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Idling performance of a hydrogen-blended methanol engine at lean conditions

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Abstract

This paper studied the idling characteristic of a hydrogen-blended methanol engine under lean conditions and three hydrogen volume fractions in the intake of 0, 1% and 2%. The test was accomplished on a spark-ignition equipped with a hydrogen port-injection system. The test results showed that the addition of hydrogen contributed to the reduced fuel energy consumption at the idle condition. Because of the reduced engine idle speed, the engine fuel energy consumption rate was further reduced after increasing the excess air ratio of hydrogen-methanol-air mixtures. Both flame development and propagation periods were shortened and HC and CO emissions were reduced after the addition of hydrogen for the methanol engine at the idle and lean conditions.

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Keywords: Methanol, Hydrogen, Idle , Lean combustion, Emissions

1. Introduction

The daily reduced fossil fuel resources and increased environmental pollution have pushed studies on developing clean alternative fuels. Methanol is generally regarded as a good fuel candidate of internal combustion engines [1]. Since the oxygen atom is contained in methanol, the combustion of methanol is more complete than gasoline [2,3]. Also, the higher octane number of methanol enables the engine to apply higher compression ratios which benefit improving the engine fuel economy. However, the high latent heat and vaporizing temperature sometimes make the combustion of methanol engines become unstable at the idle condition, which means that improving idling performance of methanol engine is crucial for the commercialization of methanol engines. Hydrogen is another green and renewable fuel candidate for internal combustion engines. Compared with methanol, hydrogen has a much wider flammability limit that enables the fuel to be fast and completely combusted at lean and high residual gas conditions [4]. Besides, the high flame temperature and propagation speed of hydrogen also help shorten

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the combustion duration and increasing the cylinder temperature. These properties of hydrogen seem to be helpful for the fully evaporation and combustion of methanol at low load and even lean conditions.

However, till now, no papers have reported the effect of hydrogen addition on performance of methanol engines at lean and idle conditions. Since the good combustion and physiochemical properties of hydrogen avail improving the methanol engine performance, this paper experimentally investigated the performance of a hydrogen-blended methanol engine at lean and idle conditions. Results from this study could propose a way for the stable, clean and high efficiency combustion of methanol engines at idle.

2. Experimental setup and procedure

2.1. Experimental setup

A 1.6 L spark-ignition engine was adopted as the test engine. By adding a hydrogen injection system which contained a hydrogen rail and four hydrogen injectors, the hydrogen and methanol can be injected into cylinders individually. The hydrogen and gasoline injection durations and timings were controlled by a self-developed electronic control unit. A combustion analysis system including a Dewe800 combustion analyzer, a Kistler BFD6117 pressure sensor and a Kistler 2613B optical encoder were applied to accomplish the combustion analysis. Toxic emissions of HC, CO and NOx were detected by a Horiba MEXA7100 DEGR emissions analyzer.

2.2. Experimental procedure

The test was begun after the warming up process. The engine main throttle was totally closed to enable the engine to run at the idle condition. To enable the engine to operate stably, the engine original electronic control unit was used to govern the opening of idle bypass valve and spark timing. The experiments were tried with three hydrogen volume fractions in the intake (α_{H2}) of 0, 1% and 2%. For each hydrogen volume fraction in the intake, two excess air ratios (λ) of 1.0 and 1.2 were adopted to investigate the effect of hydrogen addition on the performance of a methanol engine under the stoichiometric and lean conditions. α_{H2} and λ are defined by the following equations:

$$\alpha_{H_2} = [V_{H_2} / (V_{H_2} + V_{air})] \times 100\% \quad (1)$$

$$\lambda = V_{air}\rho_{air} / (V_{H_2}\rho_{H_2}AF_{st,H2} + m_{me}AF_{st,me}) \quad (2)$$

In Eqs. 1 and 2, V_{H2} and V_{air} are volume flow rates of hydrogen and air at the normal condition [L/min]; ρ_{H2} and ρ_{air} are the densities of hydrogen and air at the normal condition [g/L]; m_{met} is the mass flow rate of methanol (g/min); $AF_{st, H2}$and $AF_{st,met}$ are the stoichiometric air-to-fuel ratio of hydrogen and methanol, respectively.

3. Results and discussion

Fuel energy flow rate (Ef) is an important parameter reflecting the engine fuel economy at idle. Fig. 1 shows that the addition of hydrogen helps reduce Ef at the idle condition, due to the wide flammability and short quenching distance of hydrogen. Besides, the adoption of lean combustion is also capable of further improving the engine fuel economy. This is because the oxygen concentration is increased at the lean condition, which helps the complete combustion of the fuel-air mixtures. Furthermore, as it is seen from Fig. 2, because of the high flame speed of methanol, idle speeds was raised after the hydrogen addition. This is different from results of hydrogen-blended gasoline engines in Ref. [6]. In that study, the addition of hydrogen didn't cause the increase in gasoline engine idle speed. Comparatively, because of the reduced cylinder temperature and fuel concentration, the reduced engine idle speed is achieved at the lean conditions, which means that lean combustion is a feasible way of enhancing the fuel economy of hydrogen-blended methanol engine at idle [6].

