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Effect of fuel properties on emissions from Euro 4 and Euro 5 diesel passenger cars

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Abstract

The EN 590 specification allows up to 7% v/v FAME to be blended into conventional diesel fuel which can then be used in most light-duty diesel vehicles. It is anticipated that higher FAME levels may be needed in order to meet the 10% renewable energy target mandated by the Renewable Energy Directive (2009/EC/28). Certain diesel fuel specification properties are considered to be environmental parameters according to the European Fuels Quality Directive (FQD, 2009/EC/30) and previous regulations. These limits included in the EN 590 specification were derived from the European Programme on Emissions, Fuels and Engine Technologies (EPEFE) which was carried out in the 1990’s on diesel vehicles meeting up to Euro 3 emissions standards. These limits could potentially constrain FAME blending levels higher than 7% v/v. No significant work has been conducted to investigate whether relaxing these limits would give rise to efficiency or emissions debits or benefits. For this reason, Concawe was interested in studying the impact of these parameters in Euro 4+ vehicle technology.
A test programme has been conducted to evaluate the impact of specific diesel properties on emissions on a Euro 5 light-duty diesel vehicle. Tests were also carried out in a Euro 4 vehicle to provide comparison with previous work. Properties studied were Poly-Aromatic Hydrocarbon (PAH) content, density, and cetane number. The Fatty Acid Methyl Ester (FAME) content was an

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additional variable in the study. Results of emissions testing will be presented and discussed including effects of the above fuel properties on particulates, NO_x, CO_2 and fuel consumption.

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Keywords: diesel; emissions; direct injection

1. Introduction

Nomenclature

CN	Cetane Number
CO	Carbon monoxide
CO_2	Carbon dioxide
DI	Direct Injection
DPF	Diesel Particulate Filters
EC	Elemental Carbon
EHN	Ethyl hexyl nitrate
EN590	European specification for diesel fuel
EN14214	European specification for fatty acid methyl esters
EPA	Environmental Protection Agency
EPEFE	European Programme on Emissions, Fuels and Engine Technologies
FAME	Fatty acid methyl ester
FQD	Fuel Quality Directive
HC	Hydrocarbons
HEPA	High Efficiency Particulate Air
IDI	Indirect Injection
IQT	Ignition Quality Tester
JCAP	Japanese Clean Air Programme
NEDC	New European Drive Cycle
NO_x	Nitrogen oxides
PAH	Polyaromatic Hydrocarbons
PM	Particulate Matter
PMP	Particle Measurement Programme
PN	Particulate Number
RED	Renewable Energy Directive
RME	Rapeseed methyl ester
SOF	Soluble Oil Fraction
Tx	Temperature (°C) at which x% of the fuel has been distilled
WLTC	Worldwide Harmonized Light Duty Test Cycle

The EN590 specification allows up to 7% v/v FAME meeting the EN14214 specification to be blended into conventional diesel fuel which can then be used in most light-duty diesel vehicles. It is anticipated that higher FAME levels will be needed in order to meet the 10% renewable energy target mandated by the Renewable Energy Directive. There are a number of EN590 specification properties considered to be environmental parameters according to the European Fuels Quality Directive (Table 1) and previous regulations. These limits could potentially constrain FAME blending levels higher than 7% v/v. No significant work has been conducted to investigate whether relaxing these limits would give rise to efficiency or emissions debits or benefits. For this reason, Concawe is interested in studying the impact of these parameters in Euro 4+ vehicle technology.

Table 1. EN590 properties specified as environmental parameters in the FQD (2009/EC/30).

Property	Column A (*t*)
PAH	Max. 8% m/m
Density	Max. 845 g/m3
T95	Max. 360ºC
Cetane Number	Min. 51

These limits were derived from the European Programme on Emissions, Fuels and Engine Technologies (EPEFE) which was carried out in the 1990's on diesel vehicles meeting Euro 2 emissions standards (Hublin et. al. (1995)).

Although there have been many studies focused on the effect of diesel fuel properties on emissions and fuel economy many of them are heavy-duty vehicles studies and of the light-duty vehicles studies many of the earlier ones were focused on indirect injection vehicles which were more common in the 1990's. Amongst the first studies which included a vehicle with a direct injection engine was carried out by Trittart et. al. (1993). While there were differences between fuels tested, density, aromatics and cetane number were highly correlated and the effects were not prescribed to any one property. The same study concluded that back-end volatility in the form of T90 did not affect any of the emissions. One of the findings from the EPEFE programme (Hublin et. al. (1995)) was that vehicles with electronic direct injection (DI) systems were generally more sensitive to fuel property changes than those with mechanically controlled systems, generally indirect injection (IDI).

