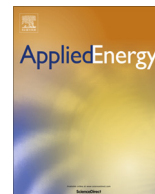




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Impact of methane addition on the performance of biodiesel fueled diesel engine[☆]

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HIGHLIGHTS

- A combined chemical reaction mechanism is developed for biodiesel and methane.
- Methane induction can significantly reduce CO and soot emissions of the engine.
- Methane induction has negligible impact on NO_x emissions.

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ABSTRACT

This study aims to investigate the impact of methane on performance and emission characteristics of diesel engine fueled by biodiesel. A combined chemical reaction model was developed including the reaction kinetics of biodiesel and methane with CO, NO_x and soot formation mechanisms embedded. The developed skeletal reaction mechanism was first validated by performing ignition delay calculations against the detailed biodiesel reaction mechanism, then it was subject to 3D numerical simulations of combustion process in a diesel engine against the experimental results under various operating conditions, good agreement has been obtained. After the validation, it was used to investigate the effect of different methane percentage on the performance of the engine. The results indicate that under various engine load conditions, with the increase of methane addition, both CO and soot emissions are significantly reduced with negligible NO_x emission change.

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1. Introduction

Global warming, the surging price of conventional fuels and stimulated fuel diversification have led to the exploration of alternative fuel for transportation. One example is the use of gaseous fuel as supplement to liquid fuel [1–7]. This kind of dual fuel operation represents an attractive way for the utilization of various gaseous fuels such as methane, propane and butane. For this kind of engine, gaseous fuel is usually drawn into the engine through the intake manifold, mixing with air to forming a combustible mixture, while liquid fuel is injected into the engine via high pressure fuel injector to initiate the combustion process near the top dead

center. Gas/diesel dual fuel engine offers the advantage of forming homogeneous fuel and air mixtures with a wide flammability range [8].

Quite a number of experimental researches have been done to investigate the combustion process and emissions in dual fuel engines. Egusquiza et al. [1] investigated the performance and emissions characteristics of an engine fueled by natural gas and diesel. In this study, most of the energy was from the combustion of natural gas, and only a small amount of diesel fuel provided ignition through high pressure fuel injection. The results indicated that a significant reduction in NO_x was achieved over a wide range of operating conditions. However, CO and HC emissions were increased compared to pure diesel fueled engine. Selim et al. [8] investigated the performance of a dual fuel engine running on natural gas and Jojoba methyl ester. The results showed that using Jojoba methyl ester as a pilot fuel improved the engine performance, brought down combustion noise and extended knocking limits. Stewart et al. [9] investigated the performance of a small dual fuel diesel engine operating with three gaseous fuels (liquefied

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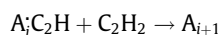
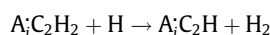
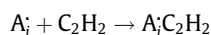
petroleum gas, compressed natural gas and butane). Their study indicated that the maximum cylinder pressure occurred at a later point within the cycle with the increase of percentage of gas substitution, and LPG showed the most promising results. Doijode et al. [10] studied the effect of compression natural gas (CNG) induction on the performance of CNG and Hongo oil methyl esters (HOME) dual fuel engine. It was found that the engine could produce acceptable emissions and improved brake thermal efficiency when operating with injection timing of 27 °BTDC and compression ratio of 17.5. Some investigators also investigated fuel injection timing on the performance of CNG and biodiesel dual fuel engine, and found that advancing fuel injection timing resulted in better performance [11–12]. Azimov et al. [13] investigated premixed mixture ignition in the end-gas region (PREMIER) in a diesel and natural gas dual-fuel engine. It was found that the flame propagated before the mixture was auto-ignited in the end-gas region. The PREMIER combustion could be controlled by fuel/air equivalence ratio, pilot fuel injection timing, exhaust gas recirculation (EGR) rate, could be used as an effective way for high load extension in dual-fuel engines. Shoemaker et al. [14] investigated the performance of a four-cylinder turbocharged diesel engine fueled by biodiesel and methane/propane. They found that dual fuel mode could reduce NO_x and smoke emissions by 33% and 50%, respectively. However, it was accompanied with higher CO and THC emissions.

Unfortunately, rare work has been done to study the impact of supplemental gas induction on diesel engine in terms of numerical simulation in this area. In our earlier works [15–16], we have investigated the impact of hydrogen induction on diesel engine fueled by both diesel and biodiesel, found that the major emissions such as CO, HC and soot could be significantly reduced with the addition of hydrogen, accompanied by a slight increase in NO_x. So far, no detailed chemical reaction mechanism is developed to model biodiesel and methane dual fuel combustion. So the present study aims to bridge this gap, i.e., numerically investigating the performance and emission characteristics of a methane assisted biodiesel combustion.

