# Performance Characteristics of a 10 kW Gas Engine for Generation Package

**Young-Jae Lee†, Young-Dug Pyo, Gang-Chul Kim, Yong-Ho Kwon*, Si-Deok Oh***

*Korea Institute of Energy Research, Daejon 305-343, Korea*

**Hyosung Corporation, Seoul 137-060, Korea*

**Key words:** Cogeneration, Gas engine, Heat, Electricity, Distributed generation

**ABSTRACT:** Cogeneration has been widely introduced in many countries for use in industrial, commercial and residential applications. However, there have been few models with an output of less than 100 kW. In the present study, a spark ignited gas engine with electric generation output of 10 kW was developed for micro cogeneration package. Developed gas engine achieved following performance characteristics such as 26.7% of electric generation efficiency, NOx emission less than 10 ppm at 13% oxygen, 82 dB of noise level, and about 3 seconds of switching time from idling to nominal power.

## 1. Introduction

Cogeneration System (CGS) is the simultaneous generation of heat and electricity in a single unit and is a highly energy-efficient (60% to 80%) technology compared to the independent generation of each product. In this sense, cogeneration system is one of the most important technologies which has to be widely introduced in many countries not only to save energy consumption but also to reduce $CO_2$ emission.(1-4)

In addition, operation of the CGS during the peak time of electricity and heat consumption, may contribute to load sharing between the electricity and gas, and may also reduce the budget required to construct large scale power plants. As a result, it is expected to be widely adopted as a distributed generation system in the future.

Most models that have been so far distributed domestically and overseas are of 200 kW capacity or above. However, as interest in the distributed generations has increased recently, miniaturization is in progress, and a residential micro CGS with an output as small as 1 kilowatt was developed in Japan.(5)

As it is well known, CGS uses internal combustion engine or gas turbine, etc. as a prime power source. However, it seems to be most economical to use internal combustion engine for micro CGS. City gas is the most desirable fuel for CGS since it is energy-efficient and its exhaust is very clean.

In this study, a spark ignited gas engine with generation output of 10 kilowatts was developed for micro cogeneration system. The gas engine micro cogeneration system can be used in the buildings where both electricity and heat are used, e.g. motels, restaurants, hospitals, and public bathrooms. In the future, it can also be used as a prime power source for GHP (Gas engine Heat Pump).

## 2. Natural gas engine and test system

### 2.1 Remodeled engine and target output

Industrial engine model B5C of Kia Motors is chosen as a base engine. The engine was

† Corresponding author
Tel.: +82-42-860-3334; fax: +82-42-860-3102
*E-mail address*: yjl@kier.re.kr

originally carburetor-type spark ignited gasoline engine and its displacement volume is 1,498 cc.

Since the rated generation output of cogeneration system to be developed is 10 kW at 1,800 rpm, the rated output of natural gas engine is aimed to be 11 kW at 1,800 rpm in due consideration of generation efficiency.

## 2.2 Main remodeled parts of the engine

### 2.2.1 Gas fuel supply system

The carburetor and the gasoline fuel pump were removed from the base engine, and the fuel supply system for natural gas was installed onto it. The fuel supply system consists of gas mixer (Impco, U.S.A.), pressure regulators (1st stage: Karl Dungs GmbH, Germany, 2nd stage: Impco, U.S.A.), and electric shut-off valve (CKD, Japan).

### 2.2.2 Ignition system

The distributor-type ignition system is identical with that of the base engine.

### 2.2.3 Intake system

Since the intake manifold of the base engine is not suitable for installing the throttle body onto it, it is replaced with the intake manifold equipped with surge tank, and throttle body was installed onto the manifold. It is possible for this replaced intake manifold to mix air and fuel properly.

### 2.2.4 Exhaust system

Since the original engine adapted an open loop fuel control, catalytic converter for exhaust gas purification was not installed. In order to reduce NOx emitted from the gas engine, three way catalytic converter is additionally installed to the exhaust manifold.

