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Full Length Article

To meet demand of Euro V emission legislation urea free for HD diesel engine with DMCC

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HIGHLIGHTS

- Experiment for HD diesel engine to meet Euro V emission legislation with DMCC was conducted on a Euro IV engine.
- The application of DMCC and DPOC helped the Euro IV engine to meet the emission limit of Euro V urea free.
- NO_X and PM emissions before DPOC from DMCC Euro V engine have met the demand of Euro V legislation.
- The increased HC, CO, HCHO and CH_3OH emissions from DMCC engine could be eliminated effectively by DPOC.

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ABSTRACT

Based on European Steady-state Cycle (ESC) test procedure, an engine test was carried out to meet the demand of Euro V legislation with diesel methanol compound combustion (DMCC) technology on a common-rail, turbocharged, inter-cooling heavy-duty and high pressure exhaust gas recirculation (HP EGR) diesel engine with meeting the requirements of Euro IV legislation. The engine was just modified with DMCC technology and combined with after-treatment device diesel oxidation catalyst coupled with particulate oxidation catalyst (DPOC). The test results show that it can fully meet the demand of Euro V legislation without the help of selected catalyst reduction (SCR). Additionally, the comparative analysis of the dynamic and economic performances between the DMCC Euro V engine and the baseline Euro IV engine was presented in this study. The regulated emissions (included HC, CO, NO_X, PM (particulate matter)) and unregulated emissions (included formaldehyde (HCHO) and unburned methanol (CH_3OH)) before and after DPOC from DMCC Euro V engine were also investigated. The dynamic performance of DMCC Euro V engine is basically consistent with the baseline Euro IV engine, while there is a slight deterioration in economic performance at certain operation conditions in terms of calorific value. Compared with the baseline engine before DPOC, the DMCC engine causes an increase in HC, CO, HCHO and CH_3OH emissions, but the NO_X and PM emissions are much better. The DPOC efficiency in the conversion rate of HC, CO, HCHO and CH_3OH is over 98% under the whole ESC test procedure, and for PM, the conversion efficiency is only around 21%. However, DPOC has no obvious influence on the conversion of NO_X emissions.

Abbreviations: DMCC, diesel methanol compound combustion; HD, heavy-duty; ESC, European Steady-state Cycle; HP EGR, high pressure exhaust gas recirculation; DPOC, diesel oxidation catalyst coupled with particulate oxidation catalyst; SCR, selective catalytic reduction; HC, hydrocarbon; CO, carbon monoxide; NO_X, nitrogen oxide; PM, particulate matter; HCHO, formaldehyde; CH_3OH, methanol; DMDF, diesel methanol dual fuel; MSR, methanol substitution ratio; ECU, electronic control unit; CA, crank angle; BTDC, before top dead center; CA50, crank angle of 50% accumulated heat release rate; LTC, low temperature combustion; IC engine, internal combustion engine; F/O equivalence ratio, fuel to oxygen equivalence ratio; HCCI, homogeneous charge compression ignition; PCCI, premixed charge compression ignition; RCCI, reactivity controlled compression ignition; CRDPF, continuously regenerating diesel particulate filter; MII, Ministry of Industry and Information; IARC, International Agency for Research on Cancer; EGR, exhaust gas recirculation; F.S., full scale; CHN, China; DOC, diesel oxidation catalyst; CO_2, carbon dioxide; NO, nitric oxide; NO_2, nitrogen dioxide; EPA, Environmental Protection Agency; ETC, European Transient Cycle; ELR, European Load Response test.

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Nomenclature

$\dot{m}_{Dneat}$	the diesel fuel consumed on pure diesel mode (kg/h)
$\dot{m}_{Ddual}$	the diesel fuel consumed on DMCC mode (kg/h)
b_{eq}	the equivalent fuel consumption rate
$\dot{m}_{Mdual}$	the methanol fuel consumed on DMCC mode (kg/h)
H_{LM}	the lower heating value of methanol (MJ/kg)
H_{LD}	the lower heating value of diesel (MJ/kg)
P_e	the power of the engine (kW)
Φ_T	total fuel to oxygen equivalence ratio
Φ_D	fuel to oxygen equivalence ratio of diesel
Φ_M	fuel to oxygen equivalence ratio of methanol

