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Methane production in an anaerobic osmotic membrane bioreactor using forward osmosis: Effect of reverse salt flux

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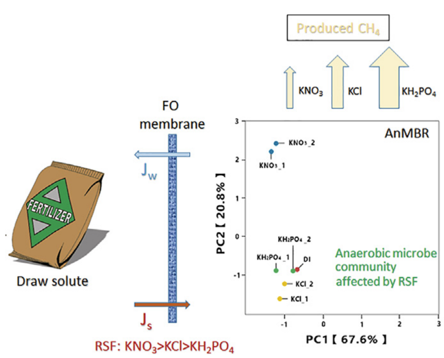
HIGHLIGHTS

- RSF's impact on CH_4 production and microbes of FDFO-AnMBR was investigated.
- Among the tested fertilizers, the higher RSF, the less CH_4 was produced.
- Variation of CH_4 production was due to microbe community change caused by RSF.
- Archaea structure was not significantly changed by the RSF.
- Bacteria structure was significantly modified by the RSF.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the impact of reverse salt flux (RSF) on microbe community and bio-methane production in a simulated fertilizer driven FO-AnMBR system using KCl, KNO_3 and KH_2PO_4 as draw solutes. Results showed that KH_2PO_4 exhibited the lowest RSF in terms of molar concentration 19.1 mM/(m^2.h), while for KCl and KNO_3 it was 32.2 and 120.8 mM/(m^2.h), respectively. Interestingly, bio-methane production displayed an opposite order with KH_2PO_4, followed by KCl and KNO_3. Pyrosequencing results revealed the presence of different bacterial communities among the tested fertilizers. Bacterial community of sludge exposed to KH_2PO_4 was very similar to that of DI-water and KCl. However, results with KNO_3 were different since the denitrifying bacteria were found to have a higher percentage than the sludge with other fertilizers. This study demonstrated that RSF has a negative effect on bio-methane production, probably by influencing the sludge bacterial community via environment modification.

1. Introduction

Water scarcity and environmental pollution have driven the development of water reuse in the urban water management (Shannon et al., 2008). A lot of efforts have been placed to develop technologies to reuse and recycle resource in municipal and industrial wastewater, including activated carbon filtration, ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO) and anaerobic membrane bioreactor (AnMBR) (Michael et al., 2013; Wei et al., 2014). Although these technologies showed a good capability to remove suspended solids, organic pollutants, and even salinity

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from the wastewater, there are still some challenges to be addressed. For instance, the emerging micro pollutants were difficult to be completely removed by AnMBR equipped with UF membrane (Cath et al., 2006). On the other hand, RO is an energy intensive treatment technology, which cannot be affordable in some developing countries where coincidently water demand is also high, such as in the Middle East and North Africa (MENA) (Ghaffour, 2009). It is therefore crucial to develop a novel technology capable of removing emerging micro pollutants at low energy cost.

Forward osmosis (FO) is a membrane separation process driven by the osmotic pressure difference between the feed solution (FS) and draw solution (DS) (Cath et al., 2006). Since this process is not driven by an external pressure, the energy consumption is much lower than RO technology. It has been reported that the fouling and scaling of FO membranes is also less severe than in RO, and mostly reversible via hydraulic cleaning (Li et al., 2015). However, FO generally needs to be coupled with another process to separate the diluted draw solution from the final product water. However, this additional recovery process requires energy and increases the capital cost of the hybrid system. Lately, fertilizer-drawn forward osmosis (FDFO) has received increased interest since the diluted DS can be used directly for irrigation purposes and therefore no recovery process is required (Phuntsho et al., 2012). In FDFO, the process is driven by fertilizers (FO draw solution) and thus the water drawn from the wastewater (FO feed solution) is used to dilute the fertilizer solution which can then be directly used for fertigation (Chekli et al., 2017; Kim et al., 2016).

By combining FDFO and AnMBR, several benefits can be achieved, namely bio-methane production, higher effluent quality than UF based AnMBR systems and sustainable fertigation via wastewater reuse. Different fertilizers have been compared in terms of water flux, bio-methane production rate and reverse diffusion (Kim et al. 2016). However, it is still not clear why different fertilizers exhibited different bio-methane production rates. It could be related to the bacterial community variation caused by different reverse diffusion rates of different fertilizers, but there is no substantial proof to support this hypothesis.

