Anaerobic membrane bioreactor for direct COD capture and biogas production in mainstream wastewater treatment

S. Kim*, M. Cha*, C. Park*

*Department of Environmental Science and Engineering, Ewha Womans University, Seoul, South Korea (E-mail: chp@ewha.ac.kr)

Abstract
The treatment of food waste-recycling wastewater (FRW) to produce bio-energy was investigated by operating an anaerobic membrane bioreactor (AnMBR) to replace the mainstream treatment of domestic wastewater at water resource recovery facilities (WRRFs). Coupling ceramic membranes into AnMBR is proved to be performing well under harsh environmental conditions such as high organic wastewater. The anaerobic ceramic MBR (AnCMBR) treating dilute mixture of actual FRW with domestic wastewater was studied to evaluate the treatment efficiencies in terms of organic matter removal and methane production. AnCMBR was operated at a constant flux of 9.2 Lm⁻²h⁻¹ (LMH) with 13 h hydraulic retention time (HRT) for approximately 200 days without chemical cleaning at an organic loading rate (OLR) of 2.95 kg COD m⁻³d⁻¹. Polyvinyl alcohol (PVA)-gel beads were added into the AnCMBR to alleviate the membrane fouling, and their mechanical scouring effect contributed positively in reducing the fouling index (FI).

Keywords
Anaerobic ceramic membrane bioreactor; biogas; ceramic membrane; food waste-recycling wastewater

INTRODUCTION
Ocean dumping of waste, such as wastewater as well as sludge from food and livestock sectors, was banned in Korea since 2012, by the Kyoto protocol; therefore, all types of waste including food wastewater should be treated and disposed properly. Certain companies collect food scraps from restaurants, grocery stores, hotels, and food processing plants, and transfer them to a facility, where they are grinded into slurry. In most cases, this liquid is sent to a domestic WRRF, where it is mixed with raw domestic wastewater and processed in a conventional aerobic system, such as activated sludge process [1]. However, in some cases WRRFs prevent the mixing of FRW with the domestic wastewater in high volumes because FRW has a high salt content that could significantly influence the existing aerobic microorganisms. Adding high volume of FRW to the anaerobic-based process could be possible at a mainstream domestic WRRF.

An AnMBR, in which membranes are integrated into the anaerobic processes, can achieve high quality effluent, less energy consumption during aeration, less sludge production, and energy production in the form of bio-methane [2]. Adding FRW to the AnMBR feed as a mainstream at WRRFs would be beneficial, because it would increase the energy production. A novel feasible approach to alleviate membrane fouling comprises the use of ceramic membranes as a replacement of polymeric membranes because of their higher membrane hydrophilicity.

To the best of our knowledge, this is the first work to suggest using ceramic membranes in the treatment of FRW mixed with domestic wastewater in AnMBR as a feasible option to produce bio-energy at WRRFs. Another objective was to investigate the allowed FRW volumes to be mixed in the feed of the mainstream AnCMBR treatment. In addition, the effect of PVA-gel beads on the membrane fouling in AnCMBR was investigated with the analysis of filtration and biomass properties.
MATERIALS AND METHODS

Reactor setup and operating conditions

The AnCMBR consisted of 24.0 L anaerobic tank (capacity = 0.05 m³/d) and 4 alumina-based ceramic membrane elements with a 0.1 μm nominal pore size. Each membrane has a 0.05 m² effective surface area, which means a 0.2 m² total membrane surface area. Biogas produced from the headspace was recycled by a diaphragm gas pump (Boxer Pumps London, Uno International, Ltd., U.K). The volume of the produced biogas was continuously measured by a drum-type gas meter (TG05, RITTER, Germany). The AnCMBR was seeded with a typical anaerobic sludge obtained from a full-scale digester at the WRRF. The feed wastewater, a mixture of raw domestic wastewater and an approximately 1.5% (v/v) FRW, was collected from the cafeteria at our institute (2,075 mg COD/L of influent). The AnCMBR was operating in the mesophilic range (30-35 °C). To maintain a safe trans-membrane pressure (TMP) value (< 0.3 bar), the back-washing was carried out every 15 min for 30 s at 100 LMH. The sludge was withdrawn only as a sample for analysis in the AnCMBR, which could be considered as infinite solid retention time (SRT).

Ceramic membrane characterization

Surface morphology of the ceramic membrane was evaluated by a scanning electron microscopy (SEM, Hitachi S-5000H, Japan) after being sputter-coated with a chromium layer. Zeta potential of the ceramic membrane was examined by measuring the electrophoretic mobility of finely crushed membrane powders in suspended solution using an optical method (Zetasizer Nano ZS, Malvern Instruments Ltd., United Kingdom).

PVA-gel beads

Porous and suspended PVA-gel beads (Kuraray Co., Ltd., Japan) with a 3-4 mm average diameter, 1.03 specific gravity, and 90% porosity were used to reduce fouling potential in the AnCMBR. After running the experiment for 100 days, an approximately 3.6 L of PVA-gel beads (15% volumetric packing ratio) were added to the AnCMBR, and kept for 100 days at the same operating conditions. The surface morphology of PVA-gel beads were evaluated before and after adding them to the reactor using field-emission scanning electron microscopy (FE-SEM) in order to investigate the effect of their physical scrubbing on the membrane surface.

