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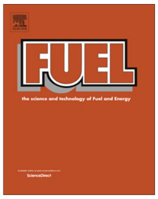

The impact of intake air temperature on performance and exhaust emissions of a diesel methanol dual fuel engine

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HIGHLIGHTS

- The intake air temperature affecting the dual fuel engine performance was investigated.
- Emissions from DMDF engine affected by the intake temperature were examined.
- DMDF indicated thermal efficiency affected by intake air temperature was studied.
- Increasing intake air temperature can reduce all of gaseous emissions but NO_X.
- Increasing intake air temperature will worsen PM emissions.

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ABSTRACT

To better understand how the intake air temperature and methanol fumigation affect the performance and emissions of diesel engine, a parametric study concerned with methanol mass fraction and intake air temperature was conducted. In this study, methanol port injection was used for preparing homogenous charge for diesel methanol dual fuel operation on a 6-cylinder turbocharged intercooler heavy duty (HD) diesel engine. The testing work was operated at a constant load and constant engine speed of 1500 r/min. The experimental results show that there was a strong coupling between the intake air temperature and the methanol fraction to performance and emissions of the engine. At dual fuel operation mode, decreasing intake air temperature reduced the indicated thermal efficiency and exhaust gas temperature and the trend was more evidently as methanol energy fraction increased. Decreasing of intake air temperature also prolonged the ignition delay, which caused a later combustion phasing and smaller peak cylinder pressure. By the induction of methanol, NO_X, NO and smoke emissions decreased markedly, while NO_2, CO, total hydrocarbon (THC), formaldehyde and methanol emissions increased. However, increasing the intake air temperature would inhibit the NO_2, THC, CO, formaldehyde and methanol emissions and increase NO, NO_X and soot emissions. The effect of intake air temperature and methanol fraction on emissions is more remarkably at a larger methanol fraction (30% or more) and higher intake air temperatures such as 60–70 °C.

1. Introduction

The increasing energy demand, depleting oil reserves and environmental pollution problems associated with the use of fossil fuels have sparked renewed interest to find out clean alternative fuels [1–4]. Alcohols such as methanol, ethanol and butanol are competitive alternative fuels due to their liquid nature, high oxygen contents, high octane number and their production from renewable biomass [4]. Among all these alcohol fuels, methanol is one of the most promising fuels as it can be easily synthesized from abundant source such as coal, nature gas and biomass, especially in the methanol adequate country such as Canada, China [1]. Methanol has been used in combustion engines since their invention. Although methanol is known to be excellent fuels for spark ignition engines due to its high octane ratings, lean flammability limits, increased thermal efficiency and low exhaust emissions. It does not carry a similar attraction when its use in diesel engines,

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Abbreviations: HD, heavy duty; THC, total hydrocarbon; NO_X, nitrogen oxides; PM, particulate matter; DMCC, diesel/methanol compound combustion; DMDF, diesel methanol dual fuel; HC, hydrocarbon; CO, carbon monoxide; NO_2, nitrogen dioxide; HCCI, homogeneous charge, compression ignition; SMD, Sauter Mean Diameter; NO, nitrogen monoxide; TDC, top dead center; ECU, electronic control unit; AVL, Anstalt für Verbrennungskraftmaschinen List; FTIR, fourier transform infrared spectroscopy; PID, proportion integration differentiation; SR_m, substitution ratio; AFR, air fuel ratio; LHV, low heat value; SR, substitution ratio.

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although methanol has many advantages as a diesel engine fuel, including lower nitrogen oxides (NO_X) forming potential, negligible particulates (PM) emissions, lack of sulfur and sulfur compounds, and easy refueling [5]. This is because there are difficulties in the ignition of air–fuel mixtures when methanol is used in diesel engines, mainly due to its low cetane number, high latent heat of vaporization and long ignition delay [3–5].

Typically there are several methods have been investigated to overcome ignition problems associated with methanol used in diesel engines. Adding ignition improvers to methanol has helped to increase the methanol fuel's cetane rating by adding compounds to the fuel, which auto-ignite very easily in unmodified diesel engines. These compounds which are typically nitrates are called ignition accelerators of improvers. However, they can be expensive and their toxicities in the raw fuel or as a component of the engine exhaust are not known [6,7]. To avoid the use of ignition improvers, investigators have utilized dual fueling, one of the progress is by diesel methanol emulsions [8–16] and the other by using two fuels simultaneously as inducting the methanol with a separate methanol fuel injector [17–23]. Both of these techniques have their advantages and drawbacks. Stabilized emulsions require use of surfactants and have a limitation of blending rate, while dual injection equipment increases cost of fuel injection systems considerably.

