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Influence of fumigation methanol on the combustion and particulate emissions of a diesel engine

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HIGHLIGHTS

- Fumigation methanol influences engine combustion and particulate emissions.
- It reduces diesel fuel consumed and increases heat released in premixed mode.
- Peak cylinder pressure is increased at high engine load but reduced at low engine load.
- It increases ignition delay and peak heat release rate but not combustion duration.
- Particulate mass and number concentrations reduced at medium and high engine loads.

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ABSTRACT

This study is aimed to investigate the effects of fumigation methanol on the combustion and particulate emissions of a diesel engine under different engine loads and fumigation level. Experiments were performed on a 4-cylinder direct injection diesel engine operating at the engine speed of 1920 rev/min with five engine loads. The combustion characteristic analysis indicates that with fumigation methanol, the maximum cylinder pressure decreases at low to medium engine loads but increases at high engine load. Fumigation methanol increases the peak heat release rate and ignition delay but does not significantly change the combustion duration. The fumigation method results in a significant decrease in particulate mass and number concentrations from medium to high engine loads, due to the increase of fuel burned in the premixed mode and a reduction of diesel fuel involved. Fumigation methanol also slightly decreases the fraction of accumulation mode particles and thus the particulate geometric mean diameter (GMD).

1. Introduction

Two major energy related issues that the world is facing today are the running out of fossil fuel and serious air pollution. Both of them are highly related to motor vehicles. In particular the high particulate and nitrogen oxides (NOx) emissions of diesel vehicles are major air pollution problems in many cities. Alternatively fuelled diesel vehicles are considered as one of the approaches to address these issues [1–3]. Methanol is a widely investigated alternative fuel for diesel vehicles due to its potential economic, national security and environmental benefits. Methanol has high latent heat of vaporization. It is oxygenated, sulfur free and has high burning speed. It has the potential of reducing both the particulate and NOx emissions of diesel engines [4]. Methanol can be readily converted from natural gas or synthesized from coal, municipal wastes and biomass [5,6]. Producing methanol from coal is especially important in countries like China which are rich in coal but poor in oil reserves.

Methanol can be used in diesel engines in the fumigation mode with diesel fuel injected directly into the engine cylinder and with methanol injected into the air intake. The fumigation mode has been widely investigated and reported in the literature [7–12]. The fumigation method allows the amount of methanol to be injected to vary depending on actual requirement. For example, Yao et al. [8] proposed to run a diesel engine on diesel fuel alone at engine start and light load to ensure cold starting capability and avoid excessive HC and CO emissions; and to run on the fumigation mode to reduce particulate and NOx emissions at medium and high loads. In the fumigation mode the amount of methanol to be applied has to be limited to avoid engine knocking. In Cheng et al. [10] fumigation methanol could provide 30% of the total

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engine load; while in Song et al. [12] the maximum methanol mass fraction reached 70%.

The combustion process in a direct injection diesel engine can be divided into the ignition delay period, the premixed combustion period and the diffusion combustion period. The amount of fuel consumed in the premixed combustion phase has a positive correlation with NOx emission, while diffusion combustion correlates with particulate emission [12]. Prior study by Choi and Reitz [13] and Song et al. [14] respectively shows that oxygenated fuels affect the combustion and particulate emission. In the fumigation mode, methanol is injected into the air manifold to form a homogeneous mixture with air, while diesel is directly injected into the engine cylinder. Once auto-ignition of the diesel fuel has occurred, further combustion consists of the simultaneous premixed combustion of the air/methanol mixture and further combustion of the diesel fuel, which has the combined characteristics of compression-ignition and spark-ignition engines [12,15]. Although several researches have been carried out on the combustion of methanol in diesel engines, however, most of them focused on the engine performance and emissions while there is lack of investigation focusing on the combustion and particulate emission characteristics. The present study is aimed to provide further experimental data on the effect of fumigation methanol on the engine combustion characteristics. At the same time, the influence of fumigation methanol and thus the combustion characteristics on the particulate emission, including both particulate mass and number concentrations, are evaluated.

2. Experimental setup and procedure

The experimental setup is shown in Fig. 1. The experiments were carried out on a naturally-aspirated, water-cooled, 4-cylinder direct-injection ISUZU diesel engine. The engine has a capacity of 4334 cc, and the maximum power is 88 kW at 3200 rev/min and the maximum torque is 285 N m at 1800 rev/min. A lot of these engines are still used in mainland China and Hong Kong. The engine was modified with a methanol fuel rail and four fuel injectors were added to supply methanol to the engine using a fuel pump at a working pressure of 0.35 MPa. An electronic control unit (ECU) was used to control the fueling rate of methanol. The engine was coupled with an eddy-current dynamometer while its speed and torque were controlled by the Ono Sokki diesel engine test control system (speed control resolution of 1 rev/min, torque control resolution of 0.1 N m and throttle control of 0.1%). A pressure transducer (Kistler piezoelectric sensor 6056A, 0.5% resolution) was mounted in the glow-plug hole in the first cylinder of the engine. This pressure sensor was used with a shaft encoder and a charge amplifier (amplifier 5011B, 5% resolution) to obtain pressure data at 0.5 crank angle intervals. In each operating condition, the cylinder pressure data were averaged over 400 consecutive cycles for the experiment. The averaged pressure data were analyzed with the DEWE-ORION-0816-100X, a software product of Dewetron, to perform heat release rate analysis.