### 2.2.5 Speed governor

In the gas engine, engine speed and load is controlled by adjusting the opening of intake throttle valve, and a speed governor is required to actuate the throttle valve. The electronic speed governor with actuator (Heinzmann, Germany) which is excellent in control accuracy is used to control the engine speed and load. To catch the control input signal, a magnetic sensor is installed near the flywheel gear of the engine.

## 2.3 Engine test system

Schematic diagram of the engine test system is shown in Fig. 1. It mainly consists of an

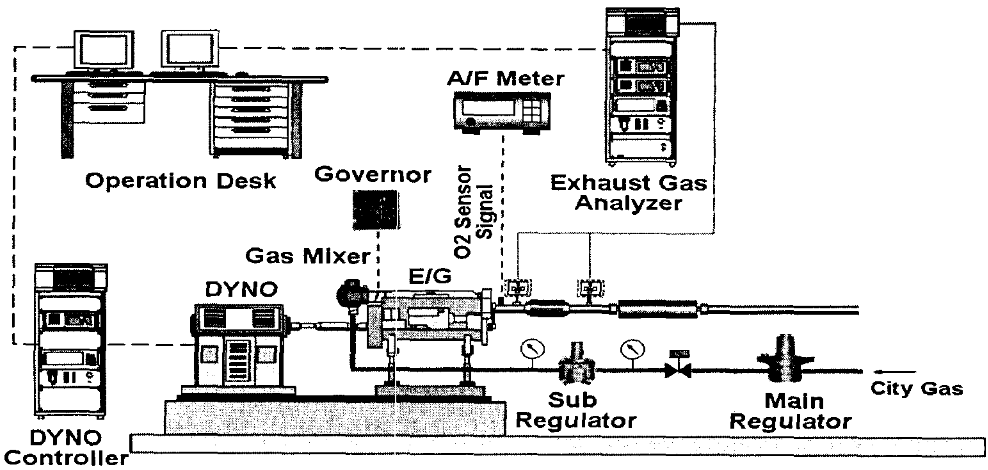



Fig. 1 Schematic diagram of engine test system.

Table 1 Specifications of test equipment

| | Specifications |
|---|---|
| Engine dynamometer | · Eddy current type<br>· Max. speed : 8,000 rpm<br>· Max. toque : 85 kg · m/3,000 rpm |
| Exhaust gas analyzer | · THC/O2 analyzer : FMA-125<br>· NO/NOx analyzer : CLA-150M<br>· CO(H/L) analyzer : AIA-120 |
| A/F meter | · Air-fuel ratio : 9 to 30 AFR |
| Differential pressure meter | · Scale : 100 mbar / 100 mmH$_2$O |
| Gas meter | · 0~18 m$^3$/hr under 0.3 kg/cm$^2$ |

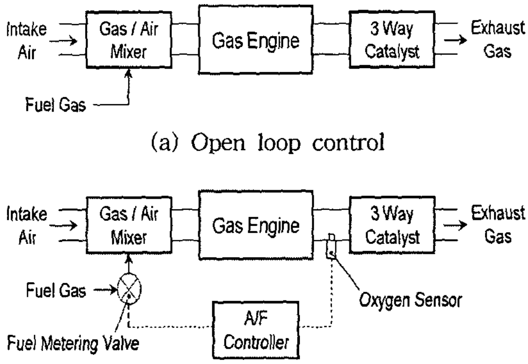
engine dynamometer, peripheral measuring equipments, and an exhaust gas analyzer. Signals from each equipment are sampled by data acquisition system for every second and then analyzed.

Measurement variables include engine speed and torque, exhaust emissions, mass flow rate of intake air, temperatures (lubricating oil, engine cooling water, intake air, etc.), pressures (intake boost pressure, lubricating oil, gas supply pressure, etc.), flow rate of cooling water, A/F (air to fuel) ratio, and fuel consumption rate. Specifications of major test equipments are shown in Table 1. The engine dynamometer, exhaust gas analyzer, A/F ratio meter, micro manometer, and gas meter in the table are products of Onosokki (Japan), Horiba (Japan), ECM (U.S.A), Furness Controls (U.S.A) and Brooks (U.S.A), respectively.

