Biological Toxicity Treatment Evaluation of a Gold Mine Effluent

James Whitlock: Whitlock and Associates, Biotechnology
315 Canyon View Lane Spearfish, SD USA 57783

Louise Grondin: Agnico-Eagle Mines Laronde Mine
Cadillac, Quebec, Canada J0Y 1C0

Richard Wagner and Liangxue Liu: Lakefield Research Ltd.
185 Concession St. Lakefield Ontario, Canada K0L 2H0

Abstract
An initial toxicity identification evaluation (TIE) protocol determined that ammonia, nitrite, cyanide, thiocyanate, cyanate, dissolved organic carbon, copper and zinc were possible toxicants in the gold mining wastewater effluent. A biological column treatment option (biofilter) is evaluated to determine the amenability of the wastewater to biological treatment options and process performance. Biological treatment is expected to provide reduced treatment costs as compared with other tested technologies.

Introduction

Agnico-Eagle Mines and Lakefield Research had evaluated a number of treatment tests, both chemical and physical to remove the toxic parameters from the Laronde site wastewaters. A decision was made to evaluate the process efficiency and potential cost saving of biological mine effluent treatment.

Biological treatment is capable of degrading high concentrations of thiocyanate and most chemical processes, with the exception of alkaline chlorination, are less efficient or incapable.

Whitlock and Associates were retained to design a program to test the amenability, process performance and cost effectiveness of biological treatment of the various Laronde potential wastewaters. Jim Whitlock, was a co-developer of the biological treatment plant at the Homestake Mine in South Dakota, and has more than 20 years experience with biological treatment of mining effluents. The Homestake plant treats more than 1000 cubic meters/hour of mine effluents, utilizing Rotating Biological Contactors (RBC's) and discharges directly into a trout fishery. Lakefield Research was selected to house and operate the biological treatment pilot test evaluation and correlate the results with other chemical/physical processes that they had evaluated for Agnico-Eagle.

Biological treatment of mining effluents has been demonstrated effectively with aerobic attached growth and suspended growth systems as well as anaerobic systems. An aerobic system was selected due to the high thiocyanate concentrations in the Laronde wastewaters. Anaerobic systems are not effective in thiocyanate removal.

A column biofilter process with attached biological growth was selected to test the amenability of the Laronde effluent to biological treatment. The biofilter pilot concept was selected for ease of construction, operation and correlation of results to other potential biological treatment technologies.

Biological Treatment Concepts

A number of different types of bacteria, indigenous to most mine sites, are capable of degrading or otherwise tolerating the toxic components found in mining wastewaters. This process involves the degradation of cyanide, metal complexed cyanide, thiocyanate, cyanate and the nitrification of ammonia to an intermediate nitrite and on to nitrate. Heavy metal toxicity is reduced by adsorptive and absorptive mechanisms at the cell wall of bacteria. End products of these degradations or oxidations are carbonate, sulfate, and nitrate with the associated removal of metals.

Bacteria which are commonly involved include *Pseudomonas, Alcaligenes, Achromobacter, Flavobacterium, Nitrosomonas, Nitrobacter* and others.

The bacteria involved are predominantly autotrophic (utilize inorganic carbon such as carbon dioxide as a carbon source) although some heterotrophic bacteria (utilize organic carbon as a carbon source) are also involved in the process.

Effective biological treatment is predicated on the provision of near optimum conditions for the growth and function of these bacteria (biomass). An attached growth system must provide sufficient surface area for attachment of the biomass and contact with the wastewater. A suspended growth system needs to maintain adequate biomass in suspension to accomplish the biological treatment and not allow end products to build up to the point that they inhibit the process.

The bacteria involved operate in a pH range of about 6.5 to 9.5 with an optimum of about 7.8-8.2 and at a temperature range of 10-30 degrees C with optimum above 16 degrees C. Nutrients and other requirements of the bacteria include Carbon, Hydrogen, Nitrogen, Sulfur, Oxygen, Potassium, Calcium, Magnesium, trace metals and vitamins.

In general terms, a living biological treatment system will produce an effluent that is compatible with other living systems in the discharge environment such as a receiving stream. Treatment efficiencies generally improve over time as the biomass acclimates to the wastewater and the resistance to upset conditions is amplified.

