Wastewater lagoon solids, phosphorus, and algae removal using discfiltration

Guillaume LeBlond, Patrick M. D'Aoust, Chris Kinsley and Robert Delatolla

ABSTRACT

The microsieving discfilter technology was investigated at the pilot scale. The pilot was configured to treat the effluent from a municipal wastewater multi-lagoon facility consisting of two facultative lagoons and a third seasonally aerated lagoon that is aerated to mitigate hydrogen sulfide release. The 10 μm filter, operated without chemical enhancement, demonstrates 60.1 ± 22.6% removal of the lagoon effluent total suspended solids (TSS) during periods of operation without aeration of the third lagoon. Aeration of the third lagoon of the multi-lagoon system prior to discharge renders the 10 μm filter cloth ineffective with respect to solids removal. The 5 μm filter cloth performs effective nonchemically enhanced removal of solids even during aeration of the lagoon, removing 68.2 ± 9.85% of effluent TSS. The greater performance of the 5 μm filter was achieved at the expense of a lower maximum conveyance capacity than the 10 μm filter. The 10 and 5 μm filters decrease the effluent total phosphorus (TP) concentrations by 0.14 and 0.13 mg-P/L, respectively. Algae, characterized as Chlorophyll α, shows removal from influent concentrations of 10.25 ± 4.19 μg/L to concentrations of 4.61 ± 1.28 μg/L for the 10 μm filter, and 4.10 ± 0.65 μg/L for the 5 μm filter.

Key words | algae, discfilter, facultative lagoon, microsieve/microfilter, phosphorus, solids

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HIGHLIGHTS

- Nonchemically enhanced discfiltration shows solids removal from the lagoon effluent.
- 5 μm discfilter shows less hydraulic loadings capacity compared with 10 μm discfilter.
- Aeration of upstream lagoon may cause performance deterioration of the 10 μm discfilter.
- TP removal using 5 μm discfiltration.
- Algae/Chl. α removal using 10 and 5 μm discfiltration.

INTRODUCTION

Current challenges facing wastewater resource recovery facilities (WRRFs) include increased loadings, limited land, energy, and capital resources, and increasingly stringent effluent regulations. Wastewater treatment lagoons are the predominant passive wastewater treatment technology in rural communities and have demonstrated good performance for the treatment of municipal wastewater with respect to biological oxygen demand (BOD), but face challenges in the removal of suspended solids, phosphorus, and total ammonia-nitrogen (Pearson 2003; Van Dyke *et al.* 2003; Delatolla & Babarutsi 2005; Environmental Protection Agency 2011; Crites *et al.* 2014; Petrie *et al.* 2015; Young *et al.* 2017; Mavinic *et al.* 2018a; Tian *et al.* 2019). Total suspended solids (TSS) and phosphorus are two of the four principal contaminants targeted by the increasingly stringent regulations in Canada, the USA and the EU. This highlights the need to upgrade rural, conventional treatment systems currently in place to improve effluent quality, ensure

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compliance, and limit anthropogenic impacts on natural waters (Oleszkiewicz & Barnard 2007; Oleszkiewicz *et al.* 2015; Mavinic *et al.* 2018a). Lagoons in Canada and in the USA represent about half of the operating municipal WRRFs (Environmental Protection Agency 2011; Mavinic *et al.* 2018a; Statistics Canada 2018).

Although lagoons present mechanisms for the removal of wastewater-borne solids, the long retention times along with the availability of organic matter and nutrients create conditions favorable to the proliferation of algae in these systems and hence an increase in the suspended solids of these systems (Middlebrooks 1995; Pearson 2003). Algal suspended solids generation poses a significant and widely recognized problem in wastewater treatment lagoons. Algae proliferation in lagoons contributes to the released particulate BOD and TSS impacting receiving waters from the discharged lagoon effluent.

Upgrade technologies for the enhanced removal of solids at lagoon facilities need not only meet the solids removal requirements of the facility, but also must be appropriate with respect to the loading and operational intensity of lagoon treatment operations. In particular, upgrade technologies need to be capable of operating economically under low-flow conditions and be compatible to lagoons with respect to maintenance, energy, and land resources (Muga & Mihelcic 2008; Environmental Protection Agency 2011; Molinos-Senante *et al.* 2012; Vera *et al.* 2013; Remy *et al.* 2014; WEF 2018). Researchers have investigated multiple methods for the treatment of lagoon solids, including coagulation, constructed wetlands, dissolved air flotation, intermittent sand filtration, and membranes (Al-Layla & Middlebrooks 1975; Harrelson *et al.* 1982; Levine *et al.* 1985, 1991; Finch & Smith 1986; Rich & Wahlberg 1990; Truax & Shindala 1994; Buisine & Oemcke 2003; Fitzpatrick & Gregory 2003; Fan *et al.* 2008; Nguyen *et al.* 2009; Molinos-Senante *et al.* 2012; Yap *et al.* 2012; Crites *et al.* 2014; Remy *et al.* 2014). These tested systems have demonstrated limited to moderate effectiveness in the removal of lagoon-specific solids and have varied levels of compatibility with lagoon systems (Middlebrooks *et al.* 1974; Truax & Shindala 1994; Buisine & Oemcke 2003; Pearson 2003; Yap *et al.* 2012).

Microsieves as a technology have been installed as solids removal systems to mechanized treatment facilities since the 1980s, with recent material technological improvements having demonstrated further performance gains of these systems (Grabbe *et al.* 1998; Bourgeous *et al.* 2003; Wilén *et al.* 2012). In particular, microsieve-like physical separation processes have seen developments of new material technologies including pile-on filter cloths, needle-felt cloths, and woven polyester cloths (Bourgeous *et al.* 2003; Wilén *et al.* 2012). The discfilter technology, a type of microsieve, is a low energy and low footprint mechanized treatment process that has shown an ability to effectively remove solids from the secondary treatment effluent (Persson *et al.* 2006; Tooker *et al.* 2012; Wilén *et al.* 2012; Kängsepp *et al.* 2016; Langer *et al.* 2017). Because of these operational benefits, the discfilter technology may therefore be a promising microsieve technology for solids removal that fulfills the compatibility requirements of rural and lagoon WRRFs. There is, however, currently a fundamental lack of literature and general knowledge on the utilization of the microsieving technology applied to municipal lagoons.

