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ABSTRACTS / RÉSUMÉS
Backwash Optimization for Drinking Water Treatment Biological Filters

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Natural organic matter (NOM) removal efficiency using drinking water treatment biological filters depends at a great extent on backwashing. Backwashing is performed on a periodic basis, it has the ability to remove the accumulated biomass and particles in order to regenerate biological filters' removal capacity and prevent excessive headloss buildup.

A lab scale study has been conducted in order to examine the impacts of backwashing on biological filtration performance. The backwash strategies were evaluated based on their impacts on dissolved organic carbon (DOC) removals, biofilters' biomass, backwash water volume usage, and effluent turbidity. The filtration cycle lasted for 7 days and time was the sole criterion for biofilter run termination. The effects of employing collapse pulsing versus a water only backwash were investigated under nutrient limited conditions. Three backwash procedures were investigated under nutrient supplemented conditions and were compared to a control backwash procedure.

Collapse pulsing resulted in significantly higher DOC removals (21%) compared to the water only backwash (13%). Employing a lower bed expansion of 20% compared to the 30% control bed expansion while utilizing the same amount of water volume lead to similar % DOC removals (30%). However, employing a higher bed expansion (40%) than the control backwash lead to significantly lower % DOC removals (24%). A backwash strategy that reduced the backwash water volume usage by about 20% resulted in similar % DOC reductions observed with the control backwash. The investigated backwash procedures were also terminated by the extended terminal subfluidization wash (ETSW). ETSW demonstrated no impact on % DOC removals; however, the additional water usage resulting from employing ETSW was compensated by savings after restart as ETSW successfully eliminated the filter ripening sequence. The backwash procedures investigated in this study showed no consistent impact on biofilters' biomass concentrations as measured by the phospholipids and the adenosine tri-phosphate (ATP) methods. Moreover, none of these two analyses showed a direct correlation with DOC removal. On the other hand, dissolved oxygen (DO) uptake showed a direct correlation with DOC removals. Results from this study provide insight to researchers and drinking water treatment utilities on how to optimize their biological filters for the purpose of optimizing the overall drinking water treatment process.
Adequate water supply and treatment together with sanitation and appropriate hygiene behaviour are known collectively as WASH (Water and Sanitation, Hygiene). WASH-based interventions are among the most effective tools to improve public health and limit the incidence of diarrhoeal diseases. Children under the age of 5 years and other vulnerable populations are most at risk from preventable enteric infections, including diarrhoeal diseases, which can also lead to malnutrition and stunting as a result of the inability to retain and absorb nutrients. Further to the health benefits of reducing diarrhoea, its prevention (9.1% of global disease burden) could result in 320 million extra working days, US$7 billion in healthcare savings, and 272 million extra school attendance days per year. Recent estimates of the global population without access to safe drinking water vary between 0.8 and 1.8 billion people. In 2000, Millennium Development Goals (MDGs) were set and sought to halve, by 2015, the proportion of the population without sustainable access to safe drinking water (Target 7C) amongst other goals. The objective of the work presented here was to examine the developments in the sector and highlight where further work is needed. Official results regarding the drinking water target were said to be met as the proportion of the world population with access to water was reported to have increased from 76% to 91%. However, upon closer examination of the criteria utilised to define “access” it becomes evident that from a water quality and accessibility (i.e. time or distance to water source) perspective, this success story merits reconsideration. For example, Bangladesh was reported to have 87% (Joint Monitoring Program) of the population being served by an “improved” water source. However, when considering relevant water quality aspects (i.e. E. coli and As) it is revealed that only 53% of the population have access to safely managed drinking water. Next, if accessibility is considered, the proportion of the population with access to an improved water source is also reduced. For instance, in Ethiopia, the proportion of the population with access to an improved source of 57% would be reduced to 46% if a threshold of 30 minutes is applied as an accessibility criterion. An increased distance may also increase the likelihood of a lower quality source being used or of post collection contamination. Thus, the two considerations show that considerable work likely remains to improve conditions in many countries. This is a timely exercise in view of the new targets set in the Sustainable Development Goals (SDG) that will extend until 2030.
Online Estimation of Disinfection by Products Through Differential UV Spectrophotometry: Potential & Challenges

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Monitoring drinking water quality is an extremely important public safety procedure for municipalities. However, monitoring practices may exceed the capacities and resources of many municipalities due to the time demanding and complex monitoring procedures, especially for disinfection by-products (DBPs) monitoring. Differential UV spectrophotometry (DUVS) has the potential to be a cost-effective asset in the detection and management of DBPs for large and small utilities alike. This technique is based on the principle that using differences in UV absorbance (UVA) at specific wavelengths before and after chlorination can be correlated to certain DBP (Trihalomethanes, THMs and Haloacetic acids, HAAs) occurrence. These correlations are stronger than other conventional precursor surrogate measurements such as UVA at 254 nm, dissolved organic carbon or specific UVA (SUVA). The availability of online UVA probes with the required optical light paths for DUVS lends itself useful for the exploration of this technique for the real time estimation of regulated DBPs.

This project seeks to develop a protocol of real time DBP estimation using DUVS. Unique state-of-the-art spectrophotometer probes with light paths of up to 100 mm were used to continuously scan water before and after disinfection. The probes were installed in a water treatment plant in the region of Québec City for the estimation of four THMs and six HAAs. UVA measurements were also validated with a laboratory spectrophotometer.

Preliminary results confirmed that good site-specific correlations could be established between DUVS measurements and THMs and HAAs concentrations. Although DBP estimations through DUVS are not of regulatory value, DUVS has the potential to be used as a relatively simple, real time, and low-cost surrogate for regulated DBPs in water treatment plants. In turn, this could generate sufficient data for better informed decisions with regards to DBP control and monitoring. In addition to laboratory and field results, the challenges associated with the implementation of such a technique (e.g. installation, operation & maintenance) will also be discussed.
Capture de la Matière Particulaire d’un MBBR à Forte Charge pour Valorisation Énergétique

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Les procédés à forte charge pour l’épuration biologique des eaux usées maximisent la production de boues pour la biométhanisation et réduisent les besoins en aération. Une filière de traitement combinant un bioréacteur à lit mobile à forte charge (high rate moving bed biofilm reactor; HR-MBBR) suivi d’une séparation physico-chimique permettrait d’atteindre ces objectifs, donnant lieu à une filière de traitement secondaire compacte et peu énergivore. L’objectif général de ce projet était de maximiser la capture par flottation rapide novatrice de la matière particulaire biodégradable provenant d’un HR-MBBR pour valorisation énergétique. Les objectifs spécifiques étaient de déterminer l’efficacité de capture des matières particulaires 1) sans ajout de réactif et 2) avec ajout d’un coagulant biodégradable naturel à base de tanin.

Le procédé de flottation rapide Spidflow® (Veolia Water Technologies) a été opéré à l’échelle pilote en aval d’un HR-MBBR. Les eaux usées dégrillées d’une station de récupération des ressources de l’eau (StaRRE) étaient d’abord tamisées (6 mm) et traitées par un HR-MBBR (Fig. 1). Les essais ont été réalisés de juin à octobre 2015. Le taux de charge organique (TCO) et le temps de séjour théorique (TRH) dans le HR-MBBR, ainsi que la charge hydraulique au Spidflow® étaient contrôlés par le débit d’alimentation du pilote. La pression sur la boucle de production d’eau blanche était ajustée à l’aide d’une pompe de recirculation à vitesse variable. Le coagulant était ajouté par une pompe doseuse dans la conduite raccordant le HR-MBBR au Spidflow®*, permettant un temps de mélange de 30 à 60 s. La concentration moyenne de matières en suspension (MES) à l’effluent du HR-MBBR était de 344 ± 54 mg MES·L⁻¹. L’efficacité du Spidflow® était évaluée en termes de capture de MES.

Le Spidflow® opéré sans réactif a permis de capturer 94 ± 1% de MES, correspondant à un effluent d’une concentration de 20 ± 1 mg MES·L⁻¹. Ces performances ont été atteintes pour des pressions d’opération typiques de 5,5 à 6,0 bar, des charges hydrauliques de 10 à 15 m·h⁻¹ et une recirculation d’au moins 25% (Fig. 2). Les conditions d’opération correspondantes du HR-MBBR étaient un TRH d’au moins 35 minutes et un TCO inférieur à 50 g DCO·m⁻²·d⁻¹.

L’ajout du coagulant biodégradable à une dose optimale de 18 mg·L⁻¹ a permis d’augmenter la capture de MES à 96 ± 1% et d’abaisser les concentrations à l’effluent clarifié à 14 ± 2 mg MES·L⁻¹ pour des charges hydrauliques d’au moins jusqu’à 22 m·h⁻¹, des pressions de recirculation de 4 à 6 bar et une recirculation de 15% et plus. La biodégradabilité du coagulant a été déterminée à 0,2 g DCO/g DCO.

La capture efficace des matières particulaires provenant d’un HR-MBBR par le système de flottation rapide Spidflow®* et l’utilisation d’un coagulant naturel à base du tanin permettraient de maximiser la biométhanisation, et de réduire les besoins énergétiques pour le traitement secondaire des eaux usées.
Feasibility of Moving Bed Biofilm Reactor (MBBR) Nitrification at 1°C

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The high occurrence of ammonia as a deleterious pollutant in the aquatic environment has created a demand for upgrade technologies to achieve ammonia removal throughout the world. The most efficient and cost-effective operational approach for ammonia removal is biological nitrification, however, conventional beliefs dictate biological nitrification will cease as water temperatures decrease below 8°C. The objective of this study is to investigate the long term performance of low carbon nitrifying moving bed biofilm reactor (MBBR) systems as an upgrade technology to lagoon treatment facilities, where temperatures are capable of dropping to as low as 0.5°C for extended periods of operation in the winter months.

