Mobile Mine Drainage Treatment System in a Northern Climate[1]

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ABSTRACT

Xstrata Nickel, Raglan Mine is located in Nunavik, in the far North of the province of Québec in Canada. The area is characterised by tundra with deep permafrost and a 1 to 2 metre active layer. From fall 2006 to spring 2007, the mine exploited a small orebody named Spoon Pit. Prior to start of operations, it was recognised that the runoff from the waste rock would require treatment for a few years, due to dissolved nickel in the leachate. The waste rock would then be placed back into the open pit and covered to entirely reclaim the area. A mobile lime treatment system could be used at this site for the few years when treatment would be necessary. A mobile treatment system would be an excellent option as other nearby ore bodies are planned for exploitation in the near future. The treatment plant was designed and built with all major process equipment installed within maritime containers. The system could treat the runoff with lime as it flows by gravity toward a settling pond and then Spoon Pit itself. The lime slurry preparation system and pH control are very flexible, robust, and completely automated. As treatment is primarily for nickel (also present in the mine drainage are iron and copper), the treated water must be pumped to an acidification system for pH adjustment before final discharge. The Acid Plant is also mobile and completely contained in maritime containers. This paper describes the design of the mobile treatment system, details the results from the 2007 start-up and the successful operations from summer 2008.

Additional Key Words: Treating heavy metals, lime neutralisation, acid rock (mine) drainage (ARD – AMD), neutral drainage.

INTRODUCTION

Located in the far north region of Québec (Nunavik), the Xstrata Nickel Raglan Mine property consists of a series of high-grade ore deposits, with nickel and copper as the primary metals. The operation consists of open pit and underground mines, a concentrator, a power plant, as well as accommodation and administration buildings. The mine site is linked by all-weather roads to an airstrip at Donaldson and to the concentrate storage and ship-loading facilities at Deception Bay. The large nickel mining complex is located approximately 100 kilometres (62 miles) south of Deception Bay. The property stretches 55 kilometres from east to west, with a series of high-grade ore deposits scattered along its length.

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The area is characterised by tundra with deep permafrost and a 1 to 2 metre active layer. The Spoon project was a small high-grade Ni ore deposit 13 km from the metallurgical facility. It was exploited as an open pit from fall 2006 to spring 2007. The pit required the removal of sulphidic waste rock which was stored nearby and surrounded by a ditch to contain the drainage. As the drainage was expected to contain some dissolved Ni, Xstrata Nickel, Raglan Mine hired EnvirAubé to assist in designing a treatment system capable of removing heavy metals from solution and providing an effluent compliant with provincial and federal regulations. The expected water qualities, target effluent criteria, actual water qualities, treatment results, and project challenges are discussed in this paper.

NICKEL TREATMENT

The regulated limit for Ni in Canada (Metal Mining Effluent Regulations) and Québec (Directive 019) is 0.5 mg/L on a monthly average. A single sample limit is 1.0 mg/L. Regulations also stipulate limits for toxicity, other metals, and a pH range of 6.0 to 9.5. There are a number of different technologies that can be used for Ni treatment, including sulphide precipitation, ion exchange, and membrane systems. The most common, cost-effective, and proven technology is hydroxide precipitation. This is most often done by addition of lime as the alkali to increase the pH to levels where Ni is insoluble. This is followed by solid-liquid separation to produce a clear overflow that meets regulations for discharge.

Even though lime neutralisation is recognised as a proven treatment for Ni, site-specific runoff can sometimes require specialised needs for treatment. In some situations, a coagulant is required to improve solid-liquid separation. This is particularly true for sites where concentrations are low, as insufficient solids can form for efficient coagulation and settling of particles.

In order to properly define the needs for treatment at Spoon Pit, some samples were collected from another existing site on the Raglan property and sent to CANMET (NRCan, Mining and Mineral Sciences Laboratory) for laboratory testing. Runoff could not be collected from Spoon as the mine site was new and under winter exploitation. The tests were designed to try different pH setpoints and coagulant addition rates to define the treatment needs for the final plant. Two raw water chemistries were used as the sample collected did not contain the same concentration as that expected from the Spoon runoff. The undiluted raw water from another nearby pit contained 48 mg/L Ni while the expected concentrations at Spoon were of approximately 6 mg/L. As this was a prediction and not a certainty, the raw water was therefore tested both undiluted and diluted to 6.7 mg/L.

