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An anaerobic membrane bioreactor – membrane distillation hybrid system for energy recovery and water reuse: Removal performance of organic carbon, nutrients, and trace organic contaminants

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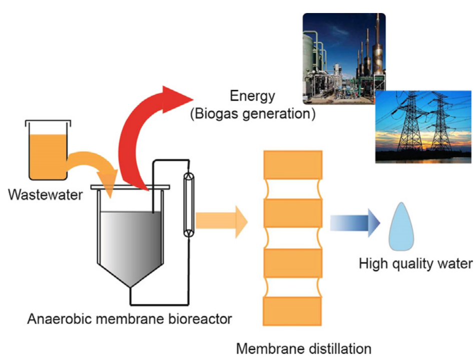
HIGHLIGHTS

- Stable biogas production and organic removal by AnMBR were observed.
- MD complemented AnMBR treatment well to enhance contaminant removal.
- AnMBR-MD achieved 76% to complete removal of all 26 TrOCs investigated here.
- Foulants accumulated in MD feed and thus induced MD membrane fouling.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, a direct contact membrane distillation (MD) unit was integrated with an anaerobic membrane bioreactor (AnMBR) to simultaneously recover energy and produce high quality water for reuse from wastewater. Results show that AnMBR could produce 0.3–0.5 L/g COD_{added} biogas with a stable methane content of approximately 65%. By integrating MD with AnMBR, bulk organic matter and phosphate were almost completely removed. The removal of the 26 selected trace organic contaminants by AnMBR was compound specific, but the MD process could complement AnMBR removal, leading to an overall efficiency from 76% to complete removal by the integrated system. The results also show that, due to complete retention, organic matter (such as humic-like and protein-like substances) and inorganic salts accumulated in the MD feed solution and therefore resulted in significant fouling of the MD unit. As a result, the water flux of the MD process decreased continuously. Nevertheless, membrane pore wetting was not observed throughout the operation.

1. Introduction

Water scarcity driven by population growth, climate change, and environmental pollution has prompted the development of new

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technologies, such as membrane distillation (MD), and the improvement of existing ones, such as membrane bioreactor (MBR) for wastewater treatment and reuse (Shannon et al., 2008). MBR integrates the membrane separation process with biological treatment to produce high standard water for recycling applications (Nguyen et al., 2012; Huang and Lee, 2015; Jegatheesan et al., 2016; Judd, 2016). Previous studies have demonstrated the capacity of MBR for wastewater treatment and reuse regarding both basic water quality parameters and high removal efficiency of a broad range of trace organic contaminants (TrOCs) (Tadkaew et al., 2011; Boonyaroj et al., 2012; Navaratna et al., 2012; Wijekoon et al., 2013; Di Bella et al., 2015; Prasertkulsak et al., 2016).

The widespread occurrence of TrOCs in municipal and industrial wastewater is of significant concern to water reuse (Acuña et al., 2015; Huerta et al., 2016). TrOCs include a diverse range of emerging chemicals that are widely used in our modern society for health care, agriculture, aquaculture, live stocking, and industrial production. They are continuously released into the environment either accidentally through agricultural and industrial activities or inevitably through human and livestock excretion. TrOCs are ubiquitously detected in wastewater and sewage-impacted water bodies at trace levels up to a few micrograms per litre (μg/L) (Osorio et al., 2012). Although the impact of long-term exposure to low concentrations of TrOCs on human health is still largely unknown, ecological data to date have evidenced their chronic effects on a range of sensitive aquatic organisms, such as fish and reptiles (Schwarzenbach et al., 2006; Guillén et al., 2012). Thus, adequate removal of TrOCs is essential for water reuse applications and environmental protection (Luo et al., 2014).

MBR can be operated in aerobic or anaerobic conditions according to the presence or absence of oxygen in the biological reactor (Huang and Lee, 2015). Recent studies have focused mostly on aerobic MBR systems as they can be readily deployed for wastewater treatment and reuse. There is also a growing interest in the development of anaerobic MBR (AnMBR) for energy efficient wastewater treatment and reuse (Stuckey, 2012). Compared to aerobic MBR, which requires significant energy input for aeration, AnMBR is more energy-efficient and can even be an energy positive system by producing biogas for beneficial usage. However, AnMBR often has a lower treatment capacity to remove nutrients and TrOCs in comparison with aerobic MBR. Recent studies have demonstrated that some TrOCs (such as carbamazapine, atrazine, and diclofenac) are poorly removed by AnMBR due to their resistance to biodegradation (Monsalvo et al., 2014; Wijekoon et al., 2015). As a result, it is necessary to complement AnMBR with an additional treatment process to achieve a suitable product water quality for reuse.

