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Review

Investigation on performance of a spark-ignition engine fueled with dimethyl ether and gasoline mixtures under idle and stoichiometric conditions

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ABSTRACT

This study investigated effects of dimethyl ether addition on the gasoline engine combustion and emissions performance under idle and stoichiometric conditions. The engine was first modified to be fueled with gasoline and dimethyl ether simultaneously. The experimental results showed that, with the increase of dimethyl ether energy fraction in the total fuel, the total fuel energy flow rate was decreased, and the flame development and propagation periods were shortened. The cycle-to-cycle variation was reduced and the degree of constant volume combustion was increased after the dimethyl ether addition. The dimethyl ether blending was beneficial for reducing hydrocarbon and nitrogen oxide emissions from 1951 and 95 ppm of the original engine to 552 and 34 ppm of pure dimethyl ether, respectively. Meanwhile, with the increase of dimethyl ether addition level, the peak cylinder pressure and carbon monoxide emission were decreased at first, whereas increased when the dimethyl ether energy fraction exceeded 49%. Furthermore, heat release rate during the low temperature reaction was enhanced with the increase of dimethyl ether addition level. The maximum heat release rate was heightened and its relevant crank angle was advanced during the high temperature reaction period after the dimethyl ether enrichment.

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1. Introduction

Nowadays, it is getting difficult to meet the economic and environmental requirements for the traditional internal combustion engine fueled by the mono fuel. Particularly, when a vehicle drives with heavy traffic in cities, the engine has to be run at idle frequently. Compared with normal driving conditions, the engine may burn more fuel and produce more harmful emissions at the idle, due to the high cyclic variation, low cylinder temperature, and weak flow intensity. Previous investigations have shown that the engine idle performance could be improved through proper ways. Yang et al. [1] attempted to use various fuels to improve engines performances at idle condition. Experimental results indicated that adding butanol in diesel or diesel/biodiesel blends was able to properly lower NOx and PM emissions. Park et al. [2] proposed that a heat storage system built using a phase-change material to recover the thermal energy through the coolant. Clenci et al. [3] confirmed that reducing intake valve lift could make improvements on both fuel economy and engine cycle-to-cycle variability at idle condition. Soloiu et al. [4] conducted a research on an n-butanol-biodiesel mixtures engine in various ignition strategies. The results proved that biodiesel combined with n-butanol port fuel injection in the premixed charge compression ignition and low-temperature combustion were very effective in simultaneously reducing soot and NOx at idling conditions. Ji et al. [5] proposed the idle elimination strategy to reduce the idling energy consumption of the hydrogen-enriched gasoline engine. They found that the adoption of idle elimination could further improve the engine fuel economy at the idle. Among these methods, improving the fuel properties is much easier to be realized, since this method has the least costs in the engine modifications.

Generally, the engine performance could be improved by adding small amounts of additional fuel according to engines working conditions. The experiment conducted by Wang et al. [6] showed that hydrogen addition could improve stability and emissions in a gasoline engine under the medium load. Wei et al. [7] designed the performance of a methanol port premixed diesel engine. The experimental results demonstrated that NOx and soot emissions were decreased with the increase of methanol, while HC and CO emissions increased significantly. Results from Merola et al. [8] found that using butanol as an alternative fuel could improve combustion and emissions characteristics in a gasoline engine. Lapuerta et al. [9] focused on the application of biofuel in a diesel engine. The experiment showed that when the cycle was started from warm conditions the new advanced biofuel blend showed significant benefits in engine efficiency, particle number, HC and CO emissions. Pradhan et al. [10] demonstrated the effects of mahua pyrolysis oil on combustion and emissions performance of a diesel engine at different loads. It suggested that the 30% mahua pyrolysis oil blend can be considered as a potential candidate to be used as a fuel in compression-ignition engines. The experiment conducted by Li et al. [11] showed that additional LPG injected into the intake manifold can significantly expand the critical firing boundary of an SI methanol engine during cold start at low ambient temperatures. These additional fuels are generally eco-friend and widely available, which could be mainly divided into low and high octane number fuels. Low octane number fuels could be used to enhance the mixtures ignitability at the starting, idle and low load conditions. Comparatively, high octane number fuels could be adopted to avoid knocking at high loads. Dimethyl ether with a high cetane number and a low octane number is a promising alternative fuel for the internal combustion engines [12]. Dimethyl ether is a colorless, relatively low boiling point and highly flammable gas which has a better evaporation characteristic as well as less negative health effects [13]. In addition, high oxygen content (34.8% by mass), low carbon-to-hydrogen ratios (C/H) and no direct carbon-to-carbon (C–C) bonds are also good features for reducing exhaust, compared with conventional fuels [14].