Concawe carried out work in 1996 using a European DI engine to investigate the effect of density on engine controls and determined that fuel density affected the fuel pump setting, injection timing and EGR operation. The effect of density on particulates could be wholly or partially removed after engine operation was adjusted to take account of the density change. Mann et. al. (1998) also showed that engine operation was a big factor in controlling emissions due to the change in density and this work was extended to other properties by Kwon et.al. (2001). They found that T95 and density were highly correlated and generally emissions improved as density decreased. In a study carried out by JCAP (Hara et. al. (2006) and Kakegawa et.al. (2007)) using a LD DI engine, it was found that engine out emissions of PM, THC, CO and NO_x could be reduced by reducing total aromatics, but fuel effects on tail pipe emissions could not be measured due to the low levels after various aftertreatment systems were deployed. Bielaczyc et. al. (2003) studied the effect of cetane number on emissions and noted that increasing cetane number reduced emissions of HC, CO and NO_x.

In this study fuels were tested containing two levels of FAME: 0 and 10% and the differences between these fuels were analysed. The addition of FAME into diesel fuel is well-known to decrease the PM emissions of diesel engines (Lamharess et.al. (2013), Williams et. al. (2006), Hasegawa et. al. (2007), Czerwinski et.al. (2012), Bhardwaj et. al. (2013), EPA (2002)). This effect is largely attributed to the addition of oxygen into the fuel which increases the local oxygen concentration in the rich area of the diesel flame (Lamharess et.al. (2013)) and by diluting aromatic hydrocarbons and especially polycyclic aromatic hydrocarbons in the diesel fuel with an aromatics-free blending component. Previous Concawe work confirmed that the addition of FAME in diesel fuel decreases the engine-out PM emissions and noted a reduction in fuel consumption penalty associated with reducing the frequency of DPF regenerations (Rose et. al. (2014)). Another study showed, however, that the vehicles were not able to compensate for the reduced energy content of RME/diesel blends through better engine efficiency on the oxygenated fuels (Concawe, 2014). In general, previous studies have showed that increasing FAME reduces HC and CO and increases NO_x to a lesser degree. However, it should be remembered that these results are from a collection of published studies that predominantly focused on heavy-duty engines (and primarily on US market engines) that were not equipped with exhaust aftertreatment and tested only over hot start test cycles. It may not be reasonable to assume that these results will be representative of modern European light-duty vehicles that are equipped with a variety of aftertreatment technologies and are certified over a cold start test cycle. There are considerably fewer publications related to modern light-duty diesel vehicles and the results that have been reported are generally less consistent than those from the heavy duty tests.

2. Test programme

The objective of this test programme was to evaluate regulated emissions and fuel consumption from modern (Euro 4 and 5) light-duty vehicle technology when operated on diesel fuels having properties extending beyond current EN 590 specification limits and containing FAME in the range 0 to 10% v/v. Tailpipe emissions were measured and included CO_2, NO_x, HC, CO, PM, and PN as well as information on the composition of the particulates from these tests, the results of which are not described in the current paper.

2.1. Diesel vehicles

Two light duty vehicles meeting Euro 4 limits (vehicle 1, no Diesel Particulate Filter, (DPF)) and Euro 5 limits (vehicle 2, with DPF) were tested. The vehicles chosen are described in Table 2 below. A forced regeneration was carried out on the DPF equipped vehicle at the end of each test day to ensure that DPF loading and regeneration did not impact the fuel consumption and emissions test measurements. The vehicles were chosen from different manufacturers and weight classes to better represent the on-road fleet.

Table 2. Description of vehicles.

