IMPROVING COLD-WEATHER AMMONIA REMOVAL IN A NORTHERN LAGOON WITH AN IN SITU, ROPE-TYPE MEDIA SYSTEM. CASE STUDY OF A FULL-SCALE DEMONSTRATION PROJECT.

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1. INTRODUCTION

Wastewater treatment lagoons in Canada are continually challenged during cold weather to achieve ammonia and BOD removal targets, since heterotrophic and nitrifying bacteria become less active at low temperatures. Upgrade options to improve cold-weather performance often recommend replacing the lagoons with a mechanical treatment plant or adding a post-lagoon treatment process.

Each of these alternatives incorporate more complex, energy-intensive processes that may result in considerably higher capital and operating costs than the lagoon. Since wastewater lagoons typically service smaller communities, these groups face significant budgetary constraints when selecting an upgrade option that can be affordably procured and operated over the long term.

The extreme cold conditions faced by many Canadian communities further complicate lagoon process improvements. Any upgrade technology that is considered must be able to maintain biological activity for ammonia and BOD removal when wastewater is at near-freezing temperature.

As water temperatures decrease below 15 ºC in conventional wastewater lagoons, the activity of suspended bacteria—especially ammonia-reducing nitrifiers—declines significantly, leading to reduced contaminant and nutrient removals (Metcalf and Eddy, 2003). Since the inactive microorganisms are merely suspended in the water column and have no substrate to attach to, they wash out easily with the hydraulic flow. This causes a significant decline in the concentration of bacteria in a lagoon and diminishes the ability of the microbial population to recover during the cold season.

Bishop BioCord™ Reactors provide wastewater-treating microorganisms with the optimal conditions for growth, proliferation and nutrient metabolism on a unique, high-surface-area polymer substrate. This rope-type media, combined with optimized fine bubble aeration, can achieve a stable biofilm that insulates microorganisms within the biofilm layers and maintains active, responsive treatment in cold temperatures. Washout of bacteria is significantly reduced to enable continuous treatment in high hydraulic loading and in winter conditions.

FIGURE 1. BIOCORD MEDIA IS A CONDOMINIUM FOR BACTERIA THAT INCREASES THE CONCENTRATION OF MICROBES TO IMPROVE COLD-WEATHER REMOVAL OF BOD AND AMMONIA

This paper presents a case study about the Gift Lake Metis Settlement in Northern Alberta and the process to assess lagoon performance and select an upgrade technology. The paper will also discuss the design of the full-scale demonstration project to install low-energy, fixed-film BioCord™ Reactors directly into the wastewater lagoon to improve the removal of ammonia and biochemical oxygen demand (BOD). BioCord's in situ design eliminates the need for additional system infrastructure such as buildings, tanks, blowers and pipes, which significantly reduces capital costs. The BioCord system will be installed while the lagoon remains in operation, which further reduces costs and minimizes disruption to wastewater services.

The full-scale demonstration project is funded substantially by the Federation of Canadian Municipalities (FCM), Green Municipal Fund, which supports innovative technologies that offer transformative potential, significant environmental, economic and social benefits and a strong implementation plan.

2. LAGOON CONFIGURATION AND ASSESSMENT

The Gift Lake Metis Settlement is located about 400 km north-west of Edmonton, Alberta and is home to about 775 residents. Wastewater from the community is treated by a lagoon system (Figure 1) that consists of two anaerobic settling cells and two facultative treatment cells.

Treated effluent from the lagoons is pumped to two storage cells located about 2.2 km to the south-east. Table 1 provides the dimensions and volumes of each treatment cell in the lagoon system.

TABLE 1. DEPTH AND VOLUME OF THE GIFT LAKE LAGOONS

	Flow rate	Cell	Description	Depth (m)	Volume (m^3)	HRT (days)
Lower Lagoon	190 m^3/day	1	Settling/holding (Anaerobic)	2.70	450	2.5
		2	Settling/holding (Anaerobic)	2.70	450	2.5
		3	R-1 Holding	1.50	10,250	55
		4	F-1 Facultative (Retention)	3.40	34,000	180

