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Pilot Treatment of Bell Mine Drainage

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ABSTRACT

Glencore's Bell Mine is a closed copper mine near Granisle, British Columbia. The mine ceased production in 1992 and is in a state of care and maintenance. The water collected on-site is directed to the open pit, which has been slowly filling with water since mining ceased. The water level within the pit is expected to continue to rise and will require treatment before it can be discharged to the environment.

AMEC conducted a three-week pilot campaign at the Bell Mine in August 2012 using the High Density Sludge (HDS) process. The objectives of the pilot plant testing were to confirm the validity of the water treatment plans as presented in the 1992 Closure Plan, verify the water treatability, and define the design parameters for the full scale plant.

The Bell Mine pilot campaign proved that the Bell pit water can be successfully treated to meet Canadian Metal Mining Effluent Regulations (MMER). By applying the HDS process, it was possible to bring the sludge solids content to more than 20% solids. Pilot testing provided detailed information concerning lime consumption, flocculant consumption, sludge production, raw water and effluent quality, and sludge properties. The sludge produced from the pilot testing was shown to be stable. The information collected during this pilot campaign is currently being used for the detailed engineering design of a full-scale treatment plant. It is expected that the full-scale HDS plant will be capable of reproducing the results from this pilot campaign. The expected effluent metal concentrations from a properly designed HDS plant, contingent on good operating practices, are equal to, or less than, half the limits from the Canadian MMER.

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INTRODUCTION

Bell Mine is a decommissioned open pit copper mine located in north-central British Columbia near Granisle on Newman Peninsula in Babine Lake. It is currently owned by Glencore Canada Corporation. The mine operated from 1972 until closure in 1992, most of the infrastructure on-site has been removed, and the mine is in a state of care and maintenance. The water collected on-site is directed to the open pit, which has been slowly filling with water since mining ceased. The level within the pit is expected to continue to rise and the water will require treatment to remove metals before it can be discharged to the adjacent Babine Lake. Glencore requested that AMEC perform an assessment of the treatability of the mine drainage with an on-site pilot plant following successful bench scale neutralisation tests. This paper provides the results from the pilot plant tests and recommendations currently being used for the detailed design of a full-scale plant.

The objectives of the pilot plant tests were to confirm the validity of existing water treatment plans, verify the water treatability, and confirm the design parameters for the full scale plant. The High Density Sludge (HDS) process using lime neutralisation was chosen as it is accepted as a best available technology for treatment of dissolved metals in mine drainage (Aubé and Zinck, 2003; Aubé and Zinck, 1999). It has been shown in the past that properly designed pilot plants can effectively represent full-scale treatment of mine drainage (Aubé, 2004; Aubé, 1999; Aubé and Payant, 1997). Testing conducted during the pilot plant operation provided detailed information concerning lime consumption, flocculant consumption, sludge production, raw water and effluent quality, and sludge properties. This information was required for the detailed engineering design of a full-scale treatment facility as well as for permitting purposes.

The pilot plant effluent results were to be compared to the Canadian Metal Mining Effluent Regulations (MMER – Canada, 2014) as this regulation will need to be met as a minimum. To determine attainable dissolved concentrations, filtered samples were analysed to low detection limits for metal concentrations and these results are detailed in the report.

PILOT PLANT SETUP

The mobile pilot plant is built inside a 40-foot maritime container. The main section contains interchangeable reactors, pH controllers, various pumps, and a clarifier. All units are modular and can be arranged to simulate a variety of different processes. The plant was operated on-site continuously from August 10th through 31st, 2012, with personnel on-site 24 hours per day. Figure 1 shows the interior of the pilot plant as well as the pilot plant exterior with a raw water tanker truck as operated at Bell Mine.

