Particle emissions from modern vehicles

Vehicle and fuel effects on particulate mass and ultra-fine particles

Ultra-low sulphur fuels have enabled the introduction of modern engine and after-treatment technologies in order to meet increasingly stringent exhaust emissions limits. Through these improvements, substantial reductions in road vehicle emissions have occurred over the past two decades with corresponding improvements in air quality. As one example, light-duty diesel vehicles meeting Euro 5 emissions limits will emit less than 5% of the particulate mass (PM) emitted by similar passenger cars just 15 years ago, with comparable improvements in other exhaust emissions.

While these improvements are being put in place, particle emissions from all sources (transport, manufacturing, farming and others) remain under regulatory scrutiny, due to increasing awareness of their impact on air quality and the potential human health effects of air pollution. Extensive studies have not yet identified exactly how these particles impact upon human health but several hypotheses are being actively investigated.

As total PM emissions from cars have dropped, accurate measurement of the remaining low-level PM emissions has become increasingly difficult. Over the past decade, several research programmes have investigated different procedures for measuring very low particle emissions, driven largely by interest within the regulatory environment. Improved procedures have been developed[1], either by modifying exhaust air filtering procedures for PM or by introducing a new metric for ultra-fine particles, called Particle Number (PN). PN is a measure of ultra-fine exhaust particles that average only about 30 nanometers in diameter, much smaller than the PM emissions that are measured by filter procedures. New European light-duty diesel vehicles entering the market after September 2011 will be required to meet a lower PM limit and a new PN emissions limit of $6x10^{11}$ particles/km (Euro 5b regulatory limit). These lower particle emissions will be achieved through the use of diesel particulate filters (DPFs) and improvements in combustion performance. The same PM performance will also be expected from gasoline direct injection (GDI) vehicles in 2011 with PN limits to be added in 2014.

Over many years, CONCAWE has studied new engine and after-treatment technologies, including the influence of fuel properties on particle emissions performance. This work has provided an important understanding of particle emissions and measurement techniques, as well as a substantial database on a wide range of vehicles, fuels and driving cycles.

In order to extend this understanding, CONCAWE conducted experiments to measure particle emissions using the new regulatory procedures and to compare the results with data already in hand from previous studies. These experiments have provided both PM and PN emissions results on modern diesel and GDI vehicles tested under the driving conditions of the New European Driving Cycle (NEDC), as well as on various transient and steady-state driving cycles.

Four test vehicles

Two modern diesel cars were tested that represented vehicle technology now available in the European market. These included a medium-sized direct injection (DI) diesel car with an oxidation catalyst (Car E) and a large DI diesel car (Car F) with an additised diesel particulate filter (DPF). Both cars were certified to meet Euro 4 emissions levels.

Two gasoline vehicles were also tested, based on GDI engine technology that is expected to represent a significant share of European new car sales in the near future. The first GDI car (Car G) operated under stoichiometric

[1] *Based on the European Commission's 'Particulates' Consortium Study (2001) and the 'Particulate Measurement Programme' (PMP) on light-duty passenger cars (GRPE-PMP-18-2: 2007) sponsored by the United Nations Economic Commission for Europe (UNECE).*

combustion conditions and was equipped with a three-way oxidation catalyst. The second GDI car (Car H) operated under both lean-burn and stoichiometric conditions depending upon the driving conditions, and was equipped with both a three-way oxidation catalyst and a NO_x trap. These cars were certified to meet Euro 3 and Euro 4 emissions limits, respectively.

Five test fuels

Three diesel fuels were tested in order to investigate the influence of extremes in fuel composition. One fuel (Fuel DB) was the same sulphur-free reference fuel used to develop the PMP regulatory procedure for Euro 5b, while the second was the same fuel doped with a chemical reagent to achieve a higher sulphur level (Fuel DA). Although this fuel is no longer relevant for today's marketplace, it provided a valuable test point for comparing results with data from previous CONCAWE studies. The third diesel fuel (Fuel DC) was a sulphur-free diesel manufactured by the Fischer-Tropsch process[2]. Such fuels are virtually free of aromatics and have a very high cetane number compared to conventional diesel fuels. No bio-components were added to these fuels.

