8.VERT-Forum – 17.March 2017, EMPA-Academy Dübendorf

NPTI

New Periodic Emission Inspection

International VERT-Project

High Priority and Urgency

A.Mayer

We have reached
Orders of Magnitude of Emission Reduction for Public Health
by Emission Control Technology

but we risk to lose Emission Stability due to serious flaws in legislation and manipulation of soft-and hardware

→ only one solution: NPTI

Modern Diesel Drivetrains are Different

Classic Diesel Engines until Euro 5/V generate and control emissions by combustion. Trade-off NOx/PM and/or NOx/Be was needed to reach the limits. Emission deterioration by aging, wear was very limited (20-50%); the **Diesel was known to be very stable** with respect to emission and fuel consumption

For new Diesel Engine Systems **Combustion and Emission Control are decoupled.** The engine is optimized for power and economy; Emission reduction takes place by catalytic emission control DPF, DOC, SCR etc.

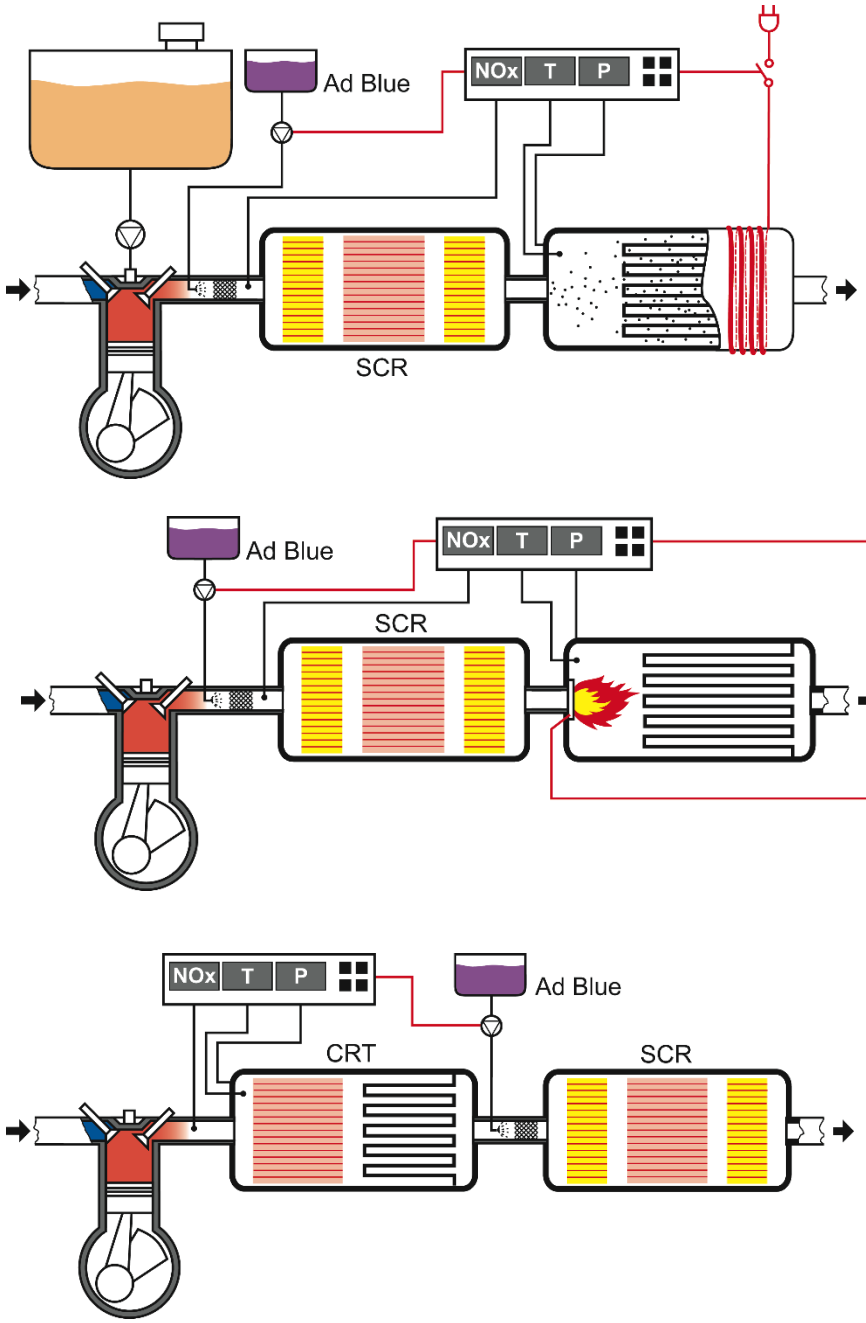
Emission Control by DPF, DOC, SCR **reduce raw emission by 2-3 orders of magnitude and we have now 100 millions vehicles on the road**. But these systems are more sensitive to aging, poisoning, manipulation, failures → **can increase emission 100-fold and more**.

Raw Emission is increased in favour of power and fuel economy relying on emission control capabilities.
Should raw emission also be controlled?

