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Investigation on the cold start characteristics of a hydrogen-enriched methanol engine

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ABSTRACT

This paper experimentally investigated the effect of hydrogen addition on the cold start performance of a methanol engine. The test was conducted on a modified four-cylinder gasoline engine. An electronically controlled hydrogen injection system was applied to realize the hydrogen port injection. The engine was started at an ambient temperature of 25 °C with two hydrogen flow rates of 0 and 189 dm^3/s, respectively. The results demonstrated that hydrogen addition availed elevating the peak engine speed and cylinder pressure during the cold start. Both flame development and propagation periods are shortened after the hydrogen addition. When the hydrogen volume flow rate was raised from 0 to 189 dm^3/s, HC, CO and total number of particulate emissions within 19 s from the onset of cold start were reduced by 68.7%, 75.2% and 72.4%, respectively. However, because of the enhanced in-cylinder temperature, NO_x emissions were increased after the addition of hydrogen.

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Introduction

The application of clean alternative fuels is a feasible way for alleviating pressures on energy shortage and environmental pollution. Methanol is a renewable fuel that can be produced from kinds of methods and sources [1]. As methanol contains the oxygen atom and has a high H/C ratio, the combustion of methanol could exhaust lower carbon-related emissions than the pure gasoline engines [2]. Besides, the methanol has a high octane number which enables the engine to adopt larger compression ratios to improve the fuel economy [3]. According to the experimental results from Gong et al. [4], by optimizing the injectors, compression ratio and spark timing, the methanol engine could gain the highest thermal efficiency larger than 30%. Also, the latent heat of methanol is roughly 1.5 times higher than that of gasoline [5]. This means that the evaporation of methanol helps cool the inlet charge and therefore benefits increasing the volumetric efficiency.

However, the high latent heat and boiling temperature of methanol make its hard be fully evaporated at low temperatures, particularly at the cold start, idle and low load conditions. Thus, starting a methanol engine is relatively difficult at low ambient temperatures. Gong et al. [6,7] found that when the ambient temperature was lower than 16 °C, the methanol engine cannot be successfully started without auxiliary start aids due to the insufficient combustible fuel–air mixtures formation. Their tests also confirmed that, by adopting the inlet charge heating or adding small amounts of LPG and gasoline, the methanol engine could be started normally.

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Unfortunately, Li et al. [8] found that increasing the LPG content in the fuel–air mixtures tended to cause the adversely raised formaldehyde emission. Besides, because of the sever fuel-film effect, the addition of gasoline tended to cause the increased HC emissions. According to previous investigations [9,10], more than 70% of HC emissions in the federal test procedure (FTP) are produced from the engine cold-start period. Thus, it is necessary to find a feasible way for ensuring a stable cold start of the methanol engine without increasing carbon-related emissions.

Hydrogen is another promising fuel candidate for internal combustion engines [11,12]. Adding small amount of hydrogen to the fossil fuel engines is able to improve the engine thermal efficiency and reduce the toxic emissions [13,14]. Simio et al. [15] found that the combustion duration of heavy-duty natural gas engine was shortened after the hydrogen addition. Mariani et al. [16] studied the combustion characteristics of hydrogen-blended natural gas engine and found that the addition of hydrogen in the fuel–air mixtures resulted in the 16% reduction of CO_2 emission. Huang and Wang et al. [17–19] investigated the effect of hydrogen addition on CNG combustion. The results confirmed that the addition of hydrogen availed increasing the burning velocity of natural gas due to the increased O, H and OH radicals in the flame. Ji and Wang et al. [20–22] found that the addition of hydrogen helped improve the fuel economy of gasoline engines. Meanwhile, the vehicle emissions level was improved from Euro-II of the original gasoline engine to Euro-IV of the hydrogen-enriched gasoline engine under the New European Driving Cycle (NEDC). They also tried to start an engine with hydrogen–gasoline mixtures and found that the addition of hydrogen was effective on reducing HC and CO emissions during the cold start. There are also some reports showing the effect of hydrogen addition on performance of alcohol-fueled engines. Yousufuddin et al. [23] studied the performance of hydrogen-enriched ethanol engine. The results indicated that the addition of hydrogen benefited improving the engine thermal efficiency and shortening the combustion duration. Ji and Zhang et al. [24] found that the lean burn limit was extended and cyclic variation was reduced after the hydrogen addition for the methanol engine.

