

The Impact of Diesel and Biodiesel Fuel Composition on a Euro V HSDI Engine with Advanced DPNR Emissions Control

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ABSTRACT

In an effort to reduce CO₂ emissions, governments are increasingly mandating the use of various levels of biofuels. While this is strongly supported in principle within the energy and transportation industries, the impact of these mandates on the transport stock's CO₂ emissions and overall operating efficiency has yet to be fully explored. This paper provides information on studies to assess biodiesel influences and effects on engine performance, driveability, emissions and fuel consumption on state-of-the-art Euro IV compliant Toyota Avensis D4-D vehicles with DPNR aftertreatment systems.

Two fuel matrices (Phases 1 & 2) were designed to look at the impact of fuel composition on vehicle operation using a wide range of critical parameters such as cetane number, density, distillation and biofuel (FAME) level and type, which can be found within the current global range of Diesel fuel qualities.

Vehicle test results from Phase 1 indicated a surprisingly large impact of CN on fuel consumption in addition to an expected effect of fuel calorific value. The CN effect was not so apparent in Phase 2 where fuels were of a much narrower cetane range. Compared to base fuels, FAME biofuel blends, at levels of B30 and below, typically showed reductions in HC emissions, a negligible impact or reductions in CO emissions and a negligible impact or

increase in NO_x emissions. B100 RME gave amongst the highest overall CO and CO₂ emissions. At equivalent blend level of B20, RME tended to give amongst the highest HC, CO and NO_x emissions compared to JME or CME.

The higher cetane premium fuels tested in this study (CN > 60), gave the lowest overall fuel consumption, HC and CO emissions. Hydrogenated vegetable oil (HVO) component offered further emissions advantages when blended at B5 level into a high cetane fuel, as well as giving significant emissions benefits at B20 level over standard European EN590 Diesel.

INTRODUCTION

The Biofuels Directive in Europe [1] is an example of several similar initiatives underway globally to encourage the introduction of bio-derived components into automotive fuels. Directive 2003/30/EC states that 2% by energy content of all transport gasoline and Diesel fuels must be bio-derived by 2005, with this percentage rising to 5.75% by 2010. The Directive has been transposed into law by European member states, with some states electing to push ahead of the Directive and propose faster introduction of higher bio quotas. In Germany, for example, the mandatory combined quota for gasoline and Diesel fuels is 6.25% by energy content by 2009; however the current EN228 and EN590 fuel standards allow only 5% by volume or 4.8% by energy

content of biocomponents. Thus, a German B7 (7% by volume) Diesel fuel standard was defined (DIN 51 628) and came into force early in 2009. Overall, it may prove difficult to meet the mandatory combined quotas in the timeframe required in Germany due to the need to consider and revise fuel standards for accommodation of higher bio levels.

These developments highlight the need for a considered approach to biofuel introduction, specifically with a view to understanding the implications of inclusion of higher levels of bio components on fuel specifications, as well as the impact on vehicle performance and emissions characteristics. This study aims to address the latter consideration, where information is currently scant. Specifically, the effects of FAME type, blend level and base blend fuel are examined in two state-of-the-art Avensis 2.2L D4-D vehicles.

PROGRAMME DESIGN

The test programme was designed to identify instantaneous effects of fuels on vehicle performance, driveability and emissions. No long-term durability effects were evaluated during this programme.

TEST FUELS & LUBRICANT – An initial test fuel matrix (Phase 1) was designed to meet the following requirements:

- Determine the differential impact of fuels utilising conventional Fatty Acid Methyl Ester (FAME) based biofuel components
- Evaluate the independent impact of fuel Cetane Number (CN), aromatics, density, distillation and sulphur content on engine operation
- Simulate the wide range of automotive Diesel fuel qualities currently available in the global market place

In-house BP data from global market surveys were used to determine maximum, minimum and typical blend properties for Diesel fuels around the world. Data from over 2650 samples were analysed to determine candidate formulations to test. Biofuel based blends were included at nominal levels of B5, B20 and B100 levels (5%, 20% and 100% biofuel contents respectively). Biofuels based on Rapeseed Methyl Ester (RME), Soya Methyl Ester (SME) and Jatropa Methyl Ester (JME) were utilised to represent potential biofuel sources from Europe, US and Asia. The B5 RME blend utilised German regular Diesel fuel as the base, and the B20 SME and B27 JME utilised US#1 Diesel. Sulphur levels of all fuels were <50ppm (Table 1).