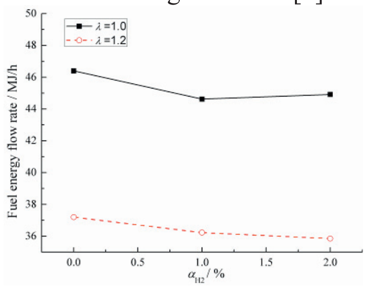


Fig. 1 E_f versus α_{H2}

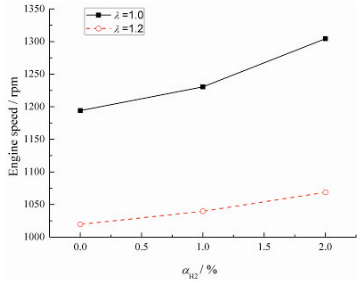
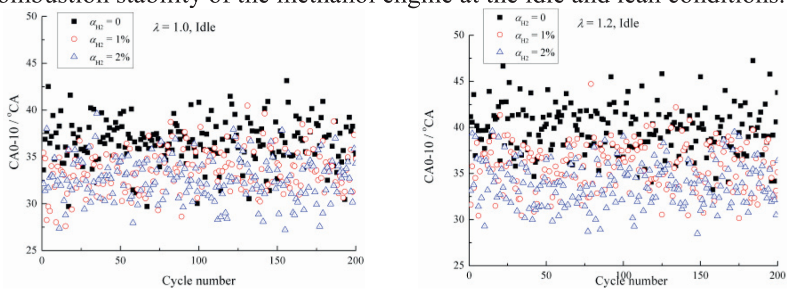


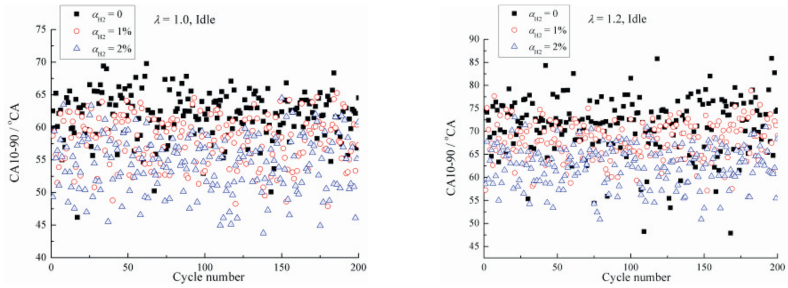
Fig. 2 N versus α_{H2}

The variations of engine flame development (CA0-10) and propagation periods (CA10-90) with cycle number are plotted in Figs. 3 and 4, respectively. It is seen that by increasing the hydrogen addition level, both CA0-10 and CA10-90 can be shortened due to the low ignition energy and high flame speed of hydrogen. Figs. 3 and 4 also demonstrate that the variations of CA0-10 and CA10-90 are converged to the average value after the hydrogen addition. This reflects that the addition of hydrogen is capable of improving the combustion stability of the methanol engine at the idle and lean conditions.



(a) λ = 1.0 (b) λ = 1.2

Fig. 3 CA0-10 versus cycle number at two excess air ratios



(a) λ = 1.0 (b) λ = 1.2

Fig. 4 Heat release fraction versus cycle number at three excess air ratios

It is found from Fig. 5 that the addition of hydrogen could reduce HC and CO emissions from the methanol engines. This is because the short quenching distance and wide flammability of hydrogen permit the fuel to be fully combusted at the same combustion condition. Fig. 5 also shows that the addition of hydrogen is more effective on reducing HC than CO emissions at the lean conditions. This is because the high latent heat of methanol makes it hard to be fully burnt at the lean conditions. Thus, as the hydrogen has a much wider flammability limit, the addition of hydrogen is very effective on reducing HC emissions at lean conditions. Comparatively, the formation of CO is closely related with the oxygen concentration. As the oxygen concentration is raised significantly at the lean conditions, the effect of hydrogen addition on reducing CO emissions is weakened by the adoption of lean combustion.

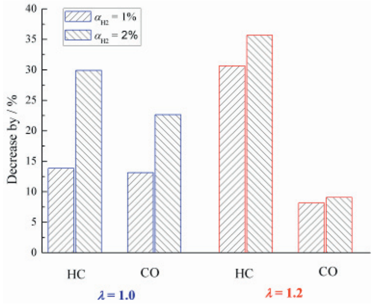


Fig. 5 Reductions in toxic emissions from the hydrogen-blended methanol engines at two excess air ratios

4. Conclusions

This paper experimentally studied the performance of a hydrogen-blended methanol engine at idle and lean conditions. The results show that the addition of hydrogen could reduce the engine fuel consumption, HC and CO emissions and shortening the combustion duration. The results suggest that the hydrogen-blended methanol engine could be run more clean and efficient at idle and lean conditions.

Acknowledgements

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