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# Biodegradation and chemical precipitation of dissolved nutrients in anaerobically digested sludge dewatering centrate

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ABSTRACT

The objective of this research was to assess specific side-stream treatment processes for biodegradation and precipitation of dissolved nutrients in dewatering centrate. In this study, characterization was made of a conventional suspended growth deammonification treatment process for transforming dissolved polyphosphate (poly-P), dissolved organic phosphorus (DOP) and dissolved organic nitrogen (DON) in two types of dewatering centrate. The deammonification process was configured as a sequencing batch reactor (SBR), combining partial nitrification and anaerobic ammonia oxidation (anammox) in a single tank. The first centrate feed studied was from the full-scale Annacis Island wastewater treatment plant (AIWWTP) located in Metro Vancouver, Canada. The second centrate feed was from a lab-scale anaerobic digester (AD) fed waste sludge from the existing City of Kelowna Wastewater Treatment Facility (KWTF), located in the Okanagan Valley, Canada. In addition, poly aluminum chloride (PACL) dosing was assessed for final polishing of dissolved nutrients. The deammonification SBR (DeSBR) process showed similar treatment characteristics for both the KWTF and AIWWTP centrates with excellent DON removal and poor non-reactive dissolved phosphorus (NRDP) removal. A statistical comparison of the DOP and poly-P through the DeSBR process suggests that DOP has a higher biodegradation potential. Future research focused on understanding the variables associated with degradation of DOP could lead to better NRDP removal through deammonification processes. Utilization of a post-anammox PACL chemical dosing stage can achieve the objective of precipitating any residual DON and NRDP and producing an effluent that has lower dissolved nutrients than the pre-digestion KWTF dewatering centrate scenario.



## 1. Introduction and context

The trend of a decreasing effluent nitrogen and phosphorus objective for wastewater effluent discharged to surface water bodies has resulted in a focus on understanding the formation and removal of dissolved organic nitrogen (DON) (Pagilla et al., 2008) and non-reactive dissolved phosphorus (NRDP) (Tooker et al., 2010). DON and NRDP make up a significant proportion of the effluent nitrogen and phosphorus in treated wastewater effluent and can be difficult to degrade within a mainstream wastewater treatment process (Neethling and Stensel, 2013). The challenge of managing effluent DON and NRDP is complicated by the secondary objective of beneficially reusing wastewater biosolids through anaerobic digestion (AD). Stabilization of wastewater biosolids through the use of AD can derive significant benefits to the overall wastewater treatment plant (WWTP) operation in terms of cost and carbon expenditures (Cakir and Stenstrom, 2005; Berg et al., 2013). AD of wastewater sludge represents an opportunity to generate biogenic methane which could be used to offset demand for conventional petroleum-based energy, thereby reducing carbon emissions (Verstraete et al., 2005). In addition, AD is able to reduce the solids content of the sludge, reducing transportation and disposal requirements of the dewatered biosolids. However, AD releases a variety of dissolved nutrients including DON and NRDP (Wilson et al., 2011; Wild et al., 1997). If returned to the mainstream treatment process, dewatering centrate associated with AD could negatively impact the final effluent quality.

DON consists of the nitrogen fraction which can be difficult to degrade. DON originates in domestic wastewater influent in a variety of forms including urea, amino acids, proteins, aliphatic N compounds and synthetic compounds, such as EDTA, N-containing pesticides and pharmaceuticals; however, DON can also be released into the treatment process through cell metabolism processes that

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excrete biomolecules, cell decay and cell lysis (WERF, 2009). Non-reactive dissolved phosphorus (NRDP) is also difficult to remove with conventional treatment, requiring advanced treatment processes with multiple stages including filtration, coagulation and adsorption (Neethling et al., 2007). As with DON, NRDP can increase through biological production in the mainstream process (Neethling and Stensel, 2013).

Published data from various full-scale WWTPs indicate a wide range of measured final effluent DON and NRDP concentrations. A survey of 197 nitrogen removal WWTPs in Virgina and Maryland reported an average final effluent DON of 0.93 mg N/L with a range of 0–2.5 mg N/L (WERF, 2009). For WWTPs with biological phosphorus removal systems, the range of final effluent NRDP measured in a separate study was 0.015–0.050 mg P/L (Neethling and Stensel, 2013). While most of the DON and NRDP enters the mainstream bioreactor as part of the raw wastewater, internal recycle streams, like dewatering centrate and sludge thickener underflow, can also represent significant contributions. Published data of DON and NRDP concentrations in dewatering centrate is limited but a recent paper reported 210 mg N/L DON and 34 mg P/L NRDP in the supernatant of a mesophilic lab-scale digester fed biological nutrient removal (BNR) sludge (Galvagno et al., 2014). The relatively high DON and NRDP concentration in anaerobically digested sludge is presumed to be the result of soluble microbial products produced through cell metabolism and decay of the anaerobic bacteria and waste activated sludge (Barker and Stuckey, 1999).

DON is measured as the difference between total dissolved nitrogen and the sum of ammonia, nitrate and nitrite (Supplementary Data, Fig. S1). Similarly, NRDP is the difference between total dissolved phosphorus and dissolved reactive phosphorus. The orthophosphate concentration (molybdate reactive phosphate) is generally accepted as a measure of the reactive phosphorus (APHA, 4500-P A).

