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THE EFFECTS OF FUEL COMPOSITION ON A MEDIUM-SIZED GAS ENGINE

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1. ABSTRACT

In recent years, amidst growing interest in environmental issues, cogeneration systems have been attracting attention. In particular, the use of medium-sized gas engines for cogeneration systems with low emission and high thermal efficiency is now expected to become widespread. It is likely that biogas, LNG, etc. will be widely used in the future with a view to reducing CO_2 emissions and increasing energy security. It is important that gas engines capable of stable operation even when the composition of the fuel gas varies be developed. This study examined the effects of fuel composition on a medium-sized gas engine with a single-cylinder test engine.

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1. INTRODUCTION

In recent years, there has been a growing concern for restraining global warming and preventing environmental pollution. Attention is therefore attracted to CHP (combined heat and power) because of the favorable effect it has on reducing CO_2 emissions. CHP ensures effective utilization of the waste heat produced at the same time when electricity is generated by the gas engine. In particular, lean-burn gas engines using biogas are widely used to power cogeneration systems with an electric power output of 300kW to 2MW (“medium-sized cogeneration systems”), achieving high generating efficiency.

In the future, it is likely that biogas will be used widely with a view to reducing CO_2 emissions. To promote the use of biogas, it will be necessary, first of all, to add a greater amount of biogas to city gas.

Meanwhile, to ensure the stability of city gas supply and of the procurement cost of LNG, it is important to import LNG from diverse regions and countries, to include shale gas and other unconventional natural gases as well as conventional natural gas. Since the composition of natural gas varies from one gas field to another, it is likely that the use of natural gas with low calorific value will become all the more important in the future.

This study examined the effects of fuel composition on the performance of a medium-sized lean-burn gas engine using simulated biogas admixture and gases of lower calorific values.

2. EXPERIMENTAL EQUIPMENT AND METHODS

In this study, the authors investigated the effects of fuel gas composition on the combustion characteristics and the performance of a medium-sized supercharged open-chamber lean-burn gas engine as well as some measures to cope with variations in fuel gas composition. The engine used for the test was a water-cooled single-cylinder engine (AVL 5307NG) with a cylinder bore of 140 mm. The major specifications of the test engine are shown in Table 1 and a schematic diagram of the test apparatus is shown in Fig. 1. To simulate the supercharged condition, compressed air kept at a constant 48□ was supplied from a compressor, and a butterfly valve was installed in the exhaust system in order to apply the back pressure equivalent to a supercharger efficiency of 65%. The fuel was a mixture of methane, propane, and carbon dioxide and the flow rate from each bottle was adjusted using a mass flow controller (Yamatake MQV0500,0200,0020). After mixing, the fuel gas was introduced into an air intake pipe at a constant rate, ahead of the surge tank. The temperature of the coolant water was 80℃ at the engine outlet and the temperature of lubricant oil was kept at a constant 80℃.

Table 1 Engine specifications

Engine type	Single-cylinder, water-cooled
Compression ratio	11.6
Bore × stroke (mm)	140×153
Displacement (cc)	2236

