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Forward osmosis with high-performing TFC membranes for concentration of digester centrate prior to phosphorus recovery

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ABSTRACT

Forward osmosis (FO), using thin-film composite (TFC) membranes, was used to concentrate digester centrate for improved phosphorus recovery. Digester centrate, obtained after the dewatering of digested sludge, contains phosphorus that can be precipitated as struvite ($MgNH_4PO_4{\cdot}6H_2O$) and used as a fertilizer. By concentrating phosphorus in the digester centrate, it is possible to increase the efficiency of struvite precipitation by decreasing reaction time, reduce tank volume, and minimize magnesium addition. A lab-scale setup FO unit with TFC membranes was used to concentrate phosphorus. Both synthetic and real digester centrate were used as feed solution, and both synthetic and real seawater were used as draw solution. The TFC membranes demonstrated a high water flux, around 17 LMH for pure water and 5 LMH for real digester centrate, emphasizing its viable use even when using digester centrate – a solution high in solids. It was possible to concentrate digester centrate to a volume concentration ratio (VCR) of 7 using seawater with a salinity of 22PSU; this correspond to an expected reduction in magnesium demand of > 30%. A phosphorus rejection > 99% was achieved without pH adjustment. Rejection of ammonium and ammonia was lower, and decreased with increasing pH. Aeration caused 57% decrease in water permeability most likely due to membrane scaling at higher pH, while cleaning with tap water could restore water permeability. Thus, FO using TFC membranes is a potential method for concentration phosphorus in digester centrate, but pH should be kept below 8 to avoid ammonia transport to the draw solution and to avoid scaling.

1. Introduction

Activated sludge contains both biologically and chemically bound phosphorus, approximately 75–300 mg L^{-1} [1], since phosphorus is typically accumulated in microorganisms or precipitated out of wastewater during the treatment process. The biologically bound phosphorus is released after digestion [2,3]. As such it stands to reason to recover phosphorus from digester centrate – the liquid removed from digested sludge during dewatering. This phosphate-rich digester centrate is typically returned to the head of the wastewater treatment plant (WWTP) causing elevated concentrations of phosphate in the WWTP, thus reducing the efficiency of phosphate removal, increasing the cost of chemical dosing and the potential for struvite to build up and foul the plant over time. Therefore, by recovering struvite from digester centrate, it is not only possible to reduce operational expenditure (OPEX) on chemical phosphorus removal and removal of struvite blockages, but also likely that a profit can be made from the fertilizer produced.

A solid pellet-like fertilizer can be precipitated from sludge in the form of struvite or calcium phosphate [4]. Currently there are a number of technologies on the market which can achieve this, such as the Unitika PHOSNIX®, DHV-Crystalactor®, or Ostara PEARL™. However, in order to achieve as efficient a reaction as possible it may be beneficial to increase the phosphate concentration in the reactor vessel. When using digester centrate from Aaby WWTP (Aarhus, Denmark), without concentrating digester centrate a P:Mg ratio of 1:1.3, the ratio currently used at Aaby WWTP, is required in order to achieve an 60% P recovery, however, by concentrating the component in digester centrate by three, the simulation in Fig. 1b shows that the recovery for a 1:1P:Mg ratio will give an 87% P recovery, we will show that a VCR of 7 is achievable, which corresponds to a 96% P recovery using a 1:1P:Mg ratio. Therefore concentrating digester centrate will allow cost savings on Mg addition while recovering a greater quantity of P. The calculation was carried out in MinTEQ assuming that only struvite is precipitated, which is a reasonable assumption [5], and using the data found in Table 1. pH 7.5 was used as this is the pH Aaby WWTP currently use in order to avoid the precipitation of heavy metals, using a pH between 9 and 10 would increase P yield since struvite precipitates readily at higher pH. While the addition of Mg is necessary, due to low

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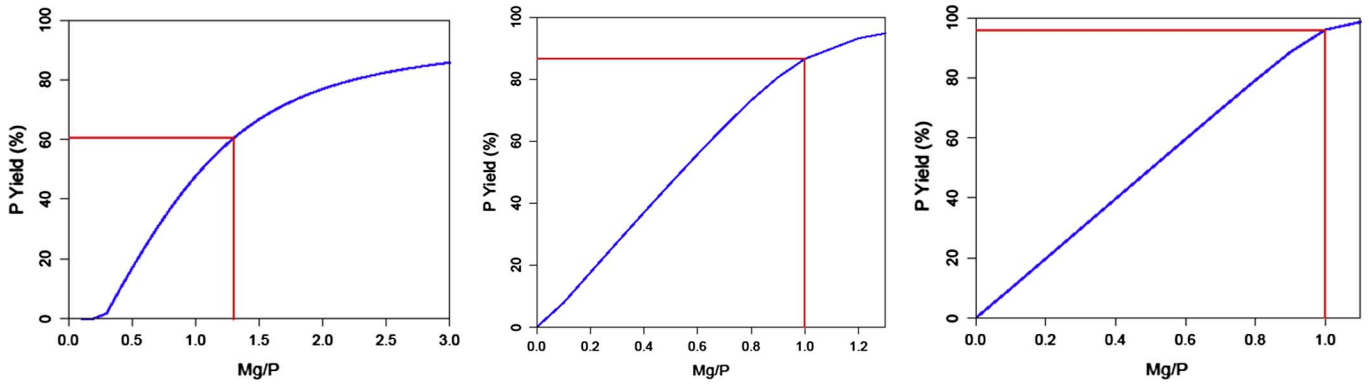

Fig. 1. P yield without and with digester centrate concentration at pH 7.5, (a) VCR 1, (b) VCR 3, (c) VCR 7.

