Development of "Compact Biogas System" to Generate Biogas from Garbage On-site

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1. Introduction

In Japan, biogas systems are not so widely used, despite efforts made to promote the use of biogas. A factor that has led to this situation is that existing biogas systems are mostly large-scale. For offices or factories that discharge small amounts of garbage and food waste, it is difficult to introduce existing devices due to economic viability and limited space available for installation.

As a solution to this situation, we have developed the "compact biogas system" to generate biogas from small amounts of garbage, which is not economically viable with existing devices. And we are also testing biogas utilization system to use biogas produced by "compact biogas system".

This paper reports on the results of long-term operation test of "compact biogas system" demonstrator using garbage discharged from restaurants.

2. Renewable Energy Trends in Japan

Japan has promoted food waste recycling since the enforcement of "Law for Promotion of Recycling and Related Activities for Treatment of Cyclical Food Resources (Food Recycling Law)" in 2001, which obligates offices or factories that discharge 100 tons or more of food waste annually to recycle the food waste. However, biogas systems have been slow to come into widespread use, although they are recommended by the Food Recycling Law and are more economical and ecofriendly than turning food waste into livestock food or fertilizer.

Meanwhile, since the enforcement of "New Act of Upgrading Energy Supply Structure" in 2009, which requires gas suppliers to expand the use of biogas and other non-fossil energy sources, it has become important to achieve technology development for efficient production and utilization of biogas.

3. Background of "Compact Biogas System" Development

A factor behind the slow popularization of biogas systems in Japan is that most offices or factories that discharge garbage and food waste discharge only less than 1 ton per day, while existing biogas systems are largely designed to process garbage at a rate of 10 tons per day or more. It is economically difficult for offices or factories with small amounts of garbage emissions of about 1 ton per day to introduce existing devices.

Targeting this untapped market, we have developed the "compact biogas system" that disposes small amounts of garbage at a rate of 0.2 to 1 ton per day economically.

4. Characteristics of "Compact Biogas System"

The compact biogas system being developed at Osaka Gas incorporates the design of wide-spread septic tank, which stably process wastewater without mechanical pump and mixer. It is compact, integrating an anaerobic section (anaerobic digester) and an aerobic section (activated sludge tank), as shown in Fig. 1.

Several tanks are provided in the system, and each tank is partitioned simply by wall boards. The system uses no transfer pump since garbage and liquids are transferred from tank to tank basically by combination of gravity separation and overflows. Consequently, unlike the conventional biogas systems, the individual tanks in the compact biogas system require no control of tank levels and pumps, leading to reduced initial and running costs.

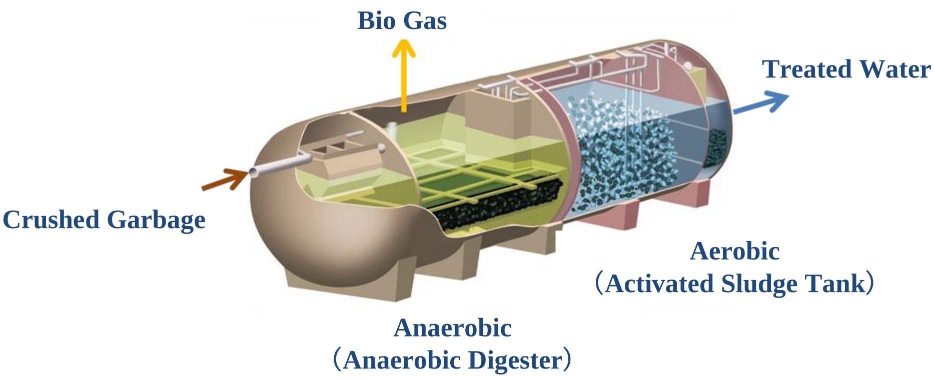

Fig. 1 Figure of Compact biogas system

5. Structure of “Compact Biogas System”

The individual tanks of the compact biogas system feature the following functions and flow processes, as shown in Fig. 2.

(1) Reservoir: Receives crushed garbage.

The reservoir allows impurities (bones, shell, etc.) contained in crushed garbage to settle down. Settled substances should be removed once or twice a year.

