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High-Rate Thermophilic Methane Fermentation on Short-Chain Fatty Acids

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I. Introduction

A research project on high-rate thermophilic methane fermentation system that is capable of simultaneous production of hydrogen and methane from solid wastes is being undertaken. In order to establish the novel fermentation system, carefully designed and optimized unit processes such as solubilization of organic solids, hydrogen fermentation and high-rate methane fermentation need to be developed. Since the first two processes, solubilization and hydrogen fermentation, can occur sequentially in the same reactor, but the methane fermentation process must be optimized as an independent process, a two-stage system has been selected as the basic configuration in the study.

II. Materials and Methods

The system flow diagram is given in Fig. 1. Thermophilic Down-flow Anaerobic Packed-bed Reactor (TDAPR) was an acrylic cylinder with the dimensions of 80mm in diameter and 1,000mm in height. It was packed with supporting medium of unwoven carbon-fiber textile in the direction of flow and had an effective volume of approximately 3 L. Contents in the reactor were moderately mixed by recirculation of fermentation liquid from the bottom to the top using a mono-flex pump at a flow rate of approximately 0.5 L/min (10 cm/min). Double-tube heat exchanger was installed in the recirculation line to maintain the operational temperature at 55°C. Defined growth media containing acetic acid and butyric acid as the major carbon sources was fed intermittently. The same reactor without the supporting medium was used in Continuous Stirred Tank Reactor (CSTR) experiment. The basic dimensions and configuration are the same as the TDAPR.

III. Results

In the CSTR experiment, the removal efficiency of acetate started to deteriorate as the Organic Loading Rate (OLR) gradually increased from 0.73 kg/m^3/day of total Chemical Oxygen Demand (T-CODcr) at 15 days hydraulic retention time (HRT) and exceeded approximately 2.0 kg/m^3/day. With the excess accumulation of acetate, the process eventually failed at the OLR of 3.4 kg/m^3/day (3 days HRT). The maximum allowable OLR in the CSTR configuration was approximately 2.0 kg/m^3/day.

In the TDAPR experiment, the OLR was gradually increased to the final OLR of 169 kg/m^3/day (1.4 hours HRT) over the period of 200 days (Fig. 2). The maximum allowable OLR achieved was 120 kg/m^3/day (1.9 hours HRT) at 190th day. The reactor became unstable and eventually failed at the OLR of 169 kg/m^3/day or greater as indicated by sudden decrease both in pH and biogas production. The alkalinity, which had been stable at approximately 2,000 mg-$CaCO_3$/L between 70th (5 kg/m^3/day OLR, 150 hours HRT) and 190th days (120 kg/m^3/day OLR, 1.9 hours HRT), also quickly diminished

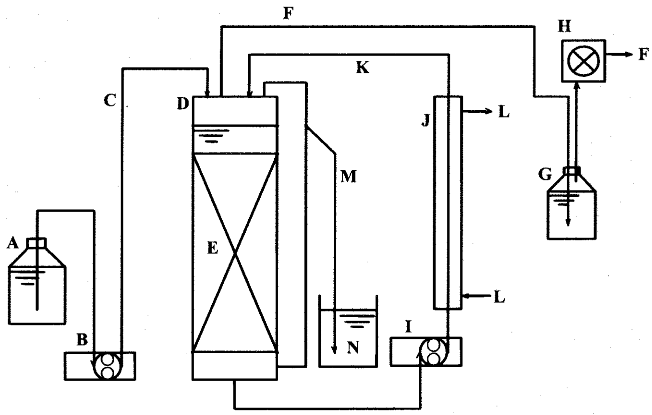

Fig. 1 System Flow Diagram
: (A) medium reservoir, (B) feed pump, (C) feed line, (D) TDAPR, (E) supporting media, (F) biogas line, (G) seal pot, (H) wet gas meter, (I) recirculation pump, (J) heat exchanger, (K) recirculation line, (L) hot water ,(M) overflow, (N) treated water

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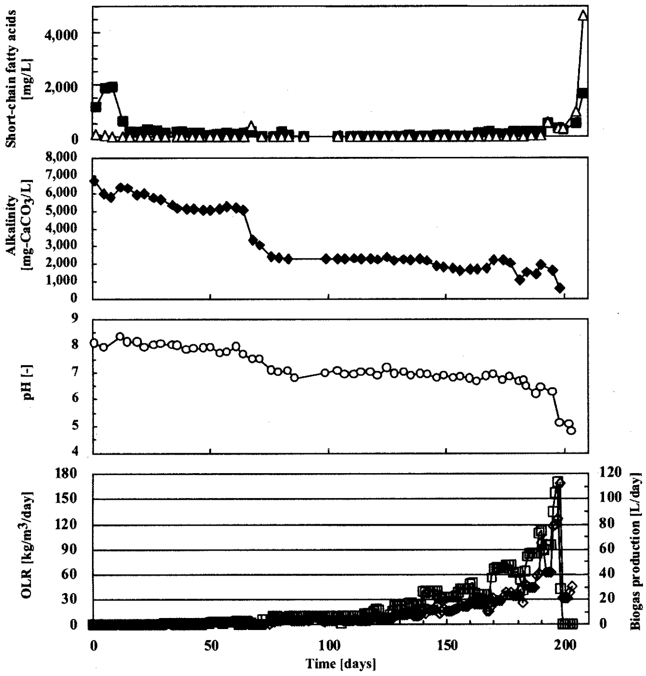

