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Keeping emissions in check

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With the European Commission preparing the ground for its post-2025 environmental standards, the effectiveness of today's Euro 6 regulations has come under close scrutiny. Ricardo's unique approach, correlating test-cycle data from the vehicles themselves with some 320,000 roadside measurements taken in real-life pollution hotspots, shows a rapidly-improving picture and fresh opportunities to boost inner-city air quality.

There can be no mistaking that the brand and reputation of diesel as a fuel for passenger cars and light commercial vehicles has been damaged in recent years. Diesel models' share of the European new-car market has slumped to a new low of 37 percent in the first half of this year – its lowest since 2001 – and some city mayors are seeking to restrict the use of older diesels at certain times.

The situation is unsettling for consumers, especially as the whole official regulatory regime has been in flux at the same time. There has been a rush of new European emissions standards, WLTP and RDE are replacing the discredited and outdated NEDC test cycles, and manufacturers are making competing claims and counterclaims about the efficacy of the many new technologies coming on to the market. No wonder the poor buyers are confused; even commentators, environmental pressure groups, automakers and legislators are delivering muddled messages.

But now, in a bid to bring some much-needed scientific clarity, Ricardo is publishing findings from a set of ongoing studies looking at the issue from where it matters most – the actual exhaust emissions of the vehicles implicated in the air quality problems suffered in urban areas right across Europe.

Ricardo Energy & Environment has built up a world-leading database of almost one-third of a million measurements of the exhaust emissions of vehicles in everyday traffic as they drive past special roadside monitoring stations. And in parallel, experts at Ricardo's Shoreham research

centre laboratories have put the official test cycles themselves to the test – by putting a selection of the very latest vehicles through the profusion of lab-test routines prescribed by the world's legislators to see how the results compare with the figures obtained during an 85-kilometre Real Driving Emissions route on public roads.

Air quality under the microscope

One effect of the 2015 dieselgate scandal is that it has shone a light not just on diesel cars and the alleged cheating of emissions tests, but also on the issue of urban air quality, in particular the part played by nitrogen oxides (NOx). Yet, says David Carslaw, the Ricardo air quality knowledge leader who is spearheading the remote sensing work, this narrow focus on diesel cars is not necessarily helpful and other vehicle types should also be looked at before rushing into any judgements. "At Ricardo we realize that NOx pollution is caused by more than just diesel cars – we need a broader view," he urges. "To understand air quality you can't make that connection if you are just focusing on one vehicle type. You

A brief history of Euro 6

The European Euro 6 diesel vehicle parc is dominated by models complying with Euro 6b, which came into force in September 2014. Diesels conforming to late EU 5 and EU 6b have dramatically lower particulate emissions than their EU 4 and 5 predecessors, thanks to the compulsory fitment of DPF systems which almost completely eliminate particulate emissions.

Euro 6c came into force this year and marked the introduction of the new WLTP test cycle and advisory parallel RDE testing to give consumers an idea of vehicle emissions performance on the road as well as in the lab.

Euro 6d-temp, coming into force in September 2019, brings in RDE conformity as a legislated part of the WLTP process: under this standard, vehicles on the RDE test are allowed a 'conformity factor' multiple of the WLTP limit values: the multiple will be 2.1 for NOx and 1.5 for particles.

Euro 6d-final will become the definitive standard for all vehicles from January 2021, though new type approvals will have to conform from 2020. This again calls for both WLTP and RDE tests, but the conformity factor will be reduced to 1.5 for most pollutants and will be below 1.43 for NOx.

Euro 7 is still under discussion and is expected to be implemented around 2025. The industry expects the new standard will bring in limit values for a much wider range of pollutants, including substances such as formaldehyde and ammonia; additionally, the particle size and number limits may be tightened still further, perhaps bringing further challenges for spark ignition engines. One of the main innovations is expected to be the separate regulation of NO_2, which is the principal cause of harmful urban air quality.

Fleet average CO_2 has been controlled at 130 g/km since 2012 and is to be tightened to 95 g/km from 2021. By 2025 the values for both cars and vans will be toughened by 15 percent, and by 2030 they will fall by 30 percent.

