Innovative, low-energy treatment to remove contaminants from process wastewater and ML/ARD

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ABSTRACT: Mines, whether active or non-operational, can generate significant volumes of wastewater from mineral extraction / processing and from surface water that infiltrates the mine and comes into contact with contaminants. Waste streams of particular concern are high strength ammonia and metal leaching/acid rock drainage (ML/ARD), which must be collected and treated to prevent adverse impacts to surface and groundwater resources. Regulations limiting these contaminants continue to be strengthened, such as recent changes to Canada's Metal and Diamond Mining Effluent Regulations (MDMER) that took effect in June 2021 and limit the monthly mean concentration of un-ionized ammonia in effluent discharge to 0.5 mg/L. This paper will highlight innovative technologies and case studies of simple, low-energy technologies that can be cost-effectively installed and operated to address challenging waste streams from active and non-operating mines. This paper will introduce a fixed-film (biofilm) technology that can be installed directly into wastewater treatment ponds to improve cold-weather ammonia removal and enable a mine site to meet more stringent discharge limits and increase the discharge rate from the plant. A recent case study will be presented to illustrate the results of a containerized pilot system that operated at a gold mine from August to December 2021. The system operated in two phases, receiving influent from two different cells of the wastewater system. This allowed the pilot system to demonstrate cold-weather nitrification at highly variable ammonia loading rates. This technology successfully demonstrated its ability to remove up to 80% of the influent ammonia and achieve compliance with MDMER. This paper will also focus on case studies for the permanent and long-term use of chemical conditioning and geotextile dewatering bags as a combined system that can be used to adjust pH, precipitate metals and capture and retain solids. This technology is particularly useful in situations where there is perpetual and unpreventable drainage from historic resource extraction sites. This technology was successfully used to treat slurried material impacted with arsenic at a concentration of 9,800 mg/L producing a treated filtrate with an arsenic concentration of 0.008 mg/L (i/e., < Health Canada DW Guidelines). These systems require little to no additional disturbance to existing sites and can accommodate a wide range of flowrates, covering seasonal fluctuations and thereby reducing the need for large pre- and post-treatment storage capacity. In some cases, the retained solids have proven to contain elevated concentrations of marketable compounds that can be considered a secondary benefit to utilizing these treatment systems. One case study will demonstrate the treatment of acid rock drainage using geotextile technology that has led to the recovery of valuable rare earth elements while preventing adverse impacts to downgradient waterbodies. A second similar case study will describe the collection and dewatering of sludge produced from the treatment of arsenic-laden groundwater that continually infiltrates a gold mine.

1 INTRODUCTION:

Mines, whether active or non-operational, can generate significant volumes of wastewater during mineral extraction and processing, and from surface water that infiltrates the mine and comes into contact with contaminants.

The wastewaters must be collected and treated to prevent adverse impacts to the environment and to surface and ground water resources. However, the remote location of many mines poses significant challenges to the implementation of robust, affordable solutions for difficult-to-treat contaminants such as high strength ammonia and metal leaching / acid rock drainage (ML/ARD). Regulations limiting these contaminants continue to be strengthened, such as recent changes to Canada's Metal and Diamond Mining Effluent Regulations (MDMER) that took effect in June 2021 and limit the monthly mean concentration of un-ionized ammonia in effluent discharge to 0.5 mg/L.

Innovative fixed-film biological treatment and chemical precipitation followed by geotextile dewatering provide innovative, low-energy alternatives that can significantly improve the removal of contaminants without adding complex or costly infrastructure to the mine site.

2 LOW-ENERGY BIOLOGICAL REMOVAL OF AMMONIA IN COLD CONDITIONS WITH ROPE-TYPE MEDIA

Temperature is an important consideration for ammonia removal in wastewater treatment lagoons, since the nitrifying bacteria that provide ammonia removal are temperature sensitive and become less active and less effective in cold conditions. As a result, the wastewater lagoons that serve mines and other industrial sites often struggle to achieve the required ammonia target during the winter months.

