

An Assessment of Emissions from Light-Duty Vehicles using PEMS and Chassis Dynamometer Testing

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ABSTRACT

From 1 September 2014 new car types in the EU must meet 'Euro 6' emissions requirements. The 'New European Driving Cycle' (NEDC) is currently the main test for this, but the European Commission intends to also introduce PEMS (Portable Emissions Measurement Systems)-based procedures to ensure that emissions are well controlled in real use. 'Random Cycles' have also been considered and remain a possible option for 'real world' particle number measurement. At the same time, the UN Working Party on Pollution and Energy (GRPE) has developed the new Worldwide harmonized Light vehicles Test Procedure (WLTP) that is expected to be adopted in the EU in the near future. To identify and understand the differences in emissions that may arise between these various methodologies, AECC has conducted some initial tests on two modern light-duty vehicles.

Chassis dynamometer emissions tests were conducted over the NEDC, the Common Artemis suite of test cycles (CADC), the new Worldwide Light-duty Test Cycle (WLTC - the test cycle for WLTP) and a set of cycles produced by a Random Cycle Generator based on 'short trip' segments from the EU database used to construct WLTC. A Portable Emissions Measurement System (PEMS) was used to measure emissions during real driving over pre-selected routes.

The test results show that there can be substantial differences for some pollutants measured as 'real driving emissions' (RDE) using PEMS equipment, compared to the test cycles.

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INTRODUCTION

The next stage of the European light-duty emissions regulations (Euro 6) will become mandatory for Type Approval of new car types on 1 September 2014 and 1 year later for all new car registrations (Note both dates are 1 year later for light commercial vehicles - all dates in this paper refer to the dates applicable to passenger cars, category M1).

Following concerns over the 'real world' performance of vehicles approved under previous stages of EU legislation [1] - in particular the NO_x emissions of diesel light-duty vehicles - the European Commission has announced in its 'CARS 2020 Action Plan [2] its intention to include an additional test for 'Real Driving Emissions of Light-Duty Vehicles (RDE-LDV) from the start of Euro 6.

At the time of writing, it is anticipated that, following the conclusions of a European Commission working group [3], this will take the form of on-road emissions measurements using Portable Emissions Measurement Systems (PEMS) for gaseous regulated emissions. For particulate mass and/or particle number emissions, EU Member States have stated

their interest in applying the same RDE-LDV method to all pollutants, if appropriate and technically feasible. However, PEMS systems for light-duty PN measurement are at an earlier stage of development and so 'Random Cycles' remains an option for this aspect. These RDE-LDV procedures are planned to be gradually implemented from 2014 onward, initially by inclusion of test procedures in the Euro 6 Regulation, with the introduction of 'Conformity Factors' proposed from the Euro 6c stage starting in 2017.

A further aspect of development is that although emissions limits have so far been set using the New European Driving Cycle (NEDC) [4], the UN Working Party on Pollution and Energy (GRPE) has developed a Worldwide harmonized Light vehicles Test Procedure (WLTP) [5] and associated cycle (Worldwide Light-duty Test Cycle; WLTC) that is expected to be adopted in the EU in the near future. It is expected that in the EU this cycle will be first required for CO₂ measurements, but is expected to also be available for pollutant measurement.

A further set of test cycles that is widely used in Europe is the 'Artemis suite' (Common Artemis Driving Cycles; CADC) [6]. This incorporates more transient operating modes derived from real-world driving. It is not a legislative test cycle but is used as the basis of emissions factors determination for modelling of emissions in Member States that need to comply with European Air Quality legislation.

AECC has previously conducted tests comparing the NEDC, CADC and WLTC [7] as part of the validation program for WLTP, but these tests did not include the RDE-LDV proposals. To identify and understand the differences in emissions that may arise between these new methodologies and between them and existing procedures, AECC therefore conducted some initial tests on two modern light-duty vehicles. The first of these was a Euro 5 gasoline vehicle and the second a Euro 6 diesel vehicle. The tests were all conducted by a single independent laboratory.

TEST VEHICLES

The two vehicles tested were normal production vehicles taken from the EU market. The gasoline vehicle was Type Approved to the Euro 5b standards and was registered in April 2012. It had a manual (6-speed) transmission and at the start of testing had covered 4000 km. The diesel vehicle was Type Approved to the Euro 6 standard and was registered in January 2012. It had an 8-speed automatic transmission and had covered 22 900 km at the start of the test program. A summary of key characteristics is shown in [table 1](#).