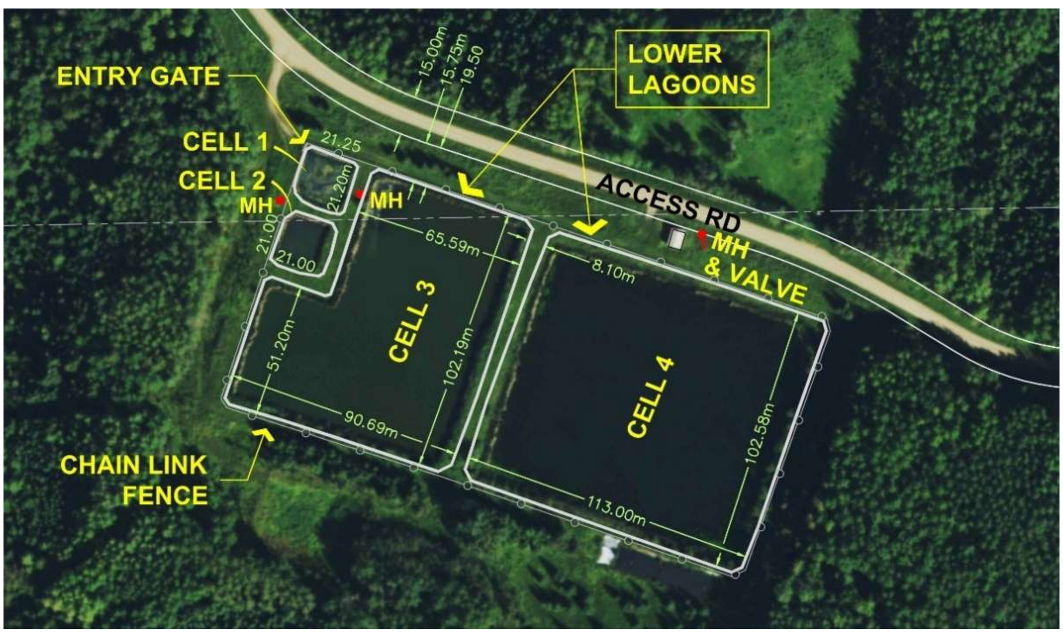

FIGURE 2. DIMENSIONS AND ARRANGEMENT OF THE GIFT LAKE SEWAGE LAGOONS

These clay-lined lagoons were constructed in the early 1980s. Originally, Cell 3 provided facultative treatment and Cell 4 provided storage of treated effluent. In 1997, two new storage cells were constructed 2.2 km to the south-east and Cell 4 was converted to a facultative treatment lagoon.

An assessment of the lagoons, conducted in 2019 by TeckEra Consulting Ltd., revealed that the treated effluent released from the lagoons during the permitted discharge period exceeded the federal Wastewater System Effluent Regulations (WSER) limit for un-ionized ammonia and biochemical oxygen demand (BOD), which are set at < 0.1 mg/L and < 25 mg/L respectively.

Upgrades to the lagoon would be required to improve the treatment performance and to increase treatment capacity to accommodate community growth, which was conservatively projected at two per cent annually.

The assessment also identified heavy sludge accumulation in the anaerobic cells, identified as Cell 1 and Cell 2 in Figure 2. The high volume of sludge significantly reduces the treatment capacity of the cells and is causing carry over of sludge into Cell 3, the first facultative cell.

3. SELECTING AN UPGRADE TECHNOLOGY

Several options for mechanical pre-treatment of influent were evaluated by TeckEra to improve the treatment capacity and performance of the lagoon system. BioCord Reactors, designed and manufactured by Bishop Water Technologies, were selected as the preferred option for the following:

- The in situ design eliminates the need to expand the plant footprint or add post-lagoon treatment components, which reduces capital costs;
- The semi-passive system is self-regulating and self-cleaning. It aligns with current lagoon operation and requires little operator attention;
- Compressors, instead of blowers, efficiently provide aeration and are the only system components that require power or regular maintenance, which reduces long-term operating costs;
- The modular system is easily expandable to accommodate population growth or more stringent discharge regulations. Capacity and performance upgrades can be completed while the lagoon remains in operation,.
- The fixed-film technology has demonstrated its ability to remove ammonia and BOD at lagoon wastewater temperature as low as 0.5°C.

BioCord performance data was presented to TeckEra and the Gift Lake Metis Settlement to support the performance capabilities and operational benefits of the system. These references included:

3.1 St. Henry, Ohio – Loading exceeds design parameters

One pilot study ran through an entire cold season (Sept. to May) at a four-cell lagoon system in St. Henry, Ohio, USA. The containerized BioCord system was designed to treat influent wastewater according to the parameters provided by the site, which were 15 mg/L ammonia and 75 mg/L BOD. Influent was drawn from Cell 2 and treated effluent from the BioCord system was released to Cell 3.

