Present Status and Future Prospects of Biogas Powered Fuel Cell Power Units

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1. Introduction

Recently adjustment of laws, development of technologies and business movement have encouraged the transition to a recycling-based society. Biogas energy is being watched with keenest interest as environmentally-friendly, alternative energy source instead of petroleum. It is proposed that biomass energy will be introduced worldwide in large quantities. Particularly for Japan, which lags behind other industrialized nations in the widespread adoption of environmentally-friendly energy sources, the utilization of "biomass from wastes," such as waste wood, wood chips, sludge, garbage, edible oil waste and animal refuse, represents a promising alternative energy source, which would serve to protect the environment from the symptoms of industrialization, such as global warming.

In 1999, Fuji Electric began developing phosphoric-acid fuel cell power units using methane fermentation gas from garbage, and to this day, the produced units have been operating successfully. From 2001 to 2002, Fuji Electric produced 100 kW phosphoric-acid fuel cell power units, which use biogas from garbage and digested gas from sewage.

This paper presents examples of a methane fermentation facility and a sewage water treatment plant. In addition, an overview of these systems is presented.

2. Differences Between Town Gas and Biogas

The gas produced through anaerobic fermentation of organic wastes is referred to as biogas. Biogas consists of approximately 60 % methane, 40 % carbon dioxide, and some impurities, such as hydrogen sulfide, ammonia and hydrogen chloride (refer to Table 1). The low heating value of biogas is approximately 23 MJ/m^3, approximately half the value of town gas. Since impurities such as hydrogen sulfide harm the catalysts used in fuel cell power units, they need to be removed in advance. Although town gas contains sulfur compounds as an odorant, biogas contains sulfur compounds several hundred times greater than that of town gas. As a result, biogas pretreatment equipment is normally provided upstream of a fuel cell power generating system. As shown in Table 2, there are various desulfurization methods. With regard to biogas, dry sulfurization is normally used because it is easy to handle and inexpensive. In addition, depending on their amount, impurities other than hydrogen sulfide are removed with an active carbon tower. Therefore, with some modification to the fuel cell power generating system for town gas or LPG (liquefied petroleum gas), the biogas can be used to generate electricity.

Table 1 General characteristics of biogas (digested gas)

Element	Biogas (digested gas)	Inlet requirements to FC power units (after treatment)	Town gas (13A)
Methane	ca. 60 %	60±2.5 %	88 %
Ethane	–	–	6 %
Propane	–	–	4 %
Butane	–	–	2 %
Carbon dioxide	ca. 40 %	40±2.5 %	–
Nitrogen	Less than 0.8 %	Less than 0.1 %	–
Oxygen	Less than 0.2 %	Less than 50 ppm	–
Hydrogen sulfide	500 to 1,000 ppm	Less than 2 ppm	–
Sulfur compound (other than H_2S)	Less than 500 ppb	Less than 50 ppb	6 ppm
Ammonia	Less than 1 ppm	Less than 1 ppm	–
Heating value (kJ/m^3)*1	21,500	21,500	41,600

