A Holistic Approach to Water and Salt Management in Mining: Biological Treatment Solution to Allow Direct Discharge of Excess Water Instead of Brine Production through Reverse Osmosis Treatment

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Abstract

Ions present in mine effluents such as Cl, SO_4, NO_3 and associated cations can be removed using a variety of technologies including membrane technologies such as nanofiltration and reverse osmosis (RO) or biological treatment in the case of NO_3. In the early stages of the mine, concentrations of ions such as Cl and SO_4 are generally below the limits imposed for direct discharge, leaving mainly nitrate (and occasionally cyanide in case of gold mining) to be removed. Biological nitrogen removal in the presence of elevated free cyanide concentrations (20 mg/L) was demonstrated using a 4 stage MBBR system consisting of 2 aerobic stages followed by an anoxic stage and a final re-aeration stage. Residual NH_4-N and NO_X-N were observed following a rapid step change in free cyanide however biological activity was not completely inhibited and the process recovered within a 24 hr following the step change. Biological treatment of nitrogen compounds is thus a viable alternative to reverse osmosis when ions such as Cl and SO_4 do not need to be removed. This allows direct discharge of treated effluent without producing an RO brine and avoids building up the concentration of highly soluble salts in the tailings ponds over time.

Keywords: Mining, Salt Management, Denitrification, Cyanide, MBBR

Introduction

Mines operating in excess water need to discharge water. Discharge limits for sulfate vary from site to site. However 1000 mg/L as maximum concentration for sulfate and 250 mg/L for chloride are not uncommon. Nitrate limits tend to be variable depending on geography. Water management to control salinity is therefore required. In gold mining, cyanide compounds can also be problematic.

Ions present in mine effluents such as Cl, SO_4, NO_3 and associated cations can be removed using a variety of technologies including membrane technologies such as nanofiltration and reverse osmosis (RO) or biological treatment.

In the case of membrane technologies, salts are removed from solution by concentrating them into a brine which needs to be managed. A common approach is to recycle the brine to the mine water storage ponds. Over time, increases in salinity will be observed, eventually reaching the technical limitations of the membrane process in place. Once the limitation of the membrane process is reached, energy intensive processes such as thermal crystallisation or cryo crystallisation will need to be implemented to continue the treatment of the excess mine water.

In the early stages of mine operation, concentrations of highly soluble salts sodium chloride and sodium sulfate are generally below the limits imposed for direct discharge, leaving mainly nitrate (and possibly cyanide in case of gold mining) to be removed. This hardly justifies the installation of membrane processes as biological treatment can provide a sustainable alternative to avoid salinity increases in the overall water infrastructure of the mine and metallurgical plant. Biological nitrate removal converts nitrate to nitrogen gas which is released to the atmosphere. The process by which nitrate is converted to nitrogen gas is called denitrification and is commonly used in both municipal and industrial applications. The process, occurring under anoxic conditions, is defined by the following equation 1:

$$NO_3^- + \mathit{Organic\ matter} \rightarrow N_2 + CO_2 + H_2O \qquad \textit{Equ 1}$$

The Moving Bed Biofilm Reactor (MBBR) developed in the 1990's is particularly suitable for nitrogen removal in challenging applications such as low temperature or effluent containing toxic compounds; its use has been well documented (Rusten 2000, Vincent 2016). The MBBR utilises a polyethylene carrier, AnoxK^{TM}5, with a large protected surface area for biofilm development. The media used is shown in Figure 1.

The carriers have a density close to that of water, making it possible to keep the carriers in suspension and constant movement by either aeration or mechanical mixing, thus allowing operation under aerobic or anoxic mode. Bacteria develop on the carriers without the need for long retention times, resulting in compact reactors. Installing several reactors in series allows the development of specific microbial communities in the individual reactors, thereby optimising the operating conditions for specific pollutant removal and allowing high removal rates to be achieved.

The MBBR process has been installed on a wide range of industrial applications, including several mines in Canada (Villermur 2015, Dale 2020). The advantages of using biological treatment for nitrogen removal over reverse osmosis are: a higher tolerance for influent solids, no requirement for heavy physical and chemical treatment of influent to prevent membrane fouling and no brine generatation. This results in lower maintenance cost and lower energy costs per m^3 treated.