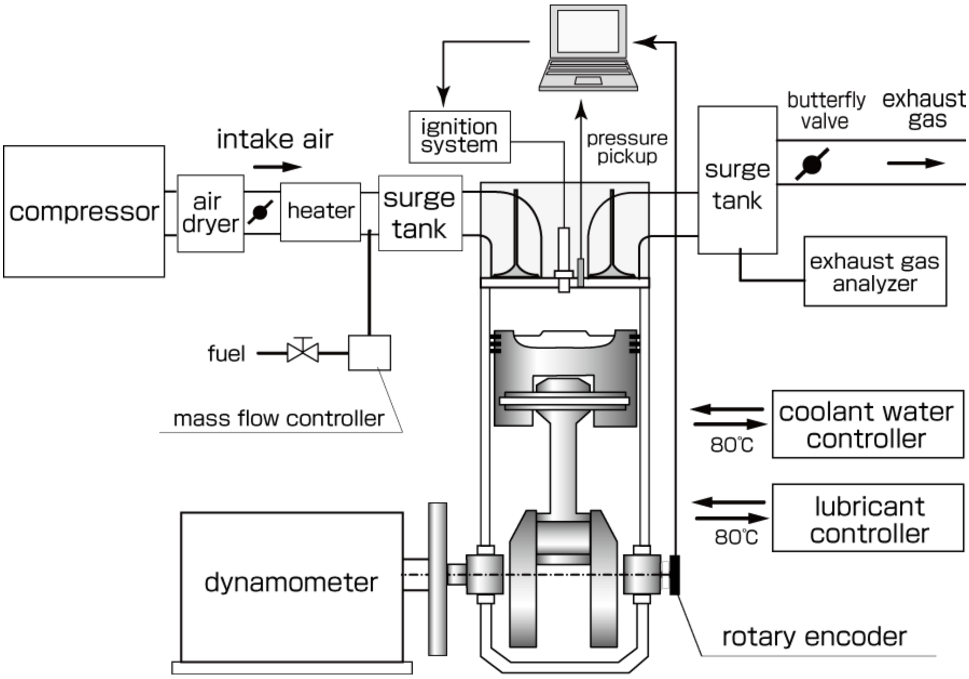

Fig. 1 Test apparatus.

The pressure inside the cylinder was measured using a pressure sensor (Kistler 6052C) and the crank angle was measured using a rotary encoder (Ono Sokki CP5720). The heat release rate, etc. were analyzed on the basis of data for 200 cycles collected using a combustion analyzer (Ono Sokki DS2000).

The exhaust gas composition was measured using an exhaust gas analyzer (Horiba Seisakusho MEXA 7100D) and the air excess ratio λ was computed from the exhaust gas composition.

The engine speed was 1200 rpm, the amount of input energy was kept at a constant 10.5 kJ/cycle and the air excess ratio λ was varied by adjusting the intake air pressure. The upper limit of air excess ratio λ was kept within the range where the coefficient of variation of indicated mean effective pressure COV_{IMEP} remained at 3.0% or less, and the lower limit was kept within the range where the maximum amplitude of the high-frequency component of cylinder pressure averaged 10 kPa or less over 200 cycles. Under these conditions, where the engine was operated using standard gas with a higher calorific value of 44.6 MJ/Nm^3 and an air excess ratio of 1.7, the intake air pressure was 115 kPa and the brake mean effective pressure was 1.38 MPa.

3. TEST FUEL GAS

Figure 2 is a schematic diagram of the test gas supply apparatus. The fuel consisted of methane, propane, and carbon dioxide supplied in separate bottles. After adjusting the pressure of each gas using a pressure-reducing valve, the flow rate of each gas was adjusted using a mass flow controller and the gases were mixed using a static mixer before being introduced to the intake pipe.

Table 2 shows the composition of the simulated biogas admixture gases used in the tests; Table 3 shows the composition of the lower-calorie gas. The compositions of the simulated biogas mixture gases were arrived at by adding a mixture of carbon dioxide (40%) and methane (60%), simulating biogas, to a mixture of methane and propane with a gross calorific value of 44.6 MJ/Nm^3, simulating natural gas. The lower-calorie gases were a mixture of methane and propane, the ratios of which were changed in order to vary the calorific value.

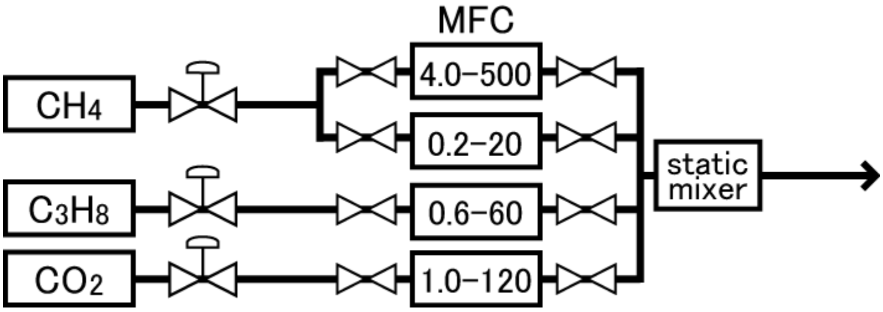

Fig. 2 Schematic diagram of the test gas supply apparatus.