1. Introduction

Because of its advantage on power and economic performance, diesel engine has become the preferred engine for heavy-duty vehicle. Environmental protection attracts more and more attention around the word, and the pollution problem caused by diesel engine is becoming more and more prominent. Data showed that the quantity of heavy-duty (HD) diesel vehicles was less than 3% of the whole motor vehicles in China, but the NO_X and PM emissions from them were more than 60% of those emissions emitted from the whole motor vehicles [1]. PM contains various carcinogenic substances, and it will cause respiratory disease or even cancer once it is breathed in [2]. NO_X is recognized as the main culprit which causes photochemical smog, and it can also cause acid rain, ozone depletion and greenhouse effect [3]. However, it is quite difficult to control the NO_X and PM emissions from a HD diesel engine only relies on in-cylinder cleaning measures because the trade-off relationship between these two pollutants exists. To meet requirements of the Euro V emission limit or stricter emission legislations, diesel engines must equip with complex after-treatment devices to reduce the NO_X and PM emissions. At present, it ordinarily tends to adopt urea-SCR technical route to meet the exhaust emission legislation after Euro IV for the HD diesel engine of commercial vehicle in China. Usually in urea-SCR technical route, it tries to control the original PM emissions by optimizing fuel injection timing and combustion process first, and makes the NO_X emission twice as many as the emission limit of Euro III legislation, roughly reaching 10 g/kWh, and then it is eliminated to 3.5 g/kWh or 2 g/kWh for Euro IV or Euro V by urea-SCR system. In this way there are several problems arose in the actual application of urea-SCR system. The first problem is that the urea-SCR system does not work under low exhaust gas temperature conditions. In this case, it is quite easy for urea solution to form deposits at the NO_X catalyst in exhaust pipe [4,5]. In addition, the problems such as ash odour, high running cost and complex system layout also exist during the application of urea-SCR system. Among these problems, high running cost is the biggest challenge during the popularization of urea-SCR system for drivers. To ensure the normal operation of SCR system for a Euro V heavy-duty vehicle, the urea solution consumption is around 6% of the diesel fuel consumption [6,7]. As we all know, there is no corresponding power output with the consumption of urea solution, but the increased running cost is just for meeting the emission legislation which belongs to social responsibility. As a result, it weakens the drivers' motivation to add urea solution initiatively. All these problems drive researches to look for a new technology which could replace urea-SCR system [3,8–11].

Methanol molecule contains oxygen atom and has no carbon–carbon double bond, thus resulting in less PM formation when an engine fuels with methanol fuel. Furthermore, the production resources of methanol are extensive. Natural gas, coal, coke-oven gas and biomass (waste biomass such as crop residues, forage, grass, crops, wood resources, forest residues, short rotation wood energy crops and lignocellulosic components of municipal wastes) [12,13] all could be used to produce methanol. Therefore, methanol has been identified as a promising alternative fuel for engine [12,14]. Previous studies showed that compared with fuelling pure diesel fuel, the engine fuelled with diesel methanol dual fuel (DMDF) led to an increase in HC and CO emissions, while the NO_X and PM emissions reduced simultaneously [15–17]. In order to investigate the performance and emission characteristics of a diesel methanol dual fuel engine, Masimalai [16] carried out an experiment on a single cylinder water-cooling diesel engine with diesel as pilot fuel and methanol as inducted primary fuel. Results showed that compared with pure diesel mode, the addition of methanol could cause evident increase in HC and CO emissions, but meanwhile, the NO_X and PM emissions reduced effectively. As methanol has the potential to reduce the NO_X and PM emissions of diesel engine simultaneously, one option that could be considered is to use methanol to replace part of diesel fuel to create a new technical route for diesel engine to meet Euro V emission legislation.

However, the immiscibility of methanol and diesel fuel could lead to fuel separation when just simply blends them directly. In addition, the cetane number of methanol is too low to be ignited in diesel engine without the assistant of spark plug. Therefore, there are methods such as diesel methanol emulsion [18], double-injectors [19] developed in the past years. Among these ways, methanol fumigation showed its advantages to realize the application of methanol on diesel engine, particularly the DMCC technology [15,20]. The DMCC system could not only realize high methanol substitution ratio (MSR) when the engine operates on DMDF mode, but also have the characteristic of flexible running mode switching between pure diesel mode and DMDF mode. Moreover, DMCC technology has the advantage of minor modification to the baseline diesel engine. As a result, methanol fumigation seems to be a promising method for the application of methanol on diesel engine. The research of the application of methanol fumigation method to diesel engine has been carried out for more than ten years by our research team. To achieve the reliable operation of DMCC system, methanol corrosion-resistant components (such as methanol-resistant pump, methanol level indicator, methanol filter and pressure regulator) and the electronic control system (ECU) for the control of methanol injection quantity and timing have been developed [21]. Wei et al. [22] investigated the regulated emissions from a DMCC engine. They found that when the DMCC engine operated on high methanol substitution ratio mode, the trade-off relationship between NO_X and PM emissions was disappeared. Moreover, the use of DOC could effectively eliminate the significant increased HC and CO emissions from DMCC engine [17,22]. From the previous studies, we can see that the DMCC engine would have a prospective future. The reasons are as follows. One reason is that the methanol fumigated does work together with diesel fuel and provides power output, another reason is that methanol is cheaper than diesel fuel, roughly saying the price of it is one third of that of diesel fuel in China. It would promote the drivers to use methanol to substitute diesel fuel. Therefore, to make HD diesel engine be equipped with DMCC system will give a new