For biological treatment to be a viable alternative compared to reverse osmosis and avoid salinity build up in the water loops as a result of RO brine discharge, biological treatment also needs to address cyanide compounds to comply with discharge standards where this compound is present. Whilst nitrate removal using MBBR is a well established process, removal of cyanide at elevated concentrations as can be found in gold processing plants effluent is not well documented.

The aim of this study was to evaluate the performance of an MBBR system in removing cyanide, ammonia- nitrogen, nitrate and nitrite associated to the gold processing plant effluent and simulate an incident of high free cyanide concentration due to an accidental discharge of cyanide into the tailings ponds. A pilot trial using a 4-stage MBBR plant

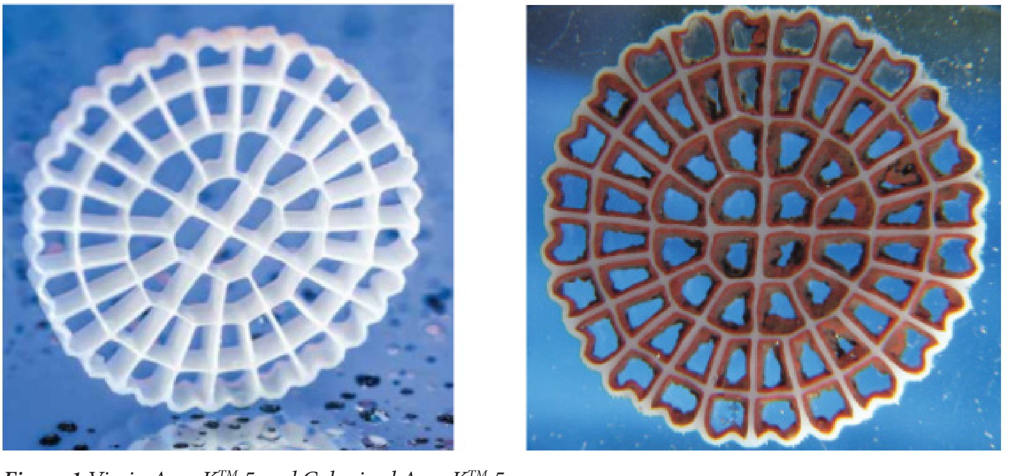

Figure 1 *Virgin AnoxK^{TM} 5 and Colonized AnoxK^{TM} 5*

Table 1 Operating conditions in each MBBR reactor

	R1	R2	R3	R4
Operating regime	Aerobic	Aerobic	Anoxic	Aerobic
Hydraulic retention time	1.3 -1.7 h	1.3 -1.7 h	1.3 -3.5 h	1.3 -3.5 h
Chemical dosing	Phosphoric acid for cell synthesis		carbon source (molasse or ethanol)	

Table 2 Characteristics of pilot plant influent wastewater

		Min	Average	95%ile
pH		6.73	7.73	8.39
EC	µS/cm	953	1394	1735
Turbidity	NTU	0.78	23	49
SCOD tot	mg/L	4	62.6	117
TSS	mg/L	1	18	42
SO_4	mg/L	99	230	329
Cu	mg/L	0.01	0.3	0.57
NH_4-N	mg/L	0.01	4.0	9.5
NO_2-N	mg/L	23.0	40.6	56
NO_3-N	mg/L	18.8	33.2	49
free CN	mg/L	0.001	0.2	1.11

was run at a mine in Ghana to demonstrate that MBBR is a viable alternative to reverse osmosis. The data from the trial is presented below.

Methods

A pilot plant consisting of 4 MBBR reactors operated in series was installed at an operating gold mine site with a gold processing plant and was operated for a period of 18 months.

The reactor configuration is described in Table 1.

The pilot plant was fed with pre-treated supernatant from the tailings pond (PTWT): pre-treatment consists of chemically assisted solids removal (Hydrex 62301 and cationic polymer) and pH correction. A solution of sodium cyanide was added to the pilot influent towards the end of the trial to increase the influent CN concentration. The free CN concentration was increased to a concentration of 20 mg/L for a 24hr period to simulate an accidental discharge of free cyanide to the tailings ponds for a short period.

