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Thermophilic Anaerobic Co-digestion of Coffee Grounds and Food Biomass

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ABSTRACT

Methane fermentation has been attracting attention as an environmental friendly process for recovering energy from food waste or waste water. Because biogas is generated through methane fermentation, containing a substantial methane content of 40–70%, electricity, hot water, and steam can be produced with Combined Heat and Power system or boiler.

Coffee is one of the most popular beverages worldwide. Approximately ten thousand tons of waste coffee grounds are annually produced in Japan. Since most of solid in coffee ground is organic substance and it is difficult to incinerate coffee ground alone due to its water content of ~60%, treating coffee ground by methane fermentation is preferred.

The objectives of the present study were to demonstrate treating coffee grounds under the co-digestion of foods produced from coffee manufacturing process and waste activated sludge from wastewater treatment process. A long term experiment using an anaerobic membrane bioreactor (AnMBR) is carried out after a batch experiment to confirm the biogas production potential of the feedstock.

In the continuous experiment, trend of the typical operation parameters, biogas production, pH, VFA and alkalinity indicated that co-digestion was stable. COD decomposition rate decreased from 67% to 48% corresponding to increasing COD loading rate from 4 to 14 kg-COD/m^3 d.

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2.1. Introduction

In Japan, two million tons of food garbage are generated by business activities annually, of which only 20% is reclyced as energy or fertilizer. The Food Recycling Law [1] was enacted in 2001 to promote recycling of food waste through specified multiple applications and encourage employers in their efforts to develop food recycling systems.

Recycling food waste is a challenge due to its water content of ~80%. It is difficult to incinerate food waste alone and when burned with other wastes because the incineration temperature is lowered, resulting in production of dioxins. On the other hand, methane fermentation has been attracting attention as an environmental friendly process for recovering energy from wet biomass or organic wastes. Because biogas is generated through methane fermentation, containing a substantial methane content of 40–70%, electricity, hot water, and steam can be produced with a co-generation system or a boiler. The conventional biogas system flow is shown in Fig. 1.

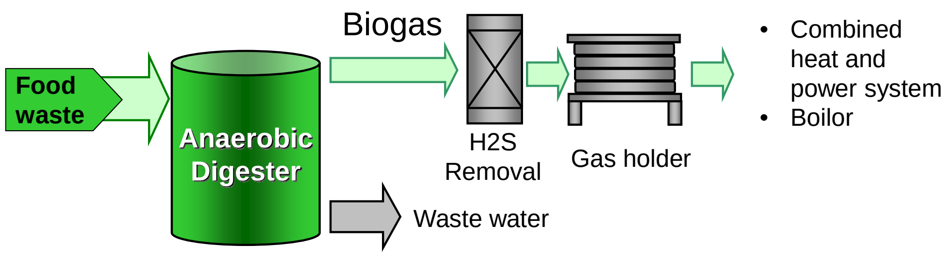

Fig.1 Configuration of conventional biogas system

Coffee was the most popular beverage worldwide [2]. In Japan, approximately ten thousand tons of coffee grounds are annually produced and used as a fuel for boilers or soil conditioner [3] because coffee grounds contain sufficient organic matter. Although attempt to treating coffee grounds by anaerobic digestion is increased, coffee grounds fermentation is difficult due to VFA accumulation [4], or due to high lipid content (30%) in coffee grounds [5].

In previous study, Li et al., applied an anaerobic membrane bioreactor (AnMBR) to coffee grounds [6]. They found that the reactor treating sole-coffee grounds failed after 82 days caused by the lack of nitrogen and micronutrients and the reactor was inhibited by the VFA accumulation to 7.2 g/L and pH drooping to 6.85. However, under co-digestion, 15% sludge as TS based was sufficient to provide trace metals. While, addition of NH_4HCO_3 (0.12 g-N/g-TS) was still required to keep pH. Conclusively, they concluded stable continuous operation of coffee grounds was achieved under the co-digestion, obtaining the COD removal of 67.4% under OLR of 11.8 kg-COD/m^3 d.

Co-digestion process (typically with sludge) were frequently proposed to increase system stability by compensating pH buffer capacity and alleviating toxic from sole-substrate as discussed in [7]. Since excessive coffee, dairy products and large amounts of waste activated sludge from the wastewater treatment process were produced during a coffee manufacturing process, there is possibility that stable fermentation of coffee grounds is achieved by providing nitrogen and trace metals from those organic materials under co-digestion.