A constant feed of pit water was provided via a tanker truck that was driven to the pilot plant. Two trucks were filled at start-up, one had an aluminum tank and the second had a steel tank. The primary feed truck tank was aluminum. It took about three days for the pilot plant to consume that first truckload. Once that first truck was drained, the steel tanker was used from August 13 to 17. Unfortunately, being in a steel tank for 3 days affected the pit water quality. It is recognized that the aluminum tank could also have affected the mine drainage quality, but since the concentrations of aluminum in the drainage are already high (>13 mg/L), a slight potential increase in aluminum was deemed acceptable. The effect of the steel tank is discussed in the results. After this single batch, only the aluminum tanker was used.

Figure 1 Pilot plant interior and exterior with raw water truck on site at Bell Mine

Pilot Testing Process

The HDS process as applied during the pilot operation is shown in Figure 2. Recycled sludge from the clarifier and lime slurry were pumped to the Lime/Sludge Mix Tank. The recycle sludge rate ranged from 80 to 200 mL/min. Reactor 1 (R1) received the raw water feed, the lime/sludge mixture, and air. The raw water feed rate for all tests was 2 L/min. Reactor 1 overflowed into Reactor 2 (R2), which was also aerated. Each reactor had a retention time of 30 minutes (60 L volume), for a total retention time of 60 minutes. The Floc Tank received the flocculant and the slurry pumped from R2. The retention time in the Floc Tank ranged from 1 to 3.3 minutes, with a flocculant dosage of 2.0 to 2.5 mg/L. The slurry from the Floc Tank overflowed to a clarifier of 1.65 m height and 0.50 m diameter, with a retention time of 2.6 hours. A bag filter followed the clarifier overflow. A 5 µm filter was used until day 8, when it was changed for a 1 µm filter for the rest of the campaign. The filter bags were backwashed periodically. Bag filtration is used here to reproduce the results expected from sand filtration in a full-scale treatment plant.

Laboratory grade hydrated lime ($Ca(OH)_2$) was used to produce a 5% lime slurry. The slurry was fed to the lime-sludge mix tank based on a pH set point in R1. For flocculation, a 0.05% solution of Magnafloc 1011 was used for the entire pilot campaign.

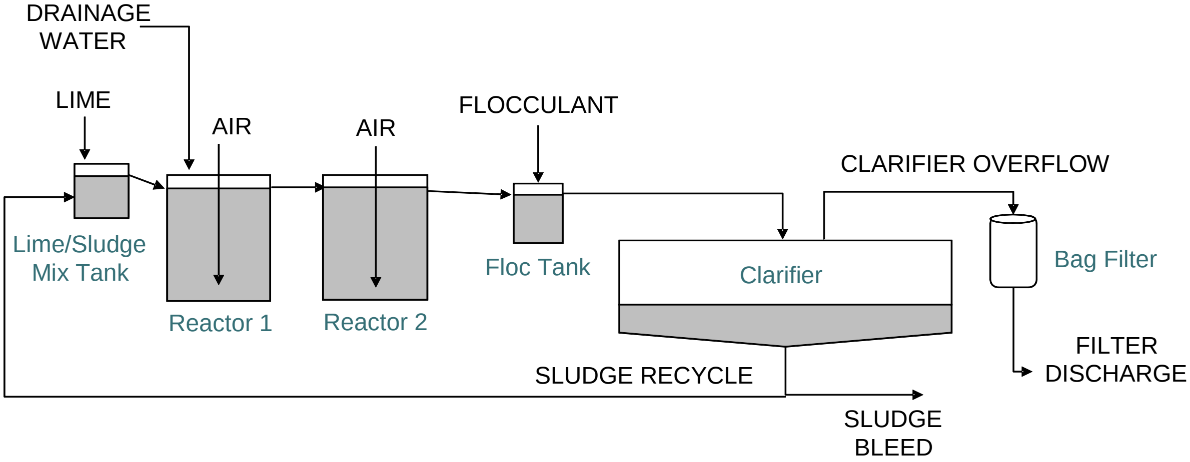

Figure 2 Process applied during pilot campaign

During pilot operation, the raw water, reactor slurries, reagents, sludge, clarifier overflow, and filter bag discharge were monitored on-site for the following parameters: flowrates, tank levels, pH, turbidity, temperature, conductivity, redox, dissolved oxygen, reactor and sludge solid contents, and total suspended solids (TSS). Water samples were collected regularly for total and dissolved chemical analyses which were completed by an external certified analytical laboratory.

