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# Effects of a catalysed and an additized particle filter on the emissions of a diesel passenger car operating on low sulphur fuels

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**Abstract**

This paper presents the emission characteristics of a diesel passenger car operated on low sulphur fuels (8 and 38 ppm) when fitted with either a catalysed diesel particle filter (DPF) or a non-catalysed one combined with a fuel-borne catalyst. Measurements were conducted over the New European Driving Cycle and a higher speed driving cycle to monitor the off-cycle DPF emission behaviour. Regulated gaseous pollutants and particle mass, number and surface were recorded. Aerosol samples were collected with a dedicated sampling system, which provided identical dilution conditions, regardless of the vehicle configuration, and allowed a distinction between volatile and non-volatile particles. The results showed that DPFs have the potential of filtration efficiencies which may exceed 99.5% in all airborne particle properties measured, over the transient cycles. As a result, the cycle average particle number was reduced from $10^{14}$ to about $10^{11}$ particles $km^{-1}$ when fitting any DPF and the particle mass was reduced from $\sim$40 mg $km^{-1}$ to the detection limit of the current measurement procedure. The exact particle concentration depended on the filter material properties. However, the efficiency in reducing mass appears lower than the airborne number, which suggests a sampling artefact of the present particulate matter measurement procedure. A nucleation mode formed at high exhaust gas temperature with the use of the higher sulphur fuel in combination with the catalysed DPF, thus decreasing the apparent DPF filtration efficiency. This was removed when any of the contributing factors (high temperature, higher sulphur fuel, catalysed DPF) were not present, suggesting sulphate particle formation downstream of the filter. Finally, results show that the DPF soot loading has an insignificant effect on particle size distribution downstream of the filter, when operating within soot-loading limits that are typically encountered in normal on-road operation.


*Keywords:* Exhaust aerosol; Nucleation mode; Diesel aftertreatment; Filtration efficiency

## 1. Introduction

Diesel passenger car registrations represented 44.3% of the total European passenger car market in 2003 and reached as much as 70% of total registrations in some countries, according to the European Automotive

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Manufacturers Association (ACEA, 2004). The main driving force for this trend is the higher fuel economy compared to gasoline and the improved drivability at low engine speeds. Additionally, ACEA is committed to reducing the mean $CO_2$ from new vehicles at 140 g km$^{-1}$ by 2008 (25% reduction over 1990 levels) in an effort to meet the European targets for the Kyoto Protocol. This reduction will basically be accomplished via increasing the market share of diesel cars.

In order to reduce the environmental impact from vehicles, European legislation introduced the Euro 4 step in January 2005, which, for diesel cars, corresponds to 0.25 g km$^{-1}$ of $NO_x$ and 0.025 g km$^{-1}$ of particulate matter (PM). Despite an ~80% reduction in diesel car emission standards over levels 10 years ago, the mean $NO_x$ emission level of diesel vehicles continues to be three times higher than their gasoline counterparts. Gasoline vehicles are also known to emit low levels of soot particles (Andersson et al., 2002; Mohr et al., 2000). Hence, future emission standards are already under consideration to further tighten emission limits for diesel vehicles.

Diesel particle filters (DPFs) are one of the most technically feasible solutions to reduce PM. DPFs are fitted in the exhaust line and collect PM by deep-bed filtration. PM accumulated in the filter is then periodically combusted by oxidizing agents in the exhaust gas in a process called regeneration. Commercial applications either use some kind of a catalyst to decrease the soot ignition temperature and increase the range of exhaust gas temperatures where regeneration can occur or apply an oxidation catalyst to increase $NO_2$ concentration, which is an efficient soot oxidation agent.

DPFs have been widely fitted to new vehicles and retrofitted mainly to buses and large construction equipment (e.g. Sequelong et al., 2004; Ball et al., 2004; Mayer et al., 1999). Extensive experience has already been accumulated with the operation and emission performance of these systems on large diesel applications (Lanni, 2003). Passenger car manufacturers started to offer compact DPF systems on a voluntary basis (Joubert and Sequelong, 2004) and some first conclusions of their operation and filtration characteristics have been collected (Jeuland et al., 2004). However, there are still open issues with regard to the performance of the systems over fully transient and real-world driving conditions of light duty vehicles, because very little data under such conditions are currently available (Durbin et al., 2003; Mathis et al., 2005).

In the present paper we try to address these issues by studying the emission performance of a current technology diesel car fitted with two different DPF systems. Measurements are conducted over the European cold-start certification cycle (New European Driving Cycle—NEDC) and an additional higher speed cycle to account for distinctly different driving conditions. The focus is on PM and airborne particle emissions which are measured using a specially developed sampling protocol and methodology to separate vehicle effects from sampling effects. Additionally, two fuels with identical properties but different sulphur content are tested to explore the additional benefit of eliminating fuel sulphur.

## 2. Experimental

### 2.1. Vehicle and fuels

A 2001 model year Renault Laguna 1.9 dCi was used in this study, equipped with a common-rail direct injection diesel engine and meeting Euro 3 emission standards. PM emissions in this vehicle are controlled by high pressure fuel injection (1350 bar max common rail pressure) and two diesel oxidation catalysts (DOCs) in series (pre-cat and main cat), which mainly decrease the volatile content of exhaust PM. This combustion system and aftertreatment configuration corresponds to one of the most widespread diesel exhaust control configurations for passenger cars in Europe today (the other one being unit injectors with DOC). The vehicle was of low mileage (~28,000 km) and it was regularly maintained according to manufacturer specifications. The lubrication oil used was a 15W-40 grade (ACEA A3/B3) with 6000 ppm wt sulphur content. The vehicle was driven for about 1000 km before the measurements. "Baseline" emission tests were performed with the vehicle in its original configuration (no particle filter). It should be stressed that the engine calibration was not changed when a DPF was installed in the exhaust line.

Two fuels were used to address the effect of fuel sulphur on particle emissions. These fulfilled the current EN590 specifications (monaromatics 14%, polyaromatics 4.3%) for automotive diesel fuel and their exact chemical character and physical properties are found elsewhere (Ntziachristos et al., 2004b). The only difference in fuel composition was their sulphur content. The higher sulphur fuel (HSF—38 ppm wt) was derived from the lower sulphur one (LSF—8 ppm wt) by doping with sulphur compounds (thiophene and di-tertiarybutyl-disulphide). These fuels were fed to the engine by an external canister to avoid sulphur contamination of the fuel transfer lines.

### 2.2. Measurement protocol

Each measurement day consisted of a series of test cycles each using the same sampling protocol. Measurements started with the certification NEDC and a hot-start repetition of the urban part (UDC) followed. Then, three cycles developed in the EU Artemis project (Andrè, 2004) were conducted to