## 3. Performance characteristics of prototype natural gas engine

### 3.1 Open loop fuel control on the engine dynamometer

A Stoichiometric A/F ratio control using three way catalytic converter keeps the A/F ratio of the engine near the theoretical A/F ratio via closed loop A/F control. Thus it can purify




(a) Open loop control

(b) Closed loop A/F control

Fig. 2 Comparison of A/F control methods.

three different emissions of NOx, CO, and HC. As shown in Fig. 2, since exhaust oxygen sensor, electronic fuel metering valve, and electronic A/F controller should be installed to preform the feedback control, it increases the cost of the engine. Therefore, this study examines first the validity of an open loop way which uses the three way catalyst without the A/F feedback control.

As shown in Fig. 3, in the case that actual A/F ratio of the engine is lower than the theoretical A/F ratio, there is little change in CO conversion efficiency of three way catalyst, but there is a dramatic decrease in NOx conver-

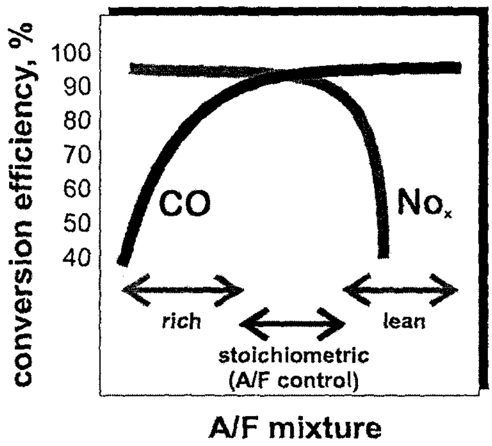



Fig. 3 Conversion efficiency of the 3 way catalyst.

sion efficiency. On the contrary, when the actual A/F ratio is higher than the theoretical one, there is little change in NOx conversion efficiency, but CO conversion efficiency is greatly decreased.[6] The conversion efficiency as mentioned above means the reduction rate of exhaust emissions between before and after catalyst.

In case that the engine is operated in open loop ways, conversion efficiency of catalytic converter for NOx can be kept as high value provided that the actual A/F ratio is always maintained higher than the theoretical one. Since NOx is the only regulated exhaust emission in gas engine cogeneration system, NOx emission at both the engine exit and catalyst exit are examined for various excess air ratio conditions of the engine.

Figure 4 shows the variations of NOx emission at both the engine exit and catalyst exit with excess air ratios under the engine operation condition of 11 kW at 1,800 rpm. In this figure, unless the catalytic converter is installed, NOx emission level at the engine exit ranges from 500 to 2,000 ppm which is rather high, and these values can not satisfy the current NOx standard of 500 ppm at 13% $O_2$ condition in Korea.

NOx emission at the catalyst exit is almost the same as that at the engine exit over the lean mixture region where the excess air ratio is larger than 1.

However, NOx emission at the catalyst exit is dramatically decreased to the values about 10 ppm over the rich mixture region where the excess air ratio is less than 0.99. Therefore, if

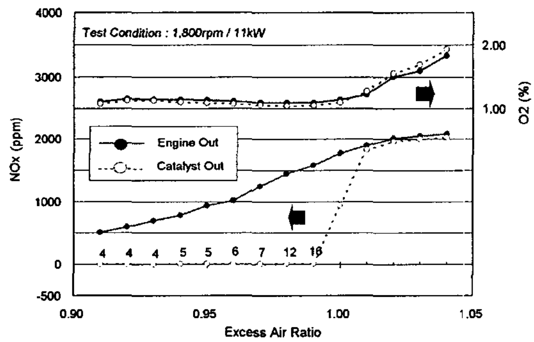



Fig. 4 NOx and $O_2$ emissions from the gas engine.