The overall objective of this study is to assess the removal of suspended solids in lagoon effluent. This research was performed at the pilot scale and in the optic of assessing regulatory compliance and meeting strict effluent discharge requirements of existing lagoon systems. To fulfill this objective, a comparison of two discfilter filters were studied at the pilot scale treating lagoon effluent wastewater across various hydraulic and solids loading rates (LRs) to quantify the solids removal performance of this technology. In addition, this research assesses peripheral performance benefits of the discfilter technology applied to lagoon WRRFs for the removal of phosphorus, and algae, characterized as Chlorophyll α (Chl. α).

METHODS

Site description

A discfilter pilot-scale treatment plant was installed at the Casselman WRRF in the spring of 2018 (Casselman, Ontario, Canada) and was fed effluent wastewater from the lagoon facility until the late fall of 2018. The Casselman lagoon facility consists of three cells: two facultative cells followed by a seasonally aerated cell to remove sulfides prior to discharge. Discharge at the Casselman WRRF occurs seasonally. This facility treats separated sanitary sewage and hauled septage. The lagoons have a rated capacity of 2,100 m^3/d. Alum is dosed at a concentration of 163 mg/L at the inlet of the lagoon for phosphorus removal within the facultative lagoon cells. Although alum dosing occurs at the lagoon WRRF, further phosphorus removal may be required at this facility to meet future stringent effluent standards. The lagoon effluent wastewater used to feed the discfilter pilot plant in this study was characterized and is indicative of a well-operated lagoon facility (Table 1). A cross-sectional view of the pilot-scale discfiltration unit is shown in Supplementary Figure 1 (Supplementary Information).

Experimental plan

To establish an understanding of the overall performance of the discfilter technology for lagoon effluent solids removal, testing was conducted on two filters, 10 and 5 μm nominal pore-size filters (Veolia Water Technologies, Sweden). The individual pilot-scale filters provided an active filtration area of 0.14 m^2. The 10 μm filter cloth used in this experiment was manufactured from twill weave monofilament polyester (Persson *et al.* 2006). The 5 μm filter used in this study was an experimental material that currently remains in development (Veolia Water Technologies, Sweden). To gather data on an appropriate sampling method, prior to this study, the filters were wetted and tested for preliminary assessment over a period of 3 weeks to isolate loading effects and potential sampling issues affecting the discfilter system. Solids were entrained from various depths within the lagoon to create a transient loading condition on the discfilter. Turbidity readings were correlated to TSS measurements during the preliminary study, and subsequently, instantaneous, on-line turbidity measurements along with on-site flow measurements were used to approximate TSS and hydraulic LRs on the filters during the testing period of the study.

Table 1 | Water quality of lagoon effluent supplied to the pilot plant discfilter unit

Parameters	Range of values	Units
Temperature	4.7–8.0	°C
pH	7.0–8.0	–
Dissolved oxygen	4.8–5.0	mg/L
TSS	3.2–72.8	mg/L
VSS	2.7–29.6	mg/L
Turbidity	2.0–200	NTU
Total phosphorus	0.15–0.83	mg-P/L
Orthophosphates	0.00–0.30	mg-P/L
Chlorophyll *α*	4.1–23.4	μg/L
Total coliforms	365.4–7,590.0	MPN/100 mL
Phycocyanin	<LOQ	μg/L

LOQ, limit of quantification.

The study testing period was performed just prior to and during the seasonal discharge period of the lagoon WRRF from October to November 2018. Three testing phases were performed to assess the performance of the discfilter filters across various hydraulic and solids loading conditions. The three testing phases were performed across a period of 6 weeks, starting just prior to the fall discharge of the lagoon WRRF (with the aeration in the third lagoon cell disengaged) and into the discharge period of the lagoon WRRF (with the aeration in the lagoon cell engaged). Overall, at least 36 samples were collected from the inflow, outflow, and backwash water for each phase. The first testing phase studied the performance of the 10 μm filter with the aeration system of the third cell disengaged. This first testing phase occurred just prior to the fall discharge period with the effluent lagoon wastewater being at an average temperature of 7.8 °C. The second testing phase studied the 5 μm filter performance with the aeration system of the third cell in operation. The testing of this condition also occurred during the fall discharge period. It occurred 3 weeks after the first testing phase, with the effluent lagoon wastewater being at an average temperature of 6.2 °C. The third testing phase studied the 10 μm filter with the aeration system of the third cell in operation. This testing phase occurred during the fall discharge period, 6 weeks after the first testing phase, with the effluent lagoon wastewater being at an average temperature of 4.7 °C.

Sampling was performed targeting two distinct hydraulic LRs, a conventional LR and an elevated hydraulic LR. Sampling of the first, second, and third phases included a minimum of 36 samples collected from the inflow, outflow, and backwash water of the filter; with a total of approximately 150 samples measured for each of the constituents analyzed in this study. Triplication for sampling and water quality analyses were performed for at least 40% of the samples during each of the three phases to quantify sampling and analytical error in the study.

Discfilter pilot unit

The pilot plant used in this study housed a Hydrotech® Mini-disc discfilter unit (Veolia Water Technologies, Sweden) (Langer *et al.* 2017). The discfilter unit itself consists of a single disc for filtration and is equipped with automatic backwash that uses filtered water, and is initiated based on headloss through the cloth. This backwash operation uses approximately 2–5% of the total filtered water produced. Backwashing in this pilot unit occurs concurrently and without interruption of the filtration process.