Fixed-film treatment systems are increasingly considered and selected as a means to improve ammonia removal through a sidestream or in-situ secondary treatment process. These treatment technologies include trickling filters, rotating biological contactors, fluidized bed, moving bed biofilm reactors, biological granulated carbon, membrane aerated biofilm and immobilized cell reactors. They offer several advantages over conventional activated sludge systems including ease of use, ability to handle shock loads, improved process stability and resiliency, lower sludge production and a smaller footprint. (Sheewa et al, 2022).

Some general disadvantages may also be encountered and include clogging of the media due to inadequate screening, excessive biofilm growth that may also cause clogging or free-floating media to sink, high energy use, and inadequate mixing or short-circuiting causing inefficient use of the media (Sheewa et al, 2022).

The introduction of rope-type media addresses these disadvantages and provides a more cost- effective, resilient and less complex process to improve ammonia removal, even under challenging conditions such as high loading rates or cold weather.

A pilot study was conducted at a Canadian gold mine to test the effectiveness of a rope-type media, called Bishop BioCord Reactors, from August to December 2021. The system is developed and manufactured by Bishop Water Technologies (Arnprior, Ontario, Canada). The BioCord media incorporates woven polypropylene loops arranged on a central support cord to maximize surface area for biofilm development (Figure 1). The key objectives of the pilot trial were to treat wastewater from the mill and tailings, assess the ability of the system to achieve cold-weather nitrification and to determine the average ammonia removal rates (grams of NH_3 removed per day) of the system.

Figure 1. A BioCord system shown during installation into a municipal lagoon. A closeup of the clean BioCord media (top right) and a the media after establishment of a robust biofilm (bottom right).

2.1 Pilot setup and operation

The components of the BioCord Pilot System were installed in a 40-foot sea container (Figure 2). Four open-top tanks, each with a working volume of 3,600 L were installed in the container. Tank 1 was used as a break tank to equalize flow prior to treatment. Tanks 2, 3 and 4 were each equipped with a BioCord Reactor that included a fine bubble diffuser tubing integrated into the base of the module. These components provided sufficient surface area and oxygen for nitrifier growth and proliferation. Wastewater was pumped from a treatment pond at the mine site to Tank 1, which was then pumped to the first treatment tank.

Figure 2. A BioCord Reactor Pilot System equipped with a break tank and three reactor modules.

The pilot system was fed with wastewater from two different locations. From August 30 to October 11, 2021 the system was fed from C2 Upper Pond (C2UP) and from October 12 to December 13, 2021 from C3 Lower Pond (C3LP). The average ammonia concentrations of C2UP and C3LP were 4.83 mg/L and 22.32 mg/L respectively. The location was changed to test the system's ability to treat the higher concentration of influent ammonia from C3LP.

2.2 *Wastewater characteristics*

Table 1. C2UP and C3LP wastewater characteristics.

Total Ammonia (NH_3/NH_4^+)			Loading (g/day)		Ammonia Removal (g/day)	Influent Temp (ºC)
Flow rate (L/min)	BioCord Reactor Influent (mg/L)	BioCord Reactor Effluent (mg/L)	Influent	Effluent		
Intake Point - C2 Upper Pond (Aug 30 - Oct 11, 2021)						
Max	9.10	4.30	128.16	53.28	119.52	21.70
Min	0.70	0.00	5.04	0.00	4.97	14.10
Average	4.83	1.13	49.44	11.67	37.77	17.79
STD	2.69	1.36	32.89	14.26	26.93	1.81
Intake Point - C3 Lower Pond (Oct 12 - Dec 13, 2021)						
Max	32.00	26.10	237.89	208.66	163.73	19.80
Min	9.67	1.15	69.62	8.28	5.18	0.50
Average	22.32	14.51	147.94	92.98	54.96	6.55
STD	5.21	7.36	35.92	45.13	40.48	5.39

A one-time metal analysis for pond C3LP by an external lab and the concentrations were compared to effluent limits set by the Canadian Council of Ministers of the Environment (CCME). The results showed that the levels of copper, iron, molybdenum, selenium and zinc exceeded the CCME limits, raising concerns that the concentrations could inhibit the nitrification rate by the BioCord biofilm.