The tests were completed using 1-L samples in beakers, where laboratory-grade hydrated lime was added to attain the desired pH of each test. In some cases, ferric sulphate was added to attain iron addition rates of 5 or 10 mg/L. The added Fe precipitates as a ferric hydroxide and acts as a coagulant to help combine the other precipitates and enhance solid/liquid separation. After mixing, the 1-L sample was allowed to sit on the counter for 24 hours of settling before collecting an aliquot just below the surface for analysis. These surface samples represent the expected water quality following treatment in the full scale with settling in a pond or pit.

All 11 test results are displayed in Figure 1. The objective for Raglan was an effluent Ni concentration of 0.3 mg/L or less, well below the 0.5 mg/L monthly average limit. For the diluted raw water, a pH of 10 with 5 or 10 mg/L Fe addition or a pH setpoint of 10.5 or higher was sufficient to meet the objective. With the undiluted raw water, it was necessary to add 10 mg/L of Fe to decrease the Ni concentration to less than 0.3 mg/L.

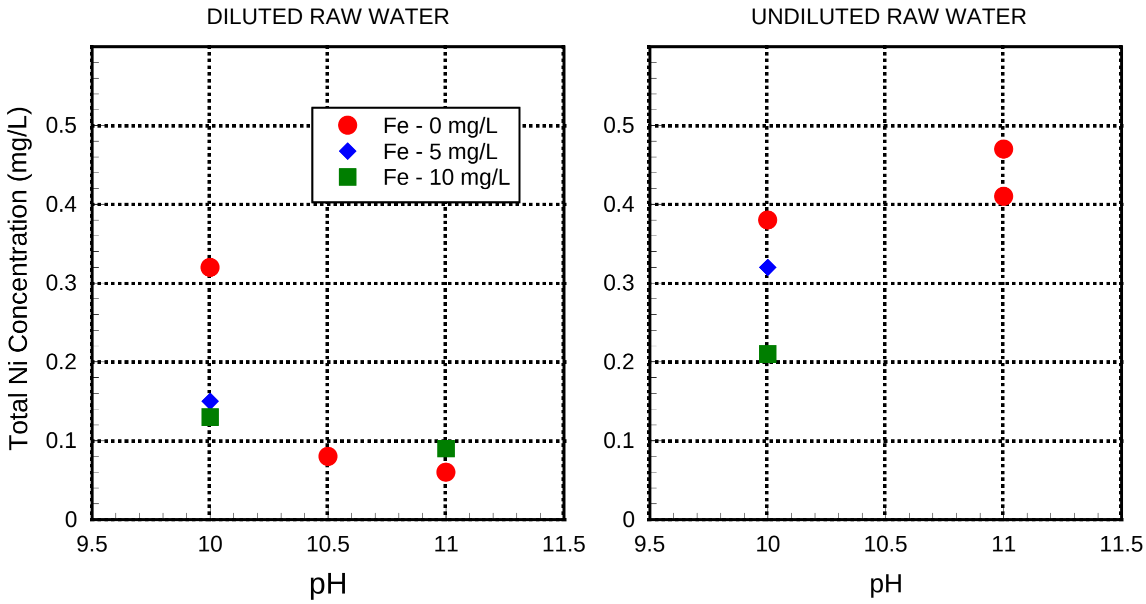

Figure 1: Laboratory Test Results – Total Ni Concentration.

The conclusions and recommendations from the laboratory tests were to design a treatment system capable of adding sufficient lime to bring the pH up to 11 and with a ferric sulphate addition system sized for up to 10 mg/L Fe addition at the maximum expected flowrate.

TREATMENT DESIGN CRITERIA

As the laboratory tests showed that treatment of Ni will require a high pH for effective precipitation, the treatment system was to be designed in two parts: 1) a lime system with Ni precipitation and settling, and 2) a sulphuric acid system to decrease the pH to regulated limits prior to release. The lime system would treat the mine drainage as it runs off the waste rock and affected area, by gravity whenever possible. The treated water, with metal concentrations meeting discharge criteria at this point but with a pH above the regulated limit, would then need to be pumped to the acid addition system. The system concept is loosely based on a previous treatment system applied on a different site at Xstrata Nickel, Raglan Mine (Aubé and Arseneault, 2003).