Emission Control by aftertreatment is indispensable

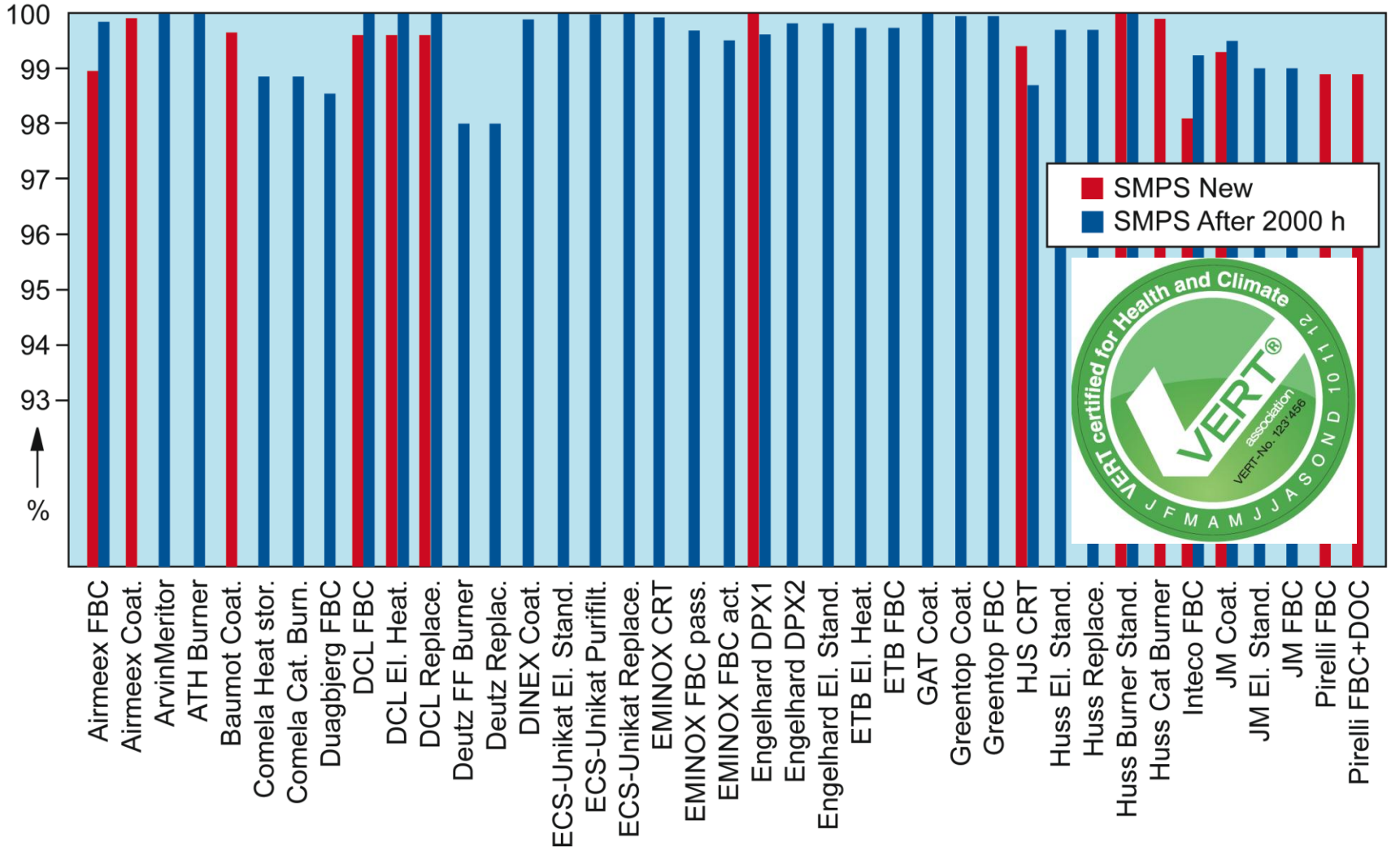
- very efficient > 99%
- but no plug and play
- depend on operation profile
- risk of wear, aging and poisoning, pollution
- risk of tampering and manipulation
- potential of intentional deterioration by defeat div.

→ Control is required



Filtration - 74 DPF VERT tested

25 % > 99.8 % within size range 20-300 nm



Risks of DPF Application

- Filters can store and release toxic solid substances
- Particles can penetrate in lung critical size range
- Filtration can break down during regeneration
- Filters can generate toxic secondary emissions
- Filters can desorb and release toxic volatiles
- Manipulation and even de-Installation is observed

→ Legislation does not take care of this

→ Filter for vehicle engines must be certified to avoid these risks - a simple overall PN-limit is not enough

Potential of NOx-Reduction

- **SCR can reduce NOx by > 98%**
  (Genset HUG ETH 1996: 99.8 %) – **2 orders of magnitude –** at NH_3 slip limit – much more than combustion measures; whithout any negative effect on power or fuel economy - if exhaust temperature is above 230 °C

What can we do in addition below 230°C ?

- Thermomanagement
- EGR with cleaned gas
- Water mixed into intake air
- TC-cooling to very low temperatures
- Engine tuning to low Nox
- Cool combustion

Risks of DeNOx by SCR

Engine manufacturers use this high DeNOx capability and tune the engine to much higher raw NOx-Emissions
→ NOx increase: 2-3 times,

→ Fuel consumption → reduction 6-8% with Euro VI

DeNOx-technology is easy to manipulate by electronic emission strategies and tampering

If the SCR fails by aging, poisoning, lack of Adblue etc. or by intentional tampering → NOx jumps up to raw emission levels higher than ever. And very strong formation of secondary toxics like NH_3, NO_2, N_2O can not be excluded.

→ **These systems require control on several levels – self control by manufacturers is not sufficient**

Potential of the Oxidation Catalyst DOC

- DOC converts gaseous HC, CO by 99%
- DOC also converts engine-out NO to NO_2
  - needed for the DPF regeneration and
  - needed for the fast SRC-reaction
  - NO_2-slip is very toxic
- DOC also converts SO2→ SO3 which a problem in most megacities in China, Asia and Latin America

Don‘t underestimate Risks of DOC

If the DOC gets aged, poisened, contaminated, dismantled, destroyed or the coating is at a lower limit for cost reasons

- HC and CO increase
- The DPF regeneration fails
- The SCR function fails – NOx goes sky-high

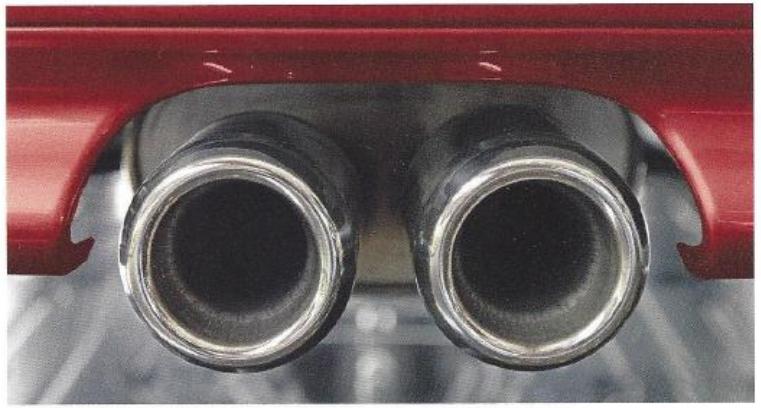
TNO-Reports 2015/2016 on effects and malfunctions of DeNOx and DPF G.Kadijk et al.

EMISSIONS OF NITROGEN OXIDES AND PARTICULATES OF DIESEL VEHICLES

DATE: 11 JUNE 2015
REPORT NUMBER: TNO 2015 R10838

TNO innovation for life

DIESEL PARTICULATE FILTERS FOR LIGHT-DUTY VEHICLES: OPERATION, MAINTENANCE, REPAIR, AND INSPECTION



DATE: 8 July 2016
REPORT NUMBER: TNO 2016 R10958

TNO innovation for life

Summary so far

- The Potential of Emission Control by Aftertreatment is a revolution, several orders of magnitude reduction of toxic air contaminant TAC – a must for public health
- But the introduction of this technology provides new technical challenges
- **and requires a different approach of legisation and control on all levels**

Basic Flaws or even Conceptional Mistakes of Legislation

Mistake 1

The legal and monetary value
of engine emissions is not defined

Mistake 2

Responsibility is not defined
Polluter pays principle not respected

Mistake 3

Different Metrics
for tailpipe and street canyon

Mistake 4

Independent Control by Autorities
is delegated to OBD

but we have
the Tools available

developed for
Emission Control of Retrofit
under Swiss BAFU-responibility

Field Control History

1994 Start VERT: DPF for tunneling
1996 Development of VERT-Field Control Instrument NanoMet
Double Sensor: Corona DC and UV-PAS by H.Chr.Siegmann et al
1999 NanoMet at Hannover Fair
2000 PMP starts with NanoMet = Golden Instrument M.Kasper
2000 METAS instrument guideline for gaseous substances in field
2002 Guideline DPF for construction sites in Switzerland «BauRLL»
PTI on site required, opacity by workshops – A.Stettler et al. BAFU
2004 Dilution and Heating for volatile particle elimination – M.Kasper
2007 PN for DPF-construction control - B.Gloor, AWEL
2012 METAS instrument guideline for PN-measurement – J.Schlatter
2014 TSI NPET presented at VERT-Forum
2015 Public fleet tests (400 vehicles) in Santiago with NPET- A.Reinoso
2015 BAFU regulation to replace opacity by PN – S.Krähenbühl
2016 VERT-NPTI proposal for DPF, DOC and SCR

