Progress on the sub-23 nm evaluations
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SUREAL-23 FINAL WORKSHOP
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The European Commission’s science and knowledge service
Joint Research Centre
Overview

Presentation considers some of the topics of Sub-23nm solid particle number (SPN) regulation development

• Current SPN regulation
• Timeline for PN10 studies
• LD exercise
• Tailpipe sampling
• Particle number PEMS
• Draft Sub23nm specifications
• Conclusions on particle number
### Current SPN regulation

<table>
<thead>
<tr>
<th>regulation</th>
<th>cycle</th>
<th>SPN (1/km or 1/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light duty (Euro 6)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA</td>
<td>2017/1151, 2017/1154</td>
<td>WLTC RDE</td>
</tr>
<tr>
<td>ISC</td>
<td>2018/1832</td>
<td>WLTC RDE</td>
</tr>
<tr>
<td><strong>Heavy duty (Euro VI)</strong></td>
<td></td>
<td></td>
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<tr>
<td>TA</td>
<td>582/2011</td>
<td>WHTC WHSC</td>
</tr>
<tr>
<td>ISC</td>
<td>2019/1939</td>
<td>On-road</td>
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<tr>
<td><strong>NRMM (STAGE V)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA</td>
<td>2017/654, 2016/1628</td>
<td>NCTC NRSC</td>
</tr>
<tr>
<td>ISC</td>
<td></td>
<td>Monitoring phase</td>
</tr>
<tr>
<td><strong>L-Category (Euro 4)</strong></td>
<td></td>
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</tr>
<tr>
<td>TA</td>
<td>2013/168</td>
<td>WMTC</td>
</tr>
</tbody>
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Giechaskiel et al., *Energies* 2019, 12(22), to be determined.

**Solid Particle Number (SPN) measured after**
1) hot dilution,
2) volatile particle remover,
3) cold dilution

**With Particle Number Counter (PNC) having d50% at 23 nm**

**Engines for non-road mobile machinery intended and suited to move, or to be moved by road,**
-- inland waterway vessels (> 300 kW), and rail traction engines (2017)
## Timeline for 10 nm studies

<table>
<thead>
<tr>
<th>TASK</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration material and CPC efficiency</td>
<td>Q1: Soot, emery oil</td>
<td>Q1: Preliminary decision on procedure / sampling set up</td>
</tr>
<tr>
<td>ET or CS/ Modified Sampling and particle losses</td>
<td>Q2: Challenging PN-system with all ICE concepts</td>
<td>Q2: GTR 15, Annex 5 Drafting</td>
</tr>
<tr>
<td>Calibrations guidelines</td>
<td>Q3: GTR 15, Annex 5 Drafting</td>
<td>Q3: Final</td>
</tr>
<tr>
<td>Verification study</td>
<td>Q4: Assessing the PN system functionality with different fuels</td>
<td>Q4: Verification</td>
</tr>
<tr>
<td>Fuels / PN study</td>
<td></td>
<td></td>
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<tr>
<td>Limit value recommendation, including DF and Ki</td>
<td></td>
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<tr>
<td>PEMS 10nm</td>
<td></td>
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</table>
Light duty Sub-23nm exercise

- 7 emission measurement laboratories
- A GDI, Euro 6b (no GPF)
- 2 CS PN-systems (CS1, CS2) with 10nm CPC and three additional CPCs circulated
  - Airmodus, TSI, AVL, Horiba
- + LabPMP (23nm) system
- Same test routines in each lab
  - 3 Cold start WLTC, 5 Hot start WLTC, 1 Steady speed cycle
- Exercise now continues in Asia
Light duty Sub-23nm exercise

- Highest variability in LabPMP results
  - Differences in calibration
  - Enhanced PN10 sampling losses
- No big differences between PN10 and PN23 variabilities (CS1)
- No clear conclusion about VPR characteristicsc (ET Vs. CS)
- **PN10 can be measured reliably with current systems**

<table>
<thead>
<tr>
<th>Reproducibility CoV PN10/PN23</th>
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</thead>
<tbody>
<tr>
<td><strong>CYCLE</strong></td>
</tr>
<tr>
<td>WLTC COLD START</td>
</tr>
<tr>
<td>WLTC HOT START</td>
</tr>
</tbody>
</table>

*CS2 reproducibility suffered from some technical issues during the exercise*
Tailpipe sampling

- An exercise (ACEA&JRC) to compare SPN-emissions from Partial Flow dilution (PD) and TailPipe sampling (TP)
- Measurement devices circulated in 7 laboratories, compared to In-lab PMP-systems → 7 different PN-systems, >7 engines
- Tailpipe sampling with PN-system having Catalytic Stripper (CS)
- In-lab PN-measurement (evaporation tube, ET) in PD