As the treatment system had to be designed before a drop of drainage had run off the affected site, historical chemistries of runoff from other nearby ore bodies were used to estimate the expected water quality at Spoon Pit. It was estimated that the Ni concentration would be near 6 mg/L and that other heavy metal concentrations would be negligible. The flowrates were then estimated using a hydrological model.

The design criteria considered a flow of up to 383 m^3/h at the lime plant. This was based on a 1 in 20 year extreme runoff event modeled for the Spoon Pit catchment basin. This maximum flowrate corresponds to 9,192 m^3/day as the highest expected flowrate in a single 24-hour period. The total expected for the year was of 49,000 m^3 (still 1:20 year recurrence). As the lime plant receives the runoff by gravity, there is no control on the flowrate during the thaw. If the water in the pit does not meet compliance criteria for metals, this water would need to be recirculated to the treatment plant. To include runoff plus recirculation, the lime plant was to be designed for slightly more than 500 m^3/h. Note that the pit capacity of 197,000 m^3 was certain to be sufficient to capture all the water expected for the year.

Once the Ni was removed from the runoff, the surface water stored in Spoon Pit was then to be pumped to the acid plant for pH correction using sulphuric acid prior to release. The sizing of the acid plant was for 140 m^3/h, based on the pumping capacity of the diesel pump purchased for the project. The acid plant itself was designed specifically for the purpose of treatment at Spoon Pit.

The overall plan was to use the lime plant at this location for a few years, then move it to a new location as the Spoon Pit area was reclaimed and treatment was required at other locations. The reactor in the ditch at Spoon Pit may not be re-useable, but the lime plant itself was to be designed with sufficient flexibility to properly treat both low and high flowrates, with differing lime consumption rates.

PLANT DESIGN

The project management was completed by Xstrata Nickel – Raglan Mine and EnvirAubé. EnvirAubé was also responsible for the conceptual engineering and process engineering of the treatment system. Génivar completed the initial detailed mechanical, electrical, and civil engineering, procurement, plus the drawings and the construction supervision. In 2008, Stavibel was involved in the project management, engineering, construction supervision, and start-up. As previously mentioned, the treatment system is divided into two separate parts – the Lime Plant and the Acid Plant. A plan view of the entire site is shown in Figure 2. The lime plant consists of a Ditch Reactor, a Lime System, and a Ferric System. Also included at the Lime Plant location are two diesel generators, a programmable logic controller (PLC), and remote communication systems.

Water Management

The runoff collection system existed prior to the mandate to construct the treatment plant. The pit itself is a depression capable of safely holding up to 197,000 m^3 of water. The waste rock is placed on the other side of a main road and surrounded by ditches to contain all runoff (Figure 2). Theses ditches flow through a culvert below the road and back towards the pit by gravity. The Ditch Reactor is placed near the pit in this ditch, prior to a relatively small excavated pond (3,000 m^3) called the Bassin Temporaire (or BT, meaning Temporary Pond). The Ditch Reactor is the point of lime addition and pH control. The overflow from the BT flows into the pit.

Down the pit ramp, a diesel pump is installed that can be moved along the ramp as the water level changes. This pump returns water either to the Ditch Reactor if it requires treatment or to the Acid Plant if it meets compliance for all but pH. All major piping is 25 cm diameter HDPE

(10” DR11). There is also a pump in the BT which can be used to direct the water from this pond to the pit, to the Ditch Reactor Feed, or to the Acid Plant.