The objectives of the present study is to demonstrate treating coffee grounds under the co-digestion of foods produced from coffee manufacturing process and waste activated sludge from wastewater treatment process. A long term experiment using an AnMBR is carried out after a batch experiment to confirm the biogas production potential of the feedstock.

2.2. Method

2.2.1. Characteristics of materials

Figure 2 shows the images of coffee grounds, waste activated sludge, milk product, coffee and mixture of the feedstock. Their characteristics are provided in Table 1. The particles size of the raw coffee grounds was around 3–4 mm and the total solid (TS) content was about 35%. The waste activated sludge was taken from the coffee wastewater treatment process. These wastes were stored at 4 degree C. The mixture was prepared by mixing them using a high speed blender (LBC-15) at 18,500 rpm for 20 min.

Fig.2 Image of the materials

(Coffee grounds, Activated sludge, Milk product, Coffee, Mixture of these feedstock)

Table.1 Characteristics of the materials

	TS(g/L)	VS(g/L)	COD(g/L)
Coffee grounds	34.7 %	34.4 %	1.60 (COD/TS)
Activated sludge	12.9 %	10.4 %	0.98 (COD/TS)
Milk products	31.3	29.1	77.8
Coffee	63.0	53.8	93.0
Mixture	74.4	70.7	119.3

2.2.2. Batch Experiment

As a preliminary experiment, the batch experiments with each material and mixture of all feedstock were conducted, respectively. The approximately 1 g-COD feedstock and amount of 70 g (1.61 g-VSS) seed sludge was contained to the closed glass vials with a working volume of 100 ml.

Subsequently, the vials were flushed by nitrogen gas, and sealed with butyl rubber stoppers and aluminum caps. The experiment was performed in duplicate at each feedstock. The vials were incubated in a shaking incubator at 55 degrees C. The gas production was measured using a glass syringe with a needle. The biogas production from the blank vials was subtracted from that from the fed vials to make correction for the biogas production from seed sludge. The biogas production was measured for 30 days.

2.2.3. Continuous experiment

Figure 3 illustrated the schematic diagram of AnMBR used in the present study. The submerged AnMBR had a total volume of 15 L (working volume of 7 L). A flat sheet microfiltration membrane module was immersed in the lower part of the reactor. The membrane was made of chlorinated polyethylene with a normal pore size of 0.2 μm, and a total area of 0.116 m^2 (Kubota Membrane Cartridge, Japan). A coarse tube diffuser was located below the membrane. Biogas in the headspace was recirculated by a pump at a flow rate of 5 L/min to provide membrane hydrodynamic shearing and reactor mixing. Permeate was suctioned by a peristaltic pump. The excess filtrate was recirculated back into the reactor because the membrane was oversized. Trans-membrane pressure (TMP) was measured by a pressure sensor located on the permeate line. The pump was operated in a 4 min on and 1 min off mode. Hot water was circulated through reactor water jacket to keep the thermophilic temperature (55–57 degrees C). Daily biogas volume was recorded by a wet gas meter. Matured seed sludge with TS content of 3.1% was taken from a thermophilic digester treating food waste.

