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Potentiale der portablen Abgasmesssysteme (PN PEMS) zur Überwachung der Realemissionen (RDE)

Potentials of the portable emission measuring systems (PN PEMS) to control real driving emissions (RDE).

Abstrakt

In verschiedenen Arbeiten der Abgasprüfstelle (AFHB) der Berner Fachhochschule (BFH) wurden Benzin- und Diesel Personenwagen mit verschiedenen PEMS auf dem Rollenprüfstand und auf der Strasse gemessen. Auch die Partikelanzahl messenden Instrumente (PN PEMS) wurden in die Untersuchungen einbezogen.
Der vorliegende Artikel wird einige Resultate und Erfahrungen mit 3 DI Benzin-, 3 Dieselfahrzeugen und 4 PEMS darstellen und die Potentiale und Grenzen dieser neuen Abgaskontrollmethodik diskutieren.

Die wichtigsten Potentiale sind: Unabhängigkeit vom Messlabor, Aufzeigen verschiedener Einflüsse der ECU & OBD, Mitberücksichtigung der Einflüsse von Umgebung, Verkehrssituation und Fahrweise, Kalibrierbarkeit, Möglichkeiten zur Bestimmung des Abgasmassenstromes ohne dem Durchflussmessgerät. Die wichtigste Grenze dieses Verfahrens ist eben durch die streuende Emissionsquelle infolge der obengenannten Einflüsse gegeben.

Abstract

In different projects of the Laboratory for Exhaust Emissions Control (AFHB) of the Berne University of Applied Sciences (BFH) gasoline- and Diesel passenger cars with different PEMS's were tested on the chassis dynamometer and on the road. Instruments measuring the particle number (PN PEMS) were also included in the investigations.

The present article will show some results and experiences with 3 DI gasoline-, 3 Diesel- cars and 4 PEMS and it will discuss the potentials and limits of this new methodology to control the emissions.

The most important potentials are: independence of Laboratory, indication of different influences of ECU & OBD, consideration of: ambient conditions, situation of traffic, driving behavior, possibilities of calibration and possibility to estimate the exhaust mass flow without a flowmeter. The most important limit of this procedure is the fluctuating emissions source due to the above mentioned influences.

Test Installations

Chassis dynamometer

Part of the tests were performed on the 4WD-chassis dynamometer of AFHB (Laboratory for Exhaust Emission Control of the Bern University of Applied Sciences, Biel, CH).

The stationary system for regulated exhaust gas emissions is considered as reference.
This equipment fulfils the requirements of the Swiss and European exhaust gas legislation.

- regulated gaseous components:
  exhaust gas measuring system Horiba MEXA-7200
  CO, CO_2… infrared analysers (IR)
  HC_{FID}... flame ionisation detector for total hydrocarbons
  CH_{4FID}... flame ionisation detector with catalyst for only CH4
  NO/NO_x... chemoluminescence analyser (CLA)

The dilution ratio DF in the CVS-dilution tunnel is variable and can be controlled by means of the CO_2-analysis.
The measurements of summary particle counts in the size range 23-1000nm were performed with the CPC TSI 3790 (according to PMP).
For the exhaust gas sampling and conditioning a ViPR system (ViPR...volatile particle remover) from Matter Aerosol was used. This system contains:

- Primary dilution - MD19 tunable rotating disk diluter (Matter Eng. MD19-2E)
- Secondary dilution – dilution of the primary diluted and thermally conditioned sample gas on the outlet of evaporative tube.
- Thermoconditioner (TC) - sample heating at 300°C.

GAS PEMS

	HORIBA MEXA 7100	**HORIBA OBS ONE**	**AVL M.O.V.E**	**TU Wien OBM Mark IV**	**SEMTECH DS**
	4x4 chassis dyno CVS	PEMS① wet	PEMS② dry	PEMS③ dry	PEMS④ dry
CO	NDIR	heated NDIR	NDIR	NDIR	NDIR
CO_2	NDIR	heated NDIR	NDIR	NDIR	NDIR
NO_x	CLD	CLD	NDUV	Zirkonium-dioxid	calculated
NO	CLD	CLD	-	Electro-chemical + NDIR	NDUV
NO_2	calculated	calculated	NDUV	-	NDUV
O_2	-	-	electro-chemical	electro- chemical	
HC	FID	-	IR	IR	-
PN	not measured	-	-	-	-
OBD logger	-	yes	yes	yes (Bluetooth dongle)	yes
GPS logger	-	yes	yes (Garmin GPS16)	yes (GPS - Bluetooth receiver)	yes
ambient (p, T, H)	yes	yes	yes	no	yes
EFM	-	pitot tube	pitot tube (SEMTECH-EFM HS)	no	pitot tube (SEMTECH-EFM)

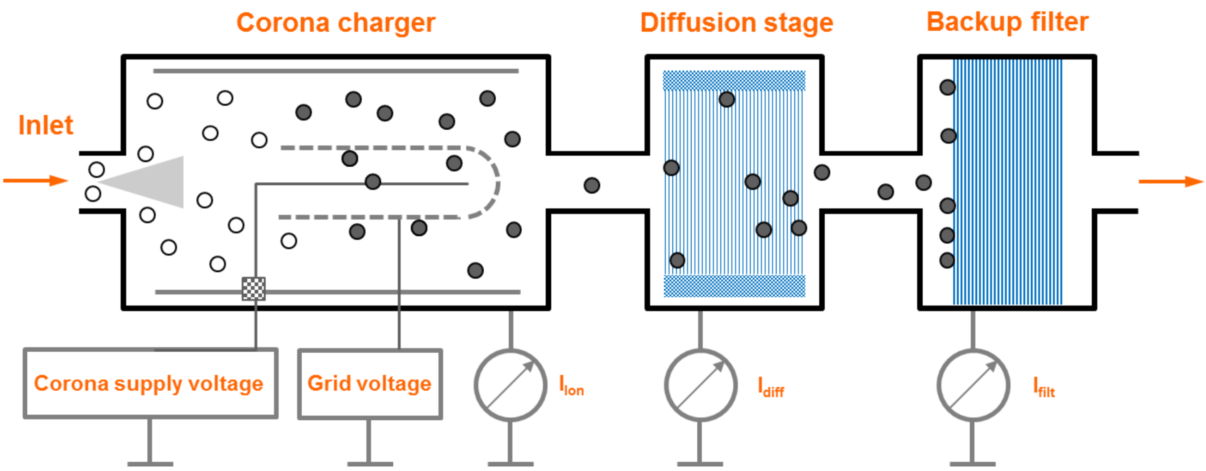
OBS - one H_2O monitored to compensate the H_2O interference on CO and CO_2 sample cell heated to 60°C
AVL – Move dry to wet correction applied

Table 1. Overview of used measuring systems.

The overview of used PEMS is given in the Table 1. Let us remark that the OBM Mark IV system does not use any flowmeter for exhaust flow measurement. It calculates the necessary parameters from the on-board data. Thanks to that this apparatus can be much simpler and quicker adapted on the vehicle.

PN PEMS

As PN PEMS for Real Driving Emissions the NanoMet3-PS from Matter Aerosol-TESTO (NM3) was used. The exhaust gas conditioning, as described above for chassis dynamometer, is integrated in this analyzer and it indicates the solid particle number concentration and geometric mean diameter in the size range 10-700 nm. TESTO NanoMet3 presents several advantages like compactness, robustness, fast on-line response and it has been considered in the preparatory activities of on-coming RDE type approval in EU as a “Golden Instrument” (see [1]). This instrument works on the diffusion charging classifier principle (DiSC), which is represented in Fig. 1.



