

Malfunctions in Selected Emissions-Related Components of Euro 4 Passenger Cars: Emissions Increase and OBD System Response

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ABSTRACT

As new passenger cars are constantly getting cleaner, their contribution to air pollution is in large part defined by the in-use emissions degradation. In this respect, malfunctions in emissions-related components may play an important role to the contribution of passenger cars in air pollution. This paper assesses the impact of malfunctions of selected emissions related components to the pollutant emissions and evaluates the response of the OBD system to these malfunctions, under legislated and non-legislated driving cycles. The emissions-related components subjected to malfunctions are, for gasoline fuelled cars oxygen sensor and catalytic converter, and for diesel cars Exhaust Gas Recirculation system (EGR) and diesel Particulate Filter (DPF). For gasoline cars, the results show that total malfunctions of the above components result in up to two orders of magnitude increase in pollutant emissions. For diesel cars, total malfunctions in the EGR system lead to 2-6 times increase of NO_x emissions. Removal of the DPF leads to 20 times increase of PM emissions, in terms of PM mass, and up to 3 orders of magnitude increase in terms of particle number. The OBD system detected these malfunctions accurately in the legislated driving cycle. However, the ability of the OBD system to detect the malfunctions in the non-legislated driving cycles presented a high variability between the different cars tested.

INTRODUCTION

The demand for improvement in air quality together with the tightening of the emission standards has resulted in the development of passenger cars, which emit only a

fraction of the mass of legislated pollutants, compared to their predecessors of two decades ago. As a result, pollutant emissions from road transport tend to depend more on the small portion of vehicles in the fleet, which present high emission levels due to poor maintenance, rather than on the large number of properly functioning, low-emitting vehicles. The problem of in-use deterioration of a car's engine and emission control system has been well demonstrated with the aid of laboratory measurements, on-board measurements, roadside vehicle inspections, tunnel studies and remote sensing observations [1,2,3,4].

The increase of pollutant emissions in the course of a vehicle's lifetime may come as a combined result of a) the normal wear of the engine components and gradual ageing of the exhaust aftertreatment system components, mainly the catalytic converters and b) the unpredictable malfunctions in emissions related components. The effect of the normal wear and ageing has been demonstrated in several experimental studies [5,6]. These studies confirmed that normal wear and ageing usually do not result in tailpipe emission levels higher than the type-approval limits. On the other hand, the environmental impact of malfunctions in emissions related components has not been extensively documented so far. This impact is rather complex to estimate, as it relies on the following parameters:

1. The nature and severity of each malfunction.
2. The frequency of the malfunctions in a vehicle's lifetime.
3. The timeliness of the detection of the malfunction, which relies on the performance of the vehicle's On Board Diagnostic (OBD) system, and the frequency

and efficiency of the Inspection and Maintenance (I/M) periodic testing.

Currently, limited knowledge exists on the impact of emissions-related malfunctions on the in-use vehicle emissions. The aim of the present paper is to examine the upper range of the emissions increase, which can be caused by malfunctions in selected emissions-related components of Euro 4 gasoline and diesel-fuelled cars. The emissions increase is examined under legislated and non-legislated driving conditions, and covers the most important of the legislated pollutants i.e. HC, NO_x and particulate mass (PM), as well as the particle number, for which an emission standard is to be introduced in the European legislation at the Euro 5 stage. In addition, the response of the OBD system to the introduction of these malfunctions is evaluated.

EXPERIMENTAL

VEHICLES AND TEST PROTOCOLS

Emission measurements were conducted on four Euro 4 level vehicles with low accumulated mileage, and were repeated on the same vehicles after introducing real or artificial malfunctions on selected emissions-related components. The small test fleet consisted of two gasoline-fuelled and 2 diesel-fuelled Euro 4 level cars. The main characteristics of the vehicles tested are described in Table 1. All measurements were conducted on the chassis dynamometer of the University of Thessaloniki.