Due to the RSF from the fertilizer draw solution (DS) and the high salt rejection of the FO membrane which retains the salts from the feed, the fertilizer concentration within the AnMBR will ultimately increase. However, this increase is a gradual process rather than a one-time intensive dosage. The bacterial community in the AnMBR is sensitive to the environment, especially the methanogens, so the one-time intensive dosage of fertilizer could significantly modify the bacterial community but might not reflect the real situation with gradual increase. Since the methanogens might be able to endure the gradual changes of environment but not a sudden significant modification, the one-time intensive fertilizer dosage may overestimate the effect of reverse diffused fertilizers on the methane production in the FDFO-AnMBR. Therefore, a systematic study is required to demonstrate the impact of RSF of different fertilizer DS on bio-methane production in the FDFO-AnMBR, especially in a parallel comparison with gradual build-up of salt.

This study investigated the impact of gradual reverse fertilizer diffusion on the methane production in a hybrid FDFO-AnMBR system by dosing three different fertilizers, which amount was predetermined via FO experiments, into parallel anaerobic fermentation bottles step by step. The methane production was monitored for all conditions to check the effects of fertilizer dosage. The corresponding sludge under different conditions were also collected and analyzed via pyrosequencing to illustrate the microbe community difference of different conditions and its relation with the methane production difference.

2. Materials and methods

2.1. Anaerobic sludge

The anaerobic sludge collected from one digester of the Wollongong Sewage Treatment Plant, located in Wollongong, Australia (Lat: 34 26 35 S Long: 150 53 50 E), was used as the seed sludge in this study. 700 mL of anaerobic sludge was filled in each bottle of the bio-methane potential (BMP) apparatus and then purged by nitrogen gas to ensure the anaerobic condition within these bottles to simulate AnMBR systems. The anaerobic sludge was characterized in terms of total solids (TS), mixed liquor suspended solids (MLSS), pH and chemical oxygen demand (COD) (Table 1).

2.2. Model substrates and reversed draw solutes

To maintain the bioactivity of the BMP apparatus, 550 mg/L glucose was dosed in the bottles every two day as substrate for the anaerobic fermentation. Glucose is a common compound utilized as model substrates in membrane bioreactor research (Ansari et al., 2015). The amount of glucose dosed every two day in this study was determined based on the synthetic wastewater recipe used in a previous study (Kim et al., 2016) assuming 1 L of treated wastewater per day.

Three fertilizers, namely KCl, KNO_3 and KH_2PO_4 were used as model draw solutes in the FDFO process for this study. These three fertilizers were chosen because they exhibited different RSF according to preliminary results (Li et al., 2017), and thus the impact of reversely diffused fertilizers on the bio-methane production could be evaluated. The experiment was conducted for 20 days, since one similar study reported that the methane production trend and microbial community dynamics in an anaerobic digester did not change after 20 days (Wang et al., 2017). In contrast with one time intensive dosage of fertilizer in a previous reported study (Kim et al., 2016), the fertilizers were gradually added in the fermentation bottles over the whole experiment period of 20 days. To simplify the simulation, the RSF was considered constant during the whole experiment of 20 days. The amount of dosed fertilizer per day was based on the detected RSF (described in Section 2.3), membrane area of 20 cm^2 and a 24-h operation.

2.3. FO experiments for RSF determination

To determine the amount of fertilizer chemicals to be added to the digested sludge, FO experiments were conducted to evaluate the RSF of different draw solutes (Supplemental Table S1 and Fig. S1 for experimental conditions and schematic diagram, respectively). During these RSF determination experiments, primary wastewater and corresponding fertilizers were utilized as FS and DS, respectively. The FS and DS of 1 L each were separately recycled in the FO system with an identical velocity of 8.5 cm/S (Table S1). The experiment was conducted for 24 h, the volume of DS increased by 240 mL for all three tested fertilizer DS. The FS and DS before and after experiment were sampled for NO_3^- and PO_4^{3-} analyses with ion chromatography system (ICS-1600, DIONEX) and K^+ analyses with inductively coupled plasma – mass spec-

Table 1
Characteristics of anaerobic sludge used in this study.

Indicator	Concentration
Total solids (TS,%)	3.05
Mixed liquor suspended solids(MLSS, mg/L)	27,900
pH	7.2
COD (mg/L)	1850