The impact of biodiesel on vehicle performance

Evaluating fuel consumption and emissions in modern diesel vehicles

Introduction

The use of bio-derived blending components in road fuels is increasing around the world as a result of legislative initiatives to reduce greenhouse gas (GHG) emissions, reduce dependence on imported fossil fuels, and support agriculture. Within the European Union, the Renewable Energy Directive (2009/28/EC), passed by the European Parliament in 2008, will require transport fuels to contain 10% of renewable products (calculated on an energy basis) by 2020. The European Committee for Standardization (CEN) is already working to change the market fuel specifications in order to enable this mandate.

For much of the coming decade, the most common bio-components will be ethanol for petrol blending and fatty acid methyl esters (FAME) for diesel fuel blending. Although progress is being made on advanced bio-components derived from biomass and other sources, these products are not expected to contribute substantially to meeting the EU renewable fuel mandate before 2020[1].

The current European diesel fuel specification (EN 590) allows blending of up to 7% v/v FAME in diesel as long as the FAME complies with the European standard (EN 14214). Many different FAME types, derived from vegetable oils and animal fats, are now used in Europe but rapeseed methyl ester (RME) is most widely used due to its especially favourable chemical and physical properties.

As vehicles adapt to new emissions requirements and the FAME content of diesel fuel increases, it is important to understand what impact changing fuel blends will have upon the fuel consumption and regulated emissions of modern light-duty diesel vehicles, particularly for newer Euro 4 compliant vehicles.

The fuel consumption (FC) of light-duty vehicles is also an important issue, as attention increasingly focuses on the GHG savings that can be achieved from FAME/diesel fuel blends. In most well-to-wheels (WTW) studies[2], the vehicle's efficiency is assumed not to change when the engine runs on an oxygenated fuel, i.e. the same megajoules (MJ) of fuel will be needed to complete a prescribed driving cycle for both hydrocarbon-only and oxygenated diesel fuels. This means that a slightly higher volumetric fuel consumption is expected for oxygenated fuels because their energy content is somewhat lower than that of hydrocarbon-only fuels. This effect will be more evident as the concentration of FAME in diesel fuel increases.

For this reason, CONCAWE was interested in measuring whether modern vehicles might be capable of recovering a portion of this volumetric penalty through better engine efficiency when running on oxygenated fuels. The published literature is not entirely clear on this point because most work has focused on the impact of FAME on emissions performance rather than on fuel consumption. In addition, the energy content of FAME is only about 10% lower than that of hydrocarbon-only diesel fuels and detecting small differences in volumetric fuel consumption can be difficult.

CONCAWE's vehicle study[3] was designed to carefully control experimental variability and collect sufficient data in order to measure small differences in fuel consumption among vehicles and fuels. The opportunity was also taken to see how significantly higher FAME levels affected both regulated and unregulated tailpipe emissions.

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[1] *Wood Mackenzie, 2009.* Food and Fuel: The outlook for biofuels to 2020.

[2] *For example, the JEC Well-to-Wheels Study, Version 2c (2007)*

[3] *SAE 2010-01-1484*

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Table 1 Diesel fuel properties

Fuel property	Units	Test method	B0	B10	B30	B50
Derived Cetane Number (DCN)		IP 498	55.5	56.1	56.3	58.1
RME content	% v/v	EN 14078	<0.1	10.7	30.6	50.9
Oxygen	% m/m	In-house method	<0.04	1.1	3.3	5.4
Density at 15°C	kg/m^3	EN ISO 12185	823.1	829.1	841.0	853.0
Lower Heating Value (LHV)	MJ/kg	ASTM D240/IP12	42.89	42.32	41.22	40.06
Volumetric LHV (VLHV)	MJ/l	Calculated	35.30	35.09	34.66	34.17

Fuels and vehicles

Four diesel fuels were specially blended and tested in this programme. One base diesel fuel (B0, complying with the EN 590 specification) was blended with commercially sourced RME (complying with the EN 14214 specification) to give diesel blends containing 10% (B10), 30% (B30), and 50% v/v RME (B50)—see Table 1. Although these RME concentrations are higher than are allowed in today's marketplace fuels, they were selected in order to magnify the effect of RME on vehicle performance and emissions and to anticipate future increases in bio-content.