The equipment for regulated emissions measurement in legislated driving cycles was used to obtain emission measurements compatible to the current EU regulations. Additionally, particle number measuring equipment was used for vehicles C and D, including an Electrical Low Pressure Impactor (ELPI), a Condensation Particle Counter (CPC) and a Scanning Mobility Particle Sizer (SMPS). A schematic representation of the measurement protocol is shown in Figure 1. The first part of the measurement consists of 3 repetitions of the European legislated driving cycle (NEDC). This part resembles the legislated procedure followed during the certification test of the OBD system. The second part consists of three “real-world” modes, forming the Common Artemis Driving Cycle (CADC, or simply “Artemis”). This is a driving cycle derived based on statistical data from road traffic, and generally involves higher speeds and more severe transient conditions compared to the NEDC [7]. The CADC includes three modes (CADC-Urban, CADC-Road and CADC-Motorway). Each of them approximates the respective driving pattern under urban, extra-urban and motorway conditions. Each mode has a duration of 18-21 minutes. In our tests, each mode was performed as a separate driving cycle, with an engine shut-off of 2-3 minutes between two modes. All modes start with a hot engine.

Table 1: Description of the vehicles tested

	Fuel type	Engine	Exhaust aftertreatment technology	Mileage [km]*
A	Unleaded gasoline, 95 RON	Naturally aspirated 1.4 [ℓ]	Close-coupled 3-way Catalytic converter, dual O ₂ sensors	1285
B	Unleaded gasoline, 95 RON	Naturally aspirated 1.3 [ℓ]	Close-coupled (main) and underfloor (secondary) 3-way Catalytic converter, dual O ₂ sensors	4239
C	Diesel (<50 ppm S)	Turbo-charged, cooled EGR (electrically operated) 2.0 [ℓ]	Underfloor DOC and DPF, with pressure sensors upstream and downstream of the DPF. Regeneration assisted by fuel-borne catalyst	96
D	Diesel, low sulphur (<10 ppm S)	Turbo-charged, cooled EGR (electrically operated) 2.0 [ℓ]	Close-coupled DOC, close coupled DPF, catalytically coated, with NO _x storage capacity, underfloor DOC.	344

*Vehicle mileage at the beginning of the baseline measurement. Includes conditioning which was done in the Lab.

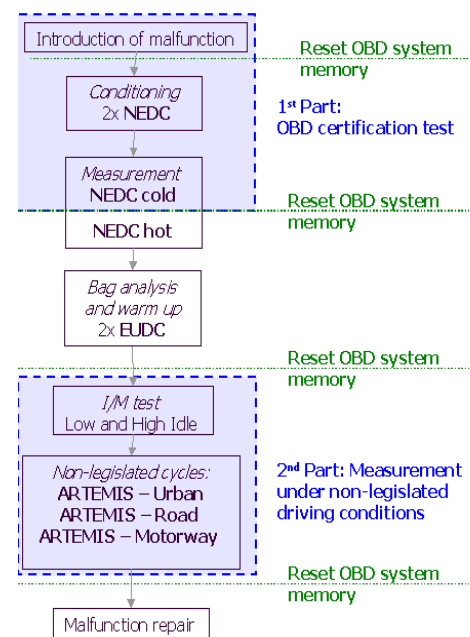


Figure 1: Schematic description of the experimental protocol

CRITICAL EMISSION RELATED MALFUNCTIONS

A large variety of emissions-related malfunctions may cause the increase of tailpipe emission levels of a modern passenger car. In the framework of this study, it

was not feasible to test the effect of all possible malfunctions of all emissions related components on the pollutant emissions. Therefore, the most critical emissions related components for gasoline and diesel vehicles were identified, according to a combination of the following criteria:

1. *Effect on pollutant emissions*: malfunctions in critical components should result to a significant increase in pollutant emissions.
2. *Frequency of malfunctions observed in the field*.
3. *Difficulty level of diagnosis by the vehicle's OBD system*: Malfunctions with the highest environmental burden are typically the ones that are most difficult to detect by the OBD system. An electrical failure of a sensor, for example, is very easy to diagnose, and therefore the vehicle user will be soon prompted by the OBD system to have the malfunction repaired. On the other hand, monitoring of other components, e.g. catalytic converters, relies on indirect assessment of the component's performance. In this case, the diagnostic strategy may affect the detection time of a malfunction, thus affecting the environmental burden.