Table 1
Data used to determine P yield, data obtained from digester centrate used in this study.

Parameter	VCR 1	VCR 3	VCR 7
Ammonium (mmol L^{-1})	157.14	471.43	1100
Phosphate (mmol L^{-1})	1.0333	3.0998	7.2328
pH	7.5	7.5	7.5

concentrations in digester centrate, reverse transport of Mg from seawater to digester centrate will reduce the quantity needed to be added, thus reducing the cost associated with Mg addition.

Membrane technologies, such as reverse osmosis (RO) and electrodialysis, have been utilised to concentrate P in digester centrate [6–8]. However, in the instance of RO the need to apply hydraulic pressure across the membrane has led to a high degree of membrane fouling and elevated OPEX, while electrodialysis requires a high energy input. Forward osmosis (FO) is an alternative method of concentrating phosphate which does not rely on hydraulic pressure or electrical potential difference as the driving force. FO is the movement of water molecules across a selectively permeable membrane from a feed solution (FS) with low osmotic pressure to a draw solution (DS) with high osmotic pressure [9]. The membrane rejects most solute molecules and ions, which enables the retention of phosphate molecules on the feed side of the membrane. The process is cost effective as it utilises osmotic pressure over hydraulic pressure [9], thus encouraging a lesser degree of fouling [10–12] than pressure driven processes.

DS selection is vital as the solution needs to have a suitably high osmotic pressure in order to adequately concentrate the feed solution, while being inexpensive. Countries with a coastline tend to have many WWTPs near the coast since it is an easy place to discharge final effluent. Seawater has varying salinity, but a higher osmotic pressure than wastewater/digester centrate, as such; utilising seawater provides an inexpensive draw solution, with only pumping costs involved [13]. Regeneration is not necessary as the seawater can be discharged back to the sea [13]. While the seawater and wastewater never meet, this raises the issue of contaminants passing through the membrane and being discharged with the seawater without any treatment. The degree to which different membrane types allow the passage of compounds other than water varies; however, existing studies have shown that FO membranes are capable of achieving > 96% rejection of contaminants such as phosphorus and ammonia (when using a cellulose triacetate (CTA) membrane) [10,14–16].

Previous studies have been done to determine FO's propensity for concentrating digester centrate. Most studies have focused on the use of CTA [17–19] and thin-film composite membranes (TFC) from HTI [19,20] and use either synthetic FS [19] or filtered digester centrate [17,20]. While using synthetic or filtered solutions will allow a higher water flux, this will not reflect the fouling potential of unfiltered FS, since using a 0.2 μm filter [20] sterilizes the feed solution. As such, while these results are indicative of FO's potential for P recovery from digester centrate, they may not reflect the technology's real-life potential. While most studies found a near complete rejection of phosphate [4], > 92% [17,18,21], NH_3 rejection is still much lower, around 82% [18] for both CTA and TFC membranes. However, the initial flux achieved varied for the different membranes with TFC membranes achieving a water flux of < 9LMH [19,20,22] and CTA membranes achieving < 3LMH [19]. A VCR of 3 was achieved using seawater draw FO [17] using CTA membranes, thus allowing a reduction in Mg addition as previously mentioned, showing the potential for seawater as a DS. However, reverse salt flux is deemed to be an ongoing issue with both membranes [23]. More recently, novel membranes such as nanofiber composite [16], and biomimetic membranes [24,25] have been utilised for wastewater treatment. Biomimetic membranes in particular show great promise in removal of trace organics, > 97%, compared to CTA membranes [25] but the flux is lower than for the TFC membranes [26]. In this study TFC membranes will be tested.

The specific objective of this study is to determine whether Porifera TFC membranes are suitable for the concentration of digester centrate to recover phosphorus using FO, as such this study employs the use of real digester centrate and seawater as FS and DS respectively. This is assessed based on flux, reverse salt flux, phosphate rejection and ammonia rejection.

2. Materials and methods

2.1. FO setup and operation

A bench-scale FO setup, as shown in Fig. 2, was adopted. Permeability experiments were conducted using a membrane cell (Sterlitech

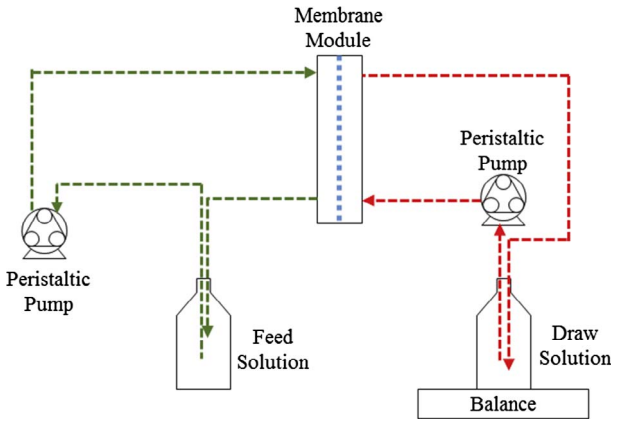

Fig. 2. Bench-scale setup.