Atmospheric Environment 44 (2010) 1054–1061

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Experimental investigation of regulated and unregulated emissions from a diesel engine fueled with Euro V diesel fuel and fumigation methanol

Z.H. Zhang[a,b], C.S. Cheung[b,*], T.L. Chan[b], C.D. Yao[a]

[a] State Key Laboratory of Engines, Tianjin University, Tianjin 300072, PR China
[b] Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 24 July 2009
Received in revised form
9 December 2009
Accepted 14 December 2009

Keywords:
Diesel engine
Methanol
Regulated emissions
Unregulated emissions
Particulate emissions

ABSTRACT

Experiments were conducted on a four-cylinder direct-injection diesel engine with part of the engine load taken up by fumigation methanol injected into the air intake of each cylinder to investigate the regulated and unregulated gaseous emissions and particulate emission of the engine under five engine loads at an engine speed of 1920 rev min^{-1}. The fumigation methanol was injected to top up 10%, 20% and 30% of the engine load under different engine operating conditions.

The experimental results show that at low engine loads, the brake thermal efficiency (BTE) decreases with increase in fumigation methanol; but at high engine loads, the BTE is not significantly affected by fumigation methanol. The fumigation methanol results in significant increase in hydrocarbon (HC), carbon monoxide (CO) and nitrogen dioxide (NO_2) emissions, but decrease in nitrogen oxides (NO_x). For the unregulated gaseous emissions, unburned methanol, formaldehyde and BTX (benzene, toluene and xylene) emissions increase but ethyne, ethene and 1,3-butadiene emissions decrease. Particulate mass and number concentrations also decrease with increase in fumigation methanol. A diesel oxidation catalyst (DOC) is found to reduce significantly most of the pollutants, including the air toxics, when the exhaust gas temperature is sufficiently high.

1. Introduction

Diesel vehicles are an important source of many air pollutants, including hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM) and other toxic species. Significant and fundamental changes to diesel engine combustion process and associated after-treatment technologies are expected for reducing these emissions and thus reducing the influence to the atmospheric environment and human health (Merritt et al., 2006). However, it is difficulty to achieve simultaneous reduction of NO_x and PM.

Recently, much attention has been given to the development of cleaner alternative fuels for reducing air pollution and for reducing the dependence on fossil fuels. Among the alternative fuels, methanol is one of the most widely investigated. Due to its high oxygen content and high H/C ratio, methanol is beneficial for reducing soot and smoke. Moreover its high latent heat of vaporization can have a cooling effect on the cylinder charge and therefore reduce NO_x emission (Bayraktar, 2008). Methanol can be used in the diesel engine either by blending it with the diesel fuel or by injecting into the air intake. The later approach is known as the fumigation method. Chao et al. (2001), Bayraktar (2008) and Canakci et al. (2008) have investigated the emission characteristics of diesel-methanol blends with different kinds of diesel engine. Their results have shown the different effects of the blended fuel on engine emissions. However, there is a limitation on the amount of methanol which can be premixed with diesel fuel for stable operation. On the other hand, the effects of fumigation methanol on engine emissions have been investigated by Popa et al. (2001), Udayakumar et al. (2004), Yao et al. (2007, 2008), Cheng et al. (2008a,b) and Song et al. (2008). Most of their results show that fumigation methanol has the potential for reducing both NO_x and PM emissions but there are increase in HC and CO emissions.

Former investigations focused on engine performance and the regulated emissions. There is lack of investigations on the unregulated emissions which are more toxic. It is already known that alcohols used in the diesel engine will emit more volatile hydrocarbons which could be harmful to human health and could enhance the formation of photochemical smog (Chao et al., 2000). It is also known that the application of oxygenated fuel in diesel engines might lead to finer particle emission, which could be more damaging to human health (Di et al., 2009). Therefore there is a need to investigate the changes specifically on the hydrocarbon emissions and the particulate emissions, as well as certain

* Corresponding author. Tel.: +852 2766 7819; fax: +852 2365 4703.
E-mail address: mmcsc@polyu.edu.hk (C.S. Cheung).

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doi:10.1016/j.atmosenv.2009.12.017

Table 1
Specifications of the test engine.

Model	Isuzu 4HF1
Type	In line, 4-cylinder, direct-injection
Maximum power	88/3200 (kW rpm^{-1})
Maximum torque	285/1800 (Nm rpm^{-1})
Bore/stroke (mm)	112/110
Displacement (cm^3)	4334
Compression ratio	19.0:1

oxygenated hydrocarbons, to identify if the emissions are becoming more harmful to human being and the environment.

The present study is aimed to provide further experimental data on the effect of fumigation methanol on the emissions of a diesel engine and the sensitivity of these emissions to the amount of fumigation methanol applied under different operating conditions. Besides the regulated emissions, certain unregulated emissions were also measured. Euro V diesel fuel containing less than 10 ppm-wt of sulfur was used in this study. In addition, the effect of a diesel oxidation catalyst (DOC) on reducing the regulated and the unregulated emissions was also investigated.

