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Impact of aftertreatment device and driving conditions on black carbon, ultrafine particle and NOx emissions for Euro 5 Diesel and gasoline vehicles

Louis Cédric [a], Mathieu Goriaux [a], Patrick Tassel [a], Pascal Perret [a],
Michel André [a], Yao Liu [a,*]

[a] *Transport and Environment Laboratory, IFSTTAR, Cité de Mobilités, 69580 Bron, France*

Abstract

Ultrafine particle, black carbon and NOx emissions from Diesel and gasoline passenger cars have been investigated in this work, as well as influences of aftertreatment device and driving conditions (the cold start, urban, rural and motorway conditions…) on emissions. Experiments have been carried out on chassis dynamometer bench with Artemis urban, road and motorway driving cycles and NEDC (New European Driving Cycle). Exhaust from Euro 5 Diesel vehicles equipped with additive and catalysed particle filter and Euro 5 gasoline vehicle with direct injection system has been taken directly from the tailpipe and diluted by Constant Volume Sampler (CVS). Tested gasoline DI vehicle emits 25% more CO_2 than Diesel vehicles for all Artemis and NEDC driving conditions. It emits 2 to 200 times more PN and BC and 5 to 150 times less NOx than Diesel vehicles. Additive DPF vehicles emit 2 times more NO2 for urban conditions (175 mg/km), comparing to Diesel catalysed DPF (80 mg/km). No significant differences have been observed between additive and catalysed DPF for CO_2 and NOx emissions. The cold start induces 10 to 20% more CO_2 emissions for all tested vehicles. It induces 3 to 20 times higher PN emission with a great uncertainty. For NOx and NO_2, the cold start induces about 40 to 60% less emissions for additive DPF Diesel vehicles. No significant impact has been observed for gasoline and catalysed DPF Diesel vehicles. DPF regeneration was observed for Artemis motorway driving cycles, with an increase of 100 – 200 times more PN emission than standard filter operation mode.

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Keywords: Emission factor; CO_2; NO_x; NO_2; particle number; black carbon; cold start; driving conditions; aftertreatment; regeneration

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* Corresponding author. Tel.: +33-472-14-24-75.
E-mail address: yao.liu@ifsttar.fr

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1. Introduction

Vehicle emissions constitute one of a major source of gaseous and particulate air pollution in urban areas. It accounts about 15-50% of total fine particle mass in urban areas (Sheesley et al., 2007). On regional and global scales, particle emissions play an important role in human health and climate change. Most of particles emitted are in the size range of 20-130 nm (Morawska et al., 2008; Jamriska et al., 2004) and might contain toxic compounds, which are associated with many health effects, mainly acute cardiovascular and respiratory diseases and chronic diseases (Grahame and Schlesinger, 2007). In Europe, exposure to particulate matter, particularly $PM_{2.5}$, was estimated to reduce average statistical life expectancy by approximately nine months (CAFE, 2005). Moreover, particles affect also the earth's radiation balance by directly absorbing and scattering solar radiation and, indirectly, through their activation into cloud droplets. Primary particles from vehicular exhaust emissions are essentially composed of organic carbon and black carbon (or elemental carbon), which is carcinogenic compound (Menon et al., 2002). This black carbon fraction might represent 60% of the particulate carbonaceous fraction (El Haddad et al., 2009), which is reported to be an important cause of atmospheric visibility impairment and the second strongest contributor to current global warming (Ramanathan and Carmichael, 2008).

The mass of particles emitted by vehicles is regulated by European emission standards (Euro 1 to Euro 6). Recently, the regulation of particle number has been introduced in the Euro 5 standard for Diesel vehicles (6.10^{11} particles/km) and Euro 6 standard for gasoline vehicles (6.10^{12} particles/km). In order to limit particle emission and fulfil European standards, different aftertreatment systems are used. However, impact of these system are not completely clear, several of them could induce an increase of fine and ultrafine particle and nitrogen compound emissions, such as NO_2, N_2O, NH_3... (Bach et al., 2008; Carslaw et al., 2007; Carslaw, 2005), which might significantly affect human health and also induce secondary particle formation. According to the CITEPA inventory (2015), the main sources of NO and NO_2 are transport that represents 58% of their total emissions in the atmosphere. However, some of these nitrogen compounds (NO_2, NH_3) are not considered as regulated compounds and are neither monitored regularly nor controlled.