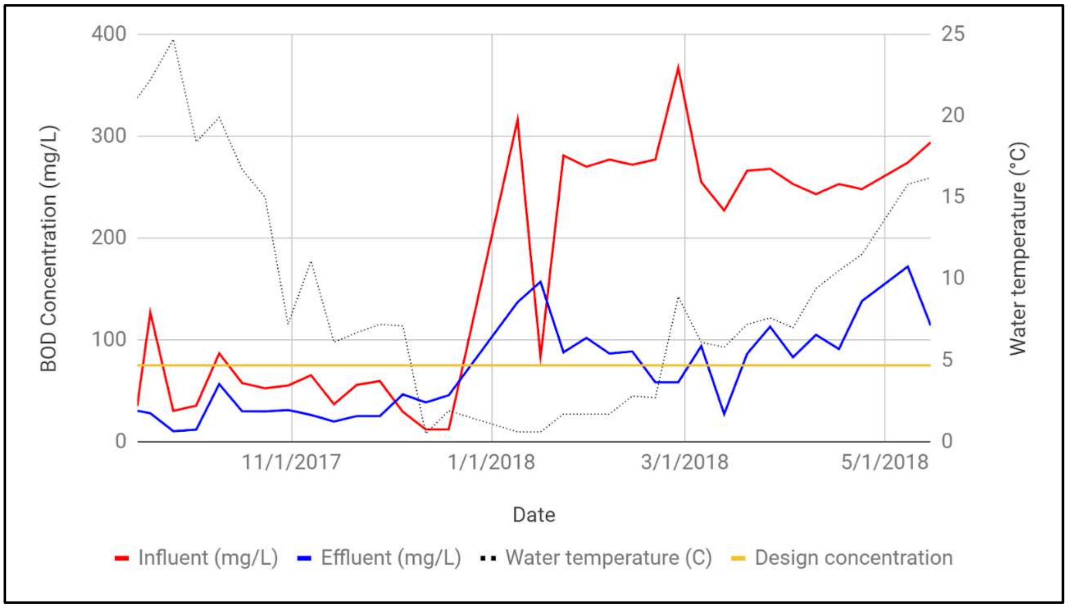

FIGURE 3. BOD REDUCTION ACHIEVED BY BIOCORD PILOT SYSTEM AT ST. HENRY, OHIO

During the first few weeks of the pilot, the influent BOD level was within the design specification for the system. However, as temperatures declined towards the end of November, BOD spiked sharply and remained well above the anticipated design load for the remainder of the pilot study. On average, the influent BOD was 166 mg/L, or about 120% higher than the design load and peaked at about five times the design load (Figure 3).

Similarly, ammonia loading also escalated and was significantly higher than anticipated. On average, the influent ammonia was 24 mg/L, or about 60% higher than the design load and peaked at almost three times the design load (Figure 4).

A significant portion of the pilot project was conducted when the wastewater temperature was below 10 °C, and at times, as low as 0.5 °C. Despite the low temperature and influent variability, the BioCord system responded to the higher loading with increased removal of ammonia and BOD. Table 2 shows the average reductions of constituents vs. design targets.

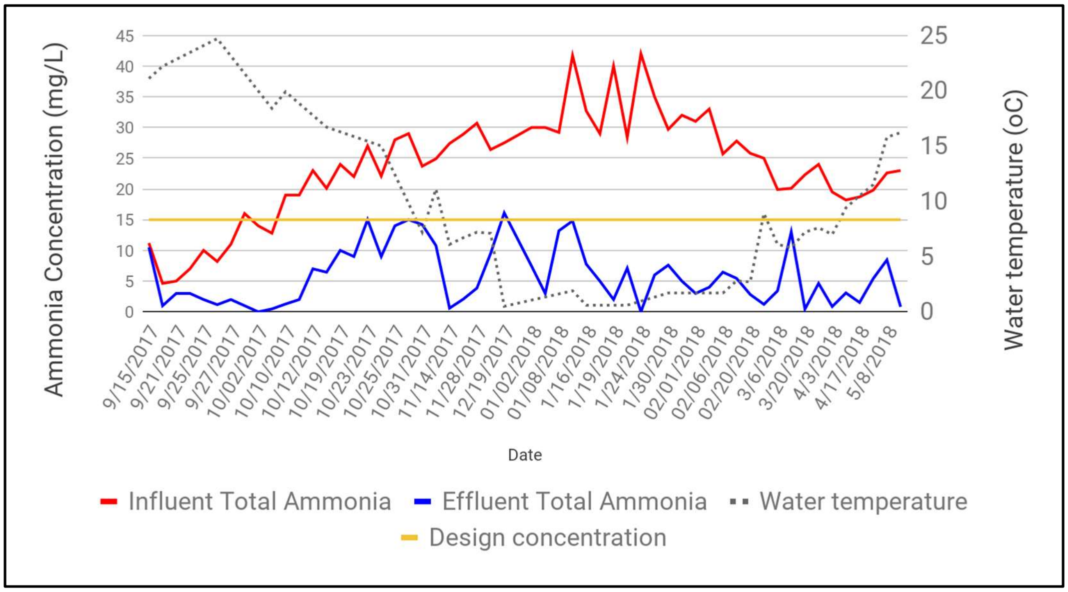

FIGURE 4. AMMONIA REMOVAL BY BIOCORD PILOT SYSTEM

TABLE 2. BIOCORD PERFORMANCE DURING SPECIFIC PERIODS (ST. HENRY, OHIO

	Avg. BOD reduction (mg/L)	Avg. ammonia reduction (mg/L)
Design target	75	15
Full project duration	97.6	17.9
WW temp < 10 °C	118.8	23.2

The single-reactor pilot system was also able to overcome the high influent BOD, which can limit nitrification. A high level of soluble BOD causes preferential growth of heterotrophic (BOD-reducing) bacteria, which grow faster and can outcompete nitrifiers to impede ammonia removal. In this case, however, the BioCord system demonstrated its ability to achieve and maintain high reduction of BOD and ammonia in challenging conditions.

3.2 Comparing BioCord cold-weather performance to a lagoon at a petrochemical manufacturing site

Another pilot study presented to the Gift Lake Metis Settlement examined a containerized BioCord pilot system was that installed at a petrochemical manufacturing site in Western Canada. This study was intended to demonstrate the system's ability to perform cold-weather ammonia removal and to evaluate its performance against the three-cell lagoon system at the site.