Table 2 Composition of simulated biogas mixtures

Biogas ratio %	CH_4 vol%	C_3H_8 vol%	CO_2 vol%
0.00	91.28	8.30	0.00
19.31	84.55	6.78	7.89
39.76	78.09	4.96	16.24
59.46	71.77	3.30	24.29
79.42	65.71	1.72	32.37

Table 3 Composition of lower-calorie gases

Higher calorific value MJ/Nm3	CH_4 vol%	C_3H_8 vol%
44.60	91.28	8.30
43.58	93.04	6.57
42.74	94.61	5.09
42.00	96.37	3.63
41.08	97.44	2.27
39.55	99.27	0.01

4. TEST RESULTS AND ANALYSIS

The relationship between the ratio of biogas added and the range of air excess ratios within which the engine would operate was investigated using the simulated biogas mixtures. The ignition timing was fixed at 29 deg.BTDC, which is the MBT at an air excess ratio of 1.7 with a methane-propane mixture simulating natural gas. The results are shown in Fig. 3. As the ratio of biogas added rose, the upper and lower limits of the air excess ratio range within which the engine would operate both fell, and at 100% biogas the engine would not operate. Figure 4 shows thermal efficiency ηe, NOx concentration, and exhaust temperature Tex for the leanest conditions under which the engine would operate at various ratios of biogas added. Up to a ratio of 60% biogas, thermal efficiency remained constant, but at 80% the exhaust temperature rose and thermal efficiency fell.

Figure 5 shows the results of tests to determine the relationship between the calorific value and the air excess ratio at which the engine would operate with lower-calorie gas. Ignition timing was fixed at 29 deg.BTDC. As the ratio of methane rose and calorific value fell, the upper limit of the range of air excess ratio at which the engine would operate remained unchanged, but the lower limit fell. Figure 6 shows thermal efficiency, NOx concentration, and exhaust temperature when calorific value was varied for an air excess ratio of 1.7. As the ratio of methane increased and calorific value decreased, thermal efficiency and NOx concentration remained constant if the air excess ratio remained constant

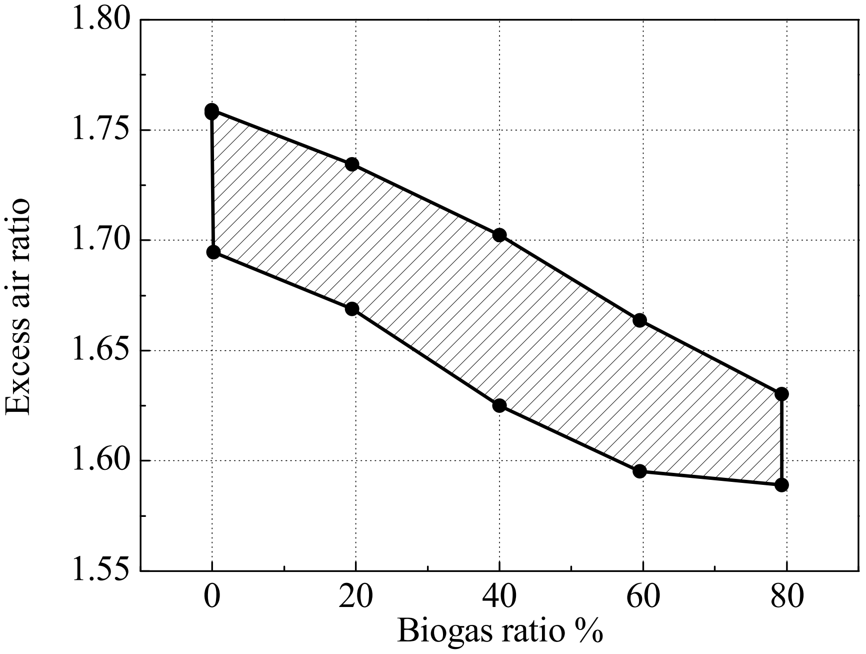

Fig. 3 Effect of biogas ratio on operating range.