The MBBR technology was operated at pilot scale between January 27, 2014 and April 24, 2014 with four MBBR reactors operating in the pilot plant. All four reactors were operated continuously at an HRT of 2.2 h and used K5 AnoxKaldnes media. The pilot MBBR was operated through the severely cold winter conditions of 2014 at Masson Angers, Quebec and subsequently through the gradual warming period observed in spring. Throughout the first sixty days, the reactor temperatures ranged between 0.5 and 2°C and the average influent ammonia concentration was 20.7 ± 0.4 mg/L NH₄/NH₃ –N.

The MBBR pilot was able to achieve a maximum removal rate of 230 gN/m³·d (Figure 1) as well as effluent ammonia concentrations below 2.20 mg/L NH₄/NH₃ –N at 1°C. Nitrogen mass balances were performed for each collection to validate the biological conversion from ammonia to nitrate with a maximum error of 4.3%. Under standard operating conditions the TSS addition due to MBBR treatment was 2.1 ± 2.4 mg/L. With regulations for TSS mandated at 25 mg/L for the majority of treatment facilities across Canada, it is unlikely downstream settling would be necessary for MBBR upgrades to lagoon facilities. However, for communities with higher effluent TSS discharge from the lagoon treatment facility or more stringent regulations, digital particle analysis demonstrated that the detached biofilm did not negatively affect solids settling characteristics. In particular, 50 ± 5% of the effluent solids settled in 30 minutes. As expected, the peripheral benefits of the MBBR system included reduction in the remaining CBOD₅ and SCOD as well as oxygenating the effluent water.

In addition to this conventional analysis, variable pressure scanning electron microscopy, confocal laser scanning microscopy and next generation sequencing (Figure 2) were applied to fully investigate impacts of low temperatures on nitrifying biofilms. *Nitrosomonas* and *Nitrospira* were identified as the most abundant ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) at all temperatures. The thickness of the biofilm, the mass of biofilm attached per carrier along with the overall quantity of active nitrifying cells were all shown to increase during exposure to cold temperatures; hence, demonstrating that the nitrifying biofilm and embedded bacterial communities attached to the MBBR carriers exist in a less active but stable state during cold temperature operation.
Figure 1: Ammonia removal rates across loading rates at 1°C
Hydrogen Sulfide Generation in Wet Stormwater Ponds: Understanding the Cause and Looking Toward Solutions

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Wet stormwater ponds are being increasingly utilized as part of stormwater management policies across the world. When specific water quality conditions are met some of these ponds are capable of releasing large quantities of hydrogen sulfide (H₂S) gas. This study observed and monitored water quality constituents in two wet stormwater ponds (RSPI and RSPII) owned and operated by the City of Ottawa over a period of 448 days. RSPI is a pond which did not exhibit H₂S gas release, while RSPII has been releasing H₂S during certain periods in the summer and under ice cover during the winter. The key conclusions of the study are the following: H₂S production events were not observed in RSPI but were observed in RSPII when low dissolved oxygen (DO) conditions were present. Ice cover conditions hinder reaeration and prolong sulfide generation events. A statistical correlation exists between a decrease in DO and the increase of H₂S and NH₃/NH₄⁺ concentrations. There was a measurable observed lag phase following the onset of low DO concentrations and the production of H₂S at depth in the water column when air temperatures were below 0°C. The dominant strains of sulfate-reducing bacteria identified via DNA sequencing are ubiquitous and were found at both RSPI and RSPII. Ultimately, due to climate change and the expected increase in the quantity of precipitations which need to be handled by watersheds, some facilities which should have been constructed in stages are instead delivered to governments and municipalities at full design scale, potentially exacerbating the problem by creating a potential for anoxic conditions to develop in certain portions of the ponds.
Combined Use of Peracetic Acid and Ultraviolet Irradiation (UV) for Wastewater Disinfection

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Problem Statement
Culture methods using indicator organisms have long been the gold standard for evaluating the effectiveness of wastewater disinfection. However, there is growing concern that a portion of microorganisms can escape detection and survive in a viable but non-culturable (VBNC) state. Bacteria in this state have the potential to regain metabolic activity and regrow once introduced to the environment. In this study, the effectiveness of combined disinfection treatment using ultraviolet irradiation (UV) and peracetic acid was evaluated. Peracetic acid is the peroxide of acetic acid and has disinfection residuals of acetic acid and oxygen. The combined use of UV and peracetic acid has also been shown to have synergistic effects due to the formation of hydroxyl radicals (*OH), a strong oxidant.

Objective
The objective of this study was to evaluate and compare the singular and combined use of peracetic acid and UV for wastewater disinfection using both traditional culture methods as well as molecular methods that provide insight into the VBNC state of indicator bacteria.

Methodologies
Bench-scale batch reactors were used with an experimental matrix of locally collected wastewater spike with pure culture Escherichia Coli at starting concentrations of 10^7 CFU/mL. EC Medium with MUG agar was used with membrane filtration to culture E.coli and compared to culture-independent method that combined DNA-intercalating dye, propidium monoazide (PMA), with quantitative polymerase chain reaction (qPCR). The use of BacLight Live/Dead molecular staining was also used.

Results
Culture methods indicated that the singular use of 2.3 mg/L of peracetic acid allowed for a 5.7-log reduction of E.coli and a nearly 7-log reduction of E.coli was observed when peracetic acid was combined with UV fluence of 40 mJ/cm^2 or 60 mJ/cm^2 (Fig. 1). PMA-qPCR allows for the detection and quantification of viable cells as indicated by a lack of membrane damage. With this method, a 3-log reduction of viable cells was observed subsequent to both the singular and combined use of peracetic acid and UV (Fig. 1). Live/dead BacLight molecular staining allowed for further visualization of viable cells and confirmed the trend observed with PMA-qPCR. The concentration of culturable E.coli was monitored after treatments and regrowth was observed after 24 hours (Fig. 2). During the regrowth period, no additional carbon source was provided and minimal media experiments ruled out the possibility that acetic acid residuals could act as food for bacteria.

Conclusions
The combined use of peracetic acid and UV is a promising chlorine-free disinfection treatment that both eliminates the risk of chlorine disinfection by-products and increases the efficiency of UV disinfection.
Results indicate that combined treatment of peracetic acid and UV were more effective at reducing culturable E.coli than either treatment used individual; however, evidence indicates that VBNC bacteria remained after all treatments. VBNC bacteria also showed potential to regain culturability given time to repair and regrow without further nutrient supplementation.

**Recommendations**
It is recommended that a full-scale testing be performed for a more realistic simulation of wastewater treatment with UV and PAA. Broadening the scope of bacteria that are studied is also recommended as is incorporating molecular methods into evaluating any new disinfection treatment.

**Fig. 1:** Inactivation of E.coli in secondary wastewater subsequent to treatment with 2.3 mg/L peracetic acid (noted as PAA), 11.6 mg/L peracetic acid, the combined treatment of 40 mJ/cm² UV and 2.3 mg/L peracetic acid and the combined treatment of 60 mJ/cm² UV and 2.3 mg/L peracetic acid as measured by culture method, qPCR and the combined treatment of PMA with qPCR.
Fig. 2: Culturable E.coli in secondary wastewater after treatment with 2.3 mg/L peracetic acid (noted as PAA), 11.6 mg/L peracetic acid, the combined treatment of 40 mJ/cm² UV and 2.3 mg/L peracetic acid and the combined treatment of 60 mJ/cm² UV and 2.3 mg/L peracetic acid immediately following treatment (0 h) as well as 2, 6, 24 and 48 hours following treatment.
Eco-friendly, cost effective and wide spectrum biocidal method is necessary in all sectors that are related with human health. Some hydrolytic and oxidative enzymes can be used for disinfection purposes. Laccase (EC 1.10.3.2), an oxidoreductase enzyme, is able to oxidize unreactive iodide to reactive iodine through laccase-mediated system. The resulting iodine represent a powerful antimicrobial compound.

In this study, we investigated the potential of a laccase-mediated system to generate antimicrobial compound iodine ($I_2$). A well-known laccase mediator (acetophenone) and an emerging contaminant potentially present in wastewaters (acetaminophen) were added in distilled water and wastewater effluent have been used as mediators to determine laccase oxidation potential and disinfection potential of the generated iodine. In this study, two different laccases enzyme have been tested. Firstly, a commercial laccase from *Trametes versicolor* and secondly partly purified laccase from *Pleurotus dryinus* have been used. In order to use that enzyme-based system in a continuous way, the potential of laccase insolubilized as cross-linked enzyme aggregates for $I_2$ generation and wastewater disinfection has been also tested.

Biocatalytic generation of $I_2$ was possible using laccase-mediated. The oxidation of iodide into iodine was more efficient in the presence of acetophenone mediator. Iodine production was affected by the initial laccase activity, and mediator concentration.

Laccase catalysed bactericidal activity in real wastewater was also determined without the addition of any mediator assuming that wastewater already contains mediators such as acetaminophen. Using that system, non fecal coliforms present in the tested wastewater were also removed.

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Sludge dewatering is one of the most challenging processes during sludge treatment. Particularly in cold climates, sludge dewatering becomes a major problem for treatment plants because mechanical equipment such as centrifuges and filter presses are difficult to operate and maintain.

This study examined the individual and combined effects of potassium ferrate additions and freeze-thaw conditioning for sludge stabilisation and dewatering. The first experiments, using primary sludge, compared potassium ferrate additions prior to freeze-thaw versus post freeze-thaw. A low dose (LD) of 1.0 g/L and a high dose (HD) of 10.0 g/L of potassium ferrate were used along with a freezing temperature of -20°C for 1, 8 and 15 days. Following the designated frozen period, the samples were removed from the freezer and thawed at room temperature for 12 hours. Sludge samples were characterised in terms of fecal coliform, total solids (TS), volatile solids (VS), capillary suction time (CST), ammonia and sulphide.

