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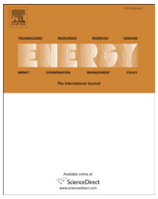

Combustion and emissions characteristics of a spark-ignition engine fueled with hydrogen–methanol blends under lean and various loads conditions

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ABSTRACT

Methanol is a promising alternative fuel for the spark-ignition engines. This paper experimentally investigated the performance of a hydrogen-blended methanol engine at lean and various load conditions. The test was conducted on a four-cylinder commercial spark-ignition engine equipped with an electronically controlled hydrogen port injection system. The test was conducted under a typical city driving speed of 1400 rpm and a constant excess air ratio of 1.20. Two hydrogen volume fractions in the intake of 0 and 3% were adopted to investigate the effect of hydrogen addition on combustion and emissions performance of the methanol engine. The test results showed that brake thermal efficiency was improved after the hydrogen addition. When manifolds absolute pressure increased from about 38 to 83 kPa, brake thermal efficiencies after the hydrogen addition were increased by 6.5% and 4.2%. The addition of hydrogen availed shortening flame development and propagation periods. The peak cylinder temperature was raised whereas cylinder temperature at the exhaust valve opening was decreased after the hydrogen addition. The addition of hydrogen contributed to the dropped hydrocarbon and carbon monoxide. However, nitrogen oxides were slightly raised after the hydrogen enrichment.

1. Introduction

Research and development in clean alternative fuels for internal combustion engines is important for energy safety and environmental protection. Compared with gasoline, methanol can be produced from kinds of ways and materials, such as biomass [1], natural gas and coal [2]. Because of the high H/C (hydrogen to carbon) ratio in methanol, the engine HC (hydrocarbons) and CO (carbon monoxide) emissions are generally low for the methanol-fueled engines. Besides, compared with diesel fuel and gasoline, the combustion of methanol produces much lower smoke and particulate emissions. Thus, methanol can be seen as a smoke-free fuel for internal combustion engines [3]. Since the methanol is an oxygen-contained fuel, the combustion completeness of methanol is also better than that of gasoline. According to tests conducted by Cay et al. [4], HC and CO emissions from the methanol engine were lower than those from the gasoline engine. Furthermore, the high octane number of methanol makes it possible to increase the compression ratio for the methanol engines, which enables the engine to gain better thermal efficiency. Zhen et al. [5] designed a new combustion to overcome the knocking for methanol engines. They also found that knocking of the methanol engine could be suppressed by adopting exhaust gas recirculation. According to the test results from Gong et al. [6], brake thermal efficiency of methanol engine could be larger than 30% through optimizing the control strategy. Especially, at high loads, the methanol engine could even gain better thermal efficiency than the diesel engine. Thus, the application of methanol is beneficial for improving the engine fuel economy and reducing toxic emissions. However, the high latent heat and vaporizing temperature of methanol are barriers for applying methanol on SI (spark-ignition) engines at cold start and part load conditions. This is because the low temperature at these conditions blocks the vaporizing of methanol and therefore deteriorates the formation of homogeneous fuel-air mixtures. According to Gong et al. [7–9], it is even impossible to start a methanol engine when the ambient temperature is below 16 °C without other starting aids. Thus, improving the cold start stability and part load performance of methanol engines is important for the commercialization of methanol engines.

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Hydrogen is another promising fuel candidate for internal combustion engines. As it can be seen from Refs. [10–12], by properly controlling the engine, the hydrogen engine could gain better performance than the traditional fuel-powered engines. Previous investigations have demonstrated that the addition of hydrogen is capable of improving the engine performance at the cold start and part load conditions of natural gas and gasoline engines. Wang and Huang et al. [13–16] found that the addition of hydrogen availed increasing the flame speed of methane-air blends. Besides, the experimental results also showed that the flame stability at early combustion stage was enhanced after the hydrogen blending. The engine test results confirmed that the addition of hydrogen was able to improve the engine thermal efficiency and extend the engine lean burn limit. Park et al. [17–19] carried out a series of experiments on heavy-duty natural gas engines. The test results showed that increasing the compressions ratio contributed to the raised thermal efficiency of hydrogen-blended methane engines. Besides, they also found that the addition of hydrogen helped extend the engine lean burn limit. Yousufuddin et al. [20] studied the performance of hydrogen-enriched ethanol engines. According to the test results, it was indicated that the blending of hydrogen benefited shortening the flame development and propagation periods. Ji and Zhang et al. [21] experimentally investigated the performance of a hydrogen-blended methanol engine and found that the addition of hydrogen was capable of extending the lean burn limit of methanol engines. Besides, their test results also demonstrated that the engine thermal efficiency was improved whereas the harmful emissions were decreased after hydrogen addition. With the development of water electrolyzing technology, the onboard hydrogen producer is capable of supplying hydrogen for vehicles. This relieves the pressure on hydrogen refueling in practical application. Ji et al. [22] tested a hydrogen-enriched gasoline engine-powered vehicle according to New European Driving Cycle. In that test, the hydrogen was supplied by an onboard water electrolysis hydrogen generator. The results showed that HC and CO emissions are decreased during the testing cycle. Dulger et al. [23] used a water electrolysis hydrogen generator to provide the hydrogen–oxygen blends for vehicles. The vehicle test results suggested that the engine fuel consumption was effectively reduced after blending the hydrogen–oxygen mixtures produced from the onboard hydrogen generator.