(2) Separator: Separates crushed garbage into solid and liquid parts.

The solid parts in the crushed garbage settle down in the lower part of the separator by gravity separation. The lower part of the tank has slit, lead to the anaerobic digester. Upward currents created by a blower transfer a certain amount of the solid parts of the garbage to the anaerobic digester. Meanwhile, the liquid parts are drained via a pipe from the upper part of the separator to the activated sludge tank.

(3) Anaerobic digester: Converts the solid parts of garbage into biogas.

The anaerobic digester anaerobically converts the solid parts of the garbage into biogas by virtue of anaerobic microbes working at 55℃. This digester tank has no opening except for the inlet from the lower part of the separator. With garbage block constantly settling at the inlet, the anaerobic digester keeps slow-growing anaerobic microbes from flowing out into the separator.

(4) Activated sludge tank: Clarifies effluent under aerobic conditions.

The activated sludge tank clarifies the effluent (liquid parts of garbage) from the separator by aeration and settling. Excess sludge produced through aeration is returned to the reservoir, mixed with the solid part of the garbage, and transferred to the anaerobic digester.

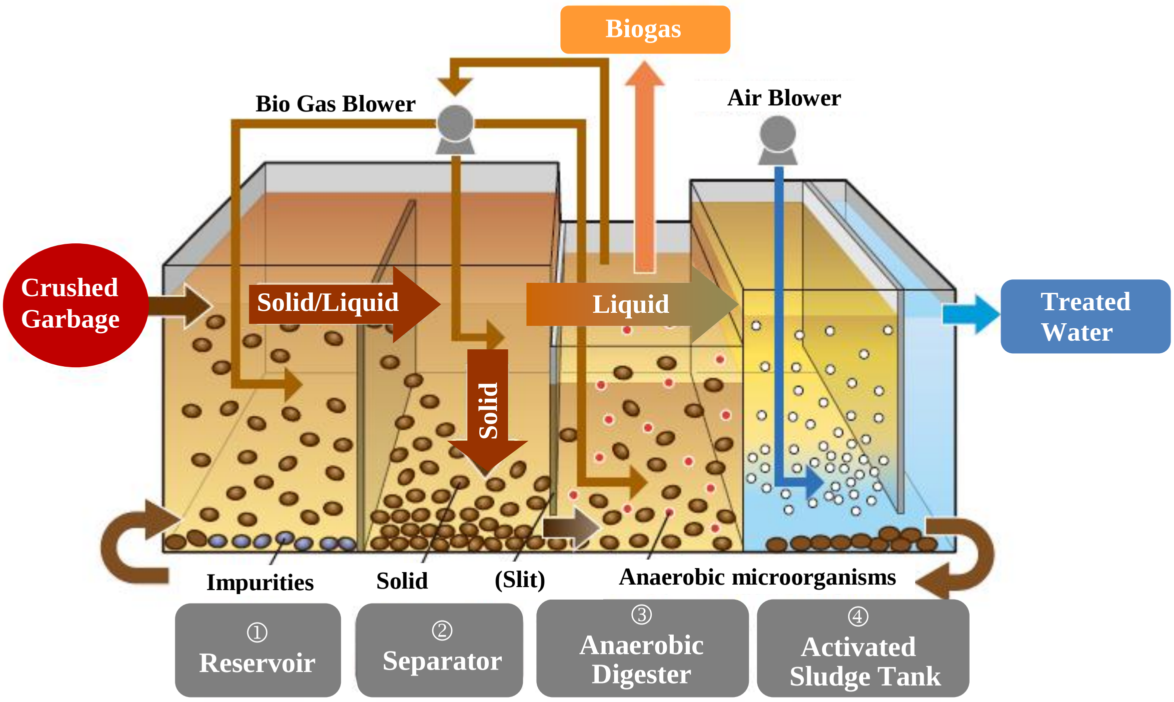

Fig. 2 Flow chart of compact biogas system

6. Target Specifications for Compact Biogas System

- Biogas production: Not less than 70 L/kg-garbage (20% solid content)
- Effluent quality: Clarification to the level applicable to the installation location
- Energy balance: Recovery of more energy than the system’s self-consumption

7. Operation Test of “Compact Biogas System”

7.1 Biogas Production

The biogas production was verified using garbage discharged by restaurants and the 100 kg model demonstrator (capacity: 100 kg/day), shown in Fig.3. In the operation test, garbage was loaded at a rate of 100 kg (wet weight) per day for five weekdays a week. A commercial disposer was used to crush the garbage. During crushing, tap water was added to transfer five-fold diluted crushed garbage.