Analytical method

The suspended biomass concentration was determined by measuring the MLSS and MLVSS in accordance with the Standard Method 2540 D/E. Chemical analyses for COD, total nitrogen (TN) and total phosphorus (TP) were carried out using HACH DR/3900 spectrophotometer, following the testing procedure of each parameter. The total organic carbon (TOC) was analysed using a TOC analyser (TOC-L CPH, Shimadzu Corp., Japan). Further, the dissolved organic matters (DOMs) was characterized using a liquid chromatography-organic carbon detection (LC-OCD) (DOC-Labor Dr. Huber, Model 8, Germany) equipped with a size exclusion column (Toyopearl HW-50S, Tosoh, USA). The composition of the headspace gas produced in the AnCMBR was quantified using a gas chromatograph (GC Systems- 7890A GC, Agilent Technologies, Santa Clara, CA) equipped with a thermal conductivity detector (TCD) and a packed column (HS-Q 80/100, 2.0 mm I.D., 1/8 inch O.D. × 8 ft., Restek Corp., Bellefonte, PA), with the injector operating at 150 °C, detector at 175 °C, and column at 290 °C

RESULTS AND DISCUSSION

The performance of AnCMBR in the treatment of FRW

The overall performance of the treatment using AnCMBR was summarized (Table 1). Although the
total COD concentration of the FRW mixture varied from 1,170 to 3,270 mg/L, the total COD concentration of the permeate was consistently lower than 70 mg/L, with an average value of 35.4 mg/L. The total COD removal efficiency was 98.3 ± 1.0 %, while the TOC removal efficiency was 97.9 ± 1.7 %. Organic removal efficiencies (COD and TOC), with an average value of 8.7 mg TOC/L in the permeate.

**Table 1. Treatment performances of the AnCMBR**

<table>
<thead>
<tr>
<th></th>
<th>Phase I (without PVA-gel)</th>
<th>Phase II (with PVA-gel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation period (days)</td>
<td>40 ~ 103</td>
<td>103 ~ 201</td>
</tr>
<tr>
<td>COD (%)</td>
<td>97.7 ± 1.7</td>
<td>98.7 ± 0.6</td>
</tr>
<tr>
<td>TOC (%)</td>
<td>96.9 ± 2.1</td>
<td>98.6 ± 0.5</td>
</tr>
<tr>
<td>DOC (%)</td>
<td>97.4 ± 1.3</td>
<td>98.6 ± 0.6</td>
</tr>
<tr>
<td>Methane Yield (L CH₄ / g COD_removed)</td>
<td>0.185 ± 0.08</td>
<td>0.222 ± 0.12</td>
</tr>
</tbody>
</table>

TMP values increased sharply after starting the reactor operation, probably due to the biomass acclimation, until it reached 0.4 bars, whereas it decreased to approximately 0.3 bars after adding PVA-gel beads. Ceramic membrane flux was maintained over 10 LMH until the steady-state was achieved, therefore, the TMP values were unstable. After the steady-state, the membrane were maintained at a constant flux (10 LMH) up to 80 days of operation, and the TMP values increased smoothly and sharply. The applied flux was then decreased to 9.2 LMH to control the severe membrane fouling.

After the first 100 days, PVA-gel beads, which are potentially capable of retarding membrane fouling, were added in the AnCMBR. Fouling index (FI) was estimated to investigate the effect of bio-carriers on the membrane fouling, while the membrane performance was commonly evaluated with the permeability (= flux/TMP). The addition of PVA-gel beads contributed positively by shearing off the cake formed on the membrane surface, which was shown in the significant reduction in the averaged FI value (Figure 1). Owing to these effects, biomass could attach or adsorb onto the surface of the PVA-gel beads in the FE-SEM analysis of the used PVA-gel beads.

![Average Fouling Index](image)

**Figure 1.** Differences in averaged FI values before and after the addition of PVA-gel beads.

**Dissolved organic matter removal**

Treatment efficiencies of DOMs were examined according to the fingerprints of the soluble fraction of the mixed liquor (SML) and permeate, such as total dissolved organic carbon (DOC), biopolymers,
humic substances, and low molecular weight substances (LMWs). Specific classification and percentages of DOMs in LC-OCD are presented (Table 2), with an example of the different peaks in LC-OCD chromatographs (Figure 2). Retention efficiency of DOC was 91.4%, and biopolymers and LMWs were almost removed by the ceramic membrane. Retention efficiency of biopolymers was 98.8%, while 88.7% of the LMWs were retained.

Table 2. Concentrations and percentages of the different fractions of the DOMs

<table>
<thead>
<tr>
<th></th>
<th>DOC (mg/L)</th>
<th>HOC (mg/L)</th>
<th>HPI (mg/L)</th>
<th>Biopolymers (mg/L)</th>
<th>HS (mg/L)</th>
<th>LMW Substances (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SML (%)</td>
<td>75.5</td>
<td>75.5</td>
<td>42.8</td>
<td>-</td>
<td>-</td>
<td>32.7</td>
</tr>
<tr>
<td>Permeate (%)</td>
<td>6.6</td>
<td>0.6</td>
<td>6.0</td>
<td>0.5</td>
<td>1.7</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>7.7</td>
<td>92.3</td>
<td>7.7</td>
<td>26.1</td>
<td>58.5</td>
</tr>
</tbody>
</table>

Figure 2. An example of organic carbon (OC) and UV chromatographs in the SML and the permeate

CONCLUSIONS

AnCMBR was successfully applied in the treatment of actual FRW with high COD and TOC removal efficiencies. With an HRT of 12 h, the membrane flux was stable at a higher biomass concentration, which consequently resulted in a higher methane production with a small fraction of dissolved methane in the permeate. Ceramic membranes could achieve excellent treatment performance in terms of DOM removal, which could be attributed to the negatively charge of the membranes.

REFERENCES