2.3 *Evaluation of BioCord nitrification performance*

The nitrogen removal performance of the system is influenced by several factors such as the NH_3-N and COD loading, DO concentration in the reactor, temperature and pH. The temperature of the influent wastewater varied from as high as 19.8ºC to a low of 0.5ºC. The first phase of the pilot, influent wastewater was drawn from C2UP, which had an average ammonia concentration of 4.83 mg/L and an average temperature of 17.78ºC. The system demonstrated its ability to achieve an average ammonia removal of 80.22% and a peak removal of 100%.

The system was then moved to draw more challenging wastewater from C3LP, which had an average ammonia concentration of 22.32 mg/L. Figure 3 shows the ammonia removal results of the pilot system. The thick gray vertical line shows where the wastewater source was changed.

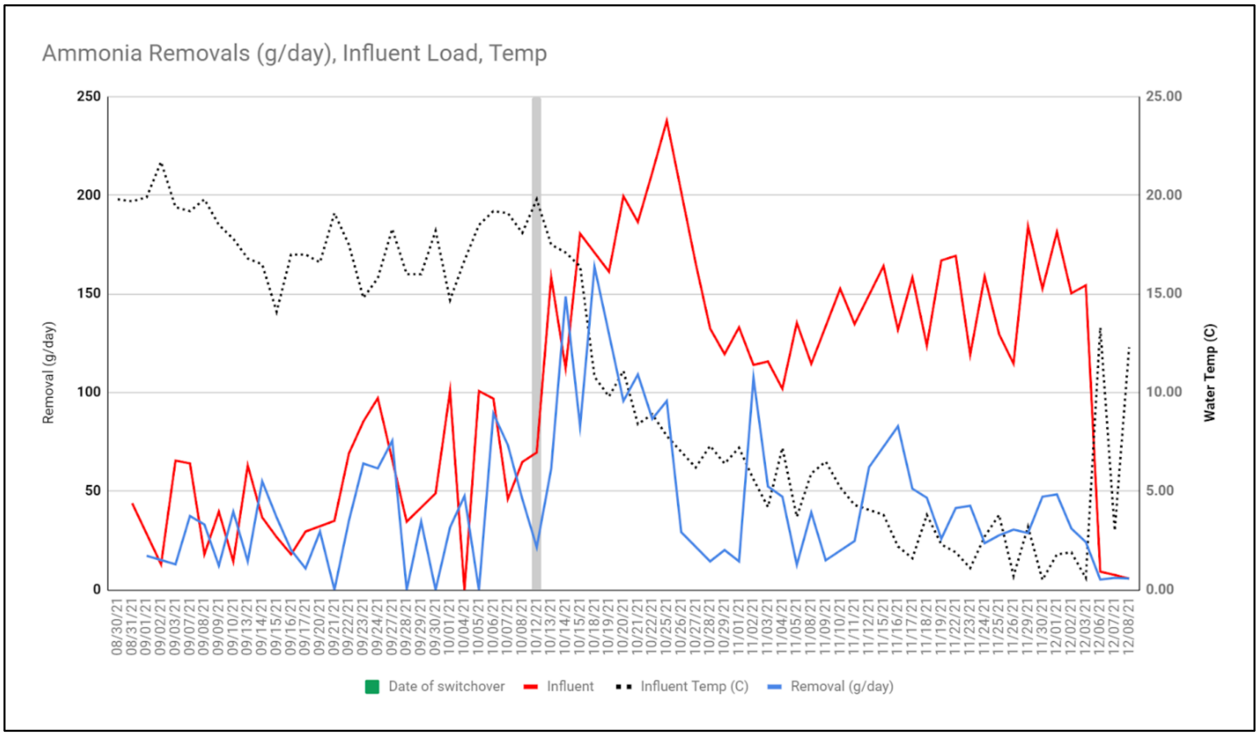

Figure 3. The combined effect of loading and temperature change on BioCord ammonia removal. The gray vertical line represents a change in the wastewater intake from C2UP to C3LP.