Fig.4 shows the biogas production from 80-days’ consecutive operation of the 100 kg model demonstrator. The daily biogas volume fluctuated substantially, partly due to no garbage being loaded on holidays. On average, biogas was produced at a rate of 71 L/kg-garbage (20% solids content equivalent), which achieved the target rate of not less than 70 L/kg-garbage.

Assuming that the COD_{Cr} of the solid part of garbage was 1.35 kg-COD_{Cr}/kg, the rate of conversion from loaded garbage to methane was 44%. This figure is lower than the conversion rate of conventional biogas systems (approx. 80%). The reason for this is that compact biogas system, which has a simple system structure, transfers water-soluble or floating organic substances, after garbage crushing, directly to the activated sludge tank instead of the anaerobic digester.

After the above-mentioned test, the system structure was modified to transfer floating garbage to the anaerobic digester so as to improve the biogas production and the methane conversion rate. The result of this modification was a 14% increase in the methane conversion rate.

Fig. 3　100 kg model demonstrator

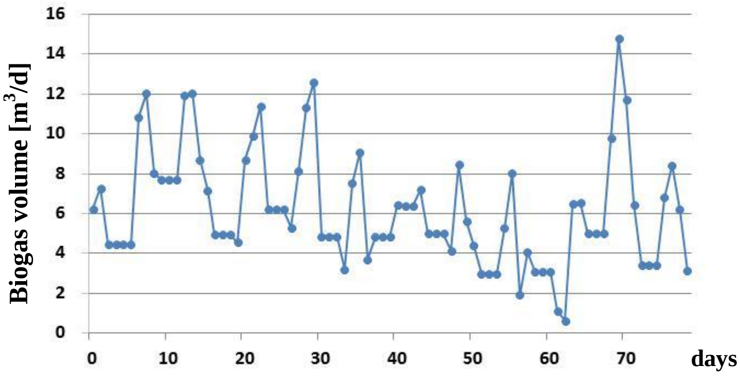

Fig. 4　Biogas produced from 100 kg/day of garbage

7.2 Study of Energy Balance

The 50 kg model demonstrator (capacity: 50 kg/day), shown in Fig. 5, was used to verify the energy balance. This demonstrator was designed to achieve a better thermal efficiency than the 100 kg model demonstrator by enhancing heat insulation to reduce heat dissipation.

Regarding the verification method, the electricity consumption was measured with a electricity meter and the heat consumption was measured using the flow rate and the inlet-outlet temperature difference of the heat exchanger. The system consumed heat to maintain the temperature of the anaerobic digester at 55ºC. The heat consumption per day was 17.4 kWh. Electricity was largely consumed by the aeration blower used for the activated sludge tank, with electricity consumption of 12.2 kWh per day. Combining heat and electricity, the self-energy consumption reached 29.6 kWh, while the energy of the produced biogas was 22.7 kWh. Consequently, the 50 kg model demonstrator failed to achieve the target specification of recovering higher energy than the system’s self-consumption.

However, the specifications for the planned commercial version envisioned the 500 kg model (capacity: 500 kg/day). Simulation of upgrading to this model, based on the results of the 50 kg model demonstrator with the surface area involved in heat dissipation taken into account, produced the following estimates: 110 kWh/day heat consumption and 110 kWh/day electricity consumption. The energy self-consumption of 220 kWh combining heat and electricity was lower than the energy production of 225 kWh. This suggests a possible favorable balance between self-energy consumption and produced energy.

