Small Scale of Anaerobic Digestion for Decentralized Energy Production and Bioresource Recycling

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Abstract

In Japan, several different electric power companies produce energy and transmit power. A major disadvantage of this system is that when a fault arises at one electric power company an entire region may be without power, as occurred during the Great East Japan Earthquake. Small-scale methane fermentation reactors are being investigated as a source of energy. The advantages of small-scale methane fermentation include a small initial investment, few required materials, and reduced costs due to materials recovery. The development of small-scale methane fermentation in Japan may allow decentralized energy production for localized areas. The use of heat from hot springs or factory exhaust instead of kerosene boilers to warm methane fermenters would reduce the costs of energy production. Energy balance (production of biogas vs. energy consumed for running reactors) became plus although it was on a small scale of reactors. Replacing a single kerosene boiler with a hot spring could reduce CO_2 emissions by about 90 tCO_2/year. Now we research for applying a small methane fermentation using exhaust heat from a fishery factory, at Shiogama, the coast area of Tohoku, Japan. Digested liquid from the reactors could be used as liquid fertilizers for cultivating vegetable or microalgae as feeds for clams. Thus, this system may provide decentralized energy production with the added benefit of nutrient-rich digested liquid used as fertilizer, and it would also help towns to better survive disasters. Especially considering the limited resources available in Japan, the introduction and promotion of small methane fermentation reactors for energy production are vital.

Decentralized energy production

The Great East Japan Earthquake and Tsunami on March 11 2011, together with the subsequent accident at the Fukushima Nuclear Power Plant, revealed vulnerabilities in electrical power systems. In Japan, there is one power company in each region. The electricity supply was once centralized, and with this, damage to one power company may result in a loss of electricity supply to the entire region. In North America in 2003, a blackout affected regions from New York City to the Midwest state of Michigan, leaving as many as 50 million people in the dark. Decentralized energy production has significant advantages in terms of the resilience of the system, and can prevent such failures. In addition, energy production from biomass, including human waste and food waste, can be applied in both cities and local areas, and multiple small-scale methane fermentation systems can facilitate decentralized energy production.

Conventional methane fermentation

Methane fermentation systems currently exist in Japan; however, these systems are typically large, with a reactor capacity of around 500 to 1000 m^3. The benefits of large-scale reactors are that they can treat a large quantity of material at one time, and so have relatively small unit costs. However, the initial investment is large (500-1000M JPY), as are the maintenance costs (50-100M JPY per year). Some methane fermentation facilities in Japan have been suspended due to such large costs.

The surface area per unit volume of a small methane fermentation system is wider than that of a large system. For example, if the reactor is spherical, the surface area to unit volume ratio is $(4\pi r^2) \div 4/3\pi r^3 = 3 / r$. For this reason, in small-scale systems the heat dissipation per unit volume is large compared with large-scale systems. Therefore, small-scale systems require more energy for heating per unit volume. In addition, since the accepted quantity of material is small, there is a disadvantage in that comparatively little energy is produced. With a 50-m^3 methane fermentation facility, the energy consumed for heating (generally required only in winter) is 20 GJ per month. In addition, energy is required for stirring (Baba *et al.*, 2013). Furthermore, the biological oxygen demand of the digested material resulting from methane fermentation may reach 500-2500 mg/L. To reduce the cost of wastewater treatment, the digested material should be used as liquid fertilizer.

Small-scale methane fermentation with heating from a hot spring

We may overcome these problems of small-scale methane fermentation using the following methods:

1. By using natural energy for heating the reactor, the overall energy balance of the small methane fermentation system will be positive.
2. Little material is required for small-scale methane fermentation systems, which means that it can be sourced locally. This in turn reduces the cost of collecting the material.
3. Digested material from the fermenter can be used as liquid fertilizer to cultivate vegetables without requiring water treatment.

In this study, we used a hot spring to heat the fermentation vessel. Materials were collected and placed inside the fermenter manually. Digested liquid was used as liquid fertilizer for cultivation of vegetables. The study site was in the Naruko hot spring area, located in the northwest of Miyagi prefecture in Japan. The Naruko hot springs are artesian aquifers, and have a temperature of >90ºC. Hot water from the spring was pumped through a tube around the methane fermentation apparatus, by which means the reactor was maintained at 55ºC.

Fig. 1 shows the layout of the methane fermentation system. Two 350-L tanks were used, and because the materials were not crushed and stirring power was not required, the energy requirements for fermentation were minimal. The principal material used was leftover foods from hotels in the Naruko hot spring resort area. Leftover food was placed into paper bags, and dropped into the reactor directly. (Suzuki, et al. 2012)

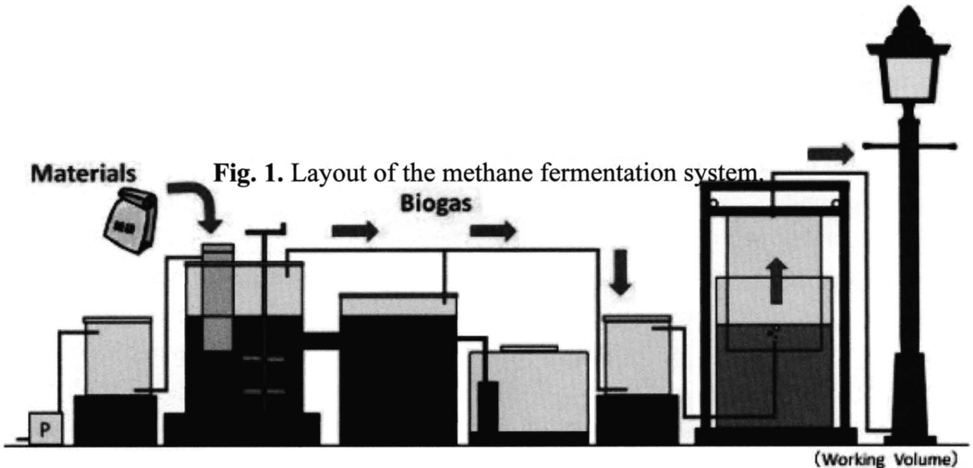
The average leftover food quantity from dinner and breakfast was ~300 g/day/person. Approximately half of this was rice. The carbon-to-nitrogen ratio was 20, which suggests that the leftover food was suitable for methane fermentation.

