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Research article

Pilot-scale evaluation of semi-passive treatment technologies for the treatment of septage under temperate climate conditions

Christine Gan, Pascale Champagne*, Geof Hall

Department of Civil Engineering, Queen's University, Kingston, Ontario, K7M 9H7, Canada

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A B S T R A C T

Population growth in rural Canada has resulted in an increase in municipal septage generation, which could overload existing treatment facilities that rely on biological treatment approaches. To address concerns associated with potential shock loading of these systems, three semi-passive wastewater treatment technologies were compared at the pilot-scale to identify a suitable approach to augment the capacity of an existing wastewater stabilization pond facility in rural Ontario. Two of these technologies, the BioDome and BioCord systems, were commercially available systems that make use of biofilm technology to improve treatment performance and enhance the robustness to temperature and hydraulic loading fluctuations. The third approach involved the use of the natural filtration capacity of zebra mussels to improve effluent quality. The three technologies were assessed against a control for reductions in regulated wastewater parameters with an emphasis on nutrient (ammonia/ammonium, orthophosphate) reductions, air cycling, energy consumption, and performance following exposure to anoxic conditions. The BioCord system was the only technology that was found to significantly outperform the control, exhibiting reductions of 69%, 47%, 77% and 81% for NH_3/NH_4^+, TN, COD and TSS, respectively. The BioCord system also had the lowest maintenance and energy requirements, likely due to its design, which provided the biofilm with optimal oxygen and substrate contact. Consequently, the BioCord system could develop a more stable, heterogeneous microbial population and maintain high levels of activity in its biofilm, even during periods of extended anaerobic conditions. This also suggested that the BioCord system would require less aeration, and hence a lower energy expenditure, than the other systems. Furthermore, the BioCord system showed the fastest rates of recovery, reaching significant levels of parameter reductions within one week of system re-initiation.

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1. Introduction

In the last 100 years, the rural communities of Canada have experienced steady population increases (Minister of Industry, 2012). These numbers are expected to continue to grow at a rapid rate throughout the next decade (Bollman et al., 2008). These increases in population, coupled with the resulting influx in septic wastewater volumes, necessarily implies that many wastewater facilities will be faced with the dilemma of costly upgrades to their current treatment approaches to conform to the recent, more stringent guidelines as outlined in Wastewater Systems Effluent Regulations by the Government of Canada (Government of Canada, 2016). This has led to a growing need for the effective management of municipal sewage, while minimizing the additional costs and energy expenditure associated with expanding infrastructure (Singh et al., 2015). In rural and Northern Canada, decentralized septic tank systems are widely employed as a means of wastewater treatment. A routine collection and management of the septage is required and one approach involves the use of passive wastewater stabilization pond (WSP) systems to treat and dispose of waste and wastewater in an environmentally sustainable manner. Storring Septic Service Limited—also called Storring Septic—is a privately-owned wastewater treatment facility located in the rural town of Tamworth, Ontario. Like many other similar wastewater treatment facilities across Canada, it has the potential to act as an eco-engineered facility that municipalities and service providers could utilize to effectively manage and dispose of their wastewaters. However, with growing demands on existing municipal infrastructure, there are concerns that increasing inclusion of third party septage could detrimentally affect the performance of

* Corresponding author.
E-mail address: pascale.champagne@queensu.ca (P. Champagne).

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existing WSP systems. To augment the robustness of existing passive treatment facilities with the capacity to safely accept septage from multiple sewage haulers, it was hypothesized that the incorporation of a biofilm or biofiltration technology solution could be employed. Commercially available technologies such as the BioDome and BioCord systems could be employed to augment the treatment performance of the naturalized WSP system, leading to the reduction of wastewater quality parameters to below their regulatory effluent discharge concentrations. This study utilized the Storring Septic Inc. WSP facility for pilot-scale testing of these technologies, to investigate the potential impact in applying these technologies on overall effluent quality when operated under temperate climate conditions.

The BioCord (Bishop Water Technologies Inc.) and BioDome (formerly "Poo-Gloos"; Wastewater Compliance Systems) systems are commercially available modular biofilm technologies that have been developed to enhance biological wastewater treatment. These aerated, submerged biofilm reactors have been designed to provide conditions that allow for the establishment of high-density microbial consortia in a biofilm, increasing organic matter and nutrient removals in comparison to more conventional suspended growth systems (Guo et al., 2009). The higher densities of microbial aggregates within stable biofilms allow for lower hydraulic retention times, while minimizing washout (Guo et al., 2009). This implies that—in contrast to microorganisms present in suspended systems—microorganisms in a biofilm can be retained in the system despite relatively high flow rates, hence allowing for a higher mean cell residence time (Tchobanoglous et al., 2004). These submerged aerated systems are also an attractive option due to their low-cost and maintenance requirements.