Table 1 Key diesel fuel properties

Diesel properties	Fuel DA	Fuel DB	Fuel DC
Cetane number	53.0	53.0	82.8
Sulphur content (ppm)	306	8	<5
Aromatics content (% m/m)	21.8	21.8	<0.1
Polyaromatics (PAH) content (% m/m)	4.3	4.4	0.0

Two sulphur-free gasolines were tested in the GDI cars, that covered extremes of gasoline qualities within the EN228 specification. This was done to evaluate the influence of gasoline volatility and molecular composition on PM and PN emissions from GDI cars. No oxygenates were added to these fuels.

[2] *The Fischer-Tropsch process is a catalysed chemical reaction that converts carbon monoxide and hydrogen into hydrocarbon products. By adjusting the molecular weight and degree of isomerisation in this product, a gas-to-liquids hydrocarbon product can be obtained having the qualities and characteristics of diesel fuel.*

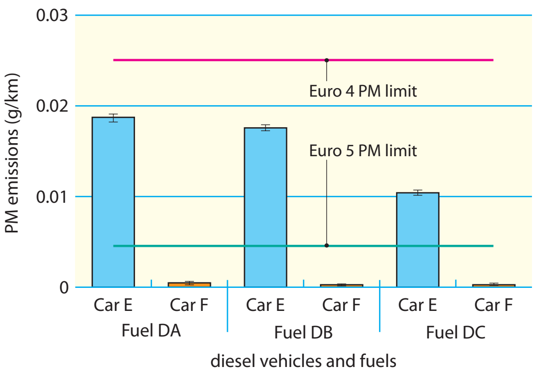
Table 2 Key gasoline fuel properties

Gasoline properties	Fuel GA	Fuel GB
Sulphur content (ppm)	<3	5
Dry vapour pressure equivalent (DVPE) (kPa)	50.2	66.3
Final boiling point (°C)	204	168
Olefins content (% v/v)	16.3	6.5
Aromatics content (% v/v)	41.5	28.4

Particulate mass (PM) emissions

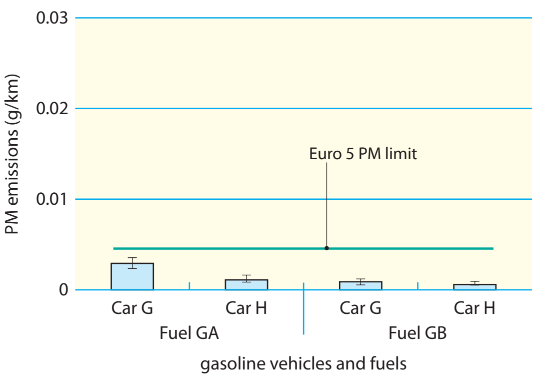
PM emissions from the diesel and gasoline cars are shown in Figures 1 and 2. Car F, equipped with a DPF, emitted very low PM over the NEDC, about 95% below the PM emissions of Car E that did not have a DPF. Although PM emissions from Car E were already below the Euro 4 limit, the high cetane diesel fuel reduced these by about 50%. The diesel fuel composition had no measurable influence, however, on the PM emissions from Car F that was equipped with a DPF.

Figure 1 PM emissions from diesel vehicles (NEDC)



A DPF reduces PM emissions by 95%, to well below the Euro 5 PM limit.

Figure 2 PM emissions from GDI vehicles (NEDC)



On the same scale, two GDI vehicles produce very low PM emissions over the same driving cycle.

