Emissions from modern diesel engines

How important are diesel fuel properties other than sulphur?

The European Commission's proposed update of Fuels Directive 98/70/EC includes the gradual introduction of sulphur-free fuels from 2005 to enable the use of advanced exhaust after-treatment technologies but does not propose further changes to other fuel properties. However, the impact of certain other fuel properties on emissions remains under discussion, especially in connection with advanced engine technologies.

EPEFE[1] provided a thorough basis for understanding the interaction between diesel fuel quality and engine technologies for both the light-duty and heavy-duty diesel fleets. However, EPEFE was carried out almost a decade ago and only included engine technologies up to Euro 2 (1996). Engine technologies continue to be developed in response to emissions legislation (Euro 3 in 2000, Euro 4 in 2005) and CONCAWE decided to quantify these relationships for more advanced, but already available, engine technologies (approaching Euro 3). To this end an extensive test programme was carried out, the complete report from which is expected to be issued in May 2002. This article gives an overview of the objectives and scope of the programme as well as the most important results.

Objectives of the programme

In EPEFE the influence of cetane number, polyaromatics, density and back-end distillation (T95) on emissions was evaluated in detail. Two important questions remained however, namely the difference (if any) between natural and additive-derived cetane and the influence of aromatics composition (mono- versus poly-). The main objective of this programme was therefore to elucidate these relationships with modern hardware operated over the Euro 3 emissions test cycles.

Selection of vehicles, engines and fuels

Three light-duty diesel vehicles and two heavy-duty diesel engines were used in the programme. They were selected to cover a range of technologies which were expected to be widely used to meet Euro 3 emissions standards. For heavy duty, a 1-litre per cylinder and a 2-litre per cylinder engine were tested, one with and one without cooled EGR[2], one with a high-pressure in-line pump and one with unit injectors. Light-duty hardware included engines with common rail injection, unit injectors as well as an advanced rotary pump.

Two fuel matrices were designed to evaluate the possible impact of mono-, poly- and total aromatic content and to allow discrimination between natural and additive-derived cetane number. The matrices were statistically designed to separately identify the effects of the fuel properties under investigation while keeping all other properties as constant as possible and close to the average market fuel quality for

[1] *European Programme on Emissions, Fuels and Engine Technologies*

[2] *Exhaust Gas Recirculation: a technology used to reduce NO_x emissions*

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Aromatics fuel matrix

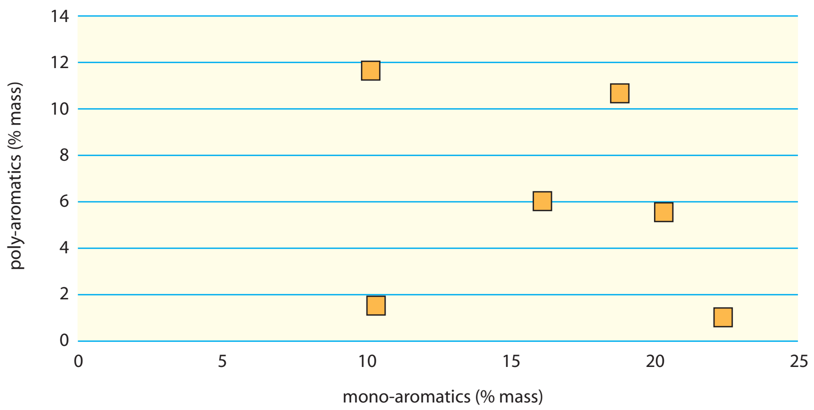


Figure 1
Mono- and poly-aromatics in the aromatics fuel matrix

the year 2000. The aromatics matrix is shown in Figure 1. The cetane matrix covered a final cetane number range from 49.4 to 58.2 with the additive derived cetane contribution from 0 to 4.7.

Test protocol

All tests were based on the legislated test cycles i.e. the year-2000 New European Drive Cycle (NEDC) for passenger cars and the European Steady-State Cycle (ESC) for the heavy-duty engines. A fully randomized block test design was used in order to minimize the risk of fuel effects being biased by unexpected effects such as carry-over or performance drift.

Table 1
Emission levels were up to 40% lower than the EPEFE fleet

Emission results compared with the EPEFE fleet

Heavy-duty, g/kWh	HC	CO	NO_x	PM
Engine 1	0.129	0.427	4.95	0.074
Engine 2	0.198	0.313	4.86	0.096
EPEFE Fleet	0.253	0.610	6.59	0.122
Heavy-duty, g/km	**HC**	**CO**	**NO_x**	**PM**
Vehicle A	0.080	0.474	0.460	0.041
Vehicle B	0.035	0.139	0.537	0.036
Vehicle C	0.052	0.275	0.629	0.065
EPEFE Fleet	0.081	0.405	0.542	0.054

Emissions levels were up to 40% lower than the EPEFE fleet

For all four emission parameters, the average emissions from the two heavy-duty engines tested here were 25–40% lower than those from the EPEFE prototype Euro 2 fleet. The light-duty vehicles tested here averaged 25–30% lower hydrocarbons (HC) and CO emissions and about the same levels of particulate matter (PM) and NO_x emissions (see Table 1).

