Enhancing Biological Nitrogen Removal from Mine Site Water in Cold Climate

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Abstract

Biological nitrogen removal from cold mine water can be challenging due to low biological activity of the biomass, which may increase the size of the treatment unit and lead to increased costs. This paper introduces some design solutions that may improve the usability of biological nitrogen removal in cold climate. These solutions include taking advantage of warmer seasons and the thermal energy of underground mine water, heating and reuse of waste heat produced in concentration plants, treating a specific water stream with a considerable nitrogen load, and pretreating the influent.

Keywords: Moving Bed Biofilm Reactor, Biological Nitrogen Removal, Nitrogen Compound, Cold Climate, Waste Heat

Introduction

Nitrogen compounds, such as ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-), in mine site discharge water can cause eutrophication in barren Northern environments, since natural background concentrations are generally low. In some mines in Nordic countries, current environmental permit regulations limit the total nitrogen concentration discharge water to 14 mg/L. In addition, authorities have been paying more attention to nitrogen loading of mine sites than before, which indicates that environmental permits are tightening.

Careful detonation or passive removal techniques are not always sufficient, or even possible, actions to reduce the nitrogen loading to the environment. In some cases, active treatment techniques are needed to keep under the environmental permit limits. A proven technology for the biological removal of nitrogen from cold mine site waters is the moving bed biofilm reactor (MBBR), which has been demonstrated to sustain long-term nitrogen removal even at temperatures around 4 °C.

Sources of Nitrogen

Nitrogen compounds reach mine site water streams from the detonation of nitrogen-based explosives. Other possible nitrogen sources are nitric acid (HNO_3), used in pH adjustment and in metal recovery processes, and cyanide (CN^-) from gold extraction. Since nitrogen discharges to water streams cannot be fully avoided, active or passive water treatment of mine site discharge water may be required to remain within environmental permit limits and to reduce environmental impacts.

The main sources of nitrogen compounds in the mining industry are explosives. The amount of nitrogen ending up in mining waters varies from mine to mine. From 0.2 to 28% of nitrogen from ANFO (ammonium nitrate/fuel oil) explosives can get into drainage water (Sjölund 1997; Morin and Hutt 2009; Jermakka *et al.* 2015). Explosive usage in underground mines can be higher compared to open-pit mines, due to overloading of some areas and incomplete detonation of loaded boreholes (Jermakka *et al.* 2015). From 5 to 20% of the loaded explosives' nitrogen in underground mining operations and 1% in open-pit operations can remain in blasted material from which it may dissolve in water. Proper mine water management can reduce the contact between blasted material and water, thus reducing the nitrogen load to water streams. This is possible especially in underground mines.

Due to the usage of explosives, mine dewatering water can be a substantial source of nitrogen discharged into the environment. Depending on the nitrogen balance of a mine, treating mine dewatering water may reduce nitrogen loading significantly, which makes its treatment beneficial. In mine dewatering water, nitrogen compounds are often in a more reduced form compared with leachates from dumping areas. This is due to the nitrification processes taking place at dumps (Nilsson 2013). In a study by Morin and Hutt, dissolved nitrogen concentrations in underground mine dewatering water were studied after blasting. It was noticed that 51–56% of the total nitrogen was present as NO_3^- while 40–46% was NH_4^+ and 2.9–4%, NO_2^-. (Morin and Hutt 2009)

Nitrogen compounds dissolve at waste rock dumps where rainfall and melted snow infiltrate through the deposits. The deposits can release nitrate and ammonia long-term. However, the ammonium and nitrate release can also be rapid when the waste rock material comes into contact with water (Jermakka *et al*. 2015). Spring flooding can cause considerable nitrogen release from the deposits due to low microbiological activity in cold water and extensive runoff volume (Mattila *et al*. 2007). Oxidation of nitrogen species in the waste rock dumps has been identified mainly during summer. At the same time, the low organic matter proportion in the deposits may limit denitrification. (Jermakka *et al*. 2015)

Another possible nitrogen source is the excess water of processing plants. In the process unit operations, blasted rock material comes into contact with water, and ammonium and nitrate may leach into the process water (Jermakka *et al*. 2015). Process water pH tends to be low. Acidic and reducing conditions lead to denitrification when the concentrations of ammonium, ammonia (NH_3), or nitrogen gas are increased. Due to the reducing environment, the main nitrogen components of processing plant effluents are ammonium and ammonia. Besides the nitrogen species originating from explosives, the use of nitric acid, ammonium chloride or ammonium hydroxide in the process may increase nitrogen discharges. (Bosman 2009)

Processing plant effluent discharges are usually led to a tailings pond with tailings material. Possible acidic pH of the effluent and tailings can cause reducing conditions at the tailings pond as well, if ammonia and ammonium concentrations are elevated.