2000 Swiss Ordinance for Field Control of gaseous emissions of Diesel engines

OFMET
EAM
UFMET

Eidgenössisches Amt für Messwesen
Office fédéral de métrologie
Ufficio federale di metrologia
Swiss Federal Office of Metrology

Richtlinie
über Abgasmessgeräte für Baumaschinen

vom 17. März 2000

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1 Gegenstand

1.1 Dieser Richtlinie unterliegen Abgasmessgeräte (Geräte), welche zur Kontrolle der Abgasemission von Baumaschinen gemäss Luftreinhalteverordnung vom 16. Dezember 1985 [1)], Anhang 2, Ziffer 88 dienen.

1.2 Die Richtlinie regelt die Anforderungen an die Bauart, das Vorgehen bei der Bauartprüfung, das Vorgehen bei den Kontrollen der im Betrieb befindlichen Geräte und die Zuständigkeiten.

1.3 Voraussetzungen für den Einsatz eines Geräts gemäss Ziffer 1.1 sind die Übereinstimmung mit der geprüften Bauart und die bestandenen Erst- und Nachkontrollen.

2012/14 New Swiss Ordinance for Field Control based on solid PN counting instruments

Ordinance of the FDJP
on Exhaust Gas Analysers
(VAMV)

Amendment of 22nd august 2012

The Federal Department of Justice and Police
hereby decrees:

I

B Measurement requirements

1 Measurement range

1.1 The measurement range for the nanoparticle number concentration is at least between 5 x 10^4 cm^{-3} and 5 x 10^6 cm^{-3}.

1.2 In case of measured values outside the measurement range, the measuring instrument must indicate whether the measured value lies below or above the measurement range. If no categorisation is possible, then no value should be displayed.

1.3 The particle number concentration of each measurement must be indicated at the ambient conditions.

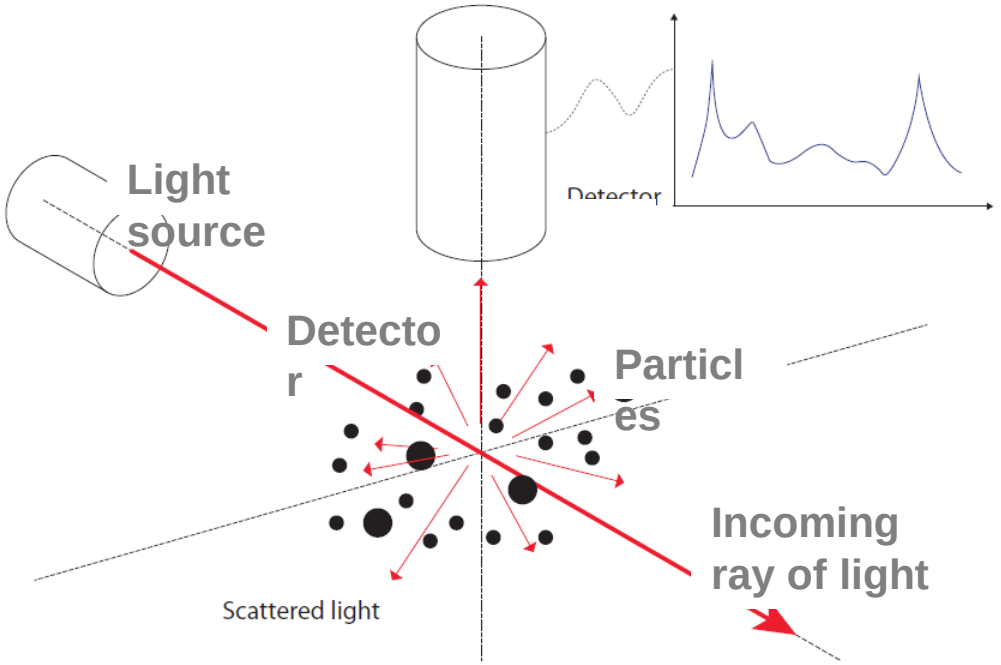
> Luftreinhaltung auf Baustellen

Richtlinie über betriebliche und technische Massnahmen zur Begrenzung der Luftschadstoff-Emissionen von Baustellen (Baurichtlinie Luft)

Ergänzung der Baurichtlinie Luft
Stand: 10. Februar 2015

Keywords:
air pollution control, construction site, construction machine, construction work, construction phase, catalogue of measures, periodic inspection