*1: Low heating value, 0°C, 1 atm standard

3. Fuel Cell Power Units Using Biogas from Garbage and Digested Gas from Sewage

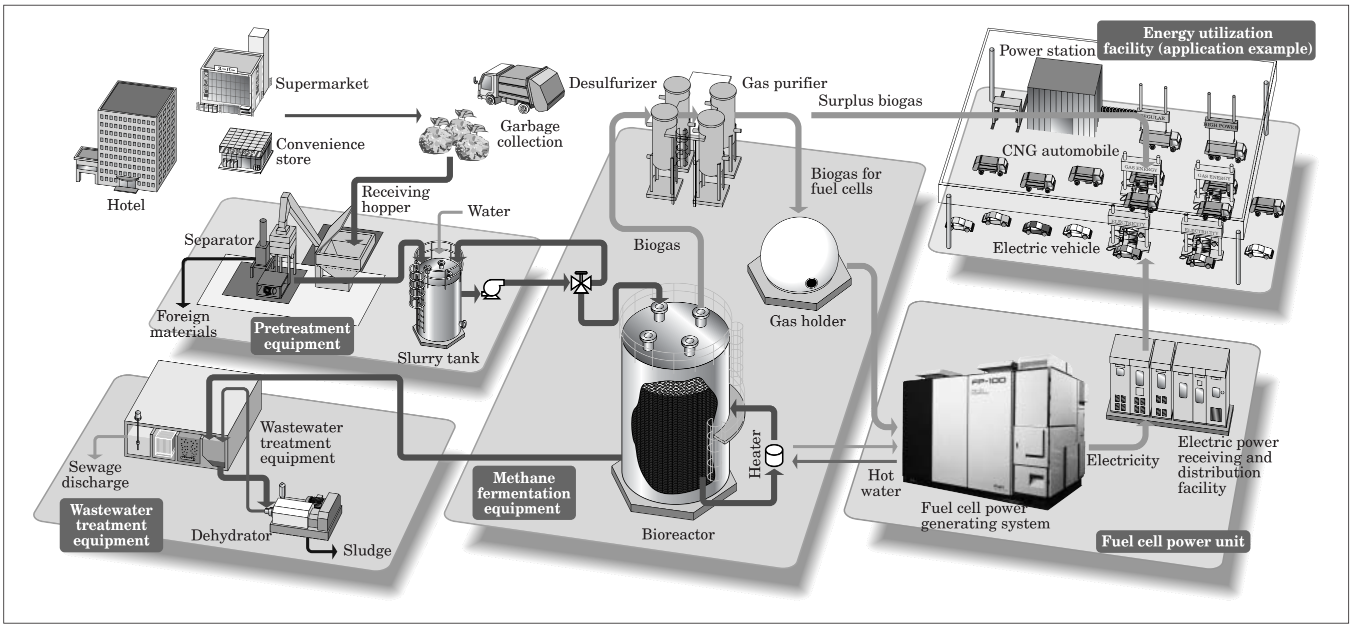
In July 2001, Fuji Electric developed a methane fermentation facility for garbage and a fuel cell power generating facility (Port Island District, Kobe City, Ministry of the Environment). In addition, a power generating system, which uses digested gas from a sewage treatment plant (Yamagata City Purification Center), was developed in March 2002.

Table 2 Comparison among various desulfurization methods

Item \ Desulfurization method	Ordinary temp. desulfurization	Hydro-desulfurization	Dry-desulfurization	Dry-desulfurization
Desulfurization agent	Zeolite family	Ni-Mo family +ZnO Co-Mo family +ZnO	Iron oxide family	Iron-Zn oxide family
Kind of sulfur	TBM (tertiary butyl mercaptan) DMS (dimethyl sulfide)		H_2S (hydrogen sulfide)	H_2S (hydrogen sulfide)
Adsorption	Physical adsorption	Chemical adsorption	Chemical adsorption	Chemical adsorption
Main reaction	—	$R\text{-}CH_2SH+H_2$ $\rightarrow R\text{-}CH_3+H_2S$ $H_2S+ZnO\rightarrow ZnS+H_2O$	$Fe_2O_3+3H_2S$ $\rightarrow Fe_2S_3+3H_2O$	$ZnFe_2O_4+3H_2S+H_2$ $\rightarrow ZnS+2FeS+4H_2O$
Reaction temp.	Ordinary temp.	250 to 300°C	Ordinary temp.	440 to 450°C
Application	Town gas, LPG	Town gas, LPG	Digested gas, biogas	Coal gasification
Fuel cell	Polymer electrode fuel cell	Phosphoric-acid fuel cell	Phosphoric-acid fuel cell	Molten carbonate fuel cell

TBM: $CH_3CH_2CH_2CHSH$, DMS: CH_3SCH_3 (methyl sulfide)