Contrary to the tailings pond, conditions at water ponds are often oxidizing. In water ponds, the fraction of nitrate has been observed to increase up to 70–95% while ammonium and nitrite fractions are 0–10% and 2–30%, respectively. Oxidation is increased during the summer season due to increased biological activity. Water ponds can remove nitrogen especially when retention time is long and a carbon source, such as some plants that may release carbon compounds, is available. (Mattila *et al*. 2007; Jermakka *et al*. 2015)

Choosing the water stream to be treated with an active nitrogen removal process depends on the nitrogen balance. It is often beneficial to target the water treatment to certain water streams with the highest nitrogen loads. The load depends on the nitrogen concentration and water flow rate. This kind of **targeted water treatment** reduces the required treatment capacity and thus decreases the investment and operating costs. Often, major nitrogen loads result from mine dewatering, and thus mine dewatering water treatment can be most beneficial. Also, waste rock dumps, with their long-term nitrogen release characteristics, generate runoff suitable for targeted water treatment.

Effect of Temperature on Biological Treatment Processes

Biological processes are strongly dependent upon temperature. As an example, nitrification rates double with a 10 °C increase, while denitrification rates double with 4 °C increase. In general, the optimal nitrification temperature ranges from 8 to 30 °C (Given and Meyer 1998).

The impact of cold temperatures on decreased microbial activity in biological treatment can be addressed and overcome with the application of moving bed biofilm reactors (MBBRs). In an MBBR, the microbial biomass grows as a biofilm on a protected surface area provided by plastic carrier elements that are freely moving within the whole reactor volume. This allows for long biomass retention times (i.e., high biomass concentrations in the reactor), and the process can be operated at low temperatures without relying on sludge age as a design parameter. As an example, treatment of mine site waters even at 4 °C has resulted in complete nitrification and denitrification (Dale *et al.* 2015). The MBBR process can be designed for even lower temperatures. However, size of the treatment unit needs adjustment based on the effect of temperature on the microbial kinetics. MBBRs are also known for compactness and for being able to handle variations in load, temperature and toxic shocks better than biological processes relying on biomass in suspension rather than on biofilm attached to carriers. Therefore, the design is a trade-off between the operating temperature and size of the process. The process could further benefit from warmer seasons, external heating, relocating the treatment facility close to a heat source, or pretreatment (Fig. 1).

Benefits from Warmer Seasons

In Northern areas, seasonal temperature variations are substantial and affect the temperature of mine site waters. In Nordic countries, mine water temperature is above 5 °C approximately five months a year depending on the site location. During summertime, referring to a three-month period from June to August, the water temperature can range from 15 to 20 °C. Most of the year, the water temperature stays below 5 °C, mostly around 1 to 2 °C, or even close to 0 °C.

Approximately 50–80% of total site runoff, caused by snow melting, occurs during the three-month summer period, depending strongly on site location and typical climatic conditions of the area. This season can be considered warm season, and the water temperature is over 5 °C. However, the main runoff peak usually occurs in late spring or early summer when the water temperature is still below 5 °C. During the snowmelt peak flow, concentrations of nitrogen and other compounds are relatively low. However, due