Varying fuel, PN dilution
Tailpipe sampling

- PN23 within 25% between partial flow and tailpipe sampling
- Also for PN10 difference between PN-systems 25%
- Tailpipe and PD comparable for both PN23 and PN10
- CS and ET PN-systems comparable for both PN23 and PN10
- Regenerations excluded
SPN-PEMS

- Uncertainty SPN PEMS: 40 – 65%
- In general CPC equipped SPN-PEMS more accurate than DC-PNPEMS
  - CPC system within 25% of reference,
  - DC systems even over >60% → charged particles
- Recently: DC system within 20% ref
- Next step is to assess PN10PEMS possibilities
  - Testing at JRC on January/2020
Sub-23nm regulation

A Word of warning:
The next three slides are only preliminary proposal for Sub-23nm measurement specifications, not a decision or even final proposal.
Sub-23nm regulation

- Next step with minimum modifications on PN systems
  - Dead line on 6/2020
  - H2020 Sub23nm results for the future development
- PMP-IWG will propose:
  \[
  \frac{fr(15\text{nm})}{fr(100\text{ nm})} < 2, \quad fr(d_p) = \frac{1}{P(d_p)}
  \]
  - GTR \(P(100 \text{ nm}) \geq 70 \% \rightarrow P(15 \text{ nm}) > 35\%
  - Catalytic Stripper (CS) losses \(\sim 20 \%\) higher than Evaporation Tube (ET)
  - PCRF is proposed to be kept as before
  \[
  PCRF = \frac{PCRF(30\text{nm}) + PCRF(50\text{nm}) + PCRF(100\text{nm})}{3}
  \]

Spark-generators produce high enough Graphite particle concentrations @ 15nm
Sub-23nm regulation

PNC parameters from current 10 nm PNCs
• At 15 nm penetration >90%
• Real d50% at around 7 nm.

Calibration with Soot-like or PAO particles
• Soot-like \( \rightarrow \) Wide distributions \( \rightarrow \) increasing uncertainty \( \sim 3\% \) due to multiple charges

<table>
<thead>
<tr>
<th>dp (nm)</th>
<th>eff. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ±1</td>
<td>65 ±15</td>
</tr>
<tr>
<td>15 ±1</td>
<td>&gt; 90</td>
</tr>
</tbody>
</table>

Here over 15% double charges
Sub-23nm regulation

- PNC-efficiency and VPR-type selection is based on minimizing artefacts
  - Artefacts are formed after VPR in PN measurement system
  - Artefacts are detected with Evaporation Tube (ET) not with Catalytic stripper (CS)
- Artefacts are detected mostly **below 10 nm**: PNCs of ≤4 nm D50%
  - Zheng *et al.* 2011, HD+DPF, ET, artefact below 10n
  - Johnson *et al.* 2009, HD, ET, artefact detected with 3 nm CPC
  - Giechaskiel *et al.*, 2017, mobed 2-stroke, ET, artefact below 10nm
- Artefacts rarely detected with PNC10 (defined in previous slide)
- **PMP IWG proposal will be that both CS and ET are approved in regulatory PN measurements**
- addition of stricter volatile removal efficiency requirement
Conclusions

• We are at the **Timeline for 10 nm studies**
  • Proposal for Sub23nm measurement system characteristics about ready one more round for comments within PMP IWG, then 1st proposal

  → PNC efficiency $(65 \pm 15)\% @ 10 \text{ nm}, > 90\% @ 15 \text{ nm}$
  → Soot-like or emery oil in CPC calibration
  → PN losses @ 15 nm < 2x losses @ 100 nm
  → VPR either Evaporation tube or Catalytic Stripper

• LD exercise suggests that **PN10 can be measured reliable with current systems** (Losses not considered)
• HD exercise suggests that **Tailpipe sampling comparable with Partial flow Dilution for both PN10 and P23**
• **Catalytic Stripper and Evaporation Tube PN-systems comparable**
  For HD, CS and ET similar although different sampling positions
• PN10PEMS evaluation in early 2020
Next steps & Thank You
Market surveillance

New type-approval framework Reg. 2018/858 (replaces Dir. 2007/46/EC) applicable from 2020 and introduces market surveillance
Will focus on environmental performance and safety (20% of tests)
Raise the quality level and independency of type-approval and testing before a car is placed on the market
– Member states will be able to take measures in their national markets, instead of having to wait for the type-approval authority of the country that issued the vehicles’ type-approval certificate.
– National type-approval authorities will be subject to a peer review
Monitoring vehicles that are already on the EU market by Member States
European oversight: Forum for exchange of information on enforcement

• Environmental performance validation includes SPN