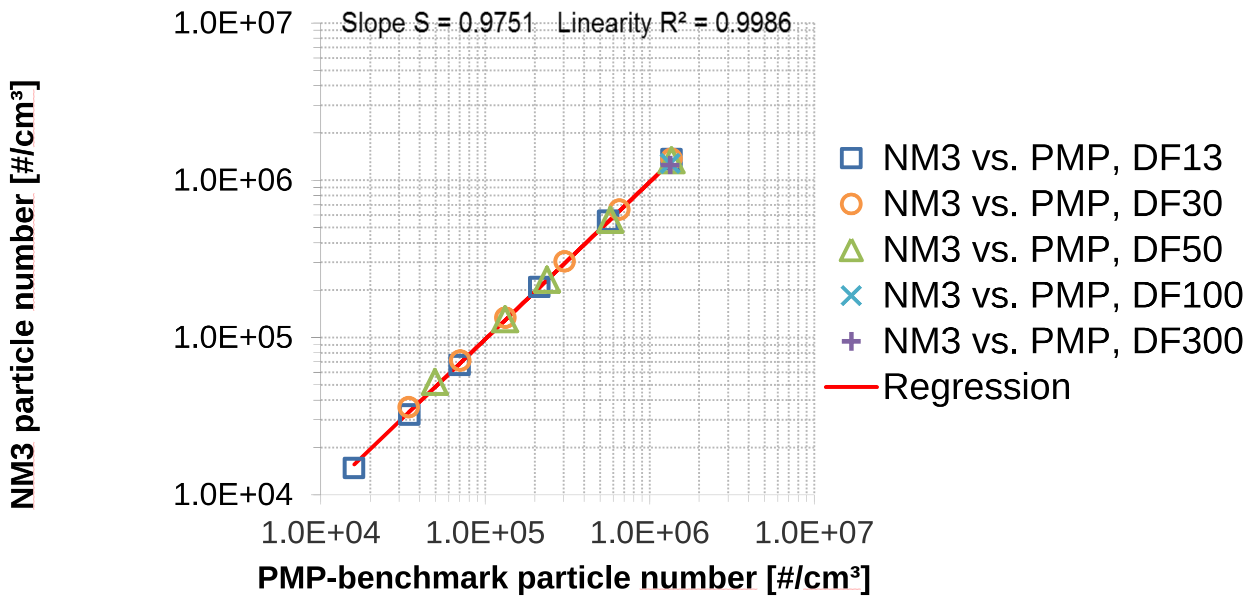
[Source: Testo]

Fig. 1: Setup of the particle sensor DiSC

Operating principle of DiSC:

- Particles are labeled with positive charges in a unipolar charger, so that they can later be detected by the current they induce
- Particles are deposited by diffusion in a "diffusion stage" and detected as an electrical current $D = I_{diff}$; Diffusion stage penetration is size-selective
- Remaining particles end up in a filter stage and also produce an electrical current $F = I_{filt}$
- DiSC Sensor measures both currents D and F simultaneously, with 1s time resolution
- Measured ratio $D/F = I_{diff} / I_{filt}$ → particle diameter
- Charge per particle is a function of particle diameter → once the particle diameter is known, DiSC computes the particle number from the total current $I_{diff} + I_{filt}$ and the flow rate
- Diffusion charger DC signal correlates well with lung-deposited (alveolar or tracheobronchial) surface area

The correlation of readings with a PMP-benchmark is very good. Example of a correlation at geometric mean diameter (70nm) is given in Fig. 2.



[Source: Testo, PMP]

Fig. 2: Correlation NanoMet 3 vs. PMP (GDM 70 nm; CAST soot generator)

Test Procedures

Driving cycles on chassis dynamometer

The vehicles were tested on a chassis dynamometer in the dynamic driving cycles. Mostly performed were: NEDC, Fig. 3 and WLTC, Fig. 4.
The first NEDC of each test series was performed with cold start (20-25°C) and further cycles followed with warm engine. Between the cycle always 3 minutes of constant speed 80 km/h in 4th gear were performed as conditioning.

In certain cases the real driving cycles were stored and reproduced on the chassis dynamometer. They were designated as RDE-CD (CD…chassis dynamometer).

The braking resistances were set according to legal prescriptions, they were not increased i.e. responded to the horizontal road.

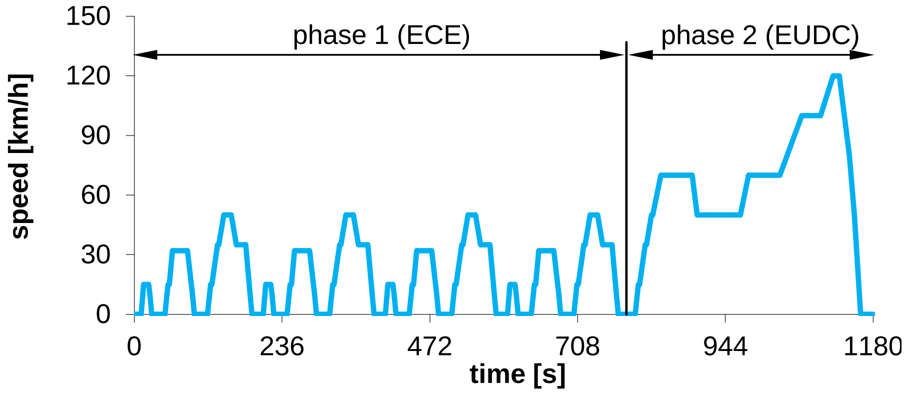


Fig. 3: NEDC European driving cycle

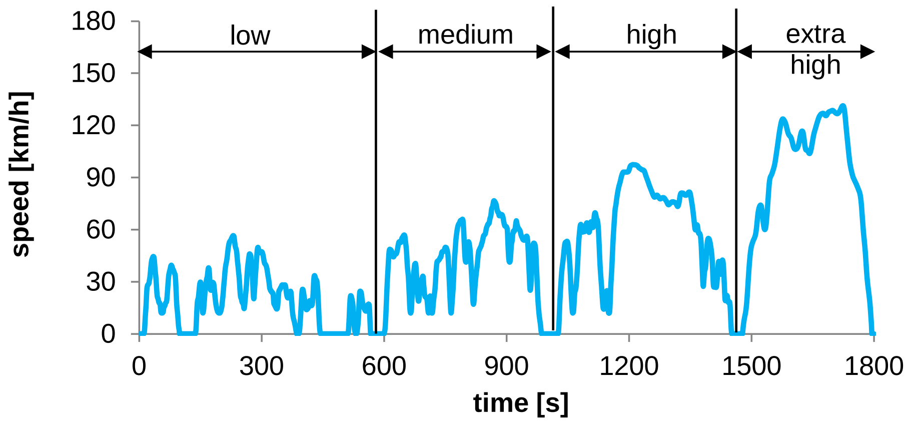


Fig. 4: WLTC driving cycle

On road testing

In order to reach the validity according to the actual requirements several road tests were performed. Finally the used valid road circuit was always the same with approximately 1.5h duration and parts of urban, rural and highway roads. Fig. 5 represents an example of a road trip from the PN PEMS test program.

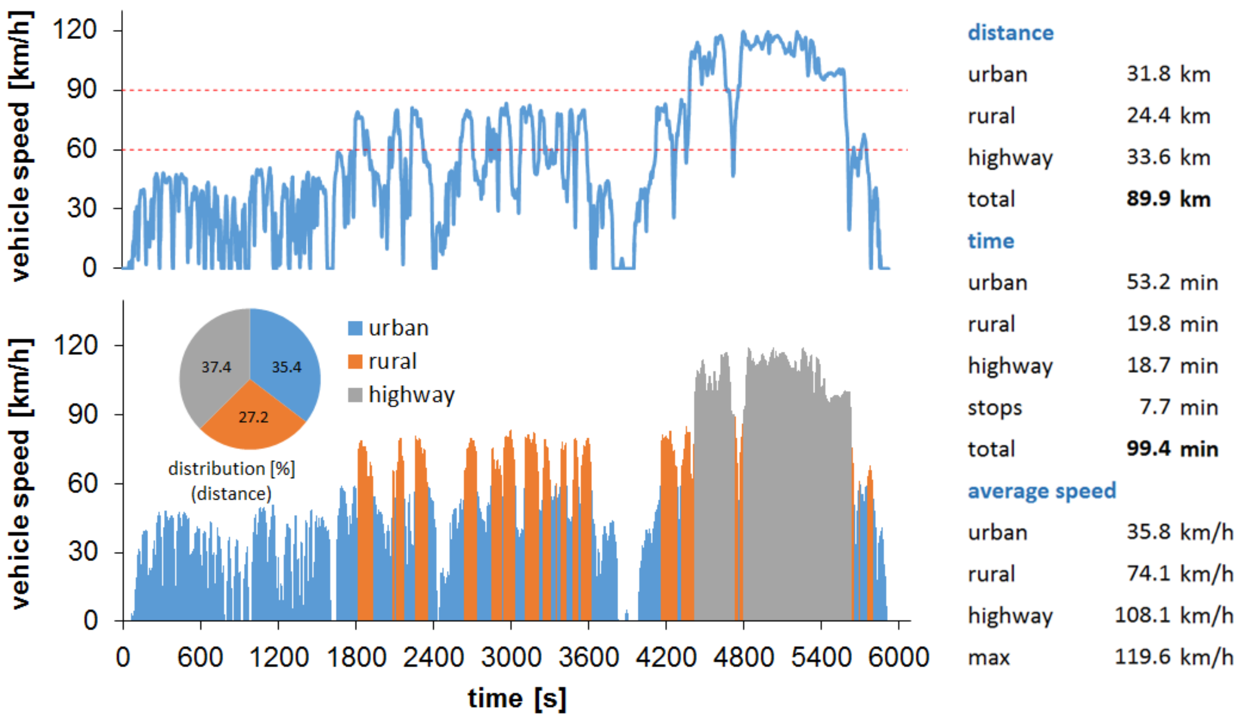


Fig. 5: AFHB, road trip for RDE; vehicle 1, PEMS 4 & PN PEMS

Results with Gasoline Cars (DI)

The data of the tested GDI vehicles are represented in the Table 2. All of them are of modern engine technology, emission level Euro 5 and first registration year between 2012 and 2015.

