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Research Paper

Activities for high-efficiency small gas engines

Yoshitane Takashima [a,*], Satoshi Katayama [a], Takahiro Sako [a], Masahiro Furutani [b]

[a] Osaka Gas Co., Ltd., 5-11-61 Torishima, Konohana-ku, Osaka 554-0051, Japan
[b] Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya, Aichi 466-8555, Japan

HIGHLIGHTS

- Our research is on various methods of improving the efficiency of small gas engines.
- In the short term, turbocharged stoichiometric combustion with EGR will be the best technology.
- In the medium-to-long term, it will be more effective to develop lower-temperature combustion.
- Turbocharged HCCI and D-EGR are the options with increased EGR ratio.

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ABSTRACT

Interest in the potential of natural gas is growing, owing to its low CO_2 emissions per unit of heat produced, and to the development of techniques for the exploitation of shale gas. Research and development relating to natural gas is also being pursued in view of its potential to increase Japan's energy security, because deposits are found around the world.

Osaka Gas is pursuing the medium-to-long term development of gas engines. Increasing compression ratio, improving combustion under lean combustion conditions, and increasing specific output will be key to improving thermal efficiency. This paper summarizes the results of tests Osaka Gas to date with a view to improving the efficiency of small gas engines.

First, tests with downsizing through forced induction were conducted. A naturally aspirated gas engine with a displacement of 3318 cm^3 was fitted with a high-efficiency turbocharger, and performance tests were conducted at brake mean effective pressure (BMEP). It was found that thermal efficiency under lean conditions reached 40%, but that NOx emissions exceeded 1500 ppm. When exhaust gas recirculation (EGR) was applied with a view to reducing NOx emissions, at the EGR limit (EGR ratio 18%), thermal efficiency was around 39% (NOx 500 ppm). With stoichiometric combustion, at the EGR limit, thermal efficiency reached a maximum of 39%.

Next, the effectiveness of multi-point ignition, pre-chamber spark plugs and homogeneous charge compression ignition (HCCI) in improving lean/diluted combustion were studied, and each was found to improve stability, extend the lean limit and increase thermal efficiency under lean combustion conditions.

Studies were also conducted in relation to the dedicated EGR system proposed by Southwest Research Institute (SwRI) as a means of improving EGR. It was determined that around 9% H_2, which has a combustion-promoting effect, was produced under conditions where the equivalence ratio was 1.5.

1. Introduction

Micro-cogeneration originally spread in Japan with a view to achieving energy and cost savings, and reducing peak power demand. Furthermore, in recent years, the emphasis has been on convenience, including the development of systems able to ensure a power supply during outages, using LPG fuel and air to supply electricity for a short time in an emergency, or running on biogas fuels. Generating efficiency has also improved, with 50 kW-class systems achieving an efficiency of 34% [1]. These improvements are largely due to improvements in the efficiency of gas engines, in which lean combustion has played a particularly important role. However, further improvements will be required to promote wider use of natural gas in the future. For instance, technical guidelines issued by the Japan Gas Association call for the efficiency of small

* Corresponding author.
E-mail address: y-takashima@osakagas.co.jp (Y. Takashima).

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Table 1
Engine specifications.

Engine type	4-cylinder water-cooled
Stroke	110 mm
Bore	98 mm
Compression ratio	13:1
Displacement	3318 cm^3
Engine speed	1500 rpm
Maximum pressure	10 MPa

gas engines with an output of 100 kW or less to be increased to 45% by 2030 [2]. Osaka Gas is pursuing the research and development of gas engines with a view to achieving this target.

This paper summarizes the results of Osaka Gas's work on improving the efficiency of small gas engines to date, and sets out directions for future technical development.

2. Technologies to improve the efficiency of small gas engines

Improving thermal efficiency will depend on, among other measures, increasing compression ratio, improving combustion under lean combustion conditions, and increasing specific output (downsizing). This section describes the results of Osaka Gas's research on these technologies to date.

2.1. Downsizing through forced induction

This technology aims to improve thermal efficiency by forced induction of fuel-air pre-mixture using a turbocharger, and increasing the specific output of the cylinder.

This study examined the performance of a naturally aspirated gas engine with a displacement of 3318 cm^3 (equivalent to 25 kW generated output) fitted with a high-efficiency turbocharger.

Stoichiometric and lean combustion were compared, and the effect of exhaust gas recirculation (EGR) on each was examined.

