Development of High Efficiency Gas Engine for Green House Gas Reduction

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Most of the methane gas generated in a coalmine at the time of coal digging is unused and discharged into atmosphere, which becomes one of the causes of global warming. Because of the low methane concentration and large variation in the concentration, the coalmine methane gas has so far been hard to put into effective use. The new technical development is based on the lean-burn gas engine using the micro-pilot ignition system in order to reduce the emission of green house gasses, and incorporates development of a gas engine capable of high-efficiency power generation while using the coalmine methane gas as fuel. Mitsubishi Heavy Industries, Ltd. (MHI) has so far learned combustion characteristics of coalmine methane gas and studied on the gas supply system suitable for the coal mine methane gas.

1. Introduction

With the global call for preventing emissions of green house gasses increasing, the reduction in emission of methane gas from a coal mine at the time of coal digging and the effective use of the gas as a source of energy are drawing attention.

Approximately 90% of the total volume of coalmine methane gas is currently being discharged into atmosphere unused. Methane gas, with a large green house effect, amounts approximately to 500 million tons in terms of the CO_2 emission per year in the world, which comes to be almost 40% of the annual emission of CO_2 in whole Japan.

Originally, methane gas is a clean energy source. However, because of the low concentration and large variation of the concentration, the coalmine methane gas has so far not been used as a fuel for boilers or gas turbines.

In order to solve such problems MHI is developing a high-efficiency, high-power gas engine capable of using the coalmine methane gas as fuel on the basis of the lean-burn gas engine "MACH-30G" using micro-pilot ignition system.

2. Outline of coalmine methane gas

Fig. 1 shows the outline[(1)] of coalmine methane gas. The methane gas in coal bed has a high degree of concentration amounting normally to 90%. However, it is recovered by pump or is leaned with air and discharged into atmosphere in order to prevent explosion in the mine cavity. The concentration of the recovered gas differs according to the coal mine and the recovery system, but with the present technology, the restored methane concentration is confined to a mere 30–50% because of the inclusion of air, etc. during the process of recovery.

Further, because of a large variation of methane concentration in the gas, methane gas is considered hard to use as a stable energy source, so that only a part of it is currently being used as a source of heat, etc.

Since methane gas is evaluated to have the global warming potential 21 times higher than CO_2, it could be an effective means of reducing the emissions of green house gasses only if the methane gas currently discharged to the atmosphere were burned and put to effective use.

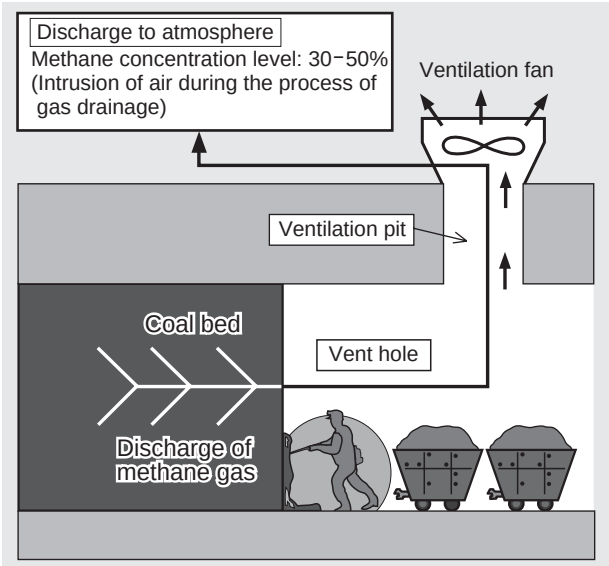

Fig. 1 Outline of coalmine methane gas
The intrusion of air during the process of gas recovery causes the gas concentration to deteriorate, with a large amount discharged into the atmosphere.

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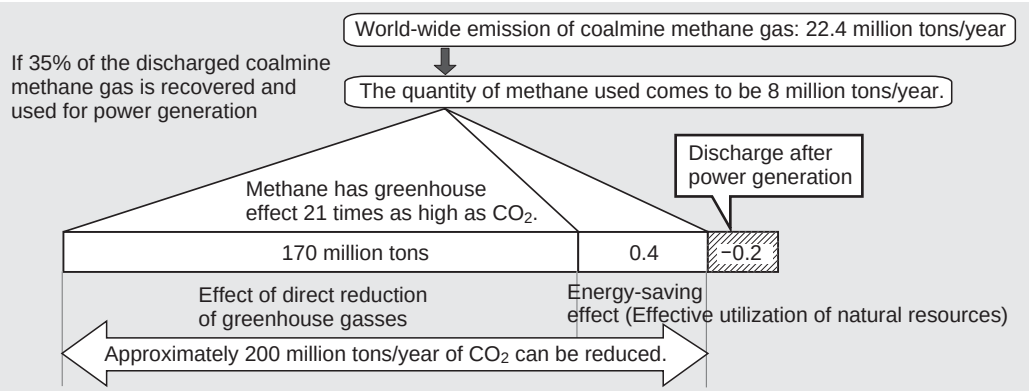

Fig. 2 Effect of coalmine methane gas power generation on reduction of greenhouse gas emissions
Not only the direct reduction, but also the reduction in emissions by reducing the consumption of other fossil fuels.

