



# Comparison of filtration and treatment performance between polymeric and ceramic membranes in anaerobic membrane bioreactor treatment of domestic wastewater

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## ABSTRACT

The feasibility of an anaerobic ceramic membrane bioreactor (AnCMBR) was investigated by comparison with a conventional anaerobic membrane bioreactor (AnMBR). With regard to treatment performance, the AnCMBR achieved higher organic removal rates than the AnMBR because the ceramic membranes retained a high concentration of biomass in the reactor. Despite a high mixed liquor suspended solid (MLSS) concentration, the AnCMBR exhibited lower membrane fouling. To elucidate effects of sludge properties on membrane fouling in the AnCMBR and AnMBR, soluble microbial products (SMPs) and extracellular polymeric substances (EPSs) were analyzed. The SMP and EPS concentrations in the AnCMBR were higher than in the AnMBR. This may be because some suspended solids bio-degraded and likely released protein-like SMPs in the AnCMBR. Hydrophobicity and surface charges were analyzed; the sludge in the AnCMBR was found to be more hydrophobic and less negative than in the AnMBR because protein was abundant in the AnCMBR. Despite the adverse properties of the sludge in the AnCMBR, it showed more stable filtration performance than the AnMBR. This is because the alumina-based ceramic membrane had a superhydrophilic surface and could thus mitigate membrane fouling by hydrophilic-hydrophobic repulsion. The findings from this study have significant implications for extending the application of AnCMBRs to, for example, treatment of high-strength organic waste such as food waste or livestock manure.

## 1. Introduction

Recently, anaerobic membrane bioreactors (AnMBRs) have received increased attention for treating domestic wastewater because they have several advantages including complete rejection of suspended solids, low sludge production, high organic removal, and biogas production [1–3]. However, despite these merits, wastewater treatment by AnMBR is often limited due to the problem of severe fouling, which leads to high operation and maintenance costs [4–7]. Therefore, a great deal of intense research has been conducted to develop effective fouling control strategies [8,9].

Most previous studies have focused on the optimization of operating conditions, such as biogas scouring intensity, hydraulic retention time (HRT), sludge retention time (SRT), and temperature [5,10–13]. A reduction in HRT can enhance the growth of biomass and accumulate

soluble microbial products (SMPs), resulting in accelerated membrane fouling [5]. At high SRT, concentrations of organic and inorganic elements become higher and thus cause the fouling layer to become denser and more compact [13]. An increase in working temperature can increase the concentrations of extracellular polymeric substances (EPSs), SMPs, and colloidal particles, which make membrane fouling more significant [11]. High gas scouring velocity can induce decreased resistance to membrane fouling [12].

Membrane surface modification (e.g., plasma treatment or surface grafting) has also been studied for mitigation of membrane fouling and to enhance membrane permeability [10,14–17]. Zhao et al. suggested the use of rapidly self-assembled coating membranes of polydopamine, with polyhexamethylene guanidine, for hydrophilic and anti-fouling properties [14]. Sainbayar et al. introduced ozone treatment followed by graft polymerization with 2-hydroxy-ethyl methacrylate (HEMA) to

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modify the surface of a hydrophobic polypropylene (PP) membrane for the improvement of hydrophilicity [16]. Zhao et al. introduced a surface modification method using plasma pretreatment and graft polymerization of polyvinylidene fluoride (PVDF) powder to fabricate a hydrophilic PVDF membrane [15]. Despite recent efforts to improve anti-fouling properties, however, most studies have been conducted using polymeric membranes with naturally high fouling potential (i.e., relatively hydrophobic properties) [18].

Recently, application of ceramic membranes has drawn great interest due to their technical merits. In drinking water treatment applications, ceramic membranes allow better achievement of high water flux and alleviation of fouling problems than conventional polymeric membranes [19–22]. For this reason, using ceramic membranes might improve the filtration performance of an AnMBR system [23–25]. Given that ceramic membranes are resistant to harsh environmental conditions due to their high chemical stability, a chemical cleaning strategy could be used to control the fouling in an anaerobic ceramic MBR (AnCMBR) due to severe fouling potential of AnMBR caused by high organic contents and sticky sludge properties [9,26]. To achieve better performance and resistance to chemical cleaning, a variety of inorganic material-based membranes (e.g., titania [27], alumina [28], mullite [29], silica [30], pyrophyllite [31] and zirconia [32]) have been employed. Furthermore, ceramic membranes composed of metal oxides could mitigate hydrophobic membrane fouling due to its hydrophilic surface [33]. However, there has not been studied to compare ceramic membranes directly with polymeric membranes in an AnMBR for domestic wastewater treatment.

The aim of this study was to evaluate the feasibility of an AnCMBR by comparing one with an AnMBR in terms of the filtration and treatment performance and sludge properties. For this, AnCMBR using alumina-based ceramic (i.e., the target experiment) and AnMBR using PVDF polymeric membranes (i.e., the control experiment) were operated simultaneously. During the operation, the removal of organics, water permeability, and physico-chemical sludge properties such as the formation of SMPs, concentrations of EPSs, relative hydrophobicity, and cell surface charges were systematically compared.

