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Application of membranes in biogas production

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ABSTRACT

In this study a laboratory scale system containing three units, an anaerobic fermenter, a membrane filtration and a gas separation unit, was designed and examined. It was found that applying external membrane filtration the solid retention time in the anaerobic fermenter could be increased, therefore the potential of biogas production can be intensified. For this step the PS-100H ultrafiltration membrane proved to be the most suitable, with increasing the organic substance concentration with 129%, and the suspended solid concentration with 70%. The concentrated material was recycled to the fermenter, and further biogas was produced.

Moreover a gas separation membrane module, containing non-porous membrane, was tested, on purpose to produce high purity biomethane. The permeability and ideal selectivity CO_2/CH_4 of single gases was determined. It was found that the separation could be carried out at ambient temperature.

Keywords: Anaerobic fermentation; Gas separation; Biomethane; Membrane bioreactor

1. Introduction

One of the most promising, environmental sound and economically attractive solutions for treatment of organic fractions of various wastes, wastewaters is the microbial degradation under anaerobic conditions [1]. The gas produced in this way is referred as biogas, consists mainly of methane (55–70%) and carbon dioxide (30–45%), but contains other gases as well [2]. Biogas production has a couple of advantages, such as producing usable energy, low sludge yield and stabilized sludge [3,4]. However there is an important drawback: the slow-growing methanogenic microorganisms [5]. In aerobic systems microorganisms reproduce rapidly, while in anaerobic systems a longer minimum solid retention time (SRT) is required to accommodate the microbes, to compensate the slower net growth rate [6,7].

In order to enhance the biogas production there are two main possibilities. Studying the metabolisms of the microbial degradation processes, it turned out that there are some possibilities, special strains, to improve the metabolic ways [8,9], on one hand. On the other hand, membranes are efficient tools for maintaining a longer SRT [10], as they completely retain all microorganisms [11–13], so they can significantly improve the anaerobic process. Moreover certain type of gas separation membranes can be used for the concentration of methane [14,15], since biogas usually contains CO_2, as well. Purified methane (''biomethane'') may be applied in more sophisticated purposes.

If membranes are coupled directly to the biogas production, the integrated system may be referred as an anaerobic membrane bioreactor (MBR) [16,17]. The aim of this study is to investigate the application possibilities of membranes to intensify the anaerobic fermentation for enhanced biogas production, moreover the gas

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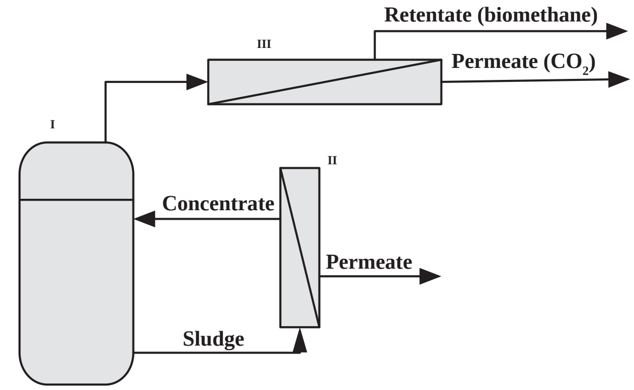

Fig. 1. Schematic representation of the anaerobic membrane bioreactor: I anaerobic fermenter, II membrane filtration unit, III gas separation unit.

is planned to be separated, to get a methane rich fraction (biomethane) by using membrane gas separation.

2. Experimental

2.1. Materials

The substrate was taken from an anaerobic sludge digester (Pálhalma, Hungary), dealing with biodegradation of liquid manure from cattle, biowastes and wastes from households. The properties of sludge were: total suspended solid (TSS) of 21.04 g/L and chemical oxygen demand (COD) of 33.62 kg/m^3. As co-substrate [1], residue of ethanol fermentation, corn stillage was applied.

2.2. Set-up

A schematic presentation of the studied system is shown in Fig. 1. The anaerobic fermenter was made of glass with a working volume of 1:l (800 cm^3 bulk liquid and 200 cm^3 gas volume). The temperature in the reactor was controlled at 37 $\pm$ 1°C. A three-dimensional membrane test equipment (3DTA, UWATECH, Germany) was used for sludge treatment in a cross-flow type of operation. The membrane test unit was supplied with a 1.5 L feed tank and cylindrical-shaped membrane module, equipped with flat-sheet membrane. This apparatus is suitable to test pressure driven membrane separation processes. The properties of the studied membranes are given in Table 1.

