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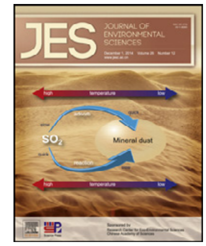

Experimental study on filtration and continuous regeneration of a particulate filter system for heavy-duty diesel engines

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ABSTRACT

This study investigated the filtration and continuous regeneration of a particulate filter system on an engine test bench, consisting of a diesel oxidation catalyst (DOC) and a catalyzed diesel particulate filter (CDPF). Both the DOC and the CDPF led to a high conversion of NO to NO_2 for continuous regeneration. The filtration efficiency on solid particle number (SPN) was close to 100%. The post-CDPF particles were mainly in accumulation mode. The downstream SPN was sensitively influenced by the variation of the soot loading. This phenomenon provides a method for determining the balance point temperature by measuring the trend of SPN concentration.

Introduction

Diesel engines are widely used as movers for vehicles, marines and engineering machines due to its high power, high efficiency, long durability and low fuel consumption. One of the challenges for diesel engines is to reduce particulate matter (PM) and nitrogen oxidizes (NOx) simultaneously with simple and low-cost technologies. PM emissions are believed to have a series of adverse effects on human health, environment and global climate (Prasad and Bella, 2010). Many investigations indicate that ultrafine particles are airborne and penetrate deep into the lungs when breathed in, which makes them more hazardous to human health than larger particles (Peters et al., 1997; Alessandrini et al., 2006). Given the research and evidence on the adverse effects of particulates, both PM mass and particle number (PN) are limited strictly in emission regulations.

The wall-flow diesel particulate filter (DPF) is effective in removing the PM by forcing the exhaust to flow through the thin walls in the ceramic filter. To meet the Euro VI legislation for heavy-duty diesel engines, the filtration behavior for both PM mass and solid particle number (SPN) should be examined. Because of sufficient sensitivity to measure the exhaust from DPF, the SPN is used to evaluate DPF in place of mass-based method gradually (Giechaskiel et al., 2014).

In Euro VI stage, the aftertreatment of a heavy-duty diesel engine commonly consists of a diesel oxidation catalyst (DOC), a catalyzed DPF (CDPF) followed with a selective reduction catalyst (SCR) system (Cloudt and Willems, 2011; Charlton et al., 2010). The DPF system could reduce PN emission significantly (Liu et al., 2012). The trapped soot in the filter can be oxidized by NO_2 to make the DPF regenerate continuously (Copper and Thoss, 1989). A high conversion rate of NO to NO_2 can be supplied by DOC and CDPF, which helps continuous regeneration achieve a high efficiency level. The NO_2 slip at the outlet of the CDPF can be reduced by the downstream SCR system. Most (or all) of the soot trapped

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in the filter for HD diesel engines is burned passively by NO_2 (Johnson, 2013).

The engine-out PM is continuously trapped in the CDPF, while the trapped soot is oxidized by the continuous regeneration. At the equilibrium, the PM deposited in the filter is equal to the oxidized mass, and the soot loading of the filter remains constant (Widdershoven et al., 1986). The balance point temperature (BPT) at this equilibrium is a key parameter to evaluate the continuous regeneration performance, and usually defined as the temperature at which the pressure drop of the filter is not changed (Oi-Uchisawa et al., 2003). A DPF system with continuous regeneration should try to decrease BPT, thus the soot can be oxidized catalytically without frequent active regeneration.

In this study a DOC–CDPF integrated aftertreatment system for heavy-duty diesel engines was tested on an engine dynamometer. The effect of DOC and CDPF on NO_2 concentration was investigated and the filtration behavior for PM mass and PN was evaluated. The experiment results showed that the SPN downstream the CDPF was influenced by the soot loading in the filter, which could be used to determine the BPT.

1. Experiment and method

1.1. Engine test bench

The engine test bench with the DOC–CDPF aftertreatment system is presented in Fig. 1. The specifications of the engine are shown in Table 1. The diesel fuel used in the experiment was purchased in Beijing market with the sulfur content below 10 mg/kg.