The effect of material loading rate on methane production was investigated. Volatile fatty acids accumulated at high loading rates. Based on this observation, microbial carriers were placed into the reactor. The biogas production rate was ~300 L/day, and the methane concentration in the biogas was 50% at a loading rate of 3 kgCOD/day/m^3(Suzuki, et al. 2013).

At the first stage of the operation, the pH was controlled using chemical additives. The liquid digested material from the second tank was returned to the first fermentation tank, so that additional pH control was not required.

Use of the methane gas

For electrical power generation using gas engine, high-quality gas-phase fuel is required, and the methane concentration should be ≥55%. The methane concentration of biogas generated from garbage



Equipment	Deodo -rizer	Fermentation tank		Digested slurry Storage tank	Desulfu -rizer	Gas Storage tank	Gas lamp
		1st tank	2nd tank				
Spec	50(42) L	350(230) L	350(305) L	300 L	50(42) L	200 L	6 MJ/h

Fig. 1. Layout of the methane fermentation system.

leftovers is typically 40-60%, and increases to >50% if the microbial flora is well controlled. In this case, we use biogas to light the gas lamp. Gas lamp could be lighted by more than 45% of methane gas. To use biogas for the gas lamp is easier than to make electricity with gas engine.

In addition, gas lamp is easy to understand for people to change biogas to light as energy. We could use this system for education about biomass energy.

Collection of raw materials

In this system, we adopted a raw material collection method whereby waste food is packed into a paper bag, and placed into the fermentation equipment. The waste accounted for 78% of leftovers, based on a survey of tourists. The waste food collection points were placed at the site 7-min walk from hotels on average, which was the ideal for the disposal of food waste.

Liquid fertilizer

Digested liquid material from the fermentation system contains nitrogen and phosphorus. There have been some reports on the use of digested liquid material as fertilizer (Hishinuma et al., 2008, Ishikawa et al. 2006, Collet et al. 2011). However, in cities, this material must undergo wastewater treatment.

Table 1 showed the composition of the digested liquid from the small methane fermentation system using hot spring. The principal material was leftover food (Tajima et al. 2013).

Experiments were carried out using the digested material as fertilizer in the hydroponic cultivation of *Brassica campestris*. The digested material inhibited crop growth; it is likely due to an increase in the electrical conductivity of the liquid due to addition of Na salts as a pH-controlling agent. Upon addition of the pH control agent, the electrical conductivity was 32 mS/cm. Typically, the electrical conductivity of the soil is less than 1 mS/cm. When fermentation was carried out without a pH control agent, the electrical conductivity of the digested material decreased to 6 mS/cm.

Table 1. Composition of digested liquids.

Digested liquids	NH_4-N (mg/L)	P_2O_2 (mg/L)	K_2O (mg/L)
leftover food	1.8	0.1	1.5
food garbage	1.0	0.5	3.0

Economic and environmental effects of the system

Carbon dioxide emissions can be reduced by using non-fossil-fuels and by heating using thermal springs. The installation cost of the system was 700,000 JPY. The waste food, which the system uses, would otherwise have a disposal cost of 30,000 JPY per ton. For these reasons, small-scale fermentation systems may be considered economically viable (Tajima et al. 2013).

Hot springs globally and in Japan

In Japan, there are many hot springs from north to south, the number of hot springs is reported 27532. 28 % of hot springs in Japan are artesian type. 50% of hot springs in Japan are more than 42 °C. In addition, there are many hotels and inns around hot springs, and collection of food waste is easy there.

Hot springs in the world, such as the United state, Indonesia, Philippine, are famous for their geothermal power generation. but they are not used as hot springs, such as Japan. In Iceland, geothermal power is used not only as electricity but as the thermal energy.

In the mesophilic fermentation, as well as high temperature fermentation at 55°C, using the waste heat or natural heat, energy balance is well maintained in the small-scale methane fermentation.

Waste heat utilization

We plan to construct small-scale methane fermentation systems using waste heat emitted from factories. The waste heat discharged from fish processing plants can be used to control the temperature of the fermentation system, as can waste heat from refrigerators and freezers be used. Heat from the cooling systems is currently discharged into the environment. When the air temperature is low, harnessing this waste heat will be problematic; however, heat recovery in the summertime is expected to be feasible. Furthermore, it may be possible to use solar energy for heating, even in winter, due to the large number of sunny days during this season.

Future development

Heat from hot springs is believed to be stable, and so it can be used to maintain the reaction tank at a constant temperature. Methane fermentation depends on temperature, and we investigated the effects of temperature variation on methane production. Methane fermentation for recovery of energy from domestic wastewater treatment has attracted recent interest(Kim et.al, 2011). The temperature used for fermentation of domestic wastewater is significantly lower than that in the waste food digester, typically 10-20°C(Kim et al. 2013). In condominiums and apartment blocks, hot wastewater from showers and baths can be used as a heat source to encourage digestion of waste materials. F garbage from households may be fermented to methane using this waste heat. Furthermore, it may be possible to use digested material as liquid fertilizer for the gardens of the source apartments.

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