Analytical methods

The study tested the concentrations of TSS, Chl. α, and phosphorus (total phosphorus (TP) and soluble orthophosphates) for all three phases operated across various hydraulic loadings, TSS loadings, and hence various backwash frequencies (duration of the backwash cycle). Influent, effluent, and backwash samples were analyzed for TSS and volatile suspended solids (VSS) (SM 2540 (TSS and VSS)); TP, soluble orthophosphates (SM-4500 E (phosphorus)); and Chl. α (modified SM-10200 H (Chl. α)) (APHA 2017; Martens 2017). Colorimetric methods were performed using a DR 6000 spectrophotometer (Hach, Loveland, CO).

Backwash samples were also analyzed for retained algae identification. Images of algae were acquired using a Zeiss LSM510/Axio imager M.1 confocal microscope (Carl Zeiss, Canada) with a 63× water submersion objective (Delatolla *et al.* 2015).

Turbidity was measured in real time in the field using a Hach Solitax SC probe (Hach, Loveland, CO). Flowrate was measured using an electromagnetic Krohne IFC 010 D flowmeter (KROHNE Messtechnik GmbH, Duisburg, Germany). Temperature was measured using a Hach HQ40D handheld field meter and a Hach LDO101 DO probe (Hach, Loveland, CO). The maintenance on the real-time probes, flowmeter, and sampling conduits was performed as specified by the manufacturer to mitigate contamination of samples and ensure the accuracy of measurements. For quality control purposes, a minimum of 40% of samples were collected in triplicate during each of the study phases to quantify sampling and analytical errors.

Statistical methods

The paired Student's *t*-test was used with a critical value of $p < 0.05$ to establish statistical significance. Average values in this study are presented along with the standard deviations. Pearson's correlations between datasets in this study were evaluated based on Pearson's *r*. Standardized multiple linear regression models (SMLRs), evaluated based on the coefficient of multiple determination (R^2), were applied between select parameters and performance variables in this study to evaluate the simultaneous impact of multiple variables on system performance utilizing the standardized partial regression coefficients (SPRCs) of the model.

RESULTS AND DISCUSSION

Influent TSS and hydraulic loading capacity

The influent solids concentrations for the first study phase (10 μm filter in operation with the third lagoon cell not being aerated) were in the range of 3.2–72.8 mg-TSS/L. For both the second and third study phases (5 μm filter in operation with the third lagoon cell being aerated and 10 μm filter in operation with the third lagoon cell being aerated), the influent solids concentrations ranged from 7.6 to 37.2 mg-TSS/L (Figure 1). The difference in the range of TSS values entering the pilot plant is likely due to the aeration effects in the third cell, where aeration limited the variance in the sizing of the solids.

The three phases of the study were performed at both a conventional low hydraulic LR ranging between 4.09 and 6.11 m/h and at an elevated high hydraulic LR (HR) ranging between 6.85 and 9.21 m/h (Figure 2(a)). Impact of water temperature on the solids removal performance of the disc-filter was assessed in during the preliminary study of this research by comparing the TSS removal performance of the 10 μm filter during similar TSS loadings across changes in temperature. The analysis demonstrated that no

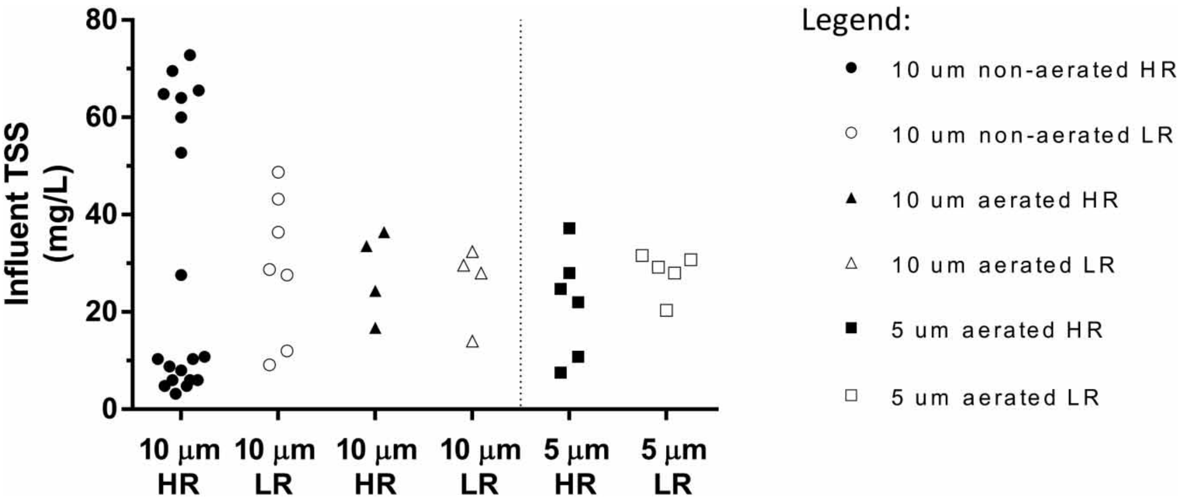

Figure 1 | Range of influent TSS concentrations for various filter types and operational conditions across hydraulic LRs.

significant correlation existed between water temperature and TSS removal on the 10 μm filter ($r = 0.109$, $p = 0.477$). Water temperatures during pilot operation ranged from 4.7 to 8.0 °C across all samples, with the preliminary study demonstrating that water temperature effects were negligible on the performance of the filter. The range in TSS concentrations and hydraulic loading resulted in an overall range of solids loadings between 25.2 and 574.1 g-TSS/m^2/h. This range of LRs are from conventional to elevated operating loadings for the discfilter technology, and the TSS concentrations were in the typical range for lagoon discharge operations (Mara 2013).