In the first part of the pilot, prior to switching the intake point, the average ammonia removal rate was 37.77 g/day, even though the temperature was declining. After the switch, the average rate was 54.96 g/day. It is important to note that the temperature of the wastewater dropped quite quickly after the intake point was changed and the ammonia load increased significantly. The BioCord system had minimal time to acclimatize and reach a steady-state condition with the new, greater ammonia loads. As a result, the overall percent removal of the ammonia declined due to the combined impact of an increased ammonia load and sharply reduced temperature. In an ideal situation, the BioCord system would be commissioned in warmer weather to reach a steady-state prior to the onset of cold-weather conditions. This will enable nitrification rates to be maintained and minimize or eliminate a decrease in the percentage of ammonia removed in the colder months of the year. It was noted that the higher concentrations of metals in the wastewater did not significantly impact the performance of the BioCord pilot system.

Canada’s MDMER, which was revised in June 2021, states that the maximum concentration limit of unionized ammonia in treated effluent is 0.5 mg/L. The pilot system consistently achieved compliance with MDMER, producing an average effluent ammonia concentration of 0.08 mg/L for C2UP and 0.27 mg/L for C3LP (Figure 4). Table 1, above, also shows the amount of ammonia that was removed on a daily basis by the system.

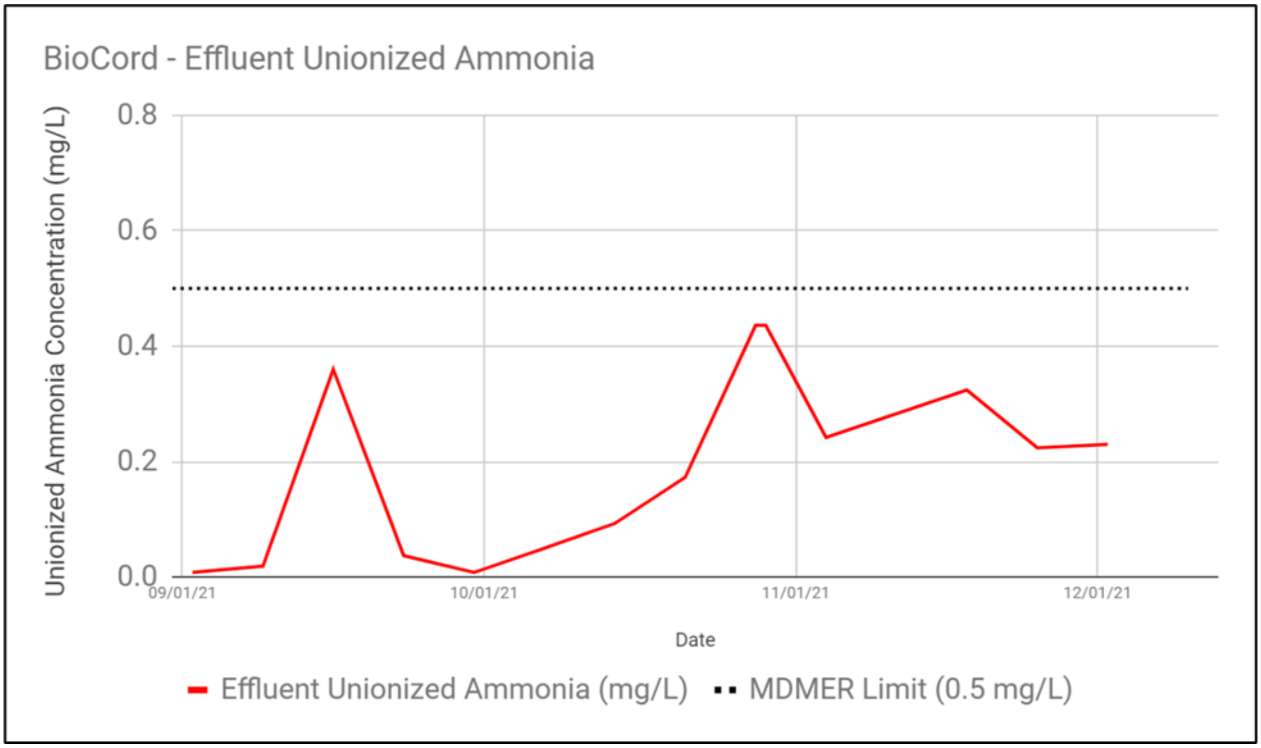

Figure 4. Effluent unionized ammonia concentrations from the BioCord Reactor System.

The data collected informs the design of the full-scale system and ensures the optimum amount of media to handle the ammonia loading under all anticipated conditions. A full-scale BioCord system can be installed directly into the treatment pond, thus eliminating the cost and additional equipment of sidestream processes that require tanks, pumps, blowers and piping to operate. The in-situ configuration, combined with an energy-efficient aeration system can enable cost savings of 50% or more, both in capital and operational expenditures.

3. COLLECTION AND DEWATERING OF ML/ARD SLUDGE WITH GEOTEXTILE CONTAINERS

The metal analysis performed for the BioCord pilot system revealed that the wastewater contained elevated levels of several metals as a result of mineral extraction and processing. Water can also become contaminated as it infiltrates the mine and comes into contact with naturally occurring minerals such as arsenic. As the water is pumped from the shafts, or seeps out naturally, it must be treated before it can be discharged to the environment.

