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Achieving Near-Zero Nitrogen Dioxide Emissions with Active Diesel Particulate Filters

Osama M. Ibrahim
Department of Mechanical Engineering, College of Engineering and Petroleum, Kuwait University, Kuwait
osama.ibrahim@ku.edu.kw

Abstract **–** This paper compares the reduction of nitrogen dioxide (NO_2) of two configurations of an active diesel particulate filter (ADPF): (1) uncatalyzed ADPF with diesel oxidation catalysts downstream (ADPF-DOC), and (2) a catalyzed ADPF with palladium-tungsten (Pd-W) catalysts (C-ADPF). Measurements of diesel engine exhaust emissions under a standard off-road test cycle of a degreened and an aged ADPF-DOC show that NO_2 emission from diesel engines is reduced by 42% and 95%, respectively, confirming that the efficiency of reducing NO_2 emissions improves as the filter ages. On the other hand, a C-ADPF coated with Pd-W catalysts resulted in extremely low NO_2 emissions. The C-ADPF was tested using on- and off-road standard test cycles, resulting in NO_2 reductions of 100% in both test cycles. ADPF-DOC and C-ADPF considerably surpass the most recent NO_2 emission verification standards set up by the U.S. Environmental Protection Agency (US-EPA) and California Air Resources Board (CARB).

Keywords**:** Diesel emissions, Nitrogen dioxide, Diesel particulate filter, sintered metal fibers.

1. Introduction

One of the primary sources of nitrogen oxide (NOx) is diesel engines. When diesel fuel burns at high temperatures, NOx—mainly nitric oxide (NO) and nitrogen dioxide (NO_2)—are produced. Although NO and NO_2 are harmful, NO_2 is the more reactive gas linked to health issues. Several studies [e.g., 1-5] show that exposure to NO_2 was proven to have adverse respiratory effects. Shima and Adachi [4] and Wargo [5] investigated the health effects of children's exposure to diesel exhaust in school buses. Their conclusions show that diesel emissions have been associated with health problems, potentially harming children near school buses. The US-EPA and CARB issued rules for diesel emissions retrofit solutions to limit the increase in NO_2 emission over engine baseline.

To clean the filter and keep engine backpressure low, NO_2 is used as an oxidant of carbon in passive diesel particulate filters (PDPF) [7-10]. This technique requires diesel oxidation catalysts (DOC) upstream of the PDPF to efficiently convert NO into NO_2 (DOC-PDPF), as shown in Fig.1. In most DOC-PDPF after-treatment configurations, an excess of NO_2 is produced and only partially used in the carbon oxidation process; thus, NO_2 can increase above the engine baseline level. An increase in NO_2 emissions caused by exhaust remediation devices is highly undesirable, and the main reason is that the US-US-EPA [11, 12] and CARB [13] have limited NO_2 increases to 20% of the engine baseline for diesel retrofits. The National Studies have also shown a significant increase in NO_2 concentrations in mine air, resulting from catalyzed PDPF filters [e.g., 14]. A ceiling concentration of NO_2 has been established to reduce miners' exposure to NO_2, a lung irritant.

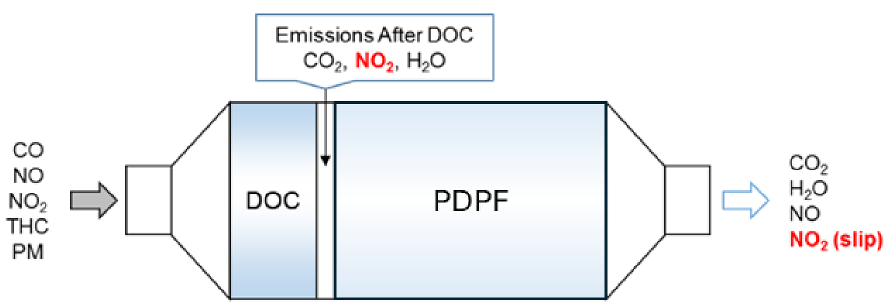

Fig. 1. Passive diesel particulate filter with diesel oxidation catalysts upstream (DOC-PDPF) [16].

Active regeneration does not rely on NO_2 as an oxidizing agent of carbon (soot), keeping NO_2 at or below engine baseline levels. Specially designed oxidation catalysts, attached to the outlet, reduce CO and THC without converting NO to NO_2. It has been well established that activated carbon is an excellent adsorbent for both gases and liquids, and it has been used as a reducing agent for NO_2 [16]. Like activated carbon, the soot can adsorb hydrocarbons and other gases as the exhaust flows through the soot layer. Soot is collected on the filter medium as a fluffy layer, resulting in a high surface area, thereby directly reducing NO_2 from the diesel engine exhaust stream by reacting with carbon.

