NanoMet a potential analyzer for legal nanoparticle measurements

Swiss contribution to GRPE Particulate Measurement Programme, Reports 2 & 3

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- Abstracts

Part I: Peugeot with DPF, VW Passat w/o DPF
- Experimental set-up
- Particulate emissions analysis
- Measuring procedure
- Results & correlations

Part II: DPF with Bypass (Opel Astra)
- Results & correlations
- Conclusions
Abstracts

The UNECE subgroup GRPE (Groupe Rapporteurs Pollution Energie) started a Particulate Measurement Program (PMP) to improve the legal exhaust gas measuring procedures for the diesel vehicles with particle filters (DPF).

For those very low emitting vehicles new special measuring devises for particles emissions or eventual modifications of measuring procedures are necessary. In this context the Swiss Federal Roads Authority (FEDRO) together with the Swiss Federal Office of Environment, Forests and Landscape (FOEFL) mandated several investigations to claire up the possibilities and necessities of supplementing the legal measuring procedures.

The Swiss nanoparticles experts group under the auspices of the Swiss Federal Office of Environment, Forests and Landscape (FOEFL) proposes a new apparatus - the NanoMet.

In the 1st part of the preliminary research program (GRPE phase 1), it was confirmed that:

• there is a good correlation between the NanoMet and SMPS results,
• due to the possibility of on-line measurement, the NanoMet has an interesting potential of analysing the nanoparticles (NP)-concentrations and NP-composition during the transient operating conditions.

In the 2nd part of the preliminary research program of FEDRO and FOEFL with NanoMet used on a modern Diesel passenger car more correlation measurements, more statistical comparisons and more data allowing the assessment of: repeatability, stability, sensitivity and dynamic aptitude were elaborated.

By means of a by-pass of the DPF the particle emission level of the vehicle was simulated between the values with and without DPF.

As previously in this preliminary research program the NanoMet was correlated with:

• Gravimetry
• SMPS and
• Opacimetry.

The research program was realised on the chassis dynamometer of Exhaust Gas Control Laboratory, University of Applied Sciences, Biel-Bienne, Switzerland (AFHB).

The most important results concerning NanoMet can be summarised as follows:

• There are very good correlations between the NanoMet- and SMPS-results at stationary and at transient operating conditions.
• It was demonstrated that PAS & DC-signals (NanoMet) are much more sensitive for low emitting cases, than the gravimetry, or opacimetry.
• The aptitude of dynamic response of PAS & DC during the free acceleration is sufficient, the sensitivity is higher, than for SMPS set on one NP-size, or for opacimetry.
• The NanoMet is calibrated by the manufacturer according to a fix procedure. There are also recommendations and different calibration possibilities for the user.
• CAST a system supplying combustion standard aerosols for calibration purposes offers a high quality of calibration.
• Diffusion battery a future option for NanoMet, which enables an on-line particle size distribution scanning showed the first very promising results.

The investigated measuring procedures for particle emissions and their most important features can be summarized in the following table:

<table>
<thead>
<tr>
<th>Opacimetry</th>
<th>NanoMet</th>
<th>SMPS set on 60 nm</th>
<th>Gravimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAS</td>
<td>DC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• sensitive to low NP-emissions</td>
<td>• cost, complexity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• calibration procedures available</td>
<td>• laboratory application</td>
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</table>
Sampling and measuring set-up for nanoparticulates analysis on the chassis dynamometer

- \text{CO, CO}_2
- \text{HC, NO}_x
- \text{DC, NM, NanoMet, vehicle exhaust, CPC, SMPS, PM}
- \text{dilution air (p, T)_{amb}}
- \text{chassis dynamometer, filter holder, CO, CO}_2, \text{HC, NO}_x
Particle Analysis

- SMPS – Scanning Mobility Particle Sizer, TSI (DMA TSI 3071, CPC TSI 3025 A)
- NanoMet – System consisting of:
  - PAS – Photoelectric Aerosol Sensor (Eco Chem PAS 2000)
  - DC – Diffusion Charging Sensor (Matter Eng. LQ1- DC)
  - MD19 tunable minidiluter (Matter Eng. MD19-2E)
Test Procedures

- Constant speeds: 50, 80, 110 km/h
- Parts of driving cycles warm: EURO-city, EURO-EUDC, FTP 75 (ht)
- Free accelerations
Peugeot 607 2.2L with DPF
VW Passat TDI 1.9 L (w/o DPF)
Constant speeds
Correlation between the integrated results of NanoMet and SMPS
VW Passat

\[ y = 0.0088x + 105663 \]
\[ R = 0.888485278 \]

\[ y = 0.004x + 24832 \]
\[ R = 0.908809 \]
VW Passat - EURO + EUDC cycle, NanoMet & CPC (SMPS) at 100 nm
Transient driving cycles
Correlation between the integral average results of NanoMet and SMPS
VW Passat

\[ y = 1.2352x + 63268 \]

\[ R = 0.930182375 \]

\[ y = 0.5403x + 24682 \]

\[ R = 0.920098 \]
SiC DPF with bypass (BP) at the tailpipe

Chassis dynamometer

\[ \Delta p_{\text{DPF}} \]

Particle trap

Bypass

Opacimeter

CVS PM

MD19 NanoMet SMPS
DPF-BP-variants

- without DPF  
- with DPF, bypass closed  
- with DPF, bypass partially open  
- with DPF, bypass 100% open
SMPS-Particle Size Distribution at \( v=80 \) km/h
with different bypass settings (BP)

mean of 3 samples
**Constant speeds**

**Correlations: DC ---> SMPS (16 - 550 nm)**

\[ y = 0.0025x + 3751.9 \]

\[ R^2 = 0.982 \]

\[ \int_{SMPS (16 - 550 \text{ nm})} \]

\[ y = 0.1619x + 5935.1 \]

\[ R^2 = 0.9852 \]
Constant speeds
Correlations: PAS ---> SMPS (16 - 550nm)

\[ y = 0.0058x + 114135 \]
\[ R^2 = 0.4047 \]

\[ y = 0.0117x + 21186 \]
\[ R^2 = 0.8231 \]
Constant speeds
Correlations: DC ---> PM;  PAS ---> PM

\[ y = 4654.6x + 7998.9 \]
\[ R^2 = 0.8392 \]

\[ y = 18490x + 13841 \]
\[ R^2 = 0.6225 \]

Only lower emissions with DPF/BP
Transient driving cycles

Correlation between the integrated results of NanoMet and SMPS
(time integral average, SMPS at 60nm)

\[ y = 6.0725x + 48027 \]

\[ R^2 = 0.9763 \]

\[ y = 1.4591x + 11814 \]

\[ R^2 = 0.959 \]
Nanomet & opacity during the free acceleration
larger scale for lowest values
Correlations of the maximal values of the particle emission parameters during the free acceleration
Conclusions

There are very good correlations between the NanoMet- and SMPS-results at stationary and at transient operating conditions.

It was demonstrated that PAS & DC-signals (NanoMet) are much more sensitive for low emitting cases, than the gravimetry, or opacimetry.

The aptitude of dynamic response of PAS & DC during the free acceleration is sufficient, the sensitivity is higher, than for SMPS 60 nm, or opacimetry.

Calibration procedures are resolved.

Diffusion Battery (available in the near future) is an option of NanoMet to scan the PSD-spectra.