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Engine and fuel effects on particles emitted from modern diesel vehicles

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As evidence grows on the potentially significant health effects of micro-particles emitted from combustion engines the research efforts of the scientific community are more and more focused on the effect of new and advanced fuel formulations and engine technologies on the emissions with emphasis placed on the particulate matter (PM).

As part of the research programme in the vehicle emissions in CORSE, a co-operation agreement on common research efforts has been signed between Agip Petroli spa (Milano, Italy) and the European Commission's Joint Research Centre (JRC, Ispra, Italy) in 1998. Within the co-operation several tests were foreseen to study vehicle emissions with the focus on the particulate matter. During a first series of tests, a comparative study of particulate emissions from a gasoline-driven vehicle with a normal multi-point injection and a gasoline direct injection vehicle has been carried out. Test results have been included in a EU Report No. 18993 on *Particulate Emissions from Gasoline and Diesel Vehicles (ERLIVE Project)*. "Fuel effects" was also identified as one of the important topics of common interest and consequently studied in the second measuring campaign (EU Report No. 19914 *Influence of Fuel Quality and Engine Technology on Particulate Emissionsof Diesel Vehicles*).

In close co-operation with Agip Petroli several tests have been performed in April 2000 on a chassis dynamometer. Following aspects were at the centre of this second campaign:

1. The interaction between fuels and fuel injection systems. Two similar diesel-driven vehicles, one with a standard fuel injection pump, and one with common rail system were tested together with a standard fuel and a "clean" low sulphur and low aromatics fuel.

2. The importance of the measurement method and sampling position. Particulate matter was measured as total mass concentration collected on a filter, as mass/size distribution sampled with low pressure impactors in the undiluted exhaust gas at the exhaust pipe's exit and after dilution in the CVS tunnel, and as number/size distribution with an SMPS after dilution in the CVS tunnel.

The parameters measured were:
- total particulate emissions
- particle number/size distributions
- particle mass/size distributions
- relation between number and mass
- relation between ECE15+EUDC test cycle and constant speed results.

Size resolved particle samples were taken during the tests in parallel with:

1. a TSI Scanning Mobility Particle Sizer (SMPS) for number/size distribution measurements in the diluted exhaust gas. The probe was located at the end of the dynamometer's dilution tunnel, measurements were performed without further dilution between probe and SMPS. The instrument was set to a sheath and aerosol flow of 3 and 0.3 l/min, giving a particle diameter range of 15.68 nm to 685.39 nm. SMPS scan times were set to 90 s up-scanning and 40 s down-scanning, samples were taken without time delay between scans. During tests at 0, 32 and 50 km/h seven scans (with 910 s for total measurement) were taken, and 3 scans (with 390 s for total measurement) at 120 km/h. The total measurement time had to be reduced for the high speed tests to avoid heat-up problems in the dilution tunnel.

2. an 11-stages Berner Low Pressure Impactor (LPI-11) for mass/size distribution measurements in the diluted exhaust gas. LPI-11 impactor stage cut-offs range from 0.008 µm to 16 µm aerodynamic diameter, the probe was located next to the SMPS probe at the end of the dynamometer's dilution tunnel. The impactor was not heated, only for some of the measurements at 120 km/h humidity deposition was observed. Diluted size segregated samples were taken over sampling times of 990 s at 0 km/h, 870 s at 32 and 50 km/h, and 390 s at 120 km/h.

3. an 8-stages Berner Low Pressure Impactor (LPI-8) for mass/size distribution measurements in the undiluted exhaust gas. LPI-8 impactor stage cut-offs range from 0.082 µm to 16 µm aerodynamic diameter, particles smaller than the indicated lowest cut-point were collected on a quartz fibre back-up filter. The probe was located directly at the exhaust pipe exit and is usually used as extraction port for gas phase analysis. In this position no strict isokinetic sampling was possible. To avoid condensation on the impactor stages, the LPI-8 was heated up to 80 °C prior to sampling. No humidity deposition on the impactor stages was observed. Raw gas samples were taken over a sampling period of 240 s at 0, 32 and 50 km/h, and 180 s at 120 km/h. Although impactor stages were not overloaded, some (not quantified) particle loss below the impactor's jet-plates was observed. From earlier investigations it is known that these losses from the main loaded impactor stage can account for up to 20% of the total mass collected on this stage.

In order to make the different data comparable, the measured mass and particle number concentrations were corrected for dilution. These values were then converted to emission quantities per time and per driven distance. For a better visibility of changes in mass/size and number/size distributions some data were also analysed as (normalised) cumulative distributions.

It should be noted that it was not intended to set up a comprehensive and complete test programme, nor to come to final conclusions for the questions under examination. The study will contribute with two specific vehicles and two specific fuels, tested under a limited number of driving conditions to the world-wide ongoing research on the influence of engines, test procedures and sampling methods on the emission pattern.

As main results it was found that:

The common rail vehicle emitted less total mass of particles than the standard direct injection vehicle.
The "clean" fuel reduced significantly (up to 50%) the total mass of particles emitted from both vehicles.
In most cases the emitted particle number concentrations (#/s) and mass/size distributions were not significantly affected by the fuel choice.
More particles of smaller diameter where observed when using the "clean" fuel at medium speed (32-50 km/h) with the direct injection vehicle and at low speed (0-32 km/h) with the common rail vehicle.
Most effects on the particles emitted were observed at constant high speeds (120 km/h), but none of these effects were observed in the results of the ECE15+EUDC test cycle due to the short high speed sequence.
Impactors could serve as a quick and easy size resolving measuring method for particulate emissions.

In conclusion it can be said that the low sulphur and low aromatics fuel reduced significantly the particle total mass emissions without significantly changing the particle mass and number size distributions. Observed changes in particle distributions depend in a complex way on the combination of fuel injection technology, mode of operation, fuel specification and measuring method.