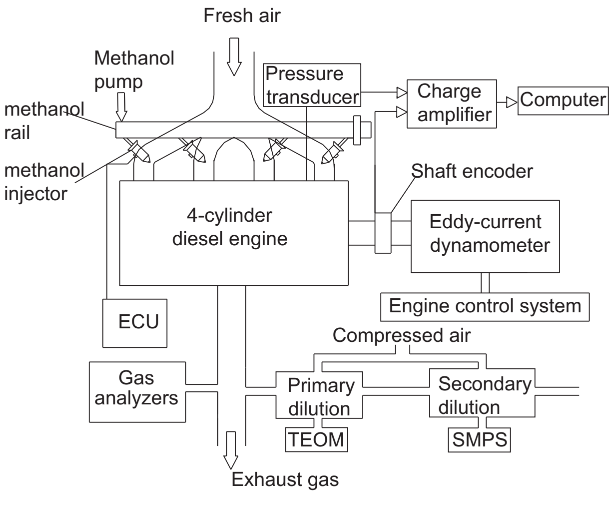

Fig. 1. Schematic of experimental system.

A two-stage Dekati mini-diluter was used for diluting the exhaust gas [16]. The dilutor provides primary dilution in the range of 8:1–6:1, depending on the engine operating conditions, while the secondary dilution system provides a further dilution of 8:1 to keep the sampling gas temperature below 52 °C. The actual dilution ratio was evaluated based on measured CO_2 concentrations in the raw exhaust, in the background air and in the diluted exhaust. CO_2 concentration was measured with a non-dispersive infra-red analyzer (CAI 300, California Analytical Instruments, Inc., 0.01% resolution). The primary dilution was delivered to a tapered element oscillating microbalance (TEOM 1105, Rupprecht & Patashnick Co., Inc., 0.2 mg/m^3 resolution) to measure the particulate mass concentration, in which the main flow rate of sample was 1.5 l/min and the inlet temperature was held at 47 °C. The number concentration and size distribution of particles in the secondary dilution was measured by a TSI 3934 scanning mobility particle sizer (SMPS, minimum concentration of 1particle per cm^3) for particles in the size range of 15–750 nm.

Experiments were performed at the engine speed of 1920 rev/min, and at engine loads of 46, 92, 138, 184 and 218 N m, corresponding to brake mean effective pressures (BMEP) of 0.13, 0.27, 0.40, 0.53 and 0.63 MPa, respectively. Experiments were firstly carried out with diesel fuel alone. Experiments were then carried out with the diesel fuel taking up 90% of the desired engine load while the rest of the desired load was taken up by fumigation methanol. Experiments were repeated with the diesel fuel taking up 80% and 70% of the desired engine loads, with fumigation methanol providing respectively 20% and 30% of the desired engine loads. In this paper, *x*% fumigation methanol or *x*% MeOH refers to the case that fumigation methanol takes up *x*% of the engine load. The diesel fuel used is Euro V diesel containing not more than 10-ppm by weight of sulfur while the methanol used is industrial methanol. Major properties of the fuels are shown in Zhang et al. [17]. Fuel consumption was measured using a measuring cylinder for the diesel fuel and using an electronic balance with a precision of 0.1 g for the fumigation methanol.

At each mode of operation, the engine was allowed to run for a few minutes until the cooling water temperature reached 80–85 °C while the lubricating oil temperature reached 90–100 °C, depending on the engine load. Fuel consumption, exhaust temperature and particulate mass concentration were continuously measured for five minutes and the average results are presented. For particle number concentration and size distribution, four samples were collected at each mode and the average values are presented. The steady state tests were repeated at least twice to ensure that the results are repeatable within the experimental uncertainty of <5%. The standard errors have been determined based on the method of Kline and McClintock [18]. The standard errors at 95% confidence level are 1.7% for mass consumption rate of fuel, 1.5% for exhaust temperature, 3.1% for pressure and heat release, 1.8% for particulate mass concentration and 1.7% for particle number concentration. The standard error of pressure was evaluated using the peak pressures obtained in the same operating condition. The same level of error is assumed in the heat release parameters which are derived from the pressure data.