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Short Communication

Removal of phosphorus by a high rate membrane adsorption hybrid system

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HIGHLIGHTS

- High rate MBR (HR-MBR) was successful in removing 90% of dissolved organics.
- Membrane adsorption hybrid system (MAHS) removed 85% of phosphate.
- Concurrent removal of organics and phosphate in a sustainable manner.

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ABSTRACT

Membrane adsorption hybrid system (MAHS) was evaluated for the removal of phosphate from a high rate membrane bioreactor (HR-MBR) effluent. The HR-MBR was operated at permeate flux of 30 L/m^2 h. The results indicated that the HR-MBR could eliminate 93.1 ± 1.5% of DOC while removing less than 53% phosphate (PO_4-P). Due to low phosphate removal by HR-MBR, a post-treatment of strong base anion exchange resin (Dowex*21K-XLT), and zirconium (IV) hydroxide were used as adsorbent in MAHS for further removal of phosphate from HR-MBR effluent. It was found that the MAHS enabled to eliminate more than 85% of PO_4-P from HR-MBR effluent. Hence, HR-MBR followed by MAHS lead to simultaneous removal of organics and phosphate in a reliable manner. The experiments were conducted only for a short period to investigate the efficiency of these resins/adsorbents on the removal of phosphorus and high rate MBR for organic removal.

1. Introduction

Membrane bioreactor (MBR) has been considered as a state-of-the-art technology in wastewater treatment during the last few decades. Admittedly, this technology has several advantages over the conventional treatment systems, such as high treated water quality, less space requirement, and less sludge production. High permeate flux plays primary role in reducing operating cost per cubic treated water, and shortens hydraulic retention time (HRT). However, operating MBR at high filtration flux also means reducing treatment efficiency and increasing membrane fouling.

Filtration flux plays an important role on organics and nutrients removal efficiency. Johir et al. (2012) studied the effect of imposed flux on fouling behaviour and organic removal efficiency in high rate membrane bioreactor. This study showed that the highest DOC removal of around 95% was achieved when the MBR was operated below a flux of 20 L/m^2 h. This removal efficiency reduced to 58–66% when the operating flux was increased to 40 L/m^2 h. Nutrient removal efficiency also presented the similar fashion as NH_4-N removal was 50% and 30–35% when operating at 20 and 40 L/m^2 h, respectively.

Biological nutrient removal is more difficult to achieve with the MBR, and phosphate (P) is the most difficult one to remove (Sun et al., 2013). Indeed, the removal of phosphate by MBR can be improved through the incorporation of polyphosphate accumulative organisms (PAO) or denitrifying poly-phosphate accumulating organisms (DPAOs) (Monclús et al., 2010). They have reported an average P removal of 88%. Further, Sun et al. (2013) tested an innovative membrane bioreactor (MBR) system (membrane filtration system coupled with a post-de-nitrification process) for effective organic degradation and nutrient (N and P) removal and the total removal of P found to be around 87%. However, this is a complex process and the efficiency reduced when the phosphate concentration was high (Long et al., 2011). On the other hand, ion exchange/adsorption processes effectively remove nitrate, phosphate and

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ammonia from water and wastewater to near zero level in a reliable manner (Samatya et al., 2006; Johir et al., 2011a). Ion exchange resins and adsorbents such as purolite A500P, purolite A520E, amberlite IRA910Cl (a strong basic macroreticular anion exchange resin), amberjet 1200Na (a strong acid cation exchanger), aluminium oxide, iron oxide, zirconium oxide, hydrotalcite, (Chen et al., 2002; Johir et al., 2011a) were successfully tested for superior P removal. Nur et al. (2014) reported a maximum adsorption capacity of 48 mg P/g by iron oxide impregnated strong base anion exchange resin. Further, Liu et al. (2008) reported a maximum P adsorption capacity of 29.71 mg P/g by mesoporous ZrO_2.

The use of ion exchange resin/adsorbent offers a number of advantages including the ability to handle shock loadings and the ability to operate over a wider range of temperatures. Furthermore, the ion exchange resin/adsorbent can be regenerated and used for several cycles before their adsorption capacity significantly decreased (Nur et al., 2014). Another major advantage of ion-exchange process is that adsorbed nutrients can be recovered during regeneration and can be used as fertigation. Johir et al. (2011a) and Samatya et al. (2006) reported a recovery of 90–95% of nitrate and phosphate by using NaCl as a regenerating solution. Other mild alkaline solution such as NaOH, Na_2SO_4 can also be used as regenerating solution. Thus, it is reliable to use HR-MBR with the intention of removing mainly biological oxygen demand (BOD) and ion exchange process for the removal and recovery of phosphate. This is considered advantageous for a smaller MBR reactor volume, and a correspondingly lower capital cost, and a lower oxygen demand, and also allows a maximum recovery of nutrients in the sludge, and a greater reuse potential of carbon from grey water.

