Emissions from Euro 3 to Euro 6 light-duty vehicles equipped with a range of emissions control technologies

J. May, C. Favre and D. Bosteels
Association for Emissions Control by Catalyst, Belgium

ABSTRACT

From 2008 to 2012, AECC, the Association for Emissions Control by Catalyst, conducted a ‘rolling programme’ of emissions tests on light-duty vehicles at an independent laboratory. In addition to assessment of regulated gaseous and particulate emissions over the legislative driving cycle (NEDC; New European Driving Cycle), the work included testing over the set of Common Artemis Driving Cycles (CADC) that incorporate more transient operating modes derived from real-world driving and that are widely used as the basis of emissions factors for modelling of emissions. All tests included particulate mass and particle number emissions using the PMP (Particle Measurement Programme) procedures developed under the UNECE – GRPE.

The vehicle range covered stoichiometric port fuel injection (PFI) and direct injection (DI) petrol vehicles, lean-burn DI petrol vehicles, and diesels with and without particulate filters. The most recent examples include diesel vehicles fitted with both NOx and particulates control systems. The vehicles chosen covered a wide selection of the European market, with engine capacities ranging from 1.2 to 3.5 litres and power outputs of between 60 and 220 kW. The results show the variations between technologies as well as the potential effectiveness of emissions control technologies over different test cycles.

1. Introduction

European emissions regulations for light-duty vehicles have developed over many years, with consequent continuous development of engine and emissions control technologies to meet the legislative requirements. In addition to limits on carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx) and diesel particulate mass (PM), the Euro 5 step (Regulation (EC) 715/2007) extended PM limits to DI Petrol vehicles and added a particle number (PN) standard (referred to in the Regulation as PM Number) for compression ignition vehicles from Euro 5b, applicable to all car registrations from 1 January 2013. For positive ignition engined vehicles, Regulation (EU) 459/2012 added a particle number limit for direct injection engined vehicles. For such vehicles a limit of 6×10^{11} particles/km applies from the start of Euro 6, but the manufacturer can choose to approve to a limit of 6×10^{12} particles/km until the start of the Euro 6c step (1 September 2017 for new types, 1 September 2018 for all registrations – these dates are 1 year later for light commercial vehicles). There is also an obligation on the European Commission to introduce, by the Euro 6c stage, a type approval test method to ensure the effective limitation of the number of particles under real driving conditions.

Figure 1 shows the main legislative limits for NOx and particulate matter from the Euro 1 to Euro 6 stages. The dates shown are those for new Type Approvals of category M vehicles.

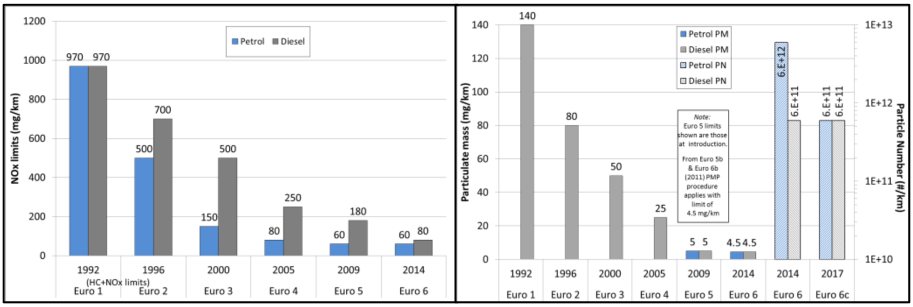

Figure 1: NOx and Particulate Matter Emissions Limits

In order to assess the performance of vehicles utilising a range of technologies, AECC conducted a series of test programmes at a single independent laboratory over the last 5 years. These tests have provided data on the emissions performance of current and future light-duty vehicles over both the legislative test cycle and in other driving conditions, particularly over the Common Artemis suite of Driving Cycles (CADC) that is used in the development of emissions factors for modelling of total light-duty vehicle emissions by the EU and its Member States.

2. Test vehicles

All tests were conducted on category M vehicles (passenger cars) intended to represent a range of emissions levels and vehicle technologies. The vehicles chosen covered a wide selection of the European market, with engine capacities ranging from 1.2 to 3.5 litres and power outputs of between 60 and 220 kW. Petrol- and diesel-engined vehicles were tested, with emissions capabilities ranging from Euro 3 to Euro 6. All vehicles had been run in for at least 3000 km as required by EU test procedures. Older vehicles tended to have substantially more mileage but were checked to ensure that they were in good condition, with normal oil consumption and no OBD faults. The vehicles tested are shown in Table 1.

