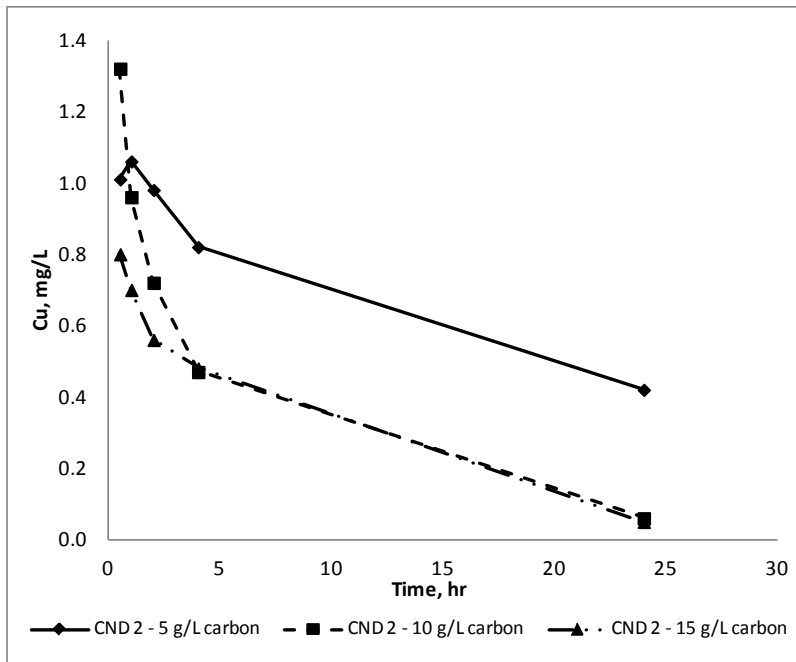


Figure 3: Carbon Adsorption Polishing Tests on CND 3 Solution – Cu in Solution

2.2.3. Polishing Treatment Using SART

The possibility of polishing treatment of the SO₂/Air product with NaSH was evaluated on Test CND 2 solution. The solution was treated at pH 3 using 120% of the stoichiometric requirement of NaSH (Test SART 4). The results are presented in Table 10. The test was unsuccessful in achieving the target copper concentration of <0.5 mg/L.

Table 10: SART Polishing Test on CND 2 Solution

Test	pH		NaHS Add. 120% Basis mg/L	H ₂ SO ₄ Conc. Add. g/L	Hydrated Lime Add. g/L	Solution Analysis				
	Target	Final				CN _T	CN _{WAD}	CNS	CNO	Cu
<i>Feed (CND 2 Solution)</i>	7.7	-	-	-	-	4.8	1	120	120	2.04
SART 4	3.0	3.0	2.0	0.5	0.45*	<0.1	<0.1	90	24	0.80

* For reneutralization of solution product

2.2.4. Polishing Treatment Using Ferrous Sulphate

The possibility of reducing the residual copper and cyanide from the SO₂/Air treated product by the addition of ferrous sulphate was investigated using Test CND 2 solution. Two ferrous sulphate levels of 5.6 and 11.2 moles Fe²⁺ per mole Cu were evaluated. The solution was maintained at approximately pH 6 for 1 hour using a dilute sulphuric acid solution.

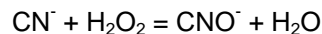
The results are presented in Table 11. The addition of ferrous sulphate at the dosage equivalent to 11.2 moles Fe²⁺ per mole Cu was successful in removing the residual copper and cyanide to the required target of <0.5 mg/L.

Table 11: Polishing Test on CND 2 Solution Using Ferrous Sulphate

Test	pH Target	FeSO ₄ •7H ₂ O		H ₂ SO ₄ Conc. g/L	Solution Analysis						
		Amount g/L	Molar Ratio Fe/Cu		CN _T	CN _{WAD}	CNS	CNO	Cu	Fe	Se
<i>Feed (CND 2 Sol'n)</i>	7.8				4.8	1	120	120	2.04	<0.05	0.084
Test Fe-1	5.8	0.05	5.6	0.012	<0.1	<0.1	99	130	1.91	<0.05	0.056
Test Fe-2	6.2	0.10	11.2	0.012	<0.1	<0.1	88	130	0.07	<0.05	0.026

2.3. Peroxide Treatment of Solution B

The removal of copper cyanide by oxidation with hydrogen peroxide was evaluated using Solution B. In this method, cyanide is oxidized to cyanate by hydrogen peroxide under slightly alkaline condition according to the following reaction:



Testing was conducted using 500 mL of Solution B, and at two hydrogen peroxide dosages of approximately 10 and 20 times the stoichiometric amount based on CN_{WAD} . Following hydrogen peroxide addition, the solution was maintained at pH 8 with hydrated lime for 90 minutes. Solution samples were taken every 30 minute during the test for analysis of residual cyanide and Cu. The results are presented in Table 12.

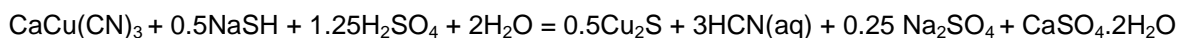
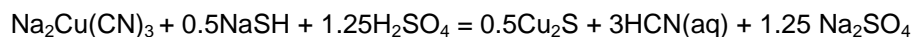
Treating Solution B using approximately 10 times the stoichiometric required of H_2O_2 (Test H-1) reduced the concentrations of CN_{WAD} and Cu to <0.1 mg/L and 0.14 mg/L, respectively. Doubling the H_2O_2 dosage to approximately 20 times the stoichiometric amount based on CN_{WAD} resulted in a further reduction of the copper concentration in solution to <0.05 mg/L.

Table 12: Peroxide Tests on Solution B

Test	Method	Cumulative Retention Time min	H_2O_2 100% Basis		Lime added g/L	Solution Composition							
			Added g/L	Stoich %		pH	EMF AgCl mV	CN_T mg/L	CN_{WAD} mg/L	Cu mg/L	Fe mg/L	CNO mg/L	CNS mg/L
<i>Feed (Solution B)</i>													
Test H-1	Batch	1	0.08	1095	0.10	8.1	182	6.4	5.4	4.89	<0.2	0.9	8.7
		30				8.7	276	...	...	...	...	...
		60				8.1	242	<0.1	<0.1	0.07	...	...
		90				8.0	234	<0.1	<0.1	<0.05	...	...
Test H-2	Batch	1	0.16	2190	0.20	8.0	220	<0.1	<0.1	0.14	<0.05	8.5	<2
		30				8.0	...	...	...	...	...	...
		60				8.0	213	<0.1	<0.1	<0.05	...	...
		90				8.0	207	<0.1	<0.1	<0.05	...	...
						8.0	206	<0.1	<0.1	<0.05	<0.05	7.9	<2

2.4. SART Removal of Copper on Solution B

In the SART process, the addition of NaHS under acidic condition precipitates copper as copper sulphide and liberates cyanide as HCN in solution. The possible reactions are presented below:



Testing was conducted in a 1-L glass kettle using 500 mL of feed Solution B. Mixing was provided with a magnetic stirrer. The feed was adjusted to the required pH using a dilute (20%) sulphuric acid solution. The required amount of NaHS was added and the solution was maintained at the desired pH for 20 minutes. Following the test, a flocculant (Magnafloc 156) was added to assist the settling of the copper sulphide precipitate. A solution sample was taken and filtered. Sodium hydroxide was added to adjust the filtrate to above pH 11 to stabilize the cyanide before submitting the sample for analysis. Another sample was then taken and adjusted with lime to approximately pH 10 to determine the lime requirement for reneutralization of the solution product. The test parameter was solution pH (pH 3 and 8) and the comparative results are shown in Table 13.

Conducting the SART test at pH 3 using 120% of the stoichiometric requirement of NaHS (Test SART 1) reduced the concentration of Cu in solution from 4.89 mg/L to 0.6 mg/L. The sulphuric acid requirement was 0.028 kg/m³ and the hydrated lime consumption for reneutralization of the solution product was 0.15 kg/m³.

Carrying out the SART test under alkaline condition (Test SART 2 at pH 8) was ineffective. The copper concentration only decreased from 4.89 mg/L to 3.61 mg/L.

Table 13: SART Tests on Solution B

Test	pH		NaHS Add. 120% Basis mg/L	H ₂ SO ₄ Conc. Add. g/L	Hydrated Lime Add. g/L	Solution Analysis			
	Target	Final				CN _T	CN _{WAD}	CN _F	Cu
						mg/L	mg/L	mg/L	mg/L
<i>Feed (Solution B)</i>	7.5	-				6.4	5.4	<2	4.89
SART 1	3.0	2.9	2.8	0.028	0.15*	6.6	6.4	4	0.60
SART 2	8.0	8.2	2.8	-	-	NA	NA	<2	3.61

* For reneutralization of solution product

NA: not analyzed

2.5. Carbon Adsorption Column Test on Solution C

The objective of the testwork was to evaluate the efficiency of copper adsorption onto activated carbon in a fluidized bed column. Testing was carried out using 5 gram of activated carbon (Calgon GRC 22) in a transparent glass column having an internal diameter of 15 mm. The feed solution was Solution C at the natural pH of approximately pH 7.8.

In a first test, the feed solution was pumped upflow through the carbon column, at a flowrate of approximately 50 mL/min for 200 minutes. It was observed in the test that at this solution flowrate, there was insignificant expansion of the carbon bed and, therefore, no fluidization of the carbon bed was achieved. Nevertheless, the test was allowed to proceed to completion. The column effluent was collected in 30-minute portions (20 minutes for the last collection) for analysis of residual copper. The results are presented in Table 14, and the details of the experiment are appended (Appendix C).

The total volume of solution processed was 9.94 litres, which was equivalent to a solution-to-carbon mass ratio of 1988. The results indicated that the test was successful in reducing the copper level from 2.13 mg/L in the feed solution to below 0.5 mg/L in the treated product.

The solution products from the first test were blended and a sample was taken for copper analysis. A 4.5 litre portion was used as feed for Test 2 to determine whether the loaded carbon from Test 1 could be

used to extract more copper from solution. The solution was pumped upflow through the same carbon column but at a much higher flowrate of 300 mL/min in order to achieve a carbon bed expansion of approximately 78%. The results (Table 14) showed that it was possible to further reduce the copper concentration in solution from 0.3 mg/l to 0.2 mg/L by reprocessing Test 1 effluent through the same carbon bed.

Table 14: Carbon Adsorption Column Tests on Solution C

Test	Lapsed Time	Solution Vol.	Flow Rate	Solution Composition						Cu Removal
				CN _T	CN _{WAD}	CNO	CNS	Cu	Fe	
	min	L	mL/min	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%
<i>Feed (Solution C)</i>	0			2.4	2.0	0.4	4.2	2.13	<0.2	
Column Test 1	30	1.36	45	...	...	...	...	0.22	...	90
	60	1.44	48	...	...	...	...	0.25	...	88
	90	1.46	49	...	...	...	...	0.26	...	88
	120	1.46	49	...	...	...	...	0.28	...	87
	150	1.48	49	...	...	...	...	0.28	...	87
	180	1.48	49	...	...	...	...	0.30	...	86
	200	1.26	63	0.78	0.79	0.4	2.9	0.40	<0.05	81
<i>Feed (Comp. of Test 1 Product)</i>	0			...	...	...	...	0.30	...	
Column Test 2	15	4.48	299	...	0.50	...	...	0.20	...	33

... not analyzed

Conclusions and Recommendations

Laboratory testwork was conducted at SGS Minerals Services Laboratory in Lakefield, Canada, to investigate various treatment options for detoxification of the KSM plant cyanide leach residue CCD Wash Water. Testwork was performing on the CCD plant Wash Water sample and on solutions prepared by diluting the CCD plant wash water with gypsum saturated water to target copper concentrations of 90 mg/L (Solution A), 5 mg/L (Solution B), and 2 mg/L (Solution C). The objective was to produce a final treated product containing less than 0.5 mg/L of residual Cu and CN_{WAD} .

The following conclusions can be drawn from the testwork:

- Hydrogen peroxide was effective for polishing treatment of solutions containing low levels of copper and cyanide. Treating Solution B (5.4 mg/L CN_{WAD} , 4.9 mg/L Cu) using approximately 10 times the stoichiometric required of H_2O_2 reduced the concentrations of CN_{WAD} and Cu to < 0.5 mg/L.
- Activated carbon adsorption was also effective for polishing treatment of solutions containing very low levels of cyanide and copper. Treating Solution C (2 mg/L CN_{WAD} , 2.1 mg/L Cu) in a fluidized bed column, at a solution flowrate of 10 carbon bed volume per minute and a solution to carbon mass ratio of 1988, reduced the Cu concentration from 2 mg/L to <0.5 mg/L. However, the effluent still contained 0.79 mg/L CN_{WAD} . Passing the solution through the same carbon bed a second time reduced the CN_{WAD} to <0.5 mg/L.
- Precipitation of low level of copper using NaSH was unsuccessful in reducing the cyanide and copper concentrations to the target <0.5 mg/L.
- It might be possible to treat solutions containing moderate levels of cyanide and copper by a combination of SART precipitation of copper sulphide and AVR recovery of cyanide followed by polishing treatment to reduce the residual CN_{WAD} and Cu in the AVR barren to below 0.5 mg/L. Testwork conducted on the Wash Water sample (176 mg/L CN_{WAD} , 145 mg/L Cu) produced an AVR barren solution containing 14 mg/L CN_{WAD} and 0.5 mg/L Cu. Treating the AVR barren solution with 10 times the stoichiometric requirement of H_2O_2 based on CN_{WAD} reduced the CN_{WAD} and Cu levels to 0.4 mg/L and 0.1 mg/L, respectively.
- It was observed during the testwork that selenium appeared to drop out of solution during AVR processing of the SART solution product. This finding should be confirmed in future testwork.
- It was also possible to use the SO_2 /Air method to treat solutions containing moderate levels of cyanide and copper to reduce the CN_{WAD} and Cu concentrations to approximately 1 mg/L, followed by polishing treatment to achieve the target <0.5 mg/L CN_{WAD} and Cu. Testwork results indicated that treating Solution A (104 mg/L CN_{WAD} , 88 mg/L Cu) with SO_2 /Air, at pH 8.5, 1 hour retention time, using 4.6 g SO_2 per gram CN_{WAD} produced treated product containing 1 mg/L CN_{WAD} and 2 mg/L Cu. Contacting the SO_2 /Air solution product with 5 g/L fresh activated carbon reduced the residual CN_{WAD} and Cu to <0.5 mg/L. Treating the SO_2 /Air solution product with ferrous sulphate, at approximately 11 moles Fe per mole Cu, also was successful in attaining the target <0.5 mg/L CN_{WAD} and Cu.
- Additional testing is recommended for selecting the polishing treatment method to meet the discharge target of <0.5 mg/L CN_{WAD} and Cu.

