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CONVERSION TO BIOGAS-FUELED ROTARY ENGINE

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ABSTRACT

From 2002, Technical Research Institute of Hiroshima Gas has performed demonstrative operations of a rotary engine cogeneration using natural gas as fuel with a remodeled rotary engine. As a result, it has been understood that the rotary engine has superior characteristics as a biogas fueled engine from a structural viewpoint in comparison with the other internal combustion engines as reciprocating engines. Consequently, from 2005 onward, we have conducted combustion test operations for only digestion gas using imitation synthetic biogas (CH4+CO2) with the technical assistance of Mazda Motor Corporation, the vendor of the rotary engine.

We confirmed that the good combustion range of the digestion biogas fuel in the engine is narrower than natural gas and the synthetic biogas (CH4+CO2) basically burns well when concentration of methane (CH4) is 50% or more. We also were able to grasp the optimal operating points in that synthetic biogas quality.

On the basis of these results, Kotobuki Industries, a machinery product company, produced a prototype model, and the demonstrative operations were performed at the wastewater treatment plant in Shunan City, Yamaguchi Prefecture during the operation period from 2006 to 2009.

As a result of the demonstrative operation, we obtained a good result which showed an average power output of 35kW during 1,800 operation hours.

However, in view of the economic viability, it was necessary to increase the power output to 40kW or more. Consequently, we remodeled the inlet pipe to increase the power output at the proposal of Mazda Motor Corporation. In consequence of the synthetic gas test operations, we succeeded in achieving the targeted power output of 40kW.

On the basis of these results, Kotobuki Industries produced a prototype unit again on the premise of its commercialization. They have performed endurance tests of the unit at the wastewater treatment plant in Hiagari, Kitakyushu City from 2009 to date. They obtained remarkable results from the endurance tests, showing an average power output of 40kW with 4,000 hours in stand-alone unit operation and 4,000 hours operation in parallel with the mains.

In March 2011, Hiroshima Prefecture has decided to employ the same type Biogas-Fueled Rotary Engine System at Ota River Tobu Wastewater Treatment Center, and that will be put into operation in March 2012.

This system generates power using sewage digestion gas as fuel with 9 units of rotary engine cogeneration (40kW 420V) to cover about 10% of the electric power (approximately 3,000MWh/year) used at Tobu Wastewater Treatment Center.

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1. INTRODUCTION

The Technical Research Institute of Hiroshima Gas was completed in October 2001,which has been tackling three fields of gas utilization technology, infrastructure technology related to gas supply and environmental technology.

Among others, from the start, we have pushed forward a demonstrating study of natural gas cogeneration such as fuel cell and gas engine which would enable us to attain highly efficient utilization of energy from the viewpoint of reducing CO2 emission and saving energy on the customer side. One of them is the demonstrating study on the natural gas rotary engine cogeneration system with Mazda Motor Corporation (hereinafter called RE-CGS).

Currently, with the announcement of "Biomass Japan Comprehensive Strategy ","Cool Earth Innovation Technology Plan", etc. by the Japanese government the momentum has been rising toward biomass energy utilization, and the technical introduction giving consideration to the environment is being encouraged in the city gas industry as well. Meanwhile, RE-CGS for biogas has the potentiality of broadly contributing to the local community from the viewpoint of local production and local consumption of energy.

The rotary engine (hereinafter called RE) has the flexibility in fuel use, and we tried conversion of RE-CGS to digestion gas fuel. This time we were able to confirm adaptability of RE to the digestion gas, and we would like to report on the test results.

2. CHARACTERISTICS OF ROTARY ENGINE

There are four main characteristics of RE when it uses biogas as fuel as mentioned below:

(1) The number of parts is less compared with the reciprocating engine and it is superior in maintenance.
(2) Because it has no air intake and exhaust valves, there is a low probability of its causing trouble of clogging.
(3) It has operational experiences with diverse types of fuels such as hydrogen.
(4) It can gain high power output compared with the reciprocating engine of the same size. (downsizing of the equipment can be expected)

3. PRELIMINARY TESTS FOR BIOGAS FUELED ENGINE

We, at Hiroshima Gas, utilized RE cogeneration for 13A city gas (higher heating value is around 46.05 MJ/Nm^3), on which we had conducted the demonstrating study to grasp the combustion properties of the biogas fuel.