For gas separation GS-MS 100 high pressure, membrane test unit, which can be heated up, was used (Fig. 2). For separation tests UBE (Japan) module, containing non-porous, polyamide, hollow fiber membrane was used. During the experiments pressure (1–15 bar) and temperature (23–50°C) were varied.

Table 1
Properties of the studied pressure-driven membrane separation membranes

Type	Material	Porous size/cut-off
MF	Cellulose	12–15 μm
		8–12 μm
		5–8 μm
		3–5 μm
UF	Cellulose acetate (CA)	45 kDa
	Polysulfone (PS-100H)	100 kDa
	Poly-ethersulfone (PES-030H)	30 kDa
	Permanently hydrophilic poly-ethersulfone (P020)	20 kDa

2.3. Analytical methods

The biogas production rate was monitored with a special gas meter and its composition was determined by a gas chromatograph (GowMac 550) equipped with GowMac X13 column, using helium as vector gas. Oven, injector and detector (TCD) temperature were set at 120°C.

The membrane filtration unit's performance was followed by measuring pH, alkalinity, TSS and COD, according to standard method [18,19].

3. Results and discussion

3.1. Membrane filtration

The anaerobic membrane bioreactor contains three units, the anaerobic fermenter, the membrane filtration module and the gas separation module. The units of the system were studied separately. In the first set of experiments the sludge treatment was examined, which was carried out with the

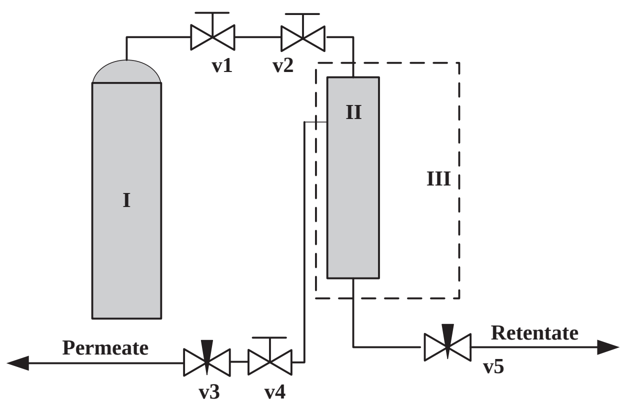

Fig. 2. Flowsheet of GC-MS 100 high pressure gas-separation unit: I gas-cylinder, II membrane module, III thermostat.

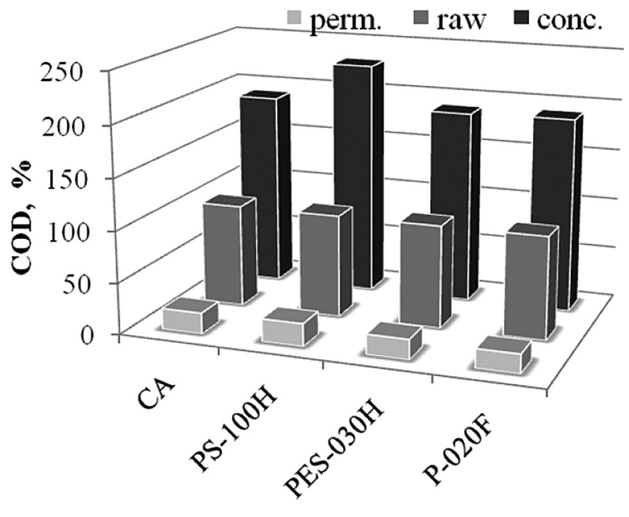

Fig. 3. COD results for the examined UF membranes.

membrane separation unit, in order to increase the sludge age in the anaerobic fermenter. From the tested MF, UF, NF, RO membranes it was found that UF membranes showed the best separation efficiency. In the Figs. 3 and 4 the COD and TSS results for the UF membranes are shown. Regarding COD, the highest concentration in the concentrate was achieved by the PS-100H membrane, that means 129% increase compared to raw substance. Concerning the TSS in the concentrate there was no significant difference between the studied membranes. The achieved increasing in concentrations was between 53–79% compared to raw substance.