Appendix A – SART followed by AVR Treatment

Project No: 12628-001

Test SART. 4

Operator: KH

August 22, 2012

Purpose: SART test on test

CND 2

at pH 3.0 and

120 stoi. of NaHS.

Procedure:

The feed was placed in a 1 L air-tight kettle equipped with a pH probe.

Mixing was provided with a large magnetic stir bar.

The NaHS solution was prepared by dissolving NaHS in DIW.

H₂SO₄ solution was added to the kettle to adjust the solution to the required pH

The required amount of NaHS was added.

The solution was maintained at the desired pH with dilute H₂SO₄.

After the test, flocculant was added if required to assist the settling of the precipitate.

Solution was decanted off and filtered using a millipore paper. The solution sample was submitted for analysis.

The remainder was filtered to collect the Cu₂S precipitate.

The precipitate was washed with deionized water then saved in a cup.

The filtrate was neutralized with lime slurry or sodium hydroxide solution to pH ~10.

Feed:

0.50 L of Test	CND 2	1 mg/L CN _{wad}
4.8 mg/L CN _r	<0.10 mg/L CN _F	0.00 mg/L Zn
2.04 mg/L Cu	120 mg/L CNS	<0.05 mg/L Fe
		0.00 mg/L Au
		0.00 mg/L Ag

63.55	Na	22.99
107.87	S	32.06
65.39	H	1.01
58.69	NaSH	56.06

pH: 3.0 with 20% sulphuric acid solution **Temperature:** Ambient (~20 °C)

NaHS:

120% stoich. requirement Purity 69%

Dissolve 0.50 g NaHS in 99.50 g DI water

Mass of NaHS solution 0.16 g

Retention Time:

20 minutes

Time min	NaHS solution g	pH	H ₂ SO ₄ solution g	Remarks
0	0	3.0	20 %	
		7.7		Feed CN _F (add NaOH) 0
0		2.9	1.24	Adjust to pH first
5	0.16	3.0	0.00	Add NaSH.
10	***	3.0	0.00	
15	***	3.0	0.00	
20	***	3.0	0.00	Sample CN _r , CN _{wad} , Cu, Fe, CN _F (+NaOH).
Total	0.16		1.24	Floc M 156 0.5 g/L: 1.117 g
			0.50	kg H ₂ SO ₄ /m ³ Note: no precipitate formed
				1.117 g Saved ppt.

Renutralization:

Volume of solution 100 mL

pH	Cum. Lime	
	g	kg/m ³
3.3	0.00	0.00
3.8	0.00	0.02
5.6	0.01	0.13
9.6	0.05	0.45

Final Solution Analysis, mg/L							
CN _F	CN _r	CN _{wad}	Fe	Cu	CNS	CNO	NH ₃ /NH ₄
0	<0.1	<0.1	<0.05	0.8	90	24	15.5

Project No: 12628-001 Test SART 4 Operator: KH Date: August 22, 2012

Summary of Results:

Sample	pH	H ₂ SO ₄ Add. 100% Basis g/L	Lime for Re-neutr. g/L	CN _f mg/L	CN _{wad} Pictic Acid mg/L	CN _f mg/L	Solution Analysis					Solids Assay		
							Zn mg/L	Cu mg/L	Fe mg/L	SCN mg/L	Ag mg/L	Au mg/L	Dry Wt. g	S %
Feed	7.7			4.8	1.0	0	0.0	2.0	<0.05	120	0.0	0.0		
20 min Filtrate	3.0	0.5	0.45	<0.1	<0.1	0	<0.05	0.8	<0.05	90				
Cu ₂ S Precipitate													Saved	
Gypsum Precipitate														
Precip. Efficiency, %								61						
SART Feed volume:			0.50 L											
Renutralization volume			0.10 L											
														120 % stoichiometric requirement

NaSH Addition: 120 % stoichiometric requirement

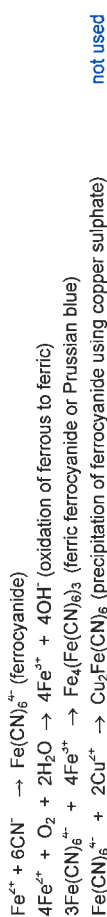
NaSH Recoverable CN in Feed: 1 mg
 CN_f Recovery: 0.00 %

Notes: Assume Fe present as Fe(CN)₆
 CN_{wad} = CN_f - CN in Fe(CN)₆

Test: FS-1 **Project:** 12628-001 **Operator:** KH **Date:** August 22, 2012

Purpose: Exploratory test on reducing concentration of Copper and CN using ferrous sulphate.

Proposed Reactions:



CN_{WAD}: <0.1 mg/L Fe: <0.05 mg/L FeSO₄·7H₂O : 10,000 mg/L at 100% stoich.
 49.76506

Feed: CND 2 500 ml at 0 % solids Solids s.g. Solution volume: 500 mL
 0 g pulp

Reagent: 100% stoichiometry FeSO₄·7H₂O : 0.025 g

Procedure: The feed was placed in a beaker and mixed with a magnetic stirrer.
 The solution pH was monitored/adjusted during the test.
 The reagent was added slowly.
 Solution sample was taken and filtered.
 The filtrate was submitted for analysis as shown below.

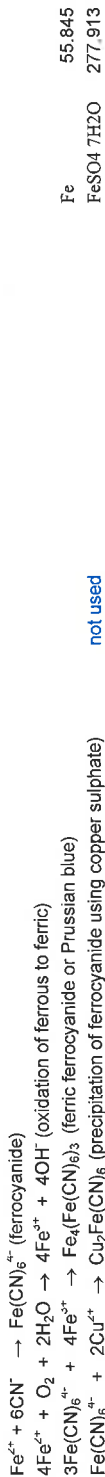
Results:

Lapsed Time	pH Target	FeSO ₄ ·7H ₂ O Amount	Stoich.	H ₂ SO ₄ 20 g/kg	Lime Ca(OH) ₂	Solution Analysis			
						CN _T	CN _{WAD}	CNS	Fe
min	5.5-6.5	g	%	g	g	mg/L	mg/L	mg/L	mg/L
Feed						4.77	1	120	2.0
0	7.8		0.07						
0	5.9	0.02	100	0.03					
10	6.0		0.17						
30	5.7		0.17						
60	5.8		0.16			<0.1	<0.1	99.0	1.9
Total		0.02	100	0.6	0.0				<0.05

Test: FS-2 **Project:** 12628-001 **Operator:** KH **Date:** August 22, 2012

Purpose: Exploratory test on reducing concentration of Copper and CN using ferrous sulphate.

Proposed Reactions:



Fe 55.845
 FeSO4 7H2O 277.913

CN_{WAD}: <0.1 mg/L Fe: <0.05 mg/L FeSO₄·7H₂O: 20.000 mg/L at 100% stoich.

99.53013

Feed: CND 2 500 mL at 0 % solids Solids s.g. Solution volume: 500 mL

0 g pulp

Reagent: 100% stoichiometry FeSO₄·7H₂O: 0.050 g

Procedure:
 The feed was placed in a beaker and mixed with a magnetic stirrer.
 The solution pH was monitored/adjusted during the test.
 The reagent was added slowly.
 Solution sample was taken and filtered.
 The filtrate was submitted for analysis as shown below.

Results:

Lapsed Time	pH Target	FeSO ₄ ·7H ₂ O Amount	FeSO ₄ ·7H ₂ O Stoich.	H ₂ SO ₄ 20 g/kg	Lime Ca(OH) ₂	Solution Analysis				
						CN _T	CN _{WAD}	CNS	Cu	Fe
min		g	%	g	g	mg/L	mg/L	mg/L	mg/L	mg/L
Feed	5.5-6.5					4.77	1	120	2.0	<0.05
0	7.8	0.30								
0	5.3	0.05	100							
10	5.9	0.00								
30	5.5	0.08								
60	6.2	0.21				<0.1	<0.1	88.0	0.07	<0.05
Total		0.05	100	0.6	0.0					

Project No: 12628-001**Test SART 3****Operator:** KH**August 10, 2012**

Purpose: SART test on test KSM Wash Water at pH 3.0 and 120 stoi. of NaHS.

Procedure: The feed was placed in a 3 L air-tight kettle equipped with a pH probe. Mixing was provided with a large magnetic stir bar. The NaHS solution was prepared by dissolving NaHS in DIW. H₂SO₄ solution was added to the kettle to adjust the solution to the required pH. The required amount of NaHS was added. The solution was maintained at the desired pH with dilute H₂SO₄. After the test, flocculant was added if required to assist the settling of the precipitate. Solution was decanted off and filtered using a millipore paper. The solution sample was submitted for analysis. The remainder was filtered to collect the Cu₂S precipitate. The precipitate was washed with deionized water then saved in a cup. The filtrate was neutralized with lime slurry or sodium hydroxide solution to pH ~10.

Feed:

2.00 L of Test	KSM Wash Water	176 mg/L CN _{WAD}		
187 mg/L CN _T	50 mg/L CN _F	2.0 mg/L Zn	0.00 mg/L Au	
145 mg/L Cu	270 mg/L CNS	3.9 mg/L Fe	0.1 mg/L Ag	

pH: 3.0 with 20% sulphuric acid solution **Temperature:** Ambient (~20 °C)

NaHS: 120% stoich. requirement Purity 69%
 Dissolve 2.00 g NaHS in 38.00 g DI water
Mass of NaHS solution 4.57 g

Retention Time: 20 minutes

Time min	NaHS solution g	pH	H ₂ SO ₄ 20 % g	Remarks
0	0	7.7		Feed CN _F (add NaOH) 50
0		3.0	4.33	Adjust to pH first
5	4.57	3.0	0.00	Add NaSH.
10	...	3.0	0.00	
15	...	3.0	0.00	
20	...	3.0	0.00	Sample CN _T , CN _{WAD} , Cu, Fe. CN _F (+NaOH).
Total	4.57		4.33	Floc M 156 0.5 g/L: 2.376 g Saved ppt.
			0.43	kg H ₂ SO ₄ /m ³ Note: no precipitate formed

Renutralization: Volume of solution mL

pH	Cum. Lime	
	g	kg/m ³
	0.00	0.00
		#DIV/0!
		#DIV/0!
		#DIV/0!

Final Solution Analysis, mg/L						
CN _F	CN _T	CN _{WAD}	Fe	Cu	CNS	CNO
155	162	156	2.2	0.38	280	12

Feed (+ NaOH)		Final (+ NaOH)	
Vol	21.7 g	Vol	28.7 g
AgNO ₃	0.41 mL	AgNO ₃	1.68 mL
CN _F	50 ppm	CN _F	155 ppm

Project No: 12628-001

Test SART 3

Operator: KH

Date: August 10, 2012

Summary of Results:

Sample	pH	H ₂ SO ₄ Add. 100% Basis g/L	Lime for Re- neutr. g/L	Solution Analysis									Solids Assay	
				CN _T mg/L	CN _{WAD} Picric Acid mg/L	CN _F mg/L	Zn mg/L	Cu mg/L	Fe mg/L	SCN mg/L	Ag mg/L	Au mg/L	Dry Wt. g	S %
Feed	7.7	...	...	187	176	50	2.0	145	3.9	270	0.1	0.0	...	...
20 min Filtrate	3.0	0.4	-	162	156	155	2.2	0.4	2.20	280			...	...
Cu ₂ S Precipitate													Saved	
Gypsum Precipitate														
Precip. Efficiency, %							-10	100			100	####		

SART Feed volume: 2.00 L NaSH Addition: 120 % stoichiometric requirement
 Renutralization volume 0.00 L

NaSH Recoverable CN in Feed: 352 mg
 CN_F Recovery: 88 %

Notes: Assume Fe present as Fe(CN)₆
 CN_{WAD} = CN_T - CN in Fe(CN)₆

Project 12628-001 Test AVR- 1

Operator: KH

Aug 9, 2012

Purpose: AVR test on solution from test SART 3.

Procedure: The feed was placed in a 2 L air-tight kettle, Mixing was provided with a large magnetic stir bar, Air was then drawn through the solution to purge the HCN into the caustic scrubber. The solution was maintained at the desired pH with H₂SO₄ 10%. The scrubber solution was titrated at 0.25, 0.5, 1, 2, 3 and 4 h (25 mL) for CN(F). After 4 h, a flocculant (M156) was added to assist the settling of the precipitate. A sample of the supernatant solution was titrated for CN(F) (NaOH added). Another sample was filtered and the filtrate submitted for analysis of CN(T), SCN, ICP MS. The precipitate (slurry) was saved. A sample of the AVR final solution was readjusted to pH 7-8 with lime slurry. The scrubber solution was titrated for CN(F).

Feed: 2.0 L of Barren Solution from SART 3.

162 mg/L CN_T 156 mg/L CN_{wAD}
155 mg/L CN_F 280 mg/L SCN
0.38 mg/L Cu 2.20 mg/L Fe

Target pH: 3 with 10% H₂SO₄ solution

Scrubber: 1.5 L NaOH 4%

Retention Time: 4 hours

Air Sparging: 2 L/min
(with sparger tube)

Time min	pH	H ₂ SO ₄ g	Air Sparging L/min	Scrubber 1.5 L mg/L CN	Remarks
0	3.3	0	---	---	
0	2.6	0.46	2	---	Start air sparging
15	2.6	0.00	2	10	Scrubber titration 25 mL
30	2.6	0.00	2	16	Scrubber titration 25 mL
60	2.6	0.00	2	29	Scrubber titration 25 mL
120	2.6	0.00	2	51	Scrubber titration 25 mL
180	2.5	0.00	2	74	Scrubber titration 25 mL
240	2.5	0.00	2	95	Scrubber titration 25 mL
300	2.5	0.00	2	110	Scrubber titration 25 mL
360	2.5	0.00	2	123	Scrubber titration 25 mL
420	2.5	0.00	2	129	Scrubber titration 25 mL
480	2.6	0.00	2	133	Scrubber titration 100 mL
Total		0.46		102	Reactor: 102 ppm CN(F) Collect ppt.