2. Numerical Approaches and experimental setup

The latest engine numerical simulation software KIVA4 coupled with CHEMKIN II was employed to conduct the simulation. The detailed mathematical models within KIVA4 can be found in Ref. [15]. The CHEMKIN is a software used to formulate and solve elementary gas-phase chemical kinetics. To improve the accuracy of the fuel spray simulation, the original Taylor Analogy Breakup (TAB) model in KIVA4 was replaced with Kelvin–Helmholtz and Rayleigh–Taylor (KH–RT) hybrid model coupled with cavitation effect developed by ourselves which can better model the spray break up process [17]. The law-of-the-wall boundary conditions were used to treat velocity and heat transfer near walls, and the temperature boundary condition is introduced by the wall heat flux $J_w = -k\nabla T\vec{n}$ when the turbulent law-of-the-wall condition is used. Generally, the heat transfer through the wall of cylinder is less than 5%. A combined biodiesel and methane oxidation model was developed in this work by integrating a tri-component biodiesel reaction mechanism [18] with the soot formation and oxidation kinetics [19]. The biodiesel reaction mechanism includes the reaction kinetics of methyl decanoate (MD), methyl-9-decanoate (MD9D) and *n*-heptane. It consists of 69 species and 204 elementary reactions with the CO and NO_x reaction mechanisms embedded, detailed description on this tri-component biodiesel reaction mechanism can be found in [18]. The soot formation mechanism embedded in this work was presented by Tao et al. consisting of series of elementary reactions leading from acetylene and hydrogen to the formation of the first aromatic ring, A₁. Subsequent reactions leading to the

formation of phenyl A₁ radical and the first aromatic ring are achieved by the successive stages of H- abstraction and C₂H₂- addition (HACA- mechanism), yielding a chain of aromatic rings. The general reaction steps to higher rings are represented as



where A_{i+1} represents a higher ring, and . indicates the corresponding radical.

When a sufficiently high order is achieved, a one-step transition from aromatic ring to soot is postulated. In this study, the high

Table 1
Engine specifications.

Engine type	Four stroke, DI, 4 cylinder inline
Bore × stroke	92 × 93.8 mm
Connecting rod	158.5 mm
Compression ratio	18.5:1
Rated power	75 kW at 3600 rpm
Charging	Turbocharged
Fuel injection system	Common rail, Denso (6 Holes)

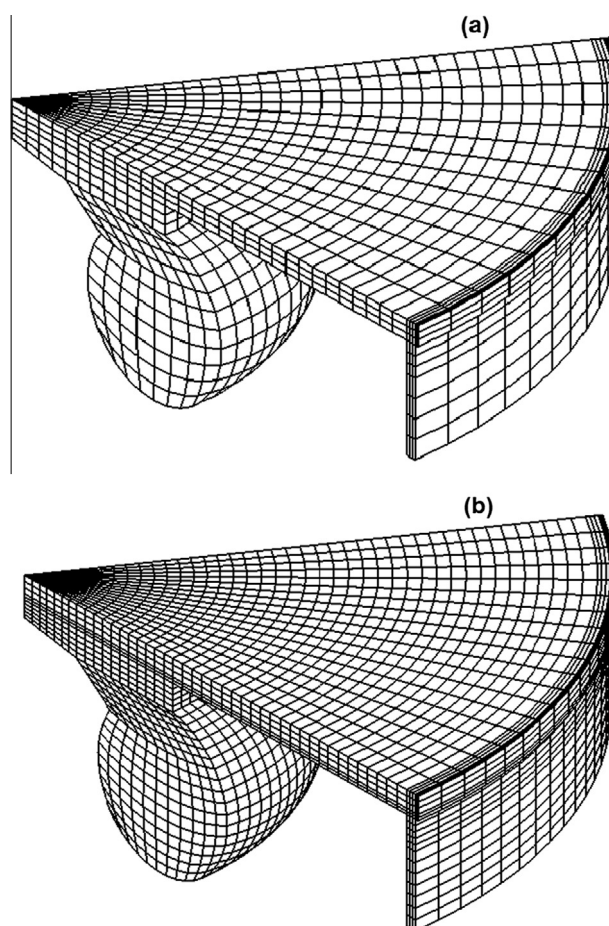


Fig. 1. The 60-degree sector mesh shown at TDC (a) medium mesh and (b) fine mesh.

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