INTER-LABORATORY TEST OF EXHAUST PARTICLE NUMBER MEASUREMENT USING CPC AND ELPI

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ABSTRACT

The French Particulate Measurement Programme (PMP) subgroup, composed by IFP, PSA Peugeot-Citroën, Renault and UTAC, has conducted an inter-laboratory test to evaluate the performances of CPC (Condensation Particle Counter). The technical program was based on tests carried out on four passenger cars, tested on the New European Driving Cycle (NEDC). Electrical Low Pressure Impactor (ELPI) is also used to determine the total particle number and the particle distribution. The regulated pollutants are also measured, as indicators of test repeatability and good working conditions.

INTRODUCTION

Currently, there are many methods for the particle number and/or size determination. The most common used in the case of vehicle exhaust gas are the Electrical Low Pressure Impactor (ELPI), the Scanning Mobility Particle Sizer (SMPS) and Particle Counters, but many others are also presented in literature. SMPS has a very good particle size resolution. However; it has an insufficient resolution time (some minutes), and thus, it cannot be used for transient particle measurement on the NEDC. Last year, another inter-laboratory exercise was conducted from the same group in order to determine the performances of ELPI. Continuing this work, the current article presents the evaluation of CPC performances.

EXPERIMENTAL SECTION

Four passenger cars were used in this study: a Euro4 gasoline PC operating under stoichiometric conditions (vehicle 1), a Euro3 Diesel PC (vehicle 2), a Euro4 Diesel PC (vehicle 3) and a Diesel PC equipped with DPF (vehicle 4). Fuels with less than 10 ppm of sulphur were used for this study. The same lubricant (<0.4% of sulphur), was used for all four vehicles.

For each vehicle, three tests were performed on the New European Driving Cycle (cold start), and regulated pollutants and CO_2 emissions were measured according to current European regulations. Particle number was measured using a TSI 3022A CPC. A DEKATI ELPI, covering particle cut size from 8 nm to 10 µm, was also used. Two additional DEKATI diluters were used in series to dilute the sample gas. The first diluter was put in front of ELPI (dilution 10 times, heated at 120°C with hot nitrogen or air). The second one was put in front of CPC (to achieve total dilution 100 times, not heated).

Tunnel backgrounds (blanks) were recorded during 20 minutes before and after each test. These values were not subtracted from the particle number of vehicles measurements. The particle numbers of the tunnel background tests are expressed in 1/Km using the same CVS volume and distance as a NEDC test.

The intra-laboratory variability (ILV) is expressed as the relative standard deviation (RSD) of the measured values. The repeatability and reproducibility between the four laboratories are calculated following the ISO 5725 standards. In this work, the intra-laboratory variability, reproducibility and repeatability is expressed as 1.96*RSD (confidence interval of 95%).

RESULTS AND DISCUSSION

Emissions of regulated pollutants and CO_2

Figure 1 of the poster shows the emission of regulated pollutants and CO_2 of the four vehicles. The emissions of CO, HC, NOx and PM are within the regulatory limits. The 1.96*RSD repeatability values are within 3-11%, 9-22%, 2-34%, 7-103% and 1-3% for the CO, HC, NOx, PM and CO_2 respectively and the corresponding reproducibility values are within 11-64%, 19-97%, 13-35%, 19-200% and 1-3% respectively. The gasoline vehicle and the DPF equipped Diesel PC have high RSD values of PM emissions due to their very low levels, which are close to the blanks. Another reason for the higher RSD values of the vehicle 4 is that only two laboratories performed these tests.

Particle number of the tunnel background tests

The particle number of the tunnel backgrounds is very low: from $7x10^8$ to $2x10^{11}$ 1/Km

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(figure 2). Due to these low values, the 1.96*RSD of the ILV is very high: from 10% to 280% without clear tendency between ELPI and CPC. The repeatability results are from 60% to 260%, while those of reproducibility are from 132% to 325%. Generally, the 1.96*RSD repeatability and reproducibility values of ELPI are lower than those of CPC. The particle number of blank measurements is in the same order of magnitude of the limit of detection of ELPI (LOD=~ $5x10^{10}$ 1/Km) and quite higher than the LOD of CPC (LOD=~$2x10^{8}$ 1/Km). The LOD calculation is linked to the measurement set-up used in this study.