The pilot study ran for only 14 weeks from, August to mid-November, as ambient and wastewater temperatures declined. The pilot system was originally equipped with only one BioCord Reactor, however, a second one was added after five weeks of operation to optimize the removal of organics and ammonia. The influent wastewater from Cell 2 of the lagoon system was high in BOD. Like the St. Henry's pilot, this resulted in abundant growth of heterotrophic, BOD-reducing bacteria on the single reactor, which was not conducive for ammonia removal. The two-reactor arrangement would permit BOD removal to continue in the first tank and enable nitrifiers to become established in the second tank.

In the following weeks, the system demonstrated its ability to achieve high BOD and ammonia removal and significantly outperform Cell 2 biological activity. The BioCord system consistently removed 93% of the influent BOD at a loading rate of 0.55 g cBOD/m^2/day. By comparison the lagoon could only remove 27% of the influent BOD during the same period (Figure 5).

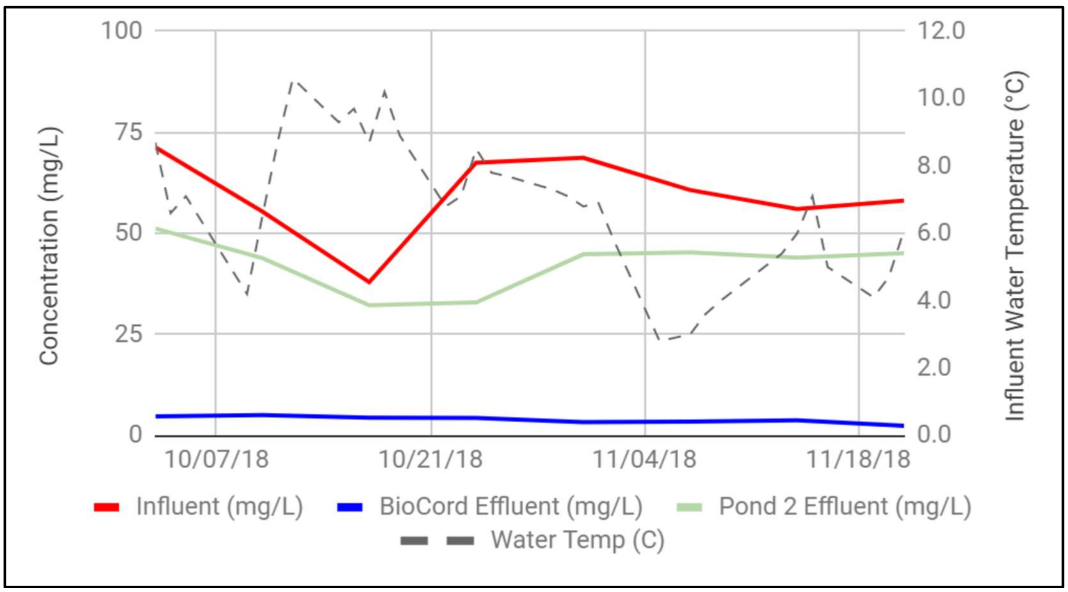

FIGURE 5. BOD REMOVAL FOR BIOCORD VS. POND 2 (WESTERN CANADA)

As the population of nitrifiers increased on the second BioCord Reactor, ammonia levels decreased. The system achieved average ammonia reduction of 67%, which is far greater than the 2% ammonia reduction that the lagoon was able to achieve over the same period (Figure 6). A longer testing period would have demonstrated the system's ability to maintain steady-state nitrification, maintain consistent ammonia removal over a longer cold period, and achieve greater average ammonia reduction. The study also reinforces best practices in system design, which consider a broad range of factors. These include peaks and variability in contaminant loading, the treatment performance of preceding lagoon stages and the appropriate level of conservatism when specifying the amount of rope-type media and aeration.

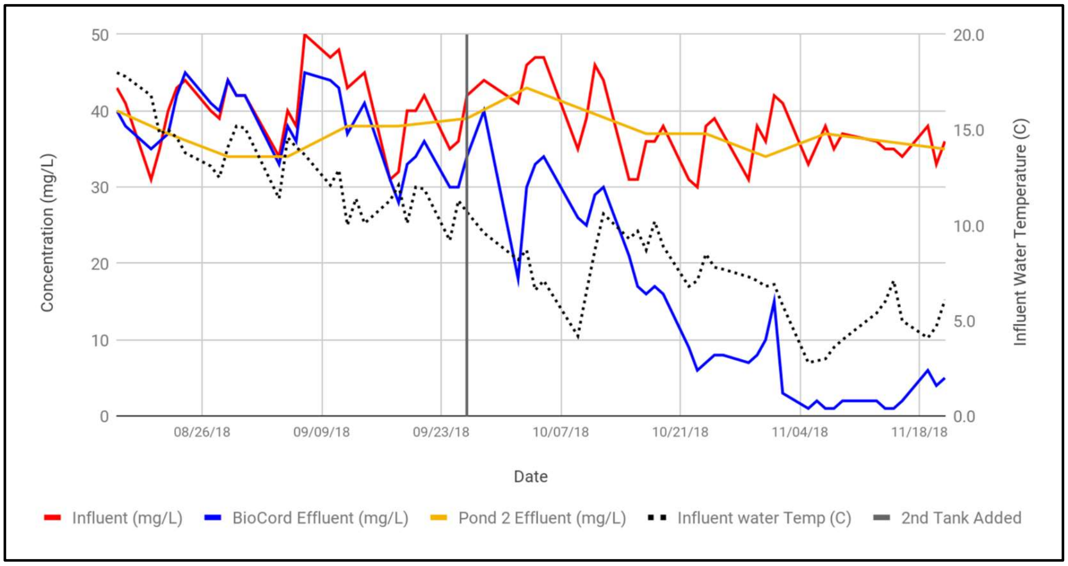

FIGURE 6. AMMONIA REMOVAL BY BIOCORD VS. POND 2

3.3. Microbial community analysis – Dundalk, ON

This study supported the operational outcomes of the others with compelling evidence that the rope-type media does develop an abundant community of productive and cold-resistant nitrifying bacteria.