Table 2: Malfunctions imposed to the vehicles tested

Veh.	Malfunction	Malfunction description
A	Total lambda sensor malfunction	Replacement of upstream lambda sensor with defective, provided by the local dealership
	Intermediate catalyst malfunction	Replacement of catalytic converter with defective, provided by the local dealership
	Total catalyst malfunction	Complete removal of catalytic converter monolith (de-catting)
B	Intermediate lambda sensor malfunction	Artificial poisoning of the upstream lambda sensor with silicone spray
	Intermediate catalyst malfunctions	1 st stage oven ageing of close coupled catalytic converter (19h at 900°C) 2 nd stage oven ageing of close coupled catalytic converter (24h at 940°C)
C	Total EGR malfunction	Tampering of the EGR system by connecting the EGR cable to an EGR valve not installed in the engine
	Intermediate DPF malfunction	Replacement of Diesel Particulate Filter with a similar defective filter. The Defective filter had been used for 120000 km on a similar car, and showed signs of clogging by ash
	Total DPF malfunction	Removal of Diesel Particulate Filter (replacement with an empty canning)
D	Total EGR malfunction	Tampering of the EGR system by connecting the EGR cable to an EGR valve not installed in the engine
	Intermediate DPF malfunction	Thermal ageing of the catalytically coated Diesel Particulate Filter (24h at 850°C)
	Total DPF malfunction	Removal of Diesel Particulate Filter (replacement with an empty canning)

Based on the above, the components on which this experimental study has focused are:

1. For gasoline engines, lambda sensor and 3-Way Catalyst: Malfunctions in these two components

represent approximately 50% of all MIL illuminations in vehicles with mileage higher than 75000 miles (120700 km) in the USA [8]. The performance of these two components can be estimated only based on indirect assessment methods. Moreover, malfunctions in these components may result in a broad range of increase of pollutant emission levels, depending on the severity of each malfunction.

2. For diesel engines, EGR system and DPF: these two components play a major role at the reduction of the most important pollutants for diesel engines. EGR is the main measure used to control NO_x emissions. The DPF on the other hand, is an aftertreatment device with a reported efficiency of more than 90% on PM emissions.

The malfunctions introduced to the vehicles tested are summarised in Table 2. The idea behind the selection of the malfunctions was to introduce to each component one "total" malfunction that would cause the maximum increase in the emission levels. Since the effect of each malfunction was not known in advance, it turned out that some of the malfunctions imposed were not as severe as it had been anticipated. Therefore, "total" malfunctions were not imposed on all tested components. The introduced malfunctions, with the exception of the lambda sensor malfunction, had no noticeable effect on the driveability of the vehicle. Thus, detection of these malfunctions would rely either on the OBD system, or on the periodic inspection program. Further details on the malfunctions introduced and on the experimental procedure can be found in reference [9].

EMISSION MEASUREMENTS

This section presents the emission measurements for the gasoline and diesel-fueled vehicles. The distinction is made between emissions measured in the legislated cycle and in the non-legislated cycle. The emissions of the non-legislated cycle refer to the average emissions of all 3 modes of the CADC cycle. Moreover, emissions are presented as average of the different vehicles tested.

GASOLINE-FUELLED VEHICLES

Figure 2 presents the average HC emissions from the two gasoline-fueled vehicles tested. HC emissions at the baseline configuration were well below the type approval limit of 0.1 g/km, and were in fact lower for the non-legislated cycle, due to the absence of a cold-start phase. The introduction of the total lambda sensor malfunction had a significant impact on HC emissions, which climbed to 0.53 g/km in the NEDC, approximately 10 times higher than the baseline measurement. This effect was even more pronounced in the real-world cycles, where HC emissions reached 2.72 g/km, approximately 27 times above the emission standard and 270 times above the baseline measurement. This malfunction was a real in-use malfunction: the damaged sensor that we installed in vehicle A had been provided by the local dealership, and came from a private car, which had it replaced for having the same malfunction.