DON and NRDP can occur as part of the raw wastewater and resist degradation or increase through the biological treatment process, thereby contributing to the final effluent nutrient load (Arnaldos and Pagilla, 2010). Once in the receiving water environment DON can become bioavailable, contributing to algae growth and negatively impacting the receiving environment. Using a 14-day bioassay, Urgun-Demirtas et al. (2008) were able to show that up to 61% of the effluent DON was available for algae growth. The dissolved phosphorus in WWTP effluent can also be bioavailable. Through algae bioavailability studies Liu et al. (2011) demonstrated that 67–90% of the dissolved organic phosphorus (DOP) is bioavailable. This study also showed that DOP is the most recalcitrant form of phosphorus remaining in highly treated effluents and contributes 22%–89% of the bioavailable soluble effluent phosphorus.

In this study, Kelowna Wastewater Treatment Facility (KWTF) has been selected to serve as the test case; but the proposed approach could be applicable to other similar wastewater and sludge management scenarios. KWTF is one of seven tertiary WWTPs which operate in the Okanagan Lake basin (BC, Canada), a phosphorus-sensitive watershed. To mitigate impacts to the Lake, the KWTF utilizes a BNR (modified Bardenpho) process. The KWTF has effluent criteria of total nitrogen (TN) < 6.0 mg N/L and total phosphorous (TP) < 0.25 mg/L on an annual average basis. Other WWTPs discharging effluent to the lake system have a similar standard.

The KWTF final effluent contains measured DON that represents 29% of the TN on average; similarly, the NRDP represents 52% of the total phosphorus (TP) on average (Fig. 1). Based on these results, a significant proportion of the effluent nitrogen and phosphorus consists of DON and NRDP.

As effluent nutrient standards become more stringent in the Okanagan Lake watershed, understanding the formation, fate and treatment characteristics of NRDP and DON will become more important. Furthermore, as the KTWF service population grows, more energy efficient and compact sludge stabilization techniques are becoming desirable. However, the uncertainty of the fate of DON and NRDP through AD processes and the potential associated impacts on the KTWF effluent quality have served as an obstacle to adopting these technologies.

Suspended growth partial nitritation coupled with an anaerobic ammonia oxidizing (anammox) step has shown to be an effective and energy efficient processes for removing ammonia from AD dewatering centrate (Wett et al., 2007a). Previous research has also demonstrated the capacity of a similarly configured deammonification process for removing a large proportion of DON but to a lesser extent NRDP from dewatering centrate (Galvagno et al., 2014). Therefore, the primary objective of this research was to assess the transformation of polyphosphates (poly-P) and DOP through the deammonification process. This aspect of the research was intended to understand the poor NDRP biodegradation capacity of the process. The current investigation focusses on determining whether the relative fraction of poly-P and DOP changes through the deammonification process and if there is a gain in either constituent. The biodegradability of DON and NRDP centrate generated from a bench-scale AD fed BNR sludge was also characterized.

Finally, the success of implementing an AD within a BNR environment will ultimately be measured by the quality of the side-stream treatment effluent. Under ideal conditions, an anammox process coupled with a struvite recovery process should remove more than 90% of the dissolved nitrogen and reactive phosphorus contained in the centrate (Hassan et al., 2013). Under upset conditions or where the NRDP needs further control, a final treatment barrier would be beneficial. Therefore, as a secondary objective of this research, the impact of dosing the DeSBR effluent with poly aluminum chloride (PACL) was assessed. PACL was selected for the following reasons. PACL is supplied as a pre-polymerised liquid with the active aluminum species hydrolyzed with a base which reduces alkalinity demand (Jiang and Graham, 1998). In addition, previous research demonstrated that PACL is superior for TP removal compared to aluminum sulphate (Hatton and Simpson, 1985).

## 2. Material and methods

### 2.1. Anaerobic digester set-up/operation

The 5.0 L (effective volume) anaerobic digester (New Brunswick BioFlo® 115 glass fermenter) was started up on January 16, 2012 and had been operating continuously throughout the current testing. The digester was operated as a mesophilic process (37 °C) at a sludge retention time (SRT) of 20 days and fed mixed sludge from KWTF. The mixed sludge feed consisted of thickened waste activated sludge (TWAS) and fermented primary sludge (FPS) at a percentage ratio of 66:34 by volume, at a total solids (TS) content between 4.0% and 5.0% by weight. Organic loading rate of the digester ranged between 1.73 and 1.93 g volatile solids (VS)/L of digester/d. Mesophilic sludge inoculum was taken from the City of Penticton WWTP which operated a digester fed FPS as substrate. More detailed operating data for the AD is documented in previous research (Galvagno et al., 2014).

Waste sludge from the AD was manually dewatered using BASF Zetag 7587 as a flocculant at a dosage of 50 mL, 0.5% solution per litre of sludge. Dewatering was undertaken using a Thermo Sorvall XT centrifuge operated at 3900 rpm, 3300× *g* for 20 min in 750 mL containers. Prior to dewatering, the waste sludge was stored in a