A full-scale, in situ BioCord project was conducted over a two-year period to investigate the roles of temperature and wastewater characteristics on the biofilm that develops on the media. The study would examine whether the biofilm provided an insulating effect from the cold water, while still allowing oxygen and ammonia to reach the microorganisms. Another hypothesis proposed that the aeration compressors transferred sufficient heat into the air line to warm the water around the biofilm and provide additional protection from the cold.

Ten BioCord Reactors were installed near the outlet of Lagoon 4 at the Dundalk Wastewater Treatment Lagoons in Dundalk, Ontario. Biofilm samples were collected in October and November, The reactors were then removed, cleaned and reinstalled near the outlet of Lagoon 2. Biofilm samples were taken in October and December of the following year.

DNA and RNA were extracted and analyzed to identify the microorganisms in the biofilm samples. Figure 7 shows the relative abundance of nitrifiers that became established on the media in both locations. The results also show that the variation in microbial communities was significantly impacted by the location of the BioCord media in the lagoon system, but not by wastewater temperature.

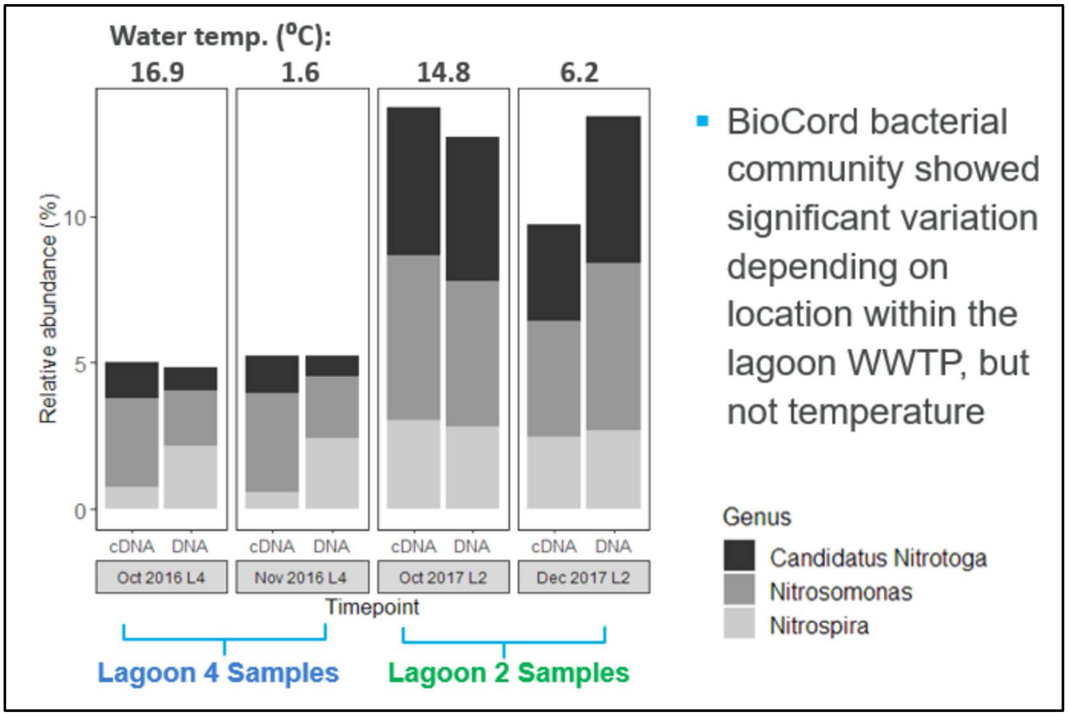

FIGURE 7. LAB TAXONOMY OF NITRIFYING BACTERIA SAMPLED FROM BIOCORD MEDIA

The abundance of nitrifiers in Lagoon 4 ranged from 2.7 to 2.9% and increased to a range of 4.7 to 5.6% once the reactors were relocated to Lagoon 2. Conversely, no significant change in nitrifier abundance was observed as water temperature decreased from 16.9 °C to 1.6 °C in Lagoon 4 or from 14.8 °C to 6.2 °C in Lagoon 2.

The analysis also showed that the dominant species in the lagoon samples was *Candidatus nitrotoga*, a nitrite-oxidizing bacteria (NOB). This bacterium is well adapted to cold temperatures and proliferates even when reactants for cellular respiration are in short supply, which makes it ideal for the fluctuating conditions experienced in lagoons (Gan, 2020). The dominant presence of *Candidatus nitrotoga* may also indicate that the environmental conditions within BioCord Reactors are well suited for developing robust biofilms of nitrifying bacteria.