Ultrafine particles, black carbon, NO_x and NO_2 have been observed in-situ in tunnels and close to urban streets or motorways (Jezek at al., 2015a and 2015b; Wang et al., 2012; Westerdahl et al., 2009; Ntziachristos et al., 2007). However, it is difficult, with this method, to attribute emissions to vehicles with their specific characteristics (fuel, technology, vehicle age, driving mode…). Several studies have also focused on characterization of vehicle exhaust with chassis dynamometer measurements under controlled dilution conditions (Alves et al., 2015; Köhler, 2013; Mamakos et al., 2013; Bach et al., 2008; Casati et al., 2007; Giechaskiel et al., 2005). These studies allowed characterizing vehicle emissions with specific characters. However, tested vehicle number is relatively limited and modern vehicles with more advanced aftertreatment devices (Euro 5) are rarely tested. The work of Alves et al., 2015, illustrated emissions of CO, CO_2, NO_x, HC, twenty organic compounds, particulate matter and its carbonaceous content of eight vehicles using NEDC and Artemis urban and road driving cycles. However, only two Euro 5 vehicles (one Diesel and one gasoline) have been tested. The work of Köhler, 2013 focused on regulated compound emissions for gasoline vehicles with direct injection (DI) technology and particle filter. Emissions have been followed with the NEDC (New European Driving Cycle), US 06 and WLTC (Worldwide harmonized Light Vehicles Test Cycle) in accordance with Commission Regulation (EC) 715/2007. Moreover, particle number emission - taking into account of the sub 23 nm part of particles - has been investigated with two Euro 5 Diesel with DPF (Diesel Particle Filter) by Mamakos et al., 2013, with varying temperature conditions with NEDC and Artemis cycles. They indicate that there is an increasing scientific and legislative interest in the possibility to extend the lower detectable particle size in the legislated procedure towards smaller sizes.

Currently, ultrafine particles, black carbon and NO_2 related to road transport emission are not well assessed. Main reasons are driven by the insufficient test data due to the high diversity of vehicles, aftertreatment technologies, types of combustion and different driving conditions. In this context, this work aims at improving the knowledge on NO_2, black carbon and ultrafine particle emissions from Euro 5 Diesel and gasoline passenger cars with diverse recent technologies. Impacts of driving conditions, cold start and aftertreatment devices have also been investigated. Four Euro 5 vehicles with three different technologies have been tested and all experiments have been performed with real-world Artemis and NEDC driving cycles.

Nomenclature

Art URB Hot	Artemis Urban driving cycle with hot start	PN	Particle Number
Art URB Cold	Artemis Urban driving cycle with cold start	PM	Particle Matter
Art ROAD	Artemis Road driving cycle	BC	Black Carbon
Art MW	Artemis Motorway driving cycle	EC	Elemental Carbon
NEDC	New European Driving Cycle	NO_x	Nitrogen oxide
DPF	Diesel Particle Filter	NO	Nitric oxide
CVS	Constant Volume Sampler	NO_2	Nitrogen dioxide
PMP	Particle Measurement Programme	CO_2	Carbon dioxide

2. Materials and methods

2.1. Vehicle characteristics

Four Euro 5 vehicles currently in use have been tested in this study: Euro 5 gasoline vehicle with direct injection system (G-DI); two Euro 5 Diesel vehicles with additive particle filter (DPF add); Euro 5 Diesel vehicle with catalysed particle filter (DPF cat). Principal technical characteristics of tested vehicles were presented in Table 1.

Table 1. Technical characteristics of the four tested vehicle.

Vehicle	N° 1	N° 2	N° 3	N° 4
Size class	1,6 HDI	1,4 HDI	1,5 DCI	1,4 TSI
Technology	Diesel	Diesel	Diesel	Gasoline Direct Injection
European emission standard	Euro 5	Euro 5	Euro 5	Euro 5
Empty mass (kg)	1185	1020	1090	1241
Mileage (km)	39 600	45 150	87 073	20 822
Gearbox type	Manual (5 gears)			Automatic-Tiptronic
Aftertreatment device	Oxidation catalyst DPF additive		Oxidation catalyst DPF catalysed	Oxidation catalyst
Registration date	06/06/2012	22/07/2011	17/02/2012	08/06/2012
Test date	29/09/2014	06/10/2014	03/05/2015	04/11/2014

2.2. Experimental setup

2.2.1. Sampling system

Emission measurements have been performed on the chassis dynamometer bench of the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), Laboratory Transports and Environment. Vehicle exhaust from tailpipe was diluted with filtered ambient air through the CVS (Constant Volume Sampler) system, and then lead to different analytical instruments.