Raw Water Feed

A summary of the raw water quality measured over the duration of the pilot campaign is shown in Table 1. All parameters in the pit water for the pilot tests were representative of previous pit water samples with the exception of the water from the steel tank for days 3 to 7. For this duration, the dissolved iron concentration was 4.7 mg/L, which is 2.2 mg/L higher than the average. This water also had a higher turbidity and is believed to have affected the effluent quality.

Table 1 Raw water quality

Parameter	MMER	Raw Water for August 2012 Pilot Testing Dissolved Average	Raw Water for August 2012 Pilot Testing Total Average
pH	6.0-9.5	-	4.4
Hardness (mg/L)	-	2973	2980
Aluminum (mg/L)	-	23	23
Cadmium (µg/L)	-	7.6	7.6
Calcium (mg/L)	-	360	360
Copper (mg/L)	0.3	8.0	8.0
Iron (mg/L)	-	2.5	4.2
Magnesium (mg/L)	-	504	505
Manganese (mg/L)	-	8.1	8.1
Nickel (mg/L)	0.5	0.39	0.39
Sulphate (SO4) (mg/L)	-	2970	2980
Zinc (mg/L)	0.5	1.2	1.2

The raw water did not meet MMER discharge quality for pH, Cu, and Zn concentrations. Ni concentrations were close to MMER discharge quality. Other parameters are not included in the table as they were well below regulated discharge limits. The main parameter requiring treatment – the most elevated as compared to the limit – was Cu. This is the parameter used to evaluate the treatment efficiency in the following sections.

Pilot Results

Two pilot tests were completed and are summarised in Table 2. The main differences between the two tests are the reactor pH set point and test duration. A pH of 9.5 was used for Test 1 and it was run for 18 days. Changes were made during the test to optimise treatment and verify minimum applicable flocculant dosages. The second test was run to determine if a higher pH would improve effluent results and also to measure the sludge generation and lime consumption rates. Test 2 was run for 3 days with a pH setpoint of 10.5. Given the short duration of Test 2, the reactors were not cleaned out and sludge from Test 1 was used to initiate the test.

Table 2 Summary of pilot tests

Test	Test Conditions			Test Results		Clarifier Overflow (last 24h)	
	Duration (days)	pH	Floc Dosage (ppm)	Lime Consumption (g/L)	Solids Production (g/L)	Turbidity (NTU)	TSS (mg/L)
1	18	9.5	2.2	0.39	0.36	1.0	6.7
2	3	10.5	2.5	0.65	0.67	1.0	5.1

As shown in Table 2, lime consumption increased by 66% to 0.65 g/L for Test 2. Solids production increased by 86% as compared to Test 1. The average turbidity at the end of each test is the same, but there was an improvement in TSS with the higher pH of 10.5 used for Test 2.

Figure 3 shows the evolution of the clarifier overflow turbidity, the sludge solids content and the solids content in Reactor 1 for the entire pilot campaign. Effluent turbidity for these tests was correlated with copper concentration with an R^2 value of 0.89, which means that it can be used as a strong indicator of treatment performance. Results show that the effluent quality was excellent with turbidities of approximately 2 NTU as of day 2. At the end of day 3, when the raw water source was changed to the one which had aged in an iron tank for three days, the effluent quality deteriorated. This was quickly restored when a new water source was used as of day 7. The steel tank was not used again in the pilot campaign.

The sludge density is shown to increase gradually as the solids are built up, then it stabilised from 10 to 15 days. This period represents the best operating conditions for sludge density, with a recycle sludge rate of 120 to 150 mL/min and flocculant dosage of 2.5 ppm. This resulted in a clarifier turbidity of less than 3 NTU with 17 to 23% solids in the sludge and 12 to 16 g/L solids in the reactors. The best operating conditions for effluent quality are in the final 24 hours, after the recycle rate was decreased and the reactor solid content was near 10 g/L.