Table 1 shows the specifications of the test engine and maximum pressure limit. Fig. 1 shows the experimental setup. Engine speed was 1500 rpm and brake mean effective pressure (BMEP) was 1.33 MPa (equivalent to 50 kW generated output). In every case, maximum brake torque (MBT) ignition timing was used, and the fluctuation of maximum in-cylinder pressure and indicated mean effective pressure was within the specified range.

Fig. 2 shows the relationship between change in thermal efficiency and NOx concentration. Lean combustion showed greater thermal efficiency than stoichiometric combustion, reaching 39.7%.

However, although the thermal efficiency of stoichiometric combustion is lower, it allows the reduction of NOx emissions using a three-way catalyst.

Since three-way catalysts are unsuitable for lean combustion, it is necessary to use other NOx reduction technology. Urea selective catalytic reduction is a possible way to reduce NOx emissions, but issues such as the method of providing the supply of urea make it impractical. It is also possible to use storage and reduction catalysts, but these use fuel as the reducing agent, which would lead to a fall in thermal efficiency. EGR was identified as a potentially simple and convenient means of NOx reduction. Increasing the EGR ratio caused a fall in NOx concentration, but even at the EGR limit of 18%, the NOx concentration was 500 ppm, and there is scope for further research. The use of EGR also reduced thermal efficiency.

EGR was identified as a potential means of increasing thermal efficiency with stoichiometric combustion, because three-way catalysts can be used for NOx reduction. The Figure shows that NOx emissions fell as EGR ratio increased, as with lean combustion, but thermal efficiency increased. This was largely due to a reduction in cooling loss, caused by the fall in gas temperature in the combustion chamber.

Thus, downsizing through forced induction increases thermal efficiency. However, with highly efficient lean combustion, NOx reduction becomes an issue, while with stoichiometric combustion, NOx reduction is unnecessary, but thermal efficiency is low compared with lean combustion. It is therefore likely to be necessary to adopt a combination of stoichiometric combustion and three-way catalysts in the short term, and to pursue NOx reduction technology compatible with lean combustion in the medium-to-long term.

In these tests, output was limited to 50 kW. Increasing output further would make it possible to increase thermal efficiency, but it would be necessary to avoid knocking in engine.

2.2. Improving lean/diluted combustion

As stated in the previous section, lean combustion will be the best option for increasing thermal efficiency, but there are issues with NOx reduction. If lean combustion can be further improved, NOx post-processing will become unnecessary, but stable ignition and combustion will be necessary if the lean limit is to be extended. For this reason, the use of multi-point ignition, pre-

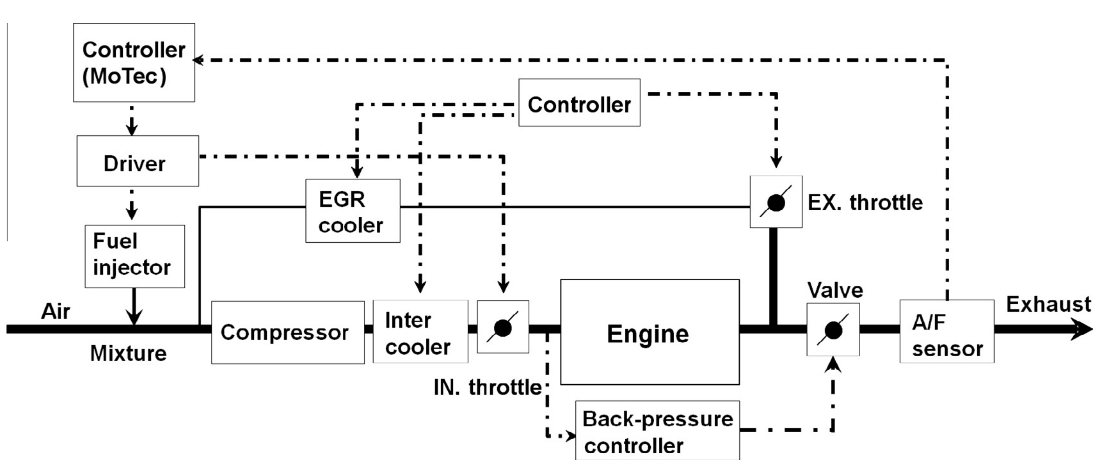

Fig. 1. Schematic diagram of experimental setup.

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