Further, if it could be used as a fuel for power generation, the consumption of other fossil fuels could be cut down, contributing to the reduction in CO_2 emission (**Fig.2**). Accordingly, power generation using coalmine methane gas is drawing attention of the world in recent years.

3. Objective

The brake mean effective pressure (BMEP) of a conventional spark ignition gas engine is approximately 0.6 –0.8 MPa when coalmine methane gas is used. The output is lower than a diesel engine or a natural gas engine of the same class. Further, the ignition was unstable when the methane concentration level in the coalmine methane gas became lower, causing a problem for continuous operation of the engine.

This research, therefore, aims at developing a coalmine methane gas engine to correspond to the high-power, high-efficiency and variation in gas concentration, based on the MACH-30G gas engine with highest level of efficiency in the world. This paper introduces, as the first step, the fundamental combustion test and verification test for practical performance in order to develop the required fundamental technologies. The tests are carried out by using a small-size gas engine testing equipment. The objectives of development using the small-size testing equipment are given in **Table 1**.

4. Technical Problems and Countermeasures

4.1 Ignition system

The pilot ignition system[2] used in MACH-30G gas engine was adopted as the ignition system for the gas engine corresponding to coalmine methane gas.

In the case of a conventional spark ignition gas engine, the air-fuel mixture with the air-fuel ratio close to the theoretical air-fuel ratio level is supplied to the pre-combustion chamber. The air-fuel ratio varies due to the change in fuel gas concentration, resulting in unstable ignition. The output was also limited in order to ensure longer ignition-plug life.

In the case of micro-pilot ignition system, however, a small quantity of liquid fuel is injected into the pre-combustion chamber to allow self-ignition. Since the ignition energy in this system is large, stable ignition for lean air-fuel mixture can be ensured. In other words, there is no need to supply air-fuel mixture with the air-fuel ratio close to the theoretical level, ensuring stable ignition even for the coalmine methane gas with variable fuel gas concentration.

The pilot ignition system is compared with the spark ignition system in **Fig. 3**.

Table 1 Performance target levels

Output	5 000 kW class
Efficiency at generator terminal	38 % or above
Variation in methane concentration	35~50 %

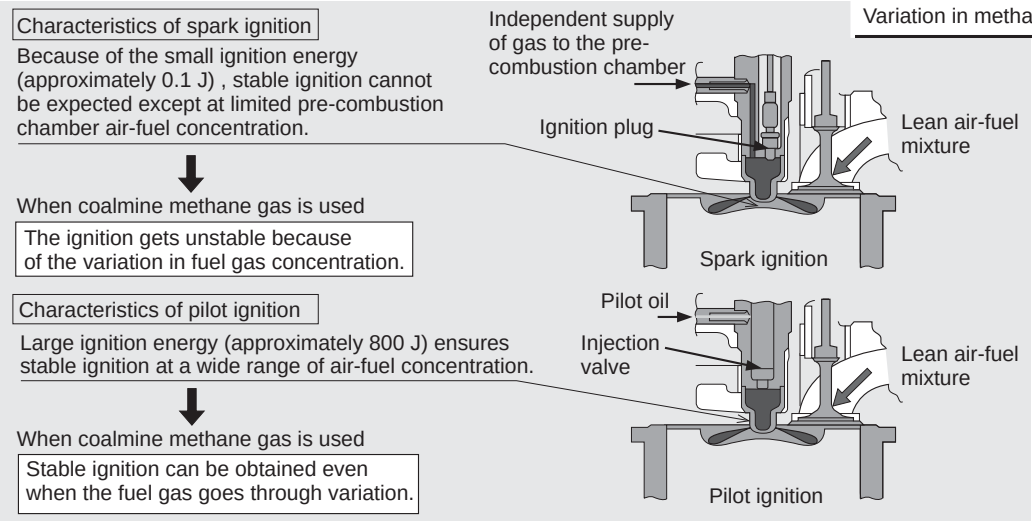

Fig. 3 Comparison of ignition systems
Adoption of pilot ignition system corresponds to the variation in gas concentration

4.2 Gas supply system

The coalmine methane gas has about 1/2-1/3 the calorific value of natural gas, so that the methane gas 2–3 times the quantity of natural gas must be supplied to a gas engine.