M156 (0.5 g/L) Floc added: 0 g

Renutralizatio AVR final solution 100 mL

Lime slurry 2.5 % w/w

pH	Cumulative Lime	
	g 2.5%	g/m ³
7.5-8.5		
2.8	0	0
3.0	0.23	57
6.2	0.44	109
9.2	0.58	145

AgNO ₃	Aliquot		CN(F)
	Target	Actual	
0.09	25	25	9.6
0.16	25	26.05	16.3
0.28	25	25.87	28.7
0.5	25	26.07	50.9
0.73	25	26.07	74.3
0.93	25	26.08	94.6
1.08	25	26.13	109.7
1.21	25	26.14	122.9
1.27	25	26.06	129.3
1.31	100	26.14	133.0
0.96	50	25.07	101.6

Appendix B – CND and Polishing Treatment

Test Batch 1 **Project 12628-001** **Operator: KH** **Aug 8, 2012**

Purpose: Batch SO₂/Air Cyanide Destruction Test on diluted KSM Wash Water (Solution A)

Procedure: The cyanide effluent was placed in the reactor. Air was added and the solution was well agitated. The required amount of copper sulphate was added. Na₂S₂O₈ solution was pumped to the reactor. The air flowrate and agitation rate were adjusted to obtain >4 mg/L dissolved oxygen. The effluent was maintained at the required pH by the addition of lime slurry. The treated effluent (overflow) was collected in containers. Samples were taken during the test and analyzed for CN(WAD) using picric acid method. The target residual CN(wad) was <1 mg/L.

Apparatus: **Reactors 1.0-L volume (10 cm I.D.) with baffles.**
 Reactors 1.0-L volume (10 cm I.D.) with baffles.
 Lab agitators with a 6-bladed turbine impeller (9.0 cm diameter x 1.5 cm high).

Feed Pulp: **Test KSM Wash Water (Solution A)**

CN _T	108.0 mg/L	CN _F	-
CN _{WAD}	104.0 mg/L	Zn	0.0 mg/L
CNO	17 mg/L	SCN	160 mg/L
Cu	87.8 mg/L	pH	8.1 mg/L
Fe	1.5 mg/L	Pulp density	0.0 % solids

pH: Approx. 8.5 with lime slurry Temperature: Ambient (18-22C°)

Results:

Agitator Speed:

Flowrates:

Average Feed:	13 g/L
Na ₂ S ₂ O ₈ :	1.00 mL/min
Lime:	0.65 mL/min
Air:	2 L/min

Retention Time:

Treated Pulp:

pH:	8.5
CN _T :	0.0 mg/L
CN _{WAD} :	<0.1 mg/L (by Picric acid method)
Cu:	0.00 mg/L
Fe:	0.00 mg/L

Reagent Added:

SO ₂ (equivalent)	4.98 g/g CN _{WAD}	0.52 g/L pulp
Lime	3.85 g/g CN _{WAD}	0.40 g/L pulp
Cu	0.00 g/g CN _{WAD}	0 mg/L solution
Cu		0 mg/L pulp

Test Batch 1

Project 12628-001

Operator: KH

Aug 8, 2012

Batch SO2/Air Cyanide Destruction Test on diluted KSM Wash Water (Solution A)

Lapsed Time	pH	EMF	Air Flow-rate	Dis-solved O ₂	Agitation	Na ₂ S ₂ O ₅ Volume in Grad. Cylinder	Equiv SO ₂ Add	Lime Slurry Bottle Wt.	CN _{WAB} by Picric Acid	Cu	Fe	Remarks
min		mV	L/min	mg/L	rpm	mL	g/g CN _{WAB}	g	mg/L	mg/L	mg/L	mg/L
Feed	8.1	52	2	10.4	500		...		104	87.8	1.5	CN _F
0	8.1	52	2	10.4	500	250	...	690				Zn 0 Ni 0
25	8.6	61	2	8.5	500	225			33			
60	8.5	206	2	8.5	500	190		650	<0.1			

Feed: 1.0 L of pulp at
 Solution volume: 1.00 L
 Na₂S₂O₅: 13 g/L at 1 mL/min.
 Cu: 0 mg/L added 0.0 mg Cu 0 mg CuSO₄ 5H₂O
 Lime: 10 g/kg lime slurry
 Retention time: As required to achieved <1 ppm residual CN_{WAB}
 CN_{picric}: CN_{WAB} by picric acid method.

Impeller: 6-bladed turbine, 1.0 cm diameter x 1.5 cm high
 Reactor: 1 L with 4x1 cm baffles

0 % Solids

Test CND 1

Project 12628-001

Operator: KH

Date: Aug 9, 2012

Continuous SO2/Air CND test on diluted KSM Wash Water (Solution A)

Procedure:
The treated solution from the batch CND was used as starting effluent. Air was added to the reactor. The solution was well stirred. Na₂S₂O₅ solution was pumped to the reactor.

The air flowrate and agitation rate were adjusted to obtain >4 mg/L dissolved oxygen. The reactor was conditioned for approximately 5 minutes.

The feed pump was switched on to start the continuous test.

The solution in the reactor was maintained at the required pH by the addition of lime slurry.

The treated solution (overflow) was collected in containers.

Samples were taken during the test and analyzed for CN_{NAD} using picric acid method.

The target residual CN_{NAD} was < 0.5mg/L.

A composite sample of the product was filtered and the filtrate was submitted for analysis.

Apparatus:

Reactors 1.0-L volume with baffles.
Lab agitators with a 6-bladed turbine impeller (5.0 cm diameter x 1.5 cm high).
Other standard laboratory equipment were used as required.

Feed Pulp:

KSM Effluent

CN _F	108.0 mg/L	CN _F	
CN _{NAD}	104.0 mg/L	Zn	0.0 mg/L
CNO	17 mg/L	SCN	160 mg/L
Cu	87.8 mg/L	pH	8.4 mg/L
Fe	1.5 mg/L	Pulp density	0.0 % solids

pH: Approx. 8.5 with lime slurry

Temperature: Ambient (20-25C°)

Results:

Agitator Speed:

Flowrates:

Agitation:	500 rpm
Average Feed:	16 mL/min
Na ₂ S ₂ O ₅ :	1.00 mL/min
Cu:	0.00 mL/min
	57 min
	8.7
	4.77 mg/L
	1.00 mg/L (by Lab)
	2.04 mg/L
	<0.05 mg/L
	4.84 g/g CN _{NAD}
	2.73 g/g CN _{NAD}
	0.00 g/g CN _{NAD}

Retention Time:

Treated Pulp:

(mg/L solution)

Lime:	10 g/kg
Air:	0 L/min
	1.00 mg/L (by Picric acid method)

Reagent Added:

Lime

Cu

Cu

SO ₂ (equivalent)	4.84 g/g CN _{NAD}
Lime	2.73 g/g CN _{NAD}
Cu	0.00 g/g CN _{NAD}
	0.52 g/L pulp
	0.29 g/L pulp
	0.0 mg/L solution
	0.0 mg/L pulp

*Additional Assays

CNS

CNO

NH3+NH4

mg/L

120

120

12.7

Test CND 1

Project 12628-001

Operator: KH

Date: Aug 9, 2012

Continuous SO2/Air CND test on diluted KSM Wash Water (Solution A)

Lapsed Time min	pH	EMF mV	Air Flow-Rate L/min	DO ₂ mg/L	Mixer rpm	SMBS in Grad. Cyl. mL	CuSO ₄ Cyl. mL	Lime Slurry Bottle g	CN _{WAD} mg/L	CN _T mg/L	Cu mg/L	Fe mg/L	CN _F mg/L	Zn mg/L	Remarks
0	8.4	209	2	9.0	500	1000		644	104	108	87.8	1.5			Condition reactor
5	8.1	222	2	8.7	500	995									Start feed
30	8.5	188	2	7.8	500	970			0.2						405 mL Overflow 30 mL
60	8.6	162	2	7.8	500	940			0.7						510 mL Overflow 30 mL
90	8.5	172	2	8.4	500	910			0.9						485 mL Overflow 30 mL
120	8.6	165	2	7.2	500	880			1.2						500 mL Overflow 30 mL
150	8.4	176	2	4.8	500	850			1.2						490 mL Overflow 30 mL
180	8.6	156	2	2.9	500	820			1.0						500 mL Overflow 30 mL
210	8.7	155	2	2.5	500	790		548	1.0	4.77	2.04	<0.05			460 mL Overflow 80 mL
Composite Sample									1.0	4.77	2.04	<0.05			Total Overflow Vol. 3350 mL

Reactor: 1.0 L (10 cm diameter) with baffles
 Impeller: 6-bladed turbine, 5.0 cm diameter x 1.5 cm high
 Na₂S₂O₅: 12.0 g/L at 1 mL/min. Actual 1.0 mL/min
 CuSO₄: 0.0 mg/L Cu at 1 mL/min. Actual 0.0 mL/min
 or 0.00 g CuSO₄ 5H₂O per 500 mL
 Lime: 10 g/kg slurry

Feed: 0 % Solids
 Solution volume: 1.00 L
 Solution volume: 4.7 g SO₂/g CN_{WAD}
 Target feed flowrate: 16 mL/min
 Target retention time: 60 min
 16 actual mL/min
 57 actual min

ACTUAL REAGENT DOSAGE AND FEED FLOWRATE

Time	Parameters	Lime	Cu	metabisulphite	SO ₂	Feed
Total	Volume used (mL)	96	0	210		3304
Reten	Flowrate (mL/min)	0.4569	0.00	1.00		16.12
	Dosage (g/gCN _{WAD})	2.73	0.00	7.16		4.84
	Dosage (g/L pulp):	0.29	0.0	0.76		0.52

Total O/F Collect

Test CND 2 **Project 12628-001** **Operator: KH** **Date: Aug 9, 2012**

Purpose: Continuous SO₂/Air CND test on diluted KSM Wash Water (Solution A)

Procedure: The treated solution from the batch CND was used as starting effluent. Air was added to the reactor. The solution was well stirred. Na₂S₂O₅ solution was pumped to the reactor.

The air flowrate and agitation rate were adjusted to obtain >4 mg/L dissolved oxygen. The reactor was conditioned for approximately 5 minutes.

The feed pump was switched on to start the continuous test.

The solution in the reactor was maintained at the required pH by the addition of lime slurry.

The treated solution (overflow) was collected in containers.

Samples were taken during the test and analyzed for CN_{NAD} using picric acid method.

The target residual CN_{NAD} was < 0.5mg/L.

A composite sample of the product was filtered and the filtrate was submitted for analysis.

Apparatus: Reactors 1.0-L volume with baffles. Lab agitators with a 6-bladed turbine impeller (5.0 cm diameter x 1.5 cm high). Other standard laboratory equipment were used as required.

Feed Pulp:

KSM Effluent	
CN _T	108.0 mg/L
CN _{NAD}	104.0 mg/L
CNO	17 mg/L
Cu	87.8 mg/L
Fe	1.5 mg/L
	Pulp density
	0.0 % solids

pH: Approx. 8.5 with lime slurry Temperature: Ambient (20-25C°)

Results:

Agitation Speed: 500 rpm

Flowrates:

Average	16 mL/min	Lime:	10 g/kg	0.894 mL/min
Feed:	1.00 mL/min	Air:		0 L/min
Na ₂ S ₂ O ₅ :	63 g/L			
Cu:	6.55 g/L			

Retention Time: 52 min

Treated Pulp: 8.6

(mg/L solution)	
CN _T :	10.30 mg/L
CN _{NAD} :	- mg/L (by Lab)
Cu:	1.52 mg/L
Fe:	<0.05 mg/L

<0.1 mg/L (by Picric acid method)

Reagent Added:

SO ₂ (equivalent)	5.40 g/g CN _{NAD}
Lime	5.29 g/g CN _{NAD}
Fe	0.004 g/g CN _{NAD}
Fe	0.5 mg/L pulp
	0.68 g/L pulp
	0.56 g/L pulp
	0.5 mg/L solution
	0.5 mg/L pulp

*Additional Assays

CNS	mg/L
CNO	130
NH ₃ +NH ₄	120
	17.2

Test: CA-1 **Project:** 12628-001 **Operator:** KH **Date:** 22-Aug-12

Purpose: To determine the efficiency of copper stripping using carbon adsorption kinetics on treated CND 2 solution from the KSM effluent.

Procedure: The feed was Test CND 2 solution. 5 g of dried preatritrioned carbon was added and the bottle was placed on the rolls for 24 hours. Solution samples were removed at 0.5, 1, 2, 4 and 24 hours. The solution was submitted for Cu assay

Feed: CND 2 treated effluent

Kinetics

Sample	Time h	Volume mL	mg/L Cu Solution Cu, mg/L
1	0.5	300	1.02
2	1	300	1.03
3	2	295	0.84
4	4	290	0.70
5	24	285	0.45

Feed: 300.0 mL CND 2 (effluent)
Carbon: 5.00 g +16 mesh GRC22
Samples: 5 mL solution
Final Solution: Cu

Test: CA-2 **Project:** 12628-001 **Operator:** KH **Date:** 22-Aug-12

Purpose: To determine the efficiency of copper stripping using carbon adsorption kinetics on treated CND 2 solution from the KSM effluent.

Procedure: The feed was Test CND 2 solution. 10 g of dried preatritioned carbon was added and the bottle was placed on the rolls for 24 hours. Solution samples were removed at 0.5, 1, 2, 4 and 24 hours. The solution was submitted for Cu assay

Feed: CND 2 treated effluent

Kinetics

Sample	Time h	Volume mL	Solution Cu, mg/L	mg/L Cu mg/L Cu
1	0.5	300	0.93	
2	1	300	1.04	
3	2	295	0.67	
4	4	290	0.46	
5	24	285	0.16	

Feed: 300.0 mL CND 2 (effluent)
Carbon: 10.00 g +16 mesh GRC22
Samples: 5 mL solution
Final Solution: Cu

Test: CA-3 **Project:** 12628-001 **Operator:** KH **Date:** 22-Aug-12

Purpose: To determine the efficiency of copper stripping using carbon adsorption kinetics on treated CND 2 solution from the KSM effluent.

Procedure: The feed was Test CND 2 solution. 15g of dried preatritioned carbon was added and the bottle was placed on the rolls for 24 hours. Solution samples were removed at 0.5, 1, 2, 4 and 24 hours. The solution was submitted for Cu assay

Feed: CND 2 treated effluent

Kinetics

Sample	Time h	Volume mL	mg/L Cu	
			Initial Preg Solution: mg/L Cu	Final Barren Solution: mg/L Cu
1	0.5	300	0.63	
2	1	300	0.70	
3	2	295	0.45	
4	4	290	0.28	
5	24	285	<0.05	

Feed: 300.0 mL CND 2 (effluent)
Carbon: 15.00 g +16 mesh GRC22
Samples: 5 mL solution
Final Solution: Cu

Test: CA-4 **Project:** 12628-001 **Operator:** KH **Date:** 22-Aug-12

Purpose: To determine the efficiency of copper stripping using carbon adsorption kinetics on treated CND 3 solution from the KSM effluent.

