

April 11, 1996

Royal Oak Mines Inc.
Giant Mine
Yellowknife, NWT
X1A 2M2

Attention: Mr. Eric Madsen
Superintendent

Dear Sir:

Re: Giant Mine

Attached are three copies of the test work report on treatment of Giant Mine pond water using the INCO SO_2/AIR cyanide destruction process.

Results indicate that an $\text{SO}_2/\text{CN}_{\text{WAD}}$ ratio of 3.5 g/g is sufficient and that no copper addition is required. Potential reagent cost savings over the use of H_2O_2 and copper sulphate are therefore available. The actual cost of $\text{Na}_2\text{S}_2\text{O}_5$ (sodium metabisulphite), delivered on site is unknown, but we can estimate a delivered cost of \$950 Cdn per metric tonne, or \$0.43 per lb. At 3.5 g $\text{SO}_2/\text{g CN}_{\text{WAD}}$, the cost per lb CN_{WAD} destroyed would be \$2.26. Based on the information that you provided regarding H_2O_2 costs (\$0.64/lb, 100%) and consumption, we calculate the cost per lb CN_{WAD} destroyed by H_2O_2 to be \$2.56. This shows a potential cost savings in oxidant reagent alone of \$0.30/lb CN_{WAD} destroyed.

Currently we cannot accurately estimate the amount of copper sulphate used during the 1994-95 treatment period utilising the hydrogen peroxide system. Based on roughly calculated dosages of 2-5 mg/L Cu^{2+} addition, we calculate a copper sulphate consumption of 15 to 40 tons/year. At \$1200 to \$1400/ton CuSO_4 , a cost of \$20,000 to \$50,000 per year would be incurred. Based on results from the attached laboratory test work report these savings would be realized if the INCO SO_2/AIR process was implemented. This combined with oxidant savings could be substantial.

Your present H_2O_2 treatment system can be retrofitted for use as an INCO SO_2/AIR system with very few modifications. The additional components would include a small blower plus air delivery lines and a suitable sparger apparatus. These are required only in Tank #1. The cost for such capital items would be quickly amortized by the operating cost savings. Estimated licensing costs, for use of the Inco process at Giant, would be approximately \$10,000 per year, which also is more than justified by the savings.

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Mr. Eric Madsen
April 11, 1996
Page 2

If after your review of the preliminary laboratory test results you confirm that the potential savings are attractive, Inco would be pleased to assist the Giant Mine with a plant trial using your present system as well as to provide technical services for the design and implementation of a permanent INCO SO₂/AIR facility.

Thank you very much for your interest in the Inco technology. If we can be of any further assistance, please do not hesitate to contact us.

Yours truly,



Dr. E.A. Devuyt
Manager, Technical Sales and Service

EAD/cm

xc: P.F. Iamarino
G.H. Robbins

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**LABORATORY EVALUATION OF
THE INCO SO₂/AIR PROCESS
FOR POND WATER TREATMENT
AT THE GIANT MINE
"ROYAL OAK"**

INCO LIMITED

April 12, 1996

TABLE OF CONTENTS

	PAGE
1. SUMMARY	1
2. INTRODUCTION	2
3. EXPERIMENTAL PROCEDURES	3
3.1 Laboratory Set Up	3
3.2 Test Procedures	3
3.3 Analytical Procedures	4
4. TEST RESULTS	5
4.1 SO ₂ Dosage	5
4.2 Retention Time	5
4.3 pH	5
4.4 Cu ⁺⁺ Addition	5
4.5 Temperature	6
4.6 Aging	6
5. CONCLUSIONS	7
APPENDIX	
Figure 1 Laboratory Two Stage Continuous Set-up	8

1. SUMMARY

The INCO SO₂/AIR cyanide removal process was successful in achieving the desired residual cyanide and base metals when treating the Giant Mine pond water in a two stage continuous mode, providing 30 minutes retention time per stage at pH 8.5.

An SO₂ dosage of 3.5 to 4.0 g SO₂ per g CN_{WAD} was sufficient to meet the target residual (CN_{WAD}) of less than 1.0 mg/L in the pond water.

Copper addition was not needed for catalytic activity and effective precipitation of the iron cyanide in solution as copper ferrocyanide, thus meeting the required residual total cyanide (CN_T) limits.

Ferric sulphate addition to the second stage at a ratio of ~3 Fe³⁺/As in solution effectively precipitated the arsenic as ferric arsenate and scavenged all base metal precipitates as post reaction occurred.

Significant post reaction occurred when the treated solution was allowed to stand for several hours open to the atmosphere and in the presence of solids. Samples were aged at low temperature.