Vehicle	Vehicle 1	Vehicle 2	Vehicle 3
Number and arrangement of cylinder	4 in line	4 / in line	4 / in line
Displacement cm^3	1197	1596	1395
Power kW	63 @ 4800rpm	132 @ 5700 rpm	103 @ 4500 - 6000 rpm
Torque Nm	160 @ 1500-3500rpm	240 @ 1600 rpm	250 @ 1500 - 3500 rpm
Injection type	gasoline DI	gasoline DI	gasoline DI
Curb weight kg	1129	1554	1275
Gross vehicle weight kg	1229	2110	1840
Drive wheel	Front-wheel drive	Front-wheel drive	Front-wheel drive
Gearbox	m5	a6	m6
First registration	10.03.2015	27.01.2012	21.01.2014
Exhaust	Euro 5 / TWC	EURO 5a / TWC	EURO 5b / TWC

Table 2: Data of tested gasoline (GDI) vehicles

PN PEMS

Including the particle number (PN) measuring device in the portable emission measuring systems (PEMS) is an important objective of the EU legislation. The Swiss developments at ETHZ, FHNW & Matter Aerosol, which were supported by the Swiss Federal Office of Environment (BAFU) gave a strong contribution to the progress of portable PN-measurements.
2015/2016 inter-laboratory comparison test series (ILCE … Inter-Laboratory-Comparison-Exercise) with PN-PEMS were organized and performed by the VELA (Vehicle Emissions Laboratory) of the EC-JRC, Ispra. For the tests a “golden vehicle” with a “golden PN-analyzer” (TESTO NanoMet3) have been circulated among different laboratories.

The comparison test series were also performed in Switzerland in the frame of collaboration between EC-JRC and BAFU.

A modern GDI car (vehicle 1) equipped with PEMS Semtech LDV (PEMS 4), both “golden” systems (Gas & PN) from the ILCE, were tested in standard test cycles (NEDC and WLTC) on the chassis dynamometer and on-road (RDE).
For the real-world testing a road circuit was fixed: approximately 1.5h driving time with urban/rural and highway sections. This circuit fulfils the actual RDE-requirements.
Portable system for measurements of nanoparticles (TESTO NanoMet3) was included in the tests and the results were compared with CPC (PMP) on the chassis dynamometer.

Fig. 6 compares the emission results obtained on chassis dynamometer and in the road circuit with PEMS.

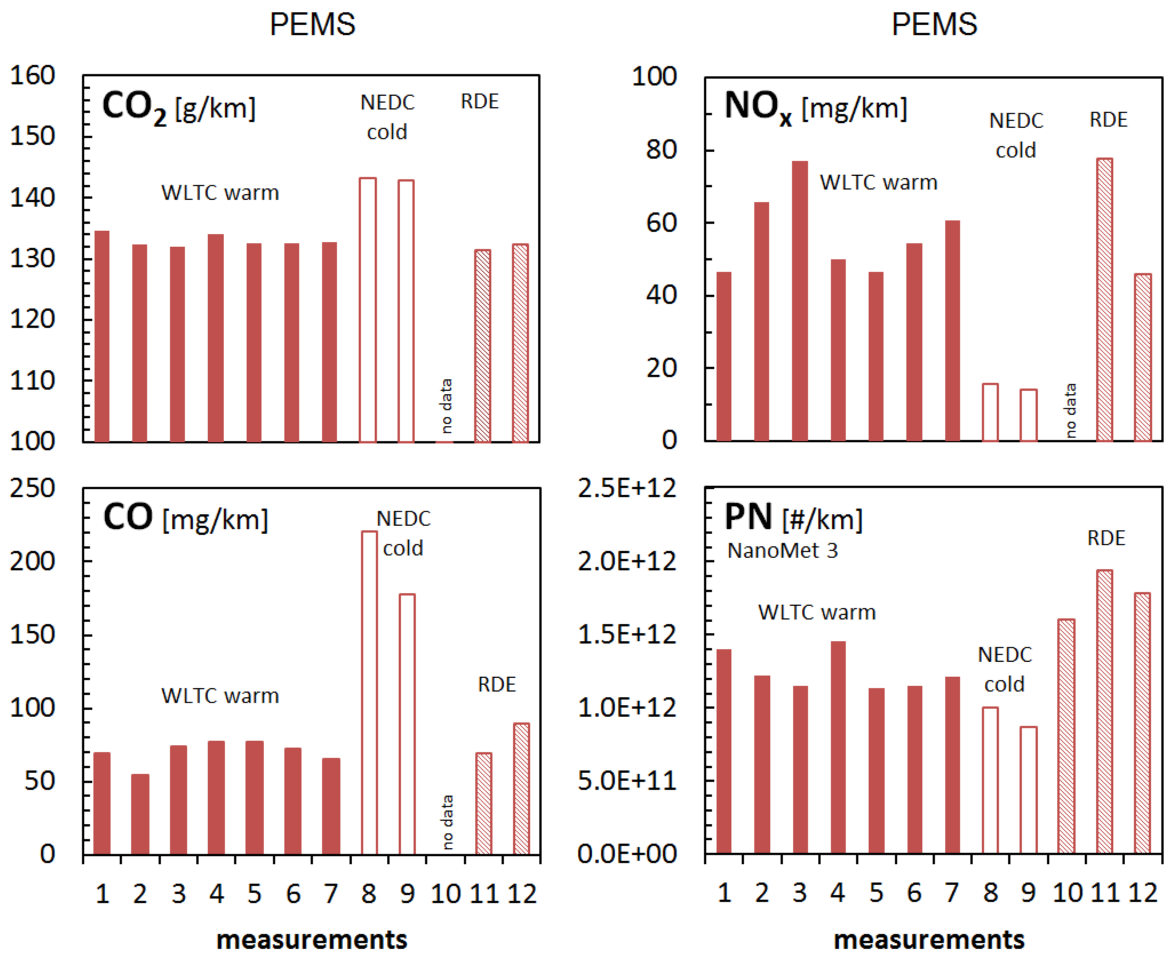


Fig. 6: Comparison of emissions in WLTC- NEDC on chassis dynamometer and RDE on road measurements, vehicle 1, PEMS 4

The average emission values, which are found with PEMS in on-road (warm) operation (RDE) are well responding to the average values in WLTC warm (measured with PEMS), which confirms that WLTC represents well the real driving behaviour.

The emissions measured with PEMS in repeated road driving circuit are generally well repetitive. Exceptions can happen due to extreme driving behaviour, special traffic situations or activities of vehicle electronic control (here especially NO_x).

Fig. 7 shows the comparisons of results obtained in WLTC warm in the present tests with the min/max/average values obtained during the JRC-ILCE.
Regarding the results from stationary installation (CVS) – CO_2 (not represented here) and PN on the lowest side of the ILCE-dispersion range – it can be supposed that the driving resistances of the chassis dyno were too low.
Regarding the PEMS-results; nevertheless, this supposition does not seem to be right.
The average values of NOx and PN measured with PEMS in WLTC warm correlate very well with the average PEMS-values from ILCE.

Analysis of data from two RDE trips was performed by means of the JRC EMROAD program using the verification method of trip dynamics with moving averaging windows (MAW), [1,3].

Some explanations from [1] are:

The Moving Averaging Window method provides an insight on the real-driving emissions (RDE) occurring during the test at a given scale of speed. The test is divided in sub-sections (windows) and the subsequent statistical treatment aims at identifying which windows are suitable to assess the vehicle RDE performance.