Particle number on the NEDC tests

The mean total particle number of the Euro4 gasoline vehicle is $4.2x10^{12}$ 1/Km measured by ELPI and $5.3x10^{12}$ 1/Km measured by CPC (figure 3). On NEDC, the intra-laboratory 1.96*RSD variability values are 10-100%, quite similar for ELPI and CPC, while the repeatability and reproducibility values are 23% and 196% for ELPI and 23% and 87% for CPC. The repeatability and reproducibility of this vehicle is better than the repeatability and reproducibility of the tunnel background tests of this vehicle. For both CPC and ELPI, the repeatability and reproducibility values are higher at the EUDC part than for the entire NEDC.

The mean total particle number of the Euro3 Diesel vehicle is $1.3x10^{14}$ 1/Km measured by ELPI and $9.2x10^{13}$ 1/Km measured by CPC (figure 4). The intra-laboratory 1.96*RSD variability values are 1-130%, with CPC having generally lower values than ELPI. The repeatability and reproducibility results are respectively 34% and 102% for ELPI and 10% and 58% for CPC, quite low compared to the values of the tunnel background tests of this vehicle. It must be noted that this vehicle is representative of the current European fleet (Euro3). The repeatability and reproducibility values of the NEDC are quite similar to those of ECE and EUDC.

The mean total particle number of the Euro4 Diesel vehicle is close to the particle number of the Euro3 Diesel vehicle: $1.3x10^{14}$ 1/Km measured by ELPI and $7.4x10^{13}$ 1/Km measured by CPC (figure 5). The intra-laboratory 1.96*RSD variability values are within 3-33%, with CPC having generally lower values. The repeatability and reproducibility values are 16% and 98% in the case of ELPI and 6% and 41% in the case of CPC. These results are similar to the results of the previous vehicle and, due to higher numbers, much better than the results of the tunnel background tests of this vehicle. As in the case of the previous vehicle, the repeatability and reproducibility values of the NEDC are similar to the values of ECE and EUDC.

The mean total particle number of the Euro3 Diesel vehicle equipped with DPF is $7.1x10^{10}$ 1/Km measured by ELPI and $1.4x10^{10}$ 1/Km measured by CPC (figure 6). Only two labs tested this vehicle for the moment; thus, the 1.96*RSD values may not be representative yet. The intra-laboratory 1.96*RSD variability values are within 33-340%, with CPC having generally lower values. The repeatability and reproducibility values are 115% and 227% in the case of CPC. There are no repeatability and reproducibility results for ELPI, as only one ELPI measurements performed by Lab4. These values are much higher than the values of the two previous Diesel vehicles and similar to the values of the tunnel background tests. The repeatability and reproducibility values of the NEDC are close to the values of ECE and EUDC.

Comparison between CPC and ELPI

CPC and ELPI give a quite similar particle number on the NEDC and consequently the total particle numbers are in the same order of magnitude for the two devices. However, for some tests, some differences can be found the results of the two devices in the EUDC part of NEDC.

CONCLUSIONS

The results of this study show that:

- The reproducibility of the tunnel background tests is quite poor, due to low particle numbers.

- On the entire NEDC, the reproducibility of total particle number determined by CPC is 87%, 58%, 41% and 227% respectively for the Euro4 gasoline, Euro3 Diesel, Euro4 Diesel and Euro3 Diesel PCs equipped with DPF.

- The reproducibility with ELPI is worse than this of CPC.

- With both CPC and ELPI, the reproducibility of low-particle-emitting vehicles is too high compared to the reproducibility of regulated pollutants emissions.

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Introduction

The French PMP group evaluated the TSI 3022A CPC.

Experimental section

Four vehicles were used: a Euro4 gasoline PC, a Euro3 and a Euro4 Diesel PC and a DPF-equipped Euro3 Diesel PC. Fuels with <10 ppm of S, and a lubricant, containing <0.4% of S, were used. Three cold NEDC tests were performed. Particle number was measured using a TSI 3022A CPC and a DEKATI ELPI. A heated dilutor (x10) was used before ELPI following by a secondary dilutor (x10) before the CPC. The repeatability and reproducibility were calculated from the ISO 5725 standard.

Results

Regulated pollutants and CO_2

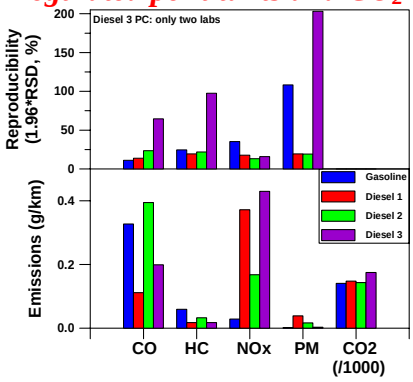

Figure 1. *Emissions of regulated pollutants and CO_2.*

The reproducibility of RP is generally low, except in the case of PM matter of the gasoline and the Diesel 3 PCs.

