Effect of water/fuel emulsions and a Cerium-based combustion improver additive on HD and LD diesel exhaust emissions

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One of the major technological challenges for the transport sector is to cut emissions of particulate matter (PM) and nitrogen oxides (NOx) simultaneously from diesel vehicles, in order to meet future emission standards, and, to reduce their contribution to the pollution of ambient air. Installation of particle filters in all existing diesel vehicles (for new vehicles the feasibility is proven) is an efficient but expensive and complicated solution, thus other short term alternatives have been proposed. It is well-known that water/diesel (W/D) emulsions with up to 20% water can reduce PM and NOx emissions in heavy duty (HD) engines. The amount of water that can be used in emulsions for the technically more susceptible light duty (LD) vehicles is much lower, due to risks of impairing engine performance and durability.

The result of the present study indicates a good potential for reductions in PM emissions from current diesel engines by optimizing the fuel composition. An experimental 6% W/D emulsion was tested for EURO-3 LD diesel vehicles and a commercial 12% W/D emulsion was tested with a EURO-3 HD engine. The results were compared to the emission reductions that could be obtained by a Cerium-based combustion improver additive.

As shown in Fig. 1 for PM, the emulsions reduced the emissions with -32% for LD vehicles (mass/km) and -59% for the HD engine (mass/kWh). However, NOx emissions remained unchanged and emissions of other pollutants were actually increased for the LD vehicles with +26% for hydrocarbons (HC), +18% for CO and +25% for PM-associated benzo(a)pyrene toxicity equivalents (TEQ). In contrast, CO (-32%), TEQ (-14%), and NOx (-6%) were reduced by the emulsion for the HD engine, and only hydrocarbons were slightly increased (+16%). The PM reduction was obtained without changing the size-mass distribution (Fig. 2). Whereas the Cerium-based additive was inefficient in the HD engine for all emissions except for TEQ (-39%), it markedly reduced all emissions for the LD vehicles (PM -13%, CO -18%, HC -26%, TEQ -25%) except for NOx, which remained unchanged (Fig. 1). The analysis of individual polyaromatic hydrocarbons (Fig. 3) revealed that the high TEQ emissions during the urban part of the test cycle was caused by a shift in the PAH composition towards the more toxic 5-6 ring members. The opposite was true for the Cerium-based combustion improver additive.

In the second part of the study the 12% W/D emulsion was tested on the HD engine in combination with a diesel particle filter (DPF) and an oxidative catalyst. The DPF (using a Fe based fuel additive for regeneration) was very efficient in reducing PM (>90% with and without emulsion, Fig. 4). However, the combustion conditions in the DPF were deteriorated by the water vapor from the 12% W/D emulsion and caused a shift in the PAH composition towards the more toxic 5-6 ring members (Fig. 3). Thus the same efficiency in reducing TEQ emissions was not observed.

Of all the examined combinations the best emission abatement was obtained by the use of the DPF together with the oxidative catalyst for the HD fueled with standard diesel (no emulsion, Fig. 4).

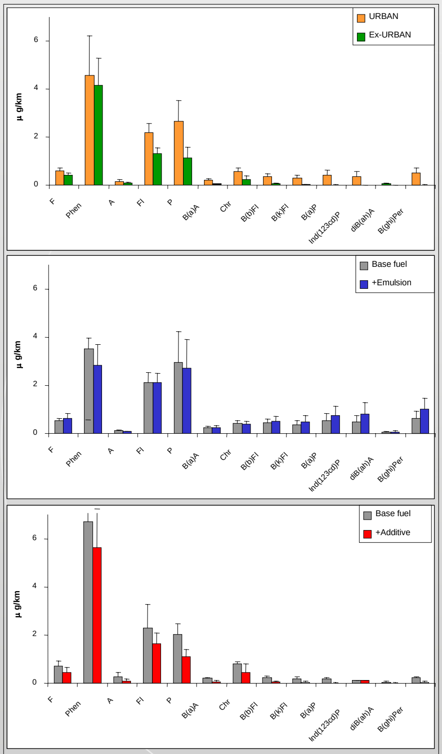

Fig. 3. Emissions of particle associated PAH from EURO-3 LD-Vehicles (overall mean for fuels and fleet ± 95% confidence interval). Top: effect of driving cycle (base fuels); Centre: effect of emulsion (combined driving cycle); Bottom: effect of combustion improver additive (combined driving cycle).