Vehicle property	Vehicle 1	Vehicle 2
Vehicle class	Upper Medium	Medium
Category	M1	M1
Emission standard	Euro 4	Euro 5
Engine Displacement (litres)	2.2	1.3
Max. Power (kW)	103	70
Inertia Class (kg)	1590	1360
Cylinder	4	4
Valves	16	16
Injection System	TDI, Common Rail	TDI, Common Rail
After-treatment device	DOC	DOC + DPF
EGR / Start-stop	Yes / No	Yes / Yes
Transmission	Manual 5-speed	Manual 5-speed
Registration date	2004	2013
Mileage at start of test (miles)	89,850	10,530

2.2. Test fuels

The reference fuel for these tests (fuel 14) was a typical European EN590 diesel with maximum 10 mg/kg sulphur. The FAME blending component was European Rapeseed Methyl Ester (RME) meeting EN14214 specifications and containing antioxidant additives to ensure oxidative stability over the course of the vehicle study. Test fuels were blended to target fuel properties of interest.

The four fuel properties which were varied were PAH (from 2 to 8% m/m), density (from 820 to 860 kg/m^3), which are most likely to impact vehicle performance and emissions, and also cetane number (from 46 to 53) and FAME (from 0 to 10% v/v). It was anticipated that T95 would vary with density. Fuels 1 to 8 tested eight of the 16 possible combinations of levels in an orthogonal half-replicate of a 2^4 factorial design (see Table 3) with the additional fuel 9 being one of the missing corners. Fuels 10 to 13 form a small 2×2 submatrix varying PAH and FAME with density and CN held constant.

Other than the fuel parameters that are being evaluated, all other EN590 specifications were met including lubricity, using a lubricity improver if needed in the blends that did not contain FAME. A standard detergent treat was also used to ensure engine cleanliness throughout the test programme. The cetane number targets were met using hydrocarbon blend components but some use of cetane improver (EHN) was used to trim the CN to the requested values. IQT data was collected on all of the final blends.

Table 3. Target fuel properties.

Fuel	Density at 15 °C (kg/m^3)		PAH (%m/m)		FAME (%v/v)		Cetane Number (min)	
	820	860	2% max	8% max	0%	10%	46	53
1	x		x		x		x	
2		x	x			x	x	
3		x	x		x			x
4	x		x			x		x
5		x		x	x		x	
6	x			x		x	x	
7	x			x	x			x
8		x		x		x		x
9		x		x	x			x
Fuel	Density at 15 °C (kg/m^3)		PAH (%m/m)		FAME (%v/v)		Cetane Number (min)	
	840		4% max	8% max	0%	10%	53	
10	x			x	x		x	
11	x			x		x	x	
12	x		x		x		x	
13	x		x			x	x	

2.3. Test protocol

The daily test protocol consisted of the New European Driving Cycle (NEDC, cold-started), which is the current type approval test in Europe, followed by the Worldwide harmonised Light-duty Test Cycle (WLTC, hot-started in this study), which is going to replace NEDC in the future. In addition, a steady-state operation point was included in order to acquire data for the particle size characteristics. A detailed flowchart of the measurement and conditioning processes is provided in Figure 1. A statistician was entrusted with the design of a concise and statistically robust vehicle and fuel testing schedule. The main elements of the testing schedule were as follows:

- One fuel/vehicle combination per day (full daily schedule as shown in Figure 1).
- Randomised block design with 3 well dispersed repeats on each test fuel. All fuels to be tested once (in a block), before moving to second test, etc.
- More repeats on the reference fuel to obtain improved estimates of baseline performance and system drift.

Some tests had to be repeated at later stages in the test programme for vehicle 2 due to technical difficulties.

Emission measurements over NEDC and WLTC were conducted following the European regulations (Directive 70/220/EEC including latest amendments). The exhaust gas was primarily diluted and conditioned by means of Constant Volume Sampling (CVS). A 6 m long corrugated stainless steel tube transferred the exhaust gas from the tailpipe to the CVS tunnel inlet. The tube was insulated to minimize heat losses and particle thermophoresis and was clamped onto the vehicle exhaust pipe with a metal-to-metal connection to avoid exposing the hot exhaust gas to any synthetic material connectors. A flow rate of approximately 600 Nm^3/h was maintained in the CVS tunnel by a positive displacement pump. The dilution air was filtered through a HEPA class H13/EN1822 filter at the inlet of the dilution tunnel. Proportional diluted exhaust samples were collected in bags for gaseous pollutant measurements.

Gaseous pollutants were measured with laboratory analysers (chemiluminescence for NO_x, flame ionization detector for HC and non-dispersive infrared for CO and CO_2). Fuel consumption was derived by means of the exhaust-to-fuel carbon balance, taking into account the oxygen content of fuels. PM samples were collected on 47 mm PTFE-coated glass fibre filters following the procedure outlined in UN regulation no. 83. A separate filter was used for each of the two driving cycles (NEDC and WLTC) for measuring PM emissions although these were combined in order to produce enough particulate for analysis, particularly in the case of the Euro 5 vehicle. After weighing and calculating PM emissions, the filters were packed in order to be used for determining the soluble organic fraction (SOF) of PM, anions and elemental carbon (EC) by difference.