Geotextile woven polypropylene bags have long been used for applications such as coastal shoreline protection and to collect and dewater slurry materials where consolidation of solids is the primary objective. This simple, low-energy approach is ideal for remote locations as an alternative to mechanical methods and conventional clarification technologies.

Several operating and non-operating mine sites have installed such systems to provide a long-term solution for collecting and dewatering chemical sludge produced resulting from the treatment of contaminated ML/ARD wastewaters. These systems can provide pH adjustment, precipitation of metals, capture of precipitate, dewatering and in some cases, permanent onsite containment. The systems have been shown to achieve volume reductions as high as 75 to 85% with acid mine drainage materials, which significantly reduces the residuals that require onsite storage or landfill disposal. (Kaye, 2016)

3.1 Dewatering and containment of ARD materials and rare earth recovery.

The Omega Mine, near Morgantown, West Virginia, USA, has been using Geotube® dewatering containers since 2016 to continuously collect and dewater ARD sludge. The treatment plant collects ARD from three different abandoned mines at a rate of about 1–2 m^3/min. The pH varies and can be as low as 2.8. The first step of the treatment process adds hydrated lime to raise the pH to 6.0 and precipitate dissolved solids. An anionic polymer is also added to flocculate the solids. The precipitate then flows to a clarifier where it settles and concentrates to about 2% solids.

Figure 5. At left, an aerial view of the dewatering cell at the Omega Mine At right the third layer of Geotube containers shown in 2018.

From the clarifier, the slurry is pumped to a large dewatering cell with multiple Geotube containers. Each container is 13.7 m (45 ft) in circumference and 74 m (243 feet) in length. As the ARD slurry is pumped in, it is retained in the Geotube and clear filtrate is released through the pores of the woven polypropylene material. Since commissioning in 2016, there have been no violations of the effluent discharge requirements. The dewatering process achieves about 45% solids by weight within seven days and 65% within 30 days.

Figure 6. A comparison of the clarifier slurry at 2% solids (left) and the dry solids at 65% from the Geotube dewatering process at the Omega Mine.