The flow to the MBBRs was modified according to the performance observed until the optimal operating conditions were found.

Daily grab samples of the influent and treated effluent were taken and analysed on site for the following parameters: free cyanide (HACH 8027), ammonia (HACH 10031), nitrite (HACH 8507), nitrate (HACH 8192). Copper was analysed in the influent using HACH 8506.

Results

The characteristics of the pilot plant influent (PTWT effluent) over the test period are summarised in Table 2.

Significant variations in influent quality were observed during the test period. The variations are due to changes in mining, gold processing plant activity and the weather. NH_4-N / NO_X-N concentrations increase during blasting operations and decrease during the wet season (April to June). Figure 2 shows the variations in free CN, NH_4-N and NO_X-N concentrations in the influent and effluent of the pilot plant.

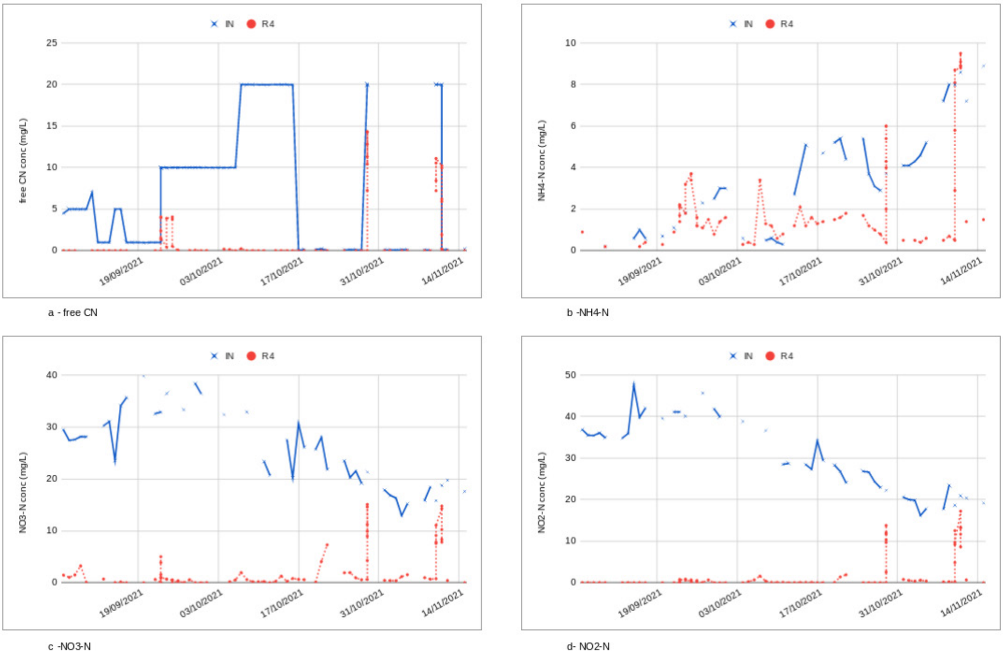

Figure 2 *Evolution of free CN (a), NH_4-N (b), NO_3-N (c) and NO_2-N (d) concentrations in the influent and effluent of the pilot plant*