The second part of the study, using anaerobically digested sludge, evaluated potassium ferrate pre-treatment and freeze-thaw at -20°C, using LD=0.5 g/L and HD=5.0 g/L of potassium ferrate. The study used lab-scale sludge drainage beds to separate the meltwater from the sludge cake samples during the thawing period. The effluent meltwater was characterised in terms of fecal coliform, soluble proteins, soluble carbohydrates, soluble chemical oxygen demand (sCOD), pH and turbidity. The sludge cake was characterised in terms of fecal coliform, TS and VS.

The study demonstrated that stand-alone freeze-thaw can reduce fecal coliform by >3-log after being frozen for only 1 day, and pre-treatment with potassium ferrate can be used to improve the effects of freeze-thaw on fecal coliform inactivation in sludge. Furthermore, the drainability of the sludge following freeze-thaw was not significantly deteriorated when potassium ferrate was added to the sludge prior to freezing, despite greater than 4-fold increases in the concentrations of soluble proteins and soluble carbohydrates.

The meltwater collected was approximately 85% of the initial sludge volume. When 5 g/L of potassium ferrate was added to the sludge prior to freezing, the meltwater collected had <0.28 MPN/mL fecal coliform, the turbidity was <10 NTU, and the pH was 9.1. Pre-treatment with potassium ferrate co-treatment can be used to stabilise sludge and reduce sludge volume.
Variation in Prediction of Natural Organic Matter Fouling Using the Silt Density Index (SDI) and Modified Ultrafiltration Fouling Index (MFI-UF) Under Variable Testing Conditions

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Prevention and control of membrane fouling are essential to ensure robust performance of membrane systems. Over the past decades, researchers have focused on developing fouling prediction tools to predict the fouling potential of membrane feed stream and to assess the pretreatment required. The SDI method (using 0.45μm flat sheet microfiltration (MF) membrane) was first developed to predict the percentage of flux decline per minute of filtration expected for a specific membrane system. The simplicity of the SDI method makes it preferable to be performed routinely by plant operators and nowadays, most membrane manufactures use the SDI to determine the quality of their product and performance. However, lack of agreement between membrane and SDI filtration operational conditions is identified major limitations of the SDI method to predict the true fouling strength. Moreover, it has been clearly proven that particles much smaller than 0.45μm, such as some NOM fractions, are responsible for fouling of membranes. As a consequence, the predictive value of SDI in fouling is doubtful. To overcome this deficiency, the MFI-UF has been developed, making use of 13 kDa hollow fiber UF membrane to predict the fouling potential by modelling a relationship between the flow rate and total volume produced as a function of time. The MFI–UF, however, has not yet been tested and evaluated for NOM fouling under different pressure and temperature conditions. The objective of this work is to assess and compare the ability of the SDI and MFI-UF methods to predict NOM fouling for membranes under various operating pressure and water temperature conditions.

The SDI and MFI-UF testing were performed according to the methods documented in ASTM, 2014 and Boerlage et al., 2002, respectively. In this study, the effect of pressure and temperature variation (1 - 3 bar and 5 - 35 °C) on NOM fouling was assessed using four model solutions: humic acid, bovine serum albumin (BSA) for protein, sodium alginate and their mixture.

Experimental results demonstrated that the operating pressure and feed water temperature have a pronounced effect on the SDI method to predict NOM fouling. The SDI experimental was found to increase substantially by increasing pressure and temperature (> 70%). The fouling order was inconsistent and uncorrelated with the concentration of NOM in the feed water. Normalization of the SDI values did not improve the SDI graph trend indicating the need for including additional parameters to the standard method to improve the efficiency of the SDI method to predict NOM fouling for membrane systems. On the other hand, the MFI-UF experimental showed less variability (< 20%) under changes in pressure and temperature conditions and better correlation with the concentration of NOM in the feed water. These results demonstrated that the use of the MFI-UF over the SDI method could be more useful to predict NOM fouling for membrane systems. Therefore, incorporating of an MFI-UF system into full scale membrane facilities would add more benefits in minimizing the doubts when evaluating membrane fouling and ultimately costs associated with pretreatment, cleaning, and replacement.
Microfiltration/ultrafiltration (MF/UF) membrane filtration processes have been increasingly used in drinking water treatment. Pretreatment by coagulation/flocculation/sedimentation is often used to alleviate membrane fouling in drinking water treatment, however there has been limited research on floatation as the pretreatment separation process. The main objective of this study is to compare the impact of sedimentation and floatation as part of the pretreatment for UF of Ottawa River water (ORW) with relatively high hydrophobic (HPO) natural organic matter (NOM) content. Water samples pretreated at two adjacent full-scale water treatment plants were subjected to multiple-day UF membrane fouling tests (constant flux with backwashing and chemical cleaning) using an automated bench-scale UF hollow fiber inside-out dead-end membrane system. Chemical cleaning with different chlorine concentrations (10, 50, 100, and 200 ppm), 0.1N NaOH and citric acid during UF of pretreated ORW was investigated. The effect of different filtration cycle lengths (30, 60, and 90 minutes) between backwashing was also studied.

Based on the samples tested, the following conclusions were drawn from water characterization test, fouling experiments, backwash efficiency calculation and resistance-in-series model calculation:

First, the pretreatment greatly reduced the NOM concentrations of these waters. The total organic carbon (TOC) and UV254 absorbance removals were in the 60-70% and 75-80% range, respectively, but there still remains significant amount of NOM which can foul the membranes. Second, the superiority of floatation pretreatment was evident from the enhanced membrane performance in terms of: a) lower membrane transmembrane pressure (TMP) developed (Fig. 1); b) greater backwash efficiency; c) lower hydraulically irreversible fouling indices; and d) lower chemically irreversible fouling indices. Third, the superiority of floatation pretreatment appears to be linked to its greater removal of the HPO fraction, as the both the TFI and HIFI indices were highly correlated to the specific UV absorbance (SUVA) ($R^2>0.92$) (Fig. 2). Fourth, enhanced chemical backwash with 100 ppm chlorine and chemical cleaning with 0.1 N NaOH & 200 ppm chlorine were found to be very effective at reducing fouling for pretreated ORW. Fifth, as expected longer filtration cycles resulted in greater fouling. Finally, to assess if floatation pretreatment is superior for most or all waters with a high hydrophobic NOM content, further testing with different source waters is recommended.
Fig. 1 Four-day 50 LMH filtration summer experiment results

Fig. 2 The relationships between (a) TFI and SUVA; (b) HIFI and SUVA

(a) \[ Y = 188.68x - 244.89 \]
\[ R^2 = 0.9562 \]

(b) \[ Y = 18.128x - 25.789 \]
\[ R^2 = 0.9217 \]
Innovative Fouling Remediation Techniques in ultrafiltration of Latex Contaminated Water and Wastewater

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The aim of the current study was to effectively control membrane fouling and enhance the ultrafiltration process of the simulated latex paint effluent using the hydrophobic Polyvinylidene Difluoride (PVDF) membranes. This study included different treatment strategies either by enhancing the PVDF membrane surface hydrophilicity or by pretreating the latex paint effluent with the aim of improving its antifouling propensity. Polyvinylidene Difluoride (PVDF) membranes with MWCO of 100,000 were used under a constant flow rate and cross-flow mode. The feed pretreatment strategies included manipulating the pH of the latex solution, and adding Linear Alkyl Benzene Sulfonate (LAS) and Cetyltrimethyl Ammonium Bromide (CTAB) as anionic and cationic surfactants at different concentrations and various treatment times. The effects of surfactants on both the zeta potential of the latex particles and the membrane surface charges were investigated. The manipulation of the membrane’s surface hydrophilicity was performed by soaking the membrane in alkaline solution or LAS at different concentrations and at various treatment times, so as to improve the negativity of the surface charge. The effects of CTAB on latex particle size distribution were also investigated at a variety of concentrations, treatment times, and agitation durations. Moreover, the combined effects of the use of pre-treated feed and the membrane's surface charge improvement on the total mass of fouling permeate flux and the specific power consumption was investigated.
Full-Scale Performance Evaluation: Hybrid Biological Aerated Filter (BAF) and Moving Bed Biofilm Reactor (MBBR) System

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Attached growth processes and specifically the moving bed biofilm reactor (MBBR) and biological aerated filter (BAF) have shown advantages compared to conventional technologies such as lower sludge generation, lower maintenance costs and smaller land footprint requirements. The BioStyr-Duo is a novel technology which combines specific advantages of the MBBR and BAF technologies into a single hybrid system. The BioStyr-Duo is designed to prudentially grow a significant portion of the heterotrophic biofilm, which is largely responsible for head loss and clogging in BAF systems, on MBBR carriers that are located closest to the influent pipe in the hybrid unit and are in constant motion in the system to prevent clogging of the carriers. Hence the BioStyr-Duo has the potential to reduce and minimize head-loss in the system, increase the carbon and nitrogen loading potential of the system and reduce the energy usage of the system while further reducing the required land footprint of the system. The study is performed on a full-scale, MBBR and BAF hybrid, demonstration cell at the newly constructed Cornwall, ON wastewater treatment plant (WWTP).

Influent and effluent samples were collected from two full-scale hybrid and conventional cells after the acclimatization period, over the course of three conditions in 2015 (winter season, melt condition and summer season). Profile samples were also collected from sampling ports at each cell and water constituents were analyzed. The influent data of the Cornwall WWTP are shown in Figure 2. Figure 2a shows the influent temperature and flowrate of both hybrid cell and reference cell. The influent wastewater temperature slightly dropped to the lowest of 6.7 °C during winter and increased to as high as 18.5 °C in summer. Figure 2b summarizes the influent quality over the same period. The sharp fluctuation of TSS concentration was due to the backwashing process.