Backwash frequency, measured as the percentage of time that backwashing is engaged during operation, is a principal metric for measuring the in-use hydraulic load capacity of the discfilter (Langer *et al.* 2017). The backwash frequency has a measurable range between 0 and 100% for a given system. At 100% backwash frequency, the filter cloth is hydraulically limited due to (i) filter cloth surface clogging from filtered solids or (ii) flowrate exceeding the hydraulic capacity of the filter cloth permeability, or (iii) a combination of both factors. The loading applied to the filters resulted in backwash frequencies of 11.8–61.0% for the 10 μm filter without aeration of the third lagoon cell, 12.2–66.0% for the 10 μm filter with aeration of the third lagoon cell, and of 26.0–100% for the 5 μm filter with aeration (Figure 2(b)). A hydraulic loading limitation was not observed with the 10 μm filter with and without the third lagoon cell being aerated across the complete TSS loading range of 25.2–574.1 g-TSS/m^2/h (Figure 2(b)). The 10 μm filter showed that TSS loading demonstrated a significant positive correlation with respect to the increase in backwash frequency ($r = 0.708$, $p < 0.001$) (Figure 2(b)). The impact of individual parameters on backwash frequency was assessed with a comparison of SPRCs from an SMLR model ($R^2 =$ 76.61%). This analysis demonstrated hydraulic loading (SPRC = 7.52, $p < 0.001$) and influent TSS (SPRC = 9.99, $p < 0.001$) as similarly weighted predictors of backwash frequency. Although both constituting parameters of TSS loading (influent TSS concentration and hydraulic loading) were significant predictors to an increase in backwash frequency on the 10 μm filter ($p < 0.001$), neither of these parameters caused a hydraulic load limitation to be observed on the 10 μm filter for TSS loadings applied in this study.

The 5 μm filter experienced constant backwash at the observed elevated hydraulic loadings above 6.85 m/h while operating at solid LRs of 53.2–269.3 g-TSS/m^2/h (Figure 2(b)). This operational condition was induced exclusively by hydraulic loading as the impact of influent solids concentration was insignificant. This is supported by the weak and nonsignificant correlations between TSS loading and backwash frequency ($r = 0.251$, $p = 0.384$) (Figure 2(b)) and between influent TSS concentrations and backwash frequency ($r = -0.366$, $p = 0.195$). The important impact of hydraulic loading on backwash frequency for this filter is

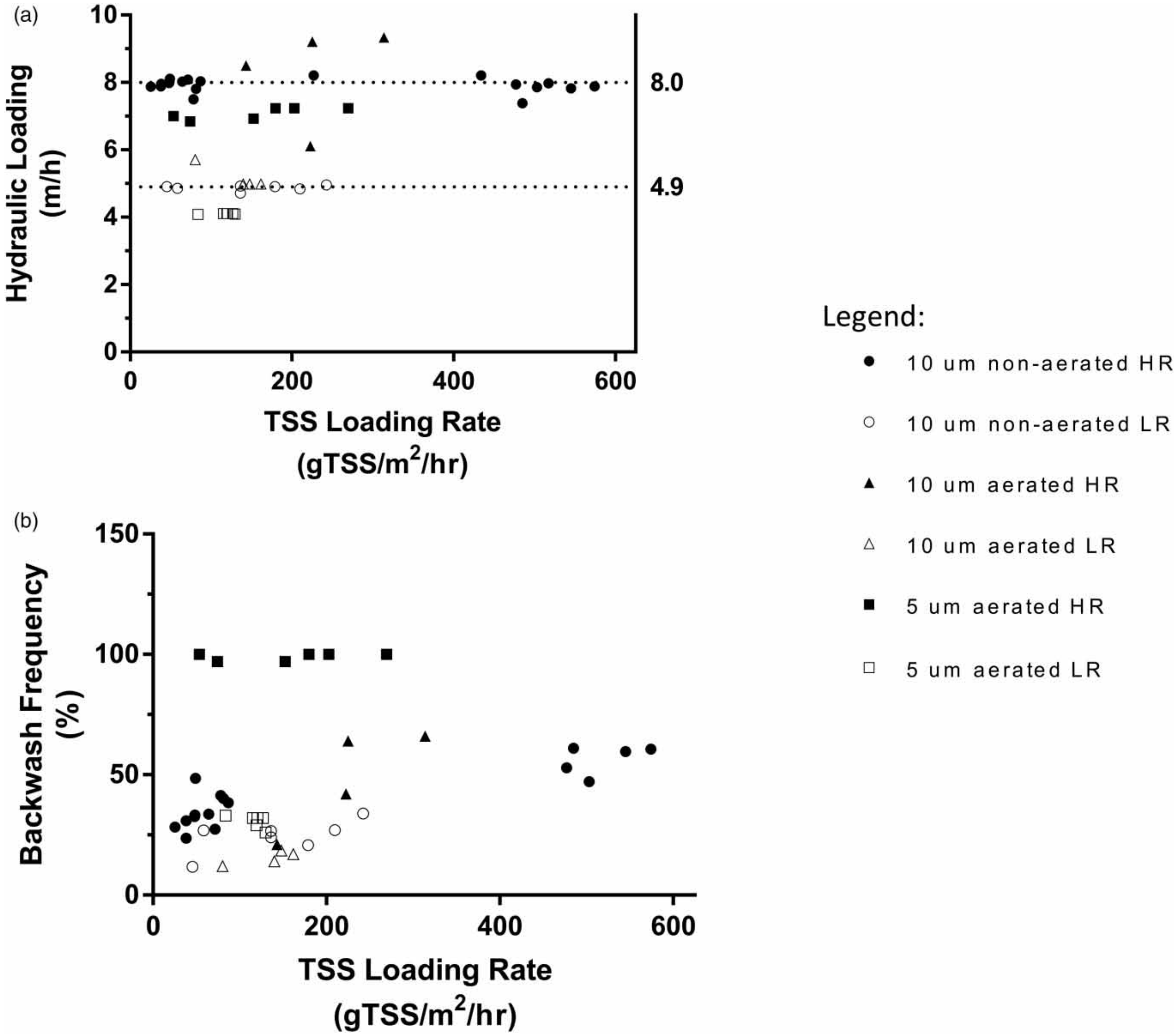

Figure 2 | (a) Hydraulic LR across TSS LR, targeted (dotted lines) and measured (symbols) hydraulic LRs versus solids LR, and (b) backwash frequency versus solids LR.

