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Effect of Diesel/methanol compound combustion on Diesel engine combustion and emissions

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Abstract

This paper introduces a Diesel/methanol compound combustion system (DMCC) and its application to a naturally aspirated Diesel engine with and without an oxidation catalytic converter. In the DMCC system, there are two combustion modes taking place in the Diesel engine, one is diffusion combustion with Diesel fuel and the other is premixed air/methanol mixture ignited by the Diesel fuel. Experiments were conducted on a four cylinder DI Diesel engine, which had been modified to operate in Diesel/methanol compound combustion. Experiments were conducted at idle and at five engine loads at two levels of engine speeds to compare engine emissions from operating on pure Diesel and on operating with DMCC, with and without the oxidation catalytic converter. The experimental results show that the Diesel engine operating with the DMCC method could simultaneously reduce the soot and NOx emissions but increase the HC and CO emissions compared with the original Diesel engine. However, using the DMCC method coupled with an oxidation catalyst, the CO, HC, NOx and soot emissions could all be reduced.
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1. Introduction

Diesel engines are widely used because of their good efficiency and reliability. However, their exhaust emissions, such as black smoke and NOx, are disgusting and harmful. Much effort is being made worldwide to reduce the smoke and NOx emissions from Diesel engines. The major difficulty lies in the simultaneous reduction of both pollutants. For new vehicles, through technological development, simultaneous reduction of the two pollutants can be achieved, as reflected in the advancement of the Euro Standards. These include the combined application of in-cylinder methods and after treatment devices [1–3]. In-cylinder methods are mostly applicable to new engines. For in service vehicles, in-cylinder methods are mostly inapplicable, while most after treatment methods do not lead to simultaneous reduction of particulates and NOx. For example, the use of an oxidation catalyst or particulate trap basically has no effect on NOx emissions.

An alternative approach is through improvement of the fuel properties such as the application of a non-alcoholic oxygenate to Diesel fuel [4–6]. Some of the oxygenates, including esters, ethers and carbonates, are found to have beneficial effects on reducing smoke and particulate emissions because their oxygen contents restrain particulate formation during the combustion process. However, they might also lead to an increase in hydrocarbon and NOx emissions.

Alcohols such as methanol and ethanol have also received extensive interest for application to Diesel engines. Methanol fueled compression ignition engines received active research in the 1980s and the early 1990s [7–11]. Methanol has a high latent heat of vaporization; it is oxygenated,

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sulfur free and has high burning speed. When burned at high temperature, it can reduce the smoke and nitrogen oxides emissions of Diesel engines. The major problems in the application of methanol in motor vehicles are the difficulty of cold start and the high aldehyde emissions at cold start, warming up and low load operations. The low cetane number of methanol makes autoignition difficult so that direct application of methanol to Diesel engines is difficult. Methanol fueled buses had once been introduced to reduce pollutant emission. However, operational problems have slowed the development of methanol fueled vehicles, leading to phasing out the methanol fueled buses from the market. Wang et al. [12] compared the emissions from Diesel buses with alternative fuel buses, including the methanol fueled ones. Their results show a reduction of particulate and NOx emissions but an increase in CO and HC emissions from the methanol fueled buses.

Because of limitations on the development of neat methanol compression ignition engines, recent interests have been focused on the partial replacement of Diesel with methanol. either premixed with Diesel or injected into the air intake. Both methods can be readily applied to in use Diesel engines.

Diesel and methanol have poor miscibility, hence, an additive has to be added if methanol blended Diesel is to be injected into the engine. Chao et al. [13] investigated the emission characteristics of a six cylinder, naturally aspirated, direct injection Diesel engine using Diesel blended with up to 15% by volume of a methanol containing additive. They conducted steady state tests as well as transient cycle tests. They found a decrease in NOx emissions but an increase in CO and HC emissions as the methanol content in the blended fuel was increased. Regarding PM (particulate matter), the results are mixed: PM emission could increase or decrease, depending on the operating conditions. Huang and his co-workers [14,15] conducted research on the combustion and emission characteristics on a single cylinder direction injection engine with a stabilized Diesel–methanol blend with less than 18% by weight of methanol. They measured the cylinder pressures and analyzed the heat release rates. They found that increasing the methanol blended Diesel will increase the ignition delay, causing an increase in the heat release rate in the premixed combustion phase and a reduction in the combustion duration in the diffusion combustion phase [14]. They reported a marked reduction in the exhaust CO and smoke, little change in HC but an increase in NOx using the methanol blended Diesel [15]. Their results are different from those of Chao et al. [13], probably due to differences in the engine and operating conditions as well as the additives used.

Methanol and Diesel can also be applied separately to the engine. Popa et al. [16] applied two fueling methods in their investigation. The first method takes in methanol through a carburetor while Diesel is supplied through the normal fuel injector (the Diesel-carburetor method). The second one uses a double injection method. The first method is the fumigation approach, which has also been reported in ethanol applications [17,18] and is unfavourable for starting and low load operation. Popa et al. [16] measured only NOx and smoke emissions. For the Diesel-carburetor method, they found that the NOx level could be significantly reduced for all engine loads, while for smoke, reduced levels were achieved only at high engine loads (>50%). They also measured the cylinder pressure and found an increase in ignition delay with an increase in methanol injection. Udayakumar et al. [19] also used the fumigation method by injecting methanol into the inlet manifold. They conducted their tests with inlet air heated to 70 °C. They reported their test results on smoke and NOx emissions, both being reduced with methanol injection.

Compared with the premixed method, the fumigation method is more flexible in operation and allows a higher percentage of methanol to be applied. In fact, methanol fumigation had been investigated for a long time [7]. In either the premixed or the fumigation method, the inclusion of methanol in starting and low load operations would lead to difficulty at cold start and high aldehydes emission. The objective of this paper is to introduce a new approach for burning pure Diesel or a combination of Diesel and methanol in a Diesel engine. We call this the Diesel/methanol compound combustion (DMCC) system. The DMCC system is similar to the fumigated engine of Refs. [16,19], but the fueling method and strategies are different. Using DMCC, methanol will be injected into the intake port of each cylinder to form a homogeneous mixture with air for combustion, while the original Diesel fuel injection system will be retained but slightly modified to limit the Diesel fuel injection. At engine start and low speed, the engine will operate on Diesel alone to ensure cold starting capability and to avoid aldehydes production under these conditions. At medium to high loads, the engine will operate on a homogeneous air/methanol mixture ignited by pilot Diesel to reduce particulate and NOx emissions. The system thus developed can be retrofitted on in use Diesel engines. This paper reports the emissions of a Diesel engine operating with the DMCC system.

The literature shows that most previous investigations were performed and assessed in isolated testing conditions. It is difficult to compare the results obtained from different engines that are operating under different conditions. For example, the results of Refs. [13,15] are quite different from each other. It is, therefore, necessary to conduct tests based on standard testing cycles so that the results could be comparable even for different engines. In this paper, the tests were conducted based on the ECE R49 13-mode tests so that the results for each mode, as well as the weighted results, can be obtained. Our review also reveals that there are increases of CO and HC emissions associated with the application of methanol to Diesel engines [12,13]. Moreover, there could be an increase in particulate emissions [13]. Thus, there is a need to investigate methods for their reductions. In this paper, we have included tests with an oxidation catalyst to assess its effect on reducing the CO, HC and PM emissions. A methanol fumigation Diesel engine with oxidation cata-

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