The dewatering cell is designed to accommodate multiple layers of Geotube containers, enabling operators to stack new empty bags on top of the full ones in the layer below. The facility is currently on its third layer of Geotube dewatering containers and has sufficient capacity to receive and dewater ARD sludge for 20 years. Table 2 shows the operational parameters of the Geotube dewatering system. (Stephens, 2019)

Table 2. Omega Coal Mine acid mine drainage treatment plant and Geotube dewatering operation

Incoming flow rate	46 m^3/hr (200 gpm)
pH range	2.3 – 3.4
Lime adjustment pH	6.0 – 7.5
Heavy metals and sulphate (ppm)	1,985
Allowable discharge limit (ppm)	3.73
General operating discharge (ppm)	< 1.0

Source: West Virginia Department of Environmental Protection

Figure 7. A comparison of a stream impacted by ARD before the commissioning of the treatment system and Geotube dewatering (left) and after (right).

3.2 Recovery of rare earth elements from ARD clarifier slurry held in Geotube containers

In 2017, the University of West Virginia sampled 152 sources of raw ARD water as part of a study to identify potential sources of rare earth elements (REEs) in the Appalachian region. They found that the average concentration of REE from ARD point sources was 410.6 grams per ton of dry solids, and included a wide range of REEs (Figure 8.). The researchers also sampled the dewatered ARD solids at the Omega Mine. The results showed that the average concentration of REE at the site was 397 grams per ton, which meant that the Geotubes were retaining almost 97% of the REEs in the sludge. As a result, each Geotube at the site could contain as much as 58 kg of REEs. At the time the study was done, researchers estimated that the REEs in the consolidated sludge at the Omega Mine would be worth about $800,000 and that their recovery was economically viable. (Stephens, 2019.)

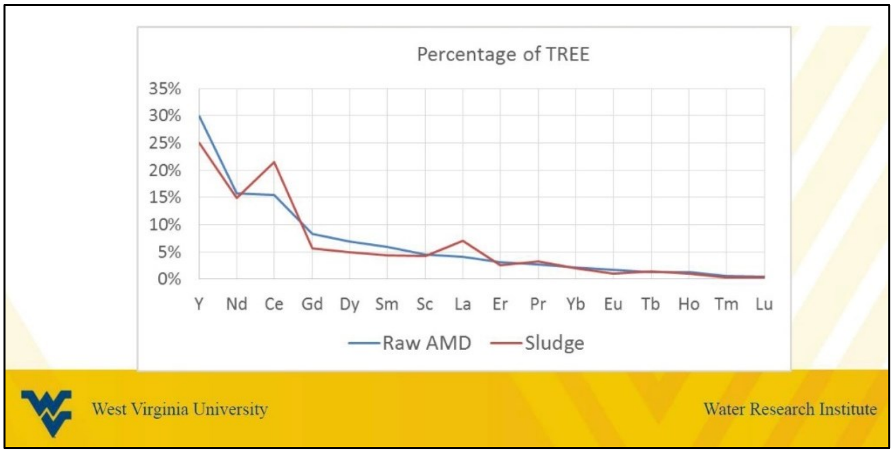

Figure 8. Percentage of REEs found in ARD sludge. West Virginia University.

3.4 Efficient, cost-effective collection, dewatering and permanent storage of arsenic sludge at a gold mine

In 2016, an underground gold mine in Western Canada installed a mobile microfiltration (MF) system to remove arsenic from groundwater that is continually pumped from the shafts. The system operates 24-hours per day since water constantly infiltrates the mine and becomes contaminated with arsenic as it percolates through the rock and contacts the naturally occurring element. During spring thaw, the rate of water infiltration can rise as high as 1,000 L/min and arsenic levels can exceed 500 ppb.

As the water is pumped out, ferric chloride is added to precipitate the arsenic before it is sent to the MF system for separation. However, the high arsenic concentration requires large doses of ferric chloride and produces a significant amount of sludge. As a result, the MF system needs to be backwashed about out every 45 minutes and produces approximately 1,900 liters of sludge each time.

The high volume of sludge was challenging to manage with the existing media filtration system and the site needed a faster, more reliable and more cost-effective way to separate and dewater the solids and ensure the final effluent met provincial regulations for discharge to a nearby creek.