Lean combustion is a good way for improving the engine thermal efficiency and fuel combustion completeness [24]. According to studies form Ma et al. [25], the properly increased excess air ratio helped reduce the engine brake specific fuel consumption and nitrogen oxides (NO_x) emissions. However, because of the decreased cylinder temperature at lean conditions, the evaporation of methanol could be further deteriorated at lean conditions, especially at part loads. As hydrogen possesses a high flame temperature and a wide flammability, the addition of hydrogen is able to improve the lean combustion capability of methanol engine at part-load conditions.

However, limited papers have concentrated on the effect of hydrogen addition on the performance of methanol engines at lean and part load conditions. Since hydrogen has many good combustion and physiochemical properties which avails improving the methanol engine performance, this paper experimentally investigated the performance of a hydrogen-blended methanol engine at lean and various load conditions. The experiment was conducted on a modified four cylinder SI engine equipped with an electronically controlled hydrogen injection system. The engine was run at a typical city driving speed of 1400 rpm. The combustion and emissions performance of a hydrogen-blended methanol engine was investigated in detail.

2. Experimental setup and procedure

2.1. Experimental setup

The test was carried out on a 1.6 L SI engine manufactured by Beijing Hyundai Motors. An electronically controlled hydrogen injection system including four hydrogen injectors, a hydrogen rail and a HECU (hybrid electronic control unit) were first added to the test engine. A hydrogen injection system with four hydrogen injectors placed in the intake plenum of each cylinder is first added to the engine intake manifolds. This system allows the hydrogen to be injected into each cylinder sequentially and therefore avoids backfire. The schematic diagram of the experimental system is given in Fig. 1. It can be seen from the figure that the hydrogen is injected into the intake port of each cylinder by the hydrogen injector. The hydrogen used in this experiment has a purity of 99.99%, which was stored in cylinders at 16.0 MPa outside the lab. When the experiments began, the hydrogen pressure was reduced to 0.3 MPa through two steps of pressure regulation. The hydrogen cylinder, pressure regulator and hydrogen rail were connected though stainless steel pipes. The HECU could gain signals from the engine OECU (original electronic control unit) and a calibration computer. Besides, the HECU was also connected with the spark module and hydrogen and methanol injectors through screened cables. Therefore, by changing the controlling parameters in HECU, the injection timings and durations of hydrogen and methanol and the spark timings could be adjusted online.

During the test, the engine was loaded by a GW160 eddy current dynamometer (measurement uncertainty: ±0.28 Nm in torque, ±1 rpm in engine speed). The methanol flow rate was measured by an FC2210 fuel mass flow meter manufactured by Powerlink (measurement uncertainty: $< \pm 0.33$ g/min). The hydrogen flow rate was detected by a D07-19BM thermal mass flow meter manufactured by Sevenstar (measurement uncertainty: $< \pm 0.02$ L/min). The air flow rate was measured by a 20N060 thermal mass flow meter manufactured by Tociel (measurement uncertainty:

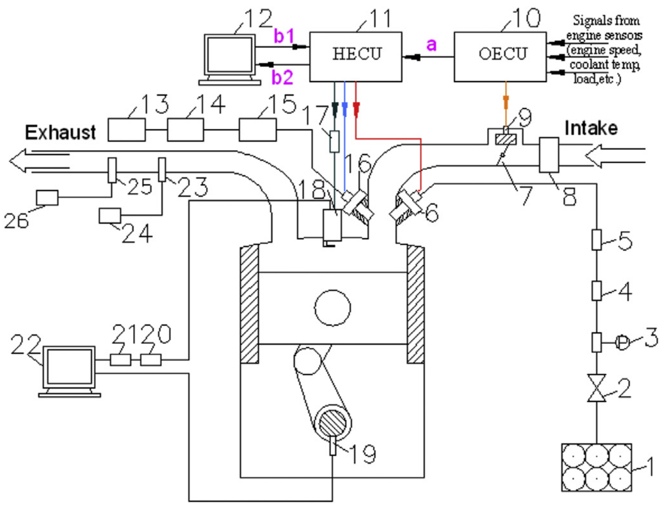

Fig. 1. The schematics of the experimental system. 1. Hydrogen cylinder container 2. Hydrogen pressure adjusting valve 3. Hydrogen pressure meter 4. Hydrogen mass flow meter 5. Backfire arrestor 6. Hydrogen injector 7. Throttle 8. Air mass flow meter 9. Idle valve 10. OECU 11. HECU 12. Calibration computer 13. Methanol tank 14. Methanol mass flow meter 15. Methanol pump 16. Methanol injector 17. Ignition module 18. Pressure transducer with a spark plug 19. Optical encoder 20. Charge amplifier 21. A/D converter 22. Combustion analyzer 23. O_2 sensor 24. A/F analyzer 25. Emissions sampling pipe 26. Horiba MEXA-7100DEGR emissions analyzer a. Signals from the OECU to the HECU b1. Calibration and control signals from the calibration computer to the HECU b2. Data signals from the HECU to the calibration computer.