Real-Driving Emissions from a Gasoline PHEV with and without a GPF

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Association for Emissions Control by Catalyst (AECC AISBL)

AECC members: European Emissions Control companies

- Exhaust emissions control technologies for original equipment, retrofit and aftermarket for all new cars, commercial vehicles, motorcycles, and non-road mobile machinery
Content

- PHEV test programme set-up
  - Real-Driving Emissions (RDE) testing on the road
  - RDE testing on the chassis dyno towards the RDE boundary conditions
- PN RDE results without and with a GPF
- NOx RDE results and impact of ICE cold-start peak
- Summary
Test programme set-up

- **Objective:** measure the real-world behaviour of a market-representative Plug-in Hybrid Electric Vehicle (PHEV)
- **Vehicle:** C-segment, 1.5l class GDI engine, Euro 6b, E5 market fuel
- **Test Matrix**
  - All 4 driving modes: Electric, Hybrid, Charge and Sport
  - Variation in initial battery State of Charge (SOC)
  - RDE on-road and on the chassis dyno
  - 2 tests repeated with a coated Gasoline Particulate Filter (GPF) replacing the second (underfloor) Three-Way Catalyst (TWC)
- Emissions are compared to similar GDI vehicle tested in 2016 AECC test programme*

* Real-World Emissions Measurements of a GDI Vehicle without and with a GPF, Demuynck, et al., SAE 2017-01-0985
8 combinations of mode and initial battery SOC tested

Change in battery SOC (State of Charge) during on-road RDE tests

<table>
<thead>
<tr>
<th>SOC</th>
<th>Electric</th>
<th>Hybrid</th>
<th>Charge</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>1x</td>
<td>1x</td>
<td>-</td>
<td>1x</td>
</tr>
<tr>
<td>85%</td>
<td>1x</td>
<td></td>
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<tr>
<td>55%</td>
<td>1x</td>
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<td></td>
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<tr>
<td>25%</td>
<td>1x</td>
<td>1x</td>
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</tr>
</tbody>
</table>

Comparison to WLTP definitions

- **Charge depleting:** Electric – 100%
- **Charge sustaining:** Hybrid – 85% and Electric – 25%
RDE route and speed profile

![RDE Cycle Route from GPS](image)

- Rural
- Motorway
- Urban

![Vehicle speed vs. Distance](image)

- Vehicle speed vs. Time

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On-road data within RDE boundary conditions

Excess or absence of driving dynamics

- covered
- trip average
- moderate boundary
- extended boundary

Ambient temperature (°C)

Altitude (m)

Excess or absence of driving dynamics

V̄ x̄apos;95%

RPA

Avg veh speed (km/h)
Impact of RDE boundary conditions tested on the chassis dyno

Severitised RDE (SRDE) visualised with 2016 GDI data; PHEV tests with combination of step 1-3

1. Change accelerations

2. Change dyno load

3. Change ambient temperature
Most urban PN emissions higher than GDI with GPF

Electric mode – full battery: urban part entirely run electric → zero urban tailpipe PN emissions
Charge mode – empty battery: high power demand on ICE → highest PN emissions

ICE: Internal Combustion Engine
Electric mode – full battery: ICE operates for 2/3 of trip, but PN emissions as high as other modes

Charge mode – empty battery: high power demand on ICE → highest PN emissions

ICE: Internal Combustion Engine
PN spikes at cold ICE start during high power demand

- **Charge mode – empty battery**: PN peak at start of trip → highest PN level
- **Electric mode – full battery**: PN peak in middle of trip → overall same PN level as other modes

ICE: Internal Combustion Engine
All Severitized RDE PN w/o GPF above Euro 6d NTE limit

Note: 1.6 factor for extended ambient temperature included where applicable
All PN results with GPF are below Euro 6d NTE limit

Note: 1.6 factor for extended ambient temperature included where applicable

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All total RDE NOx emissions below Euro 6d NTE limit

- Reference GDI result is in the middle of PHEV total NOx range
- Total NOx emissions of PHEV with fully-charged battery are consistently the lowest
Reference GDI result is in the middle of PHEV urban NOx range

NOx emissions of PHEV with fully-charged battery are consistently the lowest

Electric mode – full battery: urban part entirely run electric ➔ zero urban tailpipe NOx emissions

Electric mode – 55% battery SOC: highest NOx emissions
All Severitized RDE NOx emissions below Euro 6d NTE limit

Note: 1.6 factor for extended ambient temperature included where applicable
NOx peak at cold ICE start impacts overall NOx level

- **Electric mode – full battery**: higher peak in SRDE test → highest SRDE NOx level
- **Electric mode – 55% battery SOC**: lower peak in SRDE test → lower SRDE NOx level
- **Hybrid mode – full battery**: higher peak at start of trip → higher SRDE NOx level

ICE: Internal Combustion Engine
Summary

AECC PHEV test programme
- Tested 1 Euro 6b C-segment vehicle
- Raw data is shown, without RDE post-processing

PN and NOx Real-Driving Emissions
- Zero tailpipe emission capability at point of use
  - in electric mode when battery has been fully charged
  - trip distance within electric range
- Higher emissions than reference GDI observed under other conditions
  - NOx results are all below Euro 6d NTE limit
  - timing of cold ICE start during RDE trip strongly impacts NOx and PN emissions
- High PN spikes observed at cold ICE start are well controlled by GPF
THANK YOU!

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