The “normality” of the windows is concluded by comparing their CO_2 distance-specific emissions with a reference curve. The test is complete when the test includes a sufficient number of normal windows, covering different speed areas (urban, rural, motorway).

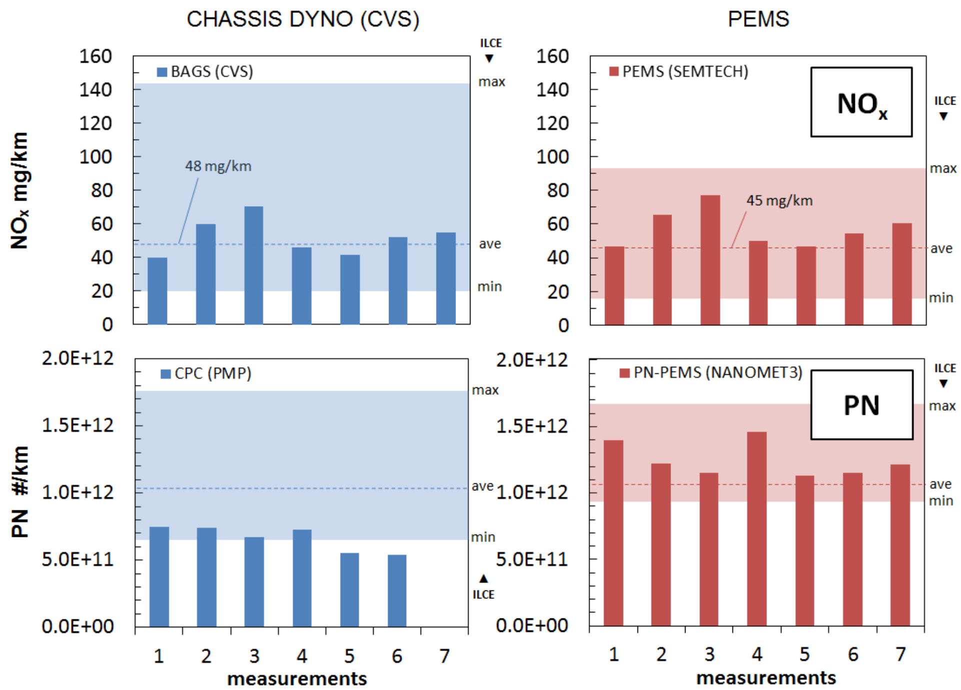


Fig. 7: Comparison of Emissions in WLTC warm Chassis Dynamometer, vehicle 1, PEMS 4

During the evaluation the following steps are performed:

Step 1 Segmentation of the data and exclusion of cold start emissions
Step 2 Calculation of emissions by sub-sets or “windows”
Step 3 Identification of normal windows
Step 4 Verification of test completeness and normality
Step 5 Calculation of emissions using the normal windows.

The following data are not considered for the calculation of the CO_2 mass, the emissions and the distance of the averaging windows:

- the periodic verification of the instruments and/or after the zero drift verifications
- the cold start emissions
- vehicle ground speed < 1 km/h
- any section of the test during which the combustion engine is switched off.

The reference dynamic conditions of the test vehicle are set out from the vehicle CO_2 emissions versus average speed measured at type approval and referred to as “vehicle CO_2 characteristic curve”.

In Fig. 8 such CO_2 characteristic curves are represented for one of the evaluated trips. The trip and its dynamic conditions are normal, since the characteristic curves are in the primary tolerance of +/- 25% (of the average WLTC-CO_2-values).

The emissions resulting from EMROAD-evaluation are generally considerably lower, than the values of integral averages (without any exclusion). The differences are caused mainly by excluding the cold start emissions from the EMROAD-evaluation, Fig. 9.

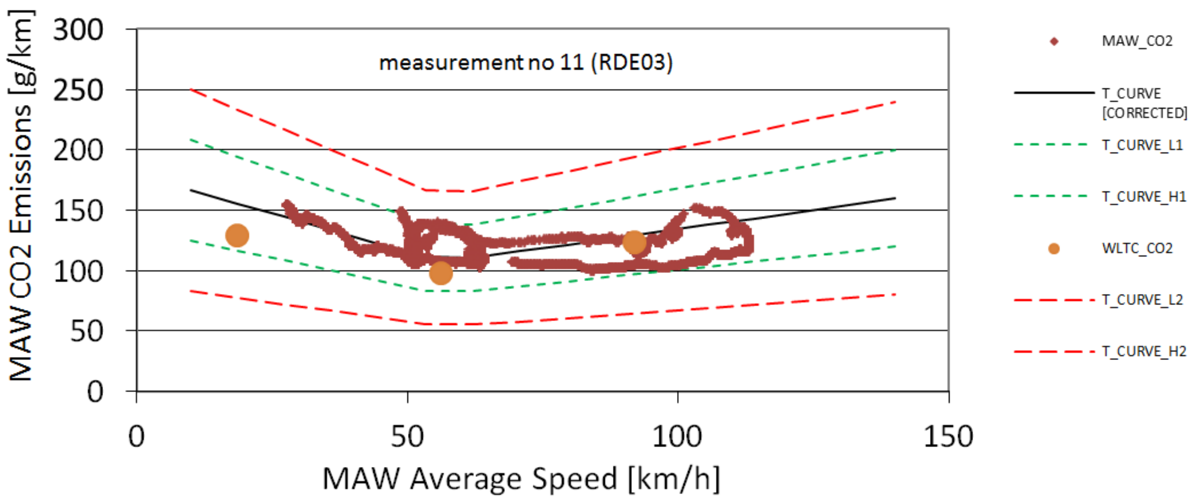


Fig. 8: JRC / EMROAD test, normality verification (CO_2 vs speed, MAW… moving average windows)

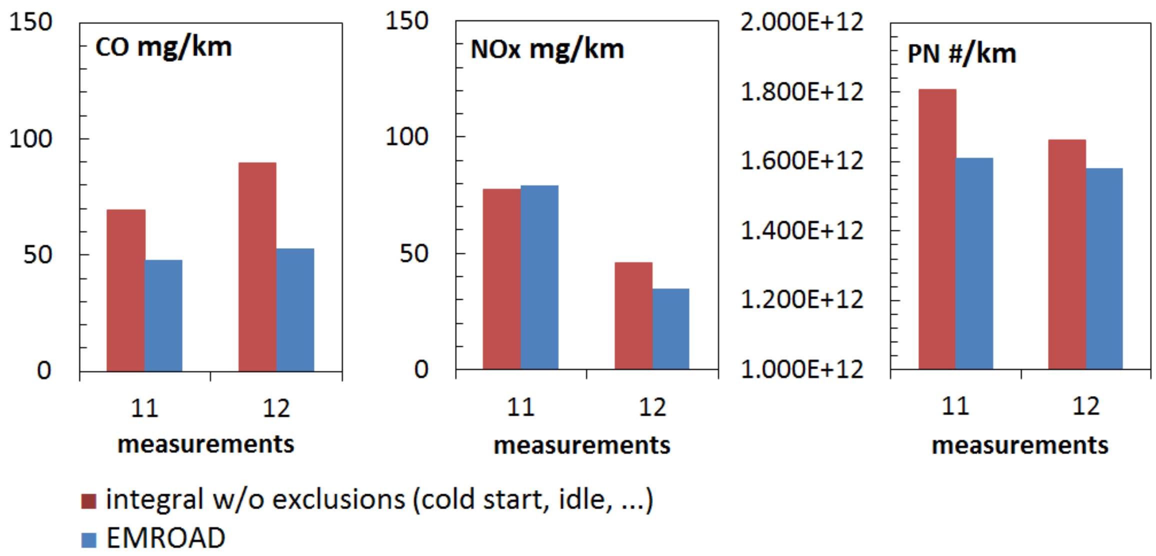


Fig. 9: Comparison of results in RDE EMROAD vs integral calculation (SEMTECH-DS & NanoMet 3)

Other findings

In a test program with vehicle 2 and PEMS 1 several previous findings were confirmed. Here three examples are given:

1. The DC-apparatus (NanoMet3, NM3) tends to indicate higher PN-values due to higher sensitivity in the lowest particle sizes than the CPC (according to PMP, with cut-off below 23 nm). Fig. 10 shows the examples of correlations NM3-CPC in WLTC, both systems measuring at tailpipe.
2. The average emission values in the road circuit are near to the average values in WLTC on chassis dynamometer (WLTC mixed with cold and with warm start), Fig. 11.
3. A CO-peak occurs at the beginning of the highway parts; this suddenly increasing CO-amount during highway attains different levels depending on acceleration and on the initial state of engine exhaust system; this peak influences massively the accumulated end result, [2]. Fig. 12 gives examples of two tests on the circuit.