Particle emissions from modern vehicles

Vehicle and fuel effects on particulate mass and ultra-fine particles

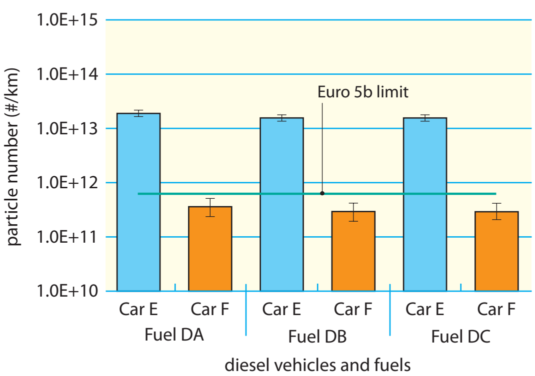
In comparison, the two GDI vehicles emitted a very low level of PM under the same NEDC condition and PM measurement procedure. Although PM emissions are not yet regulated for gasoline vehicles, it is interesting to note that the PM emissions from both GDI vehicles are comparable to those from the DPF-equipped diesel car. The PM emissions also improved between the Euro 3 and Euro 4 gasoline vehicles. The fuel composition had some impact on the total PM emissions, although the absolute PM emissions were very low.

Particle number emissions

In the new Euro 5b regulatory procedure for measuring PN, a portion of the vehicle's exhaust is separated, diluted and heated in order to stabilise the ultra-fine particles in the exhaust for measurement. The resulting stream of 'dry' carbonaceous particles having particle diameters averaging about 30 nm is measured with a particle counter.

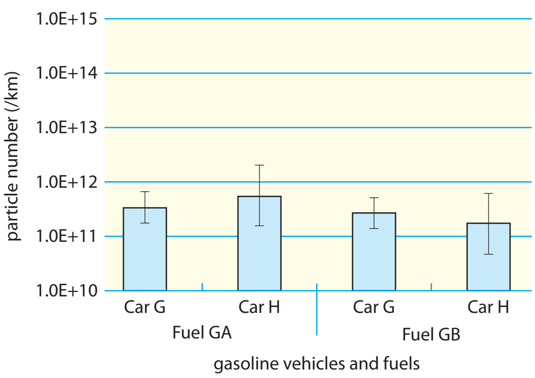
DPFs can be effective in reducing PN emissions, while the fuel properties have no effect.

Figure 3 PN emissions from diesel vehicles (NEDC)



PN emissions from GDI vehicles are comparable to those from DPF-equipped diesel vehicles under the same test conditions.

Figure 4 PN emissions from GDI vehicles (NEDC)



Comparing the results of the diesel vehicles in Figure 3, the DPF in Car F successfully lowered the PN emissions to a level just below the Euro 5b regulated level while reducing the PM emissions at the same time. As seen in Figure 4, the absolute PN emissions for the two GDI vehicles are comparable to those from the DPF-equipped diesel car. Fuel properties had no significant influence on PN emissions in either the diesel or gasoline vehicles.

In summary

Very low PM and PN emissions can be achieved by today's engine and after-treatment technologies operating on ultra-low sulphur fuels. Implementing these technologies is expected to bring continuing improvements in auto emissions as the vehicle fleet is modernised. For diesel vehicles, DPFs substantially reduce PM emissions, by more than 95% in the tests reported here, to levels that are well below the next stage of European PM emissions limits.

DPFs are also effective in reducing the ultra-fine particles, lowering the PN emissions over the NEDC by about two orders of magnitude compared to a vehicle without a DPF. Although gasoline vehicles achieve very low PM emissions already, the PN emissions from GDI vehicles are comparable to those from DPF-equipped diesel vehicles. Additional improvements in the combustion and after-treatment systems are likely to further improve the emissions performance of these vehicles. More testing is needed, however, on vehicles operating on transient and steady-state cycles to ensure that PM and PN emissions are reduced under all operating conditions.

As these new engine and after-treatment technologies are introduced, the potential for additional vehicle emissions improvements through changes in fuel properties appears to be insignificant.