highlighted by a strong positive correlation between hydraulic loading and backwash frequency ($r = 0.997$, $p < 0.001$) (Figure 2(b)). Additionally, the comparison of SPRCs of an SMLR model ($R^2 = 99.71\%$) comparing the impact of influent TSS concentration and hydraulic loading and backwash frequency highlighted hydraulic loading (SPRC = 34.79, $p < 0.001$) as the principal predictor compared with the influent TSS (SPRC = −2.20, $p = 0.009$). Therefore, the TSS concentration was not a principal predictor of backwash frequency for the 5 μm filter data. Furthermore, it should be noted that the filtration performance is not inhibited by backwater conditions as this does not affect solids removal performance directly, rather the hydraulic limitation lowers the process efficiency (Persson *et al.* 2006; Langer *et al.* 2017).

Solids removal performance

The solids removal performance of the 10 μm filter was evaluated across TSS loadings while being fed from the maturation lagoon cell that was either not aerated or aerated during operation of the discfilter unit. While the maturation pond was not aerated, the TSS removal of the 10 μm filter was on average 60.1 ± 22.6%, ranging from 6.7% to 91.78% across TSS loadings of 25.2–574.1 g-TSS/m^2/h (Table 2). A significant difference in the TSS removal

Table 2 | TSS removal performance of discfilter

Filter	Third lagoon cell operation (aerated/ nonaerated)	Mean removal (%)	Range of removal (%)	Removal significance	*p*-value
10 μm	Nonaerated	60.1 ± 22.6	6.7–91.7	Yes	0.029
10 μm	Aerated	17.2 ± 20.5	2.7–67.0	No	0.256
5 μm	Aerated	68.2 ± 9.8	54.9–82.3	Yes	<0.001

performance of the 10 μm filter was observed when the third lagoon cell was aerated compared with when the cell was not aerated ($p < 0.001$). Although the 10 μm filter showed good removal performance without aeration of the third lagoon cell, the deterioration of TSS removal during aeration was substantial, at which point the 10 μm filter was no longer capable of performing statistically significant removal of the TSS. This reduction in removal efficiency occurs across TSS concentrations of 14.0–36.4 mg/L and notably across a lower range of TSS loadings of 80.0–313.7 g-TSS/m^2/h compared with the 10 μm filter in nonaerated conditions (Figure 3(a)). The deteriorated performance of the filter that coincided with the use of aerators in the third lagoon cell may have been due to the aerators promoting the resuspension of smaller settled particles from the lagoon benthic zone, which are poorly removed by the 10 μm filter.