Table 1: List of test vehicles

No.	Working Principles	Engine Capacity (litres)	Power (kW)	Emission level	First use date	Gear box	Mileage (km)	Test date
1	Diesel, no DPF	1.9	85	Euro 3	1999	M6	180 000	2008
2	Petrol PFI	2.0	85	Euro 3	1999	M5	120 000	2008
3	Diesel with DPF	2.0	100	Euro 4	2004	M6	15 500	2008
4	Diesel, no DPF	1.9	77	Euro 4	2005	M6	45 000	2008
5	Diesel with DPF	2.0	100	Euro 4	2008	M6	15 000	2008
6	Diesel with DPF	1.9	77	Euro 4	2006	M6	61 000	2008
7	Diesel with DPF	1.9	77	Euro 4	2007	M6	14 250	2008
8	Petrol PFI	2.0	85	Euro 4	2001	M5	60 000	2008
9	Petrol lean DI	2.0	105	Euro 4	2008	M6	3 000	2008
10	Diesel, DPF+deNOx	3.0	155	Euro 4	2008	A7	6 250	2008
11	Petrol λ1 DI	1.4	92	Euro 4/5	2008	M6	9 750	2008
12	Diesel, DPF+deNOx	3.0	180	Euro 6a*	2009	M6	25 000	2010
13	Diesel, DPF+deNOx	2.0	103	Euro 6a*	2008	A6	10 000	2010
14	Diesel, DPF+deNOx	3.0	155	Euro 6a*	2010	A7	8 750	2010
15	Petrol lean DI	3.5	215	Euro 5	2009	A7	18 000	2010
16	Petrol λ1 DI	1.6	115	Euro 5	2009	M6	14 000	2010
17	Petrol λ1 DI	1.2	63	Euro 5	2010	M5	4 000	2011
18	Petrol λ1 DI/MPI	1.8	125	Euro 5b	2012	M6	4 000	2012
19	Diesel, DPF+deNOx	3.0	180	Euro 6b	2012	A8	22 900	2013

* = The three 'Euro 6a' vehicles were equipped with candidate systems to meet the first Euro 6 requirements.
For gearbox, M=manual, A=automatic; the number indicates the number of gears.

For petrol engines the technologies tested covered stoichiometric port fuel injection (PFI), stoichiometric direct injection, a combined system, and lean-burn direct injection. The emissions control aftertreatment systems for petrol vehicles comprised 3-way catalysts for stoichiometric vehicles and catalyst plus deNOx system for lean-burn direct injection systems. All diesel vehicles tested used direct injection (unit injectors for some of the earlier vehicles or common rail systems for more recent examples). The emissions control aftertreatment systems on the earliest vehicles comprised only Diesel Oxidation Catalysts (DOC), with Diesel Particulate Filters (DPF) used on all others and DPF+deNOx (either Lean NOx Traps or Selective Catalytic Reduction) systems on the most recent.

3. Test procedures

All vehicles were tested on the legislative New European Driving Cycle (NEDC) specified in current emissions legislation and the Common Artemis Driving Cycles (CADC) that incorporate more transient operating modes derived from real-world driving and that are widely used as the basis of emissions factors for modelling of emissions. The CADC suite comprises an Urban, an Extra urban and a Highway cycle. In addition, by the time that vehicles 18 and 19 were tested, the new Worldwide harmonized Light vehicles Test Procedure (WLTP) (1) was sufficiently developed for it to be also assessed.

The NEDC (2) comprises 4 repeats of an urban cycle and one extra-urban cycle, totalling nearly 11 km and with regulated gaseous and particulate emissions measured from key-on. Except for Particulate Mass (PM), separate measurements were made over the first two urban cycles (NEDC Urban 1+2) which represent the cold-start portion (from the standard laboratory temperature of 25±5°C), the combined third and fourth urban cycles (NEDC Urban 3+4) which represent warm urban operation, and the extra-urban cycle (EUDC). Results over the full NEDC can be calculated from these data. For PM, measurements were made using a single sample filter over the full cycle to give maximum accuracy in the weighing of sample filters, as specified in the latest version of the emissions regulations.