The total flow of CVS was fixed at $9m^3$/min for Artemis urban cycle and $11m^3$/min for Artemis motorway cycle. Different pollutants were sampled directly from CVS dilution tunnel by diverse on-line gas phase and particulate phase analysers. Main experimental conditions and pollutant measurements were in Table 2. Each experimental condition was repeated six or ten times, except for Artemis urban cycle with cold start for which only two repeated experiments were performed. For NEDC driving cycle, only one measurement has been done for each vehicle.

Table 2. Principal experimental conditions with different pollutant measurements.

Vehicle	Driving cycle for all vehicles	CVS (m3/min)	Repeat test number	Measurement for all vehicles
N°1 D Euro 5 DPF add **N°2 D Euro 5 DPF add** **N°3 D Euro 5 DPF cat** **N°4 E Euro 5 ID**	NEDC [#] cold start	9	1	NO_x NO NO_2 CO_2 BC * PN [$]
	URB [¤] cold start	9	2	
	URB hot start	9	10	
	MW [£] hot start	11	6	
	ROAD [&] hot start	9	6	

#: New European Driving Cycle
¤: Artemis urban driving cycle
£: Artemis motorway driving cycle
&: Artemis road driving cycle
*: Black Carbon
$: Particle Number

2.2.2. Driving cycles

All experiments were conducted with the NEDC and the real-world Artemis driving cycles (André, 2004). The Artemis cycles contain several contrasted driving conditions that allow characterizing the driving conditions in very detailed situations. The average speeds and sampling durations are 34, 61, 116 and 17 km/h and 1181, 862, 736 and 921 s, respectively, for NEDC, Artemis road, Artemis motorway and Artemis urban cycles. All experiments were conducted with commercial fuel (Sulphur content less than 10 ppm) from the same gas station in order to minimize the variability of the fuel composition and its impact on emissions.

2.2.3. Analysis device

Regulated compounds, such as CO, CO_2, NO and NO_x, and total hydrocarbons, were monitored by non-dispersive infrared, chemo-luminescence and flame ionization detection, respectively. NO_2 concentration was determined by subtracting NO from NO_x.

Total particle number was measured by Condensation Particle Counter (CPC, 3775 TSI). The CPC contained a butanol condensation chamber that allowed for particle detection with diameter greater than 4 nm. The operating flow rate of CPC was fixed at 1.5 L/min. Experimental data were collected every second with a concentration range from 0 to 10^7 particle/cm^3. For Euro 5 and Euro 6 vehicles, the PMP (Particle Measurement Programme) system has been proposed as a regulatory approach for measuring particle number (EC regulation). This system allows removing the volatile particles with a 50% cut-point size at 23nm. One of the main reasons for cutting volatile particles is that the measurement of non-volatile particles is more repeatable. However, our previous experiments showed that most of particles emitted by tested vehicles were ultrafine particles with diameters lower than 23 nm, especially during Artemis motorway driving cycle and particle filter regeneration. In order to have the most complete information on total particle number emission, we did not use the PMP method. Furthermore, taking into account this volatile part, standard variations of particle number quantification with six repeated experiments were quite low, ranging between 7 to 11%.

Black carbon was measured by an Aethalometer (AE 33-7, Magge Scientific). Experimental data were collected every second at a flow rate of 5 L/min. The detection limit for 1 h was 5 ng/m^3 with a concentration range from 10 to 10^5 ng/m^3. Light attenuation has been measured on seven wavelengths (370, 470, 525, 590, 660, 880 and 940 nm) from UV to IR. 880 nm corresponding to maximum absorption of black carbon has been used in this study for black carbon quantification.

3. Results and discussion

3.1. Emission factor

Average emission factors of particle number (PN), black carbon (BC), NO_x, NO, NO_2 and CO_2 were reported in Table 3 for all tested vehicles with Artemis road, urban and motorway driving cycle and with the New European Driving Cycle (NEDC).

Table 3. Emission factors of CO_2, NO_x, NO, NO_2, particle number and black carbon for four tested Euro 5 vehicles with Artemis and NEDC driving cycles.