Procedure: The feed was Test CND 3 solution. 5 g of dried preatritioned carbon was added and the bottle was placed on the rolls for 24 hours. Solution samples were removed at 0.5, 1, 2, 4, 4 and 24 hours. The solution was submitted for Cu assay

Feed: CND 3 treated effluent

Kinetics

Sample	Time h	Volume mL	Solution Cu, mg/L	mg/L Cu	mg/L Cu
1	0.5	300	1.01		
2	1	300	1.06		
3	2	295	0.98		
4	4	290	0.82		
5	24	285	0.42		

Feed: 300.0 mL CND 3 (effluent)
Carbon: 5.00 g +16 mesh GRC22
Samples: 5 mL solution
Final Solution: Cu

Test: CA-5 **Project:** 12628-001 **Operator:** KH **Date:** 22-Aug-12

Purpose: To determine the efficiency of copper stripping using carbon adsorption kinetics on treated CND 3 solution from the KSM effluent.

Procedure: The feed was Test CND 3 solution. 10 g of dried preatritioned carbon was added and the bottle was placed on the rolls for 24 hours. Solution samples were removed at 0.5, 1, 2, 4 and 24 hours. The solution was submitted for Cu assay

Feed: CND 3 treated effluent

Kinetics

Sample	Time h	Volume mL	mg/L Cu	
			Initial Solution	Final Solution
1	0.5	300	1.32	
2	1	300	0.96	
3	2	295	0.72	
4	4	290	0.47	
5	24	285	0.06	

Feed: 300.0 mL CND 3 (effluent)
Carbon: 10.00 g +16 mesh GRC22
Samples: 5 mL solution
Final Solution: Cu

Test: CA-6 **Project:** 12628-001 **Operator:** KH **Date:** 22-Aug-12

Purpose: To determine the efficiency of copper stripping using carbon adsorption kinetics on treated CND 3 solution from the KSM effluent.

Procedure: The feed was Test CND 3 solution. 15g of dried preatritioned carbon was added and the bottle was placed on the rolls for 24 hours. Solution samples were removed at 0.5, 1, 2, 4 and 24 hours. The solution was submitted for Cu assay

Feed: CND 3 treated effluent

Kinetics

Sample	Time h	Volume mL	mg/L Cu	
			Initial Preg Solution:	Final Barren Solution:
1	0.5	300	0.80	0.80
2	1	300	0.70	0.70
3	2	295	0.56	0.56
4	4	290	0.48	0.48
5	24	285	<0.05	<0.05

Feed: 300.0 mL CND 3 (effluent)
Carbon: 15.00 g +16 mesh GRC22
Samples: 5 mL solution
Final Solution: Cu

Appendix C – Dilution Wash Water Testwork

Test AC-1

Project 12628-001

Operator: KH

Purpose: Carbon Adsorption test on diluted Wash Water

Procedure: The 20% HCL was added to the carbon and placed on hotplate for 20 min at 120 °C.
 The carbon was separated using the strainer and placed in DI water for 30 min.
 The carbon sample was placed in the oven
 A few drop of DI water was spread on dry carbon and placed in oven at 70°C for 15 min and quenched in DI water.
 In order to reserve the surface of carbon, the wet carbon was placed in the column and estimation was made for dry weight.
 The exact weight of carbon was determined after the test.
 DI water was pumped at 50mL/min rate and carbon expansion determined.
 After confirming the flowrate, the sample solution was pumped and flow rate adjusted.

Feed: Diluted effluent sample Test H-1 :

CN_T: ~2.4 mg/L CN_{WAD/Picric}: 2.0 mg/L CN_F: < mg/L CNS: 4.2 mg/L
 Cu: ~2.13 mg/L Fe: <0.2 mg/L CNO: 0.4 mg/L Zn: <mg/L pH: 7.8

Equipment: 15mm ID columnTemperature: Ambient (22-26C°)Feed Volume: 10.0 L orSolution Volume: 10.00 LFlow rate: 50 mL/min**Data**

Lapsed Time min	Solution Volume L	Solution Analysis						Notes
		CN _T mg/L	CN _{WAD} CN _{Picric} mg/L	Cu mg/L	Fe mg/L	CNO mg/L	SCN mg/L	
0								
30	1360			0.22				8.5
60	1440			0.25	---		---	8.5
90	1460			0.26				8.5
120	1460			0.28	---		---	9.0
150	1480			0.28				8.5
180	1480			0.30				8.5
200	1260			0.40	<0.05	0.4	2.9	8.5
Total	9940							60
Composite	4.48			0.3				
2nd stage	4.48			0.2				

Project No: 12628-001**Test SART 1****Operator:** KH**August 2, 2012**

Purpose: SART test on Diluted KSM Wash Water (Solution B) at pH 3.0 and 120 stoi. of NaHS.

Procedure: The feed was placed in a 1 L air-tight kettle equipped with a pH probe. Mixing was provided with a large magnetic stir bar. The NaHS solution was prepared by dissolving NaHS in DIW. H₂SO₄ solution was added to the kettle to adjust the solution to the required pH. The required amount of NaHS was added. The solution was maintained at the desired pH with dilute H₂SO₄. After the test, flocculant was added if required to assist the settling of the precipitate. Solution was decanted off and filtered using a millipore paper. The solution sample was submitted for analysis. The remainder was filtered to collect the Cu₂S precipitate. The precipitate was washed with deionized water then saved in a cup. The filtrate was neutralized with lime slurry or sodium hydroxide solution to pH ~10.

Feed: 0.50 L of Test Diluted KSM Wash Water (Solution B) 5.4 mg/L CN_{WAD}
 6.4 mg/L CN_T <2 mg/L CN_F <0.7 mg/L Zn 0.00 mg/L Au
 4.89 mg/L Cu 8.7 mg/L CNS <0.2 mg/L Fe <0.08 mg/L Ag

pH: 3.0 with 20% sulphuric acid solution **Temperature:** Ambient (~20 °C)

NaHS: 120% stoich. requirement Purity 69%
 Dissolve 0.50 g NaHS in 100.00 g DI water
Mass of NaHS solution 0.40 g

Retention Time: 20 minutes

Time min	NaHS solution g	pH	H ₂ SO ₄ 20 % g	Remarks
0	0	7.5		Feed CN _F (add NaOH) n/a
0		3.0	0.34	Adjust to pH first
5	0.40	3.0	0.00	Add NaSH.
10	...	2.9	0.00	
15	...	2.9	0.00	
20	...	2.9	0.00	Sample CN _T , CN _{WAD} , Cu, Fe. CN _F (+NaOH).
Total	0.40		0.34	Floc M 156 0.5 g/L: 0.9 g Saved ppt.
			0.14	kg H ₂ SO ₄ /m ³ Note: no precipitate formed

Renutralization: Volume of solution 100 mL

pH	Cum. Lime	
	g	kg/m ³
3.0	0.00	0.00
4.1	0.01	0.06
10.2	0.01	0.11
10.7	0.02	0.15

Final Solution Analysis, mg/L					
CN _F	CN _T	CN _{WAD}	Zn	Cu	
3.90	6.62	6.42	0.07	0.6	

Feed (+ NaOH)	Final (+ NaOH)
Vol 26.21 g	Vol 25.86 g
AgNO ₃ 0 mL	AgNO ₃ 0.11 mL
CN _F 0 ppm	CN _F 11 ppm

Project No: 12628-001

Test SART 1

Operator: KH

Date: August 2, 2012

Summary of Results:

Sample	pH	H ₂ SO ₄ Add. 100% Basis g/L	Lime for Re- neutr. g/L	Solution Analysis										Solids Assay	
				CN _T mg/L	CN _{WAD} Picric Acid mg/L	CN _F mg/L	Zn mg/L	Cu mg/L	Fe mg/L	SCN mg/L	Ag mg/L	Au mg/L	Dry Wt. g	S %	
Feed	7.5	...	...	6.4	5.4	<2	0.7	4.9	<0.2	8.7	<0.08	0.0	...	...
20 min Filtrate	2.9	0.1	0.15	6.6	6.4	4	0.1	0.6	...		0.0	0.0	...	...
Cu ₂ S Precipitate													Saved		
Gypsum Precipitate															
Precip. Efficiency, %							90	88							

SART Feed volume: 0.50 L NaSH Addition: 120 % stoichiometric requirement
 RENEUTRALIZATION volume 0.10 L

NaSH Recoverable CN in Feed: 3 mg
 CN_F Recovery: 72 %

Notes: Assume Fe present as Fe(CN)₆
 CN_{WAD} = CN_T - CN in Fe(CN)₆

Product CN(T)
 2230

Project No: 12628-001**Test SART 2****Operator:** KH**August 2, 2012**

Purpose: SART test on test Diluted KSM Wash Water (Solution B) at pH 7.5 and 120 stoi. of NaHS.

Procedure: The feed was placed in a 1 L air-tight kettle equipped with a pH probe. Mixing was provided with a large magnetic stir bar. The NaHS solution was prepared by dissolving NaHS in DIW. H₂SO₄ solution was added to the kettle to adjust the solution to the required pH. The required amount of NaHS was added. The solution was maintained at the desired pH with dilute H₂SO₄. After the test, flocculant was added if required to assist the settling of the precipitate. Solution was decanted off and filtered using a millipore paper. The solution sample was submitted for analysis. The remainder was filtered to collect the Cu₂S precipitate. The precipitate was washed with deionized water then saved in a cup. The filtrate was neutralized with lime slurry or sodium hydroxide solution to pH ~10.

Feed: 0.50 L of Test Diluted KSM Wash Water (Solution B) 5 mg/L CN_{WAD}
 6 mg/L CN_F <2 mg/L CN_F <0.7 mg/L Zn 0.00 mg/L Au
 5 mg/L Cu 8.7 mg/L CNS <0.2 mg/L Fe <0.08 mg/L Ag

pH: 7.5 with 20% sulphuric acid solution **Temperature:** Ambient (~20 °C)

NaHS: 120% stoich. requirement Purity 69%
 Dissolve 0.50 g NaHS in 100.00 g DI water
 Mass of NaHS solution 0.41 g

Retention Time: 20 minutes

Time min	NaHS solution g	pH	H ₂ SO ₄ 20 % g	Remarks
0	0	7.7		Feed CN _F (add NaOH) 0
0		8.3	0.00	Adjust to pH first
5	0.41	8.3	0.00	Add NaSH.
10	...	8.3	0.00	
15	...	8.2	0.00	
20	...	8.2	0.00	Sample CN _T , CN _{WAD} , Cu, Fe. CN _F (+NaOH).
Total	0.41		0.00	Floc M 156 0.5 g/L: 2.394 g Saved ppt. 0.00 kg H ₂ SO ₄ /m ³ Note: no precipitate formed

Renutralization: Volume of solution mL

pH	Cum. Lime	
	g	kg/m ³
	0.00	0.00

Final Solution Analysis, mg/L					
CN _F	CN _T	CN _{WAD}	Zn	Cu	
<2	NA	NA	0.02	3.61	

Feed (+ NaOH) **Final (+ NaOH)**
 Vol g Vol 25.14 g
 AgNO₃ mL AgNO₃ 0 mL
 CN_F #DIV/0! ppm CN_F 0 ppm

Project No: 12628-001

Test SART 2

Operator: KH

Date: August 2, 2012

Summary of Results:

Sample	pH	H ₂ SO ₄ Add. 100% Basis g/L	Lime for Re- neutr. g/L	Solution Analysis									Solids Assay	
				CN _T mg/L	CN _{WAD} Picric Acid mg/L	CN _F mg/L	Zn mg/L	Cu mg/L	Fe mg/L	SCN mg/L	Ag mg/L	Au mg/L	Dry Wt. g	S %
Feed	7.7	...	...	6.4	5.4	<2	0.7	5.0	<0.2	9	<0.08	0.0	...	...
20 min Filtrate	8.2	0.0		NA	NA	<2	0.02	3.6	...		0.0	0.0	...	...
Cu ₂ S Precipitate													Saved	
Gypsum Precipitate														
Precip. Efficiency, %							97	28						

SART Feed volume: 0.50 L NaSH Addition: 120 % stoichiometric requirement
 Renuutralization volume 0.00 L

NaSH Recoverable CN in Feed: 3 mg
 CN_F Recovery: %

Notes: Assume Fe present as Fe(CN)₆
 CN_{WAD} = CN_T - CN in Fe(CN)₆

Product CN(T)
2230

Appendix D – Preparation of Caro Acid

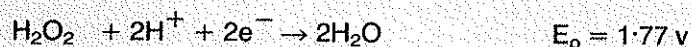
CARO'S ACID LABORATORY PROCEDURE FOR HYDROMETALLURGY

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1. INTRODUCTION

Caro's acid, also known as peroxymonosulphuric acid, is one of the most powerful and versatile oxidising agents that is in use on an industrial scale.

Caro's acid is most conveniently prepared by the reaction between hydrogen peroxide and sulphuric acid. In appearance it resembles sulphuric acid of similar strength, likewise for many of its physical properties. Compared to hydrogen peroxide Caro's acid is a stronger oxidising agent and possesses greater stability to catalytic decomposition by transition metal ions, especially at elevated temperatures. The theoretical redox potential for both peroxygens are as follows:



Although the preparations described here are small batch operations, on a large industrial scale Caro's acid is generated by both batch and continuous processes. A generator unit is normally located at the user's site with rate of production linked directly to size of demand, and with flexibility to match a fluctuating demand.

Being a liquid, Caro's acid is easily handled on both a laboratory and a commercial scale. Also, since Caro's acid reacts very quickly even at ambient temperatures, processes can be controlled easily at a fixed redox potential thus avoiding any excess of oxidant in subsequent stages. Its decomposition products add only sulphuric acid (or sulphate) and water to the reaction system.

2. PREPARATION OF CARO'S ACID

The method recommended by Interlox for the production of Caro's acid, on any scale, is the controlled addition of hydrogen peroxide to strong sulphuric acid (>90% H_2SO_4), with cooling to remove the heat of dilution of the acid and the heat of reaction:



As the equation above shows, the preferred route to Caro's acid from hydrogen peroxide is an equilibrium reaction. One or both of the following techniques is therefore employed to maximise the yield of H_2SO_5 :

- * Use reagents of the maximum commercial strength available to keep the amount of water in the reaction mixture to a minimum.
- * Use a molar excess of sulphuric acid to drive the forward reaction towards completion.

Typical product compositions are shown in the following table for Caro's acids made from 50%, 60% and 70% hydrogen peroxide and 98% sulphuric acid in the range of $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$ molar ratios of 1:1 to 3:1.