Fig.1 Schematic diagram of a power generating system using biogas from garbage



3.1 Power generating facility using biogas from garbage

3.1.1 Overview of the facility

As shown in Fig. 1, the facility consists of pretreatment equipment, a methane fermentation system, wastewater treatment equipment, a fuel cell generating system and energy-utilization facilities, which will be installed in the future. The methane fermentation system is a "high-temperature methane-fermentation organic- wastes-treatment system" (trade name: METAKURESU) and is commercialized by Kajima corporation. The fuel cell generation system is a "100 kW phosphoric-acid fuel cell power unit" (trade name: FP-100), which is manufactured and commercialized by Fuji Electric. A laboratory-level performance evaluation of both systems was reported in the, "FY 1999 New Industrial Creative Proposal Publication Work", which was sponsored by NEDO (New Energy and Industrial technology Development Organization). But, this is the first time the practical type system has been installed. Figure 2 shows an exterior

Fig.2 Exterior view of power generating facility using biogas from garbage

view of the power generating facility, which generates biogas from garbage.

Outline of the facility is described below.

(1) Pretreatment equipment

Garbage (6 t/day) discharged from hotels in Kobe City is carried by garbage collection trucks into the facility and is transferred into receiving hoppers. After bags are broken and garbage is crushed, foreign materials such as plastic wrap, metal chips and disposable chopsticks are separated by an oil hydraulic press separator. Once separated, the biodegradable organic matter is processed into paste. Since paste-form organic matter is high in viscosity and is rather coarse, water must be added to the paste-form organic matter in a slurry tank before it is micro-crushed by a crushing pump (cutter pump). Once adequately crushed, the garbage slurry is discharged into a downstream bioreactor.

In order to collect garbage, the Ministry of the Environment supplies hotels (garbage discharger) with biodegradable plastic bags, which are biodegraded in downstream wastewater treatment equipment, even if they are not removed by the oil hydraulic press separator.

(2) Methane fermentation equipment

The body of the bioreactor is a stainless-steel fixed-bed cylinder, which is 5,200 mm in diameter and 8,500 mm high. The inside of the bioreactor consists of a cylindrical carbon-fiber biological carrier, which is 100 mm in diameter and 6,500 mm long. Micro-crushed garbage slurry is charged through the top in the methane fermentation tank. This slurry is anaerobically fermented by high-temperature anaerobic (principally methane) microbes as it flows down through the tank. Average retention time is approximately eight days. Fermented liquid drawn out from the bottom of the reactor is heated to 55°C via a heat exchanger and is then returned to the top of the reactor. Hot water from a fuel cell power unit is utilized as a heat source for the exchanger.

Biogas produced through high-temperature anaerobic fermentation consists principally of methane, carbon dioxide, and some impurity gases, such as hydrogen sulfide and ammonia. Since these impurity gases adversely affect the downstream fuel cell power generating system, they are removed while passing through a desulfurization (iron oxide) and refinery tower (active carbon). Following this process, the biogas is fed into the fuel cell power generating system.

Part of desulfurized and refined biogas is stored in a double-balloon structure gas holder, which is 30 m^3 in capacity. This feature allows the system to adequately store the fluctuating volumes of produced biogas.

(3) Wastewater treatment equipment

Fermented wastewater which overflows from the bioreactor and discharged wastewater from various processes are collected into wastewater treatment equipment in the facility. After subjected to an anaerobic and aerobic treatment, they are discharged to a sewage line, which passes through a penetration membrane. Sludge produced through the wastewater treatment is dehydrated and discharged outside the facility.

(4) Fuel cell power unit

A phosphoric-acid fuel cell power unit produces a direct current (DC) via a chemical reaction between hydrogen (H_2), which is reformed from the methane (CH_4) in biogas, and atmospheric oxygen (O_2). The reformer is situated inside the fuel cell package. The direct current produced is converted into a 200 V, 60 Hz alternating current (AC), and is supplied to the facility. All of the service-power in the facility is covered by the fuel cell power unit, and a surplus totaling 40 % of the generated power can be effectively used.

(5) Energy utilization facilities (future plan)

In this project sponsored by Ministry of the Environment, surplus electricity and gas are planned to be utilized for recycling projects appropriate for the region with the goal of creating a recycling-based society.

Installation of “a gas filling station for gas vehicles” and “an electricity-charging station for electric vehicles” is under review.