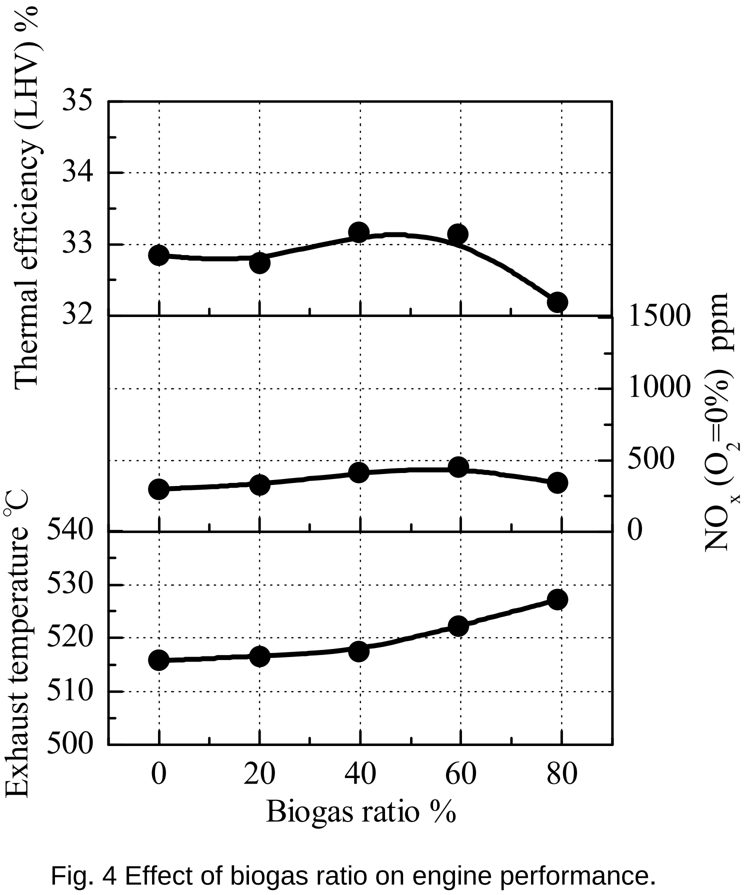

Fig. 4 Effect of biogas ratio on engine performance.