## 2. Experimental methods

### 2.1. Experimental setups for AnCMBR and AnMBR

One AnCMBR with a working volume of 6.3 L and one AnMBR with a working volume of 4.0 L were operated to compare their filtration and treatment performance in relation to the membrane materials (i.e., ceramic and polymeric membranes) used. As tested membrane materials (alumina and PVDF) have been widely utilized in real applications [34,35], they were selected as a representative. A flat-sheet alumina-based ceramic membrane and a flat-sheet PVDF polymeric membrane were tested for identical anaerobic membrane bioreactor treatment. Detailed information about both membranes is presented in Table 1.

**Table 1**  
Properties of ceramic and polymeric membranes.

	Ceramic membrane	Polymeric membrane
Manufacturer	Meidensha Corp., Japan	Toray, Japan
Type	Flat-sheet	Flat-sheet
Material	Alumina (Al <sub>2</sub> O <sub>3</sub> )	PVDF
Filtration mode	Out-in filtration	Out-in filtration
Nominal pore size (μm)	0.1	0.08
Membrane area (m <sup>2</sup> )	0.05	0.045
Pure water permeability <sup>a</sup> (L m <sup>-2</sup> h <sup>-1</sup> bar <sup>-1</sup> )	1666	1080

<sup>a</sup> The filtration test was performed using deionized water at 25 °C.

The two systems were operated in the inside-out filtration mode and were equipped with pH, oxidation reduction potential (ORP), and level sensors. Fouling was controlled using biogas scouring at a flow rate of 2 L min<sup>-1</sup>. The biogas produced was re-circulated using a gas diaphragm pump (Boxer Pumps 10K, London, UK) to scour the membrane surfaces.

### 2.2. Operating parameters for AnCMBR and AnMBR

The AnCMBR and AnMBR systems were inoculated with anaerobic digester sludge collected from a full-scale domestic wastewater treatment plant in South Korea. The initial concentration of the mixed liquor suspended solid (MLSS) in both reactors was set at 10 g L<sup>-1</sup>. The recipe for the synthetic wastewater used in these systems, which contained glucose as the sole carbon source and had chemical oxygen demand (COD) of 878.6 mg L<sup>-1</sup>, can be found in our previous study [28]. The filtration cycle was performed as follows: 4 min on (i.e., suction) and 1 min off (i.e., stop). A digital pressure gauge (KELLER PR-21Y, Switzerland) connected the membrane and a peristaltic permeate pump (Masterflex L/S, Cole-Parmer, IL) to measure the trans-membrane pressure (TMP) in each AnMBR system. Sludge from both systems was withdrawn only as samples for analysis; therefore, the SRT of the bioreactors could be considered infinite. The details of the operating conditions in this study are summarized in Table 2.

The AnCMBR and AnMBR systems were operated at a mesophilic temperature of 30–35 °C under two different HRT conditions (28 h and 22.5 h, respectively) while keeping the membrane flux constant because the permeated flux is one of the key factors governing membrane fouling [36]. Future research should investigate the treatment performance at more realistic temperature operations at both similar HRT and flux operations in different two bioreactors. To understand the membrane fouling behaviors in the two systems, the specific water permeability was employed, and was obtained as follows in Eq. (1):

$$A_{\text{spec}} = \frac{J_w}{\text{TMP} \times C_{\text{MLSS}}} \quad (1)$$

where  $A_{\text{spec}}$  is the specific water permeability (L<sup>2</sup> m<sup>-2</sup> h<sup>-1</sup> bar<sup>-1</sup> g<sup>-1</sup>, LMH bar<sup>-1</sup> g<sup>-1</sup> L),  $J_w$  is water flux (L m<sup>-2</sup> h<sup>-1</sup>, LMH),  $\text{TMP}$  is trans-membrane pressure (bar), and  $C_{\text{MLSS}}$  is the concentration of the MLSS (g L<sup>-1</sup>).

### 2.3. Analytical methods

The concentrations of MLSS and mixed liquor volatile suspended solid (MLVSS) were measured according to Standard Methods 2540 D/E [37]. COD was analyzed using a HACH DR/3900 spectrophotometer following the standard methods, and turbidity was analyzed using HACH 2100Q potable turbidimeter. The biogas sample was collected from headspace in the reactors and its methane content was analyzed using a gas chromatograph (GC) (GC Systems-7890A GC, Agilent Technologies, Santa Clara, CA). The GC was equipped with a thermal conductivity detector and packed column (HS-Q 80/100, 2.0 mm I.D., 1/8 in O.D. × 8 ft., Restek Corp., Bellefonte, PA). The operating temperature was set as 150 °C for the injector, 175 °C for the detector, and

**Table 2**  
Operational conditions of the lab-scale AnCMBR and AnMBR.

	AnCMBR	AnMBR
Temperature (°C)	33 ± 2	33 ± 2
pH	7.0 ± 0.5	7.0 ± 0.5
Working volume (L)	6.3	4.0
Average membrane flux (L m <sup>-2</sup> h <sup>-1</sup> , LMH)	4.5 ± 0.5	4.0 ± 0.6
Hydraulic retention time (h)	28	22.5
Organic loading rate (kg COD m <sup>-3</sup> d <sup>-1</sup> )	0.6	0.74
Initial MLSS concentration (g L <sup>-1</sup> )	10	10

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