MD is a thermally driven membrane separation process and has been recognized as an emerging technology in wastewater treatment and reuse (Wijekoon et al., 2014a; Wijekoon et al., 2014b; Nguyen et al., 2016). During MD operation, water in the vapour form transports under a partial vapour pressure gradient across a microporous and hydrophobic membrane from a high temperatue solution to a low temperature solution. MD can utilize low-grade waste heat and solar thermal that is otherwise unusable by other means. Thus, MD can potentially be used for the futher purification of wastewater effluents, particularly after anaerobic treatment where thermal heat from the combustion of produced biogas can be utilized as energy input to the MD process. Kim et al. (2015) have demonstrated that MD could further treat effluent from an anaerobic moving bed biofilm reactor by achieving complete rejection of phosphorus and >98% rejection of dissolved organic carbon. Similarly, Jacob et al. (2015) reported 90% rejection of chemical oxygen demand (COD) and ammonia from AnMBR effluent by MD. Nevertheless, data from these previous studies were from batch test experiments and little is known about the MD performance when simultaneously operated with AnMBR.

This study aimed to investigate the performance of an integrated AnMBR-MD system for water reuse and energy recovery from wastewater. The hybrid system performance was examined in terms of biogas production, biomass characteristics, contaminant removal, and membrane fouling. Removal of organic matter, nutrients, and TrOCs by both the AnMBR and MD processes were evaluated. Fouling behavior of the MD membrane was delineated.

2. Materials and methods

2.1. Synthetic wastewater and trace organic contaminants

A synthetic solution, simulating high strength domestic wastewater, was used and was prepared daily to consist of 4000 mg/L glucose, 750 mg/L peptone, 2250 mg/L sodium acetate, 175 mg/L potassium dihydrogen phosphate, 175 mg/L magnesium chloride, and 175 mg/L urea. Key physicochemical properties of the synthetic wastewater were determined every four days throughout the experiment. In particular, the synthetic wastewater contained 6252.3 mg/L COD, 166.8 mg/L total nitrogen (TN), 195.4 orthophosphate (PO_4^{3-}), and 34.7 mg/L ammonium (NH_4^+). The electrical conductivity and pH of the synthetic wastewater were 4.01 mS/cm and 7.0, respectively. It is noteworthy that anaerobic treatment is not viable for biogas production from low strength wastewater due to the low methane production over heating requirement ratio. As a result, it is necessary to pre-concentrate municipal wastewater to increase the COD content by processes such as forward osmosis prior to anaerobic treatment (Ansari et al., 2016). Thus, the synthetic wastewater with higher strength than typical municipal wastewater was used in this study.

A set of 26 TrOCs was selected for study. These TrOCs represent four major groups of chemicals of emerging concern that are ubiquitously present in domestic wastewater, including pharmaceuticals and personal care products, endocrine disruptors, industrial chemicals, and pesticides. Key physicochemical properties of these TrOCs are summarized in Table S1, Supplementary data. Based on their effective octanol –

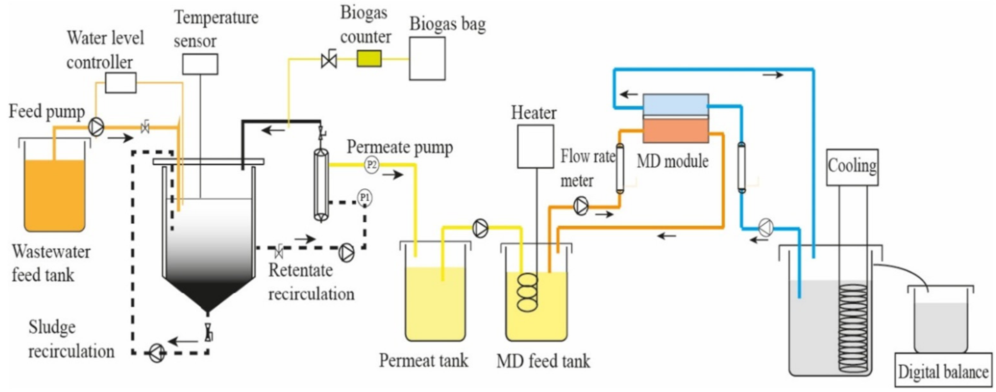

Fig. 1. Schematic diagram of the laboratory scale AnMBR-MD hybrid system.