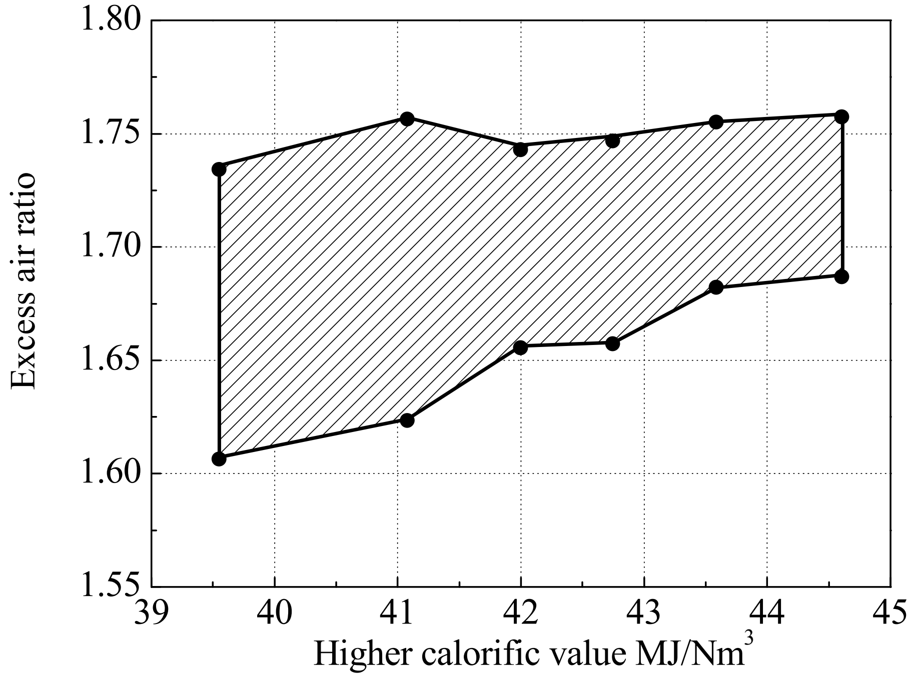

Fig. 5 Effect of calorific value on operating range.

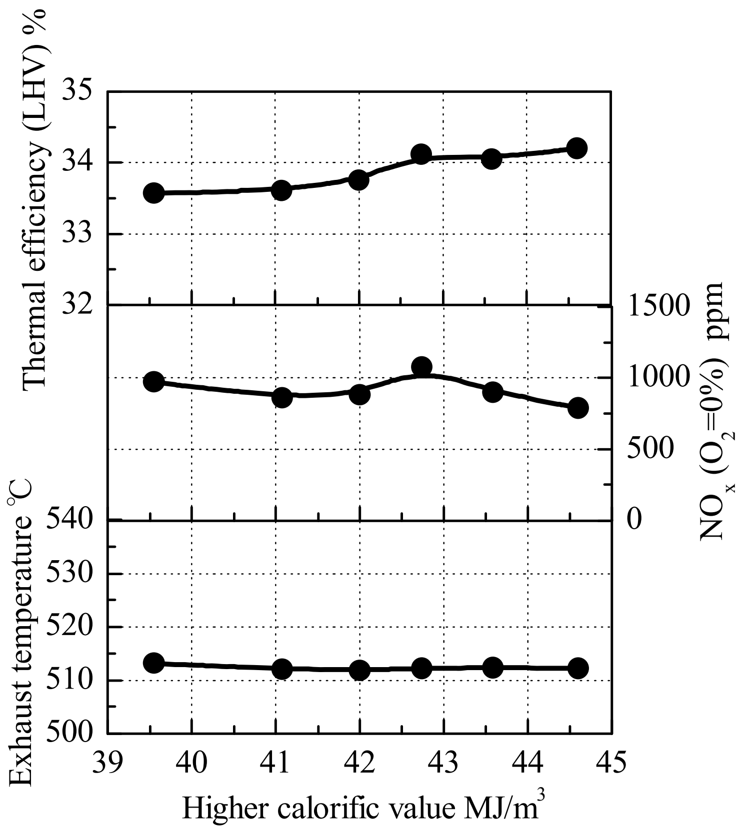

Fig. 6 Effect of calorific value on engine performance.

5. CONCLUSIONS

With a view to determining the effects of biogas and lower calorific gas fuels on medium-sized lean-burn gas engines, the effects of fuel composition on engine performance were investigated using a test apparatus based on a single-cylinder test engine, designed to simulate an actual gas engine. With fuels simulating biogas mixtures, the ratio of biogas added, as the ratio of biogas added rose, the upper and lower limits of the range of air excess ratios within which the engine would operate both fell. A comparison of thermal efficiency under which the engine would operate at various ratios of biogas added showed that thermal efficiency fell when the biogas added ratio was 80% or higher. With lower calorific gases, as calorific value fell, the upper limit of the range of air excess ratios within which the engine would operate remained constant, but the lower limit fell. As calorific value fell, if the air excess ratio remained constant, thermal efficiency and NOx concentration remained constant.

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