Even though many researches were conducted on the removal of phosphorus using different types of adsorbent but they were mainly confined to batch and column adsorption studies only. Practically, no study was conducted with MAHS for the removal of phosphate from HR-MBR effluent. This study used a dual membrane system consisting of a high rate MBR mainly to remove organic matters and MAHS to remove nutrients to near zero level with short term experiments. The use of MBR as an upstream process to the ion exchange process eliminates the flow resistance in the ion exchange column as all particulate matter (causing turbidity) would have been removed by the MBR. The incorporation of MAHS will ensure reliable removal of nutrients and also pave a way for recovery of nutrients. Thus, this study will be very useful in the design of continuous membrane absorption systems for the removal of phosphorus and organic simultaneously.

2. Methods

2.1. Synthetic wastewater

The experiments were conducted using a synthetic wastewater based on previous study (Nguyen et al., 2012). This represents high strength domestic wastewater. The synthetic wastewater consists of DOC of 120-130 mg/L, COD of 330–360 mg/L, ammonium nitrogen (NH_4-N) of 12–15 mg/L and orthophosphate (PO_4-P) of 3.3–3.5 mg/L as source of organic and nutrients. The ratio of COD:N:P was 100:5:1).

The synthetic feed contained mostly biodegradable dissolved COD which is easily biodegradable. On the other hand, the real feed contains wide range of physico-chemical and microbiological pollutants. The suspended solid concentration in real feed varies significantly and also contains both particulate and non-biodegradable COD. However, the synthetic feed has advantages over real feed in the experimental investigation as its physico-chemical and microbiological characteristics can be kept constant. Further, it is also easy to vary the influent concentration of the substrate in the synthetic feed by changing the quantities of the ingredients. The use of real wastewater will also lead to similar trend of results.

2.2. HR-MBR description

In this study, a HR-MBR was operated at a flux of 30 L/m^2 h which corresponded to a hydraulic retention time (HRT) of 2.5 h. From literature, it is found that different full-scale MBRs used an operating flux ranges between 21–33 L/m^2 h (EUROMBRA, 2005). As such, in this study, an operating flux of 30 LMH was used. Past study also suggested that HR-MBR can be suitable for organic removal (Johir et al., 2011b). A flat sheet membrane with surface area of 0.2 m^2 and an average pore size of 0.14 μm and was placed in the reactor. The volume of reactor used in this study was 15 L. The membrane module had 8 vertical sheets and the gap between adjacent vertical membrane sheets was 12 mm. A predetermined aeration of 1.5 $m^3/m^2_{membrane\ area}$ was used to provide oxygen to microorganism and to provide shearing stress on the membrane surface. The HR-MBR was stopped for 8 mins (relaxation mode), for every 120 min of operation. No backwashing was applied during experiment. The trans- membrane pressure (TMP) was monitored continuously using a pressure transducers and the reading were recorded in the data logger.

2.3. Membrane adsorption hybrid system (MAHS) for phosphorus removal from HR-MBR effluent

In this study, 2 different types of ion-exchange resins/adsorbents namely Dowex*21K XLT (strong base anion exchange resin), and zirconium (IV) hydroxide were used in the post treatment of membrane adsorption hybrid system (MAHS) for the removal of phosphate from HR-MBR effluent. The properties of these resins/adsorbents are presented in Table 1.

The effluent from HR-MBR was used as feed to MAHS. Hollow fibre micro-filter membrane module (MANN + HUMMEL, Singapore) with an area of 0.1 m^2 made of hydrophilic modified poly

Table 1
The properties of the adsorbents/ion exchange resins used in this study.

Parameters	DOWEX*21K XLT	Zirconium (IV) hydroxide
Matrix structure	Type I strong base anion, styrene-DVB, gel	H_4O_4Zr
Functional groups	Quaternary amine	–
Ionic form (as shipped)	Cl^-	–
Particle size range (microns)	525–625	<35
Uniformity coefficient, max.	1.1%	–
Particle density (kg/m^3)	1080	1100–1300
Total exchange capacity	1.4 eq/l min	–
Total swelling (Cl ⇒ OH), approx.	18–20%	–
Maximum operating temperatures	100 °C (Cl^- form)	–
pH range	0–14	
Water content	50–60%	–