

Biological Treatment of Tailings Solution at the Nickel Plate Mine

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Abstract

During the closure of the Nickel Plate Mine, located in south central British Columbia, there was a need to remove cyanide and other contaminants from water stored in the tailings impoundment prior to releasing the water to a nearby stream. Several water management and treatment alternatives were considered including land application, biological treatment, breakpoint chlorination, hydrogen peroxide, and the Inco SO₂/Air process which was already in use at the mine.

After extensive evaluations, the decision was made to use a combined aerobic and anaerobic biological treatment system for removal of residual cyanide, thiocyanate, ammonia, and nitrate, coupled with a High Density Sludge (HDS) process for removal of residual metals.

The aerobic biological process utilized expertise and experience associated with the original biological treatment process still in use at the Homestake Gold Mine located in Lead, South Dakota, USA. The anaerobic biological process utilized experience developed through bench scale and pilot plant evaluations at the Nickel Plate mine.

This paper will discuss the development and operation of the combined full scale biological treatment process. The discussion will include the decant or reclaim water characteristics, the basic process chemistry, the original bench and pilot plant evaluations, design considerations, effluent limitations, and an evaluation of the full scale operation in 2000.

BACKGROUND

The Nickel Plate Mine was an open pit, gold mining operation located near Hedley, 50 km west of Penticton, in south central British Columbia. During operations, water used in the mill circuit was recycled through the tailings pond. No water was discharged to the environment. Closure of the mine in October 1996 required treatment and release of the seepage collected from, and solution stored in the tailings pond. Several water management and treatment alternatives were considered including land-application, biological treatment, breakpoint chlorination, hydrogen peroxide, and the Inco SO₂/Air process, which was already in use at the mine. The parameters requiring treatment included not only cyanide and metals, but also thiocyanate, ammonia, and nitrate. Also of interest were elevated levels of total dissolved solids (TDS) and sulphate. The water treatment process selected had to produce a non-toxic (both acute and chronic) effluent and had to meet very stringent discharge criteria.

Biological treatment was chosen as the preferred treatment alternative because the chemical oxidation processes considered (involving hydrogen peroxide and sulfur dioxide), do not remove thiocyanate, ammonia, and nitrate. And, although breakpoint chlorination does remove these three constituents, it produces residual total dissolved solids (TDS) and chloride concentrations in an effluent that remained toxic to fresh water fish.

Although the use of biological treatment in the mining industry is somewhat rare, the application at the Nickel Plate Mine is especially unique in that the existing metallurgical plant, used in the extraction of gold and silver, was retrofitted into the full scale biological treatment facility with only minor modifications.

Start-up of the full-scale treatment system began in October 1996, with discharge of treated water achieved in February 1997. Flow rate began at 25 to 50 US gallons per minute (gpm) and then gradually increased to a flow rate

of 200 gpm once the system was meeting effluent specifications. The plant was then operated for several months at the 200 gpm rate. The rate was gradually increased during the spring months to 350 gpm in 1997 and 450 gpm in 1998 to complete the removal of the tailings pond solution. Once the tailings pond water was removed, the flow rate was reduced to match the seepage pump-back rate, which is in the order of 75 gpm.

NICKEL PLATE RECLAIM WATER CHARACTERISTICS AND EFFLUENT CRITERIA

Nickel Plate mine operated with a zero discharge water management loop. Water used in the mill circuit was discharged with tailings material to the tailings impoundment, and reclaim water was then returned to the plant site from the impoundment area as required. Fresh water intake was minimal. Reclamation plans at closure required that the water stored in the tailings impoundment be treated and released to the environment. The chemical characteristics associated with the reclaim water prior to treatment are provided in Table 1. These chemical characteristics have fluctuated to a certain degree following closure due to ongoing natural degradation processes, precipitation and evaporation.

The focus of the biological treatment process at Nickel Plate is on the removal of cyanide, thiocyanate, ammonia, and nitrate from the reclaim water, while chemical treatment, using the High Density Sludge (HDS) process, focuses on removal of residual metals through precipitation. The overall treatment system was developed and designed to achieve the following effluent criteria (Table 2). Permit criteria are also included for comparison.