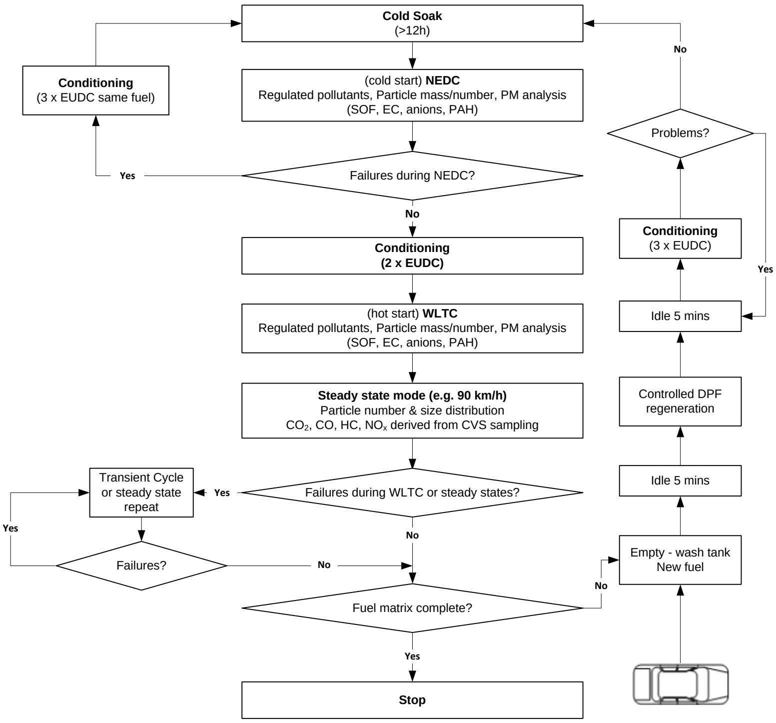

Fig. 1. Daily testing sequence.

3. Results and discussion

3.1. Statistical analysis

Recognised data evaluation and analysis techniques have been employed to identify corrupted data points, outliers and trends. Data points identified through engineering reasoning to be invalid have been rejected from the data analysis, as have statistical outliers which would obscure real fuel effects in the analysis if retained. Trend correction has been limited to minimise data treatment and has only been applied where deemed necessary to correct for drift in the data which would otherwise obscure real fuel effects.

Table 3 summarizes the effect of each of the four fuel properties on each emission for each vehicle and cycle. Thus, for example, in vehicle 1 in the NEDC, estimated CO2 emissions range from 148.8 to 151.5 g/km as density increases from 820 to 855 kg/m^3 with the other three properties held constant at the mid-point values CN = 50, PAH = 4.75%m/m and FAME = 4.75%v/v. The density effect is significant at $P<0.1\%$ (or 99.9% confidence). The effects in Table 3 have been estimated by fitting a simple multiple regression model to each emission with linear terms in the four properties. These models are then used to estimate emissions across ranges representative of the properties actually measured across the 14 fuels. A more detailed examination of the results including searches for nonlinear responses and/or interactions between fuel properties will be presented in subsequent publications.

3.2. Summary of results

Estimated effects on emissions of changes in fuel properties for each vehicle and cycle are shown in Table 3.

Table 4. Estimated effect on emissions of changes in fuel properties for each vehicle and cycle.