The CADC (3) comprises an Urban, Extra-Urban and a Highway cycle, run consecutively as a composite procedure totalling some 50 km. All of these are hot-start so were normally run immediately after the NEDC tests, with the engine fully warmed up. Data are available for each of these elementary test cycles as well as the complete suite of three cycles. In most uses, each of these three CADC cycles include 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. Data are also available from continuous measurements to enable calculation of emissions over the shorter cycles. The CADC tests are normally used in hot-start form, but to provide some comparisons, several of the vehicles were additionally subjected to single cold-start Artemis Urban tests after a normal soak procedure.

WLTP was still being finalised at the time of testing, but was sufficiently mature to allow vehicles 18 and 19 to be tested over the low, medium, high and extra-high speed phases that the test cycle (WLTC) comprises, giving a total distance of approximately 23 km for the main class of vehicle. An important aspect of WLTP, though, is that the vehicle inertia weight to be used for measurement of pollutant emissions will be higher than that used for current test procedures. For vehicle 18, a decision was made to run all tests at the higher WLTP inertia of 1930 kg, with a single NEDC test at the lower (NEDC) inertia weight of 1590 kg for comparison. For vehicle 19, the NEDC and CADC tests were made using the standard (NEDC) inertia weight, with the WLTP inertia used only for that test procedure. In this case a comparison was made by running a single CADC test at this higher inertia.

Measurements were made by using the regulatory test procedures - non-dispersive infra-red analysers for CO and CO_2, flame ionisation analyser for total hydrocarbons (HC) and chemiluminescence analyser for nitrogen oxides (NOx). For particulate mass (PM) and the number of particles (PN), the PMP procedures (4) that are now defined in UN Regulation No.83 were used. In this, PM is measured by weighing of the particulate matter collected on a PTFE or PTFE-coated glass fibre filter and PN is measured continuously using a condensation particle counter following a dilution/evaporation procedure to remove volatile particles. The range of particle sizes measured by this process is from 23 nm (set as the d_{50} 50% cut-off of the particle counter) to 2.5 µm (set by the 50% cut-point of a cyclone pre-classifier).

All vehicles were subjected to a minimum of 3 tests on each cycle, and the results presented below are the average of these tests except where stated.

4. Petrol engine vehicles

4.1 NEDC tests

All petrol engined vehicles met even the current (Euro 5/6) limits of 1000 mg/km CO, 100 mg/km HC and 60 mg/km NOx. For CO, the Euro 3 vehicle (No.2) and the first Euro 4 vehicle tested (No.8) gave the highest results at 855 and 753 mg/km respectively. All others apart from vehicle 16 gave results below 250 mg/km, with three of the most recent vehicles below 100 mg/km. For HC the results from the Euro 3 vehicle were the highest (74 mg/km) and there was a general trend for lower emissions with each emissions stage, but no clear relationship to engine or emissions system technology. For NOx, all results were between 15 and 40 mg/km, with no definitive trend.

For petrol engine vehicles there was no limit on particulate matter until the Euro 5 step at which point a PM limit was implemented for DI engines. In addition, a particle number (PN) limit has now been set for DI petrol engines, applicable from Euro 6 (5). Nevertheless, all AECC tests included both PM and PN measurements to provide data on the development of particulate emissions from petrol engine vehicles. As might be expected, all results on the NEDC showed PM emissions from both PFI and DI vehicles to be within the Euro 5/6 limits applicable to DI engines.

For PN, emissions on the NEDC were all above the eventual Euro 6c limit of 6×10^{11} particles/km except for the most recent vehicle (vehicle 18). Nevertheless, all the petrol engine vehicles, which were designed to meet the Euro 3, 4 or 5 standards – both PFI and DI - met the interim PN emissions limit of 6×10^{12} particles/km that will be a ‘manufacturer’s option’ until Euro 6c in 2017.