In the case of MACH-30G gas engine, the gas is supplied at the position immediately before each cylinder. The fuel gas feed pressure must be higher than the inlet manifold pressure. The engine efficiency is down when coalmine methane gas with high flow rate is used, because the power for raising fuel gas pressure increases.

In the case of medium- and small-size gas engine, the power for raising fuel gas pressure is not necessary because the air-fuel mixture is formed before the turbo charger. However, approximate measures have to be taken against the back fire inside the inlet manifold and the blow by of air-fuel mixture.

Fig. 4 shows comparison between the system supplying gas before cylinder and the system pre-mixing gas and air before turbocharger. As for the testing equipment, the pre-mixing system was adopted in the simulated gas test to verify the applicability to the MACH-30G gas engine.

4.3 Control system

MACH-30G gas engine uses a unique combustion control technology called Mitsubishi Real-time Intelligent Control System (M-RICS)[3]. In this system real-time diagnosis of the combustion condition is carried out based on the combustion pressure data in each cylinder, and ensures high-efficiency operation while averting the abnormal combustion (**Fig. 5**).

The utilization of M-RICS ensures instantaneous correspondence to the variation in fuel gas concentration even when coalmine methane gas is used as fuel, enabling high-efficiency and stable operation **(Fig. 6)**.

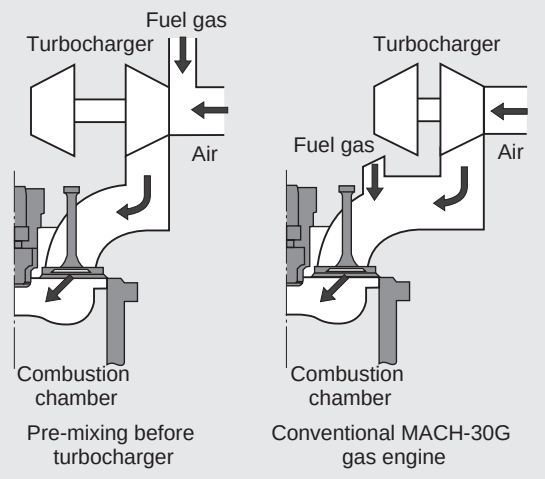

Fig. 4 Comparison of gas supply systems
The system conventionally adopted in MACH-30G compared with the mixing system before turbocharger

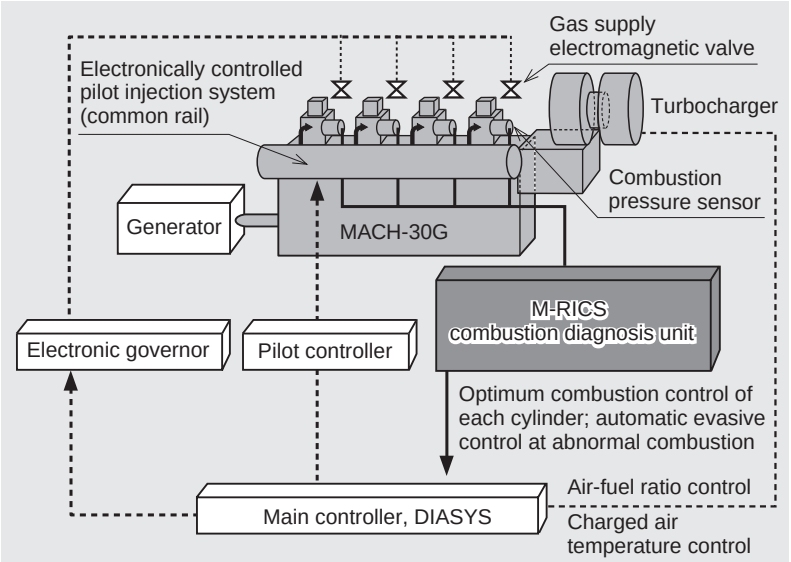

Fig. 5 Outline of M-RICS
The system detects the combustion pressure to control each cylinder, ensuring both high efficiency and stability.