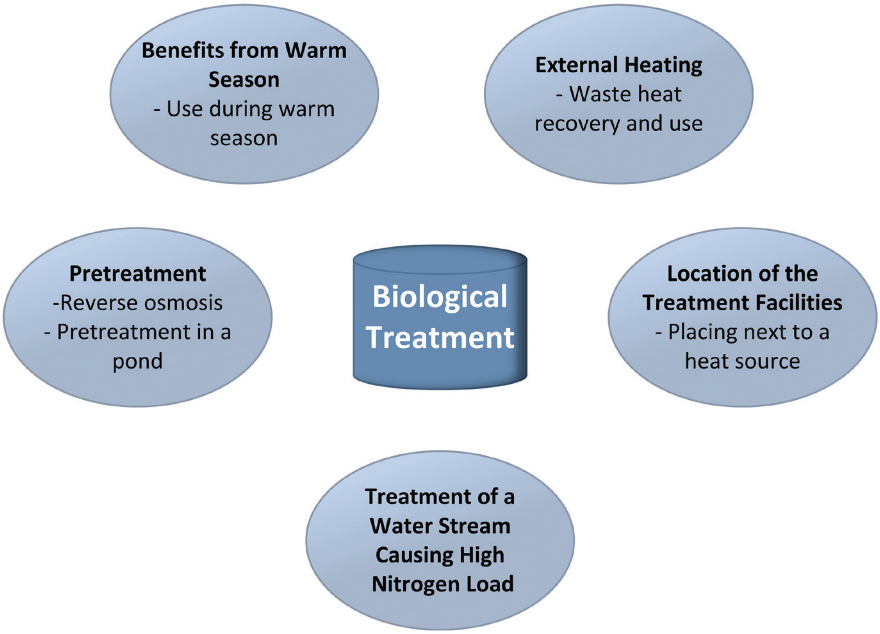

Figure 1 *Enhancing Biological Nitrogen Removal Processes in Cold Climate.*

to high flow rates, environmental loading can become high. The runoff peak period may be a challenge for biological nitrogen treatment due to high flow rate and low temperature.

Part of the runoff peak is usually retained on the mine site and stored in water ponds. To enable nitrogen removal, it might be beneficial to store the nitrogen-containing water streams until the summer period to take advantage of the natural temperature increase. Such operations, however, require careful site water management.

External Heating

In biological processes, heating is most beneficial during start-up to improve biomass activity. When the biological process is working, external heating becomes less important. Also, during the coldest season, heating may be required to increase biological activity.

In Nordic mines, the heat source for buildings and domestic hot water production is often a fuel, such as wood chips burnt in a boiler. The produced heat is distributed with a district heating system. During peak consumption, more expensive fuels, such as oil, natural gas, or liquefied petroleum gas, can be burnt in the boilers. Heating nitrogen-containing water with external heating sources can similarly be done. However, heating large volumes of water increases operating costs of biological treatment considerably and causes environmental impacts, although it is one of the most effective ways to enhance biological nitrogen removal.

Mines consume a lot of energy, for example, in extraction, processing, and mineral transportation, as well as to sustain operations and to avoid environmental risks (Patsa *et al.* 2015). Use of energy causes waste heat generation, which, until now, has been relatively poorly recovered in the mining industry. Waste heat usage can reduce environmental impacts by reducing the use of required energy sources. A possible waste heat source of mine sites are concentration plants where, for example, compressors and grinding circuits generate waste heat and need cooling. The compressors generate remarkable amounts of heat since 100% of energy fed into the compressors turns into heat. Most of the heat can be recovered from the cooling system by using heat exchangers and transferring the energy, for example, to a water circuit. In a case study, available water-heating power of screw compressors was estimated to be 100–150 kW. (Holopainen *et al.* 2013)

High temperature processes, such as autoclaves and digesters, are also possible waste heat sources. Recovered heat is already consumed, for example, in the preheating of incoming materials. However, heat recovery potential still exists. As an example, recovery from calcination exhaust gases has been identified in aluminium production. (Brough and Jouhara 2020) Mine exhaust air has also been described as having potential for waste heat recovery. In a case study, the exhaust air temperature was 15 °C and its energy content was estimated to be substantial (Holopainen *et al.* 2013).

In addition, renewable energy sources such as geothermal energy have substantial potential. Until recent years, geothermal energy had rarely been used in the mining industry (Boynton *et al.* 2018). Mine dewatering water is often described as a heat resource from which geothermal energy can be recovered (Obracaj and Sas 2018). However, if mine dewatering water requires biological or other treatment which benefits from elevated temperatures, heat recovery from dewatering water is not advisable. In such a case, geothermal energy should be recovered from another source.

