

Efficient methane fermentation from organic solid wastes by using bioelectrochemical system

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Abstract

Organic solid wastes were treated in various types of methanogenic bioelectrochemical reactors, equipped with an external electrochemical system to control electron flow and improve microbial activity. At a high organic loading rate, cathodic bioelectrochemical reactors demonstrated greater decomposition of artificial garbage slurry and higher methane production than both anodic bioelectrochemical reactors and the control reactor without electrochemical control. Higher prokaryotes and methanogens thrived on cathodic electrodes than on anodic or control electrodes since the cathodic reaction could positively control the electron flow and alter the microbial metabolism, which enabled the stabilization of methane fermentation. Furthermore, a carbon fiber fabric was attached to the working electrode in the methanogenic bioelectrochemical reactor to retain more microorganisms, and consequently enhance performance. This improved cathodic bioelectrochemical reactor displayed higher decomposition of a mixture of artificial garbage slurry and rice straw, and concomitantly increased production of methane than the control reactor. The improvement effectively enhanced the reactor performance and led to a higher ratio of methanogens to prokaryotes in the suspended fractions of the cathodic reactor compared to the control. Finally, the working of the improved reactor was investigated at a scaled-up volume of 4.0 L by using actual organic solid waste to determine its universal utility that combined electrochemical control and supporting material. The developed cathodic bioelectrochemical reactor containing carbon fiber fabric was found to achieve better decomposition of thickened sewage sludge and higher production of methane at a short hydraulic retention time than the control reactor containing carbon fiber fabric without electrochemical control. Moreover, at longer hydraulic retention times, the methanogenic reactor of stirred tank type lacking the carbon fiber fabric deteriorated faster. Thus, the universal effectiveness of the technology that combined electrochemical control and use of a modern support material has been demonstrated.

Keywords

Bioelectrochemical system; methane fermentation; organic solid waste; carbon fiber fabric; biogas

INTRODUCTION

Large amounts of organic solid wastes (municipal solid waste, garbage, agricultural remains, etc.) are being produced worldwide. Anaerobic digestion using methane fermentation is attracting much attention for the treatment and utilization of these wastes because of its low environmental impact, low production of residual sludge, and ease of recovery of biogas for use as an energy source (Lee et al., 2009). Methane fermentation consists of hydrolytic-acidogenic, acetogenic, and methanogenic stages (Ahring 2003; Thauer et al. 2008) in which electrons get transferred from organic solid wastes to various acceptors in the methanogenic stage (Stams et al., 2003). The consumption rate of the volatile fatty acids (VFAs) has been shown to increase by the addition of Fe(III) salts, which act as electron acceptors in the methane fermentation process (Coates et al., 2005). Therefore, it may be plausible to increase the methane fermentation ability by controlling the electron flow.

Microbial metabolism is known to be altered by monitoring the electron flow in a bioelectrochemical system (Thrash and Coates, 2008). The use of an external electrochemical system is effective in controlling electron flow and consequently improving microbial activity in methane fermentation. In the present study, a methanogenic bioelectrochemical reactor has been applied toward the treatment of organic solid waste, and its performance was further improved by adding a novel support material. Moreover, the efficiency of the reactor with respect to scaling up was also investigated.

METHANOGENIC BIOELECTROCHEMICAL REACTOR

Artificial garbage slurry was used as a model for the organic solid waste (Sasaki et al., 2010). An H-type two-glass chamber (working volume, 250 ml) was used as the bioelectrochemical system for all the experiments (Sasaki et al., 2010). A three-electrode system, consisting of a working electrode, a reference electrode, and a counter electrode was applied, and the oxidation-reduction potentials of the working electrodes were electrochemically controlled at pre-determined values by using a potentiostat. All the chambers were operated in a semicontinuous mode at 55 °C. For this purpose, a pre-determined volume of suspension in the chamber was discharged and a constant amount of artificial garbage slurry was added once daily. The cathodic bioelectrochemical reactors having an oxidation-reduction potential of -0.6 or -0.8 V (vs. Ag/AgCl) showed greater removal of the dichromate chemical oxygen demand (COD_{Cr}) and higher methanogenesis than the anodic bioelectrochemical reactors having an oxidation-reduction potential of 0.0 or -0.3 V (vs. Ag/AgCl), or the control reactors lacking electrochemical control at an organic loading rate of 26.9 g COD_{Cr}·L⁻¹·day⁻¹. The cathodic bioelectrochemical reactor also displayed stabilization of methane fermentation at a high organic loading rate and quantitative analyses showed higher concentration of prokaryotes and methanogens on cathodic electrodes than on anodic or control electrodes. Interestingly, an analysis of the microbial community structure showed that the same hydrogenotrophic and acetoclastic methanogens inhabited all the reactors. Thus, external electrochemical control with cathodic reactions could enhance methane fermentation from organic solid waste.