TABLE 1 Reclaim Water, 1995. Chemical characteristics prior to treatment.

| Parameters | Characteristics |
|--|----------------------------------|
| pH | 7.5 to 8.0 |
| Alkalinity as CaCO ₃ | 200 - 400 mg/L CaCO ₃ |
| Total Cyanide (CN) | 2 - 7 mg/L |
| Weak Acid Dissociable Cyanide (WAD-CN) | 0.2 - 3.0 mg/L |
| Cyanate (CNO) | 200 - 350 mg/L |
| Thiocyanate (SCN) | 500 - 1400 mg/L |
| Ammonia (NH ₃) | 50 - 100 mg/L as N |
| Nitrate | 10 - 50 mg/L as N |
| Nitrite | 1 mg/L as N |
| Sulphate | 2500 - 4000 mg/L |
| Chloride | 800 - 900 mg/L |
| Metals | |
| Arsenic | 0.5 - 3.0 mg/L |
| Calcium | 800 - 900 mg/L |
| Cobalt | 1 - 6 mg/L |
| Copper | 0.3 - 2.0 mg/L |
| Iron | <0.03 mg/L |
| Nickel | 0.05 - 0.5 mg/L |
| Zinc | <0.002 - 0.02 mg/L |

TABLE 2 Treated Water. Chemical characteristics as per 1995 design criteria

| Parameters | Process Design Criteria | Permit Criteria |
|---|-------------------------|-----------------|
| pH | 6.5 – 8.5 | 7.0 – 10.0 |
| TSS | 25 mg/L | |
| Total Cyanide (CN) | 0.2 mg/L | |
| Weak Acid Dissociable Cyanide WAD-CN | 0.1 mg/L | 0.2 mg/L |
| Cyanate (CNO) | <5 mg/L | |
| Thiocyanate (SCN) | <5 mg/L | |
| Total CN and SCN | | 3.0 mg/L |
| Ammonia (NH ₃) | 10 mg/L | 1.0 mg/L |
| Nitrate | 10 mg/L | 10 mg/L |
| Nitrite | 1 mg/L | |
| Sulphate | 1800 mg/L | 3500 mg/L |
| Toxicity (96 hour toxicity test on trout) | LC 50 - 100% | LC 50 - 100% |
| Metals | | |
| Arsenic | 0.2 mg/L | 0.07 mg/L |
| Calcium | 800 mg/L | |
| Cobalt | 6 mg/L | |
| Copper | 0.2 mg/L | 0.04 mg/L |
| Iron | 0.5 mg/L | 0.5 mg/L |
| Nickel | 0.1 mg/L | |
| Zinc | 0.1 mg/L | |

BENCH AND PILOT PLANT SCALE EVALUATIONS

In 1995, Nickel Plate Mine evaluated biological treatment for removal of thiocyanate, ammonia, and nitrate, as well as cyanide and cyanate, firstly by bench scale lab tests and then with an on-site pilot plant program to examine the reliability and effectiveness of various attached and suspended growth systems. The two biological systems chosen for evaluation included (1) an activated sludge process for removal of thiocyanate, ammonia, and nitrate, and (2) rotating biological contactors (RBC's), an attached growth process for removal of thiocyanate and ammonia (in use at the Homestake Gold Mine, South Dakota).

Continuous flow pilot plant evaluations were conducted from late 1995 through most of 1996. The initial bacterial seeds used in the pilot plant studies were collected from several places through the mine site, including the interface of the tailings solution and tailings beach areas and seepage collection sumps. The pilot plant continues to remain in operation in case a seed source of conditioned bacteria is required, in the event the plant process becomes disrupted.

The activated sludge process was found to be suitable for treating high concentrations of contaminants, such as are present in the Nickel Plate reclaim water, due to its ability to accommodate the large suspended biomass levels generated during treatment. The RBC process was more suitable to treating lower constituent concentrations, such as those of dilute industrial wastewaters.