The gaseous emissions were sampled from the raw exhaust by AVL FTIR (AVL List GmbH, Graz, Austria), measuring hydrocarbons (HC), CO, NO, NO_2 and N_2O simultaneously. The PM mass and SPN were measured using AVL SPC472 and AVL CPC489 (AVL List GmbH, Graz, Austria), and the number-size spectrum of the particles was obtained by DMS500 (Cambustion Ltd., Cambridge, Britain). The pressure drop of the aftertreatment was monitored by differential pressure sensor, and the temperatures upstream and downstream were measured with thermocouples. The engine was connected to an AC electrical dynamometer FC2005 (Xiangyi Power, Changsha, China). The engine operation parameters and gaseous emissions were recorded by the dynamometer control system.

1.2. DOC and CDPF specifications

The specifications of the DOC and the CDPF are listed in Table 2. The DOC used a cordierite monolithic substrate coated with a catalyst containing platinum (Pt) and palladium (Pd), converting NO to NO_2 for continuous regeneration. The CDPF utilized a wall-flow cordierite substrate, coated with Pt–Pd catalyst to lower the soot oxidation temperature.

1.3. Test method

The DOC, the CDPF and the coupled DOC–CDPF were tested individually on the bench to investigate their effects and performance. The effects of the DOC and CDPF on gaseous emissions were tested under different temperatures and space velocities (SVs) by adjusting the engine operating conditions.

The number-size spectrum of the particles was measured under separate steady state conditions of a 13-mode European steady state cycle (ESC). The engine speeds at A, B and C points

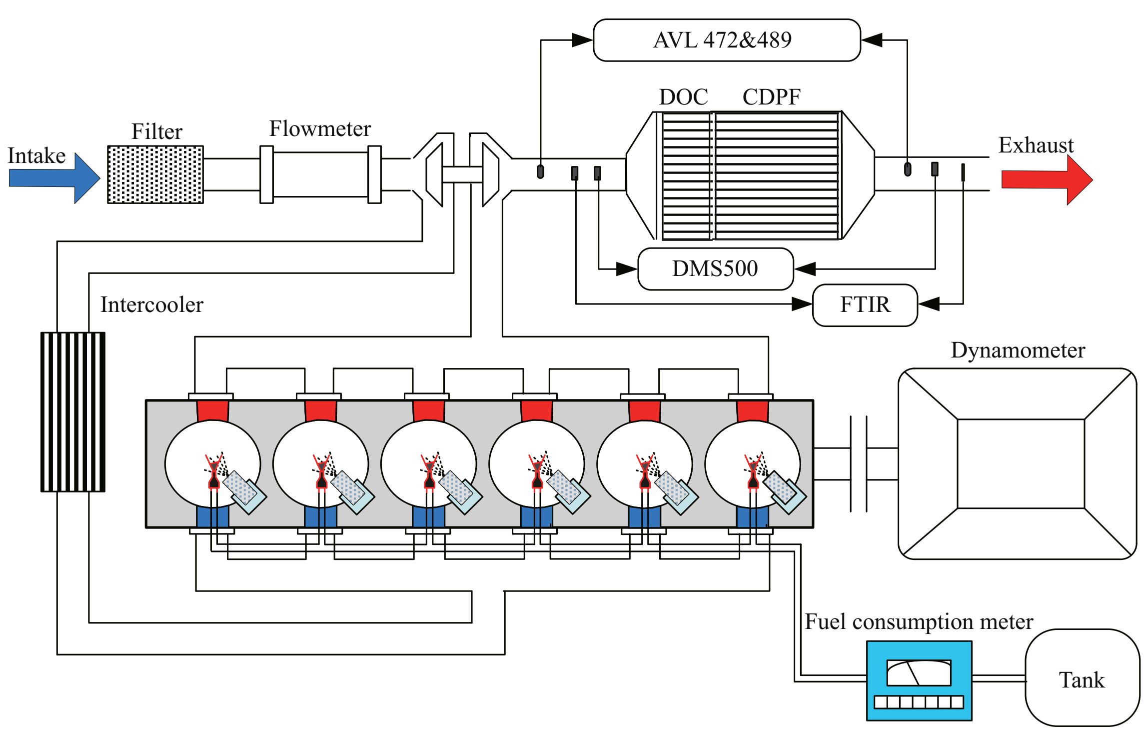

Fig. 1 – Schematic diagram of the engine test bench.