Driving cycle	Art URB hot [¤]	Art URB cold [β]	Art ROAD [&]	Art MW [£]	NEDC [#]
vehicle N° 1	**Euro 5 Diesel with additive Diesel particle filter**				
CO_2 (g/km)	150 ± 1	172 ± 2	89 ± 0.5	131 ± 0.3	114 ± 2
NO_x (mg/km)	763 ± 188	413 ± 25	424 ± 13	495 ± 20	212 ± 43
NO (mg/km)	578 ± 160	332 ± 5	297 ± 8	385 ± 10	172 ± 34
NO_2 (mg/km)	185 ± 28	81 ± 20	127 ± 6	109 ± 17	23 ± 5
BC (µg/km)	1.5 ± 0.7	48-165	1.2 ± 0.4	0.7 ± 0.6	13 ± 3
PN (#/km)	< LQ	$(5\text{-}20)\ 10^{10}$	< LQ	$(2.4 \pm 1.2)\ 10^{11}$	$(20 \pm 4)\ 10^{9}$
vehicle N° 2	**Euro 5 Diesel with additive Diesel particle filter**				
CO_2 (g/km)	142 ± 3	169 ± 2	87 ± 1.2	130 ± 1	114 ± 2
NO_x (mg/km)	591 ± 140	332 ± 7	384 ± 39	910 ± 42	162 ± 33
NO (mg/km)	424 ± 79	283 ± 2	285 ± 20	640 ± 14	144 ± 29
NO_2 (mg/km)	166 ± 61	49 ± 6	99 ± 21	270 ± 46	19 ± 4
BC (µg/km)	< LQ	18-69	1.2 ± 0.2	2.4 ± 2	24 ± 5
PN (#/km)	< LQ	$(1.2\text{-}10)\ 10^{10}$	< LQ	$(3.5 \pm 6)\ 10^{11}$	$(45 \pm 9)\ 10^{9}$
vehicle N° 3	**Euro 5 Diesel with catalysed Diesel particle filter**				
CO_2 (g/km)	145 ± 5	167 ± 3	92 ± 1.5	135 ± 2	114 ± 2
NO_x (mg/km)	586 ± 21	723 ± 167	485 ± 121	746 ± 31	315 ± 63
NO (mg/km)	506 ± 20	649 ± 147	364 ± 93	387 ± 34	262 ± 52
NO_2 (mg/km)	80 ± 15	74 ± 20	121 ± 35	359 ± 11	53 ± 11
BC (µg/km)	8 ± 4	13-926	2 ± 0.6	< LQ	5 ± 1
PN (#/km)	$(9 \pm 2)\ 10^{9}$	$(0.2\text{-}31)\ 10^{11}$	< LQ	$(3 \pm 1.7)\ 10^{11}$	$(6 \pm 1)\ 10^{9}$
vehicle N° 4	**Euro 5 Gasoline with Direct Injection**				
CO_2 (g/km)	233 ± 3	256 ± 1	120 ± 1	137 ± 1	144 ± 3
NO_x (mg/km)	128 ± 31	116 ± 19	23 ± 7	5 ± 1	213 ± 43
NO (mg/km)	123 ± 29	111 ± 18	22 ± 7	5 ± 1	197 ± 39
NO_2 (mg/km)	5 ± 2.7	5 ± 1	1 ± 0.4	0.2 ± 0.05	15 ± 3
BC (µg/km)	498 ± 249	1531 ± 207	139 ± 23	218 ± 19	---
PN (#/km)	$(20 \pm 6)\ 10^{11}$	$(56 \pm 3)\ 10^{11}$	$(65 \pm 8)\ 10^{10}$	$(10 \pm 3)\ 10^{11}$	$(33 \pm 7)\ 10^{11}$

PN were measured with Condensation Particle Counter
< LQ: Value to lower limit of quantification
---: No measured
[#]: New European Driving Cycle

[£]: Artemis motorway driving cycle
[&]: Artemis road driving cycle
[¤]: Artemis urban driving cycle with hot start
[β]: Artemis urban driving cycle with cold start

CO_2 emissions were strongly affected by driving condition; lower emission has been observed with Artemis road cycle (87 to 120 g/km) and higher emission with Artemis urban cycle with cold start (167 to 256 g/km). Three Euro 5 Diesel DPF vehicles had similarly CO_2 emission, which was 40% lower than gasoline vehicle with direct injection in urban driving condition. These observations were consistent with Alves et al. (2015). They observed that the gasoline vehicles emitted more CO_2 than diesel (+25% with Artemis and NEDC cycles). No significant difference on CO_2 emission has been observed between Euro 5 additive and catalysed DPF vehicles.