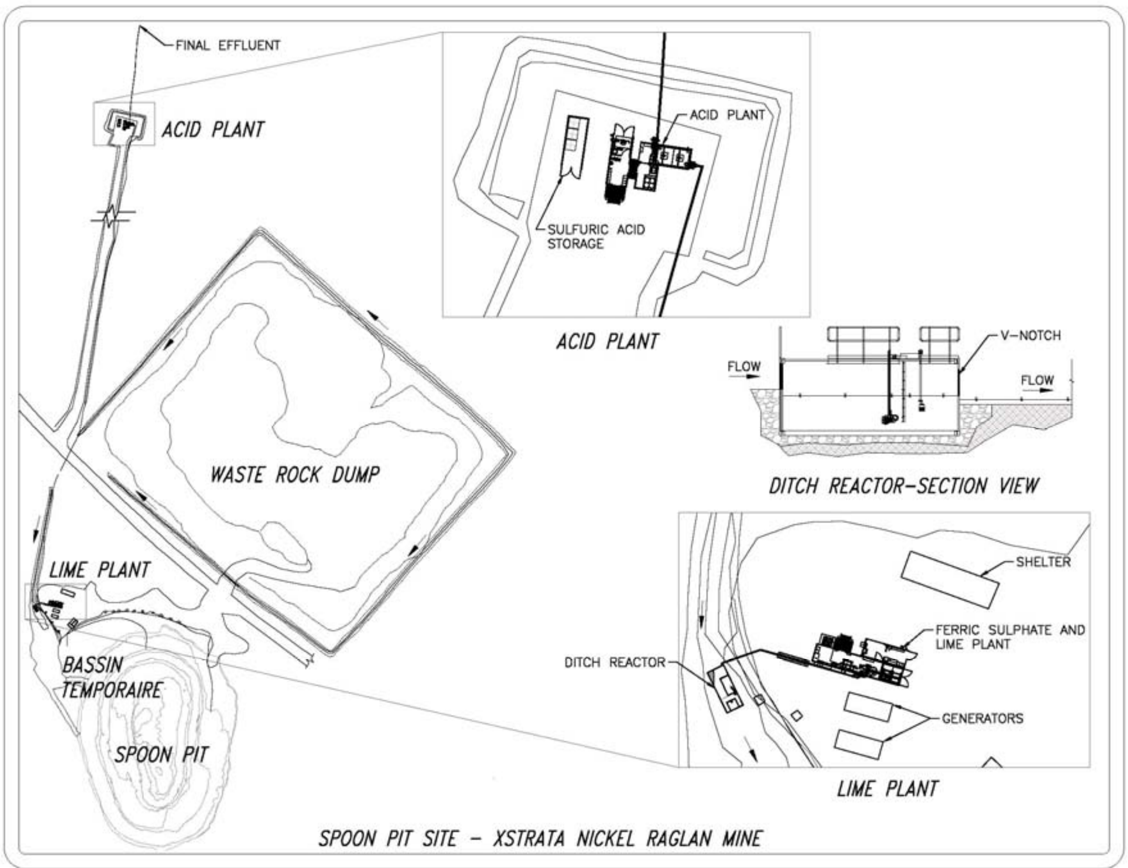

Figure 2: Plan View of Spoon Pit Site

Ditch Reactor

The Ditch Reactor consists of a modified 6-m shipping container with a separator wall to force the water to flow from top to bottom and divide a reactor section from a calm section where the water flowrate is measured. A cut-out is shown in Figure 2. The reactor section is equipped with a submersible agitator to properly dissolve the lime. The second section contains a small submersible pump to return water to the lime plant for measuring pH and for fabricating the lime slurry. The overflow from this reactor is through a standard V-notch for flowrate measurement. A staff gauge is installed for manual readings and a level sensor for automatic readings via the PLC. The PLC is programmed with the curve function to translate this to a flowrate and the PLC also calculates the flowrate of ferric sulphate required for a desired dosage.

Lime System

The entire lime plant is shown in a three-dimensional view in Figure 3. The shelter was built from three insulated maritime containers: a 12-m (40-ft) high-cube superimposed with a 3-m (10-ft) container, and a 6-m (20-ft) container attached to the side. The process equipment and PLC are in the 12-m container. The 3-m container was superimposed to increase the height in this section of the shelter in order to have a chain hoist for loading bags of lime on a hopper. The 6-m container is divided into an electrical room and a small laboratory for sample preparation.