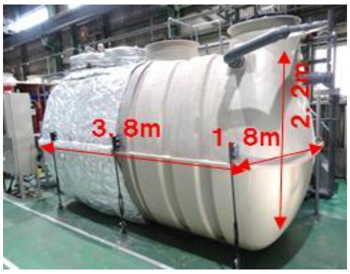

Fig. 5 50 kg model demonstrator

Table 1 Energy balance of 50 kg model demonstrator

Input	Heat	17.4 kWh/d	29.6 kWh/d
	Electricity	12.2 kWh/d	
Output	Biogas		22.7 kWh/d

Table 2 Energy balance of 500 kg model simulation

Input	Heat	110 kWh/d	220 kWh/d
	Electricity	110 kWh/d	
Output	Biogas		225 kWh/d

7.3 Environmental Assessment

Using the energy balance verification results of the 50 kg model demonstrator, we conducted an environmental assessment for the following three cases: (1) Bio-gasification by compact biogas system; (2) Outsourced incineration; and (3) Outsourced composting. Assuming that 50 kg of garbage would be treated each day, CO_2-equivalent volumes of greenhouse gas (CO_2, CH_4 and N_2O) emissions were calculated (CH_4:CO_2 = 1:21 and N_2O:CO_2 = 1:310).

The calculation methods shown below were used to determine greenhouse gas emissions for each case. Carbon dioxide emissions from garbage incineration or degradation were not counted because they are carbon neutral.

(1) Bio-gasification: Subtract the energy recovered as produced biogas from the energy self-consumption. Using the result of subtraction, calculate CO_2 emissions from electricity generation corresponding to the consumed electricity and N_2O produced from effluent treatment.

(2) Incineration: Calculate CO_2 emissions from transportation to the treatment plant and N_2O emissions from incineration. Carbon dioxide emissions associated with electricity consumption during incineration are not counted, since the garbage in question is burned together with other commercial refuse at an existing incineration plant.

(3) Composting: Calculate CO_2 emissions from transportation to the treatment plant and CH_4 and N_2O emissions from the composting process. Subtract, from this result, CO_2 emissions from the manufacturing process of chemical fertilizers replaced with the produced compost.

Fig.7 shows greenhouse gas emissions per ton of garbage for the treatment of garbage at a rate of 50 kg/day calculated under the above conditions. The use of the compact biogas system for converting garbage into biogas emits the least amount of greenhouse gas among the three cases assumed. The reasons for this are that CO_2 emissions from transportation are not applicable to on-site treatment and that the energy recovered as biogas is counted as negative in terms of greenhouse gas emissions.

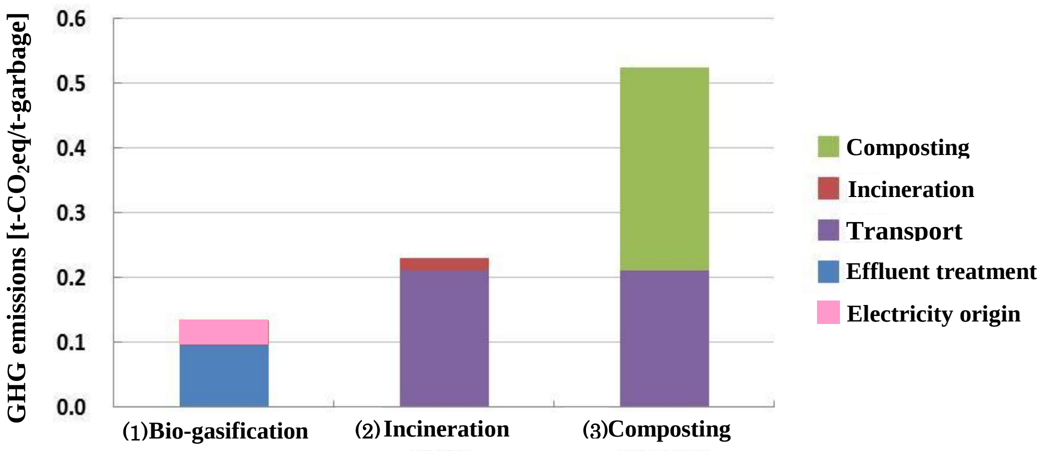

Fig. 6 Greenhouse gas (GHG) emitted from 50 kg/day garbage treatment

7.4 Biogas Utilization System Demonstration

Biogas production is an irregular process, varying in volume and quality. In addition, it is impractical to operate a gas engine only using biogas produced by compact biogas system whose biogas volume is some 70 m^3 from 1 ton of garbage. To meet this challenge, we have developed the “biogas-natural gas mixer” that mixes small quantity of biogas into the fuel for a gas engine within the gas engine’s permissible heating-value fluctuation range according to the volume of biogas.

