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# Combustion and emissions characteristics of a S.I. engine fueled with gasoline-DME blends under different spark timings

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ABSTRACT

Dimethyl ether has high cetane number and low temperature reaction characteristics. These mean that blending small amount of dimethyl ether to the spark-ignited engine would be helpful for improving the performance under lean conditions. Spark timing is one of the important factors influencing the engine combustion. Thus, it is necessary to investigate performance of the dimethyl ether-blended gasoline engine under various spark timings. The engine was run at 1400 rpm, a manifolds absolute pressure of 60 kPa and a constant excess air ratio of 1.20. Test results showed that the addition of dimethyl ether resulted in the raised indicated mean effective pressure for the gasoline engine. Over increased and decreased spark timing tended to cause the dropped indicated mean effective pressure. The coefficient of variation in indicated mean effective pressure was diminished with the spark timing advances and dimethyl ether addition. NOx and HC emissions were dropped with the spark timing decrease. NOx emissions from the dimethyl ether-mixed gasoline engine are decreased with the decrease of spark angle.

## 1. Introduction

Nowadays, many researches have shown great interest in highly efficient and clean internal combustion engines (ICEs), due to the implementation of stricter emission norms and the rapid development of industry [1–4]. Numerous innovative techniques on ICEs have been developed to meet the requirements and achieve better performances, such as optimizing the injection and ignition strategies [5,6], thermal management control system [7], friction and lubrication systems [8], and adopting alternative fuels [9], etc. The application of alternative fuel is a feasible method, which has played an important role for ICEs. China has been facing with the significant challenge of energy security for many years. Developing alternative fuel is one of the main self-supporting approaches to adjust energy structure and develop clean energy. The principal alternative fuels include hydrogen [10], biofuel [11], alcohol [12,13], natural gas (NG) [14,15] and liquefied petroleum gas (LPG) [16]. It is common that gaseous fuels could be used as an extender in the case of bi-fuel or multi-fuel engines, which generates higher efficiency and lower emissions [17–20]. The previous studies [21–25] reported that the hydrogen addition could decrease ignition delay times and combustion duration, leading to the decrease of cycle-by-cycle variations and emissions. Dimethyl ether (DME), as a gaseous fuel, is considered to be a clean alternative fuel compared with the diesel and gasoline. It can be obtained from a variety of abundant sources, such as renewable materials and fossil fuels [26]. Moreover, DME is a colorless gaseous fuel at normal temperature and pressure, but it could be switched to a liquid when subjected to modest pressure or cooling. These excellent properties make DME transported and stored easily. In addition, high oxygen content and no sulphur or other noxious compounds in DME leads to a relative clean combustion. Huang et al. [27,28] experimentally and numerically investigated the basic combustion characteristics of DME. The laminar burning velocities of DME and DME/methane blends are measured on various conditions in constant volume bomb, and the kinetic analysis were conducted using the up-to-date kinetic mechanism. The results indicated that the laminar flame speed of DME-methane-air mixtures was increased and the reaction pathway was changed after DME addition. This implied that DME addition could improve the mixtures combustion status. In addition, a reduced chemical kinetic model for DME combustion was developed by this group [29]. The results showed that the reduced DME mechanism could be used to simulate the combustion and emission formation processes of engines. Thus, DME as an alternative fuel has remarkable potential for ICEs [30,31].

At present, most of investigations focused on the pure DME combustion or effects of DME quality on compression-ignited (CI) engine fuel economy and emissions. Park et al. [32] dealt with the combustion

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**Nomenclature**

| | |
|---|---|
| DME | dimethyl ether |
| $\beta$ | dimethyl ether-to-gasoline energy ratios |
| TDC | top dead center |
| $\lambda$ | dimethyl ether-gasoline-air mixtures |
| ICEs | internal combustion engines |
| LPG | liquefied petroleum gas |
| CNG | compressed natural gas |
| BAIC | beijing automotive industry corporation |
| MAP | manifolds absolute pressure |
| $H_2$ | hydrogen |
| CCV | cycle-to-cycle variation |
| CoVimep | coefficient of variation in indicated mean effective pressure |
| Imep | indicated mean effective pressure |
| BTDC | before top dead center |
| ECU | electronic control unit |
| CA0-10 | crank angle duration from spark discharge to 10% heat release of the total fuel |
| CA10-90 | crank angle duration of 10 to 90% heat release of the total fuel |
| SI | spark-ignited |
| CI | compression-ignited |
| Pmax | peak combustion pressure in-cylinder |
| Tevo | cylinder temperature at exhaust valve opening |
| CO | carbon-monoxide |
| NOx | nitrogen oxides |
| PM | particulate matter |
| HC | hydrocarbons |
| CA | crank angle |
| rpm | revolutions per minute |
| $V_{air}$ | air volume flow rate |
| $V_D$ | air density |
| $\rho_{air}$ | DME density |
| $\rho_D$ | mass flow rate |
| $AF_{st,D}$ | stoichiometric air-to-fuel ratio of DME |
| $AF_{st,G}$ | stoichiometric air-to-fuel ratio of gasoline |
| $L_D$ | DME lower heating value |
| $L_G$ | gasoline lower heating value |
| $m_G$ | gasoline mass flow rate |