The superior performance, coupled with the ease with which a full scale system could be constructed using existing equipment, were the reasons that the activated sludge process was finally selected for full scale treatment of the tailings impoundment solution.

TREATMENT THEORY

An activated sludge process consists of a reactor tank(s) followed by a settling chamber or thickener. The reactor(s) is fitted with aerators which add oxygen to the solution in the case of an aerobic circuit and provide mixing for both aerobic and anaerobic circuits. Effluent enters the aerated reactor and contacts large numbers of aerobic microorganisms including bacteria, protozoans and rotifers. The reactor contents are referred to as the *mixed liquor*.

The microorganisms withdraw dissolved and colloidal nutrients from the water and produce cell mass. The thickener then separates these organic solids from the liquid and reintroduces them to the reactor chamber, allowing the liquid to exit the system. The recycling of the cell mass creates the very high cell densities in the mixed liquor which allow efficient treatment of water.

The solids are kept in suspension in the reactor through mixing to provide good contact between the microorganisms and their food. The thickener, which is quiescent, allows agglomerations of cells, called flocs, to settle by gravity.

The microbial composition of the mixed liquor is important to the formation of flocs and therefore the settling ability of the solids. Poor settling ability causes a portion of the solids to be lost from the thickener, which lowers the quality of the effluent. Better floc formation is partly achieved by encouraging, through control of process parameters or regular inoculations, certain microbial genera. Genera that form spheres and rods, such as *Pseudomonas*, *Zoogloea* and *Mycobacterium*, will settle well, while species forming filaments, such as *Thiothrix* and *Geotrichum* will not. The presence of filamentous organisms causes a phenomenon called bulking. Bulking is likely to prevent complete removal of solids in the thickener. The presence of protozoa and rotifers is also important for their ability to consume dispersed, unflocculated or incompletely flocculated solids that are difficult to settle. Contaminants such as metals may also have an effect on flocculation and settling ability.

The microbial performance may be controlled through a parameter called *sludge age*. The sludge age is the length of time, on average, that solids are retained in the reactor. The proper sludge age will optimize the rate of growth of the microorganisms, and therefore the rate of uptake of nutrients. Additionally, the microorganisms start to produce extra-cellular polymers at the proper age. These polymers help to glue the organisms together to improve flocculation and settleability. Optimum sludge age will vary according to the type of waste being treated.

Sludge age is controlled through *wasting*. This involves the removal of a portion of the cell mass on a regular basis. Once the optimal sludge age is reached, the wasting rate should be equal to the rate of new cell growth.

The performance of the system also depends on the *loading rate*. The growth of the microorganisms is dependent on the availability of their food; the growth rate will decrease with crowding and competition. Water treatment, however, depends on a large number of organisms; low cell densities will reduce treatment effectiveness. There is an optimum loading rate between the two extremes. This balance is measured by the Food to Microorganism ratio (F:M ratio). The F:M ratio may be controlled by varying the throughput of the plant (or sizing the plant for a certain throughput), changing the sludge wasting and recycling rates, and also by changing the aeration rate.

PROCESS BIOCHEMISTRY

A combined aerobic and anaerobic activated sludge system was developed for Nickel Plate. A basic description of the process biochemistry associated with the various stages of the process is outlined below.

Thiocyanate Oxidation (Aerobic Circuit)

Thiocyanate is converted to ammonia, sulphate and carbon dioxide according to Equation (1).



Biological oxidation of thiocyanate is carried out by a number of aerobic, autotrophic organisms which can use inorganic carbon sources (i.e. Soda Ash), including *Thiobacillus thiooxydans*, *Thiobacillus thiooxydans* and *Thiobacillus denitrificans*. In addition, thiocyanate can be oxidized by several species of the *Pseudomonas* genera, which are heterotrophic (require an organic carbon source – e.g. Methanol).

Nitrification Process (Aerobic Circuit)

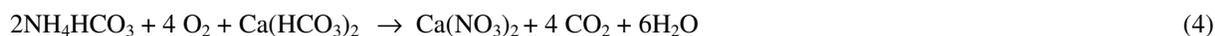
Concurrent to thiocyanate oxidation, ammonia is oxidized by nitrifying organisms in two steps: first to nitrite and then to nitrate according to Equations (2) and (3).