3.1.2 Introduction benefits of biogas power generation

With the introduction of the system mentioned above, the following benefits are expected:

(1) Reduction of fossil fuels and suppression of carbon dioxide emissions due to a reduction in the volume of garbage without incineration
(2) Reduction of fossil fuels and suppression of carbon dioxide emissions due to utilization of surplus electric power
(3) Reduction of fossil fuels and suppression of carbon dioxide emissions due to utilization of surplus gas
(4) Reduction in whole waste volume due to separate garbage collection
(5) Repercussions due to the practical environmental training on the theme of this project

Implementation and verification of the project is scheduled to run three years in duration.

3.2 Power generating system using digested gas from a sewage treatment plant

Anaerobic treatment of sewage sludge is currently conducted at approximately 300 facilities in domestic sewage treatment plants. Overall, digested gas generated in these facilities totals approximately 260 million m^3/year. This gas is currently utilized for heating digested gas holders, for digested-gas power generation, and as an auxiliary fuel for sludge combustion. Approximately 15 % of the digested gas utilized for power generation is utilized for gas engines. Recently, fuel cells have been introduced because they are superior to gas engines in terms of their power

Fig.3 Schematic flow diagram of the fuel cell power generating facility for Yamagata Purification Center

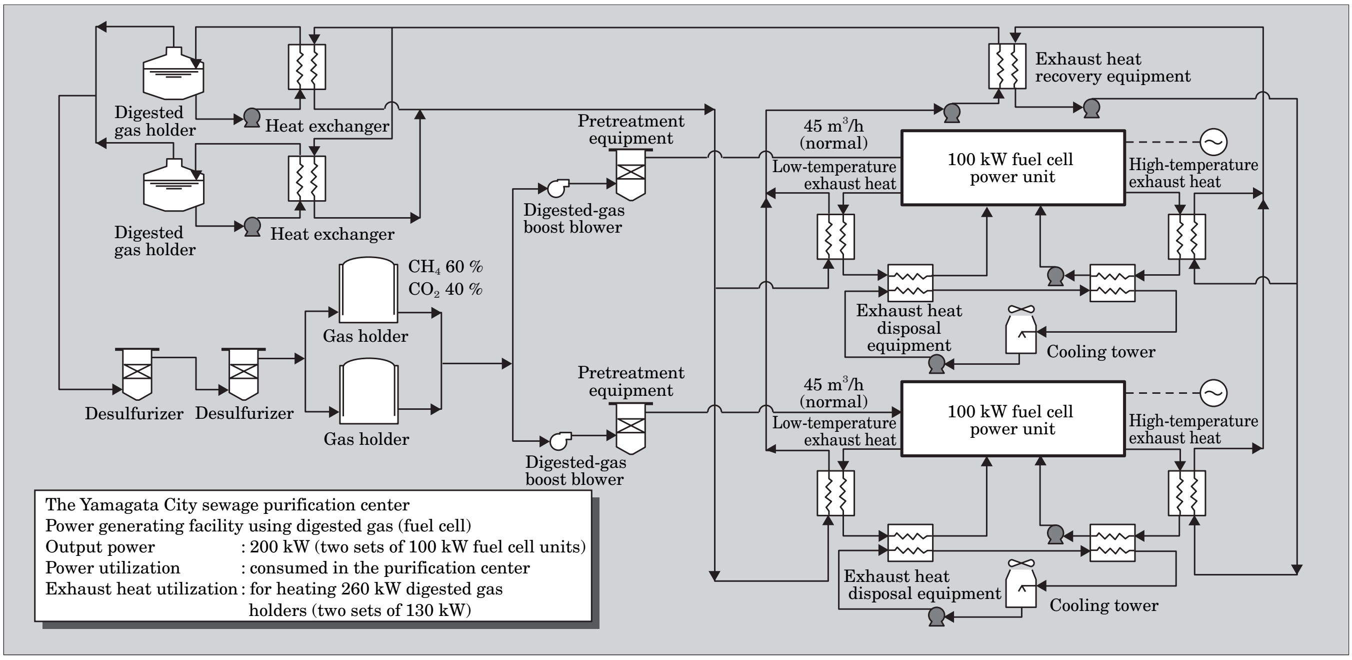


Table 3 Specifications of the fuel cell power unit for Yamagata City Purification Center