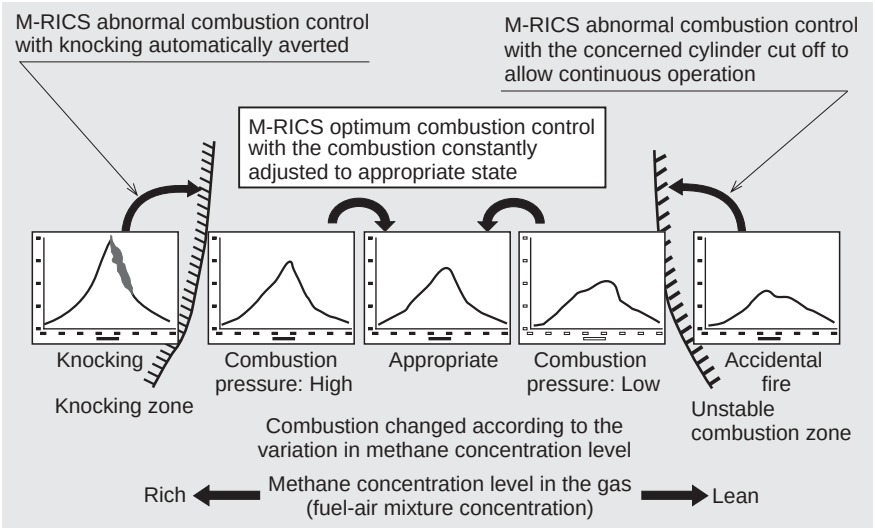

Fig. 6 Combustion control using M-RICS
The M-RICS ensures control corresponding to the variation in methane gas concentration.

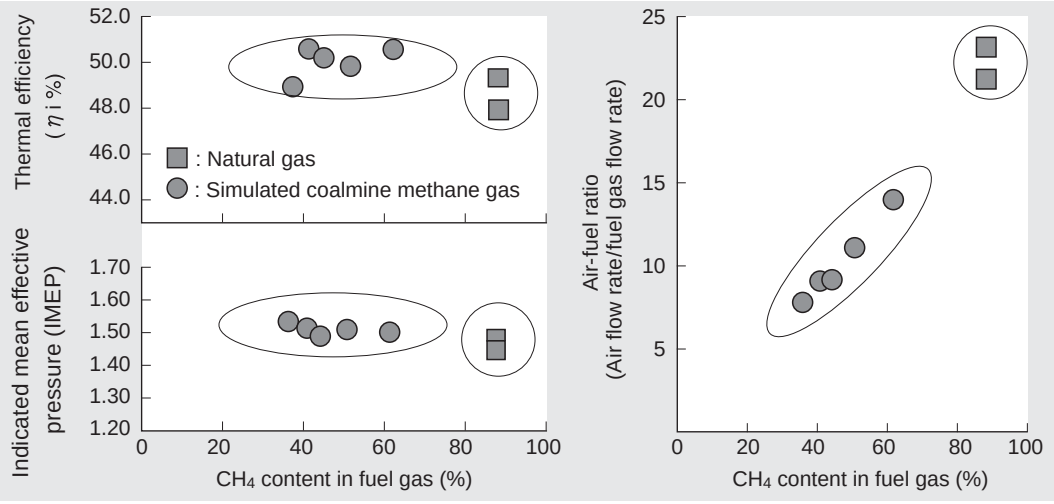

Fig. 7 Results of elementary combustion test
The results indicate methane concentration during combustion vs. thermal efficiency and air-fuel ratio.
Even the coalmine methane gas can give the combustion performance equivalent to that of natural gas through optimization of air-fuel ratio.

5. Fundamental combustion test

5.1 Testing equipment

A S6R engine manufactured by General Machinery & Special Vehicle Headquarters of MHI was remodeled into a pilot ignition type gas engine. The remodeled engine was used as the testing equipment for coalmine methane gas fundamental combustion test. The test was carried out using simulated gas. The specifications of the testing equipment are given in **Table 2**.

5.2 Combustion test results

The main test results are shown in **Fig. 7**. The results show that, with the adoption of micro-pilot ignition technology, stable operation can be obtained even by using coalmine methane gas with the output and efficiency as high as that of natural gas. Further, the optimum air-fuel ratio per gas concentration rate was learned.

Table 2 Specifications of testing equipment

Item	Specification
Rated output	400 kW
Rotational frequency	1 500 rpm
Number of cylinders	6
Bore × Stroke	170 mm × 180 mm
Compression ratio	10.0
Combustion system	Pre-combustion chamber type
Fuel	Gas, light oil

6. Application to actual machine

Based on the study and combustion test results so far obtained, the MACH-30G using coalmine gas as fuel is on the way to commercialization.

At present, verification using simulated gas is under way to verify the control system when coalmine methane gas as used for MACH-30G engine as fuel.

7. Conclusion

A gas engine capable of high-efficiency power generation is under way by using the coalmine methane gas so far discharged in great amount into air as fuel in order to reduce emissions of greenhouse gasses. The combustions tests and studies so far made indicate that the adoption of pilot ignition system ensures the power generation efficiency level equivalent to that of natural gas.

MHI is determined to make further verification of the system in order to put the MACH-30G engine using coalmine methane gas into practical use.

The research has been a part of the "Joint Research Program of Technological Development in the Private Sectors" for fiscal year from 2002 to 2004 of the Research Institute of Innovative Technology for the Earth (RITE). Corporation to this regard by a large number of concerned people is highly appreciated.

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