The oxidation of ammonia to nitrite, and then nitrite to nitrate is carried out by two groups of bacteria, *Nitrosomonas* and *Nitrobacter*. These organisms are autotrophic and therefore use inorganic carbon sources.

The presence of nitrite in the overflow may be an early indicator of upset conditions prior to loss of nitrification and noticeable increases in ammonia concentrations. At high biomass inventories, however, both ammonia and nitrite concentrations will be low and the system should not be prone to upsets. Nitrite residuals in the effluent from the activated sludge system are not a major concern however, since nitrite is readily reduced to nitrogen gas in the denitrification system downstream in the treatment process.

The combined nitrification reaction consumes alkalinity and releases acidity, therefore it is necessary to control pH and maintain alkalinity to optimize the process. Alkalinity can be supplied by either soda ash or lime. The overall reaction for the nitrification process is provided in Equation (4).



Both *Nitrosomonas* and *Nitrobacter* have long generation times and low cell mass yields. Sludge age, therefore, is a critical factor in the nitrification process. Long sludge age can be achieved by operating with a high biomass inventory and by maintaining long retention times. The nitrification process is also sensitive to temperature. Operating temperatures above 15°C are desirable to achieve complete nitrification, although potentially the system can be acclimatized to operate at lower temperatures. However, below 11°C problems have been found with the operation of the biomass.

The nitrifying bacteria are also sensitive to low dissolved oxygen, low pH and the presence of toxic compounds, such as some metals. Dissolved oxygen concentrations at or above 2.0 ppm are desirable.

pH in the range of 7.8 to 8.5 is theoretically optimal, with significant losses of efficiency below 7.0. However, the Nickel Plate activated sludge system has been acclimatized to operate at a pH of 7.4 without a loss of efficiency.

Cyanide and Cyanate Removal (Aerobic Circuit)

In addition to thiocyanate and ammonia oxidation, the aerobic portion of the combined activated sludge process is capable of oxidizing and removing WAD cyanide and cyanate.

Free cyanide, if present, can be oxidized biologically by a number of species of the genera of *Pseudomonas*, *Alcaligenes* and *Achromobacter* to form cyanate, which in turn hydrolyzes to form ammonia. Alternatively, cyanide can also be converted to thiocyanate by a number of organisms including *Chromobacterium violaceum* that produce the enzyme rhodanese. This enzyme is responsible for the detoxification of cyanide in mammals. Thiocyanate formed by rhodanese is then converted to ammonia via Equation (1).

Weak acid dissociable cyanide (WAD-CN) can be removed by metal complex absorption onto biomass and subsequent internal decomposition to cyanate. Strong acid dissociable cyanides (SAD-CN) such as iron cyanide are not readily treatable biologically, but can be removed later in the process by precipitation.

The Nickel Plate tailings pond water did contain appreciable concentrations of cyanate due to production as a byproduct of the Inco-SO₂ Air cyanide destruction process. Cyanate hydrolyzes to form ammonia under neutral to acidic conditions (Equation 5), but can be quite stable under alkaline conditions.



Nitrate Removal and the Denitrification Process (Anaerobic Circuit)

The biological process of denitrification involves the conversion of nitrate and nitrite to gaseous nitrogen species. The gaseous product is primarily nitrogen gas but also may contain nitrous oxide or nitric oxide. The denitrification process is carried out, under anaerobic conditions, by facultative bacteria of the genera *Pseudomonas*, *Micrococcus*, *Achromobacter*, and *Bacillus*. These organisms are heterotrophic and therefore require an organic carbon source such as methanol. The conversion of nitrate to nitrogen gas is a two-step process. However, both steps are carried out by the same organisms. The overall energy reaction for nitrate removal can be described by Equation (6).



Additional methanol is required to consume any dissolved oxygen present in the solution.