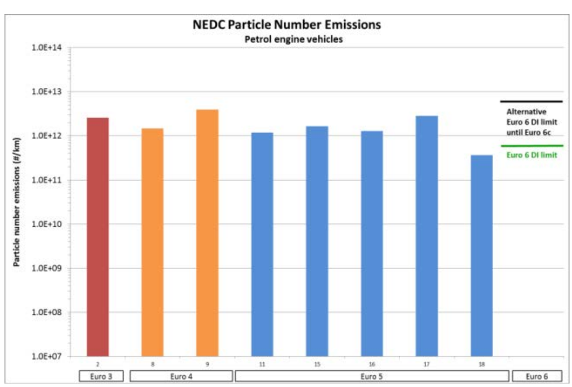

Figure 2: Particle Number emissions for Petrol Vehicles on the NEDC

The results for the two PFI vehicles (numbers 2 and 8) are somewhat higher than would have been expected from other work. An evaluation of PN results reported to the UN GRPE, for instance, (6) indicated PN from PFI vehicles to be around an order of magnitude lower than DI vehicles, and below 6×10^{11} particles/km. Similarly an examination conducted by the European Commission's Joint Research Centre (7) showed two PFI vehicles to consistently have PN emissions below 6×10^{11} particles/km when measured using the PMP procedure. A comparison of the continuous PN emissions data, shown in Figure 3, indicates that both of these PFI vehicles emitted substantial numbers of particles during the Extra-Urban part of the cycle, which appears to be the main source of the high emissions.

In addition, vehicle 11 shows a somewhat higher peak of particle number emissions closer to the start of the test than do the other vehicles. Such a peak at start-up is not uncommon and may relate (particularly for DI engines) to lower cylinder wall temperatures. The magnitude of the peak may well depend on a number of parameters including fuelling strategy and lubricant type.

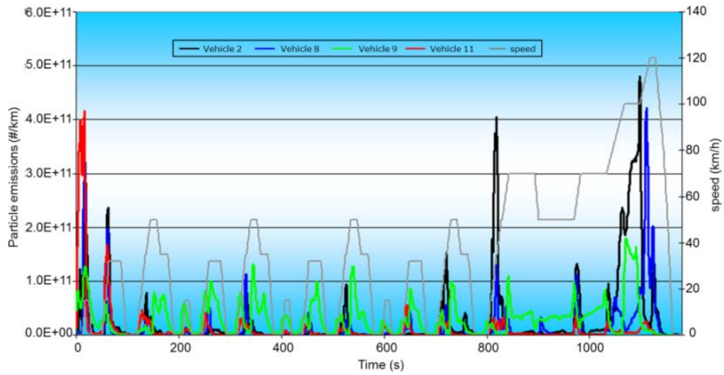

Figure 3: Continuous traces of PN emissions on the NEDC

4.2 CADC tests

For most of the vehicles, the emissions of CO and HC over the Artemis (CADC) cycles were lower than on the NEDC. The fact that the catalyst would have reached light-off on these hot-start CADC tests would have a significant influence on these results. In order to assess the effects of the start conditions, the Euro 5 vehicles were also subjected to a cold-start CADC Urban cycle following an overnight soak, in line with NEDC procedures. In all cases the cold-start CADC Urban results were lower than the results for the cold-start 'ECE1+2' portion of the NEDC but higher than for the hot-start CADC Urban test. It may be that the higher acceleration rates on the CADC result in faster catalyst heating than on NEDC.
These results are shown in Figure 4.

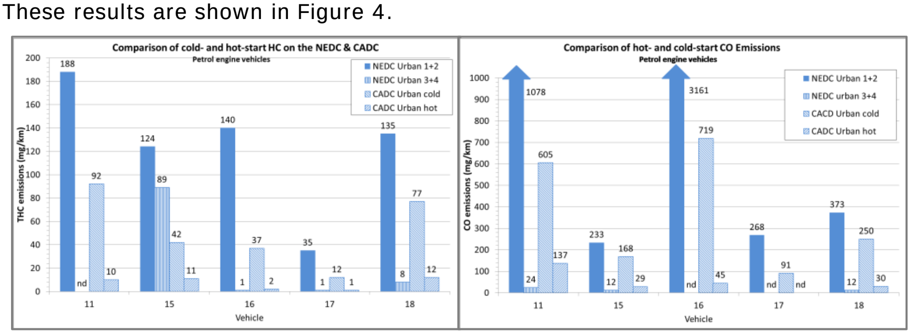

Figure 4: CO and HC results over cold- and hot-start urban cycles

The full-cycle results for CO, HC, NOx and PM are shown in Figure 5.
Vehicle 17 gave a substantially higher CO result on the CADC than on the NEDC, with emissions of 2613 mg/km over the full CADC, compared to 81 mg/km on the NEDC. This was due to an extremely high level of CO emissions on the Highway portion of the CADC test and was repeatable, with levels of 4858, 4308 and 4294 mg/km being recorded in the three repeat tests. This vehicle was the lowest-powered of those tested, which may well have had some influence on this test cycle in which comparatively high speeds are sustained for much of the test and must have required higher engine torque.