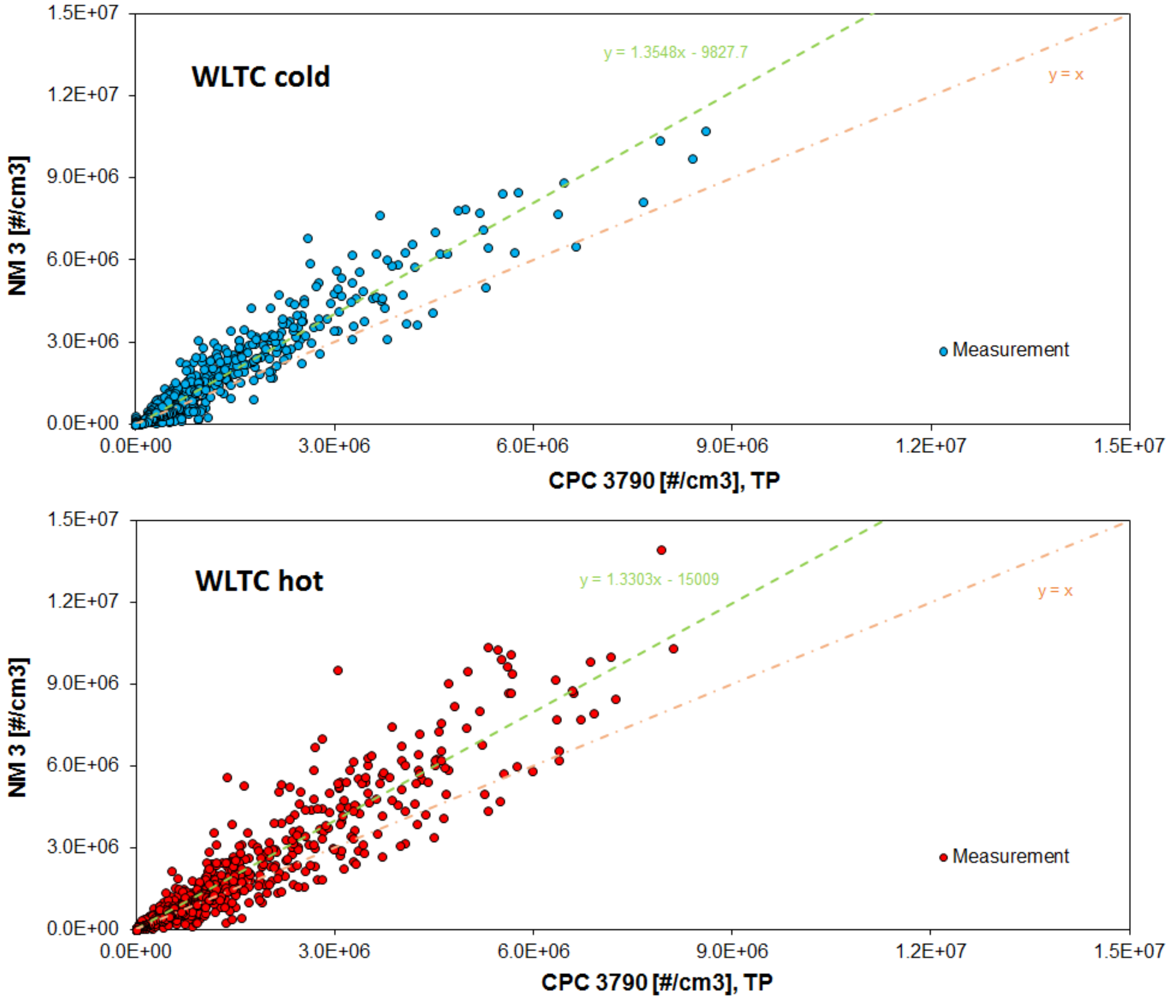


Fig. 10: Correlation of results CPC – NanoMet3 (PN-PEMS) in WLTC chassis dynamometer, vehicle 2

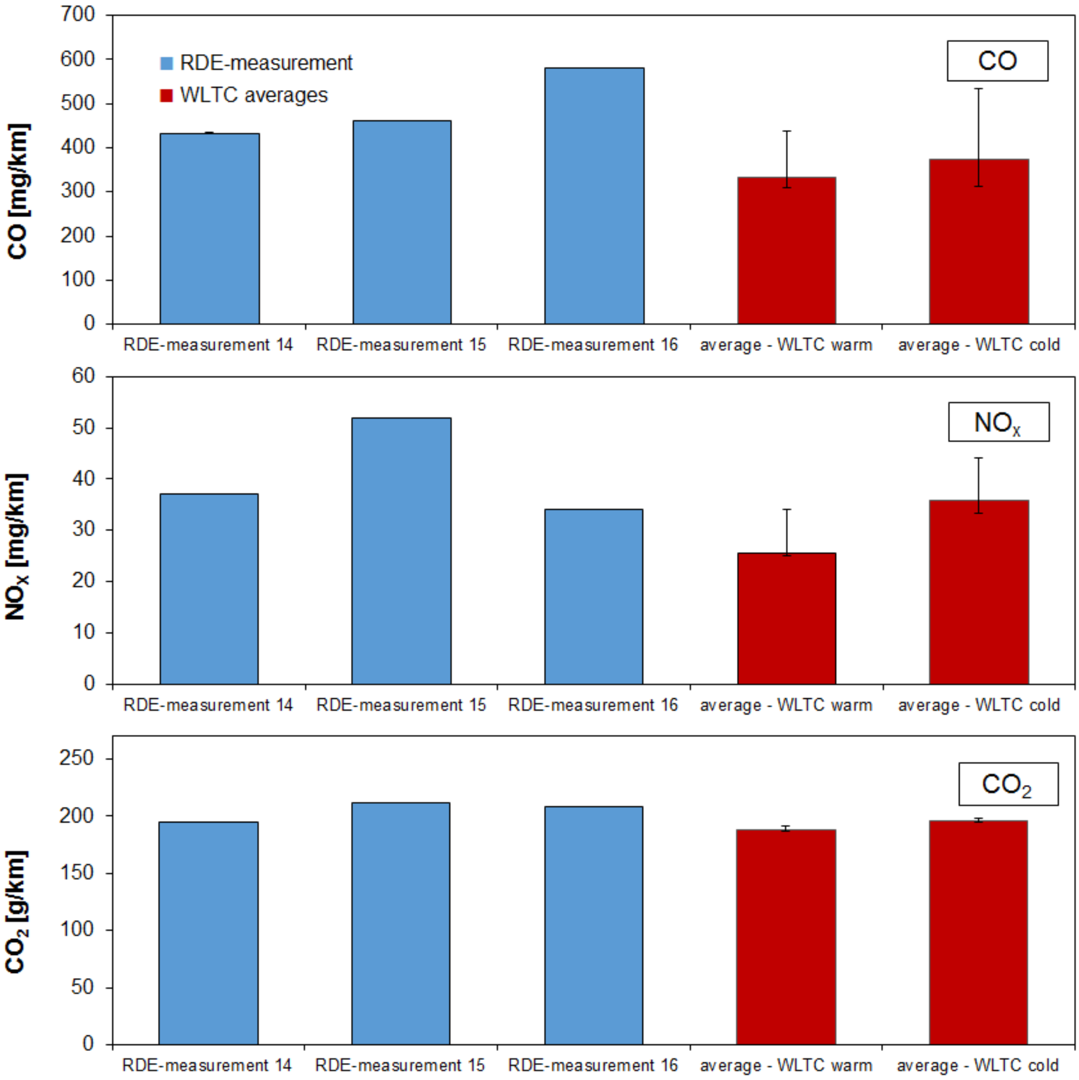


Fig. 11: Comparison of results PEMS-RDE with average values in WLTC chassis dynamometer, 5 WLTC hot, 3 WLTC cold, vehicle 2 PEMS 1