Denitrification produces alkalinity as nitrate is removed, requiring the addition of sulphuric acid to control pH in the optimum range of 6.5 to 7.5. The rate of nitrate removal drops as the temperature drops. The process will operate at temperatures as low as 5°C but generally requires temperatures greater than 10°C. The process is very sensitive to temperature, with the reaction rate doubling with every 4°C increase. The biomass yield of the denitrification process is small. Therefore, maintaining high biomass inventories and sludge ages reduces the potential for upsets and loss of the process.

THE COMBINED ACTIVATED SLUDGE AND HIGH DENSITY SLUDGE PROCESSES AT NICKEL PLATE

In order to construct the full scale water treatment plant, the metallurgical circuit in the Nickel Plate mill, consisting of several large stir tanks, was converted into a series of activated sludge reactors with only slight mechanical modifications. These modifications included trimming the prop blades to reduce shear of the biological floc, adding diffusers to supply dissolved oxygen for thiocyanate and ammonia removal, applying spray foam insulation to the tanks, and covering the tanks with floating plastic balls to exclude oxygen in the anaerobic denitrification step of the process, as well as to control heat loss and reduce foaming.

Currently, manpower requirements for the water treatment plant stand at 10 - plant manager, general plant foreman, environmental sampler, 4 shifters and 3 analysts. The plant operates 24 hours a day and 7 days a week.

The full-scale combined biological and chemical water treatment at Nickel Plate consists of the following three separate steps (see Figure 1):

1. an aerobic activated sludge treatment step for the conversion of thiocyanate (SCN) to ammonia (NH₃) and for the oxidation of the ammonia (NH₃) formed to nitrate (NO₃),
2. an anaerobic denitrification treatment step to reduce nitrate (NO₃) to nitrogen gas (N₂), and
3. a High Density Sludge (HDS) - ferric sulphate treatment step to precipitate arsenic (As), some sulphate (SO₄) and other residual metals in the effluent.

The Aerobic Circuit

Reclaim water from the barge in the tailings impoundment is pumped to the two internal reclaim tanks at the mill. The reclaim water is then heated in a submerged combustion propane-fired heater rated for delivery of 4.0 X 10⁶ BTU/h. The heater is capable of raising the feed temperature to 20°C at 200 gpm. Under extreme conditions of minus 15°C air temperatures and a 25 kph wind, the system will ensure that the operating temperatures are controlled between 15° and 20°C. The heater consists of an insulated tank, combustion air preheater, burner, blower, combustion chamber, fuel trains and controls. Operation of the heater is monitored by temperature measurements taken daily in the first aeration tank, as well as by a temperature probe in the heater overflow line which will limit maximum discharge temperature of the heater.

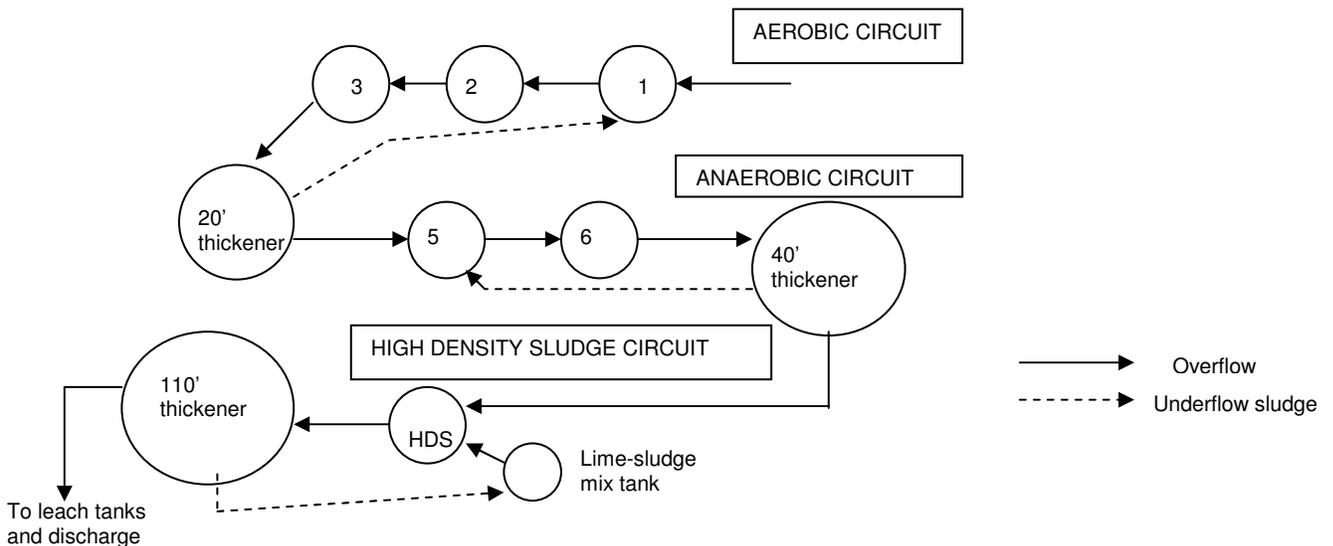
The activated sludge treatment system consists of three 40 foot diameter agitated aeration tanks fitted with three banks of diffusers (24 each bank). The existing mill compressors supply process air. Lime and soda ash are added to aeration Tank No. 1 to control the pH at 8.5. Most of the demand for alkalinity is supplied by lime, while soda ash is used only to supplement inorganic carbon as required for thiocyanate and ammonia removal. The bulk of the demand for alkalinity is from the nitrification process. pH is controlled with a PID controller. A small amount of phosphoric acid is fed to the first aeration tank to supply phosphorous to the biological process. The phosphoric acid metering rate is set manually according to analytical results from the aerobic circuit thickener overflow samples.

