Emissions from modern gasoline vehicles

A problem essentially solved?

Over recent years, vehicle technologies have developed rapidly with significant improvements in emissions control. Exhaust catalysts were first required on European gasoline cars with the introduction of Euro-1 emissions limits in 1993, with subsequent evolution to the Euro-3 emissions limits of today and 'near-zero' Euro-4 limits from 2005. The current challenge on gasoline cars is to further reduce CO_2 emissions, with vehicle manufacturers currently working towards the voluntary agreement for a European passenger car fleet average of 140 g/km CO_2 emissions by 2008.

In order to meet these targets, a range of advanced gasoline engine and exhaust gas after-treatment technologies are expected to be introduced, facilitated by sulphur-free fuels to enable the most advanced technologies to be employed with maximum fuel efficiency (see companion article on sulphur-free fuels, page 8). The revised EU Fuels Directive mandates the introduction of 10mg/kg maximum sulphur fuels but does not require any additional changes to other fuel properties, recognising that there is a need to first assess the impact of the new Euro-4 vehicles and fuels. It places further consideration of fuel effects in a subsequent review, to be carried out by 2005.

Given the evolution in vehicle and fuel technologies, there is a need to establish sound information on the influence of fuel qualities on exhaust emissions from the more advanced technologies, to provide a firm foundation for future debates.

To contribute to this task, CONCAWE is continuing to test new vehicles as they enter the market. The work described here has evaluated the impact of fuel qualities on emissions from advanced gasoline vehicle technologies available in the market in 2002. Although sulphur reduction is mainly aimed at long-term durability and fuel efficiency of advanced after-treatment systems, short-term effects are also of interest in view of the potential impact on the existing vehicle fleet. The overall study has therefore evaluated the influence of gasoline sulphur content, as well as other gasoline properties: aromatics, olefins, volatility and final boiling point. Only the sulphur results are discussed here, as the CONCAWE report on this part of the work is soon to be published. Testing on the influence of the other fuel properties is currently being completed and will be reported separately.

Test vehicles, fuels and design

Four vehicles were selected for evaluation in this programme, chosen to provide examples of those advanced gasoline vehicle technologies expected to become more significant in the near-term future car populations. A brief description of the vehicle characteristics is given below.

The influence of fuel sulphur was evaluated by doping a low sulphur unleaded base gasoline with thiophene in order to achieve a range of sulphur levels. Four fuels with sulphur contents from 4 to 148 mg/kg sulphur were tested.

	Vehicle A	Vehicle B	Vehicle C	Vehicle D
Displacement (cm^3)	1998	1796	1997	1598
Max power (kW @ rpm)	103@5500	85@5500	107@6000	81@5800
No. of cylinders	4	4	4	4
Valves per cylinder	4	4	4	4
Combustion/injection/ control system	Stoichiometric DI*	MPI** Variable valve actuation	Lean DI	Lean DI
Catalyst system	TWC***	TWC	TWC + NO_x trap	TWC + NO_x trap
Emissions compliance	Euro-3	Euro-4	Euro-3	Euro-4

** direct injection ** multi-point injection *** 3-way catalyst*

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A rigorous statistically-based test design was employed, providing several long-term repeat tests on each vehicle/fuel combination. Specific vehicle conditioning and de-conditioning procedures were used in order to minimise any effects from sulphur carry-over. Exhaust emissions were measured over the standard European test cycle (NEDC), with data evaluation over the full cycle, in addition to the ECE (urban driving part) and EUDC (extra urban driving cycle) segments. Continuous raw exhaust analysis pre- and post-catalyst was also carried out to support understanding of the basic test cycle data.

Sulphur effects on regulated emissions

The main interest of this work was the effect of gasoline sulphur content on the regulated emissions: NO_x, HC and CO. Plots of the mean NEDC emissions for all four cars are shown in Figures 1 to 3 below, compared with the Euro-3 and Euro-4 emissions limits.

In all four vehicles, there was little short-term response of emissions to fuel sulphur content. There were no statistically significant sulphur effects over the NEDC cycle for any pollutant in any vehicle, and no evidence of higher emissions sensitivity at low sulphur levels.

In all cases, the vehicles achieved very low levels of emissions, well beyond their certification levels. Car A, the Euro-3 stoichiometric DI, was just above the Euro-4 limit for NO_x, but well below the Euro-4 limits for HC and CO. Car B, the advanced MPI technology vehicle, was well within the Euro-4 limits for all three emissions. Car C, the Euro-3 lean-burn DI, was close to the Euro-4 limits for HC and NO_x, and well within the Euro-4 limit for CO. Car D, the Euro-4 lean-burn DI was well within the Euro-4 limits for all emissions.

In order to check whether higher sulphur effects on the catalysts could be observed during the hot part of the emissions test cycle, when the catalyst is fully operational, the EUDC data were examined. In all cases, emissions during the EUDC part of the cycle were very low. Statistically significant sulphur effects on HC and CO emissions were demonstrated in some cars, though these effects were small in absolute terms. For NO_x, there was no statistically significant sulphur effect in any car.

Figures 1, 2 and 3

- car A *(Euro-3 stoichiometric DI)*
- car B *(Euro-4 MPI)*
- car C *(Euro-3 lean-burn DI)*
- car D *(Euro-4 lean-burn DI)*
- Euro 3 limit
- Euro 4 limit

Advanced gasoline test vehicles showed low emissions of NO_x, HC and CO, but little sensitivity to fuel sulphur content.