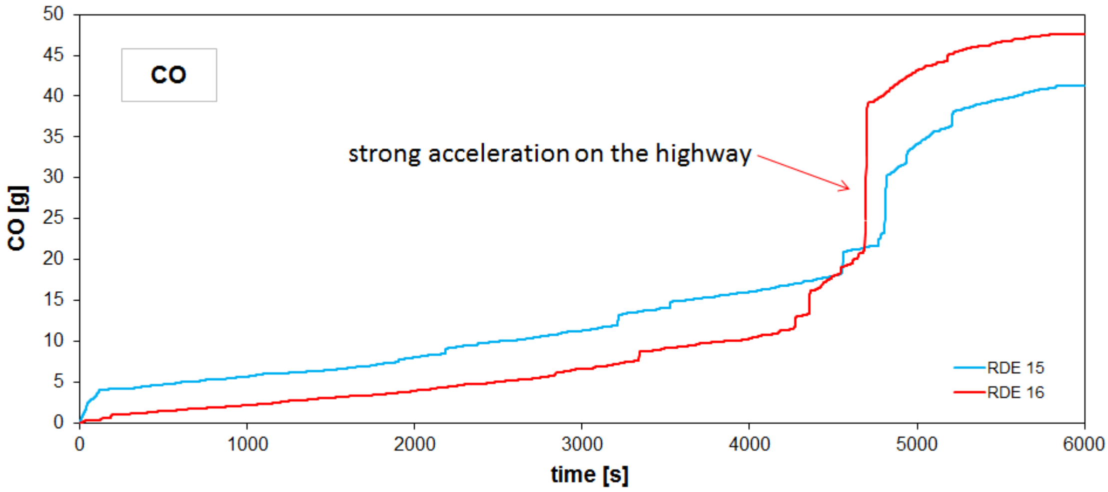
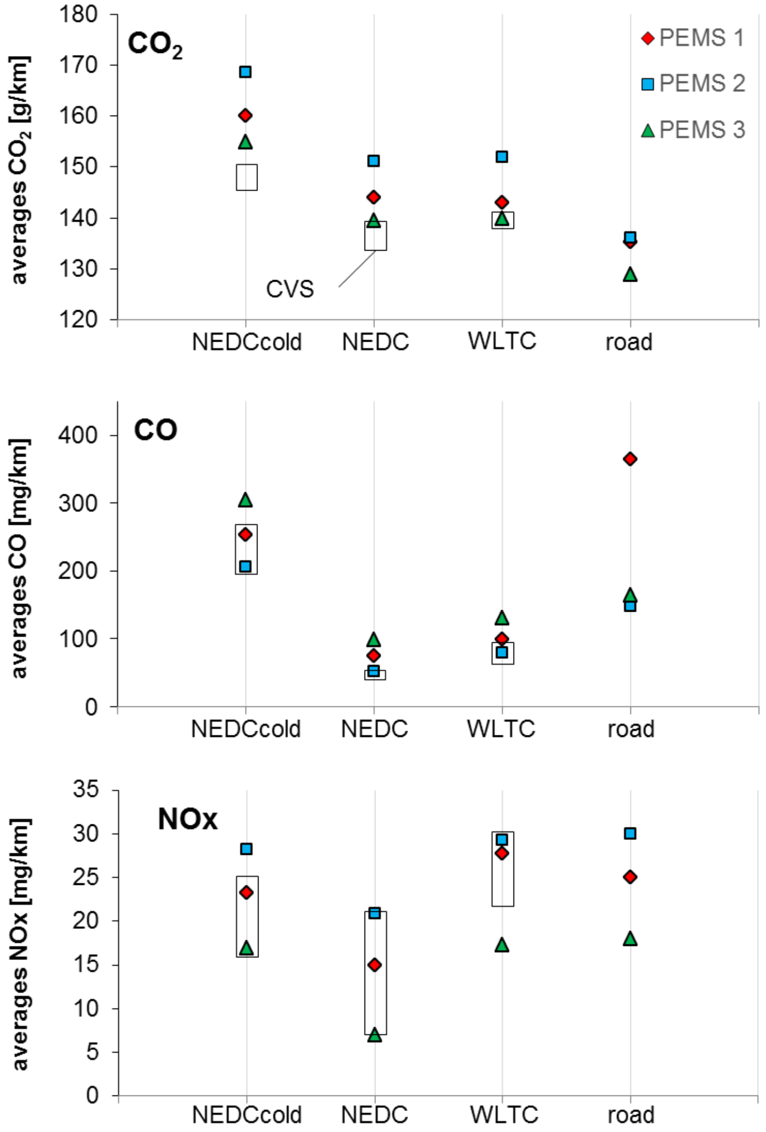


Fig. 12: Influence of driver on CO-Emissions on-road RDE, vehicle 2 PEMS 1

<u>Comparisons of Gas PEMS</u>

In another test program the results with PEMS 1, 2 & 3 on vehicle 3 were compared in vehicle operation on the chassis dynamometer and on-road. <u>Fig. 13</u> summarizes the results of CO_2, CO and NO_x. It can be remarked, that PEMS indicate most frequently higher values of CO_2, CO than the stationary measuring system (CVS).

There is a strong dispersion of CO & NO_x in the road trips. This is especially caused by the quite dynamic driving in the first part (urban) of road tests.
It can be said for CO and NO_x that the WLTC depicts the best the average road driving in this circuit. CO_2-emissions measured on road are lower, than on chassis dynamometer.



<u>Fig. 13</u>: Comparisons of average values between road trips and cycles on chassis dynamometer. PEMS 1, 2, 3; vehicle 3

A general comparison of average results: CVS versus all three PEMS's is represented in Fig. 14 for $NEDC_{cold}$ only and for all performed driving cycles. The general higher readings with PEMS's are confirmed. CO and NO_x have very low concentrations, so they have generally higher standard deviations, than CO_2.
Each of the tested systems has some little and some big deviations. This conducts us to the statement that in the average view there is no best or worst system. All of them represent a similar balance of advantages and disadvantages and their measuring quality can be regarded as similar. There still are, of course, big potentials for improvements.

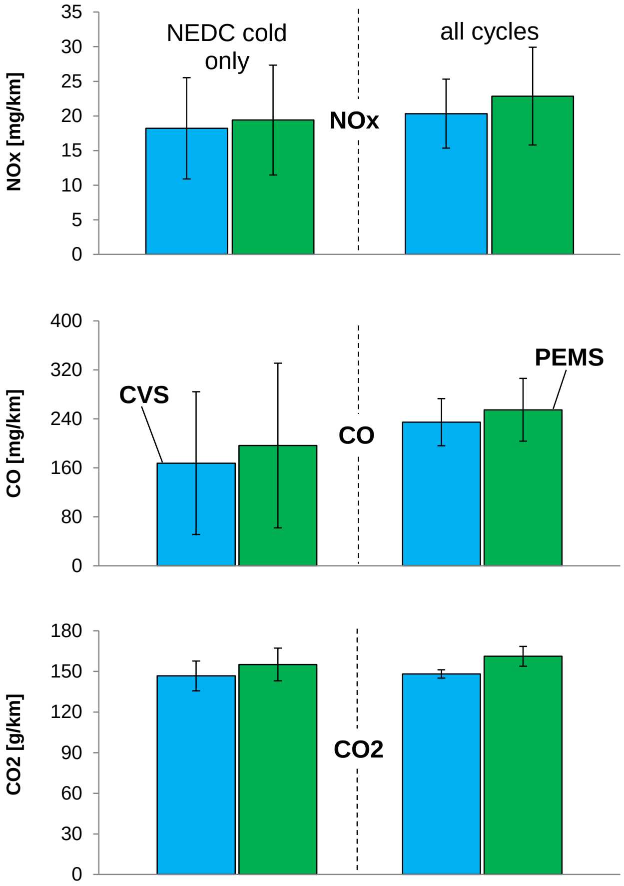


Fig. 14: Comparisons of average results: CVS versus RDE three PEMS's.

What can be the reasons of general higher readings with PEMS ?
The mass flow ($\dot{m}_x$) of an emissions component "x" is calculated as:

$$\dot{m}_x = \dot{V}_{exh} \cdot k_x \cdot \varrho_x$$

$$\left[\frac{kg_x}{s} = \frac{m^3{}_{exh}}{s} \cdot \frac{m^3{}_x}{m^3{}_{exh}} \cdot \frac{kg_x}{m^3{}_x}\right]$$

where:

$\dot{V}_{exh}$ … volumetric flow of exhaust gas

k_x … volumetric concentration of component "x" in the exhaust gas

ϱ_x ... density of the component "x"

For dynamic measurements with PEMS in the real-world transient operation there is a challenge to well synchronize the signals of all three parameters, which are continuously changing with the operating conditions. (The instantaneous density varies with the pressure and temperature of exhaust gas).

