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Combustion performance test of a new fuel DME to adapt to a gas turbine for power generation

Min Chul Lee *, Seok Bin Seo, Jae Hwa Chung, Yong Jin Joo, Dal Hong Ahn

Power Generation Laboratory, Korea Electric Power Research Institute, Korea Electric Power Corporation, Yusung-Gu, Taejon 305-380, Republic of Korea

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Abstract

Recently, DME (dimethyl ether, CH_3OCH_3) has attracted a great deal of attention as an alternative fuel owing to its easy transportation and cleanliness. This study was conducted to verify the combustion performance and to identify potential problems when DME is fueled to a gas turbine. Combustion tests were conducted by comparing DME with methane, which is a major component of natural gas, in terms of combustion instability, NO_x and CO emissions, and the outlet temperature of the combustion chamber. The results of the performance tests show that DME combustion is very clean but hard to control. The CO emission level of DME is lower than that of methane, while the NO_x emission level of DME is as low as that of methane. When firing DME, the pressure fluctuation in the combustion chamber caused by combustion instability is lower than that occasioned when firing methane. From the results of the outlet temperature of combustor we have ascertained that DME combustion is more likely to flash back than methane combustion and this property should be considered when operating a gas turbine and retrofitting a burner.

Keywords: DME (dimethyl ether); Alternative fuel; Gas turbine combustion

1. Introduction

1.1. Backgrounds

Environmentally friendly and new fuel DME, which has appeared on the scene as a solution for the shortage of fossil fuels and worsening environmental problems is highly attracted. DME has the potential of being put into practical use within a few years because of the advantages it offers in terms of easier storage and transportation, fewer pollutant emissions, and the option of utilizing existing infrastructures of LPG, since the physical characteristics of DME are similar to those of LPG. So, a lot of studies have been conducted to estimate the DME as an alternative fuel in terms of availability, performance, economics, technology, versatility, national security and environmental emissions [1–4].

For the mass production of DME, mass consumers such as thermal power plants are required. In addition to such necessities, this study can impact on the diversification of power generation fuel, the reduction of power generation costs, and the reduction of air pollutant emissions.

1.2. Fuel characteristics of DME

DME is a clean fuel that can be produced from diverse materials including natural gas, coal, coal-bed methane, biomass, etc. DME is expected to be used as an alternative fuel in near future because DME from biomass, so-called Bio-DME is one of the very good solutions for mitigating climate change problem. In addition, DME from natural gas resources available from presently unused small or middle scale gas wells might offer the economical production cost. Table 1 shows the physical and chemical properties of DME in comparison to those of other fuels. The lower explosive limit is higher, while saturated vapor pressure, boiling point, and specific gravity are similar to those

* Corresponding author. Tel.: +82 42 865 5488; fax: +82 42 865 5489.
E-mail address: lmc@kepri.re.kr (M.C. Lee).

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Nomenclature

DME	dimethyl ether
LNG	liquefied natural gas
LPG	liquefied petroleum gas
DLN	dry low NO_x
Re	Reynolds number
$\overline{U}$	mean velocity at the combustor inlet
D_h	hydraulic diameter
D_{burner_out}	outer diameter of burner
D_{burner_in}	inner diameter of burner
D_{swirl_in}	inner diameter of swirler
D_{swirl_out}	outer diameter of swirler
v	kinematic viscosity
ppm	part per million
ϕ	equivalence ratio
T_3	exit gas temperature of combustion chamber

Table 1
Properties of DME, methane, propane, and butane

	DME	Methane	Propane	Butane
Chemical formula	CH_3OCH_3	CH_4	C_3H_8	C_4H_{10}
Boiling (°C)	−25.1	−161.5	−42	−0.5
Liquid density (g/cm^3)	0.67	0.42	0.49	0.57
Specific gravity (vs, air)	1.59	0.55	1.52	2.01
Vapor pressure (atm @ 0 °C)	6.1	246	9.3	2.4
Flammable limits in air (%)	3.4–17	5–15	2.1–9.4	1.9–8.4
Ignition temperature (°C)	235	650	470	365
Max. burning velocity (cm/s)	50	37	43	43
Equivalent A/F ratio (kg/kg)	9.0	16.9	15.7	15.5
Low heating value (MJ/kg)	28.8	49.0	46.3	45.7

of propane and butane. Thus DME can be handled like LPG which primarily contains propane and butane. However DME has a faster combustion speed, a lower auto-ignition temperature and lower heating value. The use of DME may also cause problems such as flashback and combustion instability when applied to a DLN (dry low NO_x) gas turbine. Therefore, this study is being conducted to evaluate the fuel performance as a gas turbine fuel and to quantify the potential applications problems.

1.3. Prior studies on DME fired gas turbines

To use DME in power plants, the fuel feed system and combustor have to be retrofitted. To this end, Hitachi of Japan has developed a 25 MW class DME combustor to test the various shape design variables of combustors with multiple cluster burners in terms of combustion vibration, exhaust gas, and combustion efficiency. The results of these tests were analyzed by signal/noise ratio analysis to obtain an optimal shape [5]. Mitsubishi heavy industries (MHI) has carried out combustion exhaust gas measurements with a G-type combustor and reported that DME has exhaust characteristics that are similar to those of natural gas. General electric (GE) has conducted combustion experiments with a mixture of DME, methanol, and water using a bench-scale combustor, and reported that such mixtures can be used in commercial GE combustors [6]. GE has obtained patent rights for the mixture ratio and scope of use. Tokyo Electric Power Corporation (TEPCO) conducted the performance tests on micro gas turbines (Capston C30; 30 kW of output power) with DME and LPG, and reported good interchangeability, performance and operational stability [7]. Even though it is very important to observe the combustion characteristics through flame visualization when new fuel is adapted to gas turbines, none of the above studies report any data about flame structure of DME flame, primarily because it is difficult to make visual combustor chamber observations. This study reports about the flame images that show significant differences of combustion characteristics between DME and other fuels.

2. Combustion test apparatus

2.1. Introduction to the gas turbine combustion test facility

In this study, an atmospheric gas turbine combustion test facility (60 kW of output power) was constructed for the combustion testing of DME and methane. Fig. 1 shows a schematic of the air compressor, air receiving tank, air pre-heater, water sprinkler for cooling exhaust gas, atmospheric pressure combustor, control system, and external stack, in addition to the DME supply system. The supply system is composed of a DME tank, a DME vaporizer and DME pre-heating line. By providing a critical flow conditions for both the fuel and air in the upstream of the combustor, the pressure fluctuations generated in the combustion don't affect the conditions in the upstream, thus preventing the perturbation of air and fuel flows.

2.2. Model gas turbine combustor

The atmospheric DLN combustor was designed and fabricated by simplifying the commercial gas turbine combustor on a small scale. Fig. 2 shows the design drawing of the model gas turbine combustor and the part names shown in Fig. 2 are described in Table 2. This premixed combustor is constituted with a dump type combustion chamber in the downstream, and a pilot fuel and a fuel–air mixture are supplied through a double pipe at the end of the dump chamber. A combustion chamber was made with a quartz tube to visualize the flame. The tube was sealed with a graphite ring at the connection with the burner. A spark ignitor was installed in the middle of the