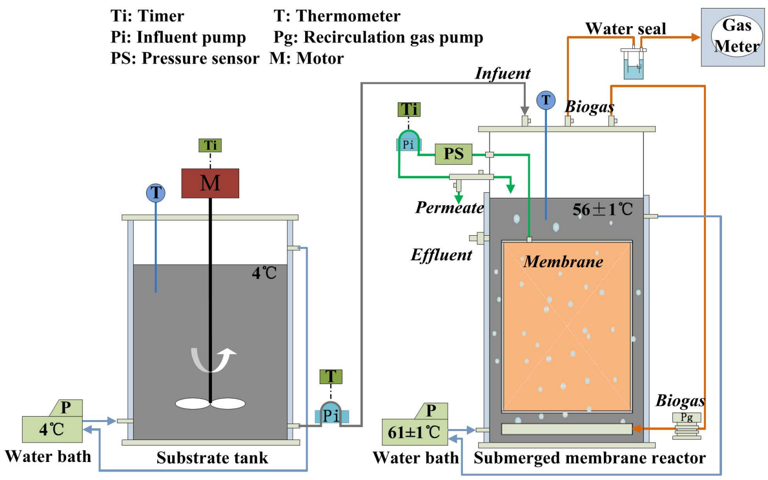

Fig. 3 Schematic diagram of the experimental apparatus

2.2.4. Analytical Method

The pH, alkalinity, COD, ammonia and TS were measured according to the Japan Standard Testing Method for Wastewater (JSWA, 1997). The amount of VFA was determined by a Agilent-6890 gas chromatograph. The biogas composition, CH_4 and CO_2 were measured by a Shimadzu GC-8A gas chromatograph. The elemental compositions of C, H, O, N and S were analyzed by an elemental analyzer (DKSH Elementar). Metals were analyzed by an inductively coupled plasma mass spectrometer (ICP-MS, Agilent Technologies HP4500) with a detection limit of parts per trillion. Carbohydrate was measured using H_2SO_4/phenol oxidation and a calorimeter method. Protein was measured using the Folin/Ciocalteu method. Lipid was determined by marginal/chloroform extraction and the weighting method. All analyses were conducted in two replicates. For COD, carbohydrate, protein and lipid analysis, samples were pre-grounded by high speed blender (LM-Plus) at 20,000 rpm for 5 min.

2.3. Results and discussion

2.3.1. Batch experiment

Figure 4 shows biogas productions during the batch experiment of (a) coffee grounds, (b) waste activated sludge, (c) milk products, (d) coffee and (e) mixture. Table 2 shows the summary of the batch experiment.

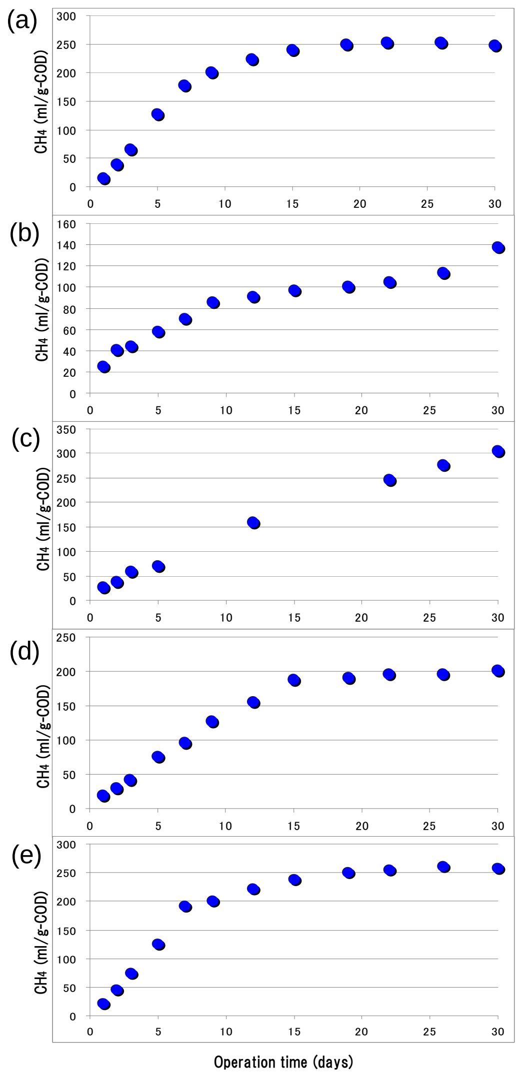

Fig.4 The biogas production in the batch experiment. (a) coffee ground, (b) activated sludge, (c) Milk products, (d) Milk and (e) Mixture.

Table 2 Summary of the batch experiment

	COD decomposition rate (%)	Methane production potential (ml-CH_4/g-COD)	CH_4 concentration (%)
Coffee grounds	72.2	252	57.9
Activated sludge	32.3	141	66.3
Milk products	83.3	321	62.3
Coffee	57.3	206	53.5
Mixture	71.3	260	60.1

As shown in table 2, COD decomposition rates of each feedstock are 83.3% of milk products, 72.2% of coffee grounds, 57.3% of coffee, 32.3% of activated sludge and 71.3% of mixture. Because COD decomposition rates are sufficient high, it is therefore assumed that to treat the present materials under co-digestion is possible.