The lime system first consists of a chain hoist to lift the bags of lime onto the hopper. The hopper and lime slurry mix system were purchased as a turnkey unit with instrumentation to properly control the lime slurry density. The system is equipped with load cells to measure and control the mass of lime added when producing lime slurry. The hopper is equipped with a vibrator and screw feeder to convey the hydrated lime ($Ca(OH)_2$) to the lime slurry storage tank. This tank is equipped with an agitator, a level sensor, and an automatic solenoid valve for water addition. The system is programmed to add lime and water when the level in the storage tank reaches a pre-specified trigger level. The PLC is programmed to produce lime slurry of a desired solid content to a 1 or 2% accuracy. The setpoint for lime in 2008 was 7% solids, but the system can operate with less than 1% up to 20% solids without modification or control issues. This offers considerable flexibility given that the runoff water qualities and flowrate can vary significantly.

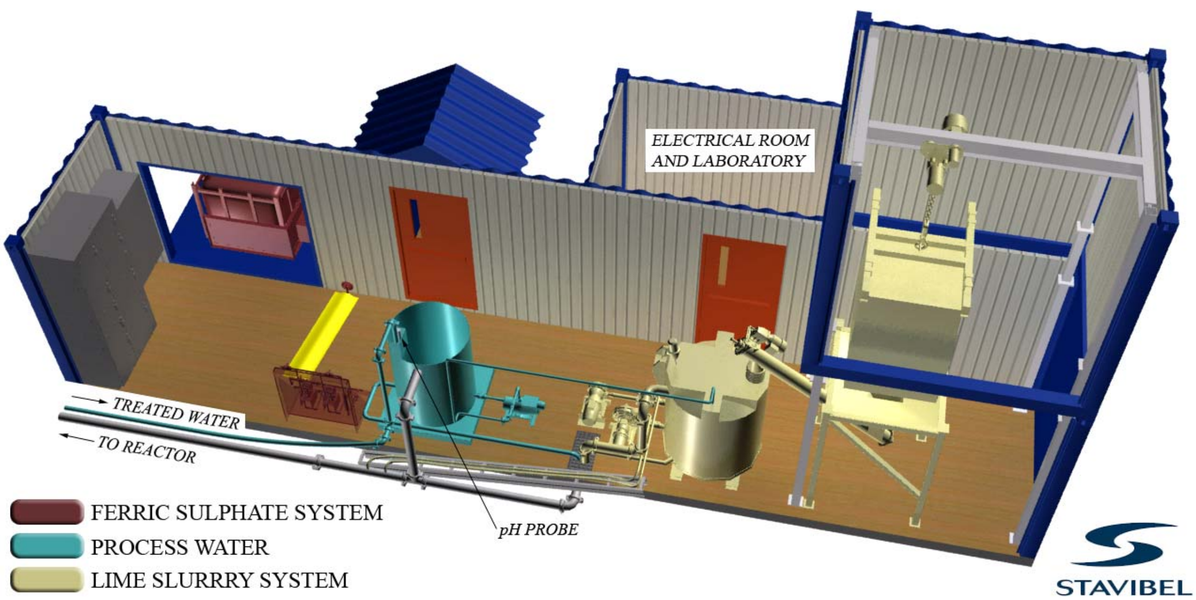

Figure 3: Three-Dimensional View of Lime Plant

The lime slurry is fed to the Ditch Reactor via one of two peristaltic pumps of different capacities (cream-colored pumps in Figure 3). The pump speed is controlled by the PLC on a pH control loop. The pH is measured inside the lime plant building in a small receptacle receiving treated water from the Ditch Reactor. Following pH measurement, this small receptacle overflows to the process water tank. This is the water used for producing the lime slurry and for general water usage.

The pH control system operates on a standard control loop (PID – proportional, integral, and derivative) controlling the speed of the peristaltic pumps. The two pumps were chosen of different sizes in order to increase flexibility. With this system, it is possible to treat a wide range of raw water qualities and flowrates.

Ferric Sulphate System

Due to the laboratory results and predicted water qualities, a ferric sulphate addition system was included in the original design of the treatment plant. It was determined that approximately 10 mg of Fe per L of raw water would be required. As an operator was to be on-site 24 hours per day, the system was designed to be manually operated. The ferric sulphate system is colour-coded in Figure 3. The solution is provided from a tote bin located outside the building. It is fed directly to the reactor by one of two motor-driven metering pumps. The pump speed is controlled manually and the flowrate can be regularly verified using a graduated cylinder included as part of the dual metering pump dosing package.