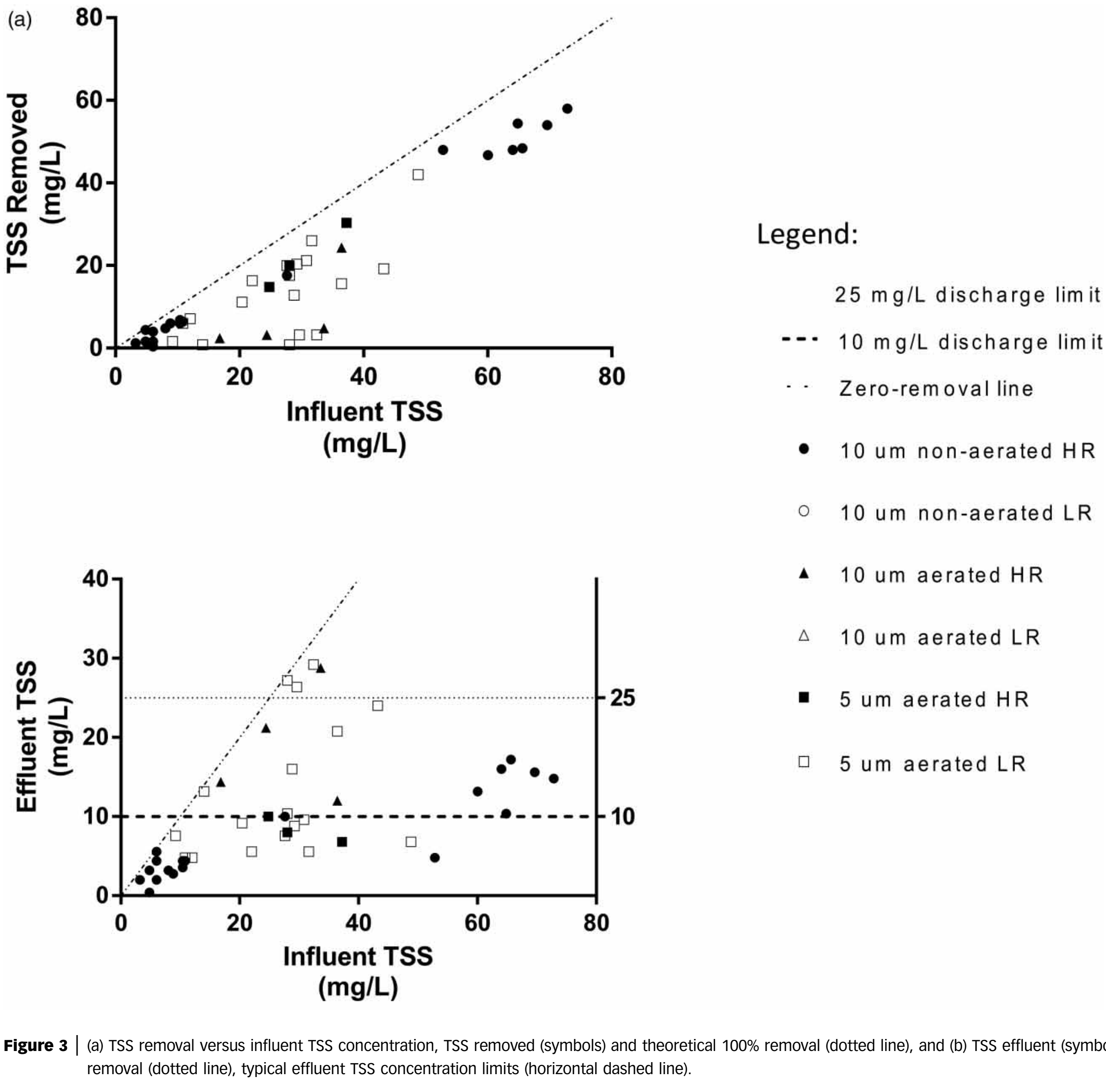

Figure 3 | (a) TSS removal versus influent TSS concentration, TSS removed (symbols) and theoretical 100% removal (dotted line), and (b) TSS effluent (symbols) and theoretical 100% removal (dotted line), typical effluent TSS concentration limits (horizontal dashed line).

While the 10 μm filter demonstrated poor solids removal performance during aeration of the third cell, the 5 μm filter demonstrated an average solids removal efficiency of 68.2 ± 9.85%, ranging from 54.9% to 82.3% across the range of loadings of 53.2–269.3 g-TSS/m^2/h and TSS concentrations of 7.6–37.2 mg/L (Figure 3(b)). The 5 μm filter therefore demonstrated a significant improvement in solids removal when compared with the 10 μm filter while the third lagoon cell was aerated. This observation supports the likelihood of aeration in the third lagoon cell resuspending smaller particles, which were removed by the finer filter. Based on this observation, the size of the resuspended particles is likely to be in the 5–10 μm range. Regarding the impact of hydraulic loading on solids removal performance, there was no significant correlation observed between hydraulic loading and TSS removal efficiency for both filters.

The effluent TSS concentration is an important metric to evaluate if the filters are capable of providing the effluent quality required to meet typical design targets (10 mg-TSS/L) and typical effluent regulation (25 mg-TSS/L) (Mavinic *et al.* 2018b) (Figure 3(b)). The 5 μm filter demonstrated robust solids removal and enhanced effluent quality compared with the 10 μm, both with and without aeration in the third lagoon cell. The 10 μm filter was not able to meet typical discharge regulation of 25 mg-TSS/L for 80% of the data points under aerated lagoon conditions. In contrast, the 5 μm filter demonstrated an ability to meet design targets of 10 mg-TSS/L for all data points measured. Therefore, the 5 μm filter provided more robust lagoon solids removal compared with the 10 μm filter. These findings support the theory that fine particle characteristics changed in the lagoon during aeration of the third cell. It should be mentioned that the addition of a coagulant, flocculant, and/or polymer at the filter unit with the 10 μm filter may increase the TSS removal and produce the effluent TSS concentrations at the target value. The advantage of this solution would be the preservation of hydraulic flexibility/capacity provided by the 10 μm filter, while potentially reducing effluent TSS concentrations to target values.

Discfilter peripheral benefits of TP and Chl. α removal

TP influent concentrations that entered the filter unit ranged from 0.15 to 0.83 mg-P/L as TSS concentrations range from 7.6 to 64.8 mg-TSS/L. Statistical analysis shows that influent TP concentrations were positively correlated with influent TSS as concentrations increased ($r = 0.569$, $p = 0.005$). As such, the majority of phosphorus in the effluent appears to be in the solid phase. It should be noted that the average influent TP concentrations of 0.40 ± 0.13 mg-P/L observed in this study fall in the lower range of TP concentrations measured in lagoons and of those found in other studies on the discfilter (applied to mechanized wastewater treatment plants) focusing on phosphorus removal with and without coagulants or flocculants (Bourgeous *et al.* 2003; Tooker *et al.* 2012; Wilén *et al.* 2012; Kängsepp *et al.* 2016; Langer *et al.* 2017). The lagoon effluent TP concentrations were low due to an alum dosing for phosphorus control in the influent of the lagoon facility.

The 10 μm filter provided significant TP removal during the nonaerated condition of the lagoon ($p = 0.029$) with the average removal of 80.0 ± 28.2% or 0.34 ± 0.23 mg-P/L (Table 3 and Figure 4). Conversely, TP removal by the 10 μm filter operated during aeration of the third lagoon cell was not significant ($p = 0.256$). The 5 μm filter provided an average removal of 32.7 ± 18.2% or 0.12 ± 0.06 mg-P/L and demonstrated significant TP removal ($p < 0.001$) in aerated conditions. Higher TP removal is observed in this study for the 10 μm filter under nonaerated third lagoon cell conditions at elevated concentrations of influent TSS (Figure 4). In addition, higher TP removal is again observed in this study for the 5 μm filter conditions under aerated third lagoon cell conditions at elevated TSS concentrations (Figure 4). Soluble orthophosphates did not show significant removal with respect to either the 10 μm or 5 μm filters.