Table1: Specifications of RE Cogeneration for City Gas

Engine type	Rotary engine 13B
Total engine displacement	1,308[cc]（654×2rotors）
Engine speed	1,800[rpm]
Compression ratio ε	11
Electricity output(City Gas)	20 [kW]

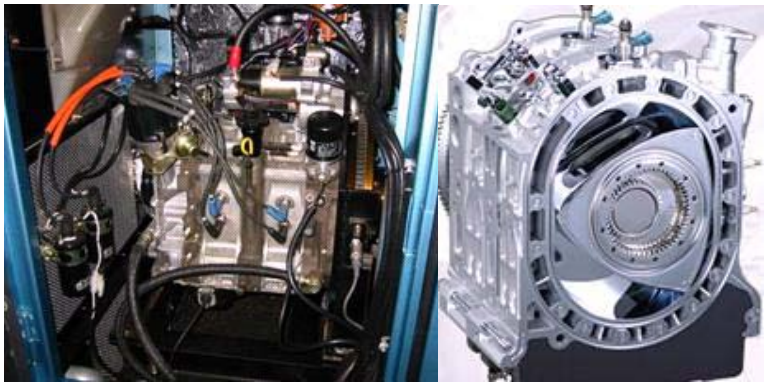


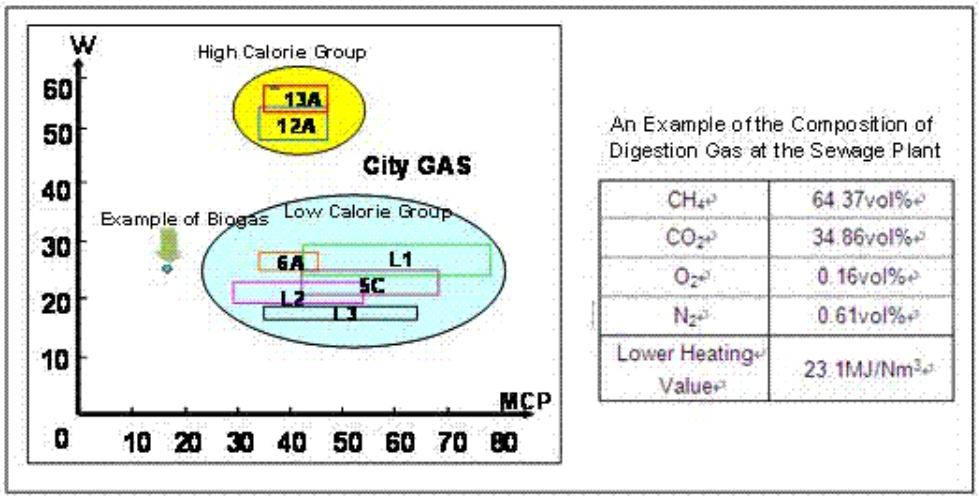
Figure1: Rotary Engine 13B

Table1 shows specifications of cogeneration for 13A city gas. The electricity output is 20kW with revolution of 1,800 rpm. The engine is a diversion product of an automobile engine 13B as shown in Figure1.

4. COMBUSTIBILITY OF BIOGAS

Figure3 shows as index indicating combustibility of gas. Horizontal-axis MCP(Maximum Combustion Potential) shows combustion speed, and vertical-axis WI (Wobbe Index) shows [calorific value/(gas specific gravity)$^{1/2}$]of gas.

The combustion speed of the digestion gas is so slow as about one-half of that city gas, and WI is also one-half compared with city gas, as shown in Figure3. Therefore, it is necessary to change the gas mixer nozzles and scale up each equipment of the other fuel gas system to convert fuel from city gas to digestion gas.