Composition of Caro's Acid Equilibrium Mixture

Starting Materials % w/w	H ₂ SO ₄ :H ₂ O ₂ Molar Ratio	Composition %w/w		
		H ₂ SO ₅	H ₂ SO ₄	H ₂ O ₂
98% H ₂ SO ₄ 70% H ₂ O ₂	1:1	42	31	10
	2:1	39	46	2
	3:1	29	60	1
98% H ₂ SO ₄ 60% H ₂ O ₂	1:1	33	35	11
	2:1	35	46	3
	3:1	28	58	1
98% H ₂ SO ₄ 50% H ₂ O ₂	1:1	23	40	13
	2:1	28	49	4
	3:1	26	58	2

It can be seen that there is considerable flexibility available in the choice of reagent strengths and ratios. For experimental work the choice made depends on the following considerations:

- (i) Availability at the point of use of hydrogen peroxide and sulphuric acid of particular strengths.
- (ii) Tolerance of proposed end use to small amounts of unreacted hydrogen peroxide.
- (iii) Effect of proposed end-uses of extra acidity arising from the use of excess sulphuric acid.

The preparation of Caro's acid using 98% sulphuric acid and 70% hydrogen peroxide at a H₂SO₄:H₂O₂ molar ratio of 3:1 is described in LABORATORY METHOD 1 on page 7. This procedure is ideally suited for production of up to 1 kg of a Caro's acid equilibrium mixture.

3. DILUTION OF CARO'S ACID

For some applications using Caro's acid, particularly in the laboratory where the volumes involved may be very small, it is preferable to use the Caro's acid in a more dilute form. The preferred procedure for dilution is the controlled addition of the concentrated equilibrium mixture to water. Since the dilution is exothermic some cooling is required. Practically it has been found that dilution to give a solution of 10% H₂SO₅ is adequate for the vast majority of applications.

From a consideration of the equation for Caro's acid production it would be expected that the additional water would drive the equilibrium from right to left:



This is not usually observed in practice, the relative amounts of the components remain unchanged on dilution of the concentrated solution even after several weeks' storage.

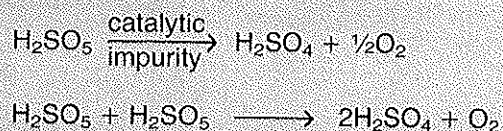
4. STABILITY AND STORAGE OF CARO'S ACID

The quantity of Caro's acid prepared in the laboratory is usually sufficient for many experiments and the surplus acid may be stored for future use, in either dilute or concentrated form. The following storage temperatures are recommended for the different Caro's acid strengths:

"As-made" or Concentrated Caro's Acid -10°C
Solutions containing 10% H_2SO_5 0 to 5°C

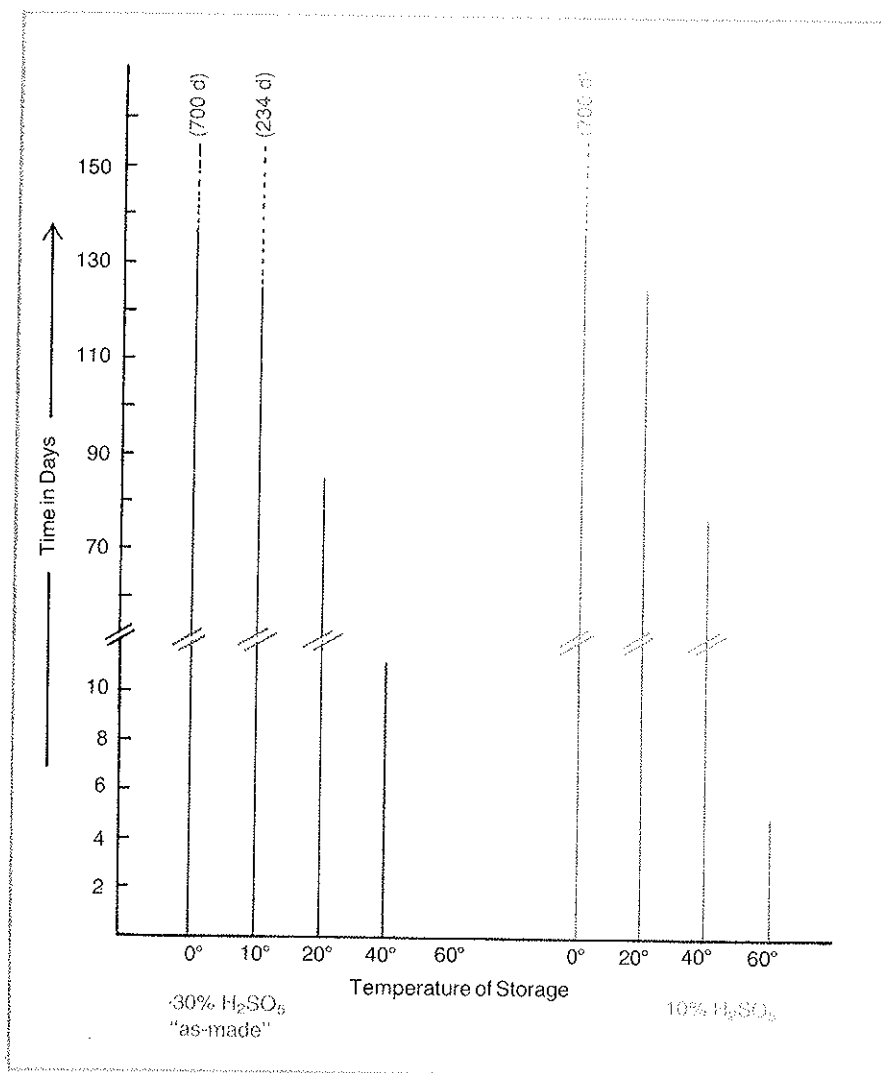
At these temperatures storage for several weeks is possible with no detectable change in composition.

At higher temperatures some decomposition occurs due to catalytic impurities in the sulphuric acid, and some self-decomposition.



The "half-life" or time taken to reach 50% of the original H_2SO_5 concentration for various Caro's acid equilibrium mixtures is shown in the following graph. The mole ratio of $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$ is 3:1, but other mole ratios used have very little effect on stability.

Stability of
Caro's Acid –
Time to 50%
original
concentration



Thus, even storage at normal laboratory temperatures will result in only slight decomposition over several days. On a full scale plant this means that only very slight decomposition of the Caro's acid is likely during periods of unplanned stoppage.

It should be noted that Caro's acid can be used in reactions at elevated temperatures without any major decomposition occurring, since the rates of reaction are fast compared to the rate of decomposition.

5. PROPERTIES, HANDLING AND MATERIALS OF CONSTRUCTION

Caro's acid of a given strength is similar in many of its physical properties to H_2SO_4 . However, it is also a very strong oxidising agent and, like other oxidants, concentrated solutions may cause fires on contact with organic materials such as wood, paper, cotton or straw. It can react very vigorously with reducing agents and violent self-ignition may occur if strong Caro's acid is mixed with oxidisable organic substances such as alcohols and aldehydes. In addition, unstable organic peroxides can be formed even with dilute Caro's acid if it is mixed with ketones and some other organic materials. Low boiling organic solvents such as acetone should therefore never be used to dry laboratory apparatus before use with Caro's acid.

Contaminated solutions of Caro's acid may decompose rapidly with a swift rise in temperature and evolution of large volumes of oxygen. If the acid is strong enough it can actually boil. All apparatus should therefore be provided with the largest possible free vent. Work under pressure should be avoided, but if absolutely essential, the apparatus should be fitted with a bursting disc in addition to a conventional relief valve. Caro's acid should never be handled or stored in sealed equipment as a pressure burst may occur.

Self-heating of Caro's acid can occur when samples are left in the open laboratory near a source of heat such as a hotplate or in direct sunlight. Similarly, catalytic decomposition may cause self-heating by contamination from external sources. If self-heating occurs, the sample should be dumped into a large quantity of cold water. Self-heating does not occur if the recommended storage procedures are followed.

Its oxidising properties make Caro's acid even more aggressive to human tissue than H_2SO_4 of a comparable strength. Acid-proof protective clothing suitable for use with H_2SO_4 should be worn consisting of at least safety spectacles, gloves and a plastic apron. All operations should be carried out in a fume cupboard if strong acid is being handled. Equipment such as safety pipettes should always be used for all strengths.

If contamination of eyes and skin occurs, the affected part should be washed immediately with copious amounts of water and medical attention obtained. A safety shower is desirable if large quantities are being handled. Contaminated clothing should be removed and immediately soaked well in running water and then washed before re-use.

When working with Caro's acid on a laboratory scale, it is preferable to employ glass for all surfaces likely to be in contact with the acid. However, some other materials such as 316 stainless steel (or steel of equivalent composition) are resistant to attack by Caro's acid and may be used in its preparation.

If there is a need to use materials other than those described above, it is recommended that their suitability be discussed with Interlox.

6. INTEROX TECHNICAL SERVICE

A complete range of technical support is available from Interlox for companies in the metal extraction industry. This includes the following:

- * Visits by Interlox personnel to discuss performance of peroxy compounds in metal extraction processes, choice of the most effective peroxy compound, and method of application.
- * Demonstration of preparation of Caro's acid in Interlox or customer's laboratory.
- * Advice on storage, handling, and safety aspects of peroxy compounds.
- * Laboratory scale testwork (leaching, solution purification) using peroxy compounds.
- * Other booklets as follows:
 - A.O. 5.4 "Interlox Peroxygen Systems for Hydrometallurgy"
 - general introduction to peroxy compounds for metallurgists containing some typical results obtained with hydrogen peroxide and Caro's acid in hydrometallurgical applications.
 - P.1 1.1 "Hydrogen Peroxide" – a general description.
 - P.1 2.1 "Hydrogen Peroxide" – data manual.
 - P.1 3.1 "Hydrogen Peroxide" – manual for handling and storage.

7. LABORATORY METHODS

Introduction This laboratory method is suitable for the preparation of Caro's acid from hydrogen peroxide ($\leq 70\%$) and concentrated sulphuric acid ($\leq 98\%$) at any molar ratio. If it is necessary to prepare a Caro's acid from stronger reagents then it is recommended that the **ADVICE OF INTEROX SHOULD BE SOUGHT**.

The following procedures and precautions are necessary when working with peroxy compounds in the laboratory:

The preparation should be carried out in a fume hood or suitable screened area. Protective clothing, including safety spectacles, must be worn by everyone handling Caro's acid.

Apparatus in contact with Caro's acid or hydrogen peroxide must first be pickled with nitric acid (60–70% analytical grade) either at 70°C for two hours or overnight at ambient. After rinsing thoroughly with distilled or demineralised water the apparatus should be air dried. If stored in polythene bags after use, repeat pickling of the apparatus is not necessary. The apparatus must be freely vented.

Thermometer must either be of the alcohol type or 316 stainless steel probe.

Grease must not be used on any part of the apparatus. Burette or dropping funnel taps should be of the PTFE type.

PREPARATION OF CARO'S ACID

Reagents Concentrated sulphuric acid and hydrogen peroxide, both of known concentrations. Some quantities of reagents are given in the following table for the preparation of three typical Caro's acids, all of which are prepared using a molar ratio of 3:1 ($\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$).

H ₂ SO ₄		H ₂ O ₂		% H ₂ SO ₅ in Caro's Acid
%	g	%	g	
98	100	70	16.2	29
98	100	60	18.9	28
94	100	70	15.5	27
98	100	50	22.7	25

Magnetic Stirrer.

PTFE Magnetic Stirrer Bar.

Alcohol Thermometer.

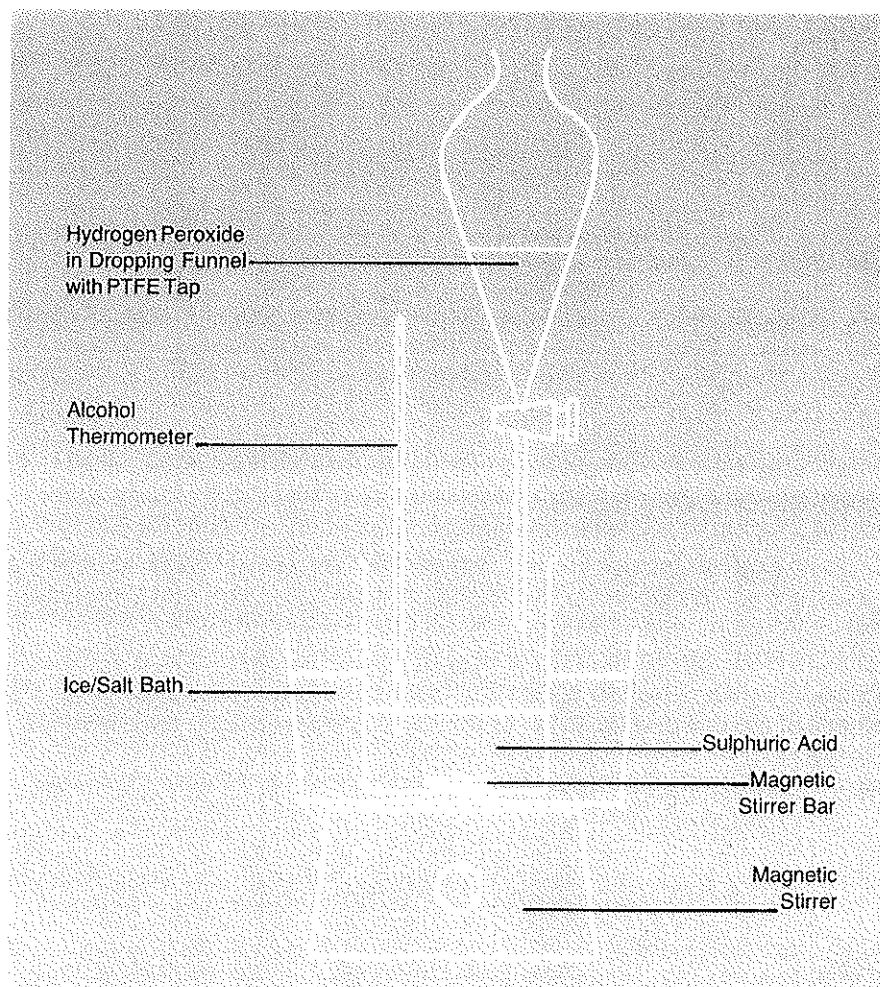
Dropping Funnel (or Burette) fitted with PTFE Tap.

Beaker – size dependent upon quantity of Caro's acid to be made.

Container for ice/salt bath

(acetone/solid CO₂ must not be employed).

Apparatus



Additionally 2 or 3 Beakers are required for weighing reagents.

If other mole ratios are required the level of sulphuric acid or hydrogen peroxide may be adjusted accordingly. Thus to prepare a Caro's acid from 70% H₂O₂ and 98% H₂SO₄ at a mole ratio of 1.5:1 H₂SO₄:H₂O₂ requires 2 × the weight of peroxide shown.