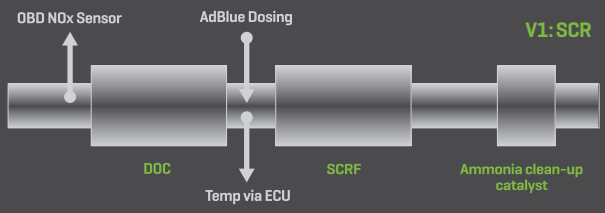
The Ricardo-Concawe study

A collaboration between Ricardo and the oil industry environmental body Concawe, this study sought to inform the debate on modern diesel car emissions performance, as part of a broader study considering the comparative impacts of diesel, plug-in hybrid and electric vehicles on a well-to-wheels basis. Three diesel vehicles with differing aftertreatment solutions and meeting different EU6 emissions standards were put through several of the world's principal test cycles as well as prescribed on-the-road RDE tests. Additionally, a demanding urban cycle was run on the laboratory chassis dyno to validate the on-road urban RDE results.

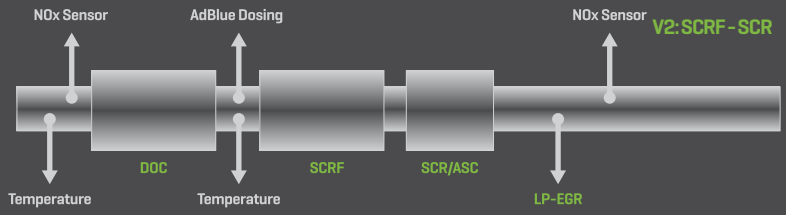
The testing showed the state-of-the-art diesel vehicles to be fully compliant with Euro 6c emissions values on the NEDC cycle and performing well in the RDE, achieving the necessary conformity factors. The vehicle with the simpler early Euro 6b-standard passive SCR and lean NOx trap system performed less well in the WLTC and poorly on the higher speed sections of the RDE, but best of all for short urban trips. The authors conclude that sophisticated aftertreatment systems are capable of low on-road local NOx emissions, and extremely low emissions of NO_2 – a factor which will become more important in upcoming rounds of European legislation. In future, says the study, multiple deNOx brick (LNT + SCR/SCRF) solutions will enable very low NOx irrespective of drive cycle.

Test Vehicles & Aftertreatment (all with DPF functionality)

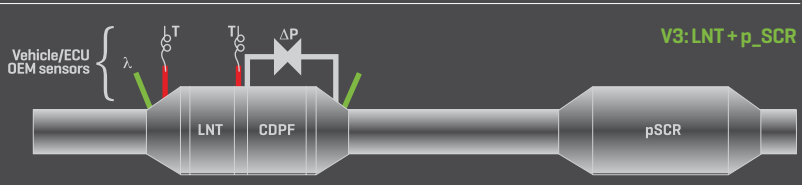
Vehicle 1
Later Euro 6b
» D class
» NOx control via HP-& LP-EGR and urea SCR



Vehicle 2
Euro 6c ("6dT-ready")
» E class
» NOx control via dual EGR and urea SCRF - SCR
» Closed-loop urea dosing



Vehicle 3
Euro 6b
» C class
» NOx control via HP-EGR, LNT & passive SCR (p_SCR)



need that holistic view of emissions to understand whether it makes sense to think about controlling some vehicles ahead of others."

Though Ricardo's remote sensing work does show the very latest diesel cars to be significantly cleaner than their predecessors, they are not the sole answer. In the light of today's air quality issues there has understandably been a lot of focus on these most recent models, but, as Carslaw says, "we don't improve air quality by adding new cleaner vehicles as such, but by removing vehicles with higher emissions. So we need to look at the wider fleet to design the most effective mitigation options."

Broadly comparable conclusions are reached by parallel studies carried out by a team under Jon Andersson, Ricardo's global technical expert on emissions measurements and standards, on behalf of Concawe, the oil industry's environmental body. After conducting

several dozen test procedures involving three different vehicle types and four different regulatory cycles on chassis dynamometers and on the public road, Andersson concludes that the results provide evidence of a significant shift in the ability of vehicles to have genuinely low NOx emissions. "Historically, NOx has definitely been the most difficult pollutant for diesels to deal with," he says, "but with the advent of the most advanced emissions control technologies as per Vehicle 2 in our study, we believe control can be really excellent, everywhere."

What this means in practice is that the latest and most sophisticated diesel vehicles conforming to Euro 6d (see panel) can offer very clean operation across a far wider spectrum of operating conditions than before. This has been prompted by the shift in testing regimes from NEDC to WLTP, and the associated on-the-road RDE tests that force vehicles to perform cleanly across all conditions of everyday normal driving. The move to RDE, says Andersson, is pushing manufacturers to fully explore the potential of exhaust aftertreatment systems in combination with advanced engine measures for comprehensive control of emissions. Further potential, he predicts, will be unlocked once clean-burning low-carbon fuels such as biomass to liquid become available: diesels could then offer a better overall greenhouse gas balance than most other forms of propulsion.

