The AVL Particle Counter: APC 489
Experience from VPR and PNC validations

06.12.2011
Outline

Introduction

PNC calibration / validation / check

VPR calibration / validation / check

Conclusions
Past and present

AVL has reported some issues

PNC

  Linearity

  Drift

  CAST and Emery oil differences at 23 and 41 nm

VPR

  Calibration procedures

New topics

  Validation procedures and on-site checks
Outline

Introduction

PNC calibration / validation / check

VPR calibration / validation / check

Conclusions
PNC (CPC) calibration / validation setup

Primary method

Secondary method (used by AVL)

Aerosol Electrometer

Electrometer

Aerosol conditioner

Particle Generator

excess

Dilution Bridge

Filter

DMA

Makeup Flow

Flow Splitter

Mixing Orifice or Chamber

PNC_{Test}

PNC_{Ref} or

Giechaskiel, December 2011, JRC
AVL experience

- Non-linearity has been reported for the 3790 (and 3772)

- AVL experience from validations of >40 3790s shows that the non-linearity is usually within +/-3% (or +/-7% with 2 σ).

- This means that max and min concentrations differ by 3% or 7% sometimes
AVL experience

- Emery oil and CAST have differences
- Approximately 0.15 at 23 nm and 0.07 at 41 nm
- This difference should be taken into account in the validation of the CPCs
- The >40 validations confirmed this
### AVL validations

**Serial number**: 70831244  
**Test Aerosol**: Soot (CAST) with thermal pre-treatment  
**Date**: 4-May-11

#### Inlet Flow (Volumetric)

<table>
<thead>
<tr>
<th>Units</th>
<th>Low Limit</th>
<th>High Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Flow Rate l/min</td>
<td>0.95</td>
<td>1.05</td>
</tr>
</tbody>
</table>

#### Temperature and Pressure

<table>
<thead>
<tr>
<th>Units</th>
<th>Low Limit</th>
<th>High Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Temperature °C</td>
<td>-8</td>
<td>-28</td>
</tr>
<tr>
<td>Saturator Temperature °C</td>
<td>38</td>
<td>38.7</td>
</tr>
<tr>
<td>Condenser Temperature °C</td>
<td>30.5</td>
<td>32</td>
</tr>
<tr>
<td>Optics Temperature °C</td>
<td>39.8</td>
<td>40.2</td>
</tr>
<tr>
<td>Cabinet Temperature °C</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>Ambient Pressure kPa</td>
<td>88</td>
<td>108</td>
</tr>
<tr>
<td>Pressure Drop across Orifice kPa</td>
<td>70</td>
<td>88</td>
</tr>
<tr>
<td>Pressure Drop across Nozzle kPa</td>
<td>1.9</td>
<td>3.2</td>
</tr>
</tbody>
</table>

#### Lower Detection & Concentration Linearity Test Results

<table>
<thead>
<tr>
<th>Units</th>
<th>Low Limit</th>
<th>High Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>23nm Particle Counting Efficiency %</td>
<td>38</td>
<td>62</td>
</tr>
<tr>
<td>41nm Particle Counting Efficiency %</td>
<td>90</td>
<td>-</td>
</tr>
<tr>
<td>Linearity Test: Slope (up to 10000p/cm³)</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td>Linearity of Regression (R²)</td>
<td>0.97</td>
<td>-</td>
</tr>
<tr>
<td>Internal k factor (taken into account)</td>
<td>0.9</td>
<td>1.1</td>
</tr>
</tbody>
</table>

#### Zero Count Test

<table>
<thead>
<tr>
<th>Units</th>
<th>Low Limit</th>
<th>High Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration Average over 3 Minutes p/cm³</td>
<td>0</td>
<td>0.001</td>
</tr>
</tbody>
</table>

#### Linearity Response: CPC vs. Calibrated CPC 3790

<table>
<thead>
<tr>
<th>Units</th>
<th>Low Limit</th>
<th>High Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 p/cm³ CPC Concentration % Diff</td>
<td>-10</td>
<td>10</td>
</tr>
<tr>
<td>100 p/cm³ CPC Concentration % Diff</td>
<td>-10</td>
<td>10</td>
</tr>
<tr>
<td>1000 p/cm³ CPC Concentration % Diff</td>
<td>-10</td>
<td>10</td>
</tr>
<tr>
<td>5000 p/cm³ CPC Concentration % Diff</td>
<td>-10</td>
<td>10</td>
</tr>
<tr>
<td>10000 p/cm³ CPC Concentration % Diff</td>
<td>-10</td>
<td>10</td>
</tr>
</tbody>
</table>

---

Decision has to be made for pass / fail criteria corrections applied. No correction for material applied. Slope, the most important value. K factor is included.
Degrading over time

2 out of 5 drifted (40%)
The reason is the wick (where the super-saturation is achieved)
The critical point: **No light indicator identified this degrading**

New results:
15 out of 41 drifted (37%)

Giechaskiel, December 2011, JRC

Giechaskiel and Bergmann 2011, JAS, 42, 195-203
PNC (CPC) on site check

Soot generator
Ref PNC (d50=23 nm)
Linearity check
PNC polydisperse check (theoretically)

Legislation limits

correction factor is needed
Equivalency of mono- and polydisperse checks (experimentally)

CMD = 75 nm

CMD = 90 nm
Conclusions PNC

Linearity of PNCs is very important. Although the results should be within +/- 10%, for a specific PNC the difference between low and high concentrations should be within +/-5% (e.g. from -10% up to 0%).