Fuel effects were small

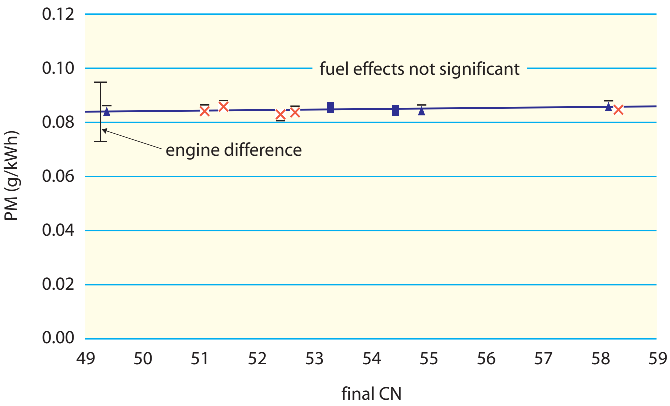
Fuel effects were generally found to be small compared to engine technology effects and test variability. Despite the rigorous test design, statistically significant fuel effects were difficult to identify.

Increasing cetane number had no significant effect on the critical emissions, NO_x and PM, in either the heavy-duty engines or the light-duty vehicles tested. Increasing cetane number directionally reduced HC and CO emissions, though these emissions were well below the Euro 3 limits. In the heavy-duty engines, HC effects were not significant and only one engine showed a significant CO effect. In the light-duty vehicles, statistically significant reductions in HC and CO emissions were seen in all but one case. No emission differences were observed between natural cetane fuels and those where the cetane number was boosted using ignition improver additive.

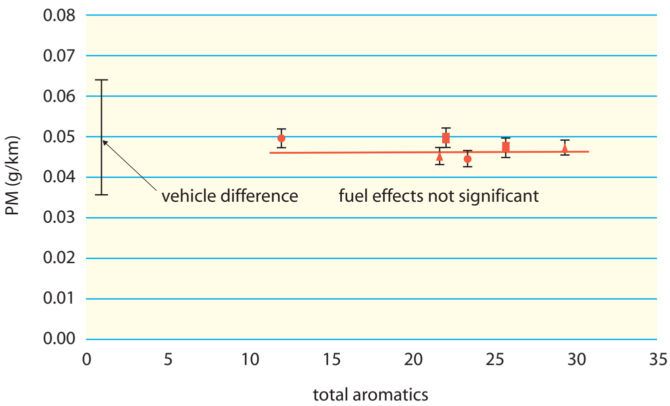
Aromatic effects were small. In the heavy-duty engines, reducing aromatics reduced HC emissions but had no significant effect on PM, NO_x or CO emissions. In the light-duty vehicles, aromatic effects varied between vehicles. Only one vehicle showed significant effects on NO_x and PM emissions, NO_x emissions decreasing as aromatics were reduced while PM emissions increased. There were no consistent trends in HC emissions, but CO emissions tended to decrease with lower aromatics. As the total aromatic effects were small, it was not possible to separately quantify the relative contributions from mono- versus poly-aromatics.

Figures 2 and 3 are illustrative examples of the trends, showing heavy-duty and light-duty fleet average PM emissions as a function of cetane and total aromatics respectively.

Heavy-duty fleet average PM emissions vs. cetane number



Light-duty fleet average PM emissions vs. aromatics



The report also contains additional light-duty vehicle test data carried out with another fuel matrix also designed to investigate aromatic effects. These data show small but more consistent NO_x effects. On average a 10% reduction in mono- or poly-aromatics reduced NO_x emissions by around 3%. The relative impacts of mono- and poly-aromatics appeared similar. Aromatic effects on PM, HC and CO emissions showed variation between the different vehicles tested.

Outlook

It is clear that the effects of fuel aromatics and cetane on modern diesel engines emissions are small and difficult to differentiate from the experimental 'noise'. Drawing firm conclusions from tests on a few vehicles is risky. Indeed a rigorous protocol is necessary to identify significant trends and testing of a range of engines/vehicles is needed for a meaningful fleet coverage. This reinforces the value of major cooperative programmes such as EPEFE. In the near future, the introduction of Euro 4 and Euro 5 engine technologies, along with sulphur-free fuels, is expected to result in extremely low emissions levels and the remaining fuel effects will be even more difficult to evaluate. Nevertheless CONCAWE plans to investigate such effects as soon as advanced engine technologies become available and believes that a joint programme with our partners from the motor industry would lead to the most valuable data-set.

Figure 2 (above left)
In the heavy-duty fleet, increasing cetane number had no significant effect on PM emissions.

Figure 3 (above right)
Average PM emissions (light-duty fleet) as a function of aromatics: aromatic effects varied between vehicles; fleet average effect was not significant.