Location of the Treatment Facilities

In treatment of underground mine dewatering water, the biological water treatment unit can be located in an underground mine to prevent on-surface heat losses. In general, mine water temperature is approximately 10 °C at 100 m below the ground surface, and it increases by 1 °C when depth increases 100 m; however, temperature is location dependent. (Holopainen *et al.* 2013).

Mine water temperature and dewatering flow rate are affected by surface water flow into the mine. Surface water inflow causes substantial monthly flow rate and temperature variations. The amount of surface water inflow to underground mines varies from mine to mine.

Space availability may limit locating a water treatment unit underground, as biological treatment can require large treatment units. Alternatively, the treatment unit could be located on ground-surface level close to the mine portal where on-surface heat losses from the mine water would still be minimized.

Similarly, the biological process could be located next to its potential external heat source. If external heating is done with the energy of the heat plant or waste heat of the concentration plant, locating the treatment close to the heat source, if mine site layout allows, is beneficial.

Pretreatment

RO

Reverse osmosis has been studied as a concentration method prior to biological processes. In a study, actual mine water having relatively low ammonium concentration, 9.48 mg/L, was concentrated up to 104 mg/L NH_4-N. It was observed that the permeate quality did not deteriorate considerably in the concentration of feed above a volumetric reduction factor of 20. RO produces purified water to be used in other processes or to be let into the environment. However, besides nitrogen compounds, salt and metals may concentrate in the process, which can cause metal toxicity to microorganisms. (Häyrynen *et al.* 2008) Ammonium concentration can become a limiting factor in the concentration process. If ammonium concentration increases above 1 gN/L, ammonia may be generated at high pH levels, which may inhibit biological activity.

The concentrated stream produced in RO can be treated biologically. The concentration process considerably decreases the volume of basins required in the biological process. Also, concentrated water volume reduces heating costs and may reduce the use of fresh water if the permeate can be used instead. However, pretreatment increases investment and operating costs, estimated to be 0.31–0.34 €/m³ in a study by Häyrynen *et al.* and 0.488 US$ in a study by Grossi *et al.* (Häyrynen *et al.* 2008; Grossi *et al.* 2021).

Pretreatment in a Pond

Nitrogen removal requires nitrification, where nitrogen in reduced form is oxidized. In the second phase, nitrate can be reduced in anoxic conditions to nitrogen gas. As a pretreatment method, nitrogen compounds can be pre-oxidized in ponds through biological processes. The phenomenon occurs in relatively low temperatures, although cold temperature slows down the process and increases the formation of nitrite and ammonia. Vegetation can also take up a fraction of nitrogen. The process can be enhanced with aeration when contact with air is improved or with the implementation of MBBRs downstream of lagoons (LagoonGuard™ MBBRs; AnoxKaldnes_VWT).

In gold-processing plants, cyanide (CN^-), and cyanide-derived compounds thiocyanate (SCN^-) and cyanate (CNO^-) can be present in effluents. Prior to biological treatment, their oxidation can be enhanced with the addition of oxidizing chemicals, such as H_2O_2 or Caro's acid (Kratochvil *et al.* 2017), but also biologically using specially designed MBBRs for this effect (Tracer™Cyanides – MBBR; AnoxKaldnes-VWT).

Conclusion

Biological processes are commonly used methods for nitrogen treatment of waters from the mining industry. Nevertheless, biological activity decreases in low temperatures typical of cold-climate regions.

One possibility to enhance biological treatment processes is to implement biological treatment technologies that are able to cope with colder temperatures and process variations, such as MBBRs, and/or to preferentially treat biologically during warmer seasons when water temperature naturally increases. This requires water storage during winter and peak runoff seasons. Water heating with an external source is also possible, although it adds to the operating costs and increases environmental air emissions. Recovery of waste heat and its use in water heating is an interesting topic and could have potential in biological water treatment.

Depending on the feed water quality, pretreatment can also enhance the biological treatment process. For example, oxidation of nitrogen compounds with aeration or with chemicals can improve and simplify the actual biological treatment process. Another pretreatment process is reverse osmosis, which can be used as a concentration method to reduce the size of biological treatment basins and thus decrease the investment costs.

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