4. BIOCORD DESIGN: GIFT LAKE FULL-SCALE DEMONSTRATION

The BioCord Reactor system has been designed to treat the lagoon system average daily flow of 190 m^3/day and achieve the treatment requirement shown in Table 3.

TABLE 3. BIOCORD REACTORS DESIGN PARAMETERS

	Influent – peak (mg/L)	BioCord effluent target (mg/L)	Removal rate (kg/day)
BOD	35	< 5	5.7
Ammonia	10	≤ 1*	3.857

* Enables unionized ammonia concentration of < 0.1 mg/L to comply with WSER

Nine BioCord Reactors will be installed near the outlet of Cell 3 in the Lower Lagoon System (Figure 8). The installation can be completed in just a few days, while the lagoon remains in operation.

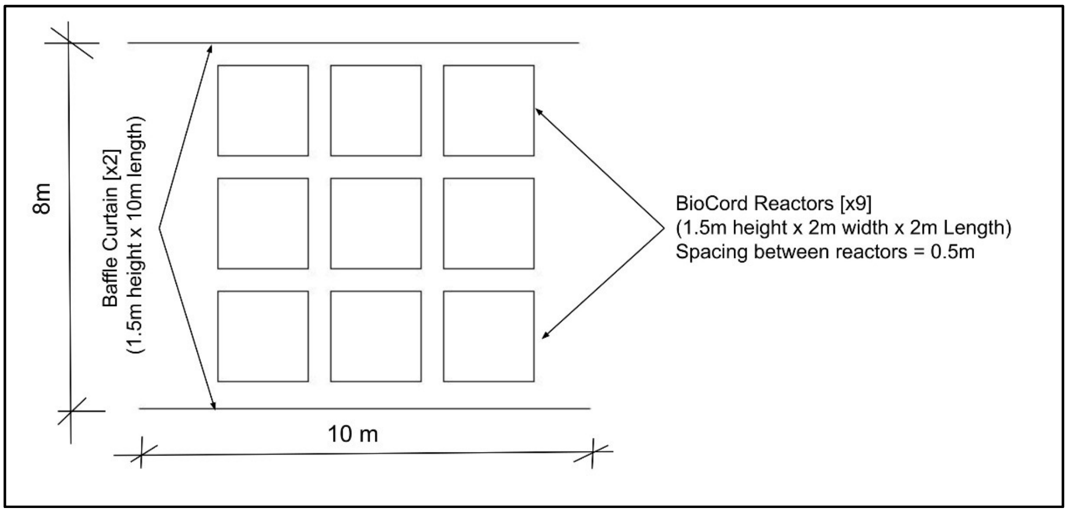

FIGURE 8. NINE REACTORS WILL CREATE AN IN SITU CELL AT GIFT LAKE. BAFFLE CURTAINS WILL DIRECT WASTEWATER THROUGH THE MEDIA AND PREVENT SHORT CIRCUITING.

The dimensions of each reactor will be 2 m x 2 m x 1.5 m (LWH), with the height the units customized to match the depth of the lagoon. The sizing was calculated based on wastewater characteristics provided to Bishop Water and a BioCord surface area removal rate (SARR) of 0.5 g NH_3-N/m^2/day. The SARR rate was based on data collected during similar operational conditions at full-scale and pilot-scale projects and from research studies conducted by academic partners.

Baffle curtains will be installed to create an in situ, fixed-film treatment cell. The curtains will help direct the flow of wastewater through the reactors to maximize contact with the biofilm and to minimize short circuiting. Computational Fluid Dynamics (CFD) analysis and simulation will be completed prior to installation to further optimize retention time and flow through the reactor cell. The CFD analysis will inform the ideal configuration and placement of the components to maximize biofilm contact and treatment.

FIGURE 9. BIOCORD REACTORS CAN BE SHIPPED TO SITE FULLY ASSEMBLED AND INSTALLED IN JUST A FEW DAYS, WHILE THE LAGOON REMAINS IN OPERATION (FILE PHOTO).

Once installed, the compact treatment cell will occupy a footprint of only 80 m^2, a small fraction of the total lagoon area of nearly 6,000 m^2, leaving considerable space for expansion to meet future treatment needs.