DENSITY (820–855 kg/m³)[a]	Vehicle 1		Vehicle 2	
	NEDC	WLTC	NEDC	WLTC
CO_2 (g/km)	148.8–151.5***	132.9–135.2***	113.8–116.2***	103.4–105.1***
Energy consumption (MJ/100km)	202.8–204.1*	180.9–181.2 NS	155.4–156.6*	140.7–140.9 NS
Fuel consumption (l/100km)	5.742–5.594***	5.121–4.966***	4.400–4.291***	3.986–3.861***
NO_x (g/km)	0.213–0.218 NS	0.450–0.448 NS	0.178–0.222**	0.576–0.586 NS
PM (mg/km)	15.49–17.47***	13.47–15.94**	0.830–0.696 NS	0.416–0.428 NS
HC (g/km)	0.022–0.030***	0.002–0.002 NS	0.029–0.041***	0.006–0.003**
CO (g/km)	0.244–0.336***	0.011–0.008 NS	0.173–0.253***	0.005–0.006 NS
CETANE NUMBER (46–54)[b]	Vehicle 1		Vehicle 2	
	NEDC	WLTC	NEDC	WLTC
CO_2 (g/km)	150.2–150.2 NS	134.2–133.9 NS	115.5–114.6**	104.5–104.0 NS
Energy consumption (MJ/100km)	203.6–203.3 NS	181.1–181.0 NS	156.6–155.3**	141.1–140.5 NS
Fuel consumption (l/100km)	5.669–5.667 NS	5.043–5.045 NS	4.362–4.329**	3.930–3.918 NS
NO_x (g/km)	0.212–0.220*	0.453–0.444 NS	0.196–0.205 NS	0.590–0.573 NS
PM (mg/km)	14.79–18.17***	13.46–15.95**	0.786–0.740 NS	0.416–0.429 NS
HC (g/km)	0.031–0.021***	0.002–0.002 NS	0.044–0.025***	0.005–0.004 NS
CO (g/km)	0.359–0.222***	0.010–0.009 NS	0.260–0.166***	0.005–0.005 NS
PAH (2.0–7.5%m/m)[c]	Vehicle 1		Vehicle 2	
	NEDC	WLTC	NEDC	WLTC
CO_2 (g/km)	150.3–150.0 NS	133.7–134.4*	115.2–114.9 NS	104.3–104.3 NS
Energy consumption (MJ/100km)	203.9–203.0 NS	180.7–181.4*	156.4–155.6 NS	140.9–140.8 NS
Fuel consumption (l/100km)	5.679–5.657 NS	5.031–5.057*	4.354–4.337 NS	3.923–3.924 NS
NO_x (g/km)	0.215–0.216 NS	0.449–0.448 NS	0.203–0.198 NS	0.578–0.585 NS
PM (mg/km)	15.93–17.03*	13.92–15.49*	0.720–0.806 NS	0.442–0.402 NS
HC (g/km)	0.026–0.027 NS	0.002–0.002 NS	0.035–0.034 NS	0.004–0.005*
CO (g/km)	0.289–0.292 NS	0.009–0.010 NS	0.222–0.204 NS	0.005–0.005 NS
FAME (0.0–9.5%v/v)[d]	Vehicle 1		Vehicle 2	
	NEDC	WLTC	NEDC	WLTC
CO_2 (g/km)	150.1–150.2 NS	134.0–134.1 NS	115.0–115.0 NS	104.1–104.4 NS
Energy consumption (MJ/100km)	203.5–203.4 NS	181.2–180.9 NS	156.2–155.7 NS	140.8–140.8 NS
Fuel consumption (l/100km)	5.629–5.708***	5.012–5.076***	4.321–4.370***	3.895–3.952***
NO_x (g/km)	0.212–0.219*	0.441–0.457*	0.200–0.201 NS	0.572–0.591 NS
PM (mg/km)	17.55–15.41***	16.11–13.30***	0.799–0.727 NS	0.442–0.402 NS
HC (g/km)	0.026–0.026 NS	0.002–0.003 NS	0.037–0.033*	0.003–0.005*
CO (g/km)	0.302–0.279 NS	0.010–0.009 NS	0.222–0.204*	0.005–0.005 NS

[a] Estimated responses over the density range 818–859 kg/m³ with CN = 50, PAH = 4.75%m/m and FAME = 4.75%v/v.
[b] Estimated responses over the CN range 46.3–55.9 with density = 837.5 kg/m³, PAH = 4.75%m/m and FAME = 4.75%v/v.
[c] Estimated responses over the PAH range 1.5–8.5%m/m with density = 837.5 kg/m³, CN = 50 and FAME = 4.75%v/v.
[d] Estimated responses over the FAME range 0.0–9.6%v/v with density = 837.5 kg/m³, CN = 50 and PAH = 4.75%m/m.
Significance of effects: *** P<0.1%, **P<1%, * P<5%, NS not significant at P<5%.
Significant positive effects are shown in blue, significant negative effects are shown in red.