Concerning PN, Diesel emissions with Artemis road and urban hot start were close to the background (1.1010 #/km). Only two Artemis urban cycles with cold start were performed for each vehicle and a high variability between the two repeated tests were observed for PN and BC emissions. Du to this variability, PN and BC emission factors of each test have been showed in Table 3 instead of an average value. This variability might be partly explained by vehicle functional condition that was a random variable. However, even with this strong variability, results shown a clear tendency that gasoline vehicle emitted more PN and BC than Diesel. According to Köhler (2013), gasoline vehicles with direct injection system emitted more PN, which was about 1000 times more than the same generation Diesel DPF vehicles. Moreover, we observed also that black carbon emissions were proportional to PN emissions, except for motorway cycles, due to DPF regeneration. Influence of driving conditions and technology on emissions has been discussed in section 2.2.

NOx emissions for Diesel vehicles were between 162 to 910 mg/km and depending on vehicle technologies and driving cycle. Average emissions of NOx for Artemis cycles were 2.5 times higher than NEDC. Diesel with catalysed filter emitted more NOx (315 mg/km) than additive DPF (162-212 mg/km) with NEDC test. That was above Euro 5 European standard (180 mg/km). For all Artemis driving cycles, NO and NOx emissions were similarly with uncertainty for three Diesel vehicles. However, NO_2 emissions shown a significant variability depending on the aftertreatment device of tested vehicles: for hot start Artemis urban cycle, NO_2 emissions were 185 and 166 mg/km for Diesel additive DPF vehicles and 80 mg/km with catalysed DPF. NOx emissions from gasoline vehicle were 5, 20 and 150 times lower than Diesel vehicles for Artemis urban, road and motorway conditions, respectively.

3.2. Influence of driving conditions and technology

Emission factors of particle number (PN), black carbon (BC), NO_x and CO_2 were examined with five different driving conditions with the Artemis cycles and NEDC cycle. NEDC is composed of constant accelerations / decelerations phases and stable speeds. It is used for the approval of vehicles and does not represent real driving conditions.

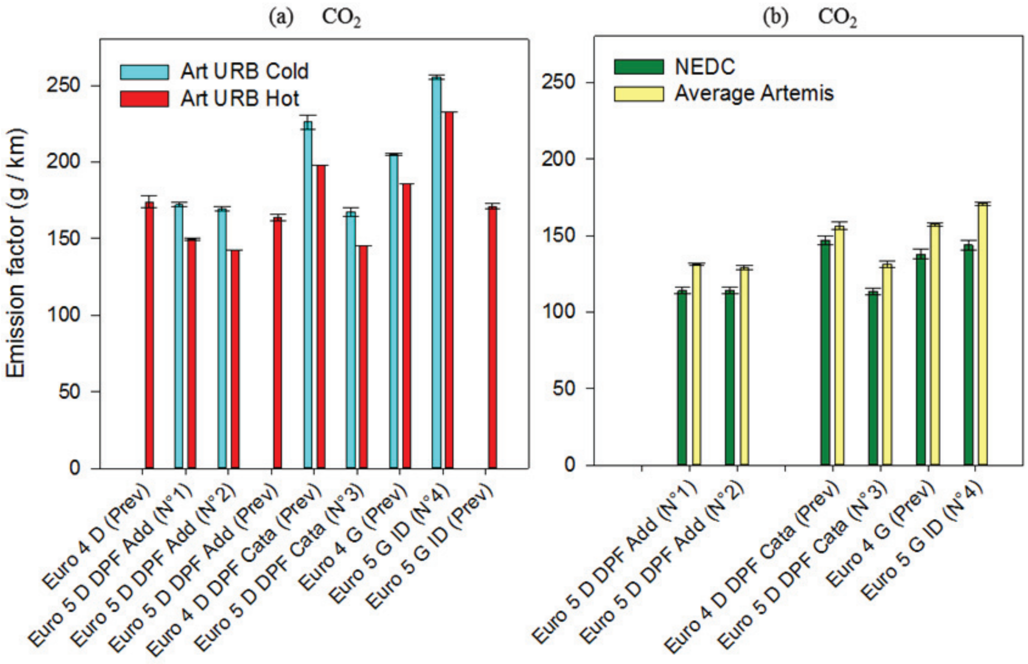

Fig.e 1. Emission factors of CO_2 (g/km) for four tested vehicles (N°1 to N°4) with (a) Artemis urban cycles; (b) NEDC and average Artemis cycles. Emissions were comparing with results obtained from previous work (Prev). D: Diesel; G: Gasoline; DPF Add and DPF Cata: Additive or Catalysed Diesel Particle Filter; ID: Direct Injection technology.