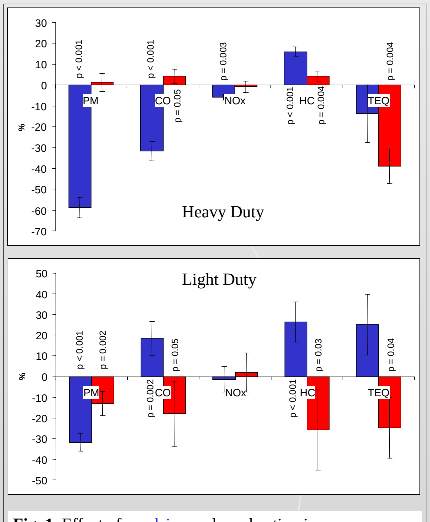

Fig. 1. Effect of emulsion and combustion improver additive on emissions from a EURO-3 HD diesel engine and EURO-3 LD diesel vehicles (mean ± 95% confidence interval).

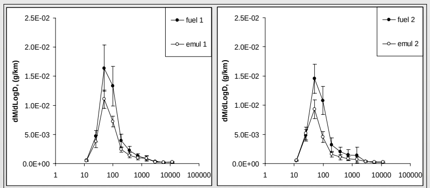

Fig. 2. Effect of emulsion on the size-mass distribution of PM emitted by EURO-3 LD diesel vehicles (overall mean for fuels and fleet ± 95% confidence interval).

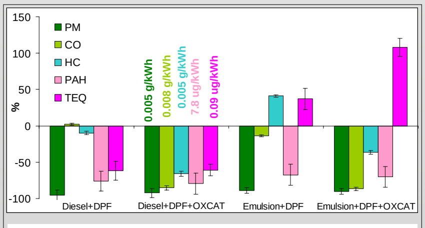

Fig 4. Effect of emulsion and particle filter (DPF) on emissions from a EURO-3 HD diesel engine run with standard diesel or a 12% W/D emulsion (average ± 95% confidence interval).

Experimental. Seven different Euro-3 LD diesel vehicles, with an approximate 2L displacement and exhaust gas recirculation (EGR), were used and compared to a common Euro-2 LD diesel vehicle, representing the common rail system, the unit injector technology, and the old rotary pump technology. As representative of the European heavy duty sector, a Euro-3 HD engine with a 10L displacement 6 cylinders, no EGR, and a maximum power of 316 kW was selected. Regulated pollutant emissions from LD vehicles were measured using a chassis dynamometer and a conventional constant volume sampling (CVS) system. CO, NOx and PM emissions were measured on diluted exhausts while HC were measured continuously on raw exhaust using a heated sampling line. Regulated pollutant emissions from the HD engine were measured using a full flow dilution tunnel and a CVS system. All exhaust sampling was carried out on diluted exhausts in a dilution tunnel. After determining the particulate mass by weighing the collected filters PAHs were Soxhlet extracted and purified (solid phase extraction). The extracts were analysed for PAHs with a 6890 HP Series Plus+ GC system with HP-5MS column (5% Phenyl Methyl siloxane; 30m x 0.25mm x 0.25µm) and a 5973 HP Mass Selective Detector with Electron Impact Ionisation source. The benzo(a)pyrene toxicity equivalents were calculated from the emission factors of the individual PAHs based on the TEF approach (EPA, 1994; OEHHA,Children's Environmental Health Protection Act, California 2001). A detailed analysis of the presented material has been published elsewhere: G. Martini, C. Astorga, A. Farfaletti, M. Rey,U. Manfredi, A. Mueller, A. Krasenbrink, B. R. Larsen, and G. De Santi: *Effect of reformulated fuels on pollutant emission from vehicles. Part 1: Combustion improver additive* (EUR 21380/EN/1, 2004); *Part 2. Diesel fuel / water emulsions* (EUR 21380/EN/2, 2005; A. Farfaletti, C. Astorga, G. Martini, U.Manfredi, A. Mueller, M. Rey, G. De Santi, A. Krasenbrink, and B. R. Larsen. Effect of water/fuel emulsions and a Cerium-based combustion improver additive on HD and LD diesel exhaust emissions. *Environmental Science and Technology (in print, 2005).*

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