Typical treatment results are summarized below.

Stream	pH	Assays (mg/L)					SO ₂ Dosage (g/g CN _{WAD})	Fe ³⁺ Dosage (mg/L)	Fe ³⁺ Ratio (g/g As)	Treatment Temp. (°C)
		CN _T	Cu	Fe	Ni	As				
Pond Water Feed	8.1	28.0	14.0	1.9	1.4	14.5	-	-	-	-
Treated Solution	8.5	0.3	0.1	<0.1	0.2	-	4.2	65.8*	4.4*	6
Aged, 21 hrs.	8.3	0.1	<0.1	<0.1	0.1	<0.1	-	-	-	10
Treated Solution	8.5	1.6	2.8	0.1	<0.1	-	3.0	60.2*	4.0*	11
Aged, 18 hrs	8.3	0.1	0.4	<0.1	0.2	<0.1	-	-	-	10
Treated Solution	6.7	0.4	0.4	0.1	0.2	<0.1	3.6	48.2**	3.2**	10

* Arsenic assumed to be 20 mg/L in the feed.

** Arsenic analysis in feed = 14.5 mg/L

CN_T ?

2. INTRODUCTION

The purpose of the test work was to evaluate the performance of the INCO SO_2/AIR process in the treatment of Giant's pond water, for comparison with the current hydrogen peroxide treatment system.

The main objective was to determine the required retention time, treatment pH, and reagent consumptions, to achieve less than 1.0 mg/L total cyanide (CN_T) in the pond solution.

Pond water was obtained by drilling through the ice near the discharge point. A total of 40 litres were retrieved and stored in two 20 litre containers. Solution assays indicated that the sample was homogeneous and each container representative.

The INCO SO_2/AIR cyanide removal process oxidizes cyanide (CN^-) to cyanate (OCN^-). It uses a mixture of SO_2 and O_2 as the oxidizing agent in the presence of soluble copper which acts as a catalyst. The O_2 is usually obtained from air addition, and the copper required is often present in the feed as a copper cyanide complex or added as a solution of copper sulphate. All weak-acid dissociable cyanide (CN_{WAD}), which includes free cyanide, zinc cyanide, copper cyanide, and nickel cyanide are converted to OCN^- . The metals once freed of cyanide are precipitated as metal hydroxides. The strong iron cyanide complex is precipitated as an insoluble metal ferrocyanide salt. In addition, a minor amount of thiocyanate (SCN^-) and other thio-species ($\text{S}_2\text{O}_3^{2-}$) are oxidized. The SO_2 added is converted to SO_4^{2-} during the oxidation process. It is precipitated as calcium sulphate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), with the calcium present in the feed and from the lime that is added for pH control.

3. EXPERIMENTAL PROCEDURES

3.1 Laboratory Set Up

The cyanide destruction experimental set up was comprised of two reactor vessels (overflowing at 0.80 L). The cyanide destruction reactor (stage 1) was equipped with a 46 mm diameter Rushton turbine, an inlet tube for air, baffles, a pH probe, a specific ion electrode for free cyanide, and a dissolved oxygen probe. The discharge outlet was equipped with a small mix box over flowing into the second reactor. The arsenic removal reactor (stage 2) was equipped with mild agitation and a pH control system (Figure 1).

In addition, reagent reservoirs were required for sodium metabisulphite solution ($\text{Na}_2\text{S}_2\text{O}_5$), ferric sulphate solution and calcium hydroxide suspension ($\text{Ca}(\text{OH})_2$). Larger holding reservoirs were used for the feed and treated effluent. The air flow during treatment was controlled with a needle valve and monitored with a rotameter.

3.2 Test Procedures

Similar to Colomac, solution treatment required an initial batch test to lower the CN_{wAD} to below 1 mg/L and to establish the catalyst.

The treated solution obtained from the batch test was used as the starting material for continuous treatment. In all the subsequent tests, the treated solution remaining in the reactor was the starting material for the next experiment.

The feed was metered with a peristaltic pump at the desired rate into the reaction vessel. The desired amount of sulphur dioxide (SO_2) was added as an aqueous solution of $\text{Na}_2\text{S}_2\text{O}_5$. The reactor 1 agitator was operated at 800 rpm. Air was added at a rate of 1.0 L/min as required to maintain the dissolved oxygen in the desired range. The oxidation of cyanide was monitored with a cyanide sensing electrode. The reactor 2 agitator was operated at 300 rpm. The ferric solution was metered at the desired rate into

the reaction vessel and pH was controlled with $\text{Ca}(\text{OH})_2$ suspension.

Samples of treated solution were aged for approximately 1 to 21 hours in the presence of the solids and open to the air at 10°C .