An Example of the Composition of Digestion Gas at the Sewage Plant

CH_4	64.37vol%
CO_2	34.86vol%
O_2	0.16vol%
N_2	0.61vol%
Lower Heating Value	23.1MJ/Nm^3

Figure 2: Index Indicating Combustibility Gas

5. COMPOSITION OF BIOGAS TESTS

Because it is really difficult to conduct tests with digestion gas which is actually generated, we installed device which can alternatively make arbitrary concentration of imitation digestion gas by mixing CH4 with CO2, and we carried out the tests.
(Storage capacity: 120m^3, RE-CGS possibility operation time: about 4 hours)

Figure 3: Imitation Digestion Gas Making Device

6. PRELIMINARY TESTS

Using the imitation biogas（CH_4 : 60%,CO_2 : 40%）, we conducted performance confirming operation beforehand with the machine. Although the electricity output decreased by approximately 20%, we were able to operation the machine by an adjustment of the air ratio and ignition timing.

Subsequently, we confirmed the combustion range and were able to confirm that the combustion range of imitation biogas is narrower compared with that of city gas. Figure 4 shows the result.

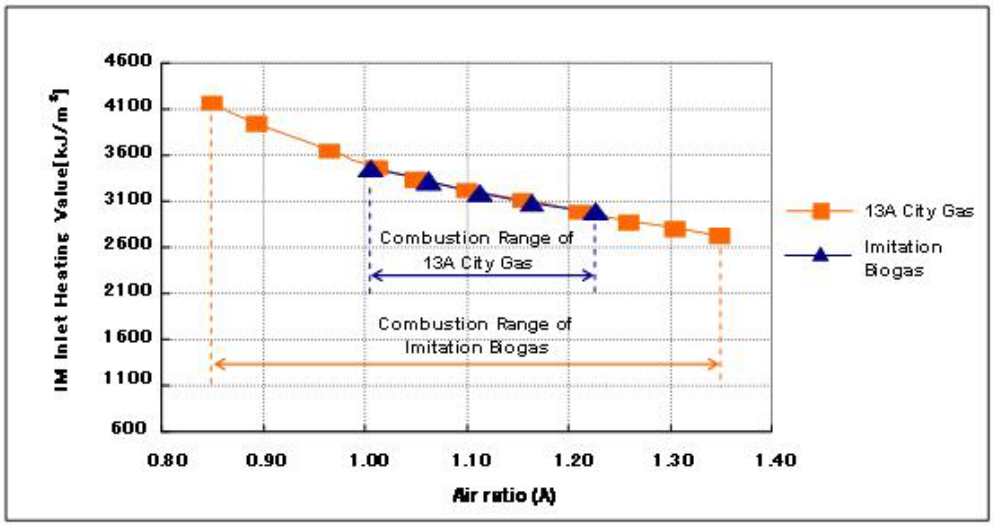


Figure 4: Operation of the Initial Testing Machine with Imitation Biogas (Combustion Range)

7. TARGETS OF THE DEVELOPMENT

Allowing for marketability and seasonal changes of the digestion gas composition,

- Electricity output: 35kW
- To be compatible with methane concentration of 50% or more
- To be exclusively used biogas for fuel

Electricity output of 40kW to 50kW is required for city gas to gain electricity output of 35kW by biogas

Items of remodeling of the initial testing machine:

- The engine speed from 1,800 rpm (rotor speed is 600rpm) → to 3,600 rpm (rotor speed is 1,200 rpm)
  - ■ Engine speed = Rotor speed×3
- Expansion of the gas mixer nozzles

Table 2: Target Specifications of the RE After Remodeling

Engine type	Rotary engine 13B
Total engine displacement	1,308[cc]（654×2rotors）
Engine speed	3,600[rpm]
Compression ratio ε	11
Electricity output (Biogas)	35[kW]