At the present, most of investigations related with the dimethyl ether applications are generally completed in the compression-ignition engines [15]. In order to overcome the disadvantages of poor lubricity and low heating value of dimethyl ether, dimethyl ether are often used as fuel additives in engines. The performance, emissions characteristics, and combustion stability of a compression-ignition engine fueled with *n*-butane blended dimethyl ether fuel were discussed by Lee et al. [16]. The results showed that *n*-butane blended dimethyl ether fuel has the potential to enlarge the dimethyl ether market. Wang et al. [17] studied the combustion and emissions performance of a diesel engine with DME as port premixed fuel. The results showed that the dimethyl ether quantity played an important role in combustion and emissions control. The peak value of the heat release rate was heightened and its relevant crank angle was advanced with the increase of dimethyl ether addition level. The peak combustion pressure and maximum average cylinder temperature were increased with dimethyl ether quantity, which could help fuel burn completely. Lee et al. [18] condensed an overview of dimethyl ether fuel application for compression-ignition diesel engines. The fundamental fuel properties of dimethyl ether, such as the spray, atomization, combustion and exhaust emissions characteristics were first carefully studied. Then, some technological problems on its application and the field test results of developed dimethyl ether-fueled engines were also discussed [19]. Besides, Park et al. [20] dealt with the combustion and exhaust emissions characteristics in a dimethyl ether-ethanol dual-fuel engine. The results indicated that the emissions from dimethyl ether-ethanol combustion were lower than those of diesel-ethanol and biodiesel-ethanol dual-fuel combustion.

On the other hand, adopting the dimethyl ether as a fuel additive in spark-ignition engines could improve the engine ignition process, due to its high cetane number and low temperature reaction characteristic. Thus, dimethyl ether could also be implemented in the spark-ignition engines. Lee et al. [21] investigated the effects of dimethyl ether addition on performance of a LPG engine. Results showed that the dimethyl ether-blended LPG fuel could be applied to the actual vehicle in view of the results from emissions and fuel economy. Thus, dimethyl ether could be seen as a feasible fuel additive for the spark-ignition engines. Ji et al. [22] carried out experimental investigations to study the effects of dimethyl ether addition on improving the ethanol engines fuel economy and emissions performance under various loads. The results showed that the addition of dimethyl ether benefited reducing the combustion duration due to the elevated flame speed of mixtures. It was further confirmed that the addition of dimethyl ether could contribute to the elevated engine efficiency, shortened combustion duration and enhanced stability. Experimental investigations were also conducted in a SI methanol engine [23]. The experimental results showed that the addition of dimethyl ether was an effective way for realizing the stable operation at idle condition. In addition, Ji et al. [24] carried out an experimental study aiming at improving part load performance through dimethyl ether addition in a gasoline engine. The results showed that, with the increase of dimethyl ether enrichment level, thermal efficiency was improved, meanwhile, NOx and HC emissions were obviously reduced. These results showed that the dimethyl ether addition could be beneficial for combustion and emissions characteristics of SI engines.

Although many researches have studied the effects of dimethyl ether addition on the performance of the internal combustion engine, few attentions have been paid to the effects of dimethyl ether