From 41 CPC validation only a few had a non-linearity issue of 7%, the rest <3%.

Emery oil and CAST have different counting efficiencies. Differences are 0.15 and 0.06 for 23 and 41 nm particles respectively. This should be taken into account for the validations.

Drift of PNCs 5-10% every 3-6% is common. From 41 CPC validations 15 (37%) drifted >20%.

Validations check PNC: flow, 23 nm, counting efficiencies, linearity and slope.

k factor should be taken into account or not?

The critical point for PN results is the slope. Flow? 23 nm? +/-10%
Conclusions PNC

The polydisperse on-site check was proven to be equivalent with the monodisperse calibration / validation

A soot generator that produces a size distribution with median around 70 nm and a reference PNC are only needed.

Open issue remains the results that have been conducted with ‘failed’ devices
Outline

Introduction

PNC calibration / validation / check

VPR calibration / validation / check

Conclusions
VPR calibration setup

AVL setup

- CAST (or mini CAST)
- Thermal pre-treatment (350 °C)
- One neutralizer upstream (370 MBq)
- Reference PNC for monitoring stability of Generator
- Upstream / downstream same flow rates, correction for PNC inlet pressures
- PNCs with d50=10nm

\[ \text{PCRF} = \frac{N_{\text{in}}}{N_{\text{out}}} \]
Calibration set up

Particle Generator → Thermal pre-treatment & Dilution → Classifier → DMA → Makeup Flow → Mixing Orifice or Chamber → PNC_{mon} → APC → MFC

excess

Particle Generator → Thermal pre-treatment & Dilution → Classifier → DMA → Makeup Flow → Mixing Orifice or Chamber → PNC_{mon} → PNC_{Ref} → APC → MFC

Concentration 1.47E+3 P/CC

ESC

Condensation Particle Counter

Thermal pre-treatment & Dilution

PNC_{mon}

PNC_{Ref}
VPR calibration setup

System under calibration

DMA and PNCs

Particle Generator (Mini CAST)
VPR calibration: Repeatability

Repeatability

95% of calibrations within ±6%

Recalibration of five VPRs (APCs from AVL) units after two days (no modification), after 5-11 months (guidance rods and springs were changed) and after 9 months (rotating disk also changed).

Error bars show 2 standard deviations.
Comparison of AVL’s calibration lines

CS: Repair center
FLZ 1: Production 1
FLZ 2: Production 2

Three APCs were calibrated either at the CS (repair center) or the production lines 1 (FLZ 1) and 2 (FLZ 2). The mean differences were 1% and the 95% of the differences within 4%.
Comparability of APCs

- Two well calibrated systems of the same manufacturer (AVL) on average <4% difference
- 95% of differences within ±10%

Comparison of two PN systems (APCs from AVL) both connected to the CVS for one heavy duty engine (different test cycles) and two different APCs for four different light duty vehicles (for the NEDC cycle). HD=Heavy Duty, LD=Light Duty, SCR=Selective Catalytic Reduction for NOx, DPF=Diesel Particulate Filter, G-DI=Gasoline Direct Injection.

Giechaskiel, December 2011, JRC

Giechaskiel et al. 2010, MST, 21, 045102
Validations

Recalibration of five VPRs (APCs from AVL) units after many months of use at the CVS Error bars show 2 standard deviations.

Giechaskiel, December 2011, JRC
VPR on site check

Soot generator with venturi (CMD=50 nm)
Reference PNC (d50=23nm)
Check of PCRF <1000
Relative check for rest PCRFs
Theoretical polydisperse PCRF
Relative checks of PCRFs
VPR conclusions

AVL calibration procedure (CAST with thermal pre-treatment, one neutralizer, monitor PNC, single PNC method with d50=10 nm). The thermal pre-treatment is important

AVL calibration procedure has +/-6% uncertainty (95% of calibrations).

Comparison of two APCs from the CVS should have less than 5% differences (+/-10%, 95% of the comparisons)

Validation of 60 units showed that there was no drift and

The uncertainty is +/-10% for low PCRFs (<2000) but can reach 30% at very high PCRFs (20000)

On site PCRF check is possible with a reference PNC (d50=23 nm). The generated polydisperse size distribution should have a median of 50 nm.

For higher PCRFs the relative check is recommended (to avoid the 30% uncertainty)

How previous results from failed VPRs are treated?