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Pilot study of cold-rolling wastewater treatment using single-stage anaerobic fluidized membrane bioreactor

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ABSTRACT

A pilot-scale single-stage anaerobic fluidized membrane bioreactor (AFMBR) was firstly used in this study to treat cold-rolling emulsion wastewater from steel industry. It was continuously operated for 302 days with influent COD concentration of 860–1120 mg/L. Under a hydraulic retention time of 1.5 d, the average effluent COD concentration of 72 mg/L achieved corresponding 90% of COD removal. The permeate flux was varied between 1.7 and 2.9 $L/m^2/h$ during operation which decreased with increased biomass concentration inside AFMBR. The *trans*-membrane pressure (TMP) was generally around 35–40 kPa, however, it increased up to 60 kPa when volatile suspended solid increased to above 2.5 g/L. Both flux and TMP data reveal the importance of biomass control for AFMBR operation. Results from terminal restriction fragment length polymorphism (T-RFLP) show the genus *Methanosaeta* was dominant on GAC and it shared dominance with the genera *Methanomethylovorans* and *Methanosarcina* in suspended sludge.

1. Introduction

With the global issues of energy crisis and water scarcity, there is an increasing interest to consider wastewaters as resources instead of wastes (McCarty et al., 2011). Because of the potentials of producing useful organic materials (such as fatty acids, solvents and bioplastics) and recovering energy in the forms of hydrogen and methane, anaerobic processes were widely proposed to replace conventional aerobic wastewater treatment in recent years (Kleerebezem and van Loosdrecht, 2007; McCarty et al., 2011; Tauseef et al., 2013). In order to overcome the disadvantages of slow growth of anaerobic microorganisms and moderate effluent quality, anaerobic membrane bioreactor (AnMBR) became an alternative system to maintain shorter hydraulic retention time (HRT) with sufficient solid retention time (SRT). Although AnMBR can improve effluent quality and reduce biosolids production, it may require significant costs for energy supply and operation due to membrane fouling problem (Aslam et al., 2017; Yoo et al., 2012). Anaerobic fluidized membrane bioreactor (AFMBR) was then proposed by combining MBR and anaerobic fluidized bioreactor (AFBR), in which granular activated carbon (GAC) is applied not only as the supporting material for microbial growth but also to provide scouring on membrane surface to reduce membrane fouling (Kim et al., 2011; Yoo et al., 2012).

As a newly developed technology, most of reported AFMBRs were lab-scale and served as second/polishing stage treating domestic or synthetic wastewater, and the researches focused mainly on fundamental properties (Aslam et al., 2014; Dutta et al., 2014; Li et al., 2017; Ren et al., 2014; Shin et al., 2014). It was found that the addition of GAC is critical for the reduction of membrane fouling, and the elevation of *trans*-membrane pressure (TMP) may be alleviated by adding more GAC (Gao et al., 2014; Kim et al., 2011). By comparing the additions of fresh GAC and pre-adsorbed GAC, Aslam et al. (2014) confirmed that GAC reduces fouling by both sorption and membrane scouring, however, the scouring might damage polymeric membrane after long-term operation (Shin et al., 2016). Despite the excellent performances of staged AFMBRs (Dutta et al., 2014; Li et al., 2017; Ren et al., 2014; Shin et al., 2014), it was argued that single-stage AFMBR can also achieve comparable results and is more promising in future application (Aslam et al., 2017; Wu et al., 2017).

The steel industry in Taiwan produced nearly a trillion NT dollars annually, and around 2000 metric tons of cold-rolling wastewater (CRW) is discharged every day. CRW usually includes caustic

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wastewater and oil-water emulsion which currently can be treated with aerobic MBR after floatation, coagulation and sedimentation, however, the aeration requires significant amount of energy input and may cause foaming due to the presence of surfactants in CRW. Nevertheless, except for the studies targeting pharmaceuticals in municipal wastewater (Dutta et al., 2014) and synthetic benzothiazole contaminated wastewater (Li et al., 2017), very limited information of treating industrial wastewater using AFMBR is available.

This study investigated the feasibility of single-stage AFMBR for CRW treatment, and the performance, in terms of chemical oxygen demand (COD) removal, was evaluated. Batch experiments were also conducted to understand the contributions of attached biofilm on GAC and suspended sludge on methane production and COD removal. Microbial community of methanogens was also monitored by using terminal restriction fragment length polymorphism (t-RFLP) technique.