A small amount of methanol is added to Tank No. 1 to provide some organic carbon (approx. 0.01 gpm at a flow of 350 gpm). The rate of methanol addition is set manually according to overall performance of the system.

The final stream added to Tank No. 1 is recycled underflow sludge from the 20-foot Thickener which provides the biomass necessary to carry out the biological treatment process. The second and third aeration tanks provide additional retention time to complete the treatment process.

Oxidation of thiocyanate is completed in Tank No. 1, while ammonia removal may need to be completed in subsequent aeration tanks. The third tank overflows to the center well of the 20-foot Thickener where a small amount of cationic flocculant is added. The biomass settles in the thickener and is pumped back to Tank No. 1. The return sludge pumping rate is set and controlled manually according to the plant flow rate. This rate is in the range of 50-100% of plant flow rate. The activated sludge system discharge contains significant amounts of nitrate (approx. 100 mg/L as N) but very low concentrations of thiocyanate and ammonia (i.e. <0.1 mg/L SCN and 0.01 mg/L NH₃ as N).

Figure 1 Water Treatment Plant Flow Chart



The Anaerobic Circuit

Overflow from the 20-foot Thickener is pumped to Tank No. 5 (first of two denitrification tanks). This tank has low speed agitation to maintain the biomass in suspension without causing significant oxygen transfer. Methanol is added at a rate of ~400 ml/min to provide an organic carbon source for the denitrification process. The methanol metering rate is set and controlled according to manual dissolved oxygen readings and on an assessment of overall performance.

Sulphuric acid was added to Tank No. 5 and controlled using a PID controller to maintain pH in the 6.5 to 7.5 range. Supplemental phosphoric acid is added to Tank No. 5 to maintain a residual of 1 mg/L as phosphate. Underflow sludge from the 40-foot Thickener is returned to Tank No. 5 to provide active biomass. Tank No. 5 overflows to Tank No. 6, where air is supplied to strip nitrogen N₂ gas, oxidize residual methanol, and prevent rising sludge problems in the 40-foot Thickener. The amount of aeration supplied to Tank No. 6 is minimized to reduce the carry-over of dissolved oxygen.

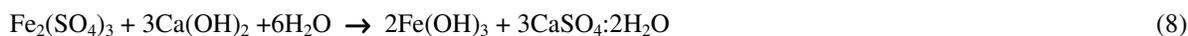
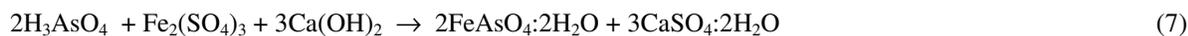
Tank No. 6 overflows to the 40-foot Thickener via gravity. Cationic flocculant is added in two stages to the overflow. The biomass is allowed to settle in the 40-foot Thickener and is returned to Tank No. 5 at a rate of 50-100% of the reclaim flow rate. The return sludge rate for the denitrification system is controlled manually.

