Expected Light Duty Vehicle Emissions from Final Stages of Euro 6

EU Refining Forum - 1 December 2017

Dr Nick Powell
What is Euro 6 and what are the stages of its introduction?

What are the challenges of complying with Euro 6 including Real Driving Emissions?

What actual tailpipe emissions do we expect?
Euro 6 diesel emissions limits are (nearly) comparable to gasoline for key emissions

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Gasoline (Positive Ignition)</th>
<th>Diesel (Compression Ignition)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxides of Nitrogen</td>
<td>NO\textsubscript{x} (mg/km)</td>
<td>60</td>
</tr>
<tr>
<td>Particulate Mass</td>
<td>PM (mg/km)</td>
<td>4.5 [GDI only]</td>
</tr>
<tr>
<td>Particle Number</td>
<td>PN (#/km)</td>
<td>$6 \times 10^{11}$</td>
</tr>
</tbody>
</table>

Source: Ricardo EMLEG
Euro 6 legislation aims to reduce the difference between legislated emissions levels and real world levels

- Euro 6 tailpipe emissions legislation is being introduced in stages to 2021

### Implementation Dates for Passenger Cars

<table>
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<tbody>
<tr>
<td>Euro 6b</td>
<td>NEDC</td>
<td>Voluntary Monitoring</td>
<td></td>
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<td>Euro 6c</td>
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<tr>
<td>Euro 6d-temp</td>
<td>WLTC</td>
<td>Temporary CF = 2.1 (1.5 for PN)</td>
<td></td>
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<td>WLTC</td>
<td>Final CF ≤1.5</td>
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Key: 
- Type Approval
- New Vehicles

NEDC: New European Driving Cycle; WLTC: Worldwide harmonized Light vehicles Test Cycle

Conformity Factor: The maximum ratio between the legislated emissions limit under laboratory testing and those measured in real driving conditions.

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The New European Drive Cycle (NEDC), used since the 1990s, requires relatively light load and low speed engine operating conditions.

Drive cycles used for Euro 6 passenger cars

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<th>Drive Cycle</th>
<th>Duration (s)</th>
<th>Average Speed (km/h)</th>
<th>Maximum Speed (km/h)</th>
<th>Maximum Acceleration (m/s²)</th>
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<td>1180</td>
<td>33.3</td>
<td>120.0</td>
<td>1.04</td>
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Source: EU Regulation, Ricardo
The Worldwide harmonized Light vehicles Test Cycle (WLTC) is more representative of real world driving conditions than NEDC

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<td>46.5</td>
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- RDE and WLTC have
  - Increased number & magnitude of accelerations
  - Higher maximum speeds

Source: EU Regulation, Ricardo
An RDE cycle is complementary to the WLTC, testing vehicles on real roads under realistic driving conditions

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<tr>
<td>RDE</td>
<td>6769</td>
<td>49.7</td>
<td>159.6</td>
<td>4.17</td>
</tr>
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Ricardo’s RDE cycle is an example of a valid high speed and high dynamic RDE test

- RDE and WLTC have
  - Increased number & magnitude of accelerations
  - Higher maximum speeds

- Environmental conditions
  - “Moderate RDE” :
    0°C to 30°C, 0 to 700m altitude
    Representative of most normal driving
  - “Extended RDE” :
    -7°C to 35°C and 1300m altitude

Source: EU Regulation, Ricardo
The implementation of WLTC and RDE from 2017 will extend the engine speed and load conditions at which emissions are regulated.

The New Engine Drive Cycle (NEDC)
- Light load and low speed engine

The Worldwide harmonised Light vehicles Test Cycle (WLTC)
- Emissions control over wider speed load range

Real Driving Emissions (RDE)
- Measured on-road using Portable Emissions Measurement System (PEMS)
- In real road and traffic conditions
Real world emissions data from public domain sources have been combined with Ricardo test data from RDE compliant testing

- This study has considered emissions under real world driving conditions from a variety of sources

<table>
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<tr>
<th>Public domain papers</th>
<th>Ricardo PEMS test data</th>
<th>Ricardo specialist opinion</th>
</tr>
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<tr>
<td></td>
<td>Production vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Development vehicles</td>
<td></td>
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- Most published domain data refers to Euro 6b vehicles
- Ricardo has tested production vehicles certified to Euro 6b and 6c, or under development to Euro 6d, fitted with combinations of NOx aftertreatment control:
  - Exhaust Gas Recirculation (EGR)
  - Lean NOx Trap (LNT)
  - Selective Catalytic Reduction (SCR)

- Vehicles tested by Ricardo over a variety of RDE compliant cycles

Note: Study completed August 2017
The stages of Euro 6 introduction show a progressive reduction in real world driving diesel NOx emissions.

**Diesel NOx under real world test conditions**

- **Euro 6b**
  - Type Approval Dates: September 2014 – August 2017
  - NOx Limit: 1600 mg/km
  - Measured Min: 0 mg/km
  - Measured Max: 2000 mg/km
  - Measured Mean: 1000 mg/km
  - Measured Median: 800 mg/km

- **Euro 6b - post 2015**
  - Type Approval Dates: September 2014 – August 2017
  - NOx Limit: 1400 mg/km
  - Measured Min: 0 mg/km
  - Measured Max: 1800 mg/km
  - Measured Mean: 1000 mg/km
  - Measured Median: 800 mg/km

- **Euro 6c**
  - Type Approval Dates: April 2016 – August 2017
  - NOx Limit: 1200 mg/km
  - Measured Min: 0 mg/km
  - Measured Max: 1500 mg/km
  - Measured Mean: 900 mg/km
  - Measured Median: 700 mg/km

- **Euro 6d temp**
  - Type Approval Dates: September 2017 – December 2019
  - NOx Limit: 1000 mg/km
  - Measured Min: 0 mg/km
  - Measured Max: 1300 mg/km
  - Measured Mean: 800 mg/km
  - Measured Median: 600 mg/km

- **Euro 6d**
  - Type Approval Dates: January 2020 –
  - NOx Limit: 800 mg/km
  - Measured Min: 0 mg/km
  - Measured Max: 1100 mg/km
  - Measured Mean: 700 mg/km
  - Measured Median: 500 mg/km

Post 2015 vehicles which meet Euro 6 NOx levels under at least one real driving test cycle.
Diesel Particle Number complies comfortably with the limit value. Gasoline technologies also expected to require particle filters.

It is expected that specific GPFs will be required on many if not all GDI gasoline vehicles to ensure gasoline compliance with PN conformity factor of 1.5.
Future Euro 6 regulations will deliver substantial reductions in real world NOx emissions for diesel vehicles – comparable to gasoline

- Although there are a limited number of Euro 6c and 6d-temp ready vehicles to date, the evidence suggests that the technical solutions applied to Euro 6d will achieve regulated conformity factors under real world driving and moderate RDE conditions.

- The evidence indicates that vehicle averaged real world diesel NOx emissions are substantially reduced by successive levels of Euro 6 legislation, from Euro 6b to Euro 6d.

- Specific and careful configuration and calibration of the emissions control systems is required for real world diesel NOx control.

- Real world diesel PN data for Euro 6c and 6d vehicles are within the Euro 6 conformity factor limits.

- A GPF is likely to be required for gasoline vehicles to meet Euro 6d PN emissions requirements on all RDE cycles.