The Artemis cycles allowed testing urban hot and cold start, road and high way driving condition with realism. For the Artemis and NEDC cold start cycles, vehicle engines had been turned off for 16 hours before the test. CO_2 emission is proportional to the fuel consumption in a first approach and it used as consumption indicator. CO_2 emission factors for Artemis urban driving cycles with cold and hot start has been compared in Figure 1a. The cold start in urban condition induced an excess of CO_2 emission of 10-20% comparing to the hot start. This result was in agreement with study of Alves et al. (2015) in which excess emission of 10% had been observed. Compared to the NEDC (Figure 2b, right), the CO_2 emission of average Artemis driving cycles (urban, motorway and road) was 12% higher. Moreover, CO_2 emissions of four tested Euro 5 vehicles were compared to our previous work. We observed that Euro 5 Diesel vehicles emitted about 20% less CO_2 than Euro 4 vehicles.

Particle number emission factors for Artemis urban driving cycles with cold and hot start were compared for both cold start tests in Figure 2. Cold start urban condition induces higher PN emission for Diesel (1.5 to 20 times) and gasoline (3 times) vehicle than hot start urban condition. Moreover, PN emission of four tested Euro 5 vehicles in this work had been compared with results obtained in our previous work and those obtained by Bach et al., (2008). In Bach's work, 12 Euro 4 Diesel and 16 Euro 4 gasoline vehicles had been tested. Diesel vehicles without DPF (Euro 4 D) was the most polluting on urban cycle ($1.3.10^{14}$ #/km), which was in agreement with Bach et al., (2008). They observed a higher emission of PN (200 times) for Euro 4 diesel without filter (DPF) comparing to DPF vehicles. With the implementation of the DPF, the particle number emission was significantly reduced. Furthermore, no significant difference had been observed between catalysed and additive DPF vehicles on PN emission.

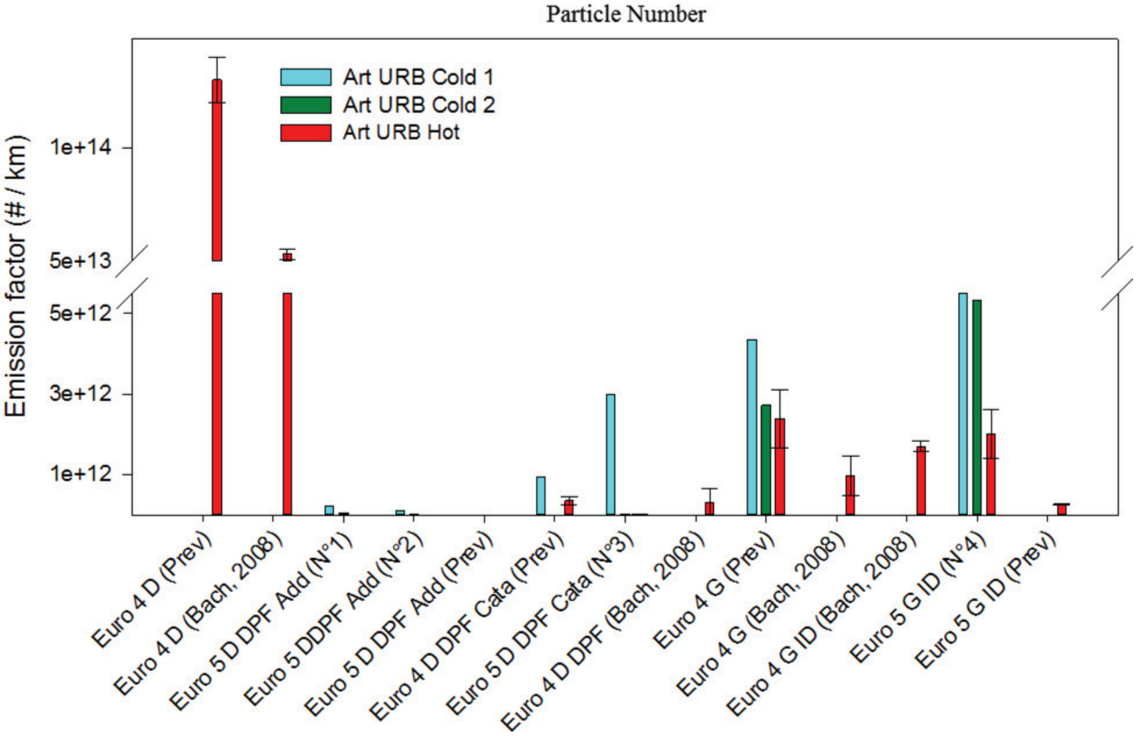

Fig. 2. Emission factors of particle number (#/km) for four tested vehicles (N°1 to N°4) with Artemis urban cycles with hot and cold start. Emissions were comparing with results obtained from previous work (Prev) and those obtained by Bach, (2008). D: Diesel; G: Gasoline; DPF Add and DPF Cata: Additive or Catalysed Diesel Particle Filter; ID: Direct Injection technology.