The effluent quality is summarized in Table 1. During winter season, the influent wastewater has relatively high concentrations of water constituents and low treatment efficiencies as compared to the other two conditions. The result of the performance of Biostur-duo and reference cell showed no significant differences in effluent water quality. Both hybrid and reference cells show the lowest removal on sCOD with the average efficiency of 40.4% and 40.1%, respectively, while the highest removal on TSS with the average efficiencies of 88.9% and 92.1%, respectively were observed. For NH₄⁺-N removal, it was observed that the efficiency increased with the increase of the temperature. The lowest removal efficiencies of 73%, 56.6% were observed during winter season and which then increased to 82.6%, 72.2% at melt condition and 90.2%, 86.5% during summer season for hybrid and reference cells, respectively. The profile water quality analysis also showed the similar trend in both Biostyr-duo and reference cell. Overall, the headlosses over time after each backwash was found to be more stable and easily managed for the BioStyr-duo technology.
Figure 2. (a) Influent temperature and flowrate of hybrid and reference cells, and (b) influent water quality through Jan. 2015 to Jul. 2015. Dots are individual measurements, representative for the daily conditions.

Table 1. Summarized effluent quality for both hybrid cell and reference cell during three separated seasonal conditions. Errors are indicated by standard deviation in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>Influent average daily</th>
<th>Effluent average daily</th>
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<tr>
<td></td>
<td>Hybrid Cell</td>
<td>Reference Cell</td>
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<tr>
<td>Winter Season</td>
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<tr>
<td>TSS (mg/L)</td>
<td>41.8 (±9.4)</td>
<td>5.2 (±1.2)</td>
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<tr>
<td>sCOD (mg/L)</td>
<td>50.6 (±10.6)</td>
<td>29.0 (±3.6)</td>
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<td>NH₄⁺-N (mg/L)</td>
<td>19.6 (±3.4)</td>
<td>5.3 (±2.6)</td>
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<td>Melt Condition</td>
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<tr>
<td>TSS (mg/L)</td>
<td>26.2 (±7.9)</td>
<td>2.5 (±1.3)</td>
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<tr>
<td>sCOD (mg/L)</td>
<td>33.0 (±3.5)</td>
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<td>NH₄⁺-N (mg/L)</td>
<td>11.5 (±1.3)</td>
<td>2.0 (±0.8)</td>
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<tr>
<td>Summer Season</td>
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<tr>
<td>TSS (mg/L)</td>
<td>26.6 (±10.6)</td>
<td>3.0 (±0.8)</td>
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<tr>
<td>sCOD (mg/L)</td>
<td>29.9 (±5.4)</td>
<td>19.1 (±1.3)</td>
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<tr>
<td>NH₄⁺-N (mg/L)</td>
<td>13.3 (±2.8)</td>
<td>1.3 (±1.0)</td>
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Protein to Polysaccharide Ratio in EPS as an Indicator of Non-optimized Operation of Tertiary Nitrifying MBBR

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Water and wastewater treatment solutions incorporating biofilm systems are becoming increasingly popular due to more stringent regulations pertaining to drinking water and wastewater effluent discharge in Canada and in other parts of the world. As a major component of biofilm, extracellular polymeric substances (EPS) have been considered as an important factor affecting the physical and chemical properties of biofilm.

In this research, the EPS of biofilms samples harvested from a pilot-scale nitrifying moving bed biofilm reactor (MBBR) was characterized at various temperatures and hydraulic retention times (HRTs) in order to investigate potential correlation between the EPS components of the nitrifying biofilm and the ammonia removal efficiency. Particularly, the protein (PN), polysaccharide (PS), and extracellular DNA (eDNA) percent concentrations of EPS of biofilms as well as their confocal Raman microscopy (CRM) spectra of EPS were investigated at various operating temperatures and HRTs. In addition, the biofilm morphology and thickness as well as the viability of the embedded cells were measured using a variable pressure scanning electron microscope (VPSEM) and a confocal laser microscopy (CLSM) in combination with live/dead staining respectively at various HRTs.

The research demonstrates that an increase in PN content and subsequently a decrease in PS and eDNA contents in the EPS of nitrifying MBBR biofilm were observed at the lowest operational HRT and the highest temperature. The EPS protein to polysaccharide (PN/PS) ratio of nitrifying MBBR systems was shown to significantly decrease below a value of 3 when the system was underloaded (observed at the highest operational temperature in this study) or hydraulically overloaded (observed at the lowest HRT in this study). As such, data obtained at lower operational temperatures, with the system no longer underloaded, and at longer HRTs, with the system no longer hydraulically overloaded, all demonstrate an EPS PN/PS ratio of approximately 3. Chemically measured EPS PN/PS ratios were shown to correlate to Raman intensity ratios of amide III to carbohydrate at 362 rel. cm⁻¹. Further, the ammonia removal kinetics and EPS response at HRT values of 0.75 and 1.0 h indicate that nitrifying MBBR systems may be optimized to operate at HRTs as low as 0.75 to 1.0 hour as opposed to conventional HRTs of 2.0 to 6.0 h.

In conclusion, this study demonstrates that the PN/PS ratio in EPS is a potential metric to identify non-optimal operation of nitrifying MBBR systems.
Graphical Abstract

Nitrifying MBBR pilot

Various temperatures

Various HRTs

EPS
Protein (PN)
Polysaccharide (PS)
Extracellular DNA (eDNA)

Substrate underloaded

Hydraulically overloaded

PN/PS ratio at various HRTs
PN/PS ratio at various temperatures
The Légumier Du Madawaska is a vegetable processing facility located near Riviere-Verte, New Brunswick. The company has been in operation since 1974, and has grown continuously since then, with 3 different expansions involving increased processing capacity. The main vegetable processed is potatoes for fresh cut French Fries, but they also process carrots, turnips and cabbages. It employs 8-15 worker’s year round, and purchases all of its vegetables from local producers.

The Légumier had recently installed a system of 4 septic tanks to improve the treatment of the wastewater generated by the vegetable processing. While effective at removing suspended solids from the wastewater stream, an increased level of treatment was required to deal with the dissolved organics and increase the pH to the level required by the New Brunswick Department of the Environment.

**BioCord Reactor Solution**

After examining several alternatives, the Légumier decided on installing BioCord Reactor Technology into their existing 4 tank septic system. BioCord Reactor Technology would provide a surface for treatment bacteria to grow, removing the organics from the wastewater treatment. A chemical dosing system was also installed to maintain the pH level.

Bishop Water Technologies prepared the full design of the BioCord Reactor system, including the aeration diffuser system and blower, stainless steel suspension brackets, and BioCord material. The pH adjustment system was provided and installed by Marathon Fluid Systems.

In partnership with Complete Energy Systems of Grand Falls, New Brunswick, installation of the BioCord, aeration and chemical dosing system proceeded quickly, taking two days. Proper scheduling allowed the Légumier to maintain full production while the installation was proceeding.

**Results**

After a period of acclimatization, the pH adjustment system was able to increase the pH from an average of 5.9 to 7.2, a level much more suitable for the development of treatment bacteria in the system. Initial concentrations of DOD range from 1300-1700 mg/L, and has been reduced to less than 400mg/L. These results are expected to improve as the amount of treatment bacteria increase on the BioCord.

These results show the effectiveness of the installation of a fixed film system for the retrofit of small industrial wastewater treatment systems. It can be done with existing tankage, in a cost effective manner with a quick, simple installation.
Figure 2: BioCord Installation

Figure 2: Légumier Results
A Combined Reed Bed and Freezing Bed Filter for Septage Treatment and Reuse in Cold Climate Regions

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Combined reed bed and freezing bed filters have been applied to treat septage (sludge from septic tanks) at a hauler’s septage lagoon in Eastern Ontario in a 5-year field-scale study. The impact of varying hydraulic and solid loading rates as well as winter freeze-thaw conditioning on filter performance have been characterized and design loading rates developed. Filtrate quality is equivalent to a low-strength domestic wastewater and is reused as irrigation water while the dewatered sludge meets biosolids standards for application to agriculture soils. This technology provides a low energy, low cost solution for septage haulers and rural municipalities with the potential for full reuse of liquid and solid residual streams.
Free Nitrous Acid Pretreatment of Thickened Waste Activated Sludge Improves Anaerobic Digestability

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Abstract

Anaerobic digestion of waste for biological methane production can be a sustainable source of renewable energy as well as an efficient waste management technique. Significant research efforts on digester design, process enhancement, and odors control are vital. Generally, the rate limiting step of anaerobic digestion of solid waste is the first one: hydrolysis or solubilization, where the cell wall is broken down allowing the organic matter inside the cell to be available for biological degradation. Therefore, many studies have been conducted to enhance the hydrolysis using feed pretreatment. In this study, the effect of free nitrous acid (FNA) on the anaerobic digestibility of homogenized thickened waste activated sludge (TWAS) was evaluated. The effect of chemical dose ranging from 0.4 to 2.8 mg N/L on the degree of disintegration as well as the anaerobic digestibility of TWAS was investigated. All of the pretreatment tests were conducted at a pH of 5.5. The results of this study showed that the soluble chemical oxygen demand (SCOD) increased by 140% from 2300 mg/L to 5600 mg/L. The biochemical methane potential tests showed an increase in methane production by 20% when the FNA dose was 1.4 mg N/L.
Production and Recovery of Bioplastic from activated sludge

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Today, plastics materials/ conventional plastics derived from petroleum are taking an important place in our daily life due to their physical properties like strength, lightness, durability and resistance to degradation; make them very convenient in utilization. However, some plastics are reused, recycled or burned for energy recovery, but a large amount accumulates in landfills, in oceans, and elsewhere in the environment. Therefore, petroleum-derived plastic production will be eventually hindered by the depletion of petroleum and the inevitable environmental pollution, which is caused by their disposal. There is the only solution to the replacement of non-biodegradable petroleum-derived conventional plastics by biodegradable plastics such as Bioplastic/ polyhydroxyalkanoates (PHAs). PHAs are produced by numerous bacteria as intracellular storage material and these are synthesized under stress conditions such as limited essential nutrients but in the excess of carbon source. Though the PHAs are good alternative of petroleum based synthetic plastics; universal application is hindered due to its high production and processing cost. The major fractions of the cost involved in PHAs production are mainly in utilization of production medium, operational conditions and recovery of the PHAs. Production costs can be reduced by using cost effective raw material such as food wastes, biodiesel industrial wastes, and activated sludge to produce PHAs over the use of the expensive synthetic medium.