Table 1. Main vehicle characteristics

	Engine size (litres)	Power (kw)	Euro standard	Engine technology	Emissions technology
Gasoline	1.8	125	Euro 5b	PFI+GDI	TWC
Diesel	3.0	180	Euro 6b	DI Diesel turbo	DPF+deNOx

TEST CYCLES

Chassis Dynamometer Tests

Test Cycles

Chassis dynamometer tests were conducted over four different cycles - the current legislative New European Driving Cycle (NEDC), the Common Artemis suite of test cycles (CADC), the new Worldwide harmonized Light vehicles Test Cycle (WLTC - the test cycle for WLTP) and a set of cycles produced by a Random Cycle Generator that was made available to the European Commission's working group on RDE-LDV. This produced cycles based on 'short trip' segments from the EU database used to construct WLTC.

The NEDC tests were performed to the current regulatory standards and the WLTC tests to the draft WLTP procedures, both being cold start tests following a soak period. The final version of WLTP incorporates variations for vehicles with lower power-to-mass ratio and maximum speed (v_{max}). The cycle used for this test program was the 4-phase test (low-, medium-, high-, and extra high-speed phases) that is applicable to the typical European vehicles tested, with power to unladen mass ratio of > 34 W/kg and $v_{max} \geq 120$ km/h (WLTP Class 3b). The CADC tests, comprising an Urban, Extra-Urban and a Highway phase, were conducted as hot-start tests as is normally the case for CADC. In most uses, each of these three CADC phases includes portions at the start and end of the cycle in which the emissions are not sampled. However, as some authorities were understood to evaluate emissions over the whole cycle, this variant was used for all AECC test work. Three repeat tests were run for each of these cycles.

For the Random Cycles, it was decided to test three different random cycles produced by the Random Cycle Generator to assess the degree of variability seen, rather than running 3 repeats of the same cycle to assess repeatability. The resultant cycles for the gasoline vehicle are shown in [Figure 1](#) and those for the diesel vehicle in [Figure 2](#). As may be seen from these two figures, there were substantial differences between the cycles in parameters such as maximum speed and the length of steady-state periods.

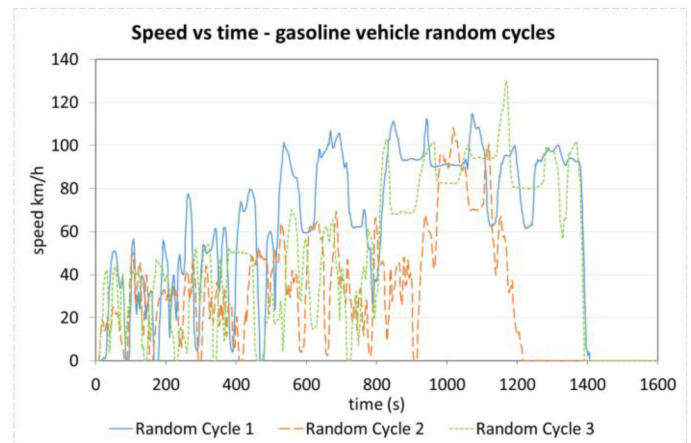


Figure 1. Random Cycles for the gasoline vehicle

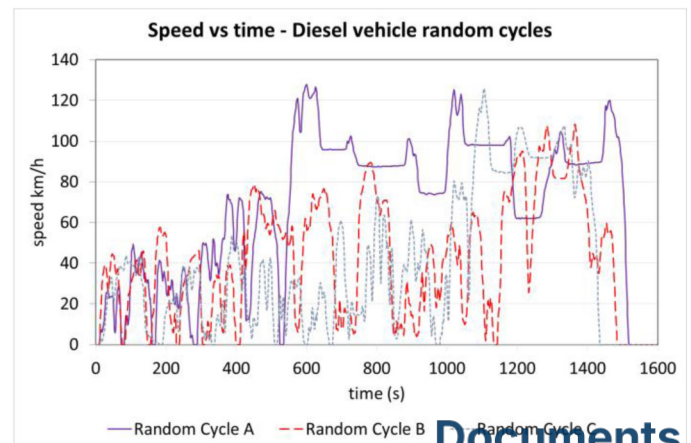


Figure 2. Random Cycles for the diesel vehicle

Measurements of carbon monoxide (CO), total hydrocarbons (HC), oxides of nitrogen (NO_x), particulate mass (PM) and particle numbers (PN) were made according to current regulatory standards set out in UN Regulation 83.

Inertia Masses

One area of significant difference between the current (NEDC) test procedures and the WLTP is the calculation of road load and setting of the test (inertia) masses.