However, the fumigation methanol seems to be more potential for it can allow the large amount of injected methanol to vary depending on actual requirements, which could achieve advanced combustion mode [24] and flexible switch between duel fuel mode and neat diesel operation [19], additionally minor modification for the engine as well. Moreover, since the methanol is mixed in the intake air it is possible to increase the power output from diesels by use of methanol diesel dual fuel [19,22]. Many investigations have been carried out related to performance and emissions with methanol fumigated diesel engine. Yao et al. [19] investigated the effect of diesel/methanol compound combustion (DMCC) on diesel engine combustion and emissions. The experimental results reported that smoke number, nitrogen oxides reduced as carbon monoxide and unburned hydrocarbon emissions increased with fumigation of methanol fuel. Wei et al. [23] and Masimalai [25] investigated a higher premixed methanol fraction (more than 70 percent methanol in the fuel energy share) in a six cylinder diesel engine and single cylinder engine respectively. Both found an increase of hydrocarbon (HC) and carbon monoxide (CO) and decrease in NO_X and particulate. It also found an increasing of nitrogen dioxide (NO_2) and formaldehyde emissions by the use of methanol fumigation. Investigations regarding fuel deliver timing reported by Liu et al. [22] and Liu et al. [17] respectively, they found that advancing the fuel delivery angle would inhibit the HC, CO, and smoke emissions but promote NO_X emissions. Liu et al. [26] investigated the effect of injection pressure on combustion and emissions of the diesel methanol dual fuel, as the diesel injection pressure increases, CO and HC emissions are decreased, however, CO_2 and NO_2 emissions are slightly increased. An investigation by Cheung et al. [20] found that by the use of a diesel oxidization catalyst the emission of HC and CO got to the same level of neat diesel operation.

Methanol has higher latent heat of vaporization than that of diesel (about 1100 kJ/kg versus 250 kJ/kg) and a lower calorific value (about 20.1 MJ/kg versus 42.8 MJ/kg) [27,28], which means methanol needs a much higher (about 9.37) evaporation heat for a given energy output. Reduction of charge temperature leads to lower the temperature in the cylinder at the time of diesel fuel injection thereby prolongs ignition delay. Meanwhile, reduction of the charge temperature also increases the intake air mass, and methanol with high oxygen content gets a much leaner A/F (air/-fuel) ratio (about 6.4 versus 15), which caused a leaner combustion [2]. Usually intake air temperature was used to modify the ignition timing of homogeneous charge, compression ignition (HCCI) combustion [29], or to extend the lambda limitation for the diesel engine. For dual fuel operation, effect of intake air temperature on diesel methane dual fuel has been concerned widely interests. Experiment investigations operated by Adb-alla et al. [30] and kumar and Raj [31] found that higher intake air temperature increases the exhaust NO_X but reduces the unburned hydrocarbon and carbon monoxide emissions. Simulation work by Papagiannakis [32] also got a similar result. For diesel dual fuel, previous studies were mainly dealt with effect of intake air temperature on combustion and emissions characteristics in a single cylinder, air cooled, naturally aspirated methanol fumigated diesel engine. Varde [33] found that decreasing inlet charge temperature reduced peak cylinder pressure and increased ignition delay period at a given methanol energy fraction. Experiment and simulation work by Su et al. found that ambient temperature shows greatly effect on the spray and atomization of diesel fuel. The increasing of ambient temperature would improve the activation of diesel fuel, accelerating the diesel fuel evaporation, change the SMD distribution and spray tip penetration [34]. For a given level of methanol energy, reducing inlet charge temperature reduced NO_X levels. The effect was more significant at lower temperatures ranging from 0 °C to −5 °C. Another investigation was made by Yilmaz [13] about the effects of intake air preheat on diesel methanol blends. Nadir found that preheating the intake air tended to reduce the production of CO and HC, while slightly increasing nitrogen monoxide (NO) emission.

In previous study, intake air temperature shows significantly impacts on combustion and emission characteristics of diesel methanol dual fuel engines. However, the experiments are operated at low level of intake charge temperature and firm methanol energy fraction. The coupling effect of intake charge temperature and methanol mass fraction has not been investigated. Actually, in our tests either on bench or in fields, we found that intake charge temperature had great impacts to the emission and fuel consumption. The effect was different at varied methanol mass fraction. To gain a better understanding of how the intake air temperature and methanol fumigation affect the performance and emissions of diesel engine, further investigation concerned with a higher mass fraction of methanol and larger intake air temperature range is needed. In this study, an experimental study was undertaken to investigate engine performance and emission characteristics versus substitution ratio at various intake air temperature. The testing diesel engine was operated at a constant load and engine speed. Performance and emission characteristic at various ratios of methanol substitution at different intake air temperature were investigated.

2. Experiment setup and procedure

2.1. Research engine

Experiments were conducted on a Weichai WP-series diesel engine, which is a typical turbo charged common rail 6 cylinder heavy duty diesel engine with a displacement of 1.621 l/cylinder. The engine specifications are listed in Table 1. Fig. 1 shows a schematic of the engine, which has been converted for dual fuel operation. For this study methanol was premixed with a methanol low pressure common rail and methanol injector, which was depicted in Fig. 1. Methanol was injected into intake manifolds with a pressure of 0.42 MPa. The methanol injection was controlled by a dedicated electronic control unit (ECU).

The properties of diesel and methanol fuel are shown in Table 2. The diesel fuel used in this study contained sulfur less than

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