This study considered two ADPF configurations to meet diesel emission standards. The first is an Uncatalyzed active diesel particulate filter with diesel oxidation catalysts downstream (ADPF-DOC), and the second is a catalyzed active diesel particulate filter (C-ADPF), as shown in Figs. 2 and 3, respectively. The ADPF's porous filter medium comprises sintered-metal-fibers, as shown in Fig. 4. The filter area can be partially regenerated by dividing it into strips, which lowers the maximum amount of electricity needed for regeneration. As illustrated in Figure 5, the pleated filter strips are assembled as active filter cartridges. The filter cartridges are kept operating at low back pressure during regular operation by a microprocessor controller, which controls regeneration cycles for the entire filter system. The ADPF considered in this study uses direct electric heating to burn off accumulated soot and regenerate (clean) the filter strips.

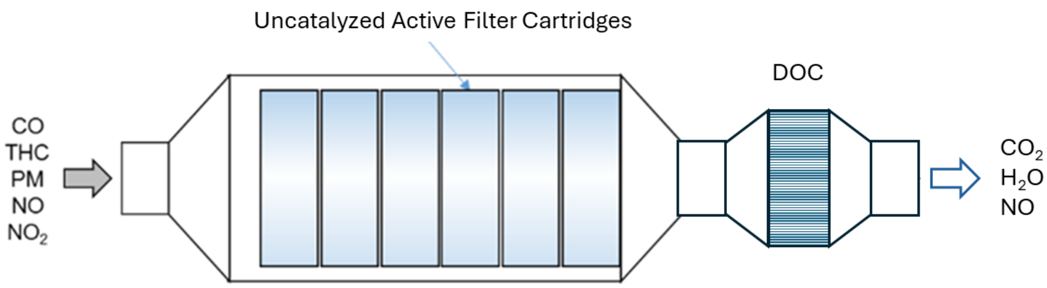

Fig. 2. Uncatalyzed active diesel particulate filter with diesel oxidation catalysts downstream (ADPF-DOC) [15].

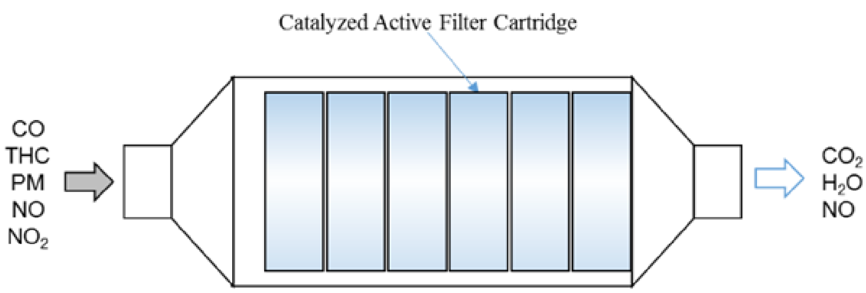

Fig. 3. Catalyzed active diesel particulate filter (C-ADPF) [16].

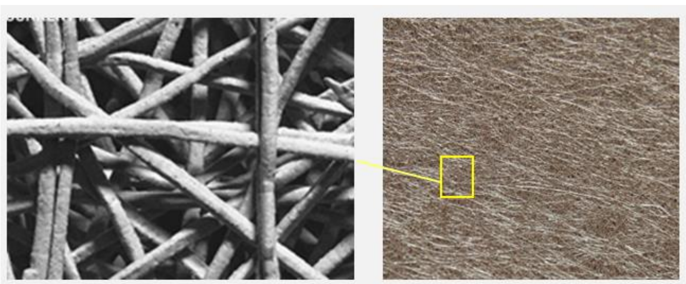

Fig. 4. Sintered metal fibers [17].

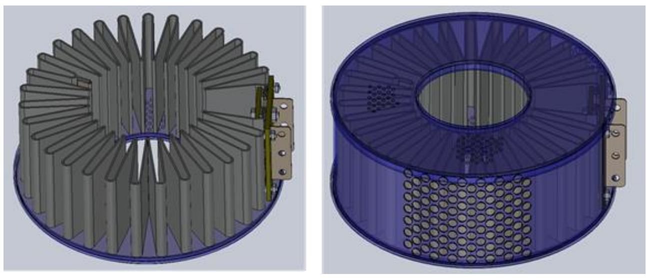

Fig. 5. Active filter cartridge [17].

2. Emissions Measurements

The emissions measurements of the ADPF-DOC were performed by Environment Canada's Emission Research and Measurement Division (ERMD). Emission measurements were determined for PM, CO, THC, NO_2, and NOx. Two ADPF-DOCs were tested: the first ADPF-DOC had been aged in a durability test of 525 hours; the second ADPF-DOC had been degreened for 25 hours. Testing occurred over the ISO 8178-D2 test cycle.