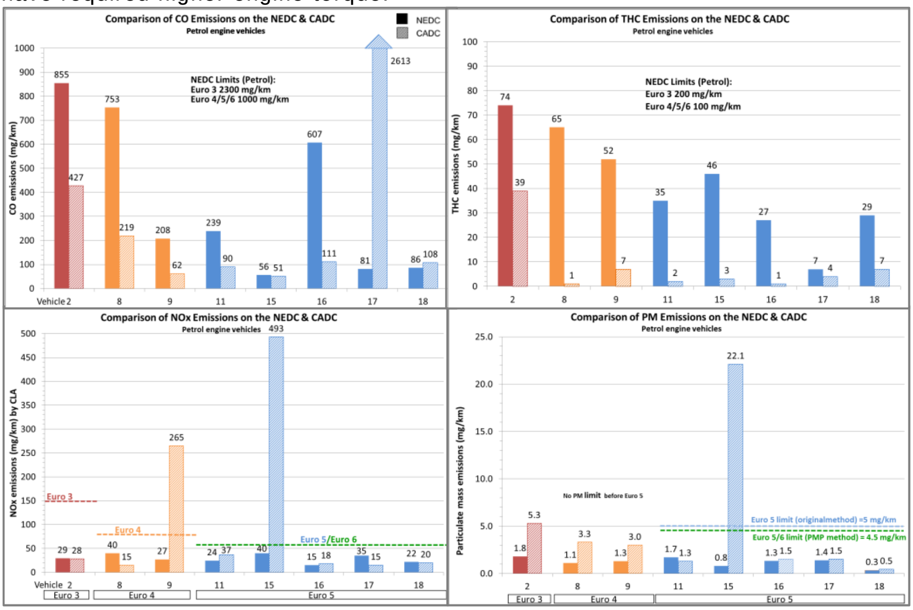

Figure 5: Petrol CO, HC, NOx and PM results over full NEC and CADC tests

For NOx, the results for stoichiometric vehicles were reasonably similar on the CADC and the NEDC, but the two lean DI vehicles gave significantly higher NOx over the CADC. NOx emissions of the Euro 4 car (vehicle 9) were 265 mg/km over the full CADC compared to 27 mg/km over the NEDC. In the case of the Euro 5 lean DI car (vehicle 15) the results were 493 mg/km over the full CADC compared to 40 mg/km over the NEDC. For both cars these high results related to the performance over the Highway portion of the CADC, with repeatable measured emissions averaging 406 mg/km for vehicle 9 and 804 mg/km for vehicle 15. Vehicle 15 also produced high PM emissions on the CADC. This too related to performance over the Highway portion of the CADC, where emissions of 43.6, 29.2 and 30.5 mg/km were recorded for the three repeat tests.

The particle number emissions for all the Euro 5 vehicles were of the same order of magnitude when measured over the CADC as they were on the regulatory (NEDC) cycle. The final petrol car tested (vehicle 18) in fact produced average PN emissions below the Euro 6 limit for DI vehicles over both the NEDC and the full CADC. The results for the individual tests are shown in Table 2.

Table 2: Particle Number results for Vehicle 18

	NEDC #/km	CADC #/km
Test 1	2.9×10^{11}	7.1×10^{11}
Test 2	3.9×10^{11}	4.3×10^{11}
Test 3	4.1×10^{11}	4.6×10^{11}
Average	3.7×10^{11}	5.3×10^{11}

4.3 WLTC tests and comparison of inertia weights

As noted under Test Procedures, all tests on vehicle 18 were conducted at the higher (WLTP) inertia weight except that, to allow the effect of inertia weight to be assessed, a single NEDC test was run at the normal (NEDC) inertia. (All other measurement used 3 repeats of each cycle). The comparison is included in Table 3 together with the average results over each of the test cycles. As might be expected, using the higher inertia weight on the NEDC generally resulted in a small increase in pollutant emissions and a significant increase in CO_2 emissions, although the PN result for the single NEDC at the lower inertia weight was actually above the range of results from the higher inertia tests (2.9×10^{11} to 4.1×10^{11} particles/km).