The concentrate of the UF unit was recycled to the anaerobic fermenter, and it was found that further biogas was formed (data not shown). The permeate after treating by RO membrane can be disposed.

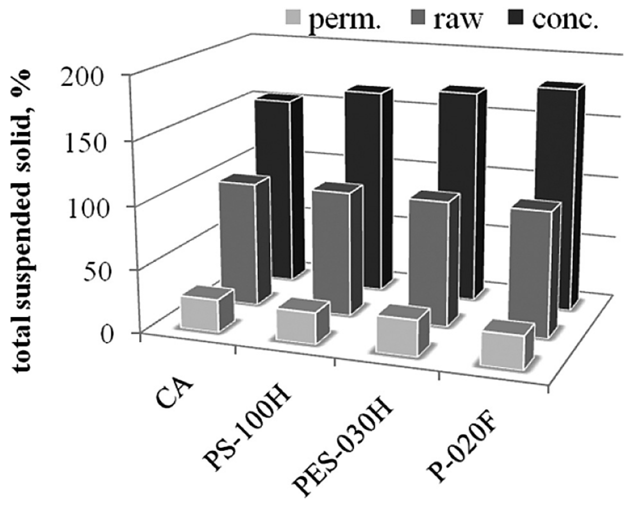

Fig. 4. TSS results for the examined UF membranes.

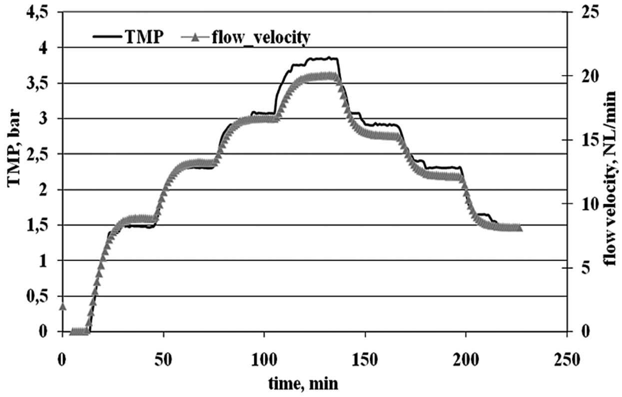

Fig. 5. Permeation of CH^4 at 30°C.

3.2. Gas separation

In the second set of experiments the gas separation module was studied. Considering that biogas mainly contains methane and carbon-dioxide, in the preliminary experiments single gases were tested, in order to determine the permeation properties of UBE module for CH_4 and CO_2. Fig. 5 shows the varied pressure (TMP) and the variation of flow rate of CH_4, as an example, as a function of time at 30°C. It can be observed that the change in flow rate has the same trend as the change in pressure.

Based on the data of measurements with single gases permeation were calculated at 5 bar. The temperature dependence of the permeation of CH_4 and CO_2 is shown in Table 2. The permeation of CH_4 and CO_2 increases with increasing temperature, but it can be noticed that the permeation of CO_2 is far higher than the permeation of CH_4. That means, after separation we will have methane rich concentrate (often referred as ''biomethane'') and CO_2 rich permeate.

Using the achieved data the ideal selectivity (CO_2/CH_4) was calculated (Fig. 5), and was found, as it is shown in Table 2, that the selectivity decreases with the temperature, so the separation of these two gases could be carried out at ambient temperature.

4. Conclusion

The units of the designed system were examined, and found that the PS-100H ultrafiltration membrane proved to be suitable for sludge treatment, namely for increasing SRT in the anaerobic fermenter. So far in gas separation the UBE module seems to be suitable for separation methane and carbon-dioxide, but further experiments are needed with model gases and with biogas samples, as well. The final aim is to have a

Table 2
Temperature dependence of the CH_4 and CO_2 permeation at 5 bar

Temperature (°C)	Permeation of CO_2 (NL/min)	Standard deviation (±)	Permeation of CH_4 (NL/min)	Standard deviation (±)	Selectivity CO_2/CH_4	Standard deviation (±)
23	111.99	0.95	–	–	–	–
30	119.01	0.54	25.08	0.45	4.75	0.24
40	118.08	0.65	28.34	0.23	4.17	0.15
50	125.04	0.87	32.54	0.32	3.84	0.28

continuously operating, integrated anaerobic MBR and gas-separation system, with the capability of producing high purity biomethane.

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