Acid Addition System

As the required pH for Ni precipitation is of at least 10.0, it is necessary to reduce the pH below the regulated limit of 9.5 prior to release into the natural environment. At Raglan, this is done using a 40% sulphuric acid solution. The acid addition system (Figure 4) consists of an independent set of maritime containers, organised as a building for all the required safety equipment, acid storage, acid feeding, pH control, agitation, flow measurement, and remote communications. The Acid Reactor receives treated, high-pH water from the Spoon site and acid from one of two solenoid metering pumps. The pH control is completed using a local pH transmitter/controller as there is no PLC at this plant.

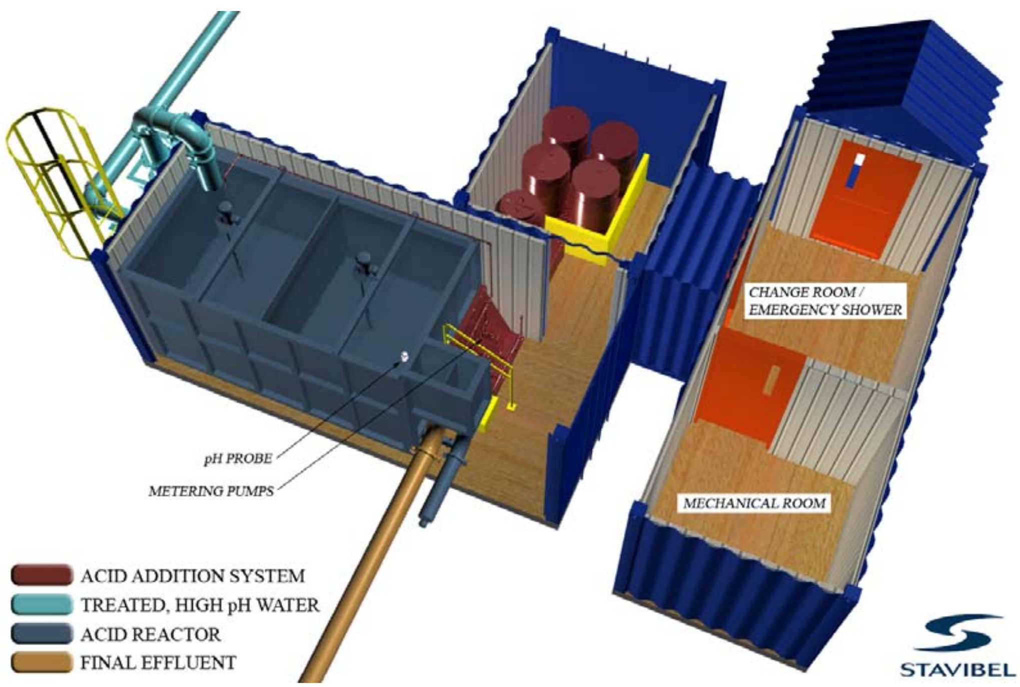

Figure 4: Three-Dimensional View of the Acid Plant

There is continuous communication from the Acid Plant to the Lime Plant through telemetry. As per Québec regulations, the final effluent flowrate and pH are monitored continuously and logged. The primary data logging is done at the mill site via a second telemetry connection between the lime plant and the Raglan mill site. A secondary backup data storage unit is included at the Acid Plant in case either of the communication systems was to fail.

INSTALLATION AND LIME PLANT COMMISSIONING

The spring thaw at Raglan can be expected sometime in June to early July. A few years ago, there was a significant thaw at the end of May, but this is unusual. The Spoon Treatment Plant installation was completed over a three-week period at the end of June and beginning of July 2007. The Lime Plant was installed first and start-up occurred immediately, on June 28th 2007. As discussed below, no water was discharged in 2007 as only the lime plant was operated.

During commissioning, flowrates and metal concentrations were much higher than expected (see Table 1). The higher concentrations may be partially due to the fact that the waste rock disposal area was also used as an ore pad during operations. As the lime system was designed to operate at different sites, there were no difficulties in supplying sufficient lime to treat this runoff. Ferric addition was not necessary as the runoff contained significant concentrations of iron. Eleven run-off samples were taken during commissioning; the Fe concentration varied from 17 to 80 mg/L with an average of 46 mg/L. The Ni concentrations varied from 10 to 51 mg/L, with an average of 28 mg/L. Copper was also present with an average concentration of 8 mg/L. By the end of 2007, it was estimated that 87,000 m^3 of water were stored in the pit. These values far exceed the original design criteria mentioned above.