Table 3: Comparison of results for vehicle 18

Cycle	Inertia	Number of tests	CO	HC	NOx	PM	PN	CO_2
	kg		mg/km				#/km	g/km
NEDC	1590	1	84	24	22	0.27	5.7×10^{11}	131.3
NEDC	1930	3	86	29	24	0.34	3.7×10^{11}	146.8
CADC	1930	3	108	7	20	0.45	5.3×10^{11}	156.8
WLTC	1930	3	55	19	33	0.48	7.4×10^{11}	145.2

It is interesting to note that, compared to the NEDC test at the standard (lower) inertia weight, the new WLTP procedures resulted in lower CO and HC emissions, but higher NOx and PM (still within Euro 6 limits). This cycle produced the highest PN results for this vehicle, but still within the initial limits for Euro 6. With regard to CO_2, the WLTC resulted in emissions similar to the NEDC at the same inertia weight, but below those for the CADC at the same inertia.

5. Diesel engine vehicles

5.1 NEDC tests

As with the petrol engine vehicles, all CO emissions were below the current (Euro 5/6) limit of 500 mg/km, with a range from 46 mg/km (vehicle 4) to 325 mg/km (vehicle 6). For diesels there are no separate total HC limits as the Directives/Regulations provide only for limits on HC+NOx. All vehicles gave very low HC results, with the highest being 68 mg/km for vehicle 6. All vehicles readily met their respective NOx standards. The Euro 3 vehicle (vehicle 3) had measured NEDC NOx emissions of 357 mg/km compared to the limit of 500 mg/km. All the Euro 4 vehicles met the Euro 4 limit of 250 mg/km and would have met the Euro 5 limit of 180 mg/km, albeit with limited 'headroom' in the case of vehicle 6 (175 mg/km). The Euro 6 vehicles exhibited a range of results within the 80 mg/km test limit, with the most recent (vehicle 19) emitting only 17 mg/km NOx. For PM, the differentiation was essentially between vehicles that had Diesel Particulate Filters (DPFs) and those that did not. The majority of DPF-equipped vehicles gave PM emissions below 1 mg/km, the only exception to this being vehicle 10 which, at 3.3 mg/km still readily met the Euro 6 limit of 4.5 mg/km.

This vehicle also gave the highest PN emissions and was the only DPF-equipped vehicle to have PN emissions above the Euro 5/6 limit of 6×10^{11} particles/km. It should be noted, though, that this vehicle was a very early example of a system combining particulate and NOx control systems. It was homologated to the Euro 4 standard, before the PN limit was applicable.

5.2 CADC tests

The results for the full CADC and NEDC tests are compared in Figure 6.

For CO and HC, most vehicles showed emissions on the CADC tests well below those on the NEDC, although some vehicles (notably vehicles 12 and 19), showed

comparable CO emissions on the two cycles. As with the petrol engine vehicles, the lower CADC results are most likely due to the hot start nature of the CADC test.
The NOx results show an entirely different pattern, though. For almost all vehicles, the CADC NOx results were substantially higher than those on the NEDC. This applies also to most of the vehicles equipped with deNOx systems, whether using Lean NOx traps (LNT) or Selective Catalytic reduction (SCR). It must be recognised, of course, that none of these vehicles were calibrated for the CADC, but nevertheless indicates the importance of the European Commission's initiative to add requirements on 'real driving emissions' (RDE) at the Euro 6c stage from 2017.