All PEMS try to perform this synchronization as to the best, but the authors presume that this is the major reason for the indicated differences. Of course the measuring accuracy of the parameters also contributes to the results. In measurements of concentrations there are for the different PEMS's different: measuring principles, wet-dry-corrections and linearization.

In order to exclude the influence of volumetric flow (V_{exh}) and density (ϱ_x) the concentrations of CO_2 were correlated: integral averages measured with PEMS against the bag-concentrations (diluted) recalculated to the non-diluted concentrations at tailpipe. This is represented at the bottom of Fig. 15 as CO_2 in [%].

The comparison of concentrations indicates much better correlations.

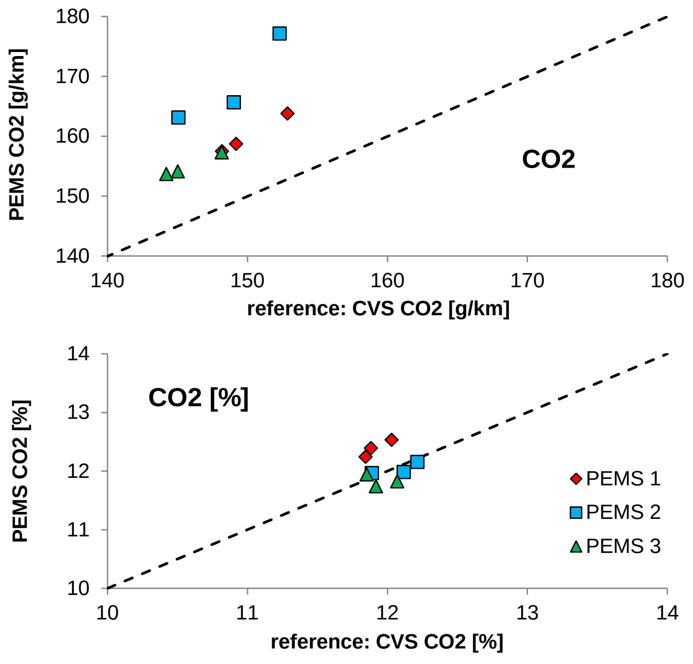


Fig. 15: Correlations of CO_2-emissions measured with PEMS and with stationary CVS-installation in NEDC cold.

Findings with Diesel cars

The most important data of the investigated Diesel cars are given in the Table 3.

	Vehicle 4	Vehicle 5	Vehicle 6
Engine	R4	R4	R4
Displacement cc	1560	2143	1994
Gear box	m6	a5	m5
First registration	2015	2010	1998
Exhaust	Euro 6b	Euro 5a	Euro 2
Aftertreatement	DPF	DPF	-

Table 3: Data of tested Diesel vehicles

Similarly to the gasoline cars the vehicles were driven in different transient cycles on the chassis dynamometer and on-road. As portable system PEMS 2 was applied. In following three examples of results are mentioned:

1. The emissions obtained with vehicle 5 in different driving cycles on the chassis dynamometer (CD) and on-road (RDE) with PEMS and with CVS are represented in Fig. 16.
   It is confirmed that in the "cold" NEDC there are higher CO-, CO_2- and PN-values and lower NO_x-values, than in a "warm" NEDC. In the same cycles performed on the chassis dynamometer PEMS indicates generally higher readings, than the stationary installation with bags (CVS).

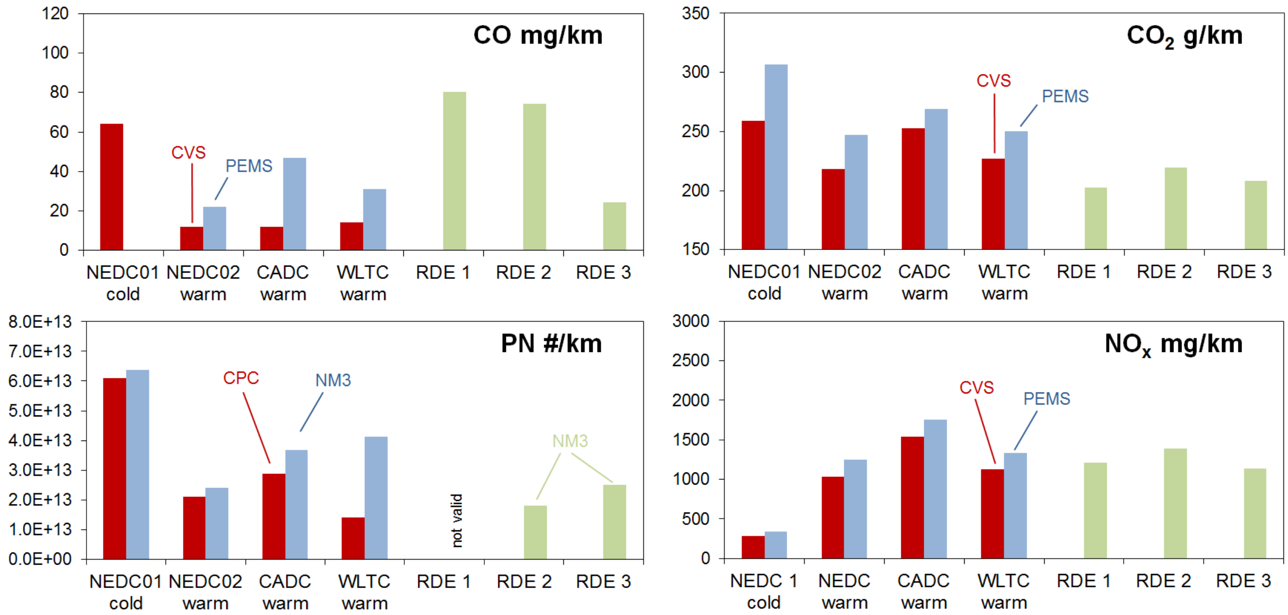


Fig. 16: Emission results of a Diesel vehicle 5 on chassis dynamometer and in road measurements (87 km)

The emissions resulting with PEMS in three repeated road circuits are (with one exception for CO and for PN) quite well repetitive. The differences of CO or PN in certain RDE-cycles are caused by different traffic and driving situations.
The average value of NO_x in warm transient operation on chassis dynamometer responds well to the average NO_x in real world driving.

2. Fig. 17 illustrates how a DPF-regeneration, which is initiated by the OBD-system of a modern Diesel passenger car, can be indicated by means of exhaust temperature and CO-emissions.
The driving cycles of RDE were stored and fed into the driving conductor system of the chassis dynamometer and finally performed on the chassis dynamometer with simultaneous measurements with PEMS ② and with the stationary system (CVS). This is designated in this figure as RDE-CD (real driving emissions – chassis dynamometer).

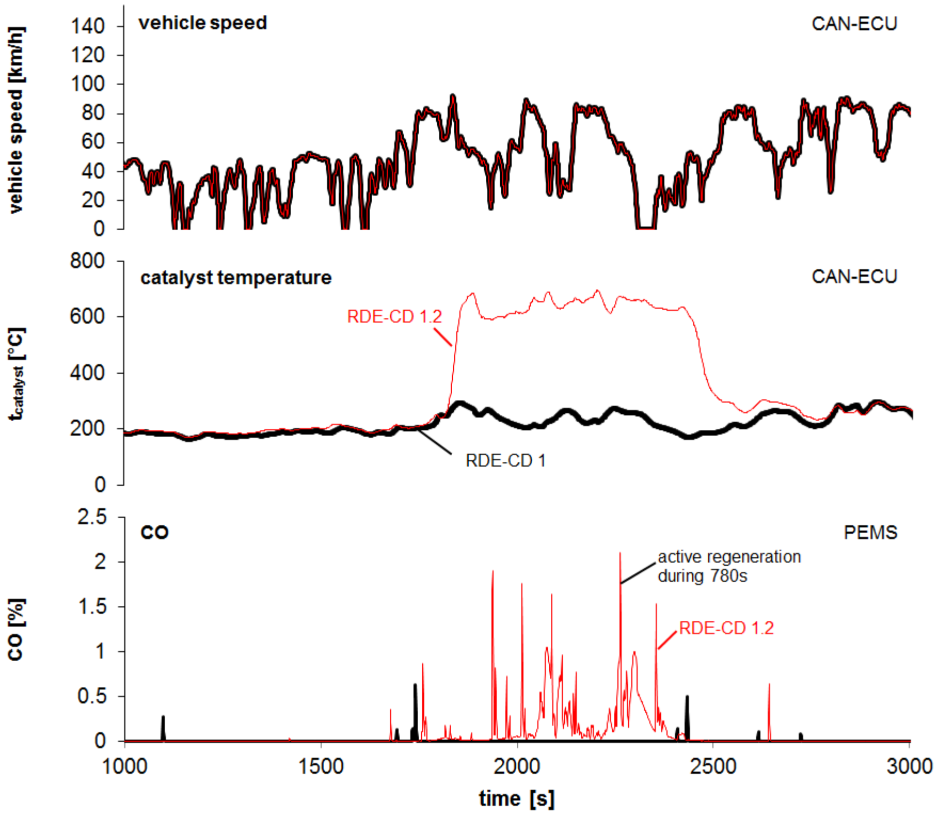


Fig. 17: Comparison of RDE-CD with and without DPF regeneration chassis dynamometer, vehicle 4, PEMS 2