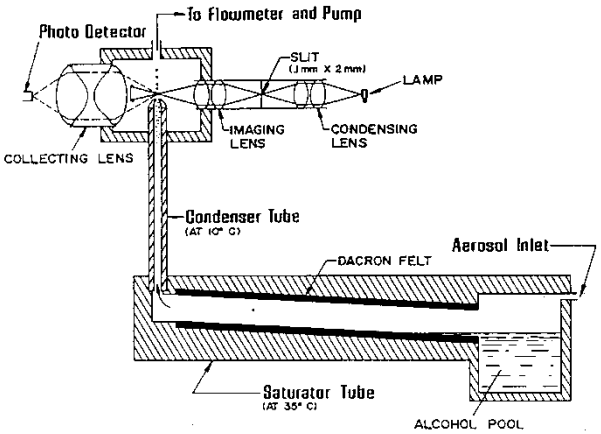
Laser Light Scattering Photometry LLSP

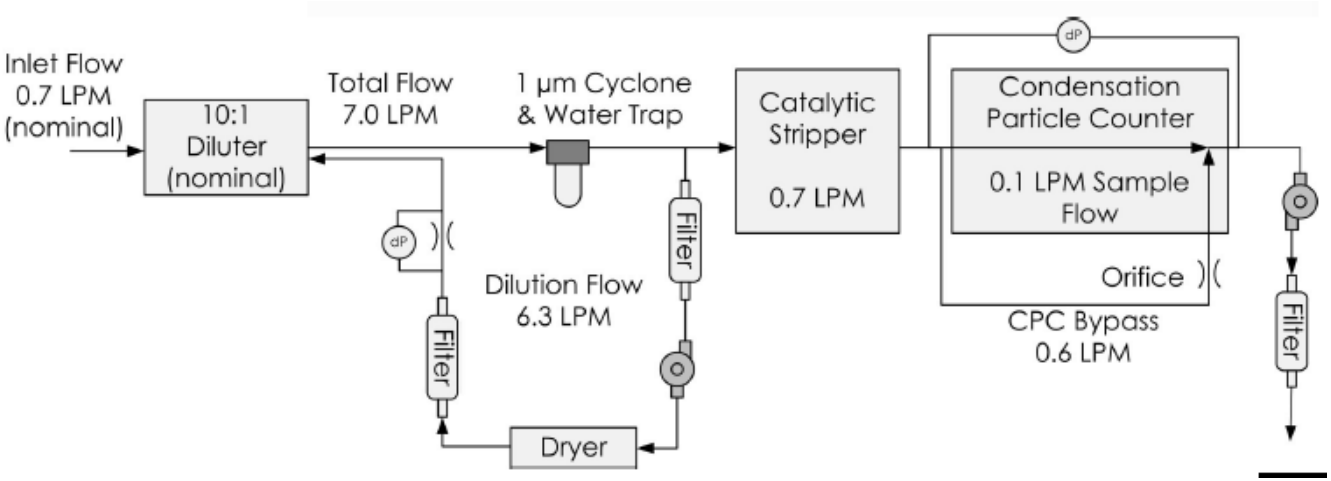


- EU TEDDIE program evaluated measurement procedure for PTI with DPF cars
- PTB-program in Germany, cooperation with Switzerland and Finland
- NTSEL-program in Japan

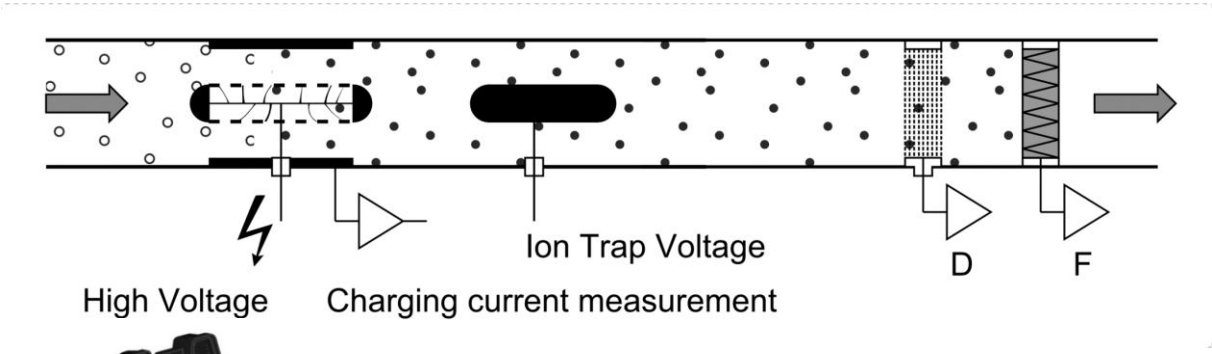
- Opacity meter does not have enough sensitivity for detecting damage with DPF
- OBD-sensors were even less sensitive than the opacity meter
- Laser light scattering photometry (LLSP) have enough sensitivity
  but are size dependent with the 5^{th} to the 6^{th} power – thereby blind for UFP

Condensation Nucleus Counter – by TSI NPET



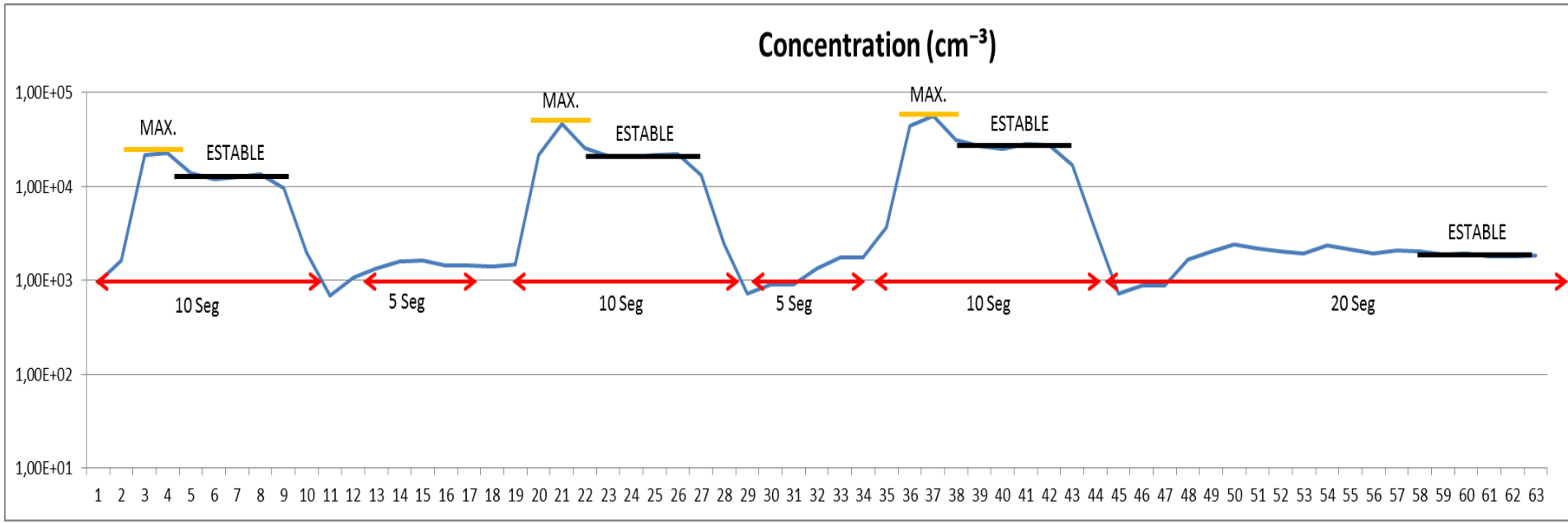


Diffusion Charging by Matter/TESTO NanoMet3 and PEPA



Measurement Roadside Santiago with NPET

Opacity and PN at exhaust exit
during free acceleration, high idle and low idle
2015 - 400 vehicles

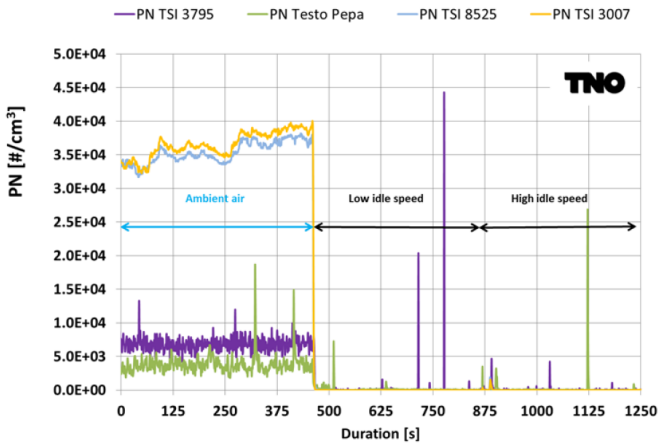


PN-Test at Low idle confirmed by TNO

TNO innovation for life

IDLE SPEED TEST WITH 4 PN-COUNTERS

PEUGEOT 308 EURO 6 @ 104,755 KM



All PN-testers measure near zero #/cm³ with a 'normal' (= well functioning) DPF.