In this context, recently in our lab, series of upstream studies on PHAs production from pulp and paper secondary sludge have been carried out but the PHAs recovery studies were not performed. Extraction of PHAs from fermentation broth is a critical step in its production. There are two main strategies applied to extract intracellular biopolymer. The first approach is the solubilisation of biopolymer using organic solvents such as chloroform, methylene chloride followed by precipitating with methanol and/or ethanol. The second approach is non-PHA cell mass (NPCM) dissolution using various chemical treatments. The organic solvents are efficient in extraction however; they are expensive, hazardous and toxic. Thus, different digestion methods have been developed to overcome these problems. NPCM could be digested using either several chemicals (such as alkali and acids, detergents/surfactants, sodium hypochlorite, enzymes) or mechanical cell disruption methods (such as bead mills; high pressure homogenization and sonication). However, so far the extraction of PHAs using non-solvent extraction methods are mainly reported for pure cultures and very limited information is available on PHAs extraction from activated sludge. Therefore, a systemic study is warranted for the extraction of PHAs employing non-toxic methods on to the activated sludge.
Figure 1: Soluble protein, carbohydrate and COD concentrations in anaerobically digested sludge following a low dose (LD) of 0.5 g/L and a high dose (HD) of 5.0 g/L of K2FeO4 with a 15-minute contact time. The figure also shows the effects of K2FeO4 and freeze-thaw co-treatment on the concentrations of soluble components in the meltwater following 1, 8 and 15 days frozen at -20°C and a 12-hour thawing period in lab-scale freeze-thaw beds with gravity drainage.
Figure 2: Effects of K2FeO4 and freeze-thaw co-treatment on the concentrations of fecal coliform in the sludge cake remaining following 1, 8 and 15 days frozen at -20°C and a 12-hour sludge thawing period in lab-scale freeze-thaw beds with gravity meltwater drainage.
Four Year Study on the Treatment of a PCP and CCA Leachate by a Constructed Wetland and a Willow Planted Filter

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The goal of this project was to determine if the leachate of treated wood pole storage yard could be efficiently treated by various types of constructed wetlands to meet municipal storm sewer discharge criteria. The leachate contained chromium, copper, arsenic (CCA), oil, pentachlorophenol (PCP) and polychlorodibenzo-p-dioxins/polychlorodibenzofurans (PCDD/Fs). The leachate was treated by four different parallel constructed wetlands (CWs) prior to being collectively treated in a willow planted filter (WPF). The units were constructed in 2012. This paper focuses on the design, performance of one of the CWs and on the WPF. The fate of contaminants and water balance are more specifically addressed.

One of the horizontal sub-surface flow wetland consisted of four sequential sections. The first one was filled with blond peat, sand and zero valent iron and was maintained under anaerobic conditions to dechlorinate congeners of PCP and PCDD/Fs. The second section was aerated and planted with Phragmites australis australis to degrade organic chemicals. The third section was filled with steel slag to remove metals and the fourth section with peat to neutralise the high pH arising from the slag section. The WPF (Salix miyabeana SX67) was filled with sand and peat and aimed to treat the residual contamination and to evaporate some of the 3.7 m³/d leachate.

The CW treated the leachate to efficiently meet discharge criteria for all metals and for PCP. Manganese (Mn), however, exceeded occasionally the discharge criteria for storm sewer (0.1 mg/L) and its average concentration increased over time. Similarly, PCDD/Fs could be efficiently removed (99.98%; average of 0.06 pg TEQ/L) but not to the level required to meet the very strict discharge criteria of 0.0031 pg TEQ/L. The removal mechanism of PCDD/Fs was not reductive dechlorination but adsorption onto the substrate as indicated by the proportional decrease of the congener profile, with most of the removal taking place in the upstream section of the CW. The residual contamination of PCDD/F is suspected to flow through the CW by being sorbed onto mobile organic colloids. Metals were adsorbed or precipitated onto the CW substrate and the PCP was completely biodegraded. Evapotranspiration in the CW reduced the effluent flowrate (1 m³/d) by approximately 17%.

The willows in the WPF were able to grow well in the pretreated effluent. PCP and CCA concentrations were below detection limit in the WPF effluent. The removal of PCDD/Fs was variable depending on the leachate contamination (99.17%; average effluent concentration of 2.1 pg TEQ/L). The Mn concentration in the WPF effluent always exceeded the discharge criteria despite showing a gradual decrease over the years (from 2.2 to 0.4 mg/L). The CW and WPF have been operating for four years, except during winter, and are still maintaining a high level of removal efficiency.
For full scale implementation, a careful selection of substrate should be made to ensure that their Mn content is not excessive and the best approach to meet the extremely strict PCDD/F criteria was considered to use an improved combination of CW sections for efficient pretreatment followed by a large enough WPF to fully evapotranspire all the leachate.
Struvite Precipitation of Ammonia from Landfill Leachate

C. Zhang; M. Sartaj

Ammonia is one of the main water quality parameters of concern. In addition to being toxic for fish, it contributes to eutrophication of lakes, estuaries and other aquatic environments. Ammonia toxicity, even at low concentrations (5 to 20 mg/L), can be a major problem for many fish species of ornamental, aqua-cultural and economic values, and may lead to mass mortality under unfavorable conditions. Extremely high ammonia concentrations (1,500 to 5,000 mg/L) measured in municipal landfill leachates can cause failure in biological treatment processes due to the ammonia inhibition effect. There’s a need for controlling and regulating the concentration of ammonia prior to its disposal into the natural environment.

Recently, struvite (magnesium ammonium phosphate, MAP, $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) precipitation has been shown to be a promising method for the treatment of high-strength ammonia wastewaters. With the addition of magnesium and phosphate source, ammonia can be precipitated as struvite under certain pH range.

As shown in Figure 1, in the first phase of this study, municipal landfill leachate was treated by struvite precipitation to investigate the effect of operational parameters of the process (pH and molar ratios of $\text{NH}_4^+ : \text{Mg}^{2+} : \text{PO}_4^{3-}$). It was found that optimum pH was in the range of 9 to 9.5 and over 98% of the ammonia can be removed from the leachate if excessive $\text{Mg}^{2+}$ and $\text{PO}_4^{3-}$ are added to form struvite. The reaction is shown as follows:

$$\text{Mg}^{2+} + \text{NH}_4^+ + \text{PO}_4^{3-} + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} \downarrow$$

To reduce high reagent ($\text{Mg}^{2+}, \text{PO}_4^{3-}$) consumptions in continuous ammonia removal, struvite samples that were thermally treated by oven heating and microwave irradiation were recycled. The struvite pyrolysate provided best performance of removing ammonia in both simulated wastewater and landfill leachate at a dosage of 60 g/L and pH in the range of 9 to 9.5, when struvite was previously heated at 105 $^\circ$C for 2.5 h. In the recycling phase (five recycling cycles), the struvite pyrolysate resulting from NaOH-mediated pyrolysis was more effective at continuously treating ammonia landfill leachate than was direct heating.

Struvite recycled with direct heating:

$$\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} \xrightarrow{\text{heat}} \text{MgHPO}_4 \cdot 3\text{H}_2\text{O} + 3\text{H}_2\text{O} \uparrow + \text{NH}_3 \uparrow$$

$$\text{MgHPO}_4 \cdot 3\text{H}_2\text{O}(s) + \text{NH}_4^+(aq) + 3\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} \downarrow + \text{H}^+$$

Struvite recycled with NaOH heating:

$$\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} + \text{NaOH}(s) \xrightarrow{\text{heat}} \text{MgNaPO}_4(s) + 7\text{H}_2\text{O} \uparrow + \text{NH}_3 \uparrow$$

$$\text{MgNaPO}_4 + \text{NH}_4^+ + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}(s) \downarrow + \text{Na}^+$$
The results demonstrated that chemical precipitation by struvite formation is an efficient method for ammonia removal from aqueous solutions and landfill leachate. In addition, by recycling the thermal residue of struvite, continuously removing ammonia can technically be achieved and the reagent consumption could be saved.
Sludge of the secondary biological treatment of wastewater treatment facilities are major concern because of their disposal problem they pose. The activated sludge contains diverse microbial population which can be utilized as source of microbes for various value addition processes to this sludge. According to Tyagi and Lo (2013) the sludge is an invaluable resource for production for various valuable products (Tyagi et al. 2009) like biofuels, bioplastics, bio flocculants, bio pesticides, proteins enzymes and other valuable products. Preliminary studies in our lab demonstrate the strong capabilities of sludge microbial consortia for its use for production of various value added products. Maintaining a stable productivity from processes using sludge as is remains a challenge.

Our research team established an extended process reported by Yan et al. (2008) for biopolymer production. The process can yield 62% (w/w) of cell dry weight as bioplastic using raw sludge. The process faced many challenges maintaining at acceptably constant level. This new research embarks upon the efforts to check upon various factors of variability responsible for process variation during the production process. The process will be characterized and defined in terms of internal C: N ratio, carbon concentrations, dissolved oxygen, suspended solids concentrations, measures for normalization of temporal variations, pH, agitation, kinetic parameters, feeding regimes, etc.

Having a stable diagnosis for the process can help us to realize a process at commercial scale and deal with the incoming fluctuations at the upstream. This research can suggest methods to bring modifications in process flow in order to get constant production levels. The research has tremendous socio-economic impact. Generation of new industries managing solids sludge waste can not only help to save on energy, raw materials and salvage the environment but also provide job opportunities to the society.