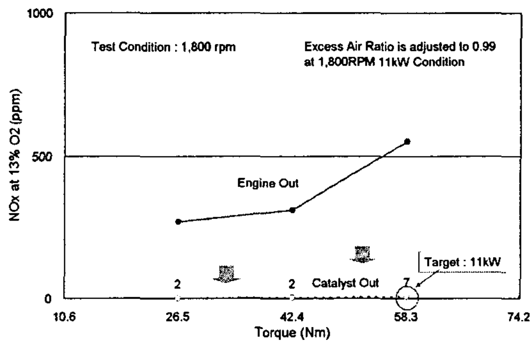



Fig. 6 NOx emission from the gas engine.

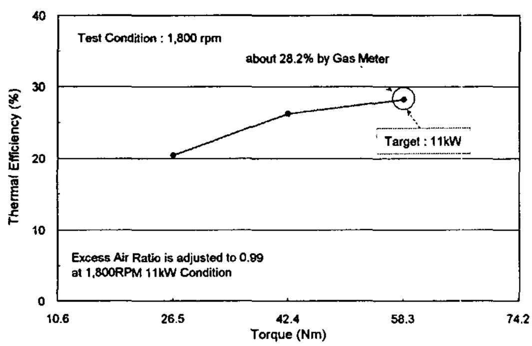



Fig. 5 Thermal efficiency of the gas engine.

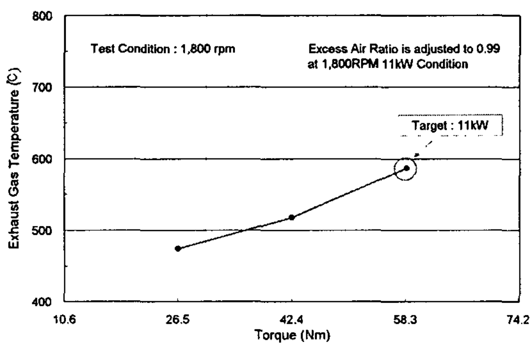



Fig. 7 Exhaust gas temperature of the gas engine.

the excess air ratio is kept less than 0.99 in the actual engine operating condition, it can be considered that the open loop A/F strategy of the engine can keep the NOx emission level far below the NOx regulation.

After setting up the excess air ratio around 0.99 at 11 kW at 1,800 rpm condition which is the target output, engine torque is changed by adjusting metering valve of the gas mixer while engine speed is kept constant at 1,800 rpm, and thermal efficiency, NOx emissions at the catalyst exit and at the engine exit, and exhaust gas temperature are investigated.

As a result, 28.2% of thermal efficiency of the engine is obtained at the target output of 11 kW at 1,800 rpm as shown in Fig. 5, and this value is similar to that of a lean burn engine jointly developed by Osaka Gas and Yanma Diesel of Japan.[7] As shown in Fig. 6, NOx emission at the catalyst exit is about 7 ppm at the target output, and there is a slight decrease as torque decreases. In Fig. 7, exhaust gas temperature is around 590℃ at the target output, and it shows a tendency, in general, to decrease as the engine load decreases.

Subsequently, while the engine start key is on, time to reach the idle speed and time to reach the target output of 11 kW at 1,800 rpm are measured. As a result, the time required to keep a stable idle speed from the engine start to is within 3 seconds, and the time to keep a stable condition of 11 kW at 1,800 rpm from engine start is within 7 seconds.

### 3.2 Closed loop fuel control on the engine dynamometer

As previously mentioned, this study is mainly supposed to examine the validity of the open loop fuel control which uses a three way catalytic converter without controlling A/F ratio. However, it was reproduced the same experiment in order to figure out the effect of close loop fuel control in which excess air ratio is kept constant at 0.99 at any engine operating conditions by manually adjusting the metering valve of the gas mixer.

It was found that no meaningful difference exists between the open and closed loop control strategies in view of thermal efficiency and NOx emission since the variation of the A/F ratio due to the change of the engine load is not so prominent provided that the engine speed is kept constant at 1,800 rpm. Therefore, the conclusion is to adopt the open loop A/F strategy for the cogeneration system.

In case of the open loop control, however, when the engine speed changes, the A/F ratio changes a lot from 'rich' to 'lean' status, and as a consequence, NOx emission at the catalyst exit is dramatically increased. However, in the case of closed loop way, low level of NOx emission at the catalyst exit less than 10 ppm can be achieved for all engine speed and load conditions. Accordingly, closed loop fuel control strategy is essential for GHP engine where the engine speed varies a lot during operation.