Although both systems promote biofilm development by providing a large colonizable surface area, methodical oxygenation cycling, and wastewater mixing, the biomass growth and proliferation approaches in BioDome and BioCord systems differ as a result of their design, substrates, and aeration mechanisms. Fig. 1 illustrates the differences in configuration between the two technologies.

The BioDome treatment technology consists of four concentrically stacked domes containing the honeycomb-like plastic packing material; these act as the media upon which the biofilm develops. One BioDome unit contains enough packing material to yield a surface area of approximately 260 m^2. When air is delivered to the diffuser manifold attached to the bottom of the BioDome system structure, air is supplied to the packing media via air diffuser tubes located at the base of each dome (seen as grey arrows in Fig. 1a). The entire BioDome structure is covered by an opaque outer shell, minimizes sunlight exposure for the biofilm environment. This increases the amount of nitrifying/denitrifying bacteria in the biofilm and reduces competition from photosynthesizing organisms such as algae and cyanobacteria (Xu and Shen, 2011). In sunlight-exposed suspended growth systems, the heterotrophic microorganisms that are able to reduce total nitrogen and phosphorus tend to be out-competed by cyanobacteria, nitrogen/phosphorus-consuming algae or other organisms requiring common substrates (Dolman et al., 2012; Oehmen et al., 2006). The BioDome system employed in this study had a bottom diameter of 1.83 m and a height of 1.22 m, and full-scale implementation of the BioDome treatment technology would require the application of multiple units and would impose an aeration demand in proportion to the number of modules installed.

The BioCord system, although lacking the benefit of reduced sunlight exposure, uses a similar principles of enhanced biofilm development through the formation of a multi-layer microbial consortium on an attachment surface to provide enhanced biological activity. The more "open", modular structure of the BioCord system, coupled with a lightweight frame, allows for easier access and direct biofilm observation in comparison to the BioDome treatment technology. This may be an important consideration in addressing operational challenges and maintenance requirements. The BioCord unit employed in this study was commissioned specifically for pilot-scale testing, with dimensions of 1.3 m H x 0.92 m W x 0.92 m L. Aeration was delivered using an air diffuser tube attached to the bottom of the module. Full-scale implementation of the BioCord treatment technology would involve the installation of multiple full size modules. Aeration to the system would also have to be increased in proportion to the size of the system. The specific surface area of the pilot-scale BioCord system employed in this study was approximately 240 m^2 based on an estimated 24 m^2 per meter of cord and 100 m of cord. Thus, the attachment media surface area of the BioDome and BioCord systems were relatively similar.

The performance of the BioCord and BioDome systems have previously been reported in independent case studies (Johnson, 2011; Yuan et al., 2012; Zhang et al., 2012). This would suggest that the BioDome and BioCord systems have the potential to enhance the treatment of secondary domestic and/or municipal wastewater in stabilization ponds operated in rural Canada. The BioCord system was employed in wastewater treatment studies conducted in Japan and China. Yuan et al. (2012) reported that the BioCord system matrix provided a high-porosity and surface area, which promoted suitable conditions for microbial growth and resulted in increased chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N) and total nitrogen (TN) removal efficiencies. Large differences in microbial quantity and diversity were noted between the surface and inner layers of the BioCord biofilm system, as well as localized microclimates within the biofilm leading to the formation of aerobic and anaerobic zones. In a study by Zhang et al. (2012), the BioCord system was found to provide a particularly effective support matrix for organic matter-reducing organisms, and was implemented as an approach for the treatment of river water in the heavily polluted Hongqi River watershed in China.

The performance of the BioDome system for wastewater treatment applications was investigated in a collaborative study by Wastewater Compliance System, Inc. and the University of Utah (Johnson, 2011). It was found that the BioDome system could enhance rural wastewater lagoon performance under winter conditions (as low as 0.9 °C). Implementation of BioDome units on a pilot-scale led to statistically significant reductions in total suspended solids (TSS), COD, NH_3, TN, alkalinity and total phosphorus (TP) in comparison to a control, during a 17-week winter trial. Zabala-Ojeda (2012) also performed a study to assess the carbon and nutrient removal potential of the BioDome system treating municipal wastewater effluent from a primary clarifier at relatively low temperatures (0.2 °C–12.6 °C). The study demonstrated that the BioDome system could considerably reduce effluent wastewater parameters such as COD, TSS and NH_3; and concluded that the BioDome system could be a practical solution for augmenting traditional lagoon treatment systems. However, no statistical analysis was presented to confirm the significance of these reductions. Higher removal efficiencies were reported with the introduction of aerobic and anaerobic cycles, particularly for NH_3, TN and orthophosphate removals (El-Shafai and Zahid, 2013; Zabala-Ojeda, 2012).

As such, a comparison between these biofilm treatment technologies could allow for the determination of aeration requirements that would improve treatment performance. Although Johnson (2011) and Zabala-Ojeda examined the effects of air cycling on effluent quality in the BioDome system, the most energy-conservative aeration cycling employed was 19 h on/5 h off. It is possible that lower aeration—and therefore energy

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