Three light-duty diesel vehicles, complying with the Euro 4 emissions regulations, were selected for this study—see Table 2. All three vehicles were equipped with direct injection (DI) common rail engines, exhaust gas recirculation (EGR) for controlling NO_x emissions, and a diesel oxidation catalyst (DOC) for reducing CO and HC emissions. Vehicles 1 and 3 were also equipped with diesel particulate filters (DPF) for controlling particulate matter (PM) emissions using two different types of DPF regeneration strategies. Vehicle 3 was the same test vehicle that had previously been used in a major European study on particulate emissions[4].

Table 2 Light-duty diesel vehicles

Vehicle characteristics	Vehicle 1	Vehicle 2	Vehicle 3
Model year	2009	2004	2005
Euro certification	Euro 4	Euro 4	Euro 4
Cylinders	4	4	4
Displacement	2.2L	2.2L	2.0L
Fuel injection system	Common rail direct injection	Common rail direct injection	Common rail direct injection
Transmission	Automatic	Manual	Manual
Diesel particulate filter (DPF)	Catalysed DPF with in-cylinder fuel injection	No DPF	Fuel-borne catalyst with in-cylinder fuel injection

Fuel consumption and tailpipe emissions data were collected over the New European Driving Cycle (NEDC), which is the European regulatory test procedure. In addition to the typical measurements used to monitor engine and vehicle operation, emissions measurements also included NO_x, CO, HC, PM and particle number (PN) emissions using standard techniques. Similar testing was conducted over a European transient driving cycle and two fixed-speed driving conditions.

The impact of RME on fuel consumption

The primary objective of this study was to find out whether modern vehicles can compensate for the lower energy content of RME/diesel fuel blends by improving their engine efficiency. Since the energy content of FAME is only slightly lower than that of diesel fuel, higher RME contents and a rigorous test protocol were used to control experimental variability. All vehicles responded in a similar way for both CO_2 emissions and fuel consumption (FC) with increasing RME content.

Over the NEDC, the vehicle is driven by a trained technician according to a prescribed cycle of speed versus time. For fuels having slightly different energy contents, this means that different volumes of fuel will be consumed over the regulatory cycle and converted to CO_2 exhaust emissions through combustion.

As shown in Figure 1, the volumetric FC was found to be proportional to the energy content of the RME/diesel

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[4] *Andersson, J.,* et al. *(2007)* Particle Measurement Programme (PMP): Light-Duty Inter-laboratory Correlation Exercise (ILCE_LD)—*Final report (EUR 22775 EN) GRPE-54-08-Rev.1*

blend over the NEDC cycle. Figure 2 shows the average percentage change in FC and CO_2 emissions versus the hydrocarbon-only diesel fuel (B0). These results demonstrate that modern engine management systems are not able to compensate for the lower energy content of FAME-containing diesel fuels through better engine efficiency when running on oxygenated fuels.