Two sharp drops in solids contents (at 4.6 and 8.8 days) were caused by sludge viscosity in the clarifier, which prevented a good sludge recycle. When this occurred, the rake drive speed and direction were changed to break up the viscous sludge and return to continuous recycle of dense sludge. The angle on the rake blades was reduced prior to Test 2 in order to prevent re-occurrence.

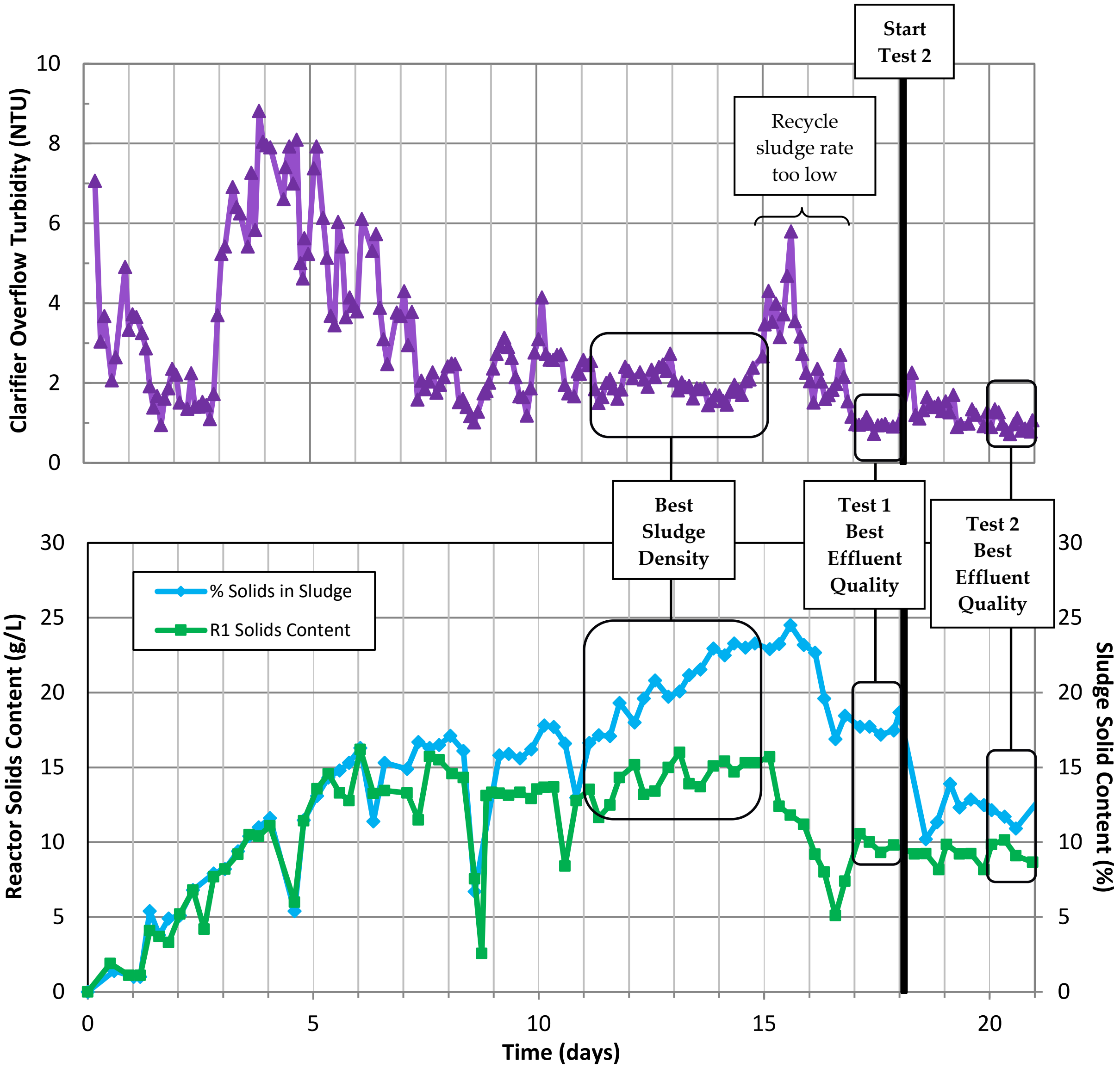

Figure 3 Pilot test results

A number of operational changes made at approximately 15 days resulted in a loss of sludge density and an increase in turbidity. One of the changes was a sludge recycle rate reduction to 80 mL/min. When this was increased to 100 mL/min, the turbidity steadily decreased to less than 1 NTU. The lowest turbidity was obtained at the end of the test when the solid contents were also lower; this suggests a compromise between effluent quality and sludge density.

Test 2 was run with a constant sludge recycle rate of 150 mL/min and constant flocculant dosage rate of 2.5 ppm. Clarifier turbidity was low at the start of the test and decreased to less than 1 NTU. The solids content varied over the course of the test with 10 to 14% solids in the sludge and 8 to 10 g/L solids in the reactors. Overall, the data indicate that a solids content of 10 to 12 g/L in the reactor slurry would be preferred. This test also had a very short duration, which did not allow for optimisation as was done for Test 1.