Fig. 2　Time Course of OLR, Biogas Production, pH, Alkalinity and Short-chain Fatty Acids Concentrations (-□-), OLR; (-◇-), biogas production; (-○-), pH; (-◆-), Alkalinity; (-■-), acetate;(-▲-), n-butyrate

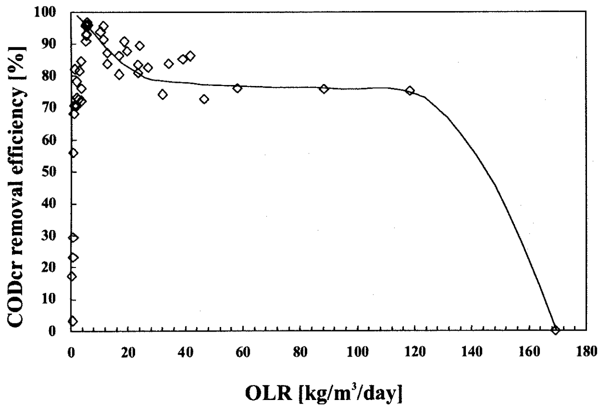

Fig. 3　Relationship Between OLR and CODcr Removal Efficiency

at the OLR of 169 kg/m^3/day.

As shown in Fig. 2, acetate concentration, which temporarily increased to 2,000 mg/L during the initial period but remained at a stable low value afterwards up to the OLR of 120 kg/m^3/day, rapidly accumulated when the OLR was raised to 169 kg/m^3/day. Similarly, butyrate concentration was low and stable up to the OLR of 120 kg/m^3/day, but rapidly rose when the OLR was increased to 169 kg/m^3/day.

T-CODcr removal efficiency decreased from 95 % at the OLR of 6 kg/m^3/day (50 hours HRT) to 75 % at 120 kg/m^3/day (Fig.3). The acetate and butyrate removal efficiencies at the OLR of 100 kg/m^3/day were 82.0 % and 91.4 %, respectively. At the maximum allowable OLR of 120 kg/m^3/day, the acetate and butyrate removal efficiencies were 65.5 % and 75.7 %, respectively. When the OLR was raised to 169 kg/m^3/day, the effluent T-CODcr was the same as in the feed and accumulation of acetate was observed.

IV. Discussion

It is widely recognized that there are two classes of acetoclastic methanogens. Genus *Methanosaeta* is known to have a high affinity to acetate, but a relatively low maximum specific utilization rate as indicated by Ks value of 20 mg/L and kmax value of 2 to 4 g-CODcr/g-VSS-day in the Monod expression for growth. On the other hand, genus *Methanosarcina* is known to have a much lower substrate affinity (Ks = 400 mg/L), but a higher maximum specific utilization rate, kmax of 6 to 10 g-CODcr/g-VSS-day than genus *Methanosaeta*.

Assuming Ks and kmax for genera *Methanosaeta* and *Methanosarcina* are 20 and 3, and 400 and 8, respectively, T-CODcr concentration of approximately 20.8 mg/L (19.5 mg/L as acetic acid) or greater would be more favorable for genus *Methanosarcina* than to genus *Methanosaeta*. Since the medium contained 1,400 mg/L of acetate in the CSTR experiment, it was likely that the predominant species was genus *Methanosarcina*. However, it is reported that most of the acetoclastic methanogens including genus *Methanosarcina* have the doubling time of approximately 2 days even under the optimal growth conditions. Thus it is speculated that the methanogens were washed out from the CSTR at the HRT of 3 days or shorter and accumulation of acetate had occurred.

In the TDAPR experiments, methanogens had sustained their activity at much shorter HRT than in the CSTR, implying that methanogens attached on supporting media in the TDAPR had much longer retention time in the reactor than HRT. Use of unwoven carbon-fiber textile appears to be advantageous for microbes to attach because bacteria with slow growth rate such as acetoclastic methanogens have hydrophobic membrane and tend to easily attach onto the supporting media. Porous surface of carbon fiber textile is also favorable for the attachment of microbes.

V. Acknowledgements

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