Urban emissions crisis

If there is a downside to the new generation of super-clean Euro 6d compliant diesels it is that they are extremely complex, and therefore more expensive than models calibrated around earlier standards; additionally, confirming David Carslaw's view, it will be a long time before they displace the Euro 4, 5 and Euro 6b models that still make up the bulk of Europe's diesel car fleet. Yet, says Andersson, even a complex diesel is still much less expensive than a plug-in gasoline hybrid of the same size, today's most favoured solution, and as manufacturers and aftertreatment module suppliers fine-tune their systems they will be able to lighten the precious metal loading in each component and thus reduce the overall system cost.

In the interim there is much that can

"Historically, NOx has definitely been the most difficult pollutant for diesels to deal with, but with the advent of the most advanced emissions control technologies as in Vehicle 2 in our study, we believe control can be really excellent, everywhere"
Jon Andersson, Ricardo global technical expert

Remote sensing reveals real emissions

By setting up monitoring stations alongside urban roads, experts from Ricardo Energy & Environment can get a measurement of each passing vehicle's tailpipe emissions at that actual instant. Cars, vans, trucks, buses and motorcycles all produce their individual emissions signatures.

Some 320,000 measurements have been taken in the past year at a score of locations across England, Scotland and Wales. This provides an unrivalled database of the actual performance of a wide range of models in everyday conditions.

The instrument shines a light beam through the passing vehicle's exhaust plume and is able to analyse the concentration of a number of gases in that stream. A major benefit of the approach is that it is non-intrusive and no contact with the vehicle being measured is necessary. At the same time a numberplate camera logs the vehicle's registration number to interrogate another database to determine the make and model of the vehicle, its emission standard and its age and mileage – and many other variables. This enables the system to provide highly disaggregated emissions data for a wide range of vehicles operating under real-world driving conditions.

The monitoring scheme is particularly valuable in urban areas, where it can be used to isolate the individual vehicle types which are putting out the highest emissions of the pollutants in question.

More complex, less durable? Not necessarily so

The latest generations of exhaust aftertreatment equipment have become highly complicated, especially on high-powered diesel cars. One model analysed by Ricardo featured both high and low-pressure EGR, a diesel oxidation catalyst, closed-loop AdBlue dosing through selective catalytic reduction and a soot filter, and an additional SCR/ammonia slip catalyst (ASC). But do such complex systems lose their effectiveness and spell trouble in the longer term?

A year's worth of measurements from Ricardo's roadside remote sensing teams would suggest not: the durability of even the most complex of systems appears very good. And, surprisingly, diesel systems retain their performance even better than their gasoline equivalents: "There is no evidence in the current data that even the highest mileage Euro 5 diesel passenger cars exhibit increased PM emissions," says David Carslaw, head of the monitoring team. "These results are reassuring and help provide confidence that DPF systems are robust, across a vehicle's lifetime, in real-world use."

But while particle filter systems on diesel vehicles can be almost 100 percent effective, those for gasoline models will need further development to exceed 80 percent.

Homing in on diesel cars, Carslaw's data reveals generally higher emissions from vehicles over 15 years old. It also reveals the substantially lower emissions of NOx for vehicles a few years old – in other words, Euro 6 vehicles. In terms of the effects of vehicle mileage on emissions, there is some indication that emissions increase with increasing mileage for vehicles that are between four and 15 years old, although the effects are not strong.

One interesting finding of the remote sensing study was that as diesel cars age, they begin to emit less NO_2, the most harmful constituent of NOx, thus benefiting the environment. This confirmed the effect of catalyst poisoning and deactivation mechanisms well understood by the engineering team.

For gasoline models, says Carslaw, the emission of NOx varies with both vehicle age and mileage. The plot shows that low-mileage vehicles, less than 15 years old, have low emissions of NOx. For vehicles less than five years old there is very little effect of vehicle mileage on emissions and emissions are low. However, for vehicles between five and 15 years old there is evidence that the emissions increase with increasing mileage.

Such information is important in informing air quality managers as to which vehicles are best targeted to reduce emissions of NOx, he notes.

be done to improve urban air quality using the tools already at the disposal of local authorities – and it is here that the findings of the roadside emissions monitoring can provide very useful guidance. Study leader David Carslaw does not, however, immediately point the finger at specific vehicles: "At Ricardo we are open-minded in terms of what we find," he says. "We essentially let the data speak for itself, and what that data tells us is that there has been a strong improvement in performance from most of the diesels that have entered the market recently. We're seeing particularly impressive NOx reductions for the larger and heavy-duty vehicles, and we've seen gasoline vehicles that are very low emitting, and consistently so."