Biological Reactions

1. $NaCN + 2H_2O + ½ O_2 + \text{Bacteria} \rightarrow NaHCO_3 + NH_3$
2. $NaSCN + 2H_2O + NaOH + 5/2\ O_2 + \text{bacteria} \rightarrow NaHSO_4 + NaHCO_3 + NH_3$

Note: metal (M+) may be substituted for Na. Per gram of SCN degraded, 0.34 g of ammonia will be produced and 1.1 g of oxygen consumed with little alkalinity consumption and little change in pH

3. $NH_4+ + 1.5\ O_2 \rightarrow 2H+ + 2H_2O + NO_{2-}$
4. $NO_2- + 0.5\ O_2 \rightarrow NO_{3-}$

* Where nitrite is an unstable intermediate that is further oxidized to nitrate or reduced to nitrogen gas.

Note: one gram of ammonia requires 7.2 grams of alkalinity as calcium carbonate to convert to nitrate and consumes 1.2-3.2 grams of oxygen with optimum pH of 7.8 to 8.5. Does not proceed below pH 7.0

5. Alkalinity consumption reaction:

$2\ NH_4HCO_3 + 4O_2 + Ca(HCO_3)_2 \rightarrow Ca(NO_3)_2 + 4CO_2 + 6\ H_2O$

pH 6.5-7.5

6. Nitrate reduction

$6NO_3 + 5CH_3OH \rightarrow 5CO_2 + 3N_2 + 7H_2O + 6\ OH-$

3.5 grams of alkalinity as calcium carbonate is produced per gram of nitrate reduced.

Pilot Test Program

The column test consisted of three columns of 12 inch diameter and twelve foot height packed with limestone rock media (3/8 to3/4 inch size) to support the attachment of the biomass. Aerobic columns 1 and 2 were connected in series and fed the influent wastewater from the top with supplemental air fed countercurrent. Column 3 (anaerobic) was fed the effluent from column 2 in an up-flow mode with alcohol addition to maintain a reducing environment.

Columns 1 and 2 were designed to oxidize or remove thiocyanate, cyanide, cyanate, metals and promote nitrification of ammonia to nitrate. Column 3 was utilized to reduce nitrate to nitrogen gas. Staging of the columns in series allows for some measure of separation between the different biological reactions that are proceeding in the system.

Whitlock and Associates identified the bacteria in the Laronde wastewater and prepared a "seed source" of grown up bacteria from the wastewater to inoculate the columns for start-up of the process. Nutrients were added to the wastewater and conditions optimized in the columns.

Conclusions

The results of acute toxicity tests for all column final effluent discharges demonstrated non-toxic results for *Daphnia magna* and rainbow trout. These test results confirm that biological treatment of the Laronde wastewaters removed the toxicity from the final effluent.

A summary of the data for influent feed and effluent discharge is presented in Table 1.

Peak rates for degradation or removal are as follows:

1. Columns 1 and 2 degraded total cyanide at a peak rate of 296 and 134 mg/sq.ft./day respectively.
2. Columns 1 and 2 degraded cyanate at a peak rate of 223 and 124 mg/sq.ft./day, respectively.
3. Columns 1 and 2 degraded thiocyanate at peak rates of 1426 and 3581 mg/sq.ft./day respectively.
4. Columns 1 and 2 nitrified ammonia at peak rates of 303 and 746 mg/sq.ft./day respectively.
5. Denitrification in Column 3 occurred at a peak rate of 2180 mg/sq.ft./day.

A third stage aerobic column could have been added to further polish the removal of target parameters.

Table 1

		CN mg/L	CNS mg/L	CNO mg/L	NH3 mg/L	NO3 mg/L	CN Cum. % Removed	CNS Cum.% Removed	CNO Cum.% Removed	NH3 Cum.% Removed	NO3 Cum. % Removed
FINAL EFFLUENT											
12/17/01	Feed 1	-	119	16	37.6	9.9	-	-	-	-	-
12/19/01	Discharge 1	-	<2	<1	<0.1	60.1	-	>99	>93	>99	-
TAILINGS WATER											
5/29/02	Feed 1	42.8	600	26	78.7	27.5	-	-	-	-	-
5/29/02	Discharge 1	12	430	<10	95.6	45.5	72	28	>61.5	-	-
5/29/02	Discharge 2	0.11	32	<10	56.2	177	99.7	94.7	>61.5	28.6	-
5/29/02	Discharge 3	0.03	-	-	9.3	2.3	>99.9	-	-	88.2	91.6