Figure 4 shows the clarifier overflow Cu concentrations for the duration of the pilot campaign. NF (not filtered) represents total concentrations, and "Filt" shows dissolved concentrations. Effluent water quality generally improved over time to its lowest Cu concentrations at the end of Test 1 and improved even further with Test 2. The spike in total Cu on day 5 can be explained by the raw water feed from the steel tank as solid/liquid separation was inefficient at this time.

The effects of filtration on effluent quality are shown by lower concentrations from the filter discharge, which are slightly higher than dissolved concentrations from the clarifier. Effluent from both tests met Metal Mining Effluent Regulations (MMER) with the exception of high pH in Test 2. Sulphate concentrations in the effluent approached 3000 mg/L. In the final 24 hrs, total Cu in the clarifier overflow was about a third of the MMER average monthly limit for Test 1 (0.10 mg/L) and a sixth for Test 2 (0.05 mg/L).

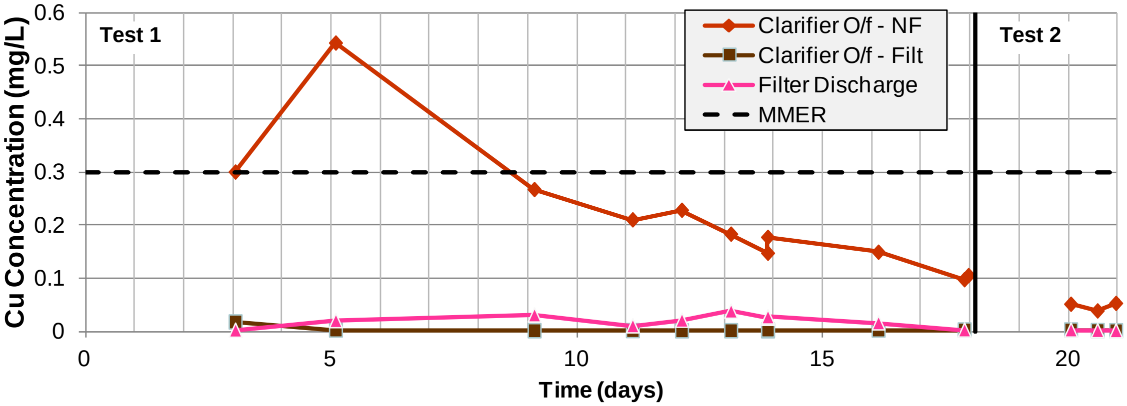

Figure 4 Effluent water quality results

Sludge

The sludge density reached a maximum of 24.5% solids in Test 1 and 13.9% in Test 2. For Test 1, this maximum was attained when the reactor solid contents were up above 15 g/L and the Cu concentration in the effluent was near 0.15 mg/L. With a lower recycle rate, a reactor solid content near 10 g/L and a sludge density of 19% solids, the effluent total Cu concentration was 0.105 mg/L. This suggests that a small compromise on sludge density may be preferred to improve effluent quality.