Figure 1 Regulated (NEDC) emissions data: NO_X

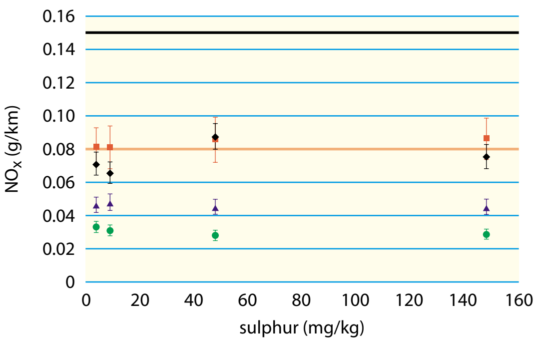


Figure 2 Regulated (NEDC) emissions data: HC

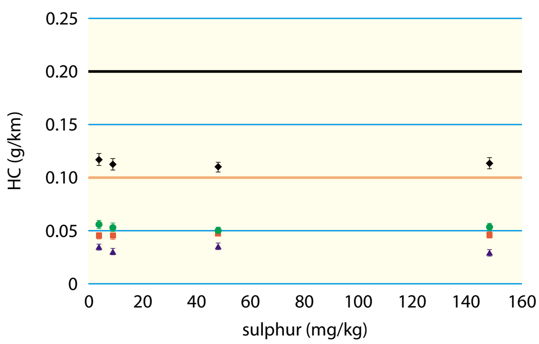
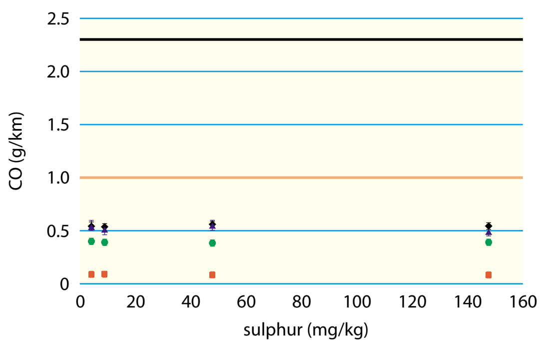


Figure 3 Regulated (NEDC) emissions data: CO



Particulate mass emissions

Although particulate emissions are not regulated on gasoline cars, particulate mass (PM) emissions were measured in order to determine whether there were any important effects. A clear ranking of PM emissions versus vehicle technologies was observed (lean-burn DI > stoichiometric DI > advanced MPI) as shown in Figure 4. However, even the lean-burn DI vehicles gave PM emissions which were an order of magnitude below the Euro-4 light-duty diesel limit of 0.025 g/km. No significant influence of gasoline sulphur content on PM emissions was apparent on any of the vehicles.

Figure 4 Regulated (NEDC) emissions data: PM

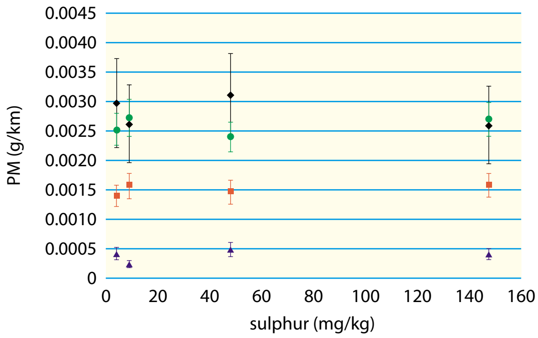


Figure 4

- car A *(Euro-3 stoichiometric DI)*
- car B *(Euro-4 MPI)*
- car C *(Euro-3 lean-burn DI)*
- car D *(Euro-4 lean-burn DI)*

A clear ranking of PM emissions versus vehicle technologies was observed. No significant influence of gasoline sulphur content was apparent.

Vehicle effects

Apart from the general differences between vehicle technologies highlighted above, several other specific effects were observed during this work which had much more influence on the overall emissions than the sulphur content of fuels. These included:

- a significant influence of dynamometer load on CO_2 emissions, especially for the more advanced technology vehicles;
- HC storage and release from the catalyst during the first 30 seconds of operation, which could dominate the total cycle emissions;
- air-fuel ratio (AFR) strategy of the 'lean-burn' DI cars was highly dependent on engine speed; and
- smaller but significant changes in AFR strategy for the stoichiometric DI car which influenced NO_x and HC emissions.

Comparison of sulphur effects with other studies

The current data were compared with previous studies of sulphur effects on emissions from gasoline cars, including studies from EPEFE, USA and California. Detailed analysis revealed that, in these studies, some vehicles showed much greater sensitivity to sulphur than others and that these vehicles could have a marked effect on the test fleet average results. Some of the lower emitting vehicles showed a low sensitivity to sulphur, as observed in the current CONCAWE work. Vehicles that showed the highest sulphur sensitivity did not necessarily have the lowest emissions.

Summary

The four vehicles tested all met Euro-3 emissions limits, and in most cases emissions were lower than Euro-4 limits. This reinforces the view that the issue of pollutant emissions from gasoline cars will be essentially solved from 2005. Focus should then shift to improving CO_2 emissions while maintaining these 'near-zero' pollutant emissions.

All four vehicles showed little sensitivity to sulphur for all pollutants measured, despite having very low emissions. Analysis of earlier studies that had shown a stronger sensitivity to sulphur showed that fleet average results were influenced by a number of very sensitive vehicles. Overall, it is concluded that low emission vehicles are not necessarily highly sensitive to fuel sulphur content; sulphur sensitivity appears to be principally influenced by catalyst system design. Several specific hardware effects were observed which can have an important influence on emissions, including CO_2.

The main driver for the introduction of lower fuel sulphur levels continues to be to enable advanced exhaust catalyst systems, including regenerative NO_x storage systems, to be introduced with maximum fuel efficiency and long-term durability. The planned sulphur reduction to 10 mg/kg seems unlikely to bring substantial emissions benefits for the existing vehicle fleet.