References
Flushing Consolidated Sewer Sediments: Characterization of Settled Flushwater Returned to the Sewer Systems

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Problem statement. In sewer systems, solids accumulation is often observed due to intrusion of solids through structural defects. When important accumulations are found, the sewer system must be flushed before it gets completely clogged, so inspection and repair prioritization can be done. Pressure water is used to resuspend the solids, while a vacuum truck recovers the flushwater with the solids downstream. Once the vacuum truck is full, settled flushwater is returned back to the sewers. Currently, no information is available on the impact this may have on the sewer system.

Objectives. The goal of this study is to characterize the flushwater that is returned to the sewer system after a short settling period and to evaluate its potential impact on combined and separate sewer systems.

Methodology. A total of eight sites have been studied in Quebec City: four in combined, and four in sanitary sewer systems. All sites were considered critical due to the high quantity of accumulated solids. During the cleaning operations, samples were taken from the flushwater that was returned to the sewer system after settling in the vacuum truck. During the initial discharge period (8–10 minutes), 1-L samples were taken every minute to evaluate the temporal variation in suspended solids. At the end of the discharge, a 10-L sample was collected. On 1-L samples, the total suspended solids (TSS) concentration and its inorganic fraction (iTSS) were measured. For the 10-L sample, the experimental protocol of Chebbo and Gromaire (2009) was applied to determine the distribution of particle settling velocities (PSV) (ViCAs, a French acronym for Wastewater Treatment Settling Velocity). Also, the particle size distribution (PSD) was evaluated using focused beam reflectance measurements (FBRMMD, Mettler-Toledo).

Results. Slightly higher TSS concentrations were observed in the settled flushwater from the combined sewer system. The average concentration was 530 mg/L in the combined system, while, in the separate system, it was 460 mg/L. However, the iTSS/TSS ratio was similar for both sewer systems (60 ± 20%). A temporal variation of the TSS concentration was observed during the first minute of discharge from the combined system flushwater, with higher concentrations compared to the samples taken subsequently. TSS concentrations were constant during the whole discharge in the separate sewer samples. By evaluating the PSV distributions, it was found that the particles in the flushwater of the combined sewer system settled faster than the particles remaining in the flushwater of the separate sewer system (Figure 1). Noteworthy, compared to other studies on wastewater samples (Hadj, 2013), the PSV was similar to particles observed in the effluent of a primary clarifier. In essence, the flushwater contained many very small particles (<200 µm) in both systems (Figure 2). No sand or gravel were present in the samples. Moreover, the data did not show a clear relationship between particle size and PSV.
**Conclusions and recommendations.** In the settled flushwater, higher concentrations of slow-settling TSS were observed compared to typical wastewater. Increasing the settling time in the truck would not improve the quality of the flushwater due to the slow PSV.

![Figure 1. Flushwater particle settling velocity distribution](image)

![Figure 2. Flushwater particle size distribution](image)
Oleaginous yeast biomass based biofuels are attractive feedstock for biodiesel production; however the harvesting of oleaginous yeast biomass from fermentation using produced wastewater sludge or synthetic medium with crude glycerol as substrate is a major economic challenge to the biodiesel industry. In practice, centrifuge is used to concentrate the lipid bearing cells, which is energy intensive process. Therefore, alternate and cost effective methods of microbial cell separation must be found. The low cost method is the use of biomass gravity settling (floculation) as an initial dewatering step. In this study, flocculation of the oleaginous yeast biomass *Yarrowia lipolytica* SKY-7 produced in different raw materials was used and a bioflocculant (Extracellular polymeric substance or EPS) was used to the cell settling. The biomass settling observed by varying different pH 2.5, 3, 4, 5 and 7 based upon settling velocity further experiments designed. In which maximum biomass settling observed at pH 5 and it was used for further study. The working volume of 1L fermentation broth used for biomass settling at pH 5 and the coagulant (ALUM) concentration 5.2 g/L kept constant and optimization of EPS concentration 7.8, 13, 15.6 and 18 mg/g biomass using jar test. Then rate of settling observed in 1 to 30 min (each 5 min). The preliminary results showed that efficiency of process maximum at pH 5, 18 mg EPS /g biomass with 5.99 mL/g SVI. Furthermore, the impact of flocculation on the subsequent dewatering process was determined and it was shown to reduce the volume up to 8.5 folds, and significantly reduce energy input and material cost of centrifugation.
Improving Activated Sludge Settleability by Addition of Natural Additives

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The activated sludge process is the most frequently used biological wastewater treatment method in the world. The principal objectives of biological treatment are to stabilize the organic matter and to coagulate and remove the non-settleable colloidal solids in municipal wastewater. The separation of solids in the activated sludge process is a very important function in order to provide well-clarified effluent and concentrated solids that are returned to the biological treatment system or are wasted to the solids processing facilities.

Previous investigations indicated that some activated sludge systems have experienced various biomass separation problems in the settling tanks. There are two main types of settling problems: (i) bulking sludge due to the proliferation of filamentous bacteria, and (ii) poor flocculation properties, e.g. formation of small and light flocs. In most cases, large, dense and strong flocs are desirable for good settling and compaction of activated sludge. Two commonly used measures developed to quantify the settling characteristics of activated sludge are the sludge volume index (SVI) and the zone settling velocity (ZSV).

SVI is the volume in milliliters occupied by 1 g of a suspension after 30 min settling and SVI values below the 100 mL/g are typically associated with good settling sludge. Also 100<SVI≤150 would indicate moderate sludge settling, and a sludge with SVI over 150 mL/g is often classified as bulking sludge. In systems that contain a high concentration of suspended solids, both hindered (or zone) settling and compression settling usually occur in addition to discrete (free) and flocculent settlements. ZSV is the settling velocity of the sludge/water interface (Vi) at the beginning of the sludge settleability test. ZSV could be obtained by linear regression of the interface height versus time data for the constant-rate period with a regression coefficient higher than 0.98.

Natural additives were used in this research to enhance settleability of activated sludge. These included: silt and clay, maize stalk, almond shell, powdered activated carbon, coconut shell, walnut shell, hazelnut shell, egg shell, peanut hull, and pine bark. These natural additives eventually will end up in the environment as solid wastes and will not cause any adverse impacts. Most have been used as adsorbents in dyes and heavy metals removal from industrial wastewaters. Average values of SVI for control (with no natural additives) sample was 823 mL/g. Optimum dosages for different additives were defined as SVI reduction to 100 mL/g (88 percent decrease). Average value of ZSV for control sample was 1.22 m/h and selected different additives were able to increase the ZSV by up to 2-3 times. Finally, it can be concluded that these natural additives don’t act as coagulant- flocculent, but probably act as ballasting agents.

**Keywords:** activated sludge, wastewater treatment, sludge volume index, zone settling velocity, natural additives
Figure 1. Position of supernatant/sludge interface versus time in settling column test and the straight line fitted on linear part of plotted curve to calculating ZSV for each sample: A) Control sample, B) Silt and clay

Table 1. Optimum dosage of each natural additive and also average values of ZSV and correlation coefficient for control sample and samples with different additives

<table>
<thead>
<tr>
<th>Additives</th>
<th>Optimum dosage (g/L)</th>
<th>Average ZSV (m/h)</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sample</td>
<td>1.222</td>
<td>0.9920</td>
<td></td>
</tr>
<tr>
<td>Silt and clay</td>
<td>1.863</td>
<td>3.827</td>
<td>0.9903</td>
</tr>
<tr>
<td>Maize stalk</td>
<td>2.774</td>
<td>2.478</td>
<td>0.9870</td>
</tr>
<tr>
<td>Almond shell</td>
<td>2.81</td>
<td>2.933</td>
<td>0.9899</td>
</tr>
<tr>
<td>Powdered activated carbon</td>
<td>1.713</td>
<td>3.732</td>
<td>0.9899</td>
</tr>
<tr>
<td>Coconut shell</td>
<td>2.238</td>
<td>2.814</td>
<td>0.9824</td>
</tr>
<tr>
<td>Walnut shell</td>
<td>2.362</td>
<td>2.765</td>
<td>0.9910</td>
</tr>
<tr>
<td>Hazelnut shell</td>
<td>2.435</td>
<td>2.909</td>
<td>0.9909</td>
</tr>
<tr>
<td>Egg shell</td>
<td>1.968</td>
<td>3.293</td>
<td>0.9841</td>
</tr>
<tr>
<td>Peanut hull</td>
<td>2.973</td>
<td>2.55</td>
<td>0.9861</td>
</tr>
<tr>
<td>Pine bark</td>
<td>3.08</td>
<td>2.753</td>
<td>0.9844</td>
</tr>
</tbody>
</table>
Development of Novel In Situ Chemical Oxidation (ISCO) Technologies for the Cleanup of Contaminated Soil and Groundwater

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In Situ Chemical Oxidation (ISCO) is being increasingly used as a means of cleaning up contaminated soil and groundwater. In this remedial practice, strong oxidants such as hydrogen peroxide (H$_2$O$_2$) and persulfates (Na$_2$S$_2$O$_8$ and NaHSO$_5$) are injected into the subsurface to initiate radical reactions that can transform contaminants into less toxic/benign byproducts. The success of ISCO depends on a number of factors, including (1) the yield of radical species (i.e., hydroxyl and persulfate radicals) from the injected oxidants, and (2) the proper delivery of oxidants to the subsurface location where the contaminants exist.

This talk discusses some of our recent findings on the efficacy of the hydrogen peroxide- and persulfates-based ISCO, and approaches that potentially can improve the performance of these technologies in the field. The kinetics, efficiency, and mechanism of contaminant oxidation by H$_2$O$_2$, Na$_2$S$_2$O$_8$, and NaHSO$_5$ under different remediation scenarios are compared. A novel approach that can enhance the delivery and activation of persulfates is presented.
Fate of Silver Nanoparticles During Sludge Conditioning and After Land Application

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Motivation: The growing use of silver nanoparticles (AgNPs) in personal care products and clothing has led to its increasing concentrations in wastewater and subsequently in sludge. Many studies have confirmed that significant fraction of silver nanoparticles entering wastewater ultimately end up in sludge raising concerns about their fate during sludge treatment and impact on soil microorganisms after land application.