8. GENERATING CAPACITY TESTS

(1) Generating output tests

- City gas Max. ; 43kW
- Imitation digestion gas (CH4:60%) Max. ; 40kW
- Imitation digestion gas (CH4:50%) Max. ; 35kW

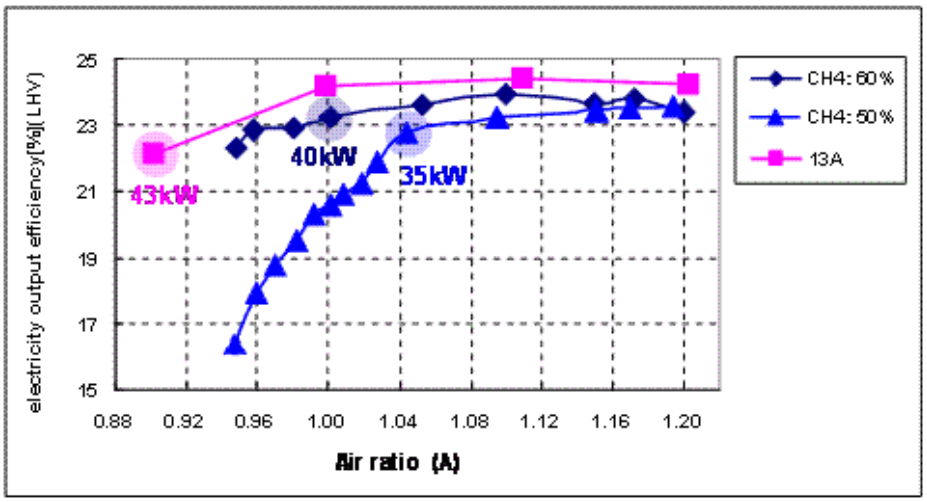


Figure 5: Generating Capacity of the Testing Machine

(2) Characteristics of exhaust gas

It has been confirmed that as the concentration of the imitation biogas becomes smaller, good combustion can be achieved by advancing ignition timing. The good combustion range of the machine can be confirmed when the methane concentration is 50%.

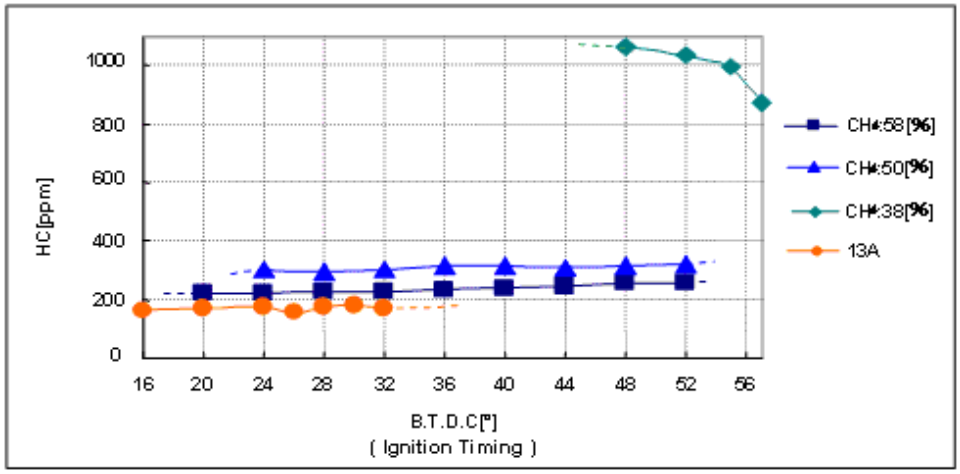


Figure 6: Characteristics of Exhaust Gas

9. FIELD TESTS AT THE PLANT

On the basis of these results, Kotobuki Industries, a machinery product company, decided to aim for commercialization of the power unit as cogeneration system for sewage digestion gas.
They produced a prototype model with the support of our company. The demonstrative operations were performed during the period of 2006 to 2009 at the wastewater treatment Plant which was actually in operation in Shunan City, Yamaguchi Prefecture.
As a result of the demonstrative operation, we obtained a good result of the average electricity output of 35kW during the operation period of 1,800 hours.