Table 1: Raw Water Characteristics at Commissioning

DATE	28/06/07	29/06/07	29/06/07	29/06/07	30/06/07	30/06/07	30/06/07	01/07/07	01/07/07	01/07/07	02/07/07
Time	18:30	5:00	11:30	18:00	5:00	11:30	17:00	5:00	12:00	17:00	5:00
pH	3.69	3.4	4.95	3.64	3.75	3.78	4.73	4.89	4.34	4.86	3.73
Cu (mg/l)	8.8	14.7	15	6.2	9.1	8.7	3.9	7.2	6.8	2.6	9.9
Fe (mg/l)	48	80	76	37	41	47	21	45	36	17	58
Ni (mg/l)	27	48	51	20	26	32	13	25	22	10	37

Treated water collected from the overflow of BT showed dissolved Ni concentrations of less than 0.1 mg/L for all but one sample – this single sample had a concentration of 1.9 mg/L and occurred following a lime system shutdown during the night. The Lime Plant only operated for one week in 2007 before the decision to shut it down for the season, as discussed below.

As Spoon Pit could easily contain all the runoff from both 2007 and 2008 for safe storage of water until release in the 2008 summer season, it was decided that treatment would be discontinued and that no release of water would occur in 2007. Modifications were planned for the lime plant to improve the operational safety and ensure that all Raglan construction standards were met. The Acid Plant was to be significantly improved to add space for indoor acid storage and to meet all safety regulations for using sulphuric acid. The 2007 treatment plant start-up clearly showed that the Lime Plant could meet all requirements for proper treatment of the Spoon Pit run-off.

MODIFICATIONS AND OFFICIAL START-UP IN 2008

Some modifications were completed to the Lime Plant. These included the addition of another building (trailer) for computer data logging and site access, rest facilities, and personnel communications. A process alarm system was added, weather-proofing was improved upon, and safety equipment was also ameliorated. All modifications are included in figures 2, 3, and 4.

An emergency shower and change room were added to the Acid Plant and another small container was installed for indoor storage of sulphuric acid. Following issues with freezing and systems failings over the winter months, some equipment needed repair at both plants. The winterisation procedures had not been properly applied at the close of the 2007 season. All improvements completed in 2008 were done under the leadership of Stavibel as the main consultant.

Treatment Plant Operations in 2008

The Lime Plant was commissioned in July 2008. Figure 5 contains two graphs showing the pit lake volume (stored water), the pit lake pH, and the Ni concentrations during lime treatment. As previously mentioned, 87,000 m^3 remained in the pit from 2007. The first level reading in the pit lake showed a total volume of 112,000 m^3. This is due in large part to the considerable amount of snow which accumulates in the open pit cavity over the winter months. Runoff from both years was treated by recirculating contaminated water stored in the Pit Lake while simultaneously treating the runoff issuing from the waste rock pile by gravity. The recirculation essentially resulted in a batch treatment of the pit water. To treat the entire body of water more rapidly, the setpoint pH at the lime plant was set to 11.75. This provided significant dissolved alkalinity to the pit lake rapidly without undue loss in dissolution efficiency, as a higher pH setpoint would produce a significant percentage of undissolved lime.