### 3.3 Engine performance test by speed governor

As mentioned above, through the performance optimization test of the gas engine which uses throttle actuator and controller attached to the engine dynamometer, expected performance, exhaust NOx emission, and transient characteristic could be obtained. Thus, by removing these and attaching the electronic speed governor, we enforced the engine performance test for transient operation condition, too.

The tests include two different cases. The first one is a sudden increase of load from zero to 11 kW and the second one is a sudden decrease of load from 11 kW to zero under the engine speed condition of 1,800 rpm.

Figures 8~10 show the time variations of engine speed, torque, and noise characteristics, respectively, for the case of a sudden increase of the load from zero to 11 kW at the engine speed of 1,800 rpm. The figures reveal that it took about 3 seconds from zero load to stable 11 kW stage. The result shows a satisfactory transient characteristic. The observed noise levels of 82 dB at 11 kW and 78 dB at zero load are to excellent results. NOx emission level was measured to be about 30 ppm at zero load and about 7 ppm at 11 kW, while hundreds ppm level is observed during transient period of the load change.

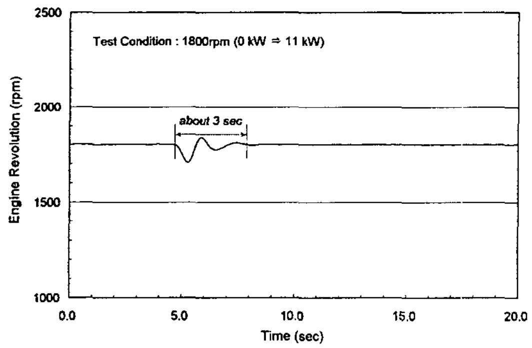



Fig. 8 Engine speed variation from 0 to 11 kW.

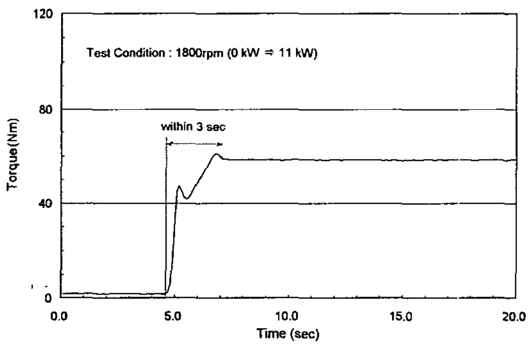



Fig. 9 Engine torque variation from 0 to 11 kW.

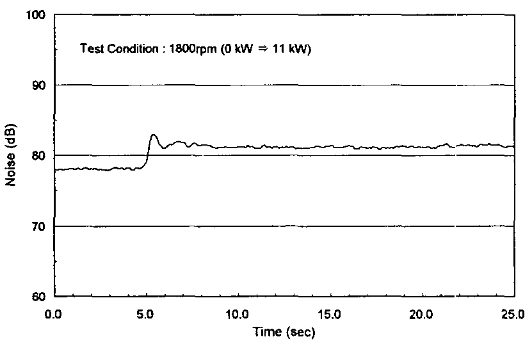



Fig. 10 Engine noise variation from 0 to 11 kW.

The engine speed, torque, and noise characteristics were measured to be similar to the above results in case of a sudden decrease of load from 11 kW to zero at 1,800 rpm. The only difference is that NOx is decreased during the transient period of the load change.

### 3.4 Load test with an electric generator

As a final stage, after detaching the test engine from the engine dynamometer and attaching it to the generator of 10 kW power output, engine performance characteristics and power generation characteristics are measured for different loading conditions varying every 2 kW step.

As a result, major targets were achieved: rated generation output of 9.8 kW at 1,800 rpm, 26.7% of generation efficiency, NOx emission less than 10 ppm at 13% $O_2$ condition, noise level less than 82 dB, speed control accuracy of 1,800±2 rpm, and favorable transient performance of 3 seconds approximately from zero load to 11 kW. More over, there was almost no change in the engine speed during transient period of the load change as shown in Fig. 11.