However, although some articles have reported that the methanol engines are hard to be started without auxiliary system or LPG blending [6–8], there are still no investigations studying the effect of hydrogen addition on the cold start characteristics of a methanol engine. Compared with LPG, the hydrogen possesses much lower minimum ignition energy and wider flammability. Thus, the addition of hydrogen seems to be effective on improving the methanol engine performance at the cold start condition. In view of the above, this paper studied the performance of a hydrogen-enriched methanol engine at the cold start.

Experimental setup and procedure

Experimental setup

The test engine is a 1.6 L spark-ignition gasoline engine manufactured by Beijing Hyundai Motors. The methanol is introduced into the inlet plenum through the original gasoline injectors. To ensure that there is no gasoline trapped in the fueling system, the fuel tank, rail and injectors are cleaned by the methanol before the test. Moreover, a hydrogen injection system with a hydrogen rail and four hydrogen injectors are fixed on the intake manifolds. Both injection timings and durations of hydrogen and methanol are governed by a self-developed hybrid electronic control unit (HECU).

The schematic diagram of the experimental system is given in Fig. 1. The cylinder pressure and crank angle position are detected through Kistler 6117BFD17 piezoelectric pressure transducer (measurement uncertainty: ± 0.3 bar) and Kistler 2613B optical encoder (measurement uncertainty: 0.1 °CA, measurement sensitivity: 0.2 °CA), respectively. A Dewe-800 combustion analyzer is adopted to analyze the pressure and crank angle data to obtain combustion parameters. A Horiba MEXA7100DEGR emissions analyzer is used to measure the untreated tailpipe emissions of CO, HC and NO_x through regulated methods (measurement sensitivity: 1 ppm for HC and NO_x emissions, 1% for CO emission; measurement uncertainty: <±1%). The number of particulate emissions is measured by a DMS500 fast particulate spectrometer (measurement uncertainty: <±10%). A D07-19BM thermal mass flow meter manufactured by Seven Star is applied to monitor the hydrogen flow rate (measurement uncertainties: <±0.02 L/min). A 20N060 thermal mass flow meter produced by Toceil is used to measure the air flow rate (measurement uncertainties:

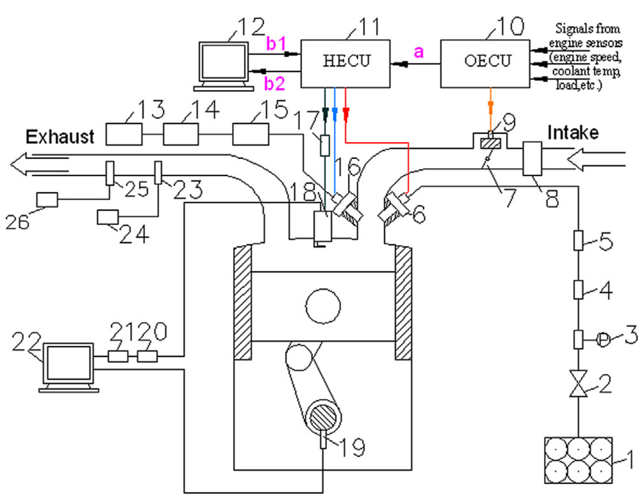

Fig. 1 – The schematics of the experimental system 1. Hydrogen cylinder container 2. Hydrogen pressure adjusting valve 3. Hydrogen pressure meter 4. Hydrogen mass flow meter 5. Backfire arrestor 6. Hydrogen injector 7. Throttle 8. Air mass flow meter 9. Idle valve 10. OECU 11. HECU 12. Calibration computer 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.

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