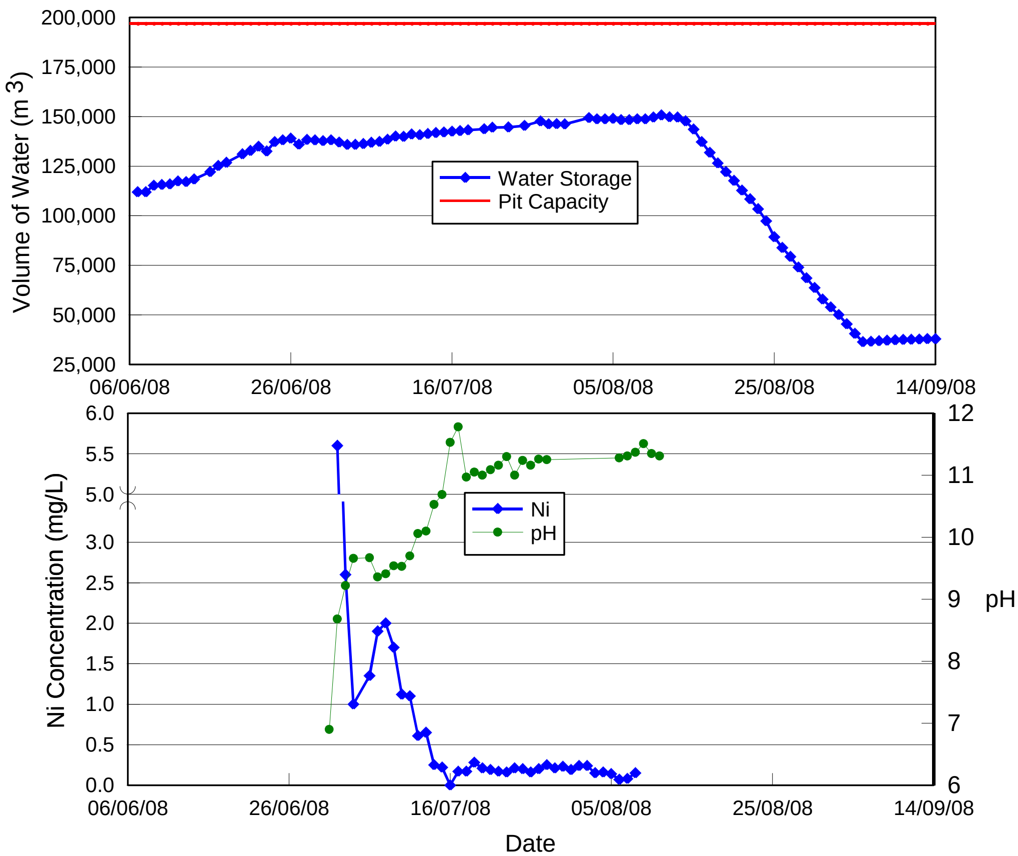

Figure 5: Pit Level and Pit Lake pH and Ni with Time

Figure 5 shows that when recirculating treatment began on July 1st the initial pH was 6.9 and the Ni concentration was of 5.6 mg/L (note that the Ni concentration axis is discontinuous). Within 2 weeks of treatment, with approximately 142,000 m^3 contained in the pit, the pH had attained 10.5 and the Ni concentration was at 0.25 mg/L. Treatment was continued longer than necessary and resulted in final Ni concentrations of approximately 0.15 mg/L with a pH of 11.3.

The Acid Plant start-up and commissioning occurred on August 13th, 2008. The plant discharged to the environment at an average flow of 222 m^3/hr for a total of 115,432 m^3. The acid plant operated for 23 days and consumed 3,463 litre of sulphuric acid (40%). When operations were discontinued on September 5th 2008, Spoon Pit contained a volume 36,000 m^3. Overall, the final effluent pH and Ni concentrations averaged 7.7 and 0.08 mg/L, respectively.

FUTURE PLANS FOR THE SPOON PIT TREATMENT SYSTEM

Due to the successful operation of the system in 2008, Xstrata Nickel, Raglan Mine is planning to increase the treatment capacity at Spoon Pit to receive runoff from another open pit operation (Donaldson) 10 km away. The lime plant can handle additional water without modification while a new acid addition system will be necessary. The original acid addition system was designed for 140 m^3/h but operated at more than 220 m^3/h in 2008. Although modifications to the existing system could bring the capacity up to 350 m^3/h, an increased capacity of 500 m^3/h is preferred as this will better meet Raglan's long-term needs. Stavibel and EnvirAubé are involved in the design of this capacity increase.

CONCLUSION

A mobile lime treatment system was designed, built, and commissioned for a small open pit on the Xstrata Nickel, Raglan Mine property. Despite considerably higher than expected metal concentrations and runoff volumes, the treatment system successfully removed the nickel and other metals from solution, producing an effluent that met all discharge requirements.

ACKNOWLEDGEMENTS

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