Ambient air is cleaned!

No solid & volatile particle emission.

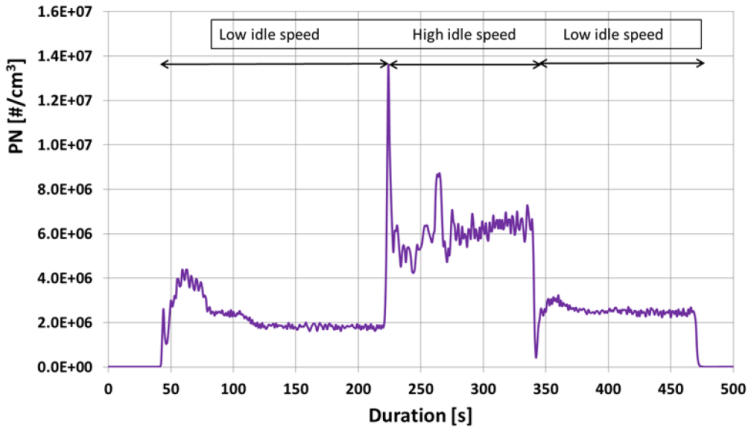
Candidate PTI test at low idle speed

TNO innovation for life

EMISSIONS POST DPF

CUS EURO 5B: LOW & HIGH IDLE SPEED

This DPF has a very serious leakage (PM = 4.7 mg/km)

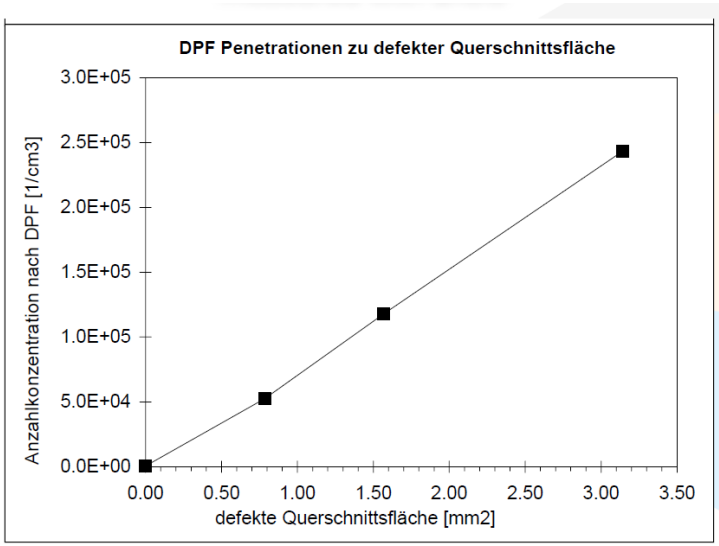


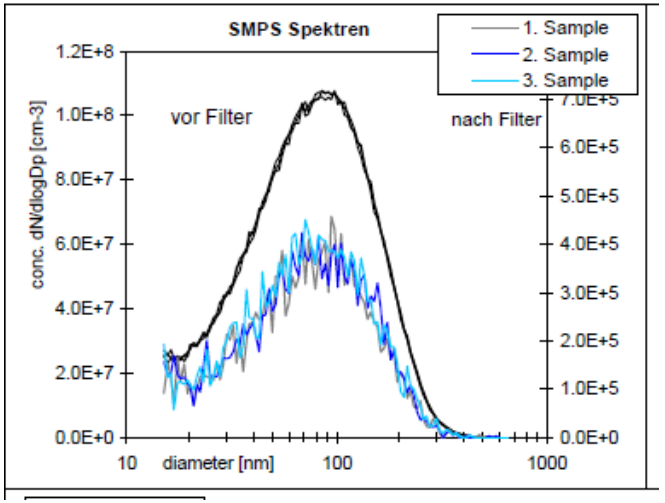
High idle speed for LD vehicles can be very different (2000-5000 rpm).

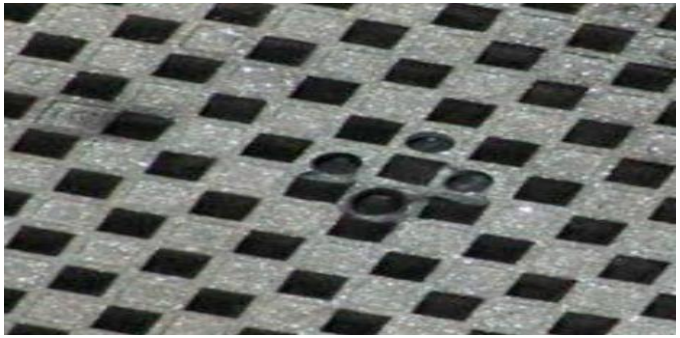
A PTI emission test at low idle speed (like the R83 Type II test for petrol vehicles) is preferred because PN emission is relatively low.

Detect Small Failures

(M.Kasper ETH-NPC 2008)

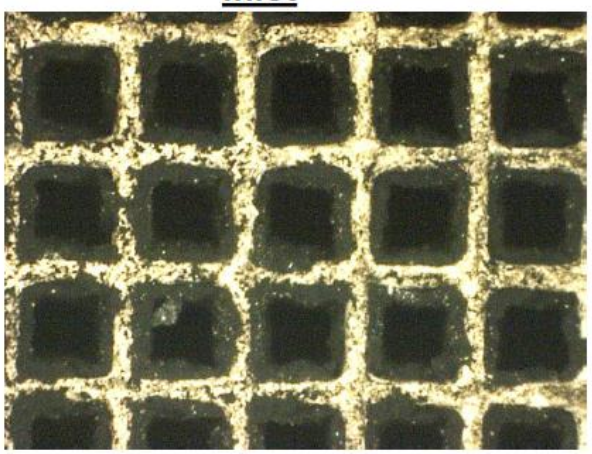


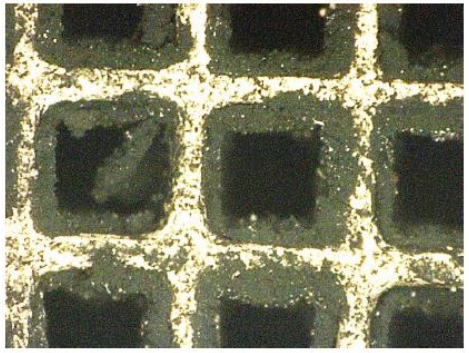




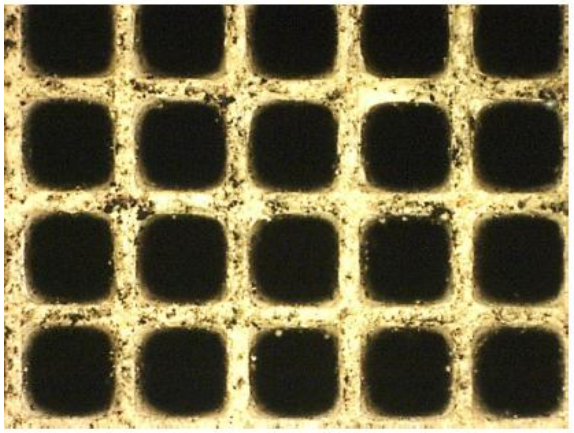
DOC might be covered by soot
or poisoned or destroyed or aged
or just not adequately coated