- Procedure
1. Weigh an approximate amount of concentrated sulphuric acid into the glass beaker/reactor and then assemble the apparatus with the exception of the dropping funnel or burette, as shown in the diagram above.
 2. Prepare an ice/water bath in the large dish surrounding the glass beaker/reactor.
 3. With continual stirring cool the sulphuric acid to about 5°C.
 4. Meanwhile, pour the required quantity of hydrogen peroxide (calculated from the concentration of reagents and molar ratio to be used) into the dropping funnel, or burette, and site it over the reactor as shown.
 5. When the sulphuric acid is cold, start adding the hydrogen peroxide slowly, dropwise at such a rate that the temperature of the reaction does not exceed 20°C. As the reaction progresses the rate of hydrogen peroxide addition can be increased.
 6. After all of the hydrogen peroxide has been added, allow the Caro's acid to cool to the bath temperature. Stir the mixture for 10 minutes before analysis.
 7. When the required amount of Caro's acid has been taken from the reactor (for dilution, storage or use) any unwanted Caro's acid must be disposed of by pouring it into a large excess of water and flushing away with copious amounts of water.

DILUTION OF CARO'S ACID

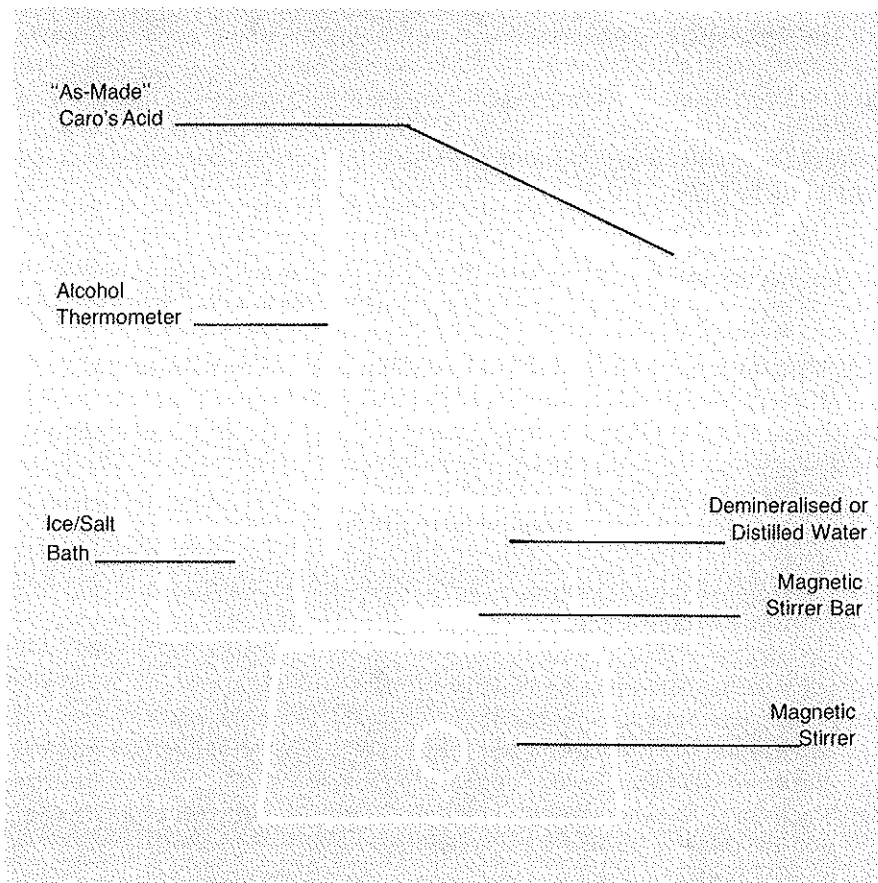
Concentrated "as-made" Caro's acid can be diluted with water so that the dilute Caro's acids contain ~10% H_2SO_5 . Always add Caro's acid to the water.

Reagents Concentrated "as-made" Caro's acid of known concentration and ice-cold distilled or demineralised water. The necessary quantities of water for the dilution of the three samples of Caro's acid in the preparation are given in the next table.

Concentrated "as-made" Caro's Acid		Water required g	% H_2SO_5 in dilute Caro's Acid
g	% H_2SO_5		
116.2	29	220.8	10
118.9	28	214.0	10
115.5	27	195.5	10

Apparatus

Large glass Beaker.
 Alcohol Thermometer.
 Magnetic Stirrer Motor and PTFE-covered Magnetic Follower, or
 Overhead Stirrer Motor and glass or PTFE Stirrer.



1. Into the large glass beaker weigh the required amount of ice-cold distilled or demineralised water. (It is preferable to use a mixture of ice and water, but the ice must be made from distilled or demineralised water; ice made from tap water should not be used).
2. Place the beaker on top of the magnetic stirrer motor and stir the water rapidly.
3. Slowly pour in the Caro's acid taking care that the temperature does not rise above 30°C. In the unlikely event of this occurring, stop the addition of Caro's acid, stir the partly diluted Caro's acid for a few minutes and place it in a refrigerator to cool before recommencing the dilution.
4. After all of the Caro's acid has been added, continue stirring to ensure that the two liquids are thoroughly mixed before analysis, storage or use.

Method

Concentrated "as-made" Caro's acid and dilute Caro's acid can be stored for several weeks in a laboratory without significant loss of oxidising power. Both types of Caro's acid must be stored in suitable containers, either loosely-stoppered conical glass flasks or vented heavy-duty polythene bottles and stood in a dish which must be large enough to hold all of the contents of the containers should they leak.

In both cases it is recommended that stored Caro's acid should be analysed prior to use.

ANALYTICAL PROCEDURES FOR CARO'S ACID

Introduction The full analysis of Caro's acid is performed in two stages, firstly to determine H_2O_2 and H_2SO_5 , and secondly to determine the total H_2SO_4 . This includes the free sulphuric acid present in the equilibrium mixture plus that derived from reduction or decomposition of the H_2SO_5 . In both cases samples of Caro's acid are weighed in glass bottles or tubes (about 15mm x 15mm) using disposable glass pipettes to transfer Caro's acid. The quantity of sample taken depends upon its concentration, so for concentrated "as-made" Caro's acid about 0.4g should be used, and for dilute Caro's acid approximately 1g is ideal. Wherever possible, analytical-grade reagents and distilled or demineralised water should be used.

ANALYTICAL METHOD FOR PEROXY SPECIES IN CARO'S ACID

Principle The sample to be analysed is diluted with cold sulphuric acid. The hydrogen peroxide content is determined by titration with ceric sulphate using ferroin as indicator. Potassium iodide is added and the liberated iodine titrated with sodium thiosulphate to determine peroxymonosulphuric acid.

Reagents Ceric sulphate solution (0.1 N).
Sodium thiosulphate solution (0.1 N).
Potassium iodide solution (100 g/l).
Sulphuric acid (approximately 2 N).
Ferroin indicator solution – dissolve 0.174 g of ferrous sulphate in 25 ml of water and stir to dissolve, add 0.371 g of 1,10-phenanthroline hydrate and stir to dissolve.
Starch solution – make a paste of 0.5 g of soluble starch with 5 ml of water, add this paste to 95 ml of boiling water and cool.

Method Measure 150 ml of sulphuric acid into a 500 ml conical flask, add 1 or 2 cubes of ice and 2 or 3 drops of ferroin indicator and titrate with ceric sulphate until the indicator changes to a pale blue colour.

Weigh (to ± 0.001 g) a suitable mass of sample into a glass weighing bottle or tube. Let the mass taken be W_1 g.

Add the weighed sample to the cold contents of the conical flask and mix. Titrate with ceric sulphate to the blue end-point. Let the titre obtained be A ml.

Add 10 ml of potassium iodide solution to the flask, mix and immediately titrate with sodium thiosulphate. Add a few drops of starch solution towards the end of the titration and continue with the titration until the dark blue colour disappears. Let the titre obtained be B ml.

Calculation

$$\text{Hydrogen peroxide, H}_2\text{O}_2 = \frac{A \times N_1 \times 1.701}{W_1} \%$$

$$\text{Peroxymonosulphuric acid, H}_2\text{SO}_5 = \frac{B \times N_2 \times 5.704}{W_1} \%$$

Where N_1 and N_2 are the normalities of ceric sulphate and sodium thiosulphate respectively.

ANALYTICAL METHOD FOR TOTAL ACIDITY AND SULPHURIC ACID CONTENT OF CARO'S ACID

A sample of Caro's acid is titrated with sodium hydroxide to a methyl orange end-point. The free sulphuric acid content of the sample can be calculated by subtraction of the peroxymonosulphuric acid content.

Principle

Sodium hydroxide (0.5 N).
Methyl orange indicator solution (10 g/l).

Reagents

Place 50 ml of distilled water into a 250 ml conical flask, add 2 or 3 drops of methyl orange and titrate with sodium hydroxide to the end-point.

Method

Weigh (to ± 0.001 g) a suitable mass of sample into a glass weighing bottle or tube. Let the mass taken be W_2 g.

Add the weighed sample to the contents of the flask, mix and without delay titrate with sodium hydroxide to the end-point. Let the titre obtained be C ml.

Calculation

$$\text{Total Acidity (as H}_2\text{SO}_4) = \frac{C \times N_3 \times 4.9}{W_2} \% \text{ w/w}$$

Where N_3 is the normality of the sodium hydroxide solution.

This gives the total sulphuric acid content of the Caro's acid, including that produced by reduction or decomposition of the H_2SO_5 .

To determine the sulphuric acid content of the Caro's acid mixture:

Let the total acidity be X % w/w.

Let the peroxymonosulphuric acid content (as H_2SO_5) be Y % w/w.

Then sulphuric acid content as H_2SO_4 is

$$X - \frac{(Y \times 49)}{114} \% \text{ w/w}$$

The information contained in this document is given in good faith and by way of a guide, but implies no guarantee. It cannot be regarded as a recommendation that our products should be used in opposition to existing patents.

National or local regulations covering work safety and hygiene are applicable in all cases and we can accept no liability where such regulations are not observed.

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Appendix E – Data

**Added Jan. 2013 by
Rescan, an ERM Group Company
for KSM Application/EIS**

Clem Pelletier

From: Dean Lindsay <dglind@telus.net>
Sent: Tuesday, August 21, 2012 10:30 AM
To: tjsmolik@comcast.net; Clem Pelletier; 'Huang, Jianhui'
Cc: 'Melashvili, Mariam (Lakefield)'; 'Cuong Trang'
Subject: FW: KSM Cu&CN Tests Update
Attachments: KSM_program.xlsx; KSM_program_prel_results.xlsx

Good morning,

The test work at Lakefield is proceeding and I have summarized some of the more interesting results to date. As you recall the objective was to look for a method of reducing the CN_{WAD} and Cu in a discharge solution to <0.5 ppm in each case.

Preliminary indications are that these results are achievable.

We are working with a high cyanide, high copper wash water solution sample which will give indicative results that should later be confirmed using pulp samples.

It looks like a carbon absorption treatment on the pulp after SO_2 /Air cyanide destruction is one possible method of achieving the objective.

The idea for the plant would be to treat the CIL pulp residue after cyanide destruction using all the (regenerated and acid washed) CIL circuit carbon before advancing it to the CIL stages.

A kinetic sampling was conducted to measure Cu absorption during the bottle roll test but the kinetic results were contaminated by suspended solids. At the moment we only have meaningful results on the filtered bottle roll solutions after 24 hours. Preliminary results are tabulated below.

Carbon Absorption of Cu on Cyanide Destruction Product (Preliminary Results)							
Sample	Source Sol'n Wash Water	Diluted Sol'n To CN destr	Cyanide Destruction Tests		Bottle Roll Carbon Absorption		
			SO_2 /Air	SO_2 /Air + 10 mg/L $FeSO_4$	Sol'n after 24 hours		
					5 gpl C	10 gpl C	15 gpl C
Cyanide Spec							
CN_T	243	126					
CN_{WAD}	176						
CN_F	50						
CNS	270	160	120	130	45	25	16
CNO	25	17	120	120	120	90	82
NH_3+NH_4 (N)		10.3	12.7	17.2	12.2	12.8	13.2
Cu	145	87.8	2.04	1.52	0.27	0.08	<0.05
Fe	3.9	1.53	<0.05	<0.05	0.08	0.22	0.18

For the above tests, the Source Sol'n wash water sample was diluted with gypsum saturated water to approximately 90 ppm Cu; a level of Cu in solution to cyanide destruction anticipated during plant operation. Final CN_{WAD} assays after the cyanide destruction are not yet available but determinations using picric acid were carried out during the test indicating CN_{WAD} values around 0.1 ppm. Achieving a low CN_{WAD} value appears to be mostly a function of SO_2 addition.

The Cu in solution was reduced from 87.8 to 2.04 ppm during the cyanide destruction process which was carried out at a pH of 8.

The solution after cyanide destruction was tested overnight in bottle rolls with 5, 10, and 15 gpL carbon addition (PFS Design carbon concentration in CIL is 15 gpL for the plant)

In each case the carbon (taken from the lab container – no regeneration or acid wash) dropped the Cu to very acceptable levels after 24 hours. The kinetic tests will need to be repeated to get a better idea for the required residence time.

Work is also underway with tests relating to the CIL discharge wash water solution. To date, only some work with SART and AVR has been carried out. Cyanide destruction and Cu reduction tests on the SART + AVR solution have not been completed. Both peroxide and Caro's acid are to be tested.