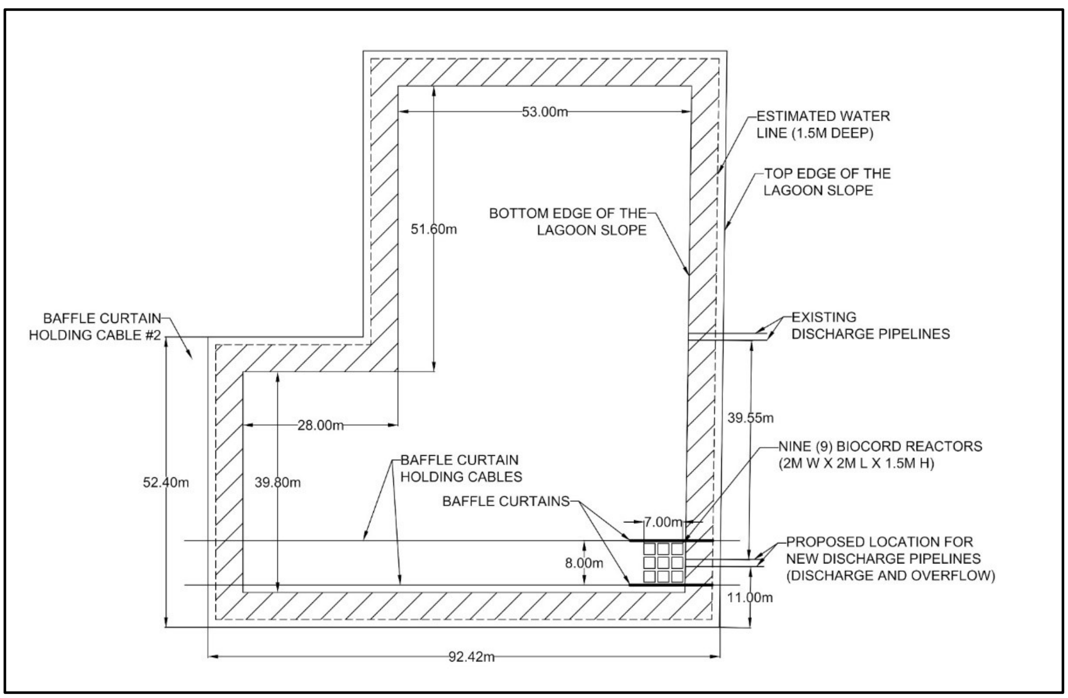

FIGURE 10. PROPOSED INSTALLATION LOCATION OF THE BIOCORD SYSTEM IN THE GIFT LAKE LAGOON. THE COMPACT CELL OCCUPIES A SMALL FRACTION OF THE TOTAL LAGOON AREA.

BioCord's modular components enable the system to be easily expanded by adding more reactors. Expansions can be added at pre-arranged intervals or as needed to accommodate greater influent volume, changes to influent characteristics or more stringent regulatory discharge limits. In this way, the treatment cell aligns with anticipated population growth and fiscal capacity.

The BioCord media does not require maintenance unless it experiences damage or serious fouling caused by an upstream upset condition. In that case, the reactors can be removed, quickly cleaned by power washing and reinstalled. Since the media is suspended from the frame and held stationary, it does not experience wear and does not require replacement.

4.1 Aeration

Each reactor will be equipped with an integrated fine-bubble aeration system in the base of the frame that will provide high oxygen transfer to the biofilm, scour excess biofilm from the media and prevent ice from forming in and around the treatment cell. Air will be supplied by nine ¾ horsepower compressors – one for each reactor. The compact size of the compressors, means they can be installed in a weatherproof cabinet or a sea container near the edge of the lagoon and do not require a more costly building to house them.

FIGURE 11. FILE PHOTO SHOWIING FINE-BUBBLE AERATION TUBING INTEGRATED INTO THE BASE OF THE REACTOR. AIR IS SUPPLIED BY LOW-ENERGY COMPRESSORS, INSTEAD OF BLOWERS.

This aeration method has proven to be very efficient both in oxygen transfer and energy efficiency compared to more common blower-powered aeration systems. Figure 12 shows a comparison of the dissolved oxygen levels achieved by the compressors and fine bubble tubing, vs blowers and coarse bubble aeration.

As shown, the compressors and bubble tubing are able to achieve a similar level of dissolved oxygen but require only half as much airflow to do so. This translates to lower energy cost and lower capital costs, since the compressors are less complex and more readily available than blowers.

The annual electrical consumption for the nine compressors has been estimated at 44, 347 kWh. Assuming an electricity cost of 13.5¢/kWh, the annual electricity cost for the system is estimated to be $5,987. Aside from electricity, the only other cost is periodic filter replacement on the compressors. The frequency of this depends on the air conditions and how often the filters require replacement. After 40,000 to 50,000 hours (4.5 – 6 years) of continuous operation, the compressors will require service to replace o-rings and other components.