The removal of Chl. α was determined for both the 10 μm and the 5 μm filters, with influent Chl. α ranging from 4.1 to 23.4 μg/L across TSS concentrations ranging from 3.2 to 72.8 mg-TSS/L (Figure 5). In this study, Chl. α of the

Table 3 | TP removal performance of discfilter

Filter	Third lagoon cell operation (aerated/ nonaerated)	Mean removal (%)	Mean removal (mg/L)	Removal significance	*p*-value
10 μm	Nonaerated	80.0 ± 28.2	0.35 ± 0.23	Yes	0.029
10 μm	Aerated	5.3 ± 18.0	0.03 ± 0.07	No	0.256
5 μm	Aerated	32.7 ± 18.2	0..11 ± 0.06	Yes	<0.001

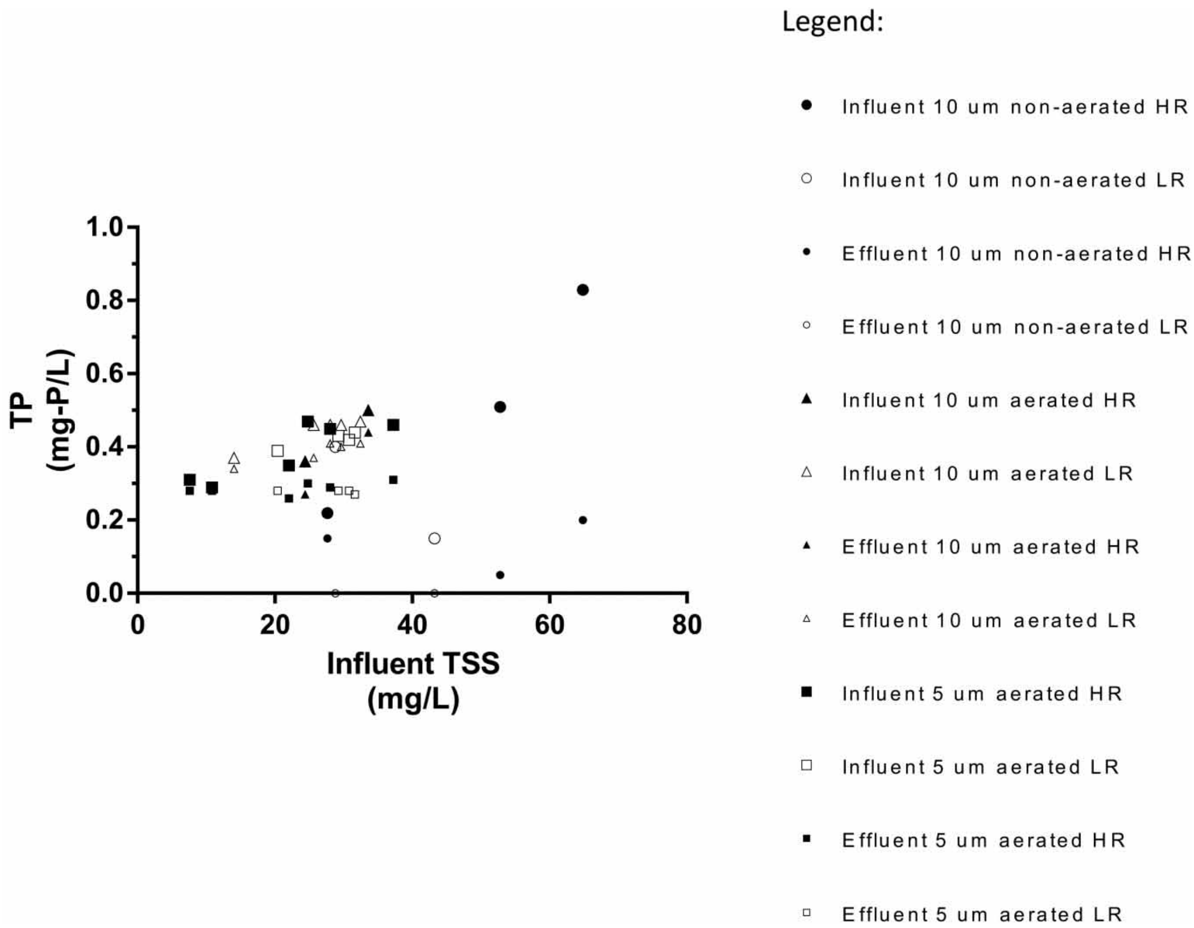

Figure 4 | Influent and effluent TP versus influent TSS.

lagoon effluent across all conditions of the two filters was correlated with influent TSS ($r = 0.859$, $p < 0.001$) and followed a linear trend with an R^2 value of 72.82% (Equation (1)). Typical Chl. α concentrations in facultative lagoons have been shown to range from 500 to 2,000 μg/L, while maturation ponds have reported levels of 200–500 μg/L (Buisine & Oemcke 2003; Mara 2013). Therefore, the Chl. α concentrations of this study are low compared with typical values.

$$(\text{Influent Chl. } \alpha)\left[\frac{\mu g}{L}\right] = 1.72 \pm 1.26 + 0.2893 \pm 0.039 * (\text{Influent TSS})\left[\frac{mg}{L}\right];\ R^2 = 72.82\% \quad (1)$$

The 10 μm filter showed significant removal in both the nonaerated condition ($p = 0.050$) and aerated conditions ($p = 0.048$). The observed removal was of 11.4 ± 6.38 μg/L and 66.1 ± 14.6% in nonaerated conditions, and of 3.6 ± 2.9 μg/L and 41.2 ± 28.7% in aerated conditions, which resulted in average effluent concentrations of 5.2 ± 1.28 μg/L and 4.0 ± 1.0 μg/L, respectively (Table 4). The 5 μm filter also demonstrated significant removal ($p < 0.001$), removing an average of 5.4 ± 2.5 μg/L and 52.8 ± 20.0%, which resulted in an average effluent concentration of 4.1 ± 0.65 μg/L. As such, the removal of Chl. α was effective in this study using both filters at all conditions and maintained a steady, low effluent Chl. α concentration across the applied TSS loading range.