3.3. Density

Volumetric fuel consumption decreases as density increases, this is observed in both vehicle and test scenarios and is expected to be due to the higher energy content injected per unit volume of fuel. Energy consumption is statistically unchanged as density changes, except in NEDC tests where there is a slight increase with density. This indicates that the injected volume is largely being adjusted via the Accelerator Pedal Position (APP) to compensate for the change in injected mass. This is happening because the vehicles are operating at part load (road load) and maintaining the same APP for a high density fuel would result in higher mass injection and therefore an increase in speed. There is a tendency for CO_2 to increase with density which is observed in both vehicles and test cycles. This could indicate that the difference in injected mass is not compensated for entirely for the higher density fuels; however is probably predominantly due to the higher C/H ratio of heavier components comprising the high density fuels.

In the NEDC results, higher density is associated with increased HC and CO which could be due to the slight mixture enrichment and higher C/H ratio corroborated by the increased CO_2. This relationship is not apparent during the WLTC cycle when the oxidation catalyst is fully warm and HC and CO levels are inherently very low. PM increases with density in the Euro 4 vehicle in both test cycles, again expected to be linked to slight enrichment and higher C/H ratio. This vehicle is not fitted with a DPF, therefore it is unsurprising that fuel effects on PM are more apparent than in the Euro 5 test vehicle. An increase in NO_x is associated with increased density only in the Vehicle 2 NEDC tests. This could be due to elevated peak combustion temperatures.

The increases primarily exemplified in CO_2 emissions observed with the current in-market vehicle technologies tested suggest that some environmental dis-benefits would result from increasing the current diesel density limit. Some of the negative effects are likely to be largely mitigated by increased sophistication of exhaust after-treatment and fuel injection hardware and calibration as vehicle technology evolves through the current Euro 6 phase and beyond. However the higher CO_2 emissions are likely to persist as a result of increased C/H ratio associated with heavy components and penalty of increased tailpipe CO_2 emissions associated with increased density fuels would have to be weighed against the benefits of reducing the volumetric fuel consumption and of widening the usable diesel fuel envelope.

No fuels tested fell substantially below the current lower density limit, however, by extrapolation the data indicate that reducing the density lower limit somewhat would have no negative effects on emissions, though it would have negative impacts on volumetric fuel consumption and potentially power.

3.4. Cetane number

Increased cetane number is associated with decreased CO_2, energy consumption and fuel consumption in the Euro 5 vehicle NEDC data, though the effects are very small. This is expected to be due to the higher CN fuels advancing combustion to a more thermodynamically efficient phasing. It is postulated that this correlation is not evident in the Euro 4 vehicle because of the less retarded – therefore less sensitive – combustion phasing employed to favour efficiency over NO_x abatement, as well as to the higher EGR rate likely to be applied in the Euro 5 vehicle. It is postulated that in some Euro 6+ technology vehicles where exhaust after-treatment rather than in-cylinder NO_x abatement strategies are common that the CN–CO_2 link would be less prevalent.

In the Euro 4 vehicle, a PM increase is associated with increasing CN. This is likely to be due to high CN fuels reducing ignition delay and therefore limiting air-fuel pre-mixing time. This effect is not observed in the Euro 5 vehicle, probably due to the use of a DPF and is therefore unlikely to be a first order concern in other Euro 5+ technology vehicles. However, higher engine out PM in DPF equipped vehicles (Euro 5+) could lead to higher fuel consumption and CO_2 due to increased engine pumping work and active DPF regeneration fuel quantity associated with DPF operation.

In both vehicles, higher CN is associated with lower CO and HC in the NEDC and there is also a benefit in EC in vehicle 2. This could be due to reduced ignition delay advancing combustion phasing allowing more time for complete combustion, whereas the positive CN–PM correlation in the Euro 4 is dominated by the pre-mixing effect. The trend in HC and CO is not observed in the hot start WLTC probably because of the inherently lower HC and CO levels commensurate with the oxidation catalyst working more efficiently at higher temperatures.

3.5. PAH

There are few significant effects of PAH on the test metrics and none of these were consistent across the vehicle/test combination except for a significant increase in PM in both test cycles in the Euro 4 vehicle. This could be linked with slower burning of heavy, carbon rich species impeding complete combustion. This association is not evident in the Euro 5 vehicle possibly because of the DPF greatly reducing PM levels, hence suppressing any fuel related signals in the PM data. This is unlikely to be a first order concern in other Euro 5+ technology vehicles due to the pervasive use of DPFs. However, higher engine out PM in DPF equipped vehicles (Euro 5+) could lead to higher fuel consumption and CO_2 due to increased engine pumping work and active regeneration fuel quantity associated with DPF operation.