and exhaust emissions properties in a CI engine. The results indicated that the emissions from DME-ethanol combustion were lower than those from diesel-ethanol and biodiesel-ethanol combustion. Meanwhile, to improve performance of the spark-ignited (SI) engine, DME can be served as additional fuel. Because of the low-temperature chemical reaction characteristic and high cetane number, the addition of DME could be capable of adjusting the fuel octane number. This could be helpful for improving the charge combustion and ignition processes for the SI engine under low speeds and loads. An experimental study aiming at improving engine fuel economy and emissions performance with the DME addition has been carried out by Ji et al. [33]. The experimental outcomes displayed that thermal efficiency was boosted by DME introduction. NOx and HC emissions were reduced with the increase of DME blending level. In general, blending small amount of dimethyl ether is a feasible approach for boosting gasoline engine combustion and emissions characteristics. Lean combustion has turned out to be a promising and attractive method on enhancing the engine performance [34–36]. Firstly, the high thermal efficiency and low fuel consumption could be acquired as a result of the lower heat transfer loss and higher specific heat ratio under lean conditions. Secondly, the burning temperature inside the cylinder can be declined under lean combustion conditions, which also helps the reduction of NOx emissions and the possibility of knock. Lean combustion strategy plays an important role on improving the combustion performance in engines according to studies of Park et al. [37]. The results manifested that the LPG lean-burning strategy could make lower fuel consumption, pumping loss and NOx emissions. Besides, this group also evaluated the effects of excess air ratio on the particulate matter (PM) concentrations and particle size distribution [38]. According to previous studies from Ji et al. [39,40], DME enrichment in the SI engines could enhance the thermal efficiency and diminish emissions significantly at lean combustion conditions.

The spark timing is a significant data to determine the initial process of combustion in ICEs. Generally, spark timing could be changed as needed so that the optimal combustion process could be obtained. Ji et al. [41] investigated the effects of spark timing on the performance of a hydrogen-blended gasoline engine at lean conditions. It was found that, at lean regions, the decreased cylinder temperature and the poor evaporation make the engine encounter intensified incomplete combustion within the cylinder, which caused longer combustion durations. To guarantee the stable combustion process, larger spark advances were required. In addition, the optimum spark timing was retarded with $H_2$ addition. It was because that the $H_2$-gasoline mixtures were ignited and burned easily. Thus, the hydrogen-blended gasoline engine could produce more negative compression work stroke before top dead center (TDC) while adopting larger spark advances. These results demonstrated the fact that spark timing could be a main index influencing engine performances, particularly for the engine combusting different fuels with different properties.

At the present, few attentions have been paid to the effects of spark angle on performance of DME-blended gasoline engine under lean burning conditions. DME has a low temperature reaction characteristic. This indicates performance of the engine fueled with DME blended could be easily affected by the spark angle. The reason is that the spark angle could directly influence the engine heat release process, particularly at the initial combustion stage, where the temperature and pressure are relatively low. While, the heat release process finally decides the thermal state within cylinder. Thus, it is necessary to investigate performance of the engine under various spark timings according to DME addition level and engine conditions to optimize the combustion process. In this paper, a series of experiments were carried out. The engine performance parameters such as the indicated mean effective pressure, flame development, propagation, and exhaust emissions were calculated and analyzed.

## 2. Experimental works

### 2.1. Description of experimental setup

The trial was performed on a 1.5 L naturally aspirated BAIC manufactured gasoline engine. The general specifications were given in Table 1 [42]. To reduce cost and complexity of the testing engine for

**Table 1**
General specifications.

| Definition | Value |
|---|---|
| Engine type | A151 |
| Number of cylinders | 4 |
| Bore × Stroke/mm | 75 × 84.8 |
| Displacement volume/L | 1.5 |
| Compression ratio | 10.5:1 |
| Max. torque/Nm/rpm | 148/3800 |
| Max. power/kW/rpm | 85/6000 |