2. Materials and methods

2.1. Configuration and operation conditions of pilot-scale reactor

In this study, a pilot-scale single-stage AFMBR was fed with cold-rolling wastewater from a full-scale wastewater treatment plant of a steel industry in Taiwan, and the configuration is illustrated in Fig. 1. The main reactor part of AFMBR is a cylinder with 0.5 m in diameter and 1.5 m in height which corresponds to nearly 300 L and a settler of around 150 L is at the top. PVDF hollow membrane modules (SUEZ, Paris, France) were installed at the upper region of the reactor, with a nominal pore size of 0.035 μm, and the total membrane surface area for each module is 0.93 m^2. Two membrane modules were firstly installed during startup, and the third module was added on day 129 to increase the flowrate of permeate. The effective size of GAC (Calgon Carbon, Pittsburgh, PA, USA) is 0.6 to 2.0 mm, and the GAC was washed to remove unwanted powders using tap water prior to use. Few cobblestones (with 10–30 mm in diameter) were placed at the bottom to evenly distribute the upflow stream and to support GAC. There are three tanks next to AFMBR, including a 250-L raw water tank, a circulation tank with about 500 L, and a 100-L wastewater tank. The CRW after floatation in full-scale wastewater treatment plant was directly pumped to raw water tank and then to circulation tank according to their water-level meters, while all water/wastewater produced in this study were temporarily stored in the wastewater tank and then transferred back to the sedimentation unit of the full-scale wastewater treatment process. The bulk liquid in AFMBR overflowed to circulation tank and mixed with CRW coming from raw water tank. The mixture was circulated back to AFMBR by a centrifugal pump to fluidized GAC particles until the membrane modules were completely submerged, while the upflow velocity was around 50 cm/min. A peristaltic pump was connected to the membrane modules to extract permeate and a pressure gauge was also connected to the permeate line to monitor the TMP.

The operational parameters, including number of membrane module, flux, HRT, influent COD, and organic loading, were summarized in Table 1. Clean GAC of 135 kg was added on Day 1, and around

Table 1
Operational conditions of the pilot-scale single-stage AFMBR.

Periods	I	II	III	IV	V
Day	1–26	27–129	130–155	156–218	219–302
Membrane module	2	2	3	3	3
Instantaneous flux (LMH)	N.D.[1]	1.7	2.5	2.3	2.9
Backwash frequency	1 min/8 min		1 min/6 min		
HRT (d)	N.D.	4.0	1.8	2.0	1.5
HRT_{system} (d)[2]	N.D.	12.7	5.7	6.3	4.8
Influent COD (mg/L)	1240	1240	930	860	870
OLR (kg-COD/m^3/d)	N.D.	0.31	0.52	0.43	0.58
Automatic pH adjustment	No	No	No	No	7.5

[1] N.A.: not determined.
[2] HRT_{system} indicates the HRT including the volume of circulation tank.

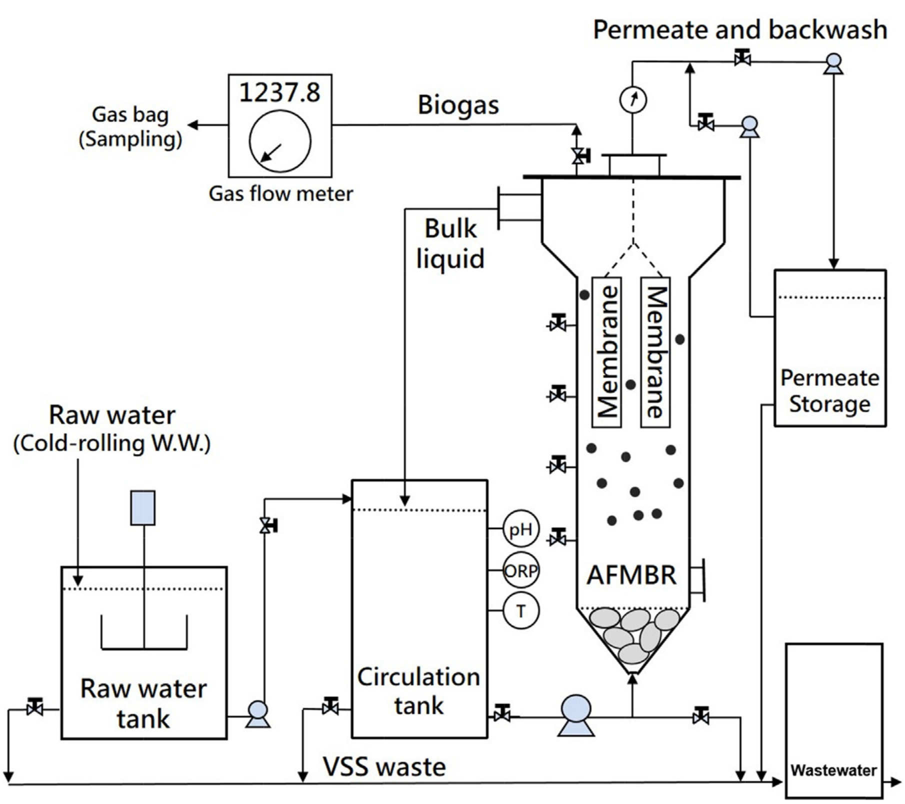

Fig. 1. Schematic diagram of pilot-scale single-stage AFMBR.