Objectives: This study addressed two important issues: the transformation of AgNPs during chemical conditioning and the effect of AgNPs on soil microorganisms after land application.

Materials and methods: Experiments were carried out in two phases. In the first phase, chemical conditioning was performed on anaerobically digested sludge using four different flocculants: lime, ferric chloride, alum, and polymer. In addition, experiments were repeated in water for comparison of results with sludge. Initial AgNP concentration was 100mg/L in both water and sludge. Sludge solid content was 2%. Transmission electron microscopy (TEM) and inductively coupled plasma mass spectrometry (ICP-MS) techniques were used to assess and compare the effect of these flocculants on the fate and removal of AgNPs. The second phase investigated the relative change in the microbial community and population in the soil after application of sludge. Biological analyses involved HPC, live/dead analysis, DNA extraction, and qPCR assay. Quantitative polymerase chain reaction (qPCR) was utilized to analyze five different phyla: Acidobacteria, Actinobacteria, Bacteroidetes, Firmicutes, and Proteobacteria. The relative changes in the bacterial population were based on using five separate phylum qPCR assay targets. Chemical analyses involved pH, sTOC, and TS.

Results: TEM images clearly showed morphological and chemical changes including changes in the size, shape and structure of AgNPs, coating, and some degradation. Lime was the most successful coagulant in the aggregation and removal of AgNPs followed by ferric chloride and alum. The synthetic polymer successfully aggregated AgNPs in water but not as much in sludge. AgNPs concentrations were measured before and after the conditioning step using ICP-MS. The results indicate that the percentage recoveries of the AgNPs were 48.5% and 53% for control water and sludge before conditioning. After conditioning, AgNP recovery was 0.39% and 0.097% in water and sludge, respectively. This confirmed that conditioning process was effective in removing AgNPs from the aqueous phase and concentrated in the solid phase. In the second phase, the results showed that 2 mg AgNPs/g sludge (dry ratio) had no effect on the microbial population in soil that was amended with 1% sludge (dry weight). However, the phyla exhibited a different growth pattern with each flocculent over 75 days. For example, the results showed that FeCl\textsubscript{3} treatment promoted the growth of all studied phyla while lime and polymer treatment decreased the growth of all phyla except Acidobacteria.
Figure 1- TEM images show the behaviour of AgNPs before and after conditioning process in both water and sludge.
Wastewaters from industrial processes and contaminated sites pose a great challenge and cost to industry and society in both their quantity and toxicity. It was reported in 2014 that Canada still has over 22,000 federal waste sites, whose remediation will cost $4.9 billion dollars in the next 20 years. In addition to the tremendous financial cost, efforts to rehabilitate and further prevent contamination have been complicated by the millions of tons of wastes released into the environment from chemical and materials processing. In particular, oil sands process waters (OSPW) represent a significant portion of Canadian wastewaters for which treatment technologies are very limited and/or costly. Novel technologies that can effectively remove contaminants from hazardous waste sites and industrial wastes will provide dual benefit of reducing treatment cost and protecting environmental and human health. This presentation discusses our on-going effort in evaluating the efficiency of heat-activated peroxydisulfate (S\textsubscript{2}O\textsubscript{8}\textsuperscript{2-}) in degrading contaminants typically encountered at sites contaminated with oil-field wastewater. S\textsubscript{2}O\textsubscript{8}\textsuperscript{2-} is a relatively new oxidant that is being proposed for treatment of wastewater, and in situ remediation of contaminated soil and groundwater. Under elevated temperature, S\textsubscript{2}O\textsubscript{8}\textsuperscript{2-} is activated into sulfate radical (SO\textsubscript{4}\textsuperscript{●}) and hydroxyl radical (OH\textsuperscript{●}), strong oxidants capable of oxidizing a wide range of organic contaminants. We investigated the production of radicals under temperatures ranging 22 - 70 °C and environmentally relevant pH (i.e., pH 7.3 - 7.8). Benzoic acid (BA), cyclohexanoic acid (CHA), and phenol were chosen as model organic contaminants. The concentrations of persulfates, contaminants and byproducts were monitored by high pressure liquid chromatography and UV-Vis spectroscopy throughout the course of each experiment to gain insights into the degradation rates and persulfate utilization efficiency (i.e., the amount of contaminant degraded per one mole of persulfate consumed). (A typical experimental data set is presented in Figure 1). The results indicate that heat-activated persulfate is capable of degrading organic contaminants with the rate and efficiency being strongly dependent on the experimental temperature and contaminant concentration (e.g., Figure 2 shows the benzoic acid degradation efficiency). This observation potentially has important implications for the design and operation of persulfate-based ISCO, but more laboratory and field experiments will be needed to gain further insights.

**Figure 1.** Peroxydisulfate (PDS) and benzoic acid loss, and stoichiometric efficiency. T = 50 °C, [PDS]\textsubscript{0} = 1 mM, [BA]\textsubscript{0} = 2 mM, pH = 7.3 – 7.8 (buffered by 20 mM phosphate).
Figure 2. Stoichiometric efficiency under different temperature and benzoic acid concentration. pH = 7.3 - 7.8, buffered by 20 mM phosphate; [PDS]₀ = 1 mM.
A Comprehensive Study of Dissolved Oxygen Characteristics of a Stormwater Pond

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Stormwater ponds are becoming increasingly important due to the negative impacts on flood mitigation and water quality control that results from rapid urbanization. Stormwater ponds are not only designed to control the discharge of large precipitation and snow melt events, but also to mitigate the water quality of the retained stormwater. The City of Ottawa, Canada currently manages and maintains over 90 wet stormwater ponds, and there are as many as 1,600 stormwater facilities that are being monitored by the province of Ontario. Consequently, anaerobic conditions in a stormwater pond result in poor water quality and generation of noxious gases. Riverside South Stormwater Pond II (RSP2) in Ottawa periodically has low dissolved oxygen (DO) concentrations and subsequently anoxic conditions at depth in the pond, especially during summer droughts and winter ice covered periods. Hydrogen sulfide gas (H2S) has been generated and released into the ambient atmosphere during these periods of lesser water quality. There is a current gap of knowledge with respect to H2S production mechanisms in these ponds. There is thus a need to understand how DO spatial distribution and seasonal change trigger and affect H2S production. The overall objective of this study is to provide a comprehensive understanding of DO seasonal characteristics at two stormwater ponds, that is characterized by a H2S emission problem (RSP2) and a reference pond (RSP1) that is adjacent to RSP2 but has not demonstrated H2S production events. A better understanding of RSP2’s unique DO conditions can guide mitigation solutions to prevent H2S generation in current and future stormwater facilities. In addition to characterizing the DO concentrations spatially and across depths in the ponds, chlorophyll-α and soluble Biochemical Oxygen Demand (sBOD) were also investigated and correlated to the DO concentrations within water columns.

DO and temperature were collected in-situ using a field optical DO meter. sBOD to sCOD ratio was calculated, and used to estimate the sBOD concentrations. Both sCOD and chlorophyll-α were measured using standard methods. RSP2 was shown to experience lower DO and longer anoxic conditions than the reference pond, RSP1, at both non-ice covered and ice covered months. In addition, anoxia was shown to be initiated at the outlet of RSP2 where the depth of the pond was a maximum. No significant statistical correlation between either chlorophyll-α or sBOD with DO concentrations was observed in either pond in the study. Interestingly, however, chlorophyll-α blooms were observed during ice covered conditions in the study, with synurids, tabellaria, and asterionella being identified as the dominant species.
Risks of Sulfide Production During the Infiltration of Denitrified Domestic Wastewater Into the Soil

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Depending on the location of the households, the management of wastewater could be carried out using centralised systems or decentralised ones. In 2011, almost 13.3 M of households across the Canada weren’t recorded to a centralized system (Statistics et al., 2011). Among them, almost 1 M were equipped with on-site wastewater systems and are located in the province of Quebec (MDDEFP, 2013). The septic systems are generally equipped with a septic tank (physical treatment) and a drainfield (final treatment) (Buchanan, 2014). In order to ensure a higher level of wastewater decontamination, tertiary processes could also be installed to remove some contaminants such as phosphates, nitrites, nitrates, etc. Therefore, autotrophic denitrification system using elemental sulfur and limestone were recently developed to remove the nitrates (< 5 mg/L) from decentralised wastewaters (Ben-Khaled, 2015; Zhou et al., 2011). Despite a good nitrate removal yield, these processes released around 100 to 200 mg/L of sulfates as sub-product. Under anaerobic conditions, sulfate ions could be reduced into sulfur by sulfate-reducing bacteria (SRB); leading to the release of hydrogen sulfide (Alani et al., 2014; Colleran et al., 1995). Generally, this latter highly depends on the optimal microbiological conditions for SRB activity (e.g., T, pH, Oxidation-reduction potential (ORP), Dissolved oxygen (DO)...) Depending on the concentration and the exposure duration, this gas has some drawbacks as it is smelly, corrosive and toxic (Chou, 2003).

The aim of this work was to evaluate the potential risks of sulfide production related to the infiltration of denitrified wastewater through the soil. Indeed, in order to confirm the performances of such new tertiary technologies, it is important to ensure the harmlessness of their sub-products.