Figure 7: Prototype Model

10. FOR FURTHER PERFORMANCE UPGRADE

On the occasion of commercialization, following requests were made by the plant supplier.

(1) Electricity output of 40kW or more is desirable
→ To aim for an increase of the electricity output by remodeling the inlet pipe system with technical support of the engine maker.

(2) We aim for durability of a two-year continuous operation (approximately 16,000 hours) .
→ To modify the engine on the basis of the one which is currently sold for more durability, were proposed by the engine maker.

The remodeling was made and test operation was conducted based on such requests.

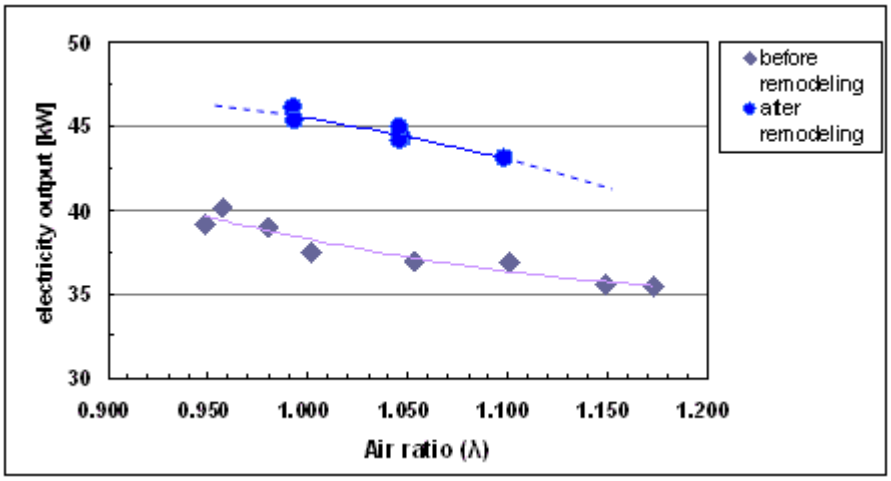


Figure 8: Electricity Output After Remodeling of the Inlet Pipe System

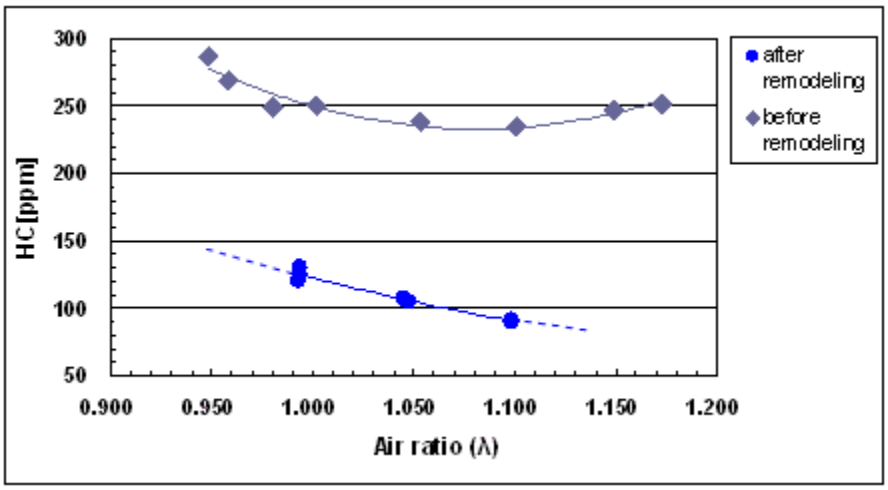


Figure 9: Combustion Range After Remodeling

Table 3: Target Specifications of the RE After Second Remodeling

Engine type	Remodeling of Rotary ZB58 (for industrial use)
Total engine displacement	1,308[cc]（654×2rotors）
Engine speed	3,600[rpm]
Compression ratio ε	9.7
Electricity output (Biogas)	40 [kW] or more

Figure 8 shows the electricity output test results in the imitation gas (CH4:60%, CO2:40%).