Item	Specifications
Rated output	100 kW (at output terminals)
Rated voltage, frequency	210 V, 50 Hz
Power generation efficiency	38 % LHV (at rated operation, at output terminals)
Overall efficiency	87 % LHV (at rated operation, at output terminals)
Fuel	Digested gas(methane: 60 %, carbon dioxide: 40 %)
Fuel consumption	45 m^3/h (normal)
Operation mode	Fully automatic operation, parallel operation with mains
Thermal output	20 % (90°C hot water) 29 % (50°C hot water)
Exhaust gas	NOx : less than 5 ppm, SOx: beyond detection
Operating noise	65 dB (A) (average value at a distance of 1 m from the unit)
Size	2.2 m (W), 4.1 m (L), 2.5 m (H)
Mass	12 t

generating efficiency and environmental impact. In March 2002, Fuji Electric delivered fuel cells to Yamagata City Purification Center. The center averagely treats 40,000 m^3 of sewage water per day and produces approximately 4,200 m^3 of digested gas per day through anaerobic fermentation. Part of the digested gas produced is utilized for a 178 kW gas engine in order to generate electricity. With the increase of digested gas, however, two sets of 100 kW phosphoric-acid fuel cells have been introduced to generate electricity and to utilize the generated heat to a digested gas holder. Figure 3 shows a schematic flow diagram of the system. Table 3 shows the specifications of the fuel cell power unit.

Energy-saving effects and environmental benefits through the introduction of fuel cells are as follows (with two sets of fuel cell units):

(1) Energy-saving effects (crude oil equivalent): 458 kL/year
(2) Reduction in CO_2: 1,140 t/year
(3) Reduction in NOx: 460 kg/year
(4) Reduction in SOx: 412 kg/year

4. Future Prospects

Unlike conventional gas powered generating machines, such as gas engines and gas turbines, fuel cells can generate electricity without fuel combustion and without first being transformed into rotational energy. As a result, exhaust gas is very clean (NOx: not more than 5 ppm, SOx: beyond detection), and power generation efficiency is very high. Hot water produced during electrochemical reaction required for power generation can be utilized through heat recovery.

Due to the implementation of the “Food Recycling Law” (Law for Promoting Reuse of Recycling Food Resources), it is envisioned by related industries that the practice of food recycling will be widely adopted without waiting (the typical) three years for verification testing. The results from these tests, which indicate that biomass from garbage can be harnessed to generate power, will be used as demonstration examples of the Food Recycling Law.

Of the sewage-digested gas facilities in Japan, approximately 100 facilities produce the required amount of digested gas for a 100 kW fuel cell power unit. However, the digested gas is currently utilized as fuel (heat energy), such as that which would be required for a boiler. It is expected that fuel cells will become widely utilized and will therefore, aid in the reduction of CO_2 emissions. In a report by New Energy Division of Advisory Committee for Natural Resources and Energy of Agency for Natural Resources and Energy, an introductory target for biomass power generation for 2010 is set at 330 MW/year, in terms of installed capacity (four times that for 1999, crude oil equivalent: 340 thousand kL/year).

In the future, Fuji Electric is determined to concentrate on the following developments to increase applications of fuel cell power units using biogas:

(1) Development of fuel cells capable of using as low as 50 % density methane gas

(2) Development of fuel cells responding to 0 to 100 % fluctuation of the amount of biogas produced

(3) Development of exhaust heat utilization suitable for methane fermentation facilities

5. Conclusion

This paper describes applied examples of phosphoric-acid fuel cell power units, which use biogas from garbage and digested gas from sewage sludge. Methane fermentation is the most suitable technology to reduce the volume of organic wastes because this process conserves energy, and the fuel cells are suitable for utilizing the produced methane gas.

It is strongly recommended that fuel cell power generation using biogas be encouraged under the assistance and guidance of all concerned parties.