The backwash water of the 10 and 5 μm filters across all conditions demonstrated prevalent algae species being removed by the discfilter from the lagoon effluent. Microscopic algae identification confirmed removal of the following genera of algae from the lagoon effluent

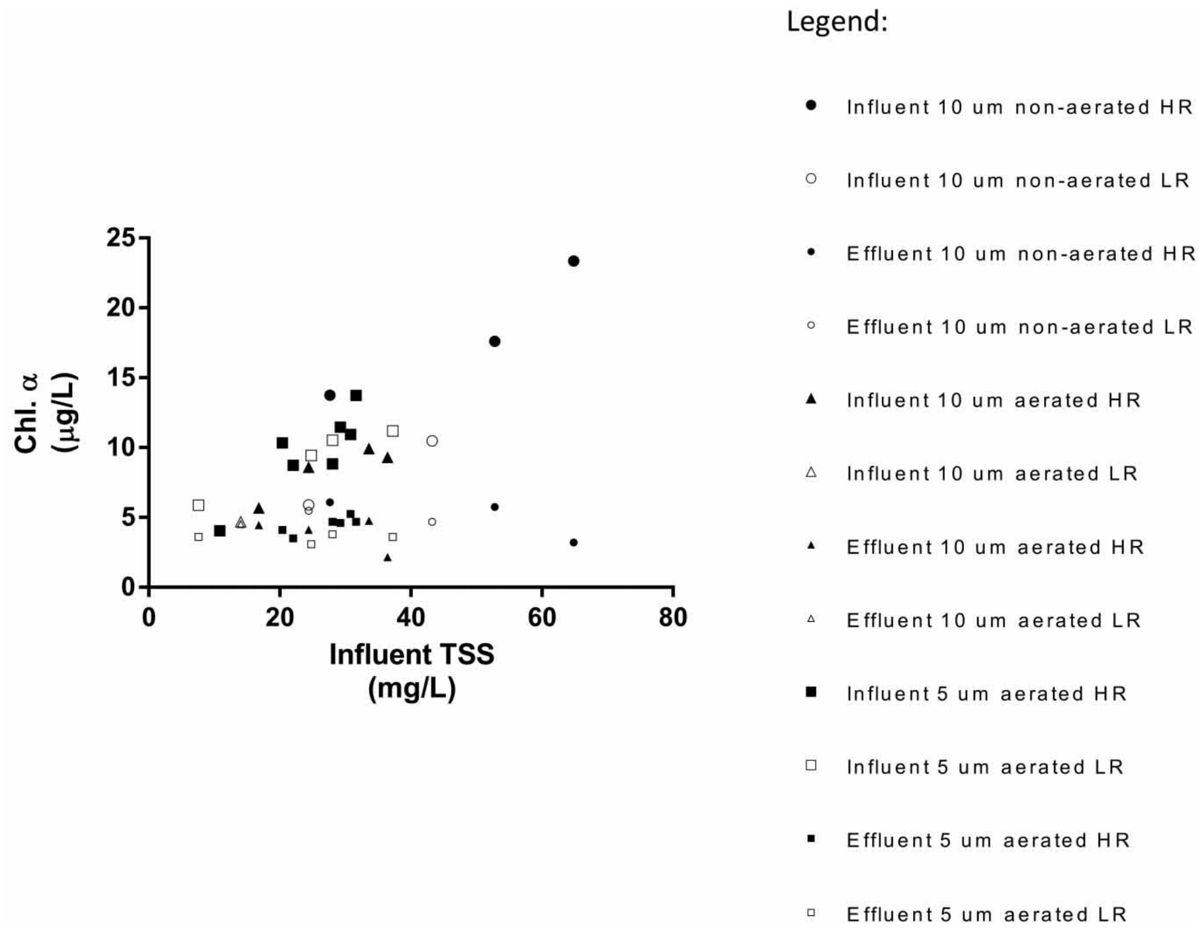

Figure 5 | Influent and effluent Chl. α concentration versus influent TSS concentration.

Table 4 | Chl. α removal performance of discfilter

Filter	Third lagoon cell operation (aerated/ nonaerated)	Mean removal (%)	Mean removal (μg/L)	Removal significance	*p*-value
10 μm	Nonaerated	66.1 ± 14.5	11.4 ± 6.4	Yes	0.05
10 μm	Aerated	41.2 ± 28.7	3.6 ± 2.9	Yes	0.048
5 μm	Aerated	58.2 ± 9.5	6.0 ± 1.9	Yes	<0.001

wastewater using the various filters: *Wilmottia*, *Desmodesmus*, *Chrolumina*, *Cynura*, and *Phacus*. These genera have been observed in previous studies in lagoon wastewaters (Buisine & Oemcke 2003; Pearson 2003).

Overall, the implementation of this technology to treat lagoon effluent will vary based on (i) lagoon type and configuration, (ii) effluent water quality, (iii) use of pre-discfiltration coagulants/polymer, and (iv) presence or absence of pre-discfiltration aeration systems. It is hypothesized that performance of discfilter systems operating year-round versus seasonally in this application will likely be affected by the broader range of lagoon conditions affecting solids characteristics, greater temperature fluctuations, as well as seasonal snowmelt and precipitation patterns.

CONCLUSIONS

The 10 μm filter was demonstrated to be able to convey the imposed flowrates across the complete applied hydraulic loadings range of 4.72–9.34 m/h, whereas the 5 μm filter demonstrated a limited flow conveyance capacity at elevated hydraulic loadings of 6.85 m/h and above. The operation of aerators in the third cell of the lagoon system limited the solids separation efficiency of the 10 μm filter, likely due to entrainment of smaller sized benthic solids into the lagoon effluent. The 5 μm filter was able to provide robust solids separation efficiency during aeration of the third lagoon cell that met typical target effluent TSS concentrations. TP removal as a peripheral benefit of the discfilter operation was significant for the 10 μm filter at nonaerated condition and 5 μm filter at aerated condition, hence following the trends observed with TSS removal performance. Algal removal performance through the removal of Chl. α was effective using both filters at all conditions with steady, low effluent concentrations being maintained across the applied TSS loading range. Overall, this study demonstrates the potential of the discfilter technology for enhanced solids removal in lagoons to improve compliance with strict effluent discharge requirements.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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