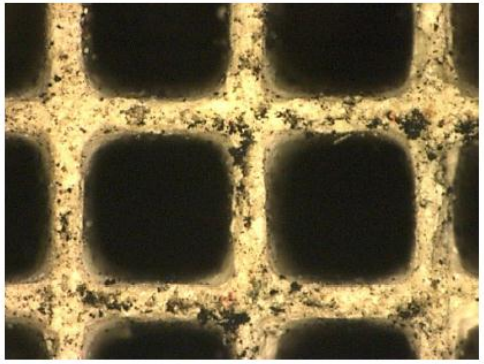
Inlet





Outlet

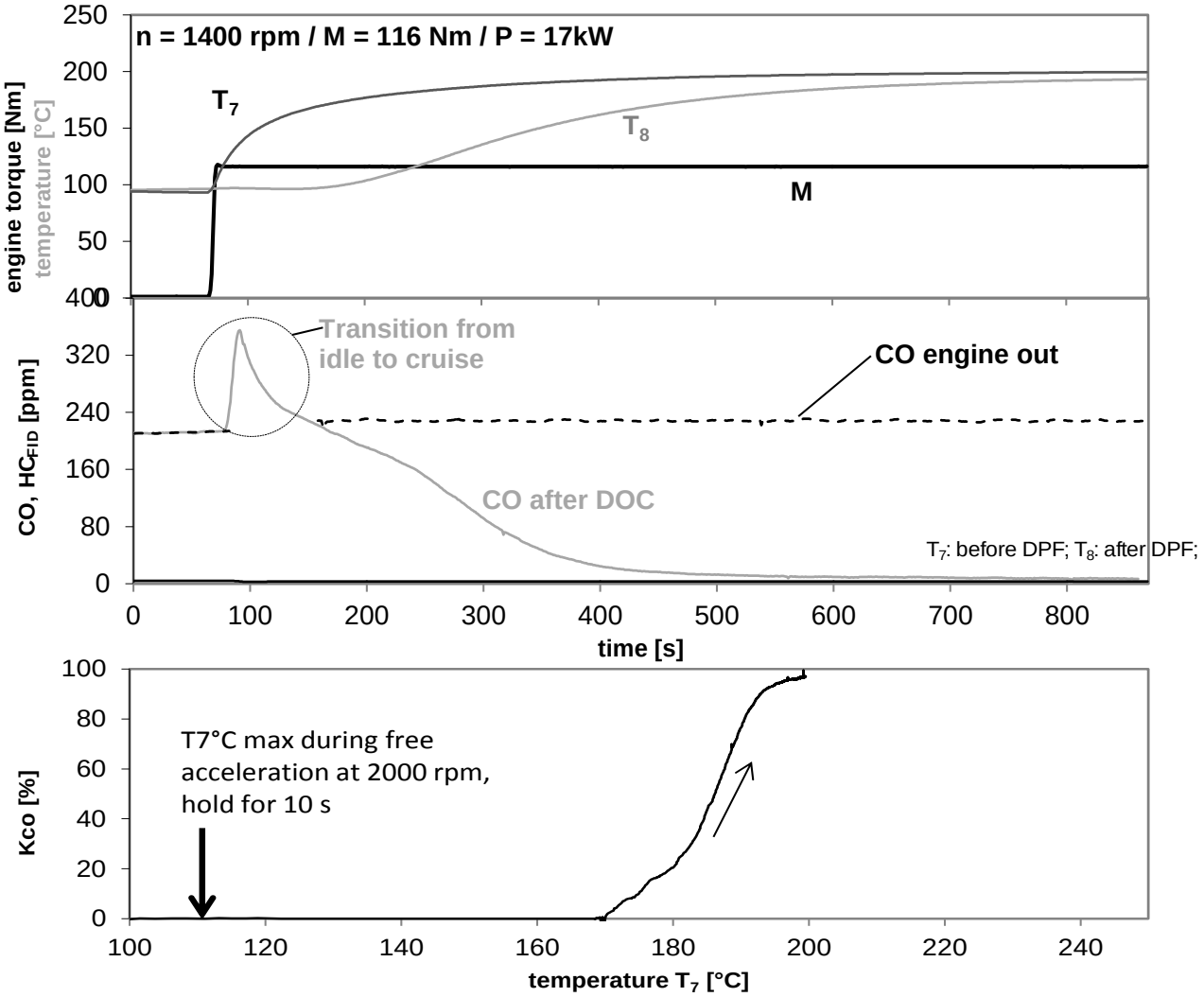


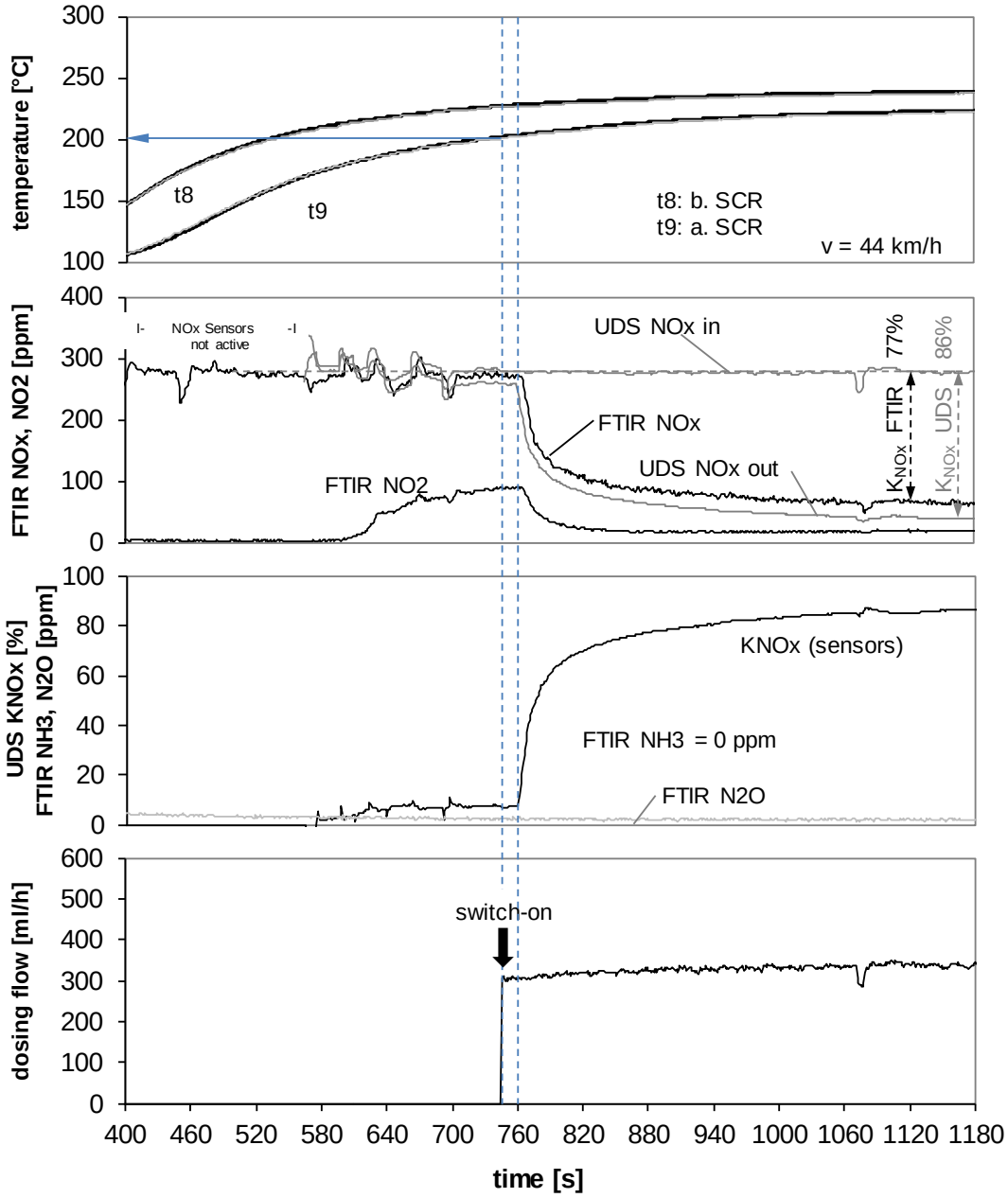


DOC light off test during Load Step

needs chassis dyno or torque converter stall - 20 sec

AFHB – J.Czerwinski





SCR Load Step

permits diagnosis of catalysis and dosing strategy flaws during loadstep by measuring NO/NO2 and NH3

AFHB – J.Czerwinski

Summary

very efficient and cost effective

100% periodic control in-use is feasable

- **PN-Test at low idle for DPF**
- **Load-Step 100°C auf 300°C at average RPM**
  - **CO-Conversion > 80% → DOC OK**
  - **NOx-Conversion > 70% + NH3 < 20 ppm → SCR OK**

This Test ist much more than just Pass/Fail

It supplies quantiative diagnostic information for the functionality of each emission control component and the engine as well and permits preventive repair and maintenance.

Condition is that OBD permits the test → Legislation

NPTI – Concept

Partners:

- METAS + PTB
- BAFU + ASTRA
- TNO + Dutch Ministeries
- UBA + Senat Berlin
- EU-JRC
- AFHB
- ETH
- VERT
- TSI, TESTO, MAHA

VERT Inspection & Maintenance

Periodic Test of Diesel Vehicles for Emission Stability if equipped with DPF, DOC, SCR-Emission Control Devices

Motivation

Emission stability of modern emission controlled Diesel powertrains cannot be guaranteed by the OEM for the lifetime of the vehicle; however, this is essential for public health. Apart from wear, poisoning, aging, fuel and lube influences and damage of both, emission control hardware and software elements, various kinds of tampering and manipulation have been observed, even being publically offered on the market. Legally required electronic onboard OBD control clearly are not sufficient. Independent 100% periodic inspection ought to be mandatory to guarantee functionality of **Particle Filters (DPF), Oxidation Catalysts (DOC, ASC), Selective Catalytic NOx-Reduction (SCR)** and other emission control systems, also called exhaust after-treatment systems of modern combustion engines.

Testing Procedures

VERT has developed inspection methods for emission-control devices, which are so efficient, reliable and cost effective that they are herewith recommended for new legal procedures covering all engines and applications:

DPF, Filtration Efficiency: Solid particle number concentration PN is measured upstream and downstream of the DPF, following the ECE-PMP protocol. Measuring being done with available handheld instruments, measurements can be performed at any load or speed, even low idling is sufficient for very accurately determining the filtration efficiency; failure for this relative value is below 1%; detection limit is $<10^3$ P/cc. Small filter substrate damage of less than 2% of the overall cell number is detectable and easily repairable at low cost. This procedure can be simplified by doing only one measurement downstream at tail pipe, however, at cost of accuracy. Since filtration of solid nanoparticles mainly depends on particle size and space velocity the measuring instrumentation must be highly sensitive for particles in the size range of 20-500 nm.