Emission factors of NO_x and NO_2 for different tested vehicles with hot and cold start Artemis urban cycle were presented in Figure 3a and 3b, respectively. Results obtained from our previous work and those obtained by Bach et al., (2008) have also been shown as comparison. Cold start induced a decrease of by a factor 2 NO_x and NO_2 emissions by a factor 2 for Diesel vehicles whereas no significant effects were observed for gasoline emissions. NO_2

emissions with cold start for both DPF devices were close, around 60 mg/km. However, with Artemis urban hot start cycle, NO_2 emissions were about two times higher for additive DPF (180 mg/km) comparing to catalysed DPF (90 mg/km). Emissions of nitrogen compounds from Diesel vehicles with and without DPF did not vary significantly with hot start Artemis cycle. These results were consistent with AFSSET (2009) which reported that emissions of NO, NO_2 and NO_x obtained with additive DPF and without DPF were quite similar.

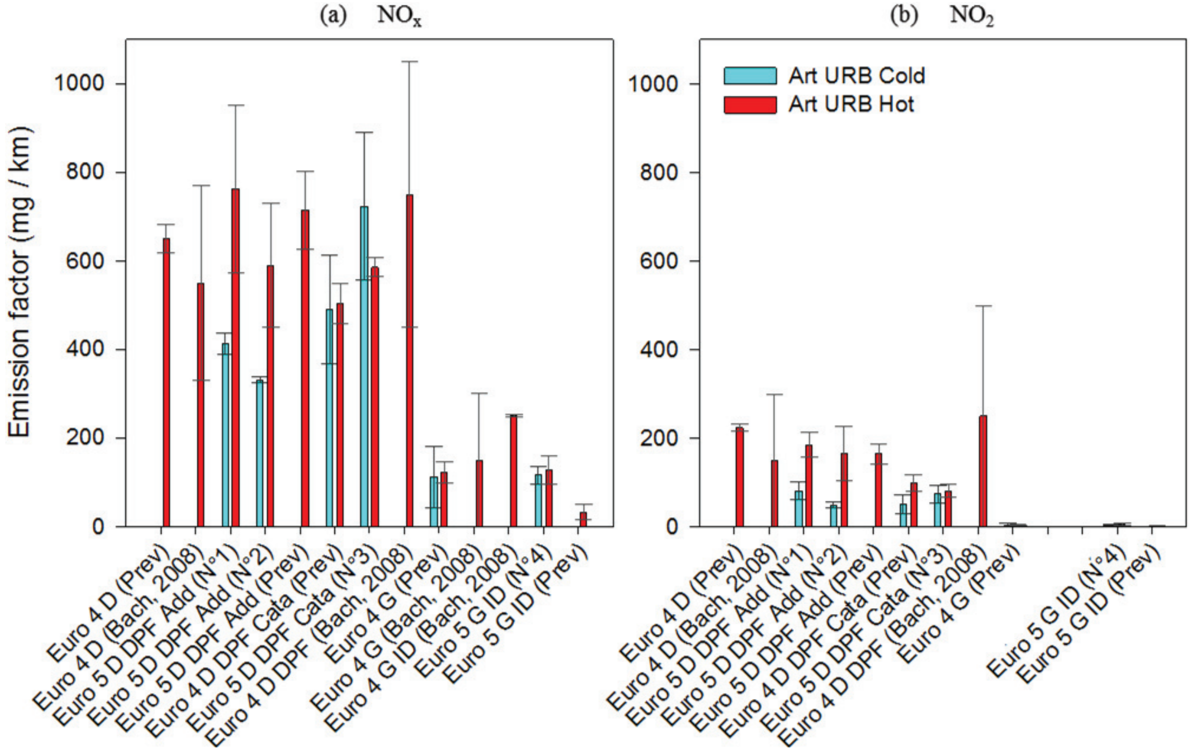

Fig. 3. Emission factors of NO_x (a) and NO_2 (b) with Artemis urban cycles. And comparison between tested vehicles in this work and results obtained from previous work (Prev) and from Bach, (2008). D: Diesel; G: Gasoline; DPF Add and DPF Cata: Additive or Catalysed Diesel Particle Filter; ID: Direct Injection technology.