Figure 12 shows a complete view of the gas

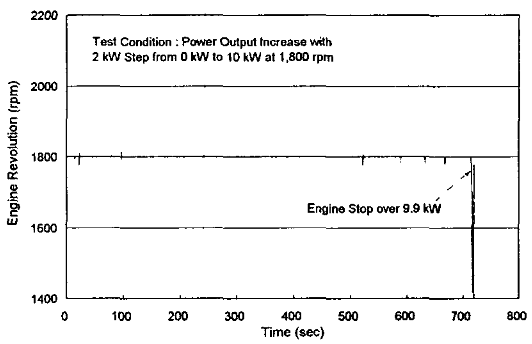



Fig. 11 Engine rpm variation with load change.

Table 2 Specification and performance of test gas engine

| Type of engine | Spark ignited natural gas engine |
|---|---|
| Number of cylinder | 4 cylinder |
| Displacement | 1,498 cc |
| Bore × Stroke | 78 × 78.4 mm |
| Compression ratio | 9.4 |
| Fuel | City gas (natural gas) |
| Type of combustion | Stoichiometric combustion |
| Norminal electric generation | 9.8 kW/1,800 rpm |
| Stability of engine revolution | 1,800 ± 2 rpm at 9.8 kW |
| Electric generation efficiency | 26.7% |
| Noise | 82 dB @ 9.8 kW/1,800 rpm |
| NOx with 3 way catalyst | Under 10 ppm @ 9.8 kW/1,800 rpm |

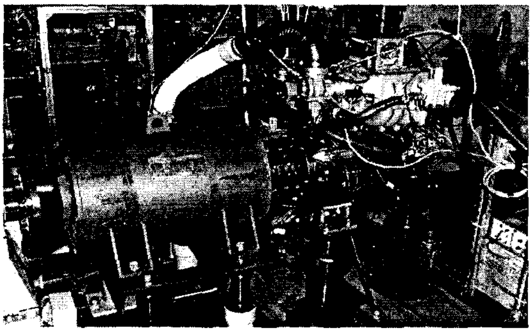


Fig. 12 Prototype gas engine with generator.

engine with a generator, and Table 2 sums up and presents the specifications and major performances of the prototype gas engine.

## 4. Conclusion

By remodeling the gasoline engine of 1,500 cc displacement, we developed a spark ignited city gas (natural gas) engine of 9.8 kW generation output (engine output 11 kW). The combustion strategy of the engine should be a rich burn with a three way catalytic converter to reduce NOx emission.

The prototype gas engine shows following performance characteristics: rated generation output of 9.8 kW at 1,800 rpm, 26.7% of generation efficiency, NOx emission less than 10 ppm at 13% $O_2$ condition, noise level less than 82 dB, speed control accuracy of 1,800 ± 2 rpm, and transient performance of 3 seconds from no load to rated output.

The performance tests related to the cogeneration system will be peformed and the durability of the engine will be improved for commercialization in the future.

## References


1. Eurocogen, 2001, A Guide to Gogeneration, Contract No. XVII/4.1301/p/99-195, p. 49.
2. Eurocogen, 2001, The Future of CHP in the European Market – The European Cogeneration Study, Project No. XVII/4.1301/p/99-169, p. 88.
3. Broomquist, R. G., Nimmons, J. and Spurr, M., 2001, Combined Heat & Power, WSUCEEP 01-013, Washington State University, p. 117.
4. U.S. DOE and EPA, 2001, National CHP Roadmap, p. 42.
5. www.honda.co.jp/tech/power/cogeneration/index.html
6. Technical material of Catalytic Mufflers, 1997, NETT Technologies INC., Web: http://www.nett.ca.
7. Yoshimoto, T., 2000, Application of Micro Gas Engine, Energy Conservation, Vol. 52, No. 11, pp. 31-34.
8. Heywood, J. B., 1989, Internal Combustion Engine Fundamentals, McGraw-Hill International Editions.