In order to investigate the risks of sulfide production downstream of an autotrophic denitrification process, some experiences of denitrified wastewater infiltration through different soils were carried out at laboratory (18-33 ml/d) and pilot scales (17-32 L/d). Three types of soil with different permeability rates (Ks = 0.028, 0.0013 and 0.00015 cm/s) were investigated to simulate the infiltration of denitrified wastewater through a drainfield. Many parameters such as pH, ORP and the concentration of sulfates, dissolved and gaseous sulfide (H₂S) and dissolved organic carbon were followed.
Despite favorable conditions, the experiments carried out at laboratory scale didn’t show the production of significant amounts of sulfide in both aqueous (< 0.2 mg/L) and gaseous (< 0.15 ppm) phases, over the 100 days of experiments. While at pilot scale, the maximum of dissolved sulfide and gaseous concentrations measured, over a year, were around 0.68 mg/L and 14 ppm, respectively. Some suggestions were emitted to explain the low concentrations of sulfide observed whereas the conditions were favorable for the growth and the activity of SRB. Moreover, a clogging phenomenon was also observed during the experiments carried out at pilot scale mainly due to two factors: the formation of biomat on the infiltrative surface of the soil and the production of an iron ochre at the bottom of the reactor (Lowe and Siegrist, 2008; Smart and Herbertson, 1992; White and West, 2003).

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Copper Inhibition of Nitrifying Biofilm Community: Sustainable Treatment of Mining Wastewaters

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Gold mining is a significant part of Canada’s 2.5 billion dollar gold production industry. Cyanide treatment is commonly used in gold mining to extract the metal, however cyanide itself is toxic and must be treated prior to disposal. Commonly, cyanide is biologically oxidized to ammonia/ammonium prior to release to natural waters. Ammonium is also introduced to gold mining wastewaters through explosives used for rock excavation. Ammonium has been declared a deleterious substance in Canada and hence its release to natural waters is regulated under the Fisheries Act of Canada. Ammonium is commonly treated using biological nitrification through various treatment technologies. Heavy metals, as in mining wastewaters, have been shown to be inhibitory to suspended growth, biological treatment technologies. Copper, specifically, has been shown to be inhibitory to suspended growth nitrification at a concentration of 0.35 mg Cu/L and above. Attached growth systems, housing biofilm, have demonstrated enhanced resistance to microbial toxicity and inhibition when compared to suspended growth technologies. The moving bed biofilm reactor (MBBR) attached growth technology houses biofilm attached to carriers and has been extensively designed to achieve nitrification. Furthermore the MBBR technology requires low operational intensity, which is a technology requirement for remote mining sites. The aim of this study is to quantify the inhibition of nitrification in an MBBR system due to sustained exposure to copper. This can be observed through i) the reduction of nitritification (oxidation of ammonium to nitrite) and nitratification (oxidation of nitrite to nitrate) and ii) the effects of bulk and sorbed copper on the biofilm. In this experiment four identical, parallel MBBR laboratory-scale reactors were operated; each being fed with an influent of 125 mg NH₄⁺ -N/L and with a different copper concentration ranging from 0.1 to 0.7 mg Cu/L. All of the constituents in this study were analyzed using standard methods. Copper concentrations were analyzed using Inductive Coupled Plasma Mass Emission (ICPME).

Inhibition of nitritification was minimal at all copper concentrations tested with all reactors removing 90+% of ammonium. Nitratification inhibition was mainly observed in the reactor fed with 0.7 mg Cu/L, where inhibition was identified as 45% of the total nitrogen conversion to nitrite as compared to 10% as nitrite at all other copper loadings. Steady state nitrification was reached after approximately 170 days (4000 hours). The sorbed copper reached steady state was reached at day 85 (2000 hours) of operation. Sorbed (adsorbed and absorbed) copper as well as bulk phase copper concentrations were used to calculate a copper mass balance across all reactors, with the average copper mass balance being 107.5 +/- 12%. Further research includes analysis of cell viability, biofilm thickness, mass and morphology as well as gene sequencing of the microbial communities at various copper loadings.
Stormwater management ponds are constructed in cities for flood attenuation and to protect the quality of downstream receiving waters. Such ponds may therefore accumulate contaminants, which pose a potential risk to wildlife attracted to these sites. The CCME (Canadian Council of Ministers of the Environment) water quality index (WQI) was computed based on in situ environmental data and water chemistry analyses for 38 stormwater ponds across the City of Ottawa, Ontario. The index was then compared to biotic data based on the abundance and diversity of Odonata (dragonflies and damselflies). The WQI varied from 28.3 (poor) to 75.6 (fair) in Ottawa urban ponds. Water quality was strongly influenced by one chemical component of the index, conductivity, which most likely reflects winter road salt usage. Odonata abundance ranged from 4 to 1059 individuals per pond and species richness from 4 to 20 per pond. We found no significant correlation between the CCME index and measures of biodiversity. This raises the possibility that the water quality index is not particularly useful in assessments of the quality of wildlife habitat and ecosystem health overall. There was some indication, however, that conductivity may be having a negative effect on Odonata abundance in urban ponds.
Feasibility of Using Polyphosphate from Wastewater Sludge for Phosphorite (Phosphate Rock) Production

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Excess quantity of phosphorous (P) in the water is one of the main triggers of eutrophication with several negative consequences, such as the growth of algae and oxygen depletion. Meanwhile, as an indispensable nutrient to life, phosphorus is also commonly processed into fertilizer from phosphorite ore (phosphate rock), which is a carbonated apatite. Considering the rising food production output, the demand for fertilizer is crucial for global agriculture. Phosphorite mineral reserves are being depleted, and they are not a renewable resource. Without obvious replacement options, this resource will need to be recovered.

To reduce the impact on aquatic systems, as well as capturing phosphorus for agriculture, phosphorus cycling is crucial (see Figure 1). Reusing phosphate collected from municipal wastewater sludge has the potential to mitigate the phosphorous crisis, since the target of less phosphate in wastewater plant effluent is accomplished by chemical precipitation from wastewater sludge.

In this study, thickened waste activated sludge (TWAS) from the Robert O. Pickard Environmental Centre (ROPEC) in Ottawa was studied to determine its suitability as a source of phosphorus for recovery in the useful carbonated apatite form. Recent studies have demonstrated that there are certain activated sludge bacteria, called phosphorus accumulating organisms (PAOs), which incorporate large amounts of polyphosphate (polyP), a long-chain polymeric condensed phosphate, into the cell biomass. The process of breaking down the bacteria cell, isolating the polyP and then converting it to a soluble phosphate is accomplished by acid digestion and/or biochemical extraction.

The measurement of the extracted soluble phosphate concentration was estimated by vanadomolybdate colorimetric assay, a spectrophotometric technique in which the intensity of the colour in solution is proportional to the phosphate concentration. PolyP and total phosphate extracted from PAO’s were determined as soluble phosphate after extraction and acid hydrolysis process, respectively.

After phosphate extraction from the sludge, crystallization was performed to generate phosphate rock from the soluble phosphates. Following the precipitation of the soluble phosphate with calcium carbonate and sodium bicarbonate, the resulting mineral was characterized by Raman spectroscopy (Figure 2). During this process, it was measured that approximately 99% of the extracted soluble phosphate was precipitated as phosphate rock.
Laboratory experiments have confirmed the preliminary feasibility of using insoluble polyP within PAOs to produce inorganic phosphate to precipitate a significant amount of phosphate rock. In the future, the pretreatment process of extracting and/or digesting polyP will be optimized for eliminating the effect of calcium.
Recovery of Phosphorus by Crystallization

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With the ever increasing global population, demand for increased phosphorus fertilizer for food production in conjunction with reduction in wastewater by-products represent a critical efficiency to be exploited. Specifically, phosphate rock, a form of carbonated apatite with the generic structure of Ca$_5$(PO$_4$)$_3$(F,OH,Cl,CO$_3$), is essential in this capacity due to its solubility in soil. Recognizing the potential to recycle phosphorus found in treated waste activated sludge (TWAS), the research group has found the concentration of inorganic phosphorus (P$_i$) to be in the range of 25-40 mM, and thus preliminary measurements are underway to confirm the feasibility of crystallizing this P$_i$ as carbonated apatite. Tests were conducted using a sodium phosphate solution (27 mM) to represent the P$_i$ available in TWAS in accordance with P$_i$ values found in the literature. Either a saturated calcium carbonate solution (0.5 mM) or a calcium hydroxide solution (4.5 mM) was added incrementally to increase the saturation with respect to carbonated apatite. Deproteinized emu bone mineral, which has a similar Ca/P content as carbonated apatite, was added as seed to approximate the desired crystal. Seeding densities ranging from 0.1 g/L to 1.0 g/L were tested. Aliquots were drawn and pH measured at regular intervals. Scanning electron microscopy (SEM) of the resulting crystals and both P$_i$ and calcium concentrations during the semi-batch crystallization process will be presented.
Recycling of Phosphate from Municipal Waste

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Phosphorus is an important component of crop fertilizer. Phosphate fertilizer is produced from a unique ore called phosphorite, which is no longer mined in Canada. However, there is another promising source of phosphorus that could be transformed into phosphorite ore. Phosphorus removal from municipal wastewater is partly achieved through phosphate-accumulating organisms (PAOs) that store phosphate as polyphosphate chains. The biomass of the bacteria that compose waste activated sludge is normally further processed then land-filled. This project aspires to capture the phosphorus within the PAOs by transforming the polyphosphate into phosphorite mineral. To demonstrate this potential, samples of waste-activated sludge were acid-digested to break down polyphosphate chains into ortho-phosphate molecules. The acidic, phosphate-rich solution was neutralized and crystallized with calcium carbonate using synthetic hydroxyapatite as a nucleation seed. The concentration of free phosphate in solution, measured by a vanadomolybdate assay, was determined as 38.67 ± 2.73 mM before and 1.62 ± 0.40 mM after precipitation, indicating that a phosphate mineral was successfully precipitated. The precipitate was characterized by ATR-FTIR to confirm the presence of phosphate by a peak at 1100-1000 cm⁻¹, analogous to synthetic hydroxyapatite spectrum. The preliminary data of this research showed that phosphate can be recrystallized from municipal wastewater as a phosphate mineral. It is hoped this method can be used to recycle phosphate for crop fertilizer, minimizing the current requirement for importing mined phosphorite ore.