3.3. Regeneration

The Diesel particle filter had been introduced on all new Diesel vehicles since the Euro 5 European standard (2011), in order to reduce particle emissions. However the DPF regeneration phase with soot burning induced a higher emission of ultrafine particles and black carbon. During our experiments, several DPF regenerations have been observed with the Artemis motorway cycle (Figure 4). Emission profiles during regeneration were typical of passive regeneration that occurred with hot engine temperature. Regeneration phenomenon had also been investigated by Mamakos et al. (2013) during NEDC cycle. In our work, we observed a sharp peak of particle emission during the strongest acceleration of the vehicle (110s from the beginning) that lasts 2-3 minutes. Characterization of the particle size distribution showed that 75% of emitted particles were ultrafine particles, with diameter less than 23 nm.

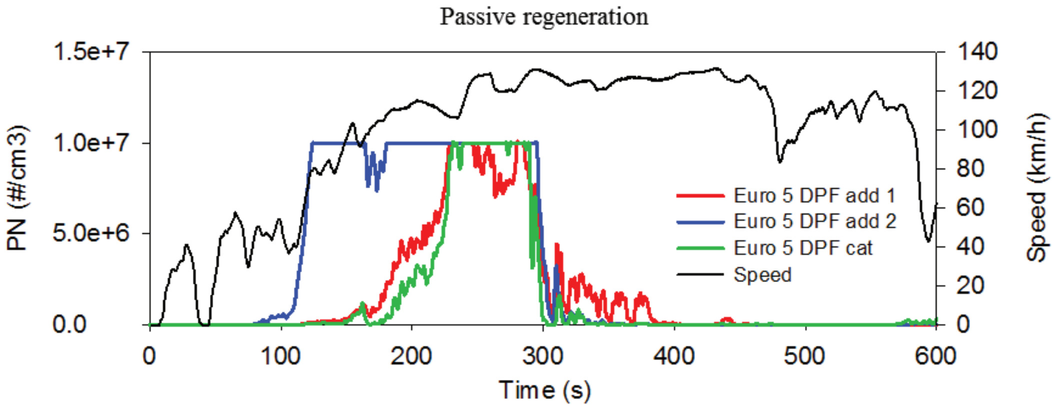

Fig. 4. Emission profiles of particle number during regeneration phase of Diesel vehicle. Emissions have been followed by Condensation Particle Counter (# / cm^3) during Artemis motorway cycle.

During regeneration, particle number emissions were 100 to 200 times higher than average emission without regeneration for the Artemis motorway driving cycle. However, both CPC and ELPI were saturated during regeneration (Figure 4), the over emission of regeneration was underestimated. More advanced studies on DPF regenerations should be done to estimate this impact on particle emissions.

4. Conclusion

In this present work, three types of Euro 5 vehicle have been tested: gasoline vehicle with direct injection system; Diesel vehicle with additive and catalysed particle filter. All experiments have been performed on chassis dynamometer bench with real-world Artemis and NEDC driving cycles in order to characterize NO_x, NO_2, CO_2, black carbon and particle number emissions. Diesel and gasoline vehicles had significant different behaviours on pollutant emissions. Tested gasoline DI vehicle emitted 25% more CO_2 than Diesel vehicles for all Artemis and NEDC driving conditions. It emitted 2 to 200 times more PN and BC and 5 to 150 times less NO_x than Diesel vehicles. Comparing to Diesel catalysed DPF, additive DPF vehicles emitted 2 times more NO_2. No significant differences were observed between additive and catalysed DPF for CO_2 and NO_x emissions. Moreover, a clear impact of cold start on emission was observed during our experiments. The cold start induced 10 to 20% more CO_2 emissions for all tested vehicles. It induced 3 to 20 times higher PN emission with a great uncertainty. For NO_2, the cold start induced a decrease of NO_x and NO_2 emissions by a factor 2 for Diesel vehicles whereas no significant effects were observed from gasoline emissions. With Artemis urban hot start cycle, NO_2 emissions were about two times higher for additive DPF (180 mg/km) comparing to catalysed DPF (90 mg/km). During DPF regeneration particle number emissions were 100 to 200 times higher than average emission. Characterization of the particle size distribution showed that 75% of emitted particles were ultrafine particles with diameter less than 23 nm. More advanced studies on DPF regenerations should be done to estimate this impact on particle emissions.

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