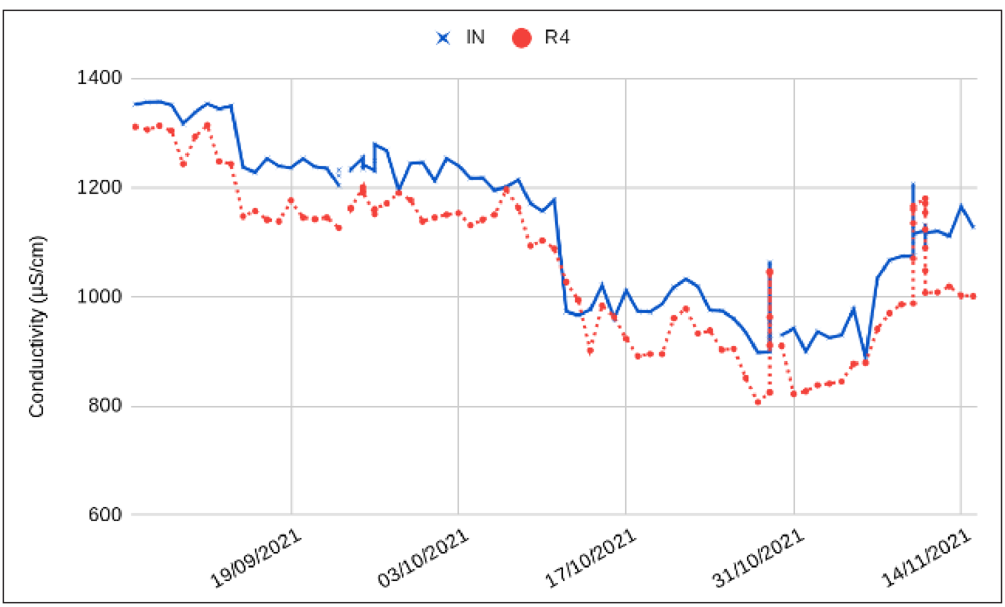

Figure 3 *Evolution of conductivity across the MBBR system*

The data presented in Figure 2(a) demonstrate that the 4 stage MBBR pilot system can handle free CN concentration up to 20 mg/L on a continuous basis following a period of acclimatisation and consistently produce an effluent with a free CN concentration < 0.2 mg/L. Nitrate and nitrite removal is not affected by the free CN since it is removed upstream of the denitrification reactor. Complete NO_X-N removal is observed.

During the spiking event at 20 mg/L free CN undertaken after 2 weeks of low influent free CN concentration (0.1 mg/L), a peak in effluent NH_4-N , NO_3-N and NO_2-N concentration is observed for a 24 hr period following the peak in free CN concentration, Figure 2 (b) (c) and (d). Complete nitrogen removal is observed within 24hrs of the step change in free CN concentration.

The average denitrification rate obtained was 1.2 gN/m^2.d however since complete NO_3-N and NO_2-N removal was observed it is likely that higher removal rates can be achieved.

The evolution in conductivity across the MBBR system is shown in Figure 3. A decrease in conductivity can be observed across the MBBR as a result of nitrate removal.

Conclusions

Biological denitrification of mine effluent has been installed at full scale at a number of mines and has proved to be a viable treatment solution. Denitrification in the presence of high free cyanide concentration that can be found in gold mine effluent is however not well documented.

A 4 stage MBBR system consisting of 2 aerobic stages followed by an anoxic stage and final re-aeration stage was installed at an operating mine and pre-treated effluent from the tailings pond was used as influent. A solution of sodium cyanide was added to increase the free cyanide concentration being tested and to challenge the system. Complete nitrogen removal was achieved with influent free cyanide concentration up to 20 mg/L. The biological treatment was further challenged by introducing a 24 hr spike of free cyanide of 20 mg/L after a 2 week period of influent free cyanide of 0.1 mg/L. Monitoring of the effluent following the CN spike showed that the nitrification and denitrification processes were both affected, residual NH_4-N and NO_X-N were observed during the spiking event and for another 24hr following the event. The tests demonstrated that the MBBR process can handle significant variations in free cyanide concentrations without completely inhibiting the biological process and recover within less than 24 Hours. Although effluent discharge would not be possible following a step change in free CN concentration, the recovery time to achieve a complete nitrogen removal is sufficiently low that recycling the effluent to the existing tailings pond or a holding pond would make this technical alternative to concentration processes environmentally and financially attractive to both the gold mining companies and the regulators.

The trial has demonstrated that biological treatment of nitrogen compounds to nitrogen gas in the presence of cyanide is a viable alternative to reverse osmosis and can avoid the gradual increase in highly soluble salt concentration and conductivity of mine tailings pond observed when RO brine is discharged to the pond. Biological treatment of mine effluent from the start of the mine operation when only nitrogen removal is required provides a sustainable framework for tailings management and could avoid negative legacy issues.

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