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Effect of mixer type on cylinder-to-cylinder variation and performance in hydrogen-natural gas blend fuel engine

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ABSTRACT

Compressed natural gas (CNG) buses were adopted in urban areas as a promising alternative to diesel buses, which emitted plenty of harmful emissions. Although CNG can meet the current emission standards, satisfying the requirements of the next EURO-VI emission regulation without an additional peripheral device may be impossible. The use of a hydrogen-compressed natural gas (HCNG) blend can help achieve a reduction in automotive exhaust emissions as well as prepare for an upcoming hydrogen economy through the construction of hydrogen infrastructure. Moreover, an HCNG engine has higher thermal efficiency than a CNG engine, producing lesser harmful emissions.

Cylinder-to-cylinder variation affects multicylinder engine operation and can considerably influence an HCNG engine because fuel composition and excess air ratio differences can contribute to cylinder-to-cylinder variations. In the present study, the effect of the mixer type on cylinder-to-cylinder variation and performance characteristics were investigated using an 11-L heavy-duty CNG engine fuelled with HCNG (CNG 70 vol%, hydrogen 30 vol%). A change in the mixer type does not affect the characteristics of cylinder-to-cylinder variation and the combustion stability of the HCNG engine. The efficiency of cylinders 1 and 6 is lower than that of the other cylinders because of the configuration of the cylinder in the in-line-type engine. The significant increase in the pressure drop under a wide open-throttle operating condition makes it difficult to satisfy the engine's specifications.

1. Introduction

The air pollution in metropolitan cities is an emerging social problem because of the increase in the number of vehicles. Since 2000, many heavy-duty diesel vehicles have been replaced by natural gas vehicles in Korea because a considerable amount of harmful emissions, including particulate matters, are discharged from public transport vehicles such as buses. Because compressed natural gas (CNG) has good combustion and emission characteristics, the use of CNG buses in the downtown area is being increased, and the demand of CNG is also increasing [1,2]. At present, approximately 28,000

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CNG buses operate in Korea. There are also continuous efforts by the government and the government subsidies to solve the problem of insufficient infrastructure for charging of CNG.

To meet the current emission regulation, nitrogen oxides (NOx) are reduced with lean combustion, and an oxidation catalyst is used for reducing the total amount of hydrocarbons (THC) and carbon monoxide (CO) released by heavy-duty CNG engines. However, future emission regulations, such as EURO-VI, cannot be satisfied with these traditional technologies; many studies have been conducted to achieve a further reduction of harmful emissions from CNG engines. Among these efforts for emission reduction, the addition of hydrogen is the most promising technique for improving the performance of CNG engines, while using the CNG infrastructure [3–5]. Hydrogen-compressed natural gas (HCNG) blends can be supplied to the engine as a monofuel because the phases of both hydrogen and natural gas are equal. Hydrogen can be produced via a reforming process of methane, whose hydrogen to carbon ratio is the highest of all hydrocarbon fuels. It is expected that HCNG can play the role of a social and technological bridge to the hydrogen era; this ideology is behind the use of HCNG as a fuel.

Hydrogen has very reactive combustion characteristics, and its flammability limit is high. The production of unburned hydrocarbons can be minimized because of hydrogen's short quenching distance, and the application of a lean-burn spark-ignition engine is easy because the self-ignition temperature is high and the burning speed is fast [4,6]. In general, an HCNG engine uses the extended flammability limit in favor of hydrogen addition so that the specific fuel consumption and the NO_x emission can be improved. Further, the strategy of using an oxidation catalyst increases THC and CO emission by lean combustion [7–10].

The cylinder-to-cylinder variation affects the operation of multicylinder engines and can considerably influence HCNG engines because the fuel composition and excess air ratio differences can contribute to the cylinder-to-cylinder variations [11,12]. Lean-burn CNG engines normally use a gas mixer, and the air-fuel mixture composition of each cycle can be considered identical for each cylinder. The change of fuel does not have an effect on the flow pattern because the individual intake manifold runner and the port geometries remain unaltered. However, there are some differences in the transition to HCNG; the total flow rate of the fuel gas increases because of hydrogen's low caloric value per unit volume. The amount of excess air also increases in favor of the extended flammability limit; this can impact the changes in the gas dynamics in the intake system as well as in the mixer and exhaust manifolds. Nonuniformity of mixture leads to a variation in the combustion phasing for each cylinder because of the burn rate changes; hence, the performance and emission characteristics deteriorate [13–16].

In the present study, the effect of the mixer type on the engine performance was evaluated and the characteristics of the cylinder-to-cylinder variation of HCNG engines were analyzed. An in-cylinder pressure and emission measurement of an individual cylinder was carried out to investigate the combustion stability, efficiency, and mixture distribution. The applicability of gas mixers was assessed as a consideration for its practical potential in the field.

2. Experimental procedures

2.1. Experimental setup

An 11-L 6-cylinder CNG engine (Doosan Infracore Inc., GL11K) meeting the EURO-V emission regulations was used in the tests, and the detailed engine specifications are listed in Table 1. The speed and torque of the engine were controlled and monitored using an eddy current dynamometer (Schenck). The spark-ignition timing and the fuel flow rate were controlled by a computer-based universal engine control unit. The electronic throttle control and the waste gate control of the turbocharger system were employed to control the excess air ratio under each operating condition.

Fig. 1 shows the experimental setup for the engine tests. CNG was supplied by eight gas fuel metering valves connected to the gas mixer after being decompressed to 0.67 MPa by a conventional regulator, for vehicles from the compressed fuel vessel, which was charged to approximately 15 MPa. A series of compressed tanks for HCNG, which were charged to around 12 MPa, were employed and connected to the conventional regulator. A 3:7 volumetric ratio of hydrogen to natural gas was selected because, based on a previous research, a 30% hydrogen concentration is considered to be the most appropriate ratio [17]; thus, the simulated HCNG fuel was prepared.

It was possible to switch fuels by using a motor-operated valve (MOV) and a control system. The CNG and HCNG were heated to 40 °C using a heat exchanger, after passing them through the regulator, because an extremely low temperature might cause the malfunctioning of the fuel supply system because of the expansion of the compressed fuel by the regulator. The flow rate of each fuel was measured by using a mass flow meter (MFM). The individual in-cylinder pressure was measured by using piezoelectric pressure transducers (Kistler Co. Ltd., 6117BFD17). To analyze the in-cylinder data precisely, a high-precision rotary encoder whose pulse per revolution was 1800 and a combustion analyzer (Dewetron Co., Dewe 800) were used for diagnosing the combustion stability. The excess air ratio of the air-fuel charge was monitored using a lambda meter (ETAS Co., LA4) located at the exhaust runner of the individual cylinder and downstream of the turbine.

To evaluate the effect of the mixer type, the in-cylinder pressure, emissions, and pressure drop between the upstream and the downstream of the mixer were measured for original and simplified mixers. The original mixer had 12 holes

Table 1 – Engine specifications.

Type	Description
Number of cylinders	6
Bore (mm)	123
Stroke (mm)	155
Displacement volume (cc)	11,050
Compression ratio	10.5
Max. power	222 kW/2100 rpm
Max. torque	1150 Nm/1260 rpm