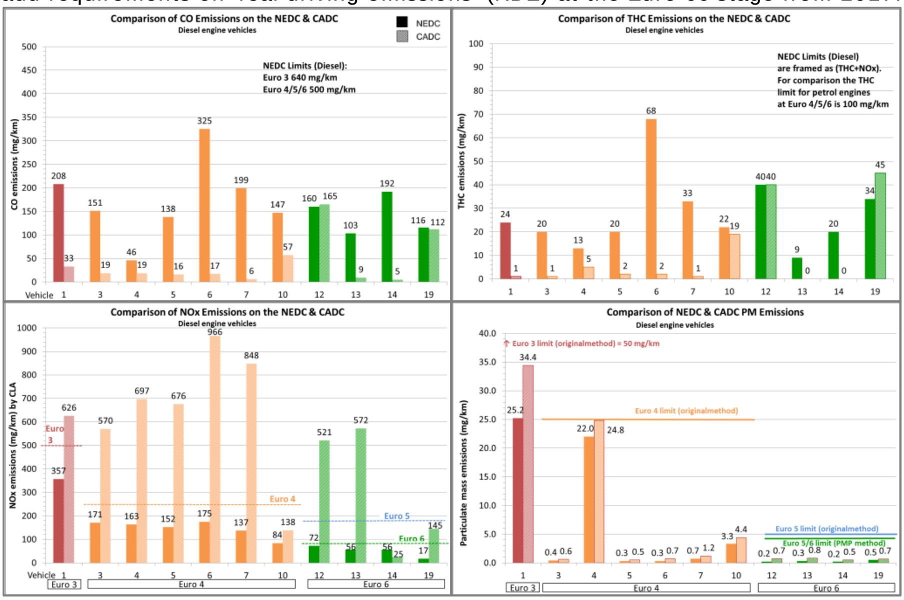

Figure 6: Diesel CO, HC, NOx and PM results over full NEDC and CADC tests

There were some exceptions to this general pattern of the NOx results. Vehicle 10 – the car with the Euro 4 PM+NOx control system - did give higher NOx results on the CADC compared to the NEDC, but these results were 138 and 84 mg/km respectively, so both would have met the Euro 5 NOx limit. Vehicle 19 showed CADC NOx results an order of magnitude higher than on the NEDC, but still only reaching 145 g/km on the Artemis test – the result on the NEDC was only 17 mg/km. The best example, demonstrating that it is possible to provide a good calibration for real world NOx emissions, was vehicle 14. This achieved 56 mg/km on the NEDC and 25 mg/km on the CADC.

The PM mass emissions on the Artemis tests again demonstrated the substantial reductions that stem from the use of DPFs in the emissions control system. The highest result for such vehicles was 4.4 mg/km for vehicle 10. The two non-DPF vehicles, Numbers 1 and 4, showed somewhat higher emissions over the CADC compared to the NEDC, but still within the relevant (NEDC) emissions limits.

With regard to particle number emissions, illustrated in Figure 7, all the DPF-equipped vehicles except vehicle 10 (the Euro 4-homologated vehicle with an early PM+NOx control system) readily met the Euro 5/6 PN limit on both cycles. Vehicle 10 also gave somewhat higher PM results, although still within the Euro 5/6 limit value. The reasons for vehicle being an outlier on PN were beyond the scope of the test programme and were not further investigated.

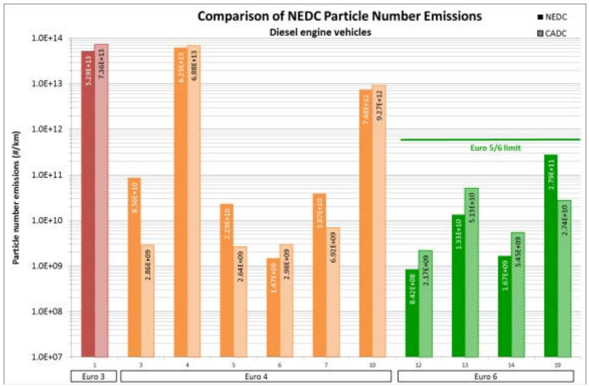

Figure 7: PN results for diesel vehicles

5.3 WLTC tests and comparison of inertia weight

For vehicle 19, all NEDC and standard CADC tests were conducted at the normal (NEDC) inertia weights, whilst all WLTP tests and a single CADC used the higher inertia weight that will be required for WLTP. As with the petrol engine vehicle the trend was generally for emissions on the CADC to be higher at the higher inertia weight. The number of particles at the higher inertia (8.3×10^9 particles/km) was lower than the average of the results for the lower inertia test, but within the range of results for the lower inertia tests (2.7×10^9 to 7.2×10^{10} particles/km).

Table 4: Comparison of results for vehicle 19

Cycle	Inertia	Number of tests	CO	HC	NOx	PM	PN	CO_2
	kg		mg/km				#/km	g/km
NEDC	2150	3	116	34	17	0.51	2.8×10^{11}	222.5
CADC	2150	3	112	45	145	0.68	2.7×10^{10}	213.2
CADC	2460	1	139	44	269	0.98	8.3×10^{9}	232.4
WLTC	2460	3	65	21	83	0.47	5.1×10^{11}	227.1

Comparing the results from the WLTC test, with its higher inertia weight, to those of the standard NEDC, the new WLTP procedures gave lower CO and HC results but higher NOx, as was seen for the petrol vehicle, although in this case the NOx results slightly exceeded the NEDC Euro 6 limit. The PM results in the two conditions were comparable. All PN results were within the Euro 6c limit.