METHANOGENIC BIOELECTROCHEMICAL REACTOR CONTAINING CARBON FIBER FABRIC

A mixture of artificial garbage slurry and rice straw was used as a model representing organic solid waste (Sasaki et al., 2011). An H-type two-glass chamber (working volume, 250 ml) was used as a component of the three-electrode bioelectrochemical system for all experiments (Sasaki et al., 2011). Carbon fiber fabric was attached to the working electrode at the side of the reference electrode as a supporting material. All the chambers were operated in semicontinuous mode at 55 °C. Accordingly, a fixed volume of suspension in the chamber was discharged and equal amount of mixture was added once daily. The improved methanogenic bioelectrochemical reactor contained both the support material for retaining the microorganisms as well as the bioelectrochemical system for altering the microbial metabolism by controlling the electron flow. The cathodic bioelectrochemical reactor having an oxidation-reduction potential of -0.8 or -1.0 V (vs. Ag/AgCl) attained a greater removal of COD_{Cr} and increased production of methane than the control reactor containing carbon fiber fabric deficient in an electrochemical control at an organic loading rate of 27.8 g COD_{Cr}·L⁻¹·day⁻¹. Quantitative analysis showed that the ratio of methanogens to prokaryotes in the suspended fractions of cathodic bioelectrochemical reactors was higher than the control reactors, indicating that the improved methanogenic bioelectrochemical reactor, which combined electrochemical control and possessed support material, was effective in enhancing the performance of the reactors.

SCALE-UP OF METHANOGENIC BIOELECTROCHEMICAL REACTOR

The universal utility of the improved methanogenic bioelectrochemical reactor containing the carbon fiber fabric was investigated by scaling up to a volume of 4.0 L (Sasaki et al., in press). The combined action of the electrochemical control and support material were tested for applicability of the technology to other organic solid wastes (Sasaki et al., in press). For this purpose, thickened sewage sludge was used as organic solid waste and introduced into the scaled-up reactor, a working chamber, which was electrochemically controlled at -0.8 V (vs. Ag/AgCl). It faced a counter chamber set in the middle of the reactor and was separated from the counter chamber by a proton-exchange membrane. The working electrodes to which carbon fiber fabrics were attached were placed in the working chamber, and a counter electrode was installed in the counter chamber. A reference electrode was located between the working and counter electrodes in the working chamber. Three types of methanogenic reactors, namely, the improved cathodic methanogenic bioelectrochemical reactor containing carbon fiber fabric, methanogenic reactor containing carbon fiber fabric without electrochemical control, and the methanogenic reactor of stirred tank type without carbon fiber fabric, were operated in a semicontinuous mode at 55 °C and compared with respect to reactor performance and microbial community. A higher gas production was achieved at a hydraulic retention time of 4 days in the improved cathodic methanogenic bioelectrochemical reactor containing the carbon fiber fabric as compared to the reactor containing carbon fiber fabric lacking in electrochemical control. Thus, the cathodic bioelectrochemical reactor containing carbon fiber fabric accomplished higher decomposition of actual organic solid wastes and concomitantly a higher methane production, leading to stabilized methane fermentation at short hydraulic retention time. On the other hand, even at a hydraulic retention time of 10 days, the methanogenic reactor of stirred tank type without the carbon fiber fabric gave unsatisfactory outcome, which demonstrated that the presence of the carbon fiber fabric enhanced the reactor performance even at short hydraulic retention times. An analysis of the microbial community structure showed the presence of three kinds of hydrogenotrophic methanogens and one kind of acetoclastic methanogen in the suspended fraction of the improved bioelectrochemical reactor containing carbon fiber fabric at the minimum hydraulic retention time, as against only three or two kinds of hydrogenotrophic methanogens in the suspended fraction of the reactor containing carbon fiber fabric without electrochemical control or the reactor of stirred tank type without carbon fiber fabric, respectively. The universal efficacy of technology that combined electrochemical control and the use of support materials was demonstrated.

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