2.3.2. Co-digestion of coffee grounds and food materials

Figure 5 shows the time course of the biogas yield, pH, alkalinity and VFA concentration during the continuous digestion feeding the mixture as indicated in table 2. Firstly, the operation was started up under HRT 30 days. However, the biogas yield was not increased and VFA was highly remained until 40 days. Secondly, 50% of matured seed sludge was replaced to fresh one to cause an increase in the activity in the reactor. After replacement of seed sludge, the typical operation parameters, the biogas production rate, pH and the VFA concentration were stable in the digester, indicating that the digester had started-up successfully.

The feeding of the AnMBR was gradually decreasing HRT from 30 to 8.5 days which is corresponding to increasing COD loading rate from 4 to 14 kg-COD/m^3 d. The biogas production rate was stable and the methane content in the biogas was maintained above 60%. The pH range was above 7.0, which is suitable for methanogenesis. Although VFA concentration is almost low after the replacement of seed sludge, it is gradually accumulated as decrease of HRT. During the experiment, total alkalinity was decreasing to 3200 mg-$CaCO_3$/L and biocarbonic alkalinity was decreased from 2500 mg-$CaCO_3$/L (HRT 15 days) to 1600 mg-$CaCO_3$/L (HRT 8.5 days) due to the VFA accumulation. Considering these operation parameters comprehensively, this results indicate that stable continuous digestion was achieved.

Continuous digestion performance is summarized in Table 3. As decreasing HRT, biogas production and VFA was increased gradually and pH, alkalinity, ammonium-nitrogen was decreased.

COD decomposition rate decreased from 64% to 46% corresponding to increasing COD loading rate from 4 to 14 kg-COD/m^3 d.

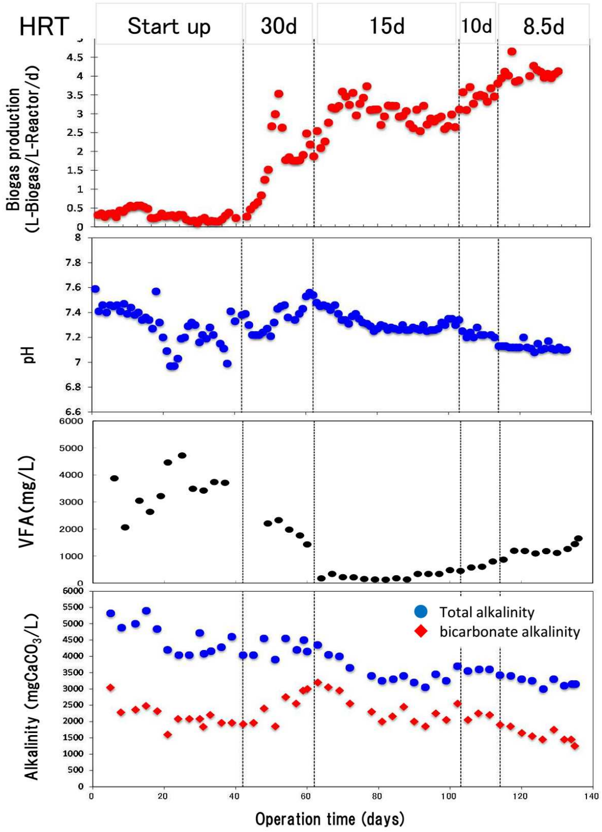

Fig. 5 Time course of biogas production, pH, VFA and alkalinity.

Table 3 Summary of the continuous operation.

COD Loading rate（kg-COD/m^3/day）	4.0	8.0	12.0	14.0
HRT (days)	30	15	10	8.5
Biogas (L/L-Reactor/day)	1.85	2.89	3.48	4.08
CH_4 Concentration (vol%)	64.0	61.8	61.9	61.3
pH	7.5	7.3	7.2	7.1
T-VFA (mg/L)	-	300	900	1600
COD decomposition rate (%)	67.2	58.7	50.1	48.3

2.4. Conclusions

We have demonstrated the co-digestion of coffee grounds and foods produced from coffee manufacturing process using the AnMBR.

- 71.3% COD decomposition rate of blended mixture was obtained by the batch experiment, assuming that co-digestion of the present materials is possible.
- In the continuous experiment, trend of the typical operation parameters, biogas production, pH, VFA and alkalinity indicate that co-digestion was stable. COD decomposition rate decreased from 67% to 48% corresponding to increasing COD loading rate from 4 to 14 kg-COD/m^3 d.

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4. List Tables

5. List of Figures