3.3 Analytical Procedures

Three to six reactor replacements were carried out before taking representative samples of treated solution. The solution was filtered and immediately processed through the spectrophotometric determination of cyanide (CN_p) using the buffered picric acid method by Inco personnel.

Filtrates were also analyzed by AA for copper (Cu), iron (Fe), nickel (Ni) and arsenic (As). All base metal analyses were conducted by Inco personnel using the available AA instrument at the Giant Mine. Treated pond water was brought back to the Inco facility where arsenic was analyzed by ICP.

Note: The cyanide determination by the picric acid method (CN_p) includes all cyanide except that complexed with iron in solution. Therefore, CN_p is greater than or equal to CN_{wAD} (weak acid dissociable cyanide) and is used interchangeably in this report. The total cyanide (CN_T) can be accurately estimated by the formula: $\text{CN}_T = \text{CN}_p + 2.795 \times \text{Fe (mg/L)}$. Where little or no iron is found in the treated solution it can be assumed that the CN_{wAD} is equal to the CN_T .

4. TEST RESULTS

Continuous flow cyanide removal tests were started after an initial batch treatment. All solution treatment tests described herein were carried out in two stage continuous flow reactors.

4.1 SO₂ Dosage

The SO₂ dosage was varied between 3.0 and 4.2 g SO₂/g of CN_{WAD} in the feed. A total of 3 tests were carried out on the pond solution. Excellent CN_{WAD} results were achieved using 3.5 and 4 g SO₂ per g CN_{WAD}. In addition aging the treated solution further decreased both the residual cyanide and base metals (copper, iron and nickel). The results are illustrated in the summary table.

4.2 Retention Time

A 30 minutes retention time per stage was found to be sufficient for the scoping tests.

4.3 pH

The pH in reactor 1 was varied from 6.7 to 8.5 during the treatment while the pH in reactor 2 was kept constant at pH 8.5 to 8.7. The tests results show that the CN_{WAD} can be effectively removed in a wide pH range in reactor 1 when aided by the implementation of the second stage for arsenic removal with ferric sulphate.

4.4 Cu⁺⁺ Addition

Copper addition was not required when treating Giant pond water. Results clearly indicate that currently sufficient copper is present in solution to satisfy both catalytic cyanide oxidation and iron cyanide precipitation.

4.5 Temperature

Treatment tests were conducted at low to medium temperatures (6-11°C) to evaluate the process performance. This temperature range does not seem to have any adverse affect on cyanide, base metals, and arsenic removal when treating Giant cold pond water at a retention time of 30 minutes.

4.6 Aging

Aging tests were carried out on the treated pond solution by allowing samples to stand for up to 21 hours in the presence of solids and open to the air at 10°C.

After aging, a portion of the supernatant solution was filtered and reanalysed for CN_{WAD} , Cu, Fe and Ni. The results show that further decrease of cyanide, copper and iron was obtained in all cases after aging. It was noted that the pH of the aged solution only marginally decreased.

5. CONCLUSIONS

1. The INCO SO₂/AIR Cyanide Removal Process was successful in obtaining the desired CN_{WAD} and CN_T concentration of less than 1.0 mg/L when treating Giant's pond water, on a laboratory scale. The desired solution quality was obtained when the discharged effluent was allowed to age for as little as 1 hour.
2. An SO₂ dosage of 3.5 to 4 g/g CN_{WAD} was sufficient to achieve a residual CN_{WAD} of under 1.0 mg/L in the treated solution at the reactor discharge.
3. A suitable operating pH range in reactor 1 is 7.0 to 8.5. A pH of 8.5 is preferred for reactor 2 for obtaining minimum residual CN_{WAD}, Cu, Ni, Fe and As consistently.
4. Based on current feed copper values in solution, further copper addition is not necessary during treatment. A ratio of ~2.3 Cu²⁺/Fe is required to reduce CN_T levels to desired limits. If copper and iron levels or their respective ratio remain the same for the duration of the treatment, copper will not be needed. A small amount of solid copper sulphate may be required for batching if the INCO SO₂/AIR process required shutting down due to mechanical problems.
5. The CN_{WAD}, copper, nickel, and iron concentrations notably decreased upon aging.
6. Treatment at cold temperature (6-10°C) did not present a problem in achieving consistent results within the required limits.

Note: The above laboratory results demonstrate the effectiveness of the Inco Process. Inco will provide assistance in selecting plant scale equipment to ensure successful scale-up of the process results. Do not use the above results for a one to one scale-up to plant size.

Figure 1
Laboratory Two Stage Continuous Set-up