Sludge solids chemistry was analysed on three samples during Test 1 and one sample collected at the end of Test 2. The major components of the sludge were Mg (16.8 to 20.0%), Al (3.7 to 5.5%), Ca (2.8 to 3.7%), Mn (1.1 to 1.6%), and Cu (1.1 to 1.6%). The sludge from Test 2 contained higher proportions of Mg and Ca due to the formation of more $Mg(OH)_2$ and $Ca(CO_3)$ as a result of the higher pH setpoint of this test.

One sample from the end of Test 1 was also submitted for stability testing with the following leachate tests: Toxicity Characteristic Leaching Procedure (TCLP – EPA Method 1311) and Synthetic Precipitation Leaching Procedure (SPLP). The leachate quality obtained via TCLP testing indicates that the sludge is not hazardous waste in accordance with the B.C. Hazardous Waste Regulations or the Canadian Transportation of Dangerous Goods Regulations. All TCLP results were well below these standards with most metals below the detection limits. Results from SPLP indicate the sludge is very stable with only Ca and Mg detected in the leachate. Sludge from Test 2 is expected to be even more stable since it was generated at a higher pH and contains more Mg and Ca.

In full-scale treatment, the sludge will be wasted through a pumping system to the Bell Mine Tailings Expansion Pond. This is a pond which was developed near the end of operations at Bell Mine and never filled. The Tailings Expansion Pond provides approximately 174 years of storage capacity under design solids production and sludge density. Additional storage capacity will be constructed adjacent to this pond should this capacity be less due to higher solids production or lower sludge density.

IMPLICATIONS FOR SCALE-UP TO A FULL-SIZE TREATMENT PLANT

Pilot testing of Bell mine drainage water showed that the HDS process can successfully treat this water with effluent concentrations of regulated metals an order of magnitude below the MMER limits, except for Cu which was measured at one third the limit. Table 3 shows a comparison of results between the two tests. The higher lime consumption and sludge production from Test 2 means that operating a treatment plant at pH 10.5 would result in more waste generation and cost significantly more than operation at pH 9.5. The final pH adjustment required for Test 2 means that an acid system would be needed, thus increasing costs and risks due to acid transportation and usage. Although operation at pH 10.5 showed an incremental improvement in effluent quality, the higher expected costs, greater sludge generation, and the added risks outweigh this advantage. Full-scale operation at pH 9.5 is recommended for Bell Mine. The solids content of the reactors at optimum operation was near 10 to 12 g/L, and this is recommended as a start-up control point for operation of the Bell Mine water treatment plant.

Table 3 Comparison between tests

Parameter	**Test 1 - pH 9.5**	**Test 2 - pH 10.5**
Water Quality	Excellent	Better than Test 1
Sludge Stability	Stable	More stable than Test 1
Lime Consumption	0.39 g/L	0.65 g/L (66% ↗)
Sludge Production	0.36 g/L	0.67 g/L (85% ↗)
Final pH Adjustment	Not required	Required

The lime consumption and solids production values measured during this campaign can be applied for plant design, but potential changes in raw water quality must be considered. An HDS plant is typically designed to operate for 25 years, during which time water management modifications or advanced oxidation of mine wastes could result in increased metal concentrations. These would in turn increase the lime consumption and solids production rates. These relative rates measured during the pilot campaign should therefore be applied to predicted water quality for an estimated maximum rate. The lime system and sludge handling systems can then be sized on these predicted values. Glencore is currently using this information for the detailed design of the Bell Mine water treatment plant.

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