Wash Water Treatment SART + AVR (Preliminary Results)			
Sample	Source Sol'n Wash Water	SART Sol'n pH=3 120 % Stoic	AVR Sol'n
<u>Cyanide Spec</u>			
CN _T	243		
CN _{WAD}	176		
CN _F	50	219	
CNS	270	280	261
CNO	25	12	<1
NH ₃ +NH ₄ (N)		15.5	16.9
Cu	145	0.38	
Fe	3.9	2.2	2.78

Best regards,
Dean

Carbon Absorption of Cu on Wash water (Preliminary Results)				
Sample	Source Sol'n Wash Water	Diluted Sol'n To CN destr	Carbon Adsorption in Column Test	
			1st stage	2nd stage
			50ml/min	300ml/min
Cyanide Spec				
CNT	243	2.41	0.78	
CNWAD	176	1.96	0.79	0.5
CNF		<2		
CNS	270	4.2	2.9	
CNO	25	0.4	0.4	
NH3+NH4 (N)				
Cu	145	2.13	0.4	0.2
Fe	3.9	<0.2	<0.05	

Treatment of Wash water by Peroxide						
Sample	Source Sol'n Wash Water	Diluted Sol'n To CN destr	Cyanide Destruction Tests			
			H2O2		SART	
					120 % stoic	
			1000 % Stoic	2000 % Stoic	pH 3	pH 8.2
Cyanide Spec						
CNT	243	6.35	<0.01	<0.01	6.62	<0.1
CNWAD	176	5.43	<0.01	<0.01	6.42	<0.1
CNF		<2			3.9	<0.1
CNS	270	8.7	<2	<2		
CNO	25	0.9	8.5	7.9		
NH3+NH4 (N)						
Cu	145	4.89	0.14	<0.05	0.6	3.61
Fe	3.9	<0.2	<0.05	<0.05		



RESCAN ENVIRONMENTAL SERVICES
ATTN: Kelsey Norlund
Sixth Floor
1111 West Hastings Street
Vancouver BC V6E 2J3

Date Received: 03-OCT-12
Report Date: 05-OCT-12 16:22 (MT)
Version: FINAL

Client Phone: 604-689-9460

Certificate of Analysis

Lab Work Order #: L1218604
Project P.O. #: NOT SUBMITTED
Job Reference:
C of C Numbers:
Legal Site Desc:

Amber Springer
Account Manager

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ALS CANADA LTD Part of the ALS Group A Campbell Brothers Limited Company

Project**Report To****ALS File No.****Date Received****Date**

Kelsey Norlund, RESCAN ENVIRONMENTAL SERVICES

L1218604

03-Oct-12 11:00

05-Oct-12

RESULTS OF ANALYSIS

	24HR SOLUTION WITH 15 G/L CARBON	ORIGINAL UNDILUTED WASH WATER SAMPLE	SO2 AIR AND SOLUTION
Sample ID			
Date Sampled	03-OCT-12	03-OCT-12	03-OCT-12
Time Sampled	00:00	00:00	00:00
ALS Sample ID	L1218604-1	L1218604-2	L1218604-3
Matrix	Water	Water	Water

Physical Tests

Hardness (as CaCO3)	1420	1540	1500
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Dissolved Metals

Dissolved Metals Filtration Location	LAB	LAB	LAB
Aluminum (Al)-Dissolved	<0.015	<0.060	<0.015
Antimony (Sb)-Dissolved	0.0180	0.0347	0.0177
Arsenic (As)-Dissolved	0.0114	0.0131	<0.00050
Barium (Ba)-Dissolved	0.0329	0.0115	0.0148
Beryllium (Be)-Dissolved	<0.00050	<0.0020	<0.00050
Bismuth (Bi)-Dissolved	<0.0025	<0.010	<0.0025
Boron (B)-Dissolved	<0.050	<0.20	<0.050
Cadmium (Cd)-Dissolved	0.000141	0.00167	0.000636
Calcium (Ca)-Dissolved	555	612	596
Chromium (Cr)-Dissolved	<0.00050	<0.0020	0.00243
Cobalt (Co)-Dissolved	0.0127	0.136	0.0170
Copper (Cu)-Dissolved	0.0674	117	2.66
Iron (Fe)-Dissolved	<0.030	0.973	<0.030
Lead (Pb)-Dissolved	<0.00025	<0.0010	<0.00025
Lithium (Li)-Dissolved	0.0174	0.475	0.0136
Magnesium (Mg)-Dissolved	8.64	2.67	2.27
Manganese (Mn)-Dissolved	0.0398	0.0090	0.0307
Mercury (Hg)-Dissolved	<0.000010	<0.00010	0.000027
Molybdenum (Mo)-Dissolved	0.211	0.531	0.301
Nickel (Ni)-Dissolved	0.0037	0.125	0.0433
Phosphorus (P)-Dissolved	1.71	<0.30	<0.30
Potassium (K)-Dissolved	88.4	8.5	7.30
Selenium (Se)-Dissolved	0.0543	0.157	0.0392
Silicon (Si)-Dissolved	3.20	2.02	1.87
Silver (Ag)-Dissolved	0.000084	0.0330	<0.000050
Sodium (Na)-Dissolved	429	425	444
Strontium (Sr)-Dissolved	1.62	1.10	1.71
Thallium (Tl)-Dissolved	<0.000050	<0.00020	<0.000050
Tin (Sn)-Dissolved	<0.00050	<0.0020	<0.00050
Titanium (Ti)-Dissolved	0.012	0.013	0.013
Uranium (U)-Dissolved	<0.000050	<0.00020	<0.000050
Vanadium (V)-Dissolved	<0.0050	<0.020	<0.0050
Zinc (Zn)-Dissolved	0.026	<0.060	0.032

ALS ENVIRONMENTAL ANALYTICAL REPORT

	Sample ID Description Sampled Date Sampled Time Client ID	L1218604-1 water 03-OCT-12 24HR SOLUTION WITH 15 G/L CARBON	L1218604-2 water 03-OCT-12 ORIGINAL UNDILUTED WASH WATER SAMPLE	L1218604-3 water 03-OCT-12 SO2 AIR AND SOLUTION	
Grouping	Analyte				
WATER					
Physical Tests	Hardness (as CaCO3) (mg/L)	1420	1540	1500	
Dissolved Metals	Dissolved Metals Filtration Location	LAB	LAB	LAB	
	Aluminum (Al)-Dissolved (mg/L)	<0.015	<0.060 ^{DLA}	<0.015 ^{DLA}	
	Antimony (Sb)-Dissolved (mg/L)	0.0180	0.0347	0.0177 ^{DLA}	
	Arsenic (As)-Dissolved (mg/L)	0.0114	0.0131	<0.00050 ^{DLA}	
	Barium (Ba)-Dissolved (mg/L)	0.0329	0.0115	0.0148 ^{DLA}	
	Beryllium (Be)-Dissolved (mg/L)	<0.00050 ^{DLA}	<0.0020 ^{DLA}	<0.00050 ^{DLA}	
	Bismuth (Bi)-Dissolved (mg/L)	<0.0025 ^{DLA}	<0.010 ^{DLA}	<0.0025 ^{DLA}	
	Boron (B)-Dissolved (mg/L)	<0.050 ^{DLA}	<0.20 ^{DLA}	<0.050 ^{DLA}	
	Cadmium (Cd)-Dissolved (mg/L)	0.000141	0.00167	0.000636	
	Calcium (Ca)-Dissolved (mg/L)	555 ^{DLA}	612 ^{DLA}	596	
	Chromium (Cr)-Dissolved (mg/L)	<0.00050	<0.0020	0.00243	
	Cobalt (Co)-Dissolved (mg/L)	0.0127	0.136	0.0170	
	Copper (Cu)-Dissolved (mg/L)	0.0674	117	2.66	
	Iron (Fe)-Dissolved (mg/L)	<0.030	0.973	<0.030	
	Lead (Pb)-Dissolved (mg/L)	<0.00025 ^{DLA}	<0.0010 ^{DLA}	<0.00025 ^{DLA}	
	Lithium (Li)-Dissolved (mg/L)	0.0174	0.475	0.0136	
	Magnesium (Mg)-Dissolved (mg/L)	8.64	2.67	2.27	
	Manganese (Mn)-Dissolved (mg/L)	0.0398	0.0090	0.0307	
	Mercury (Hg)-Dissolved (mg/L)	<0.000010	<0.00010	0.000027	
	Molybdenum (Mo)-Dissolved (mg/L)	0.211	0.531	0.301	
	Nickel (Ni)-Dissolved (mg/L)	0.0037	0.125	0.0433	
	Phosphorus (P)-Dissolved (mg/L)	1.71	<0.30	<0.30	
	Potassium (K)-Dissolved (mg/L)	88.4	8.5	7.30	
	Selenium (Se)-Dissolved (mg/L)	0.0543	0.157	0.0392	
	Silicon (Si)-Dissolved (mg/L)	3.20	2.02	1.87 ^{DLA}	
	Silver (Ag)-Dissolved (mg/L)	0.000084	0.0330	<0.000050	
	Sodium (Na)-Dissolved (mg/L)	429	425	444	
	Strontium (Sr)-Dissolved (mg/L)	1.62	1.10	1.71	
	Thallium (Tl)-Dissolved (mg/L)	<0.000050 ^{DLA}	<0.00020 ^{DLA}	<0.000050 ^{DLA}	
	Tin (Sn)-Dissolved (mg/L)	<0.00050 ^{DLA}	<0.0020 ^{DLA}	<0.00050 ^{DLA}	
	Titanium (Ti)-Dissolved (mg/L)	0.012	0.013	0.013	
	Uranium (U)-Dissolved (mg/L)	<0.000050 ^{DLA}	<0.00020 ^{DLA}	<0.000050 ^{DLA}	
	Vanadium (V)-Dissolved (mg/L)	<0.0050 ^{DLA}	<0.020 ^{DLA}	<0.0050 ^{DLA}	
	Zinc (Zn)-Dissolved (mg/L)	0.026	<0.060 ^{DLA}	0.032	

* Please refer to the Reference Information section for an explanation of any qualifiers detected.

Reference Information

Qualifiers for Individual Parameters Listed:

Qualifier	Description
DLA	Detection Limit Adjusted For required dilution

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
HARDNESS-CALC-VA	Water	Hardness	APHA 2340B
Hardness (also known as Total Hardness) is calculated from the sum of Calcium and Magnesium concentrations, expressed in CaCO3 equivalents. Dissolved Calcium and Magnesium concentrations are preferentially used for the hardness calculation.			
HG-DIS-LOW-CVAFS-VA	Water	Dissolved Mercury in Water by CVAFS(Low)	EPA SW-846 3005A & EPA 245.7
This analysis is carried out using procedures adapted from "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association, and with procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 published by the United States Environmental Protection Agency (EPA). The procedures may involve preliminary sample treatment by filtration (EPA Method 3005A) and involves a cold-oxidation of the acidified sample using bromine monochloride prior to reduction of the sample with stannous chloride. Instrumental analysis is by cold vapour atomic fluorescence spectrophotometry (EPA Method 245.7).			
MET-D-CCMS-VA	Water	Dissolved Metals in Water by CRC ICPMS	APHA 3030 B&E / EPA SW-846 6020A
This analysis is carried out using procedures adapted from "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association, and with procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 published by the United States Environmental Protection Agency (EPA). The procedures may involve preliminary sample treatment by acid digestion, using hotblock, or filtration (APHA 3030B&E). Instrumental analysis is by collision cell inductively coupled plasma - mass spectrometry (modified from EPA Method 6020A).			
MET-DIS-ICP-VA	Water	Dissolved Metals in Water by ICPOES	EPA SW-846 3005A/6010B
This analysis is carried out using procedures adapted from "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association, and with procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 published by the United States Environmental Protection Agency (EPA). The procedure involves filtration (EPA Method 3005A) and analysis by inductively coupled plasma - optical emission spectrophotometry (EPA Method 6010B).			

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
VA	ALS ENVIRONMENTAL - VANCOUVER, BRITISH COLUMBIA, CANADA

Chain of Custody Numbers:

GLOSSARY OF REPORT TERMS

Surrogate - A compound that is similar in behaviour to target analyte(s), but that does not occur naturally in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery.

mg/kg - milligrams per kilogram based on dry weight of sample.

mg/kg wwt - milligrams per kilogram based on wet weight of sample.

mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight of sample.

mg/L - milligrams per litre.

< - Less than.

D.L. - The reported Detection Limit, also known as the Limit of Reporting (LOR).

N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.

UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.

Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

Carbon Absorption of Cu on Cyanide Destruction Product (Preliminary Results)										
Sample	Source Sol'n Wash Water	Diluted Sol'n To CN destr	Cyanide Destruction Tests		Bottle Roll Carbon Absorption					
			SO2/Air CND 1	SO2/Air + 6.5 mg/L Fe CND 2	CND 1			CND 2		
					5 gpl Carb	10 gpl Carb	15 gpl Carb	5 gpl Carb	10 gpl Carb	15 gpl Carb
Cyanide Spec										
CNT	243	126	4.77	10.3	0.17	0.05	0.02	<0.1	<0.1	<0.1
CNWAD	176	104	<0.1	<0.1	0.25	<0.1	<0.1	<0.1	<0.1	<0.1
CNF		41								
CNS	270	160	120	130	44	24	12	42	21	13
CNO	25	17	120	120	110	90	75	96	78	65
NH3+NH4 (N)		10.3	12.7	17.2	15.4	14.7	15.4	43.6	40	35.5
Cu	145	87.8	2.04	1.52	0.45	0.16	<0.05	0.42	0.06	<0.05
Fe	3.9	1.53	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Wash Water Treatment SART + AVR (Preliminary Results)			
Sample	Source Sol'n Wash Water	SART Sol'n pH=3 120 % Stoic	AVR Sol'n
Cyanide Spec			
CNT	243	216	42.1
CNWAD	176	156	14.3
CNF	50	219	
CNS	270	280	261
CNO	25	12	<1
NH3+NH4 (N)		15.5	16.9
Cu	145	0.38	0.5
Fe	3.9	2.2	2.78

Treatment of CND 1 solution using various methods				
Sample	Source Sol'n SO2/Air CND 1	Cyanide Destruction Tests		
		SART pH 3 120 % Stoic	FeSO4	
			10mg/L Fe	20mg/L Fe
Cyanide Spec				
CNT	4.77	<0.1		
CNWAD	<0.1	<0.1		
CNF				
CNS	120	90	99	88
CNO	120	24	130	130
NH3+NH4 (N)	12.7			
Cu	2.04	0.8	1.91	0.07
Fe	<0.05	<0.05	<0.05	<0.05

Treatment of AVR solution using various methods				
Sample	Source Sol'n AVR Sol'n	Cyanide Destruction Tests		
		Caro's acid 500 % Stoic	H2O2	
			20mg/L Cu	0mg/L Cu
Cyanide Spec				
CNT	42.1	8.82	8.44	12.6
CNWAD	14.3			
CNF				
CNS	261	<2	270	240
CNO	<1	94	30	9.3
NH3+NH4 (N)	16.9			
Cu	0.5	<0.05	15.2	0.1
Fe	2.78	1.54	<0.05	1.86

As recieved Plant Effluent						
CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe
243	176		270	25	145	3.9

Diluted With DI

SO ₂ /Air (pH 8.4, Na ₂ S ₂ O ₃ 12 g/L)								
	CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe	NH ₃ +NH ₄ as N mg/L
Feed	126			160	17	87.8	1.53	10.3
CND 1 Final Composite				120	120	2.04	< 0.05	12.7

SO ₂ /Air (pH 8.4, Na ₂ S ₂ O ₃ 13.5 g/L, FeSO ₄ 10 mg/L)								
	CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe	NH ₃ +NH ₄
Feed	126			160	17	87.8	1.53	10.3
CND 2 Final Composite				130	120	1.52	< 0.05	17.2

