Particulate emissions of heavy duty engines on different test cycles

Urs LEHMANN
EMPA

Swiss Federal Laboratories for Materials Testing and Research
Department I.C. Engines/Furnaces
CH-8600 Duebendorf, Ueberlandstr. 129, Switzerland
urs.lehmann@empa.ch http://www.empa.ch
Goal

How are different transient test-cycles reflected by the particulate emissions of heavy duty engines. (regarding particle number – mass correlation)

What is the influence on number size distribution of emitted particles. (measured by ELPI)
# Euro 2 - HD-Engines / Cycle / Diesel Fuel

<table>
<thead>
<tr>
<th>Brand</th>
<th>Engine 1</th>
<th>Engine 2</th>
<th>Engine 3</th>
<th>Engine 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of cylinders</td>
<td>V 6</td>
<td>V 8</td>
<td>In-line 6</td>
<td>In-line 6</td>
</tr>
<tr>
<td>Displacement [ccm]</td>
<td>11’000</td>
<td>14’618</td>
<td>11’705</td>
<td>12’124</td>
</tr>
<tr>
<td>Rated power</td>
<td>248 kW @ 1900 rpm</td>
<td>280 kW @ 1600 rpm</td>
<td>280 kW @ 1500 – 1900 rpm</td>
<td>275 kW @ 1800 rpm</td>
</tr>
<tr>
<td>Max. torque</td>
<td>1612 Nm @ 1200 rpm</td>
<td>1848 Nm @ 1000 – 1400 rpm</td>
<td>1765 Nm @ 1100 – 1550 rpm</td>
<td>1720 Nm @ 1200 rpm</td>
</tr>
</tbody>
</table>

**Transient Cycles**

- ETC
- FTP hot
- FTP cold

**Fuel**

- TUG (TU Graz)
- TNO 7 kW/t
- TNO 12,5 kW/t

**Market Fuel**

- Density (at 15°C) [kg/m³]: 831.4 to 832.1
- Sulphur content [mg/kg]: 330 to 339
- Cetane number [-]: 49.1

*standard business fuel (CEC RF-03-A-84)*
6 different transient cycles:

ETC European transient cycle
FTP cold US federal test procedure, US transient cycle (started at cold condition)
FTP hot US federal test procedure, US transient cycle (started at warm condition)
TUG TU Graz Real-world test cycle according to the D/A/CH handbook data
TNO 7 kW/t Real-world test cycle [cycle-length: 3809 s] related to a power-mass ratio
TNO 12.5 kW/t Real-world test cycle [cycle-length: 3837 s] related to a power-mass ratio

(TNO: Road-Vehicles Research Institute in the Netherlands)
Experiment Set-Up

- mass flow controller
- dilution air
- mass flow controller
- sampling probe
- heat exchanger
- positive displacement pump
- dilution tunnel (for diesel engines)
- particulates
- filter holders
- mixing orifice
- coarse filter
- activated carbon filter
- fine filter
- pre-heated ambient air
- temperature and humidity controlled intake air
- electrical net
- asynchronous motor
- DYNAS 680
- IC engine
- CPC
- ELPI
- T < 191°C
- T < 51°C
- DILUTION 1
- DILUTION 2
- particulates filter holders
- mass flow controller
- sampling probe
- PDP
The particulate mass was determined using a state-of-the-art gravimetric filter measurement systems.

For the particulate measurements (CPC and ELPI), the sample was taken out of the CVS tunnel close to the gravimetric sampling system.

These 4 engines were measured on 6 cycles with at least 3 repetitions.
→ the duration of the whole program was quite long

Therefore it was very important to use always the same instruments and set-up. Also the conditioning of the instruments before a measurement-period was according a fixed protocol.
Comparison Total Number – PM

Total Particle Number [1/kWh]

Particulate Mass [g/kWh]

Total Number (CPC) [1/kWh]
Total Number (ELPI) [1/kWh]
PM [g/kWh]

engine 2
Correlation PM - Particle Number (CPC)
Correlation PM - Particle Number (CPC)

The graph shows the correlation between particulate mass (PM) and total particle number (CPC) for different engines. The correlation coefficients ($R^2$) for each engine are as follows:

- Engine 1: $R^2 = 0.6125$
- Engine 2: $R^2 = 0.6221$
- Engine 3: $R^2 = 0.6815$
- Engine 4: $R^2 = 0.6599$

The axes represent particulate mass (PM) in grams per kWh on the x-axis and total particle number (CPC) in particles per kWh on the y-axis.
Correlation PM - Particle Number (CPC)
NSD / all transient cycles / engine 3
NSD / all engines / ETC / ELPI

![Graphs showing particle size distribution for different engines]
Conclusion

• Generally, a reduction of particulate mass is correlated with a reduction of particulate number.

• The test cycle has almost no influence on the correlation between particulate mass and number.

• The correlation between particulate mass and number is more influenced by the measured engine.

• The Number Size Distribution is almost not influenced by different transient cycles.