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Research Paper

Comparison of lean burn characteristics of an SI engine fueled with methanol and gasoline under idle condition

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HIGHLIGHTS

- The potential of methanol on improving the engine idle performance with lean burn strategy was experimentally investigated.
- Methanol enables a thermal efficiency increase at lean burn conditions with its peak value of 24.7% at $\lambda = 1.4$.
- Methanol can accelerate the combustion speed in cylinder and enables more stable combustion.
- Methanol can decrease HC, CO and NO_x emissions.

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ABSTRACT

The idle lean burn characteristics of a port fuel injection (PFI) spark ignition (SI) engine fueled with gasoline and methanol was experimentally investigated. An idle lean burn control algorithm was developed to keep the engine speed around 800 rpm and maintain the excess air coefficient (λ) at 1.0, 1.2, and 1.4, respectively. The spark timing was adopted according to the maximum indicated thermal efficiency. The results showed that the SI engine fueled with methanol illustrated better lean burn performance than the engine fueled with gasoline. Compared with the engine fueled with gasoline, the indicated thermal efficiency (ITE) of engine fueled with methanol was increased; the flame development and propagation periods were shortened; the coefficient of variation in indicated mean effective pressure (COV_{imep}) was decreased, and the emissions of HC, CO and NO_x were decreased at each λ.

1. Introduction

Concerning energy security and environmental protection, the demand for substitute of fossil fuels has become increasingly urgent. For SI engines, alcohols are favorable fuels due to their low global warming potential, desirable combustion characteristics and availability [1–23]. Methanol (CH_3OH) is the simplest alcohol and has received much attention [4–27]. Compared with gasoline, methanol has a variety of admirable properties. Table 1 summarizes the properties of gasoline and methanol relevant to their application in internal combustion engine. The main favorable properties of methanol can be included as follows: (1) high heat of vaporization and low stoichiometric air–fuel ratio leading to high degrees of intake charge cooling as the injected liquid fuel evaporates, which avails to improve the volumetric efficiency of the PFI engine [7,8]; (2) faster laminar flame speed and higher octane value providing the possibility to improve the thermal efficiency of engines; (3) high oxygen content (50% in mass) making the air fuel mixture more oxygenated, resulting in better combustion of the fuel and decrease in carbon monoxide (CO) and hydrocarbon (HC) emissions.

Experimental work about testing methanol or methanol–gasoline blend as a fuel for spark ignited engine has been conducted a lot in recent years. Elfasakhany [9] investigated the effects of low content rates of alcohol–gasoline (methanol and ethanol) blends on performance and emissions in a spark-ignited carburetor engine under wide open throttle (WOT) condition. The test results showed that the use of alcohol blends could effectively decrease the CO and HC emissions, and increase the volumetric efficiency, engine torque and brake power, compared with the operation of pure gasoline. Liu et al. [10] studied the dynamic, economy and emissions performance of engine fueled with low proportion methanol–gasoline blends under wide open throttle conditions, without any retrofit of the original set of parameters. They found that the power and torque of the engine fueled with low proportion methanol–gasoline blends were decreased, while the CO, HC emissions were decreased as well. Similar phenomena were found in Wei's study [11]. Balki et al. [12] investigated the effect of alcohol (ethanol and methanol) use on the combustion and emission characteristics of a single-cylinder carburetor engine under WOT conditions. In their research, the carburetor main jet was enlarged to ensure more alcohol fuel

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Table 1
Properties of methanol and gasoline.

Property	Methanol	Gasoline
Molecular formula	CH_3OH	Various
Oxygen content by mass (%)	50	0
C/H mole ratio	0.25	About 0.445
Density (kg/L)	0.79	0.74
Lower heating value (LHV) (MJ/kg)	20.09	42.9
Stoichiometric air to fuel ratio	6.5	14.7
LHV of stoichiometric mixture (MJ/kg)	2.68	2.73
Research octane number	109	95
Heat of vaporization (kJ/kg)	1100	180–350
Reid vapor pressure (psi)	4.6	7
Laminar flame speed at the normal temperature & pressure, $\lambda = 1$ (cm/s)	42	28
Adiabatic flame temperature (°C)	1870	2002
Mole ratio of products to reactants	1.061	0.937
Flammability limit in air (λ)	0.23–1.81	0.26–1.60

