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Low-temperature cold-start gaseous emissions of late technology passenger cars ☆

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HIGHLIGHTS

- Euro 4/5/6 petrol and diesel passenger cars are tested at low temperature (−7 °C).
- Petrol cars emit at least 45% (CO) and 65% (HC) below the current legislative limit.
- Diesel vehicles emit increased NO_x emissions over the whole driving cycle (NEDC).
- A Euro 6 diesel car is tested, equipped with Selective Catalytic Reduction system.
- A NO_x limit for diesels could be introduced at −7 °C test over urban driving cycle.

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ABSTRACT

The control of exhaust emissions from modern vehicles is primarily based on the use of after-treatment devices, typically consisting in different types of catalysts. The efficiency of catalytic systems however strictly depends on their temperature, achieving certain effectiveness in reducing emissions only above the light-off temperature. Moreover, the enrichment of the air/fuel mixture during cold-start engine operation, in order to compensate for the reduced fuel vaporization and elevated engine components friction, leads to incomplete fuel combustion. These two factors generally contribute to elevated emissions during cold-start operation, especially under low ambient temperatures. We investigated the gaseous emission performance of thirteen late technology vehicles over the New European Driving Cycle (NEDC), at 22 °C and −7 °C test cell temperatures. The test fleet included gasoline vehicles both Port Fuel Injection (PFI) and Gasoline Direct Injection (G-DI) as well as diesel vehicles, amongst which a fully Euro 6 compliant vehicle equipped with a Selective Catalytic Reduction (SCR) system.

The test results showed that carbon monoxide (CO) and total hydrocarbon (HC) emissions of gasoline vehicles increased from 2.3 to 11.3 times at −7 °C over the Urban Driving Cycle (UDC), remaining however below the current legislative limits by 45% and 65% respectively. Nitrogen oxides (NO_x) emissions of gasoline vehicles at −7 °C turned out to be either higher or lower than at 22 °C, depending on the catalyst's performance and engine injection strategy. Diesel vehicles without any NO_x after-treatment system exhibited increased NO_x emissions over both the UDC and Extra Urban Driving Cycle (EUDC) when tested at −7 °C. The diesel car with the SCR system showed superior NO_x performance only over the second half of the NEDC.

1. Introduction

Cold-start operation of gasoline vehicles is typically associated with fuel enrichment to avoid misfires due to condensation effects on the cylinder walls. Part of this extra fuel does not participate in the combustion process (incomplete combustion), increasing the engine-out carbon monoxide (CO) and hydrocarbon (HC) emissions during cold-start operation. Moreover, the widespread use of Three Way Catalyst (TWC) and Diesel Oxidation Catalyst (DOC) in modern gasoline and diesel vehicles respectively, implies disproportionally higher levels of gaseous pollutants at the tailpipe during

Abbreviations: CVS, Constant Volume Sampling; DOC, Diesel Oxidation Catalyst; DPF, Diesel Particulate Filter; ECU, Engine Control Unit; EGR, Exhaust Gas Recirculation; EUDC, Extra Urban Driving Cycle; Euro, Emission Standard; G-DI, Gasoline Direct Injection; NEDC, New European Driving Cycle; PFI, Port Fuel Injection; SCR, Selective Catalytic Reduction; TWC, Three Way Catalyst; UDC, Urban Driving Cycle; VELA, Vehicle Emission Laboratory.

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cold-start operation, when the catalyst's temperature is not high enough to ensure an efficient conversion of pollutants. Obviously, at reduced ambient temperature, the engine and catalyst warm-up period is prolonged and this can have an adverse effect on the emissions.

In gasoline vehicles, nitrogen oxides (NO_x) emissions are efficiently reduced by the TWC, which however requires stoichiometric air/fuel mixture. In the latest generation of gasoline cars the TWC is able to reduce NO_x emissions to low levels a few seconds after the cold-start. Under low temperature conditions engine-out NO_x emissions may increase due to modified combustion characteristics (air/fuel ratio, Exhaust Gas Recirculation (EGR), and ignition timing), while the prolonged warming-up period of the TWC may influence tailpipe NO_x emission. Increased NO_x emissions could be expected in case of lean engine operation (e.g. lean-burn Gasoline Direct Injection (G-DI)), since the TWC cannot reduce effectively NO_x emissions under such air/fuel ratios. Most Euro 5 diesel vehicles employ in-cylinder measures to control NO_x emissions, such as EGR, and/or injection timing. However, the tightening of the NO_x emission limits at Euro 6 stage is likely to require after-treatment systems like Lean-NO_x traps or Selective Catalytic Reduction (SCR) systems. At low ambient temperatures, increased NO_x emissions could be expected due to a decreased EGR rate or its deactivation in order to avoid water condensation. In addition, NO_x after-treatment systems start working only when the exhaust gas temperature is above certain values [1]. Therefore, it is likely that at low temperature these systems will start working later than in tests carried out at temperatures >20 °C.