For WLTP, the road load relevant characteristics of the vehicle including aerodynamic drag and tyre rolling resistance are taken into account, and, unlike the current procedures, the vehicle test mass for regulated pollutants has to include the mass of optional equipment. As a result, the test masses for WLTP will often be higher than that for the current regulatory test. For the gasoline vehicle, the resulting WLTP-based inertia mass was 1930 kg, compared to 1590 kg when using current procedures. For the diesel vehicle, the WLTP-based inertia mass was 2460 kg, compared to 2150 kg under current procedures.

It was decided that all tests on the gasoline vehicle should be run at the higher (WLTP) inertia. However, to give a comparison with the current regulatory procedure, a single NEDC test was run at the lower inertia. When the diesel vehicle was to be tested, this approach was reconsidered. As a result the NEDC and CADC tests were run at the lower inertia weight, as this is what would normally be used in current testing. The WLTC and Random Cycle tests used the higher inertia as this is what would be expected for future test regimes. To provide a direct comparison of the effect of the two settings, an additional CADC test was run at the higher inertia setting.

PEMS Testing

A Portable Emissions Measurement System (PEMS) was used to measure emissions during real driving over pre-selected routes. The system comprised a Semtech-D (Sensors) system for measurement of CO, HC, NO, NO₂, CO₂ and O₂ together with an AVL photoacoustic Micro Soot Sensor. This sensor provides a measure of the soot content of particulate mass (PM) but not a measure of particle number (PN). At the time of testing PEMS equipment for measurement of PN was not available.

The gasoline vehicle was tested first, in July 2012. 3 days of PEMS testing were conducted over a fixed route, with 4 tests per day, each lasting approximately 1 hour. The tests route comprised a total of 45.8 km, of which approximately 21 km was classified as city driving, approximately 9 km as rural and approximately 16 km as motorway. The maximum altitude reached was 260 m above sea level. In the three days of PEMS testing there were very different driving conditions, ranging from a fluid traffic flow to a total traffic jam. Key characteristics for the test are shown in [Table 2](#).

Table 2. PEMS route characteristics - gasoline vehicle

		Mean	Min.	Max.
Average vehicle speed per test	km/h	36.5	21.7	44.0
Maximum vehicle speed per test	km/h	126.3	125.0	130.4
Stop duration per test	s	947.8	448.0	2182.0
Maximum acceleration per test	m/s ²	2.2	1.6	4.0
Relative positive acceleration per test *	m/s ²	0.117	0.101	0.134
Average recorded engine load per test	%	14.7	12.2	16.1

* Relative positive acceleration (RPA) has been used to characterize vehicle trips in the development of WLTC and can be interpreted as the specific acceleration work of the trip (in kW.s/kg.km).

$$RPA = \frac{\sum_{i=1}^n a_i \cdot v_i \cdot \Delta t}{s}$$

where a_i = acceleration at time step i , only if $a_i > 0$, [m/s²], v_i = vehicle speed at time step i , [m/s], Δt = time increment (=1), [s], and s = total trip distance, [m].

The vehicle was parked overnight in an unheated garage, and in each case the PEMS equipment was powered well before the engine to enable it to achieve stability. Measurement was started before the engine. The first test of each day could therefore be considered as cold start. Nevertheless, the results for the cold-start tests were not substantially different from those for the hot-start tests. For CO₂, NO_x, NO₂, and CO, all results for the cold-start tests were within the range of those achieved on the hot-start tests. For soot, one of the three results was some 10% above the highest hot-start result, with the other two being within the range of hot-start results. For HC the cold-start results bracketed those from the hot-start tests, but all test results were very low (less than one third of the Type Approval limit).

When the tests on the diesel vehicle were conducted, the guidance from the RDE-LDV group suggested that 2 different routes should be tested, one with a greater proportion of motorway driving, and that the eventual RDE requirements might be for cold-start PEMS tests. The tests on this vehicle therefore used the same route as for the gasoline vehicle for 3 tests plus a modified version of the route which gave a total length of approx. 52 km, with a split of approximately 16 km classified as city driving, 6 km as rural and 30 km as motorway. The same maximum altitude (260 m) was reached. For this series of tests, 2 cold-start tests per day were conducted. As with the gasoline car, the diesel vehicle was kept in an unheated garage between tests, the PEMS equipment was powered well before the engine to enable it to achieve stability, and measurement was started before the engine start. These tests were conducted in February 2013, so ambient temperatures were somewhat lower than for the gasoline vehicle testing period. Key characteristics for these tests are shown in [Tables 3](#) and [4](#).