On the other hand, the emissions measurements of the C-ADPF coated with Pd-W-based catalysts were performed at the Intertek Automotive Research facility in San Antonio, TX, USA. To degree the C-ADPF, the engine was driven for 10 hours at a steady condition with a medium load. Emission measurements were performed over the ISO 8178-C1 and U.S. HD FTP test cycles. PM, CO, THC, NO_2, and NOx emissions were measured.

3. Results and Discussion

The results of the degreened and aged ADPF-DOC emission reductions are presented in Fig. 6. As shown in Fig. 6, PM was reduced by 87% for the degreened unit and 93% for the aged unit. Both units show reductions of 84 and 94% in CO and reductions greater than 75% in THC. The results show a significant reduction in NO_2 for the aged system, over 90%, compared to 42% for the degreened units.

Figure 7, on the other hand, shows the C-ADPF's emission reductions under the standard off-road test cycle (ISO-8178-C1) and on-road test cycle (U.S. HD FTP). The US-FTP and ISO-8178-C1 test cycles produced comparable emissions reductions of 54% and 57% in CO, 84% and 81% in HC, and 95% and 91% in PM, respectively. NO_2 is reduced by 100% in both test cycles.

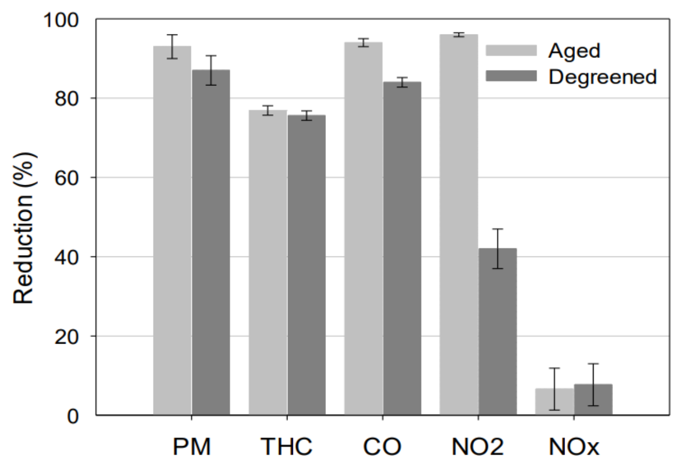

Fig. 6. Emission reductions of the uncatalyzed ADPF with DOC downstream of the ISO 8178-4 test cycle D2 [15]

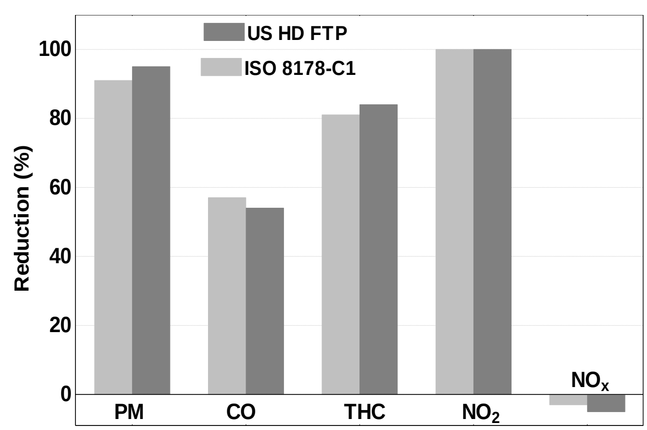

Fig. 7. Emission reductions of catalyzed ADPF of the ISO 8178-C1 and the HD FTP test cycles [17]

4. Concluding Remarks

- Passive diesel particulate filters rely on NO_2 as an oxidizer to regenerate (clean) the filter. This technique requires that NO be oxidized into NO_2 by platinum-based diesel catalysts. In most passive diesel particulate filters, an excess of NO_2 is produced and only partially used in the carbon oxidation process, thus causing NO_2 to slip into the atmosphere.

- NO_2 is potentially one of the most harmful emission gases in diesel exhaust. Worldwide, recommendations are being made to limit the conditions under which NO_2 is produced. These include diesel engine management and exhaust after-treatment. US-EPA and CARB initiated rulings to limit NO_2 emissions.
- Active diesel particulate filters, using direct electrical heating to regenerate (clean) the filter cartridges, do not rely on NO_2 as an oxidizing agent of collected soot. In the uncatalyzed ADPF, NO_2 reduction was accomplished using soot as a reducing agent. The result is over 90% reduction in NO_2 for an "aged" system. On the other hand, the catalyzed ADPF with Pd-W-based catalysts shows a reduction of NO_2 to nearly zero emissions.
- The results of this study show that using the Pd-W catalysts will result in a new generation of ADPFs with extremely low NO_2 emissions, which makes them suitable for use in underground mining equipment and school buses.

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