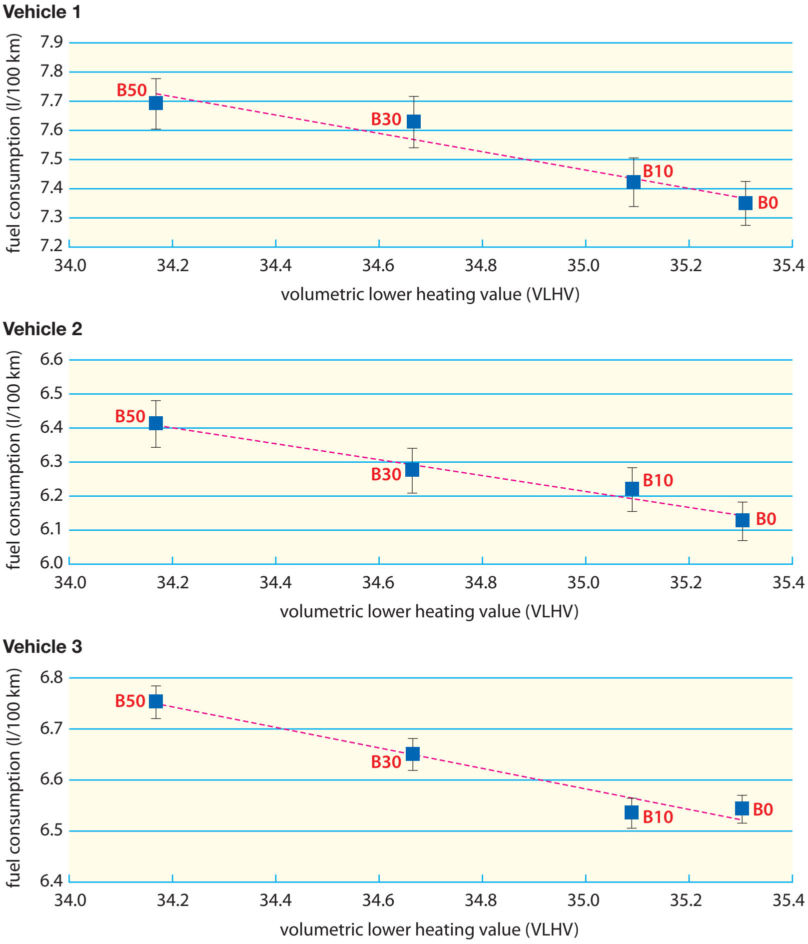
The impact of RME on tailpipe emissions

In addition to the FC data, regulated tailpipe emissions were also measured and used to evaluate the impact of RME on exhaust emissions. The average results for all three vehicles, compared to the emissions measured on the B0 fuel, are summarized in Figure 3. The changes in PM emissions are also differentiated between the non-DPF car (Vehicle 2) and the average results for the two DPF-equipped cars (Vehicles 1 and 3).

These figures show that the NO_x, CO, and HC emissions systematically increased as the RME content in the B0 diesel fuel increased up to 50% v/v. On the other hand, the PM emissions systematically decreased with increasing RME although these effects were most evident only on the non-DPF equipped vehicle (Vehicle 2). This effect has been seen in other studies in which the oxygenated RME reduces the fraction of solid PM emissions. The PN emissions also decreased with increasing RME content on the non-DPF equipped vehicle but this effect was not evident for the DPF-equipped vehicles where the PN emissions levels were much lower.

This study on modern diesel vehicles has helped to answer some key questions related to the impact of higher RME concentrations in diesel fuel on vehicle fuel consumption and tailpipe emissions. As has already been observed with the fuel consumption of ethanol/petrol blends, the lower energy content of the RME blending component increases the volumetric fuel consumption. RME also has an impact on tailpipe emissions, most notably increasing the NO_x, CO and HC emissions and reducing the PM emissions.

Figure 1 Change in vehicle fuel consumption with RME content over the NEDC


Vehicle 1

Vehicle 2

Vehicle 3

Figure 2 Average percentage change in vehicle fuel consumption over the NEDC (all cars)

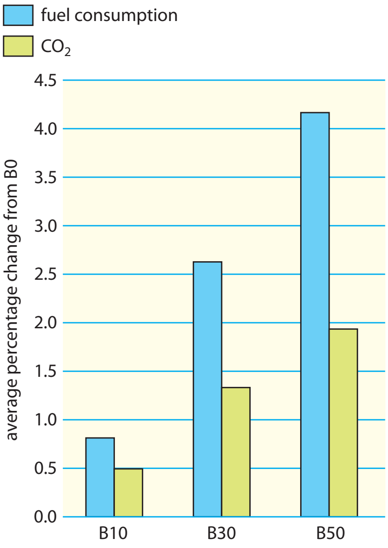


Figure 3 Average percentage change in regulated emissions over the NEDC