3.6. FAME

As expected, higher FAME levels are associated with increased volumetric fuel consumption due to the replacement of hydrocarbon species with lower energy content oxygenate species, and this is observed in both vehicles and test data sets; however there is no significant effect on energy consumption. PM is reduced with higher FAME content fuels in the Euro 4 vehicle, again as expected, due to the increased oxygen content of the fuel benefitting complete combustion. The PM effect is not evident in the Euro 5 vehicle data possibly because of the DPF greatly reducing PM levels, hence suppressing any fuel related signals in the PM data. There is a significant increase in HC associated with FAME in the Euro 5 WLTC data which is somewhat unexpected and could be an indirect effect of the correlation between FAME and density. There are reductions in HC and CO in the Euro 5 NEDC data which are more in line with expectations of FAME effects on emissions. Lower engine out PM in DPF equipped vehicles (Euro 5+) could lead to lower fuel consumption and CO_2 due to reduced engine pumping work and active regeneration fuel quantity associated with DPF operation. This could partially offset the increased volumetric fuel consumption associated with FAME containing fuels as well as low level effects on engine power.

4. Conclusions

The current specification governing automotive diesel fuel in Europe, EN590, has been developed taking into consideration environmental and economic effects of fuel sourcing, manufacturing and finished fuel quality as well as maximising the efficient operability of diesel fired vehicles. As vehicle technology evolves along with the diversification of fuel stocks, it may be prudent to re-evaluate the fuel specification to ensure it remains fit-for-purpose and not unnecessarily constraining in terms of fuel supply or vehicle operability. To this end, a test programme has been conducted to evaluate the impact of specific diesel properties on emissions on a Euro 5 light-duty diesel vehicle. Tests were also carried out in a Euro 4 vehicle to provide comparison with previous work. Properties studied were Poly-Aromatic Hydrocarbon (PAH) content, density, and cetane number. The Fatty Acid Methyl Ester (FAME) content was an additional variable in the study. Results of emissions testing have delivered the following findings:

- Density: The increases primarily seen in CO_2 emissions observed suggest that vehicle emissions penalties result from increasing diesel density above the current limit in the current in-market vehicle technologies tested over chassis dynamometer cycles. Some of the negative effects could be largely mitigated in Euro 6+ technology vehicles owing to advances in exhaust after-treatment and engine technologies, however the higher CO_2 emissions are likely to persist as a result of increased C/H ratio associated with heavy components and the penalty of increased tailpipe CO_2 emissions associated with increased density fuels would have to be weighed against benefits elsewhere of widening the usable diesel fuel envelope.
- CN: The CO_2 and associated efficiency benefits observed with higher CN fuels in the Euro 5 data are likely to be due to higher CN fuels advancing combustion to a more thermodynamically efficient phasing. This relationship is not apparent in the Euro 4 vehicle and may be limited to vehicles that employ aggressive in-cylinder NO_x control.
  - In the Euro 4 vehicle, a PM penalty is associated with increasing CN. This is likely to be due to high CN fuels reducing ignition delay and therefore limiting air-fuel pre-mixing time. This effect is not observed in the Euro

5 vehicle, probably due to the use of a DPF and is therefore unlikely to be a first order concern in other Euro 5+ technology vehicles.
  - Benefits in CO and HC emissions were only observed in the cold start NEDC where HC and CO levels are in the measurable range. Overall there is no conclusive evidence in this programme that supports the reduction or increase in the current CN minimum specification level.
- PAH: Given the lack of consistency of PAH effects on CO_2 and the reduction in likelihood of a PM effect with DPF equipped vehicles, there is little conclusive evidence to support a reduction in the PAH specification below the current limit of 8%m/m, given that the test fuel set spanned a range up to the current limit with no substantial or consistent deleterious effects on the measured parameters. Given that at least two generations of evolution of vehicle technology have elapsed since the specification was set, it is possible that current and future technology vehicles would be insensitive to levels of PAH higher than the current specification limit.
- FAME: Use of 10%v/v FAME had no deleterious effects except on volumetric fuel consumption and this could be partially offset by benefits in engine out soot reducing the fuel consumption penalties of DPF use in Euro 5+ vehicles.

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