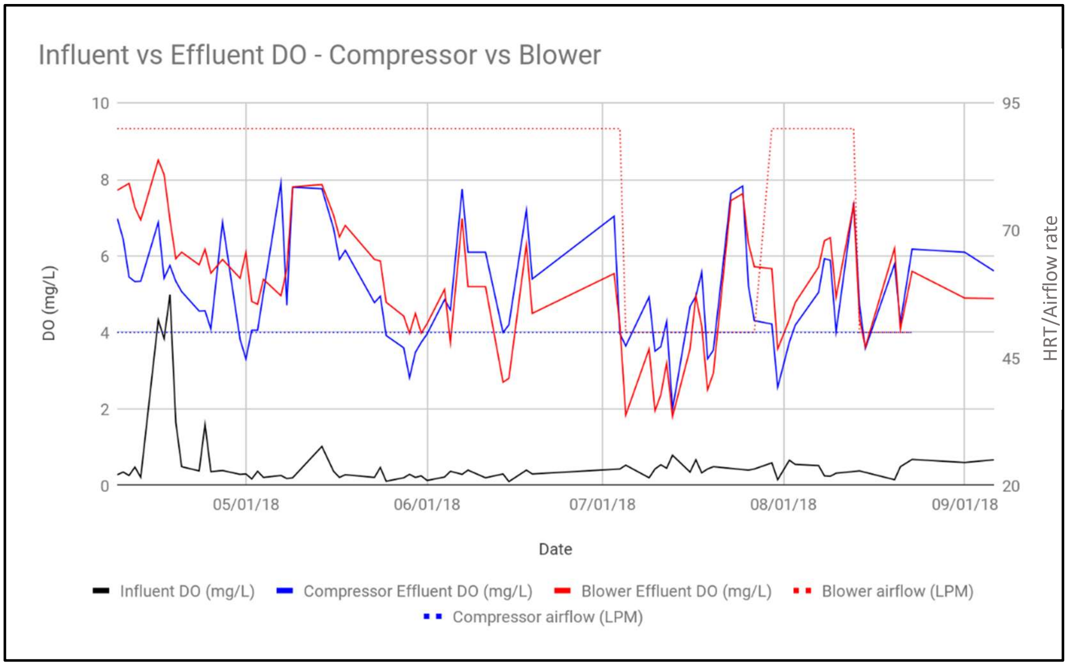

FIGURE 12. DATA FROM A RESEARCH STUDY SHOWS COMPRESSORS WITH FINE BUBBLE TUBING ARE ABLE TO ACHIEVE SIMILAR DISSOLVED OXYGEN LEVELS AS BLOWERS, BUT REQUIRE HALF AS MUCH AIR FLOW.

5. STARTUP

Once the reactors and baffle curtains are in place the aeration compressors can be activated and biofilm growth will begin immediately. The media, which is made from nylon and polypropylene fibres, has a slight negative charge and facilitates attraction and attachment of naturally occurring bacteria. Preferred strains of heterotrophic or nitrifying bacteria become established according to the concentrations of metabolic reactants in the wastewater and the rate of oxygen that is added through the fine bubble aeration system. Operators are required to only collect daily samples and ensure the compressors are operating. In this way, the system aligns well with the way lagoons are typically operated.

Removal of organics and/or ammonia will gradually increase as the microbial community grows and becomes acclimatized to the contaminants and temperature. The biofilm will typically achieve steady-state condition within six to eight weeks. The acclimatization process should occur during the warmer months when temperatures are 15 °C. BioCord Reactors are planned to be installed into the Gift Lake wastewater lagoon during the spring of 2023, which will provide ample time to establish a robust, active biofilm before cold weather sets in and wastewater temperature begins falling.

Once the biofilm is fully established and acclimatized it will function as a self-regulating, self-cleaning system that will respond to changes in the loading rates of organics and ammonia to improve cold-weather removal.

6. FUNDING

A significant portion of the funding for this project was provided by the Federation of Canadian Municipalities Green Municipal Fund, Pilot Projects : Wastewater Systems. This program provides up to $500,000 to cover up to 50% of eligible project costs. Since the population of the Gift Lake Metis Settlement is less than 20,000, the fund can award up to 80% of project costs.

To obtain the funding, Bishop Water, the Gift Lake Metis Settlement and TeckEra Consulting prepared documentation to establish eligibility and to satisfy the application process. The funding was awarded based on an evaluation and scoring system that considered the criteria shown in Table 4. Upon review, the funding was awarded for the project. The remainder of the project cost will be provided by the Gift Lake Metis Settlement.

TABLE 4. EVALUATION AND SCORING CRITERIA FOR FUNDING APPLICATION TO FCM GREEN MUNICIPAL FUND

Evaluation and scoring system

Applications for feasibility studies and pilot projects are assessed by an independent peer review committee against these evaluation criteria.

Evaluation Criteria	Points
Expected environmental benefits	25
Links to existing plans and policies	10
Systems approach	10
Community Benefits	5
Innovative practices and technologies — beyond business as usual	10
Replication potential and lessons learned	10
Project management	10
Work plan	10
Budget	10
TOTAL	**100**

7. CONCLUSION

BioCord Reactors were selected over alternatives for a full-scale demonstration project to upgrade capacity and performance of the lagoon system serving the Gift Lake Metis Settlement. Data from several references was considered in the evaluation process and compared against alternative approaches. Cold-weather performance was of particular importance as the ambient temperature can fall to -30 °C, which negatively impacts lagoon performance.

The benefits of the technology include low capital and operating costs, semi-passive process that requires little operator oversight, proven performance in cold-weather conditions and modular design that enables simple, affordable expansion.

The BioCord system will be installed directly into Cell 3 near the outlet. Nine reactors and baffle curtains will create a compact, in situ treatment cell that will enable the lagoons to consistently comply with WSER discharge limits in cold weather conditions. The project team is grateful for the opportunity to work with the Gift Lake Metis Community and for funding from the Federation of Canadian Municipalities.

8. REFERENCES

Gan, C., Bossy, K., (2020) A compact, low-energy fixed-film solution for upgrading lagoon capacity and cold-weather performance., WEAO 2020 Technical Conference

Metcalf & Eddy, Inc. (2003). *Wastewater Engineering: Treatment and Reuse.* McGraw-Hill.