Bishop Water Technologies installed its Mobile Solids Management Solution, a simple, low-energy process that uses Geotube® containers, polymers and gravity to collect and dewater the process sludge and then store the dried solids. The compact system operates inside the mine's mill building and provides reliable performance with little operator oversight. Backwashed sludge from the MF system is collected in an 88m3 mix tank. Every 12 hours, the sludge is pumped from the mix tank to one of two Geotube containers that are set up inside roll-off dewatering bins (Figure 10).

Figure 10. Two Geotube containers are set up in roll-off bins to collect and dewater the arsenic sludge. Once full, operators can easily move the bin to an onsite storage area, tip out the Geotube, and replace it with a new one.

As the sludge is pumped, Bishop Water's non-mechanical VEPAS (Venturi Emulsion Polymer Activation System) adds the optimal dose of polymer directly into the feed line to accelerate dewatering and retain solids. Clear filtrate is released from the pores of the Geotube and is pumped to another tank for testing prior to release. An operator verifies that the arsenic levels in the filtrate are below the regulatory limit of 10 ppb (0.01 mg/L) before it is released to a pond that empties into a creek.

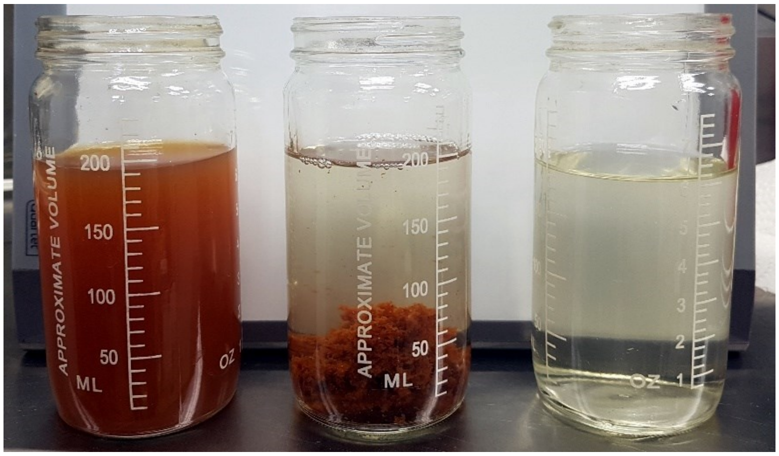

Figure 11. Jar testing shows the results of the process. From left: A sample of the sludge backwash from the MF system; solids clump together after polymer addition; clear filtrate is released from the Geotube container.

The Bishop Solids Management Solution has been operating alongside of the MF system since 2016, providing operators with a simple, reliable way to manage the backwash sludge and continually meets discharge requirements for arsenic.

Once the Geotube container is full, the roll-off bin enables the operator to easily transport it to a storage location in the tailings facility where they are left for permanent storage. After dumping the bin is returned to the mill and a new Geotube container is laid out in the bin.

4. CONCLUSION

Innovative, low-energy systems can significantly improve nutrient removal and solids management for process and ML/ARD wastewaters.

Fixed-film, rope-type media, such as BioCord Reactors, has been shown to improve ammonia removal for wastewater treatment ponds that operate in cold environments. BioCord Reactors can be installed directly into a treatment pond at lower capital cost than alternatives and provides robust, year-round ammonia removal. A pilot test conducted at a Canadian gold mine in 2021 showed that the system can remove up to 100% of the influent ammonia and is unaffected by cold conditions and not significantly impacted by higher heavy metal concentrations in the wastewater, thus enabling a mine to consistently achieve the MDMER limit of 0.5 mg/L for unionized ammonia.

Geotextile woven polypropylene containers and selected polymers also offer an energy-efficient and easy-to-use process for dewatering ARD sludge from operating and non-operating mine sites. These systems can achieve volume reductions as high as 85%, significantly reducing the volume of residuals that require disposal or onsite Research by West Virginia University has shown that the ARD sludge contains as much as 397 grams of rare earth elements per ton, suggesting that this material may be an economically viable domestic resource for manufacturing communication, energy, defense and aerospace products.

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