Turning to mainstream diesels, Carslaw points to strong differentiations in performance at each of the various legislative steps, with an average 55 to 60 percent reduction in NOx between Euro 5 and early Euro 6. "We can expect that to improve still further in the coming months and years as manufacturers implement Euro 6d temp and Euro 6d, which incorporate RDE compliance," he adds. "So it's a moving target."

This supports Jon Andersson's assertion that diesel Euro 6 has not been a failure, as some commentators have claimed: real-world NOx emissions have been reducing, and reductions have increased as the different stages of Euro 6 (6b, 6c, 6d-temp) have gone live. In the broader scheme of things, however, diesel passenger cars are only part of the air quality picture. "I would pick out the older urban buses as being particularly important," says Carslaw. "Some of the locations [we measured], in London for example, and where we have seen some of the highest concentrations of NO_2, have tended to be locations with very high flows of buses."

Remote sensing as a city planning tool

The great advantage of roadside emissions monitoring is that it can pick out individual types of vehicle to spot the types which put out the highest emissions of pollutants at any particular point.

"A key aim for us," says Carslaw, "has been to really align the measurements we make with the individual plans such as clean air zones and other strategies that cities might have for the mitigation of air pollution. By providing ground-truth data for emissions, remote sensing can put these policies onto a much firmer footing. That's where we feel the focus should be in the immediate future. Having specific emissions associated with specific urban areas is a significant advantage [for planners] and that is something we are working on."

Local authorities in possession of detailed ground-truth data covering the emissions for nearly all vehicle types in their area will at last have the necessary factual backdrop at their disposal to enable them to determine, plan and

The NOx paradox

The automotive industry has grown used to the term NOx as a catch-all for the two principal oxides of nitrogen (NO, or nitric oxide, and NO_2, or nitrogen dioxide). Of these compounds, NO_2 is the most important in terms of direct health impacts, with high local concentrations of NO_2 leading to breathing difficulties; NO oxidises in sunlight or the presence of low-level ozone to form NO_2, but has the opportunity to disperse and this process primarily happens away from the roadside.

Although the efficiency of modern catalytic aftertreatments means that the proportion of NO_2 at the tailpipe is set to reduce, there will continue to be a strong focus on the absolute emissions of NO_2 because this is likely to be specifically controlled in future legislation. Looking further ahead, it is to be expected that emissions of total NOx will be so low that the proportion emitted as NO_2 will become irrelevant from an air quality perspective. One way or another, future regulations will continue to inspire engineers and chemists to seek improved and perhaps different solutions to nitrogen reduction.

implement the most effective mitigation options for their area or region.

The outlook on emissions

Though there is a strong contrast between the three test methods – test cycles on the chassis dynamometer, RDE testing on everyday roads, and the remote sensing monitors, the fact that similar trends are being revealed by the very different measurement systems shows that the latest emission control systems are working well. And, most vitally, they continue to work robustly even outside the confines of the prescribed chassis dyno test cycle, meaning that consumers will begin to have more trust in official test results once more.

In particular, this gives grounds for optimism about the future of diesel passenger cars, ironically just as public concern is beginning to gather pace. "We can see some very good performances from latest diesel cars which show both very low emissions of NOx and NO_2," says Carslaw, "and I don't think there's any doubt that from an air quality perspective the reductions in NOx that can now be achieved are very timely – and they are what's needed right now to help reduce urban NO_2 concentrations."

"At Ricardo we are open-minded in terms of what we find; we essentially let the data speak for itself, and what that data tells us is that there has been a strong improvement in performance from most of the diesels that have entered the market recently"

David Carslaw, knowledge leader, environmental evidence & data, Ricardo

Nevertheless, while remote monitoring does reveal useful general improvements in NOx emissions performance with newer diesel cars, the fact that there is significant variability between different diesel models shows that there is still work to be done. Many of the key steps have already been implemented and diesel's clean bill of health is now in sight – but it's not quite there yet.

The message of this most recent work on Euro 6 standards is twofold. Firstly, that most modern diesels have far stronger environmental credentials than many commentators give them credit for, and secondly, that Ricardo is unique in its ability to approach the issue from both sides thanks to the fruitful strategic synergy between its top-flight engineers and the world-class air quality specialists at Ricardo Energy & Environment.

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