The High Density Sludge (HDS) Circuit

The 40-foot Thickener overflow from the anaerobic circuit is pumped to the distribution box at HDS Tank No.1. Ferric sulphate is added to provide a short contact time at pH 7.0. The ferric sulphate solution metering rate is set and controlled manually.

The HDS process is used to remove arsenic and sulphate through conventional ferric arsenate and gypsum precipitation, followed by flocculation and solids removal in a high solids density recycle system. This system also precipitates, as hydroxides, other metals (zinc, copper, etc.) that may be present in suspension or solution in the denitrification system overflow.

Arsenic precipitates with ferric sulphate to form a basic ferric arsenate, as per Equation (7). Excess iron and sulphate is also precipitated out as gypsum by lime as described in Equation (8).



Lime is added to the lime/sludge mix tank to control pH at 8.8 in HDS Tank No. 1. Recycle sludge from the 110-foot Thickener is combined with lime in the lime/sludge mix tank and then overflows to the HDS tank. The HDS Tank contains a pH probe used to control the lime addition rate to the lime/sludge mix tank. The HDS Tank overflows to the center well of the 110-foot Thickener.

Anionic flocculant is added to the center well and to the upstream of the center well to provide flash mixing.

The 110-foot Thickener separates out the suspended solids and generates thickened solids that are recycled back to the lime/sludge mix tank. Solids recycling generates high sludge densities, creates a high surface area to remove colloidal solids, maximizes metals removal and precipitates gypsum. A portion of the recycled solids is wasted periodically to the tailings pond to maintain a constant solids inventory.

The 110-foot Thickener overflow discharges to an overflow pump box, where the overflow is pumped to Leach Tank No. 4 and then flows through Leach Tank 1 by gravity, prior to entering the pipeline to Hedley Creek.

The Pipeline

The pipeline, constructed in October 1996, delivers the treated water to Hedley Creek. The pipeline is ~ 16,000 feet in length and has 4 drop boxes designed to dissipate energy formed in the 3,600 foot vertical drop down to the diffuser station, downstream of the Hedley Creek bridge. The diffuser station consists of 10 – 1 inch diameter pipes placed into mid stream about 15 feet apart.

Treated water to be discharged into Hedley Creek has to meet several criteria prior to discharge:

- it must be non toxic to Rainbow trout using the 96 hour LC₅₀ test,
- it must meet effluent discharge criteria for parameters listed in Table 2,
- the volume released must not exceed a 40:1 dilution ratio in the creek. This is to ensure that water quality objectives set for Hedley Creek are not exceeded, and
- the annual discharge volume must not to exceed 160 million US gallons per year.

Monitoring of the treated water is done daily for all parameters listed in Table 2, and on Hedley Creek water downstream of the diffuser station for sulphate. Operational controls require that most treatment tanks be sampled and analyzed daily for circuit parameters of interest, in addition to daily monitoring of pH and dissolved oxygen levels.

OVERALL WATER TREATMENT PLANT PERFORMANCE

A summary of the overall water treatment plant performance for 2008 is presented in Table 3. As can be seen, the full scale treatment plant is providing excellent removal of WAD cyanide, thiocyanate, ammonia, and nitrate, as well as reducing metals and ensuring a non-toxic discharge.

Individual reagent consumption is provided in Table 4. A summary of the overall cost of operation of the combined water treatment plant is presented in Table 5. As can be seen in these two tables, labour is the most significant individual cost, followed by power. The overall cost is just over \$0.03 per US gallon of treated water, which is very low in comparison to other widely used treatment processes.