6. Summary & Conclusions

The range of cars tested demonstrated the development of emissions controls and showed the potential to achieve excellent emissions results on the legislative test cycle. However the results of testing on other cycles indicated that further work is likely to be needed for some vehicles to ensure that the European Commission's forthcoming requirements on 'Real Driving Emissions' (RDE) can be met. In particular, the CADC test with its higher maximum speed of 150 km/h clearly provides a more stringent test of the NOx control capabilities of diesel and lean DI petrol vehicles, but the results for vehicle 14 indicate that with suitable calibration good NOx control is achievable. The high CO emissions of the lowest-powered vehicle over the highway portion of the CADC may also indicate a need to adjust calibrations for such engines when RDE procedures are introduced.

The eventual introduction of the new Worldwide harmonized Light vehicles Test Cycle (WLTC) will also have an influence. The effect of the cold start on emissions can be seen in Figure 4 and is significant for the 1180 s, 10.93 km NEDC, but it will have a lower effect on the overall emissions for the longer (1800 s) WLTC covering over 23km. On the other hand this may to some extent be balanced by the higher accelerations rates in the WLTC (a maximum of 1.6 m/s^2 compared to 1.04 m/s^2 for the NEDC). Overall, the WLTP tests conducted on the two most recent vehicles suggest that there may not be a major difference between most results on this cycle and the NEDC procedures for most pollutant emissions, either from the cycle itself or from the higher inertia weight required by WLTP. The largest effect was on the NOx emissions of the diesel vehicle, where emissions over the NEDC at current inertia were well within Euro 6 legislative limits, whilst the figure on the WLTC at the higher (WLTP) inertia just exceeded the 80 mg/km limit value. For the recent petrol engine vehicle, both NOx and PM emissions were higher for WLTP than for the current NEDC, but without exceeding current limits. Although particle number emissions for this vehicle would meet the Euro 6c limits on the NEDC and CADC (albeit with little margin for the NEDC), the PN emissions over the WLTC met only the 'interim' (Euro 6b) requirements. As this vehicle gave the best PN performance of the petrol-engined vehicles, it is clear that more work on combustion systems and control, or the use of gasoline particulate filters, will be needed to meet the Euro 6c limits for particle number.

Acknowledgements

AECC wishes to thank TÜV Nord Mobilität - IFM, Essen, Germany, for undertaking the test work that provided data for this paper and the AECC Member companies for supporting the test programmes. The AECC member companies are:
BASF Catalysts Germany GmbH, Germany; Corning GmbH, Germany; Emitec Gesellschaft für Emissionstechnologie mbH, Germany; Ibiden Europe B.V. Stuttgart Branch, Germany; Johnson Matthey PLC, UK; NGK Europe GmbH, Germany; Solvay SA, France; and Umicore AG & Co. KG, Germany.

References

(1) United Nations Working party on Pollution and Energy (GRPE) Informal group in the Worldwide harmonized Light vehicles Test Procedure (WLTP), https://www2.unece.org/wiki/pages/viewpage.action?pageId=2523179.
(2) UN Regulation No.83 (Annex 4): Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements,; www.unece.org/trans/main/wp29/wp29regs81-100.html.
(3) Michel André, The ARTEMIS European driving cycles for measuring car pollutant emissions; Science of The Total Environment Volumes 334–335, 1 December 2004, Pages 73–84. doi: 10.1016/j.scitotenv.2004.04.070.
(4) United Nations GRPE-48-11-Rev.1, Conclusions on improving Particulate Mass Measurement Procedures and New Particle Number Measurement Procedures relative to the Requirements of the 05 Series of Amendments to Regulation No. 83; (1 June 2004), http://www.unece.org/fileadmin/DAM/trans/doc/2004/wp29grpe/TRANS-WP29-GRPE-48-inf11r1e.pdf.
(5) Commission Regulation (EU) No. 566/2011 of 8 June 2011 amending Regulation (EC) No 715/2007 of the European Parliament and of the Council and Commission Regulation (EC) No 692/2008 as regards access to vehicle repair and maintenance information, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:158:0001:0024:EN:PDF.
(6) Parkin, Compilation of Existing Particle Number Data from Outside PMP Inter-Laboratory Correlation Exercise (ILCE); United Nations GRPE-55-16; January 2008, http://www.unece.org/fileadmin/DAM/trans/doc/2008/wp29grpe/ECE-TRANS-WP29-GRPE-55-inf16e.pdf.
(7) Mamakos & Manfredi, Physical Characterization of Exhaust Particle Emissions from Late Technology Gasoline Vehicles; European Commission Joint Research Centre (20122) doi:10.2788/32371.