2. Experimental section

Experiments were carried out on a four-cylinder naturally aspirated direct-injection diesel engine, which is a common engine used in the in-service trucks in Hong Kong and mainland China. Specifications of the engine are shown in Table 1. The engine was coupled with an eddy-current dynamometer and the engine speed and torque were controlled by the Ono Sokki diesel engine test system. The methanol injection system has been described in Zhang et al. (2009). The experimental setup is shown in Fig. 1. The fuels used include Euro V diesel fuel and industrial grade methanol. Major properties of them are shown in Table 2. Fuel consumptions were measured using an electronic balance with a precision of 0.1 g.

The gas and particulate measuring instruments used in this study are given in Table 3. Regulated gaseous emissions including HC, NO_x/NO_2, and CO were measured using online exhaust gas analyzers. HC was sampled through a heated line maintained at 190 °C and then measured with a heated flame ionization detector (HFID); NO_x/NO_2 was measured with a heated chemiluminescent analyzer (HCLA) with the gas sample maintained at 60 °C; while CO

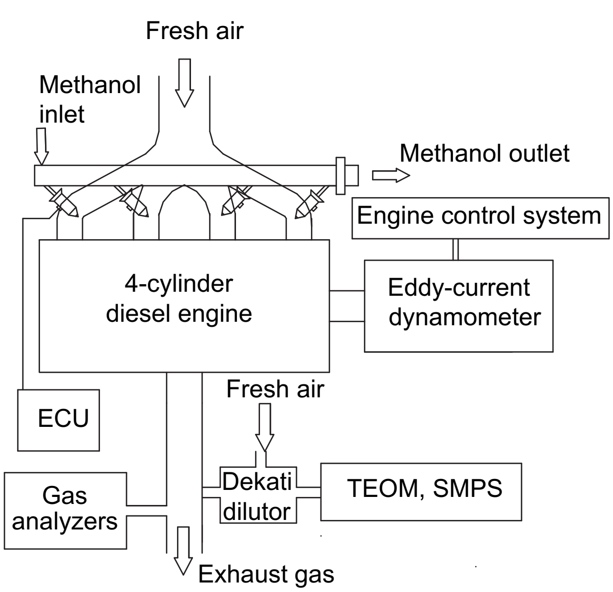

Fig. 1. Schematic of the experimental setup.

Table 2
Properties of Euro V diesel fuel and methanol.

Properties	Euro V diesel	Methanol
Molecular formula	–	CH_3OH
Molecular weight, g mol^{-1}	–	32
Stoichiometric air/fuel ratio	14.7	6.7
Cetane number	>51	<5
Flash point, °C	78	107
Ignition temperature, °C	316	470
Viscosity at 20 °C, mPa s	2.8	0.59
Density, kg m^{-3}	830	790
Lower heating value, MJ kg^{-1}	42.5	19.7
Heat of vaporization, kJ kg^{-1}	270	1178
Oxygen content, wt%	0	50
Sulfur content, ppm wt	<10	–
Flame temperature, °C	2054	1890

and CO_2 were measured with respective non-dispersive infra-red analyzers (NDIR). The gas analyzers were purchased from California Analytical Instruments, Inc. Before each test, the gas analyzers were calibrated with standard gases and zero gas. Unregulated gases including benzene, toluene, formaldehyde and methanol were online analyzed with the Airsense multi-component gas analyzer. The analyzer is an Ion Molecule Reaction (IMR) mass spectrometer, which allows dynamic studies of gaseous emission in low concentration. The detailed principle of operation of the analyzer has been described elsewhere (Villinger et al., 1993, 1996; Dearth, 1999). The gas sample was taken directly from the engine exhaust and maintained at 190 °C to the multi-component gas analyzer. In this study, benzene, toluene, formaldehyde and methanol were calibrated directly using standard gases, while other compounds were calibrated indirectly based on information provided by the equipment supplier.

A two stage Dekati mini-diluter was used for diluting the exhaust gas for particle sampling. The diluted exhaust gas was delivered to a tapered element oscillating microbalance (TEOM) for measuring particulate mass concentration and to a scanning mobility particle sizer (SMPS) for measuring the size distribution and number concentration. The SMPS consists of a TSI 3071A differential mobility analyzer (DMA) and a TSI 3022 condensation particle counter (CPC).

Experiments were carried out at various steady state operating conditions. All the gas concentrations and particulate mass concentrations were continuously measured for 5 min at the exhaust tailpipe of the diesel engine and the average results are presented. Three tests were carried out for each operating condition and the results were found to agree with each other within the 95% confidence level. For particle number concentration and size distribution, four measurements were taken at each mode and the average values are presented. The gaseous volumetric

Table 3
Exhaust emissions measuring instruments.

Instrument	Exhaust species	Unit	Manufacturer and type
Heated flame ionization detector (HFID)	THC	ppm	CAI model 300
Heated chemiluminescent analyzer (HCLA)	NO_x	ppm	CAI model 400
Non-dispersive infra-red analyzer (NDIR)	CO CO_2	ppm%	CAI 300
Multi-component gas analyzer	Benzene, toluene, formaldehyde….	ppb	V&F Airsense Net
TEOM	Particulate mass concentration	mg m^{-3}	R & P TEOM1105
SMPS	Particulate number concentration and size distribution	# m^{-3}	TSI, Inc 3071A DMA +3022 CPC