In Europe a test procedure and emission limits under low temperature conditions (Type VI test, conducted at −7 °C) were initially introduced with the Euro 3/4 emission standards [2]. The gasoline vehicles limits for CO and total HC mass were 15 g/km and 1.8 g/km respectively, applicable only over the Urban Driving Cycle (UDC) of the New European Driving Cycle (NEDC). Since then, these emission limits have never been updated as instead it happened for Type I test (20–30 °C) with the introduction of the tighter emission limits Euro 5/6 [3,4]. To this respect, the revision of the low temperature CO and HC limits for gasoline vehicles, in order to be consistent with the Euro 5/6 Type I emission standards is under discussion. In addition, the extension of the Type VI test to diesel vehicles is under consideration, especially for NO_x emissions [5].

Weilenmann et al. [6,7] investigated the influence of ambient temperature on cold-start excess emissions of both gasoline/diesel vehicles, at three ambient temperatures (23, −7 and −20 °C), employing the IUFC15 cycle [8]. The vehicles' emission certification level ranged from pre Euro 1 to Euro 4. Under low temperatures the cold-start excess CO/HC gasoline vehicles' emissions were increased, compared to 23 °C. In contrast, no evident trend could be detected for NO_x emissions of the same vehicles. Cold-start CO and HC emissions of diesel vehicles were lower than those of gasoline vehicles. Diesel vehicles up to Euro 2 emission level exhibited comparably low cold-start NO_x emissions, with no clear dependence with ambient temperature for all the vehicles tested. For Euro 4 diesel vehicles, contrary to gasoline ones, there was an evident increase of NO_x emissions as the temperature decreased. The authors explained this increase with the higher friction and consequently the higher engine loads at low temperatures.

Laurikko [9] has been evaluating the cold-start emission performance of new passenger cars since 1993. Each year a batch of 10–20 vehicles was tested at −7 °C, according to the European low ambient temperature test procedure. He concluded that for gasoline vehicles the average cold-start CO emissions decreased by more than 50% passing from Euro 2 to Euro 4, while total HC emissions improved less (30%). Diesel vehicles were also tested for their cold-start emission performance. They emitted almost one order of magnitude lower CO and HC emissions compared to the gasoline ones, mentioning that the worst performing diesel cars were close to the best performing gasoline ones.

Two recent studies of Bielaczyc et al. focused on sub-ambient temperature performance of late technology gasoline cars [10] and of both gasoline and diesel vehicles [11] certified as Euro 4/5. The results were presented in terms of g/km for CO/HC over the Type VI test, as well as in terms of non-dimensional emission factors for CO/HC/NO_x emissions (test result at −7 °C divided to the respective one at 24 °C). All the gasoline vehicles tested complied with the Type VI test emission limits, at −7 °C. The diesel vehicles tested did not employ any NO_x after-treatment system. Elevated NO_x emissions of diesel vehicles at −7 °C were reported, as well as the need to impose a limit on them.

The above-mentioned studies cover in detail mainly CO and total HC emission performance at sub-ambient temperature conditions, leaving some open issues regarding NO_x emission performance of both gasoline and diesel vehicles. In the present paper, recent Euro 5/6 diesel and gasoline vehicles were tested over the NEDC at 22 °C and −7 °C. Euro 4 vehicles were also tested for comparison. CO and total HC gaseous emission performances are analyzed and discussed. Special emphasis is given to NO_x emissions of the test fleet, which included a diesel vehicle equipped with a NO_x after-treatment system of the SCR type, as well as a lean-burn G-DI vehicle. The real-time traces of lambda, NO_x tailpipe concentration, exhaust temperature, EGR rate are used to shed light on the NO_x emission performance at both temperatures (22 and −7 °C). The revision of the low temperature test limits for gasoline vehicles, and the potential extension of such a test procedure for diesel vehicles NO_x emissions are also discussed.

2. Experimental

2.1. Vehicles

Five gasoline vehicles with Port Fuel Injection (PFI) system and three G-DI vehicles were tested. Table 1 provides their main characteristics. All vehicles were equipped with TWC.

Table 1
Gasoline vehicles' specifications (PFI: Port Fuel Injection, G-DI: Gasoline Direct Injection, L: Lean, and S: Stoichiometric).

Vehicle	Emission Standard (Euro)	Injection system	Displacement (cm^3)	Power (kW)	Mileage (km)	NEDC test repetitions (22/−7 °C)
G1	5	G-DI (L)	1995	105	8353	1/2
G2	5	PFI	1242	44	1909	5/2
G3	5	PFI	1595	75	7285	2/2
G4	5	PFI	1242	51	13,699	2/1
G5	5	PFI	1490	82	35	2/2
G6	5	PFI	1368	57	42,146	5/2
G7	5	G-DI (S)	1984	132	12,461	3/2
G8	4	G-DI (S)	4608	280	28,461	4/5