Testing of a biogas utilization system is currently underway using biogas produced by the 100 kg model demonstrator, shown in Fig. 7. In this test using the biogas-natural gas mixer, it has been verified that a 25 kW gas engine operates without no trouble within a biogas mixing rate range of 4% to 30% (instantaneous values). Moreover, it has also been confirmed that a biogas boiler operates stably owing to self-switching between biogas and city gas.

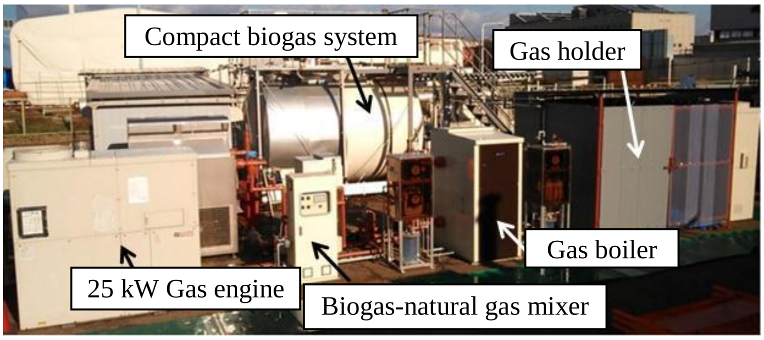

Fig. 7 Test plant of biogas utilization system

8. Summary

It has been confirmed that “compact biogas system” disposes of garbage and produces biogas as expected. And biogas utilization system, shown in Fig 8, that consumes energy recovered as biogas and allows the excess energy to be efficiently used by the system installation site has come into sight.

Compact biogas system is environmentally superior to composting and other Food Recycling Law-compliant treatment processes. Thus they are expected to be useful for garbage recycling intended for on-site distributed treatment.

The operation test of compact biogas system is still ongoing for the purpose of verified result. And it is planned to develop the 400 kg model demonstrator on a practical scale, to install it at our customer’s site, and process actual garbage on a long-term basis, thereby conducting a demonstration test comparable to actual applications.

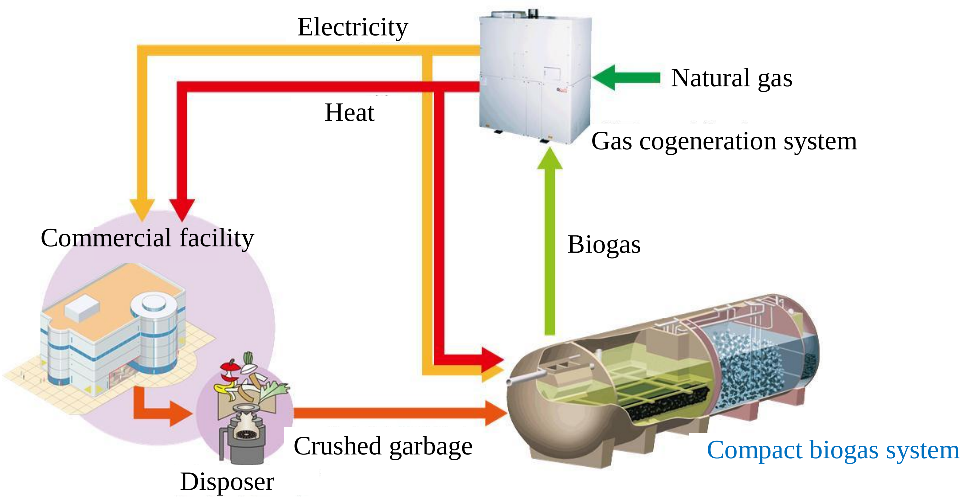

Fig. 8 Plan for production and utilization of biogas from garbage on-site