After remodeling of the inlet pipe system, the electricity output increased by 5kW or more compared with that before the remodeling. We could also confirm a good combustion range when the air ratio is within the range of 1.0 to1.1 and the hydro carbon is less than 250ppm.(See Figure9)

Based on these test results, Kotobuki Industries produced a prototype unit to perform endurance tests of the unit at the wastewater treatment plant in Hiagari, Kitakyushu City. They installed the unit in 2009 and it has been in continuous operation to date.

They obtained remarkable results from the tests with the operation period of 4,000 hours in stand-alone operation, 8,000 hours operation in parallel with the mains (as of June 2011), and the average electricity output of 40kW.

On the basis of these results, Kotobuki Industries have commercialized this system,

Figure 10: The unit at Hiagari, Kitakyushu City

In March 2011, Hiroshima Prefecture has decided to employ the same type Biogas-Fueled Rotary Engine System at Ota River Tobu Wastewater Treatment Center, and that will be put into operation in March 2012.

We would like to bring to your attention this system which generates power using sewage digestion gas as fuel with 9 units of rotary engine cogeneration (40kW 420V), it is planned to cover about 10% of the electric power (approximately 3,000MWh/year) used at Tobu Wastewater Treatment Center.

The system flow diagram outline and Ota River Tobu Wastewater Treatment Center are as shown below.

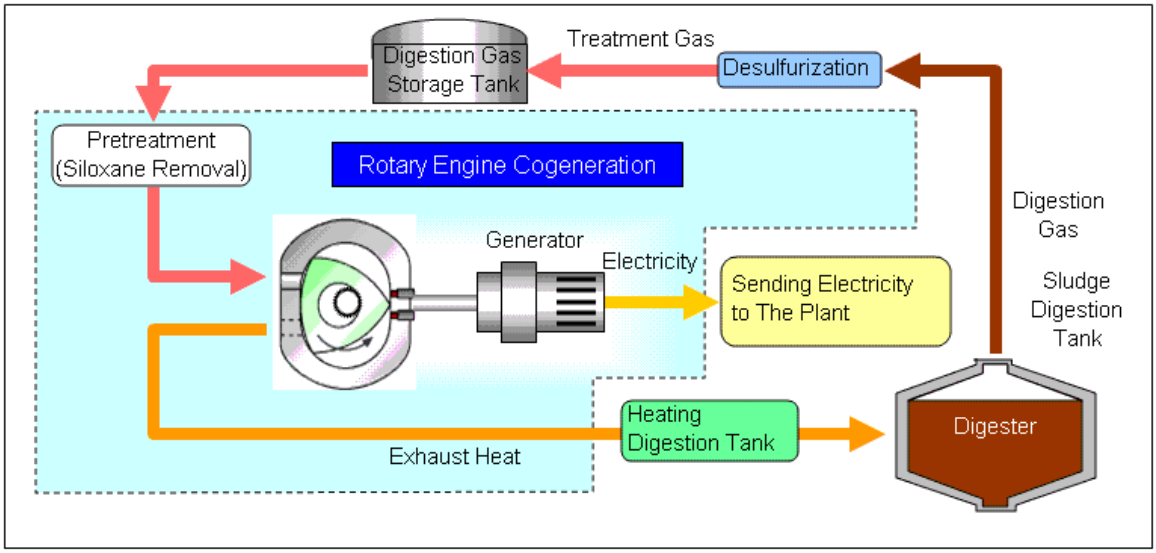


Figure 11: The System Flow Diagram

Figure 12: Ota River Tobu Wastewater Treatment Center & Sludge Digestion Tank

11. CLOSING

We sincerely thank the Mazda Motor Corporation for providing us with the technical support of the rotary engine, and the Kotobuki Industries for realizing commercialization of the digestion gas power generation system. We hope to be able to contribute to the establishment of low carbon society as much as possible through wide spread of this system to small and medium sewage plants.

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