DOC, Conversion Efficiency: A DOC may be part either of a DPF-system or of an SCR-system or even standing alone. It may be inhibited by thermal or chemical poisoning or contamination or PGM-coating might be too low from beginning. DOC-conversion efficiency depends primarily on temperature: In oxygen rich Diesel exhaust, conversion of CO to CO_2 starts at about 130°C (light-off) and it reaches its full conversion level at about 250°C. By means of a load step at constant rpm, conversion capability of a DOC is determined very accurately and in very short time. Test procedure is heating the exhaust gas up to 300°C on a simple roller-dyno or similar and measuring the CO→CO_2 conversion curve during cooling down at the tail pipe – or inverse. This procedure reveals the exact status of the DOC conversion activity within a few minutes. And if it is active for CO it will also be active for HC and NO conversion.

SCR, Functionality of Selective Catalytic NOx-Reduction: Functionality requires both, proper catalytic conversion of the SCR-catalyst system and the accurate injection of the urea-water solution "Adblue" to be done at the minimum permissible temperature. Again a simple load step at constant engine rpm enables to check all functions in one single run. Either heating the exhaust gas from idling temperature 150°C to 300°C, or following the cooling curve from 300°C to idle with a NOx sensor at the tail pipe reveals, whether urea is injected, whether the right amount is injected, whether it is injected at the right temperature and whether the catalyst conversion is on the expected level. After this simple test all required information for a fail/pass decision is available. An even more precise control test is available by an additional NOx-measurement upstream of the SCR. NH_3-measurement at the tail-pipe may be complementary.

Instrumentation

The instrumentation of handheld PN measurement has been specified by the Swiss VAMV-regulation, first published 8/2012 by the Swiss Federal office for metrology METAS http://www.admin.ch/ch/d/as/2012/5371.pdf and it includes the EU-PMP protocol to focus on non-volatile particles. Instruments meeting these specs are already on the marked by TSI, TESTO and AVL. Sensors for measurement of CO, NO, NO_2 and NH_3 are available by many manufacturers. A guideline for instruments for field measurement of gaseous emissions with handheld instruments is also available by the Swiss Federal Office of Metrology METAS. Test data are to be stored electronically and fail/pass criteria are evaluated automatically, protected against falsification or manipulation.

Application

This inspection method applies in principle to any vehicle or engine, HDV as well as LDV, on-road as well as off-road and is not limited to Diesel engines. Prerequisite is that engine control electronics must permit load step testing at standstill axles with emission control functions fully operative.

Available Experience, Operation Time and Cost

VERT experience dates back for 2 years in applying this testing method in a small scale. Required time for a complete test-run is about 10 minutes; cost for instruments will be in the range of opacity meters as used in the past.