Bottle Roll Activated Carbon (5 g Activated carbon)								
	CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe	NH ₃ +NH ₄
Feed				120	120	2.04	< 0.05	12.7
AC 1 after SO ₂ /Air				45	120	0.27	0.08	12.2

Bottle Roll Activated Carbon (10 g Activated carbon)								
	CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe	NH ₃ +NH ₄
Feed				120	120	2.04	< 0.05	12.7
AC 2 after SO ₂ /Air				25	90	0.08	0.22	12.8

Bottle Roll Activated Carbon (15 g Activated carbon)								
	CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe	NH ₃ +NH ₄
Feed				120	120	2.04	< 0.05	12.7
AC 3 after SO ₂ /Air				16	82	<0.05	0.18	13.2

Copper analysis based on unfiltered solution in carbon adsorption tests					
	Cu	AC 2 after SO ₂ /Air	Cu	AC 3 after SO ₂ /Air	Cu
AC 1 after SO ₂ /Air					
CA-1 0.5hr Sample	50.7	CA-2 0.5hr Sample	44.2	CA-3 0.5hr Sample	28.5
CA-1 1hr Sample	54.2	CA-2 1hr Sample	46.6	CA-3 1hr Sample	37.2
CA-1 2hr Sample	33.9	CA-2 2hr Sample	37.9	CA-3 2hr Sample	26.7
CA-1 4hr Sample	38.1	CA-2 4hr Sample	29.8	CA-3 4hr Sample	21.9

SART(pH 3, 120% stoich NaSH)								
	CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe	NH ₃ +NH ₄ as N mg/L
Feed	243	176	50	270	25	145	3.9	
SART 3 final Sol'n			219	280	12	0.38	2.2	15.5

AVR (pH 2.6)								
	CN _T	CN _{WAD}	CN _F	CNS	CNO	Cu	Fe	NH ₃ +NH ₄ as N mg/L
Feed			219	280	12	0.38	2.2	
Scrubber			102					
AVR-1 Final Solution				261	< 1		2.78	16.9

CN(F) in AVR scrubber solution	
Time min	Scrubber mg/L CN
15	10
30	16
60	29
120	51
180	74
240	95
300	110
360	123
420	129
480	133
Total	102

Carbon Absorption of Cu on Cyanide Destruction Product (Preliminary Results)							
Sample	Source Sol'n Wash Water	Diluted Sol'n To CN destr	Cyanide Destruction Tests		Bottle Roll Carbon Absorption		
			SO2/Air	SO2/Air + 10 mg/L FeSO4	Sol'n after 24 hours		
					5 gpl Carb	10 gpl Carb	15 gpl Carb
CNT	243	126					
CNWAD	176						
CNF	50						
CNS	270	160	120	130	45	25	16
CNO	25	17	120	120	120	90	82
NH3+NH4 (N)		10.3	12.7	17.2	12.2	12.8	13.2
Cu	145	87.8	2.04	1.52	0.27	0.08	<0.05
Fe	3.9	1.53	<0.05	<0.05	0.08	0.22	0.18

Wash Water Treatment SART + AVR (Preliminary Results)			
Sample	Source Sol'n Wash Water	SART Sol'n pH=3 120 % Stoic	AVR Sol'n
Cyanide Spec			
CNT	243		
CNWAD	176		
CNF	50	219	
CNS	270	280	261
CNO	25	12	<1
NH3+NH4 (N)		15.5	16.9
Cu	145	0.38	
Fe	3.9	2.2	2.78

CYANIDE DESTRUCTION TEST WORK USING SO₂/AIR ON WASHED CIL LEACH PULP

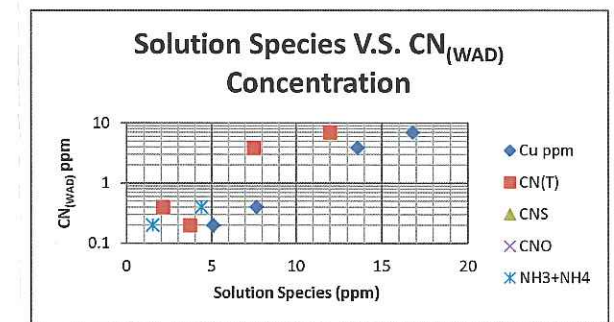
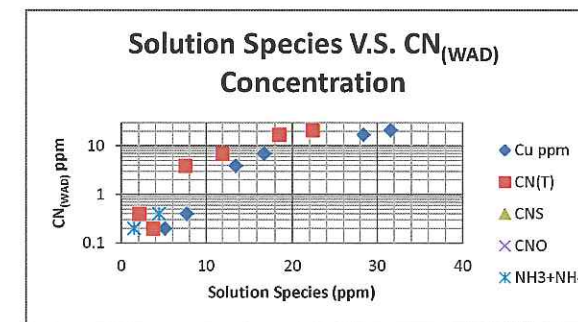
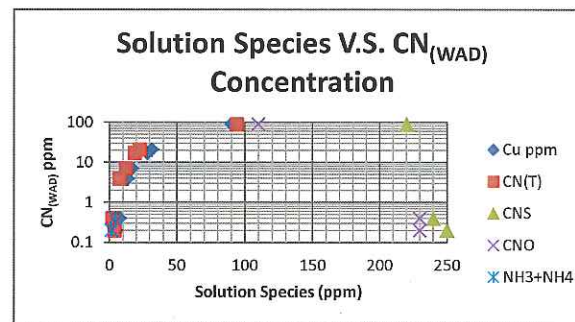
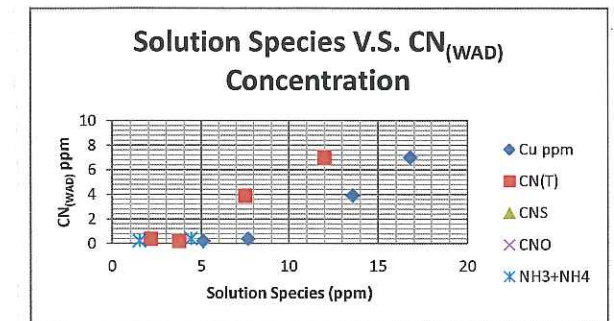
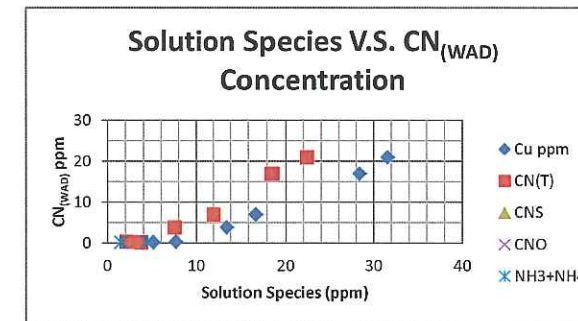
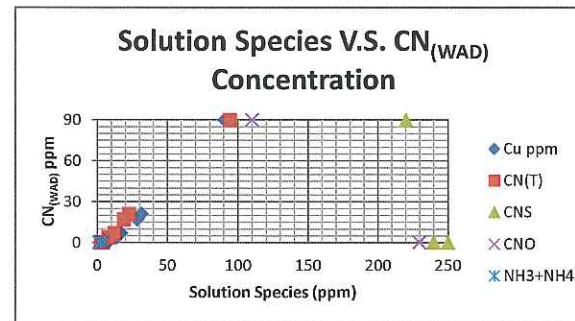
	Density %S	Retention Min	Composition (Solution Phase)								Reagent Addition						
			pH	CN _(T) ppm	CN _(WAD) ppm	CNO ppm	CNS ppm	NH ₃ +NH ₄ as N ppm	Cu ppm	Fe ppm	SO ₄ ppm	SO ₂ Eq.	Lime g/g CN _(WAD)	H ₂ SO ₄	Cu		
Feed Solution (Washed Pulp)	50		10.7	94	90	110	220										
CND2	50	86	9.8	22.4	21								4.33				
CND3	50	67	9.8	18.5	17								5.42				
CND4	50	72	8.9	7.5	3.9								6.01		16		
CND5	50	67	8.6	12	7								4.49		24.8		
CND6	50	58	9.6	3.7	0.2	230	250	1.5	5.12	0.89	2100		5.16				0.14
CND7	50	57	9.7	2.1	0.4	230	240	4.4	7.7	0.9	2800		4.03				0.14

From SGS Test Program KSM Project 12157-001

CN _(WAD)	CN _(T)	CNS	CNO	NH ₃ +NH ₄	Cu
90	94	220	110	0	90.4
21	22.4	0	0	0	31.6
17	18.5	0	0	0	28.4
3.9	7.5	0	0	0	13.6
7	12	0	0	0	16.8
0.2	3.7	250	230	1.5	5.12
0.4	2.1	240	230	4.4	7.7

CN _(WAD)	CNS	CNO
90	220	110
0.2	250	230
0.4	240	230

CN _(WAD)	NH ₃ +NH ₄
0.2	1.5
0.4	4.4

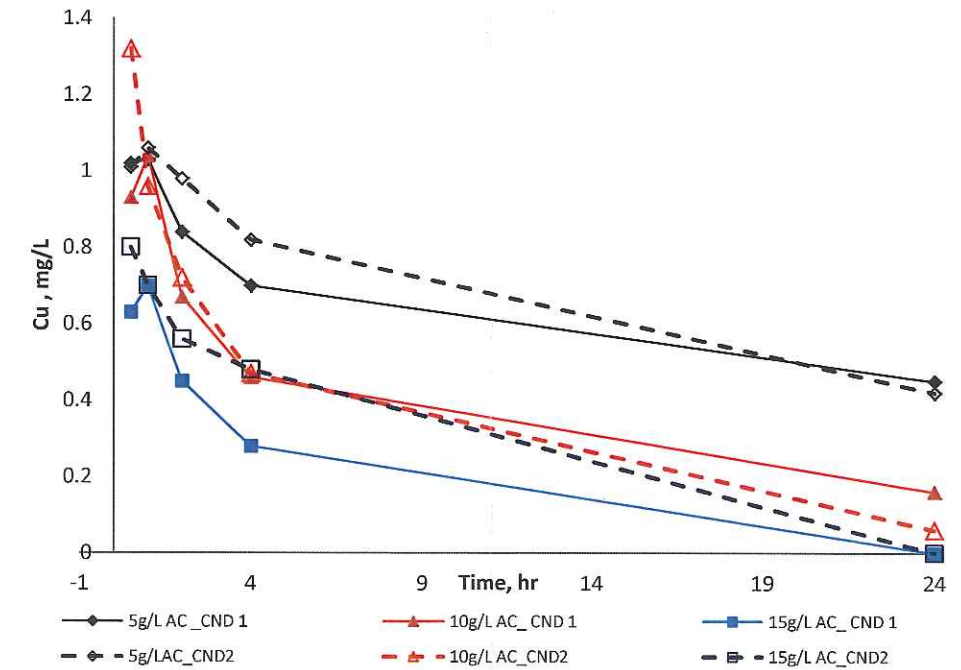


Carbon Absorption of Cu on Cyanide Destruction Product (Preliminary Results)										
Sample	Source Sol'n Wash Water	Diluted Sol'n To CN destr	Cyanide Destruction Tests		Bottle Roll Carbon Absorption					
			SO2/Air CND 1	SO2/Air + 10mg/L Fe CND 2	CND 1			CND 2		
					5 gpl Carb	10 gpl Carb	15 gpl Carb	5 gpl Carb	10 gpl Carb	15 gpl Carb
Cyanide Spec										
CNT	243	126	4.77	10.3				<0.1	<0.1	<0.1
CNWAD	176	104	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1
CNF		41								
CNS	270	160	120	130	44	24	12	42	21	13
CNO	25	17	120	120	110	90	75	96	78	65
NH3+NH4 (N)		10.3	12.7	17.2				43.6	40	35.5
Cu	145	87.8	2.04	1.52	0.45	0.16	<0.05	0.42	0.06	<0.05
Fe	3.9	1.53	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Wash Water Treatment SART + AVR (Preliminary Results)			
Sample	Source Sol'n Wash Water	SART Sol'n pH=3	AVR Sol'n
Cyanide Spec		120 % Stoic	
CNT	243	216	42.1
CNWAD	176	156	14.3
CNF	50	219	
CNS	270	280	261
CNO	25	12	<1
NH3+NH4 (N)		15.5	16.9
Cu	145	0.38	0.5
Fe	3.9	2.2	2.78

Treatment of CND 1 solution using various methods				
Sample	Source Sol'n SO2/Air CND 1	Cyanide Destruction Tests		
		SART pH 3 120 % Stoic	FeSO4	
			10mg/L Fe	20mg/L Fe
Cyanide Spec				
CNT	4.77	<0.1		
CNWAD	<0.1	<0.1		
CNF				
CNS	120	90	99	88
CNO	120	24	130	130
NH3+NH4 (N)	12.7			
Cu	2.04	0.8	1.91	0.07
Fe	<0.05	<0.05	<0.05	<0.05

Treatment of AVR solution using various methods				
Sample	Source Sol'n AVR Sol'n	Caro's acid 500 % Stoic	H2O2	
			20mg/L Cu	0mg/L Cu
			Cyanide Spec	
CNT	42.1			
CNWAD	14.3			
CNF				
CNS	261			
CNO	<1			
NH3+NH4 (N)	16.9			
Cu	0.5	<0.05	15.2	0.1
Fe	2.78	1.54	<0.05	1.86



CYANIDE DESTRUCTION TEST WORK USING H₂O₂

	Density %S	Retention Min	Composition (Solution Phase)									Reagent Addition			
			pH	EMF mV	CN _(T) ppm	CN _(WAD) ppm	CNO ppm	CNS ppm	NH ₃ +NH ₄ as N ppm	Cu ppm	Fe ppm	SO ₄ ppm	H ₂ O ₂ % Stoic	H ₂ O ₂ g/g CN _(WAD)	Cu
Feed Solution (Washed Pulp)	50		10.7	23	94	90	110	220		90.4	1.08	960			
H1	50	90	10.1		22.4	12	11			15.3			500	6.5	
SO ₂ /Air CND7 Pulp	50		9.9	96	10	10				16.6	0.96				
H2	50	90	9.9	111	6.1	5.9				6.84	0.92		500	6.6	
H3	50	90	9.9	115	5.2	4.3				5.81	0.8		500	6.6	1.5
H7	50	60	9.9	126	2	0.1				3.48			1000	13	1.5
SO ₂ /Air CND7 Solution			9.9	96	10	10				16.6	0.96				
H2		60	8.7	291	1.6	0.4				2.11	0.38		500	6.5	
H3		30	8.6	366	1.4	0.4				2.73	0.4		750	9.8	
H7		30	8.8	263	0.8	0.3				2.63	0.17		1000	13.1	