In summary, the research, development, and implementation of the combined biological and chemical water treatment process, through the retrofitting of the existing metallurgical circuit, saved many millions of dollars over other effluent treatment processes, and demonstrated that such an approach is viable and could be pursued at other mining operations. To achieve optimal results, consideration should be given at an early stage to the development of a beneficiation process to incorporate such concepts for closure.

TABLE 3 Water Treatment Plant data – averages for 2008.

| Parameter Units mg/L unless noted | Reclaim | Activated Sludge Circuit | | | Permit Criteria |
|--------------------------------------|---------------|--------------------------------|----------------------------------|-------------------------|------------------------------|
| | Influent | Aerobic Circuit Effluent | Anaerobic Circuit Effluent | HDS Circuit Effluent | Discharge to Hedley Creek |
| Volume Discharged | US Gallons/yr | | | 79,267,433 | |
| Flow – US Gallons/min | | 155.5 | | 149.9 | 40:1 ratio |
| pH – pH units | 7.72 | | | 8.27 | 7 - 10 |
| Total Dissolved Solids | 2233.5 | | | 2414.4 | 4500.00 |
| Total Suspended Solids | 7.0 | | | 5.8 | |
| Cyanide – Total | 0.458 | | | 0.285 | 3.0 CNt + SCN |
| Cyanide – WAD | 0.144 | | | 0.025 | 0.20 |
| Thiocyanate – SCN | 277.1 | 0.02 | 0.02 | 0.02 | 3.0 CNt + SCN |
| Ammonia – NH ₃ – N | 18.37 | 0.057 | 0.041 | 0.076 | 1.00 |
| Nitrate – NO ₃ – N | 4.391 | 70.668 | 0.048 | 0.359 | 10.00 |
| Sulphate | 1076.2 | 1498.2 | 1431.5 | 1505.1 | 3000.00 |
| Arsenic – Total | 0.2798 | 0.1565 | 0.0590 | 0.0009 | 0.07 |
| Arsenic – Dissolved | 0.2518 | | | | |
| Cobalt – Dissolved | 0.6745 | 0.6187 | 0.5385 | 0.5382 | |
| Copper – Total | 0.0078 | 0.0071 | 0.0062 | 0.0053 | 0.04 |
| Copper – Dissolved | 0.0058 | 0.0045 | 0.0031 | 0.0040 | |
| Iron – Total | 0.290 | 0.199 | 0.182 | 0.154 | |
| Iron - Dissolved | 0.045 | 0.022 | 0.026 | 0.022 | 0.50 |

TABLE 4 2008 Water Treatment Plant reagent consumption.

| Reagents | Consumption kg/M US Gallons | Costs/M US Gallons (in Cdn \$) | Percent of Total Costs |
|-----------------------|--------------------------------|-----------------------------------|---------------------------|
| Methanol | 2 789.6 | 3 154.37 | 60.0 |
| Ferric Sulphate | 1 449.4 | 972.51 | 18.5 |
| Sulphuric Acid | 0 | 0 | 0.0 |
| Phosphoric Acid | 64.6 | 258.00 | 4.9 |
| Soda Ash | 0 | 0 | 0.0 |
| Lime | 2 434.5 | 629.34 | 12.0 |
| Flocculant – Anionic | 28.1 | 65.48 | 1.2 |
| Flocculant - Cationic | 9.4 | 181.53 | 3.5 |
| Totals | | \$5 261.19 | 100.0 |

TABLE 5 2008 Water Treatment Plant costs.

| Category | Cost/M US Gallons (in Cdn \$) | Cents/US Gallon (in Cdn \$) | Percent of Total Costs |
|----------------------|----------------------------------|--------------------------------|---------------------------|
| Reagent Costs | 5 261.19 | 0.53 | 13.8 |
| Propane | 5 052.83 | 0.51 | 13.3 |
| Power | 4 237.28 | 0.42 | 11.1 |
| Labour | 14 235.00 | 1.42 | 37.4 |
| Materials & Supplies | 4 849.68 | 0.48 | 12.8 |
| Repairs | 3 122.86 | 0.31 | 8.2 |
| Other | 1 260.84 | 0.13 | 3.39 |
| Totals | \$38 019.67 | 3.80 | 100.0 |

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