Real-driving emission results from GDI vehicles with and without a GPF

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Association for Emissions Control by Catalyst (AECC)

AECC members: European Emissions Control companies

Technology for exhaust emissions control on cars, buses and commercial vehicles and an increasing number of non-road applications and motorcycles.
Content

• Setting the scene
• 2016 GDI test programme
  – Set-up
  – NEDC and WLTC results
  – RDE results
• Cold start GDI PN emissions
• Conclusions
Health impact of ultrafine particles

- Concerns reported because of the surface area of UFP and its translocation capability into the human body
- Conclusions of 2013 WHO Review of Evidence on Health Aspects of Air Pollution (REVIHAAP)
  - Indications for toxic effects of UFP
  - Not enough epidemiological evidence for UFP air quality guideline in addition to PM$_{2.5}$ and PM$_{10}$
  - Precautionary principle: WHO supports regulatory efforts to reduce the number of UFP (PN) in engine emissions
RDE legislation to close the gap between lab and real world emissions

<table>
<thead>
<tr>
<th>Date</th>
<th>Event/Condition</th>
<th>CF1</th>
<th>CF2</th>
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<tr>
<td>Apr/16</td>
<td>RDE monitoring (NT only)</td>
<td>CF1 = 2.1</td>
<td>CF2 = 1+0.5*</td>
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<td>(NT only)</td>
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<td>Sept/19</td>
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<td>CF1 = 2.1</td>
<td>CF2 = 1+0.5*</td>
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<td></td>
<td></td>
<td>(All)</td>
<td>*error margin</td>
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<tr>
<td>Jan/21</td>
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<td>*error margin</td>
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</tbody>
</table>

- **NTE limit = Euro 6 limit x CF**
  - CF defined for NOx, PN expected
  - Error margin to be reviewed annually
- **CF applies to urban part and total trip**
- **PEMS data post-processed with normalisation tools**
  - EMROAD (moving average window) and CLEAR (power binning)
  - Normalisation for dynamic driving conditions
  - Cold start emissions post-processing expected
The GDI particle RDE issue

- CO₂ legislation promotes fuel-efficient Gasoline Direct Injection (GDI) in the EU
- Particles emitted by DI gasoline vehicles are higher than Euro 6c limit of 6×10^{11} #/km, especially under real driving conditions
- Gasoline Particulate Filters (GPF) are an effective route to reduce the number of ultrafine particles under a range of driving conditions

Source: PMP Inter-Laboratory Correlation Exercise Final Report

Source: AECC member
Gasoline Particulate Filter (GPF)
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2016 GDI test programme within the AECC PEMS database

- Diesel vehicles → focus on NOx RDE
  1. 2013: HP+LP EGR, on market
  2. 2013: SCR, on market
  3. 2013: LNT + SCR, on market
  4. 2014: SCR on DPF, clean diesel demonstrator, CF<1.5
  5. 2015: SCR on DPF, on market, CF<1.5

- Gasoline vehicles → focus on PN RDE
  1. 2012: GDI-MPI w/o GPF, on market
  2. 2015: 1\textsuperscript{st} GDI w GPF on market
     NO\textsubscript{x} and PN CF <1
  3. 2016: GDI w/o GPF on market + GPF demonstrator; ongoing
2016 GDI test programme set-up

- Objective: investigate NOx & PN RDE without and with GPF
- At Ricardo in cooperation with Concawe
- Vehicle
  - Medium size, 1.4l engine
  - Market representative GDI technology targeting Euro 6c → only Euro 6b available
  - Original configuration w/o GPF
  - Add coated GPF demonstrator underfloor
- HORIBA PEMS equipment
  - Gaseous PEMS (CO₂, CO, NOx)
  - PEMS-PN demo unit
2016 GDI test programme set-up

- Identified parameters to evaluate
  - fuel type & quality
  - cold start PN
  - driving dynamics (RDE on dyno)
  - cold ambient temperature
  - <23nm PN

- Test matrix

- Focus of today
  - Market E5
  - NEDC + WLTC
  - RDE on road
  - no exclusions/normalisation

<table>
<thead>
<tr>
<th>Exhaust</th>
<th>Fuel</th>
<th>NEDC + WLTC</th>
<th>RDE on road</th>
<th>RDE on dyno</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original (without GPF)</td>
<td>Ref E5</td>
<td>1x</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>Ref E10</td>
<td>1x</td>
<td>3x</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Market E5</td>
<td>1x</td>
<td>3x</td>
<td>6x</td>
</tr>
<tr>
<td>With coated GPF</td>
<td>Ref E10</td>
<td>1x</td>
<td>3x</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Market E5</td>
<td>1x</td>
<td>3x</td>
<td>6x</td>
</tr>
</tbody>
</table>
2016 GDI test programme RDE route
NEDC + WLTC results w/o GPF on E5 ref fuel are below Euro 6c limits

- Data demonstrates that the vehicle is a state of the art GDI
WLTC results w/o GPF on market fuel are within Euro 6c limits, except PN

![Graphs showing emissions data with Euro 6c limit marked]

Euro 6c limit

Association for Emissions Control by Catalyst RISBL
NEDC and WLTC results with GPF on market fuel are within Euro 6c limits
Total RDE results w/o GPF

- Preliminary data, without exclusions/normalisation
Urban RDE results w/o GPF

- Preliminary data, without exclusions/normalisation
Total RDE results with GPF

- Preliminary data, without exclusions/normalisation
Urban RDE results with GPF

- Preliminary data, without exclusions/normalisation
2016 GDI programme next steps

• Investigate impact of normalisation tools
• Investigate fuel impact (reference E10 vs. market E5)
• Investigate impact of boundary conditions
• Investigate <23nm PN
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Impact of cold start on urban RDE is compared to that in test cycles

Cold: UDC1 (200s/1km)

Cold: first short trip (120s/0.61km)

Cold: first 2 short trips (151s/0.81km)

mg/km including cold

mg/km excluding cold

\[ \text{mg/km} = 2 \times 13\% - \text{cold contribution (300s/1-2km)} \]

Cold contribution

mg/km %

Association for Emissions Control by Catalyst RISBL
Impact of cold start on urban RDE is compared to that in test cycles

1. WLTC < NEDC
2. RDE: up to 80% from cold start
3. RDE raw > CLEAR > EMROAD

2012 Vehicle 1 w/o GPF

2015 Vehicle 2 with GPF
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Conclusions

• Engine-out RDE PN emissions of GDIs are higher than on the regulatory test cycles

• GPF technology is available and demonstrates PN reduction under all driving conditions

• The currently excluded 5 minutes of cold start PN emissions are significant and should be well controlled by RDE legislation

• Further work is undertaken in the current AECC 2016 GDI test programme

• Further evaluation of the AECC PEMS database is ongoing
Thank you for your attention