Tunnel background tests

Tunnel particle number is 10^9-10^{11} particles/Km. For both ELPI and CPC, these experiments are not very repeatable due to low numbers.

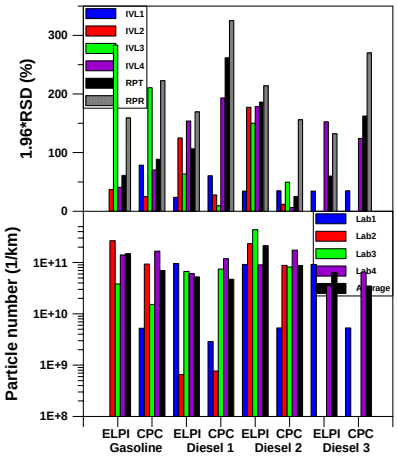

Figure 2. *Tunnel background experiments.*

Particle number

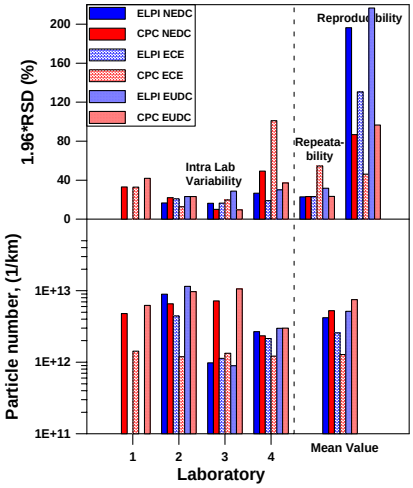

Figure 3. *Particle number of the gasoline PC.*

For all PCs CPC and ELPI give quite similar particle numbers.

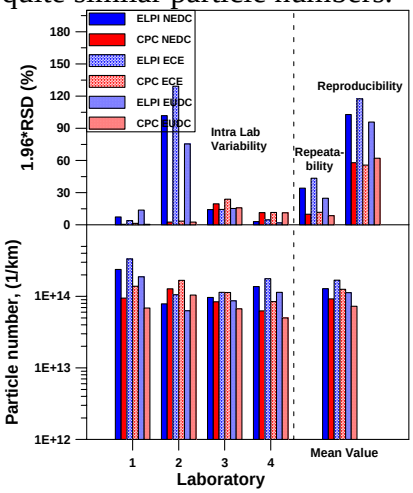

Figure 4. *Particle number of the Diesel 1 PC (Euro3).*

CPC reproducibility is generally better than that of ELPI. However, the 1.96*RSD values are generally high, especially for the low-particle-emitting vehicles.

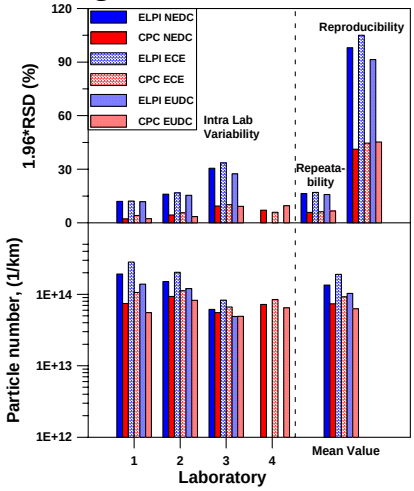

Figure5. *Particle number of the Diesel 2 PC (Euro3).*

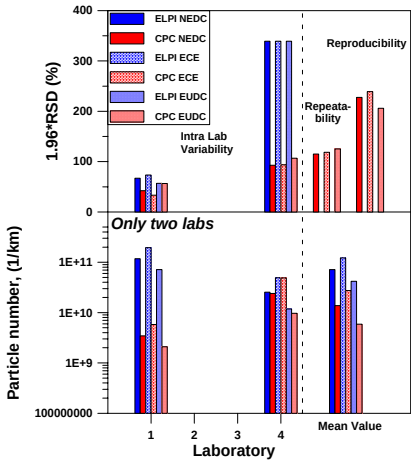

Figure 6. *Particle number of the Diesel 3 PC (Euro3 with DPF).*

CONCLUSIONS

- ELPI and CPC give quite close particle numbers.
- Particle numbers of the tunnel blanks are very low, and consequently, reproducibility very poor.
- CPC reproducibility is better than that of ELPI, but poorest than that of the regulated pollutants emissions.

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