3. Fig. 18 shows in WLTC another example of DPF efficiency: vehicle 4 with a high quality DPF represents the average particle counts reduction rate (PCRR) relatively to the highest emitting vehicle 6 of 99.998 %. The damaged DPF of vehicle 5 is visible with PCRR = 48.786 %.
The PN-values of vehicle 4 with DPF are very low (approximately 30 to 120 times lower than the actual limit value of 6.0 x 10^{11} #/km), they are at or up to 10 times below the PN background level. This impressively demonstrates the high efficiency of the DPF-technology in eliminating the nanoparticles.

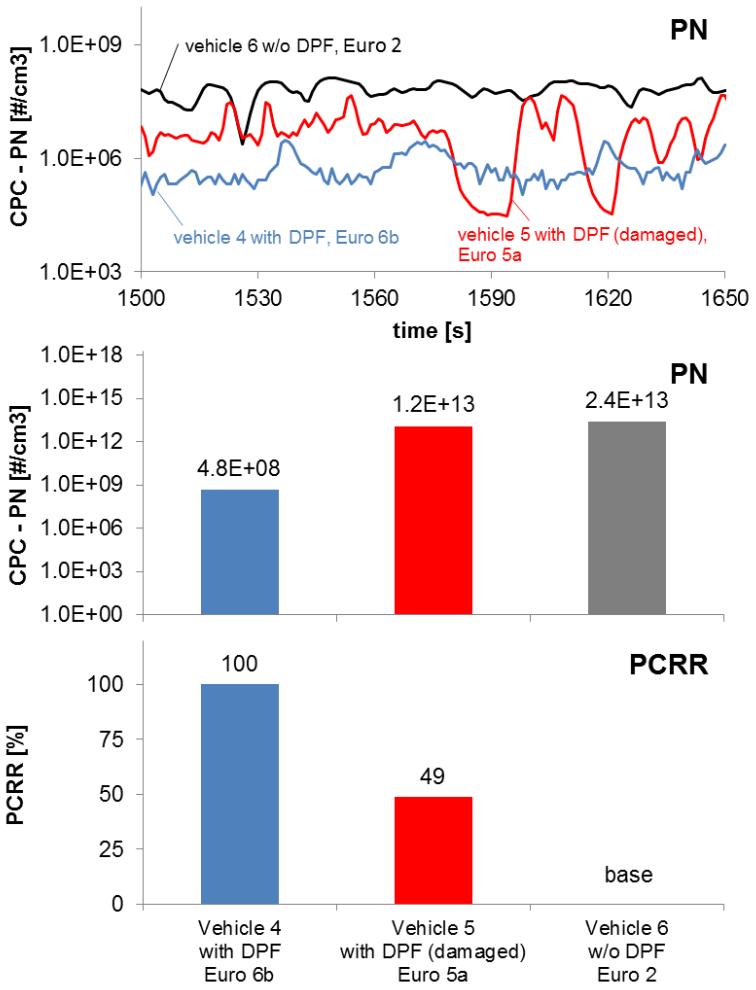


Fig. 18: Effects of DPF on Diesel passenger cars in WLTC (hot) – success of DPF technology

Conclusions

Following conclusions can be mentioned:

- PN PEMS (TESTO NanoMet3) indicates higher peak values during cold start, or dynamic events and it depicts more sensitive the variations of speed of the driving cycle, than CPC (PMP),
- PN PEMS average values at transient operation were higher, than the average values measured with CPC,
- in NEDC with cold start there are higher CO-, CO_2- and PN-emissions than with warm start,
- the emissions CO, CO_2, NO_x measured with PEMS are generally higher than the same emissions simultaneously measured in the same driving cycle on the chassis dynamometer with the stationary measuring system (CVS),
- emissions measured with PEMS in repeated road driving circuit are generally well repetitive; exceptions can happen due to traffic situations, extreme driving behaviour or due to special activity of the vehicle electronic control,
- the average values of NO_x and PN measured with PEMS in WLTC warm (chassis dynamometer) correlate very well with the average PEMS-values from ILCE (on road),

- the evaluation EMROAD with the moving averaging windows method showed that:
  - the trips were normal from the point of view of CO_2 vs. speed,
  - the driving circuit is valid,
  - the emission results from EMROAD are lower than the results of integration due to neglecting the cold start, near to zero speeds and engine stop periods,
- the PN-measuring device – TESTO NanoMet3 – is confirmed as a useful device for PEMS-application, it impressively demonstrated the efficiency of the DPF-technology in eliminating the nanoparticles,
- comparisons of different Gas PEMS's with a stationary measuring system (CVS) on a chassis dynamometer show similar behavior for all investigated instruments – different dispersion of results, depending on the considered parameter and driving cycle,
- all PEMS's indicated more CO_2 than the "CVS". The principal reason is most probably the insufficient synchronization of the transient parameters: exhaust gas mass flow, concentration and density of the measured components; further clarifications are necessary,
- from the road testing, it can be stated:
  - CO_2 emissions on-road are mostly repetitive,
  - there is a lot of dispersion in the measured NO_x; differences happen mainly during the first 10 km in the urban part,
  - a CO peak occurs at the beginning of the highway part; this peak influences massively the accumulated end result,
  - the results from the OBM system (TU-Wien), which has no EFM (Exhaust mass Flow Meter), are well correlating with the results of other measuring systems,
- there are quite numerous requirements for a trip validation of the RDE-procedures. The road traffic influences some of the validation parameters. It is recommended to select a "flexible" road circuit, which can be adapted to the actual traffic situation.

Summarizing: the PEMS and RDE testing is a new challenging task for the test laboratories.

Acknowledgement

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Abbreviations

AFHB	Abgasprüfstelle FH Biel, CH
ASTRA	Amt für Strassen (CH)
BAFU	Bundesamt für Umwelt, (Swiss EPA)
BC	board computer
CADC	Common Artemis Driving Cycle
CAST	Combustion Aerosol Standard
CD	chassis dynamometer
CLA	chemiluminescent analyzer
CLD	chemiluminescent detector
CPC	condensation particle counter
CVS	constant volume sampling
DAQ	data acquisition
DC	diffusion charging
DF	dilution factor
DI	Direct Injection
DiSC	diffusion charge size classifier
EC	European Commission
ECE	Economic Commission Europe
ECU	electronic control unit
EFM	exhaust flow meter
EMPA	Eidgenössische Material Prüf- und Forschungsanstalt
ETC	European Transient Cycle
EUDC	Extra Urban Driving Cycle
ϱ_x	density of the component "x"
GDI	gasoline direct injection
GMD	geometric mean diameter
HC	unburned hydrocarbons
ILCE	Inter- Laboratory-Comparison-Exercise
JRC	Joint Research Centre (EC)
k_x	volumetric concentration of component "x" in the exhaust gas
LFE	laminar flow element
MAW	moving averaging windows
MFS	mass flow sensor
$\dot{m}_x$	mass flow of emission component "x"
NEDC	New European Driving Cycle (ECE+EUDC)
NM3	NanoMet3
NO	nitrogen monoxide
NO_2	nitrogen dioxide
N_2O	nitrous oxide
NO_x	nitric oxides

OBD	on-board diagnostics
PCRR	Particulate Counts Reduction Rate
PEMS	portable emission measuring systems
PMP	EC Particle Measuring Program
PN	particle number
PN-PEMS	PEMS with PN measuring device
RDE	real driving emissions
TP	tailpipe
TWC	three way catalyst
$\dot{V}_{exh}$	volumetric flow of exhaust gas
ViPR	nanoparticle sample preparation with volatile particles remover
WLTC	worldwide harmonized light duty test cycle
WLTP	worldwide harmonized light duty test procedure
3WC	three way catalyst