can be sucked into the cylinder. The experimental results showed that the alcohol fuels increased the engine torque, thermal efficiency and combustion efficiency, and decreased the HC, CO and nitrogen oxide (NO_x) emissions. Zhao [13] studied the combustion performance of engine fueled with various methanol–gasoline blends under WOT conditions, based on gasoline-specified electronic control unit (ECU), namely the control parameters such as the fuel injection pulse width, the spark timing and so on were calibrated according the physicochemical properties of gasoline fuel. The results demonstrated that the combustion performance of the engine was deteriorated when the proportion of the methanol increased up to 50%, due to the reduced energy content of gasoline–methanol blends. However, better combustion performance of engine fueled with methanol was observed based on methanol-specified ECU whose control parameters mentioned above were calibrated according the physicochemical properties of methanol fuel, thanks to the increased injection mass of the methanol. Studies were also carried out about the use of methanol–gasoline blends under partial load condition, where the concentration of the air–fuel mixture can be held around the theoretical air fuel ratio by using the closed-loop control algorithm. Agarwal et al. [14] compared the performance and emissions of 10% and 20% methanol–gasoline blends with pure gasoline in a spark-ignited transportation engine under partial load condition. They found the methanol–gasoline blends can increase brake thermal efficiency, and emitted less NO, CO and smoke opacity emissions. Geng et al. [15] investigated the combustion and particulate matter emission of a PFI engine fueled with different ratios of methanol–gasoline blends. The experimental results showed that both the cylinder gas pressure and heat release rate increased significantly and occurred earlier by the use of methanol fuel. Particulate number and mass concentration were found to be decreased with low proportion methanol–gasoline blends while increased significantly with high proportion methanol–gasoline blends. Vancoillie et al. [16] compared the gasoline and methanol operation on two flex-fuel engines. The results showed that relative efficiency benefits of about 10% were obtained and less NOx and CO_2 emission were observed with methanol. In his study, he also tested the alternative load control strategies on the dedicated methanol engine and found that the load of the methanol engine can be controlled by using the exhaust gas recirculation (EGR) operation and the lean burn operation under WOT condition, leading to an efficiency improvement up to 5% compared with the traditional throttled operation.

It is reported that about 30% of the fuel was consumed under idle condition in urban traffic [17]. However the air–fuel mixture aspirated into cylinder is hard to be burned completely under idle condition due to the large residual fraction and inhomogeneity of the air–fuel mixture, making the engine suffer low thermal efficiency and poor emission performance [18]. In addition, the increased cyclic variation in combustion is usually observed under idle condition, which will cause negative fluctuation of engine speed and output torque. Lean burn is considered as an effective means to improve thermal efficiency and reduce emissions of engines [19–21], however, its application in engine fueled with gasoline is limited due to the narrow lean burn limit and slower flame speed of gasoline [22].From the above literature, it can be concluded that methanol has wide flammable range and fast burning speed, therefore, taking methanol as a substitute fuel of engine to improving the lean burn performance under idle condition seems to be promising. As far as the author's knowledge, few have paid attention to the lean burn characteristics of engine fueled with methanol under idle condition. Therefore, the aim of this paper is to compare the idle lean burn characteristics of engine fueled with methanol and gasoline, and explore an effective way to improve the economy and emission performance of engines under idle condition.

2. Experimental set-up and methodology

2.1. Experimental set-up

The specifications of the engine are listed in Table 2. Continuous variable valve timing (CVVT) was adopted in this engine to adjust the open timing of the intake valve. In order to reduce residual gas fraction and ensure the combustion stability of the engine, the opening time of the intake valve was kept at 8 °CA after top dead center (ATDC) and the valves overlap angle was 2 °CA in this paper.

The schematic of the experimental system is shown in Fig. 1. A self-developed ECU was used to control the spark timing, injection pulse width of gasoline or methanol, idle valve opening of the engine, and the control algorithm was developed by using Matlab/Simulink software. The calibration software running in the PC computer was used to calibrate and monitor the controls parameters mentioned above online through a USB/CAN card. The Kistler 6117B spark-plug type cylinder pressure sensor was installed at the first cylinder, whose output signal was collected by LMS data acquisition instrument after being amplified by the Kistler 2852A12 charge amplifier. The EPC260 incremental encoder producing 1024 pulses per rotation was installed at the free-end of crankshaft, and its output signal was transferred to LMS data acquisition instrument as the reference channel of angle domain processing. Two HZL-20 electronic scales were used to measure the consumption of gasoline and methanol, respectively. The BOSCH LSU 4.9 lambda sensor was used to monitor the λ of exhaust gas. The FGA4000XDS exhaust gas analyzer was used to sample the exhaust gas and measure the volumetric concentrations of HC, CO and NO_x emissions. The detailed parameters of the instrumentations mentioned above are listed in Table 3.

Table 2
Engine specifications.

Engine parameter	value
Cylinders, Valves	4 in-line, 16
Bore, Stroke	77.4 mm, 85.0 mm
Displacement	1599 cc
Compression ratio	10.0:1
Injection type	PFI
Rated torque	143.28 N m (4500)
Rated power	82.32 kW (6000)
IVO, IVC	8°ATDC, 56°ABDC
EVO, EVC	46°BBDC, 10°ATDC