Andreas Mayer, J.Czerwinski, Th.Lutz
VERT Scientific Committee
1.September 2016

NPTI Working Group

First Meeting
23.11.16
Biel / AFHB

Proposal for the agenda:

1. Welcome and introduction
2. Why do we need new PTI's?
3. Proposed Concept and preliminary investigations and experience
4. Investigation of other PTI-developments/activities in Europe (CITA, TNO, …..)
5. Investigation of current LD and HD PTI's and European legal framework for the implementation of a new PTI (presentation of RDW?).
6. Investigation of subjects which must be picked up by the new working group.
7. Definition of objectives and tasks of the working group.
8. Possibilities for funding and potential structure of the future project .
9. Wrap up

Invited

- NL: G.Kadijk/TNO; Louis Zuidgeest /IenM (Ministry of The Environment), Hens Peeters Weem/RDW), (Type Approval Authority)
- JRC/Ispra and/or EU-Commission Brussels: G.Martini; Dr.N.Steininger
- METAS – the Swiss metrology institute: Dr.H.Andres
- PTB - the German metrology institute: Prof. V.Ebert, Dr.A.Nowack
- ASTRA - the Swiss road authority: H.Berger
- BAFU/FOEN - the Swiss ministry for the environment: G.D'Urbano, P.Bonsack
- UBA – Umweltbundesamt Berlin: L.Mönch, H.Jahn
- Berlin Senatsbehörde: V.Schlickum
- CARB: Dr.A.Ayala
- AFHB – Emission Laboratory Biel: Prof.J.Czerwinski,
- ETH: Th.Lutz
- EMPA: N.Heeb
- Instrument-Manufacturers TSI, TESTO ?
- VERT: V.Hensel, Dr.A.Mayer

Venue: AFHB Emission Laboratory Biel/CH-2560 Nidau, Gwerdtstrasse 5

Time: November 23. 2016 9:00 am

Target: formation of a working group to develop a new PTI procedure for

NPTI Working Group

Second Meeting
7.2.2017
Kloten/VERT

University of Applied Sciences Northwestern Switzerland
School of Engineering
Institute for Aerosol and Sensor Technology

Klosterzelgstrasse 2
CH 5210 Windisch
Switzerland

Suggestion: NPTI-system for diesel engines in workshop and field

Main purpose: make sure that particle filter is existent and working properly

Definitions:
diameter: mobility equivalent diameter
nanoparticles: only non volatile fraction
number concentration: number of particles per volume (in cm^{-3})
lung deposited surface area (LDSA): particle surface area x deposition probability in respiratory tract
black carbon (BC): carbon concentration , measured by optical absorption, for example a photoacoustic sensor
total carbon (TC): total particulate carbon, including organic and elemental carbon

Engine operation condition:
- low idling during measurement (-> λ=8 -> no or only small dilution needed to avoid nucleation

Sampling at tailpipe, probe 50mm in the tailpipe (no dilution due to position of sampling probe)

Measurement: 20sec measurement, average value and standard deviation determined, for valid measurement: standard dev. <20%

Range: $5x10^4$ - $10^6 cm^{-3}$ (for values outside this range evident if below or above)
(or: 3 times higher and lower than limit value)
If metric LDSA: 170 – 3300 $\mu m^2/cm^3$ (correspondents to number concentration for 70nm particles)

Environmental conditions:
Temperature: 5°C to 40 °C
Pressure: 860 hPa to 1060hPa
Humidity: rh < 85%, no condensation
(according to OIML R 99-1

Calibration, Efficiency:
Calibration with 70nm particles
If other metric used (LDSA, .BC,...): equivalent values to number concentration at 70nm used

Particles >200nm are irrelevant, no restrictions needed

Other requirements:
- Maintenance interval: 1 year
- electromagnetic compatibility class E2
- mechanical robustness: class M2

NPTI Working Group

Third Meeting
29.3.2017
Heidelberg/VERT

I would like to confirm our Third NPTI Meeting
As announced this meeting will take place in Heidelberg,
in the Heidelberger Druck Building, close to the main station
on March 29. 2017, starting 10:00 am

Tentative agenda

- Presentation of the NL-TNO-test program on PN-PTI of DPF / G.Kadijk
- Presentation of the AFHB-test program on step test for SCR and DOC-PTI / J.Czerwinski
- Proposals for new instrument concepts and prototypes TSI and TESTO
- Proposal for a step test dyno / MAHA invited
- Instrument evaluation and certification by NMI / P.Kok,
- NPTI procedure evaluation byt JRC / R.Suarez-Bertoa
- White Book
- Next program steps
- Next meeting at NMI

NPTI Working Group

Forth Meeting

TBD

Dordrecht / NMI

Result of PUA-Hearing ? Sept. 2016, Berlin

Entwurf
(Stand: 07.02.2017)

Nr. **- Änderung der Richtlinie für die Durchführung der Untersuchung der Abgase von Kraftfahrzeugen nach Nummer 6.8.2 der Anlage VIIIa Straßenverkehrs-Zulassungs-Ordnung (StVZO) (AU- Richtlinie)**
- Muster eines Nachweises über die Durchführung der AU nach Anlage VIII StVZO

Bonn, den …
LA 27/7355.2/2

ABGASUNTERSUCHUNG

Endrohrmessung kommt zurück

UPDATE Die Abgase von allen Kraftfahrzeugen sollen ab 1. Juli 2017 wieder direkt am Endrohr gemessen werden. Das geht aus dem Entwurf zur Änderung der AU-Richtlinie aus dem Bundesverkehrsministerium hervor.

„0 Vorbemerkung

Ziel dieser Richtlinienänderung ist die Einführung der verpflichtenden Messung der Abgase aller AU-pflichtigen Kraftfahrzeuge. Damit wird die Möglichkeit des 2-stufigen Verfahrens bei Fahrzeugen mit On-Board-Diagnosesystem (OBD-System) aufgehoben. Auch bei diesen Fahrzeugen ist nun, unabhängig vom Ergebnis der Prüfung des OBD-Systems, die Messung der Abgase vorgeschrieben. Hiermit soll die Realitätsnähe der Abgasuntersuchung (AU) weiter erhöht werden und die Fehlerquote gering gehalten werden. Darüber hinaus werden die Sollwerte der Emissionsklassen Euro 6/VI angepasst, um eine bessere Erkennbarkeit von Mängeln bei diesen Fahrzeugen zu gewährleisten.

Als weiterer Schritt ist zu einem späteren Zeitpunkt die Einführung der Partikelanzahlmessung für Fahrzeugen mit Kompressionszündungsmotor vorgesehen.“

Summary

- **NPTI concept is on the table for discussion**
  - not only limit value for pass/fail
  - but quantitative test on function of DPF, DOC and SCR
- **Appropriate Instruments are available**
- **Test-Procedure < 10 min on workshop level feasable**

- **Available Instruments might be too expensive**
  new protoypes required → TSI, TESTO
  instrument validation and specification (offered by NMI)
- **Chassis dyno for Load-Step procedure** → MAHA
  Procedure validation (offered by EU-JRC)
- **Implementation Policies not discussed** yet → UBA