Phase 1 Fuels		
No.	Description	Cetane No. (ASTM D613)
1	US#1	40.0
2	Swedish Class 1	54.2
3	German Regular Winter <10ppmS	54.6
4	German Regular Winter <1ppmS	53.1
5	German Regular Summer B5 RME	54.6
6	German Premium Summer	61.0
7	JCAP J2D01 equivalent	55.6
8	B100 (RME)	48.9
9	US B20 SME	47.1
10	US B27 JME	48.4
Phase 2 Fuels		
1	Swedish Class 1	53.8
2	Euro Reg Diesel (EN590)	53.6
3	B10 RME	53.6*
4	B20 RME	51.0*
5	B30 RME	53.9*
6	B50 RME	53.8*
7	B100 RME	52.5*
8	B20 CME	54.8*
9	B20 JME	53.5*
10	B20 HVO	55.5
11	Premium	63.4
12	B5 HVO Premium	62.5

* Average of two test results

Table 1: Fuels Matrix, Phases 1 & 2

Following testing of the Phase 1 fuels, a further matrix was designed to build on the learnings from Phase 1 and to meet the following specific requirements:

- To determine the emissions response of RME component blended into a European basestock at blend levels of B10, B20, B30, B50 and B100
- To enable comparisons between different FAME types at B20 blend level
- To evaluate the effect of hydrogenated FAME components (HVO), compared to base European regular and premium fuels

The fuels tested in Phases 1 & 2 covered a wide range of cetane numbers, from 40 to ~63. Further data on other key fuel parameters are provided in Appendix 1.

The lubricant utilised in this programme was blended at a nominal sulphur level of 0.08% m/m and was equivalent for both Phases 1 & 2.

TEST VEHICLE & PREPARATION - The vehicles utilised for the testing were Toyota Avensis D4-D fitted with the 2AD-FHV engine and Diesel Particulate NOx Reduction (DPNR) aftertreatment system (Table 2). Two separate vehicles, purchased new, were used for Phases 1 & 2.

Vehicle Make and Model	Toyota Avensis 2.2L D4D
Engine type	2AD - FHV
Compression Ratio	15.8 :1
Fuel Injection	Common Rail
Max Power/ Speed (kW/ rev/min)	130/3600
Max Torque/ Speed (kW/ rev/min)	400/ 2000-2600
Aftertreatment	DPNR
Euro Stage	Eu4

Table 2: Vehicle Specifications

Vehicles were instrumented for the following:

- Engine out emissions (take-off opposite cylinder 1 away from 5th injector) (5th injector is fuel dosing injector for DPNR system)
- Thermocouples:
 - Pre-turbo, Pre-DPNR, Post-DPNR, Post-DOC
- Pressure sensors:
 - Pre-DPNR, Post-DPNR
- Combined UEGO/NOx sensor (Horiba model MEXA720NOx):
 - Pre-DPNR, Post-DPNR

All thermocouples and sensors were connected to a VBox logging system. Throughout the mileage accumulation, driveability, emissions and acceleration measurements, all signals were logged at 2Hz frequency.

Vehicle Break-In & Mileage Accumulation - On receipt of vehicles, the factory fill fuel and lubricant were drained and the oil filter replaced. Vehicles were refilled with Swedish Class 1 test fuel and the 0.08% m/m sulphur lubricant.

Following instrumentation, vehicles were operated over a repeated mixed driving cycle on a test track for 10,000km. The aim of this phase of mileage accumulation was to break-in the vehicles and provide an initial de-greening and stabilisation of the aftertreatment system.

Fuel Test Order & Initial Fuel & Lubricant Stabilisation - Following the initial 10,000km mileage accumulation, the vehicles' fuel and lubricant were drained and the fuel, oil and air filters replaced. The fuel and lubricant systems were then drained, flushed, and refilled with test fuel and lubricant. This procedure was repeated when changing to a new test fuel, after which 1,000km run-in mileage was undertaken over the weekend, prior to emissions testing the following week.

A randomised fuel testing order was employed as far as possible. Since both Phases 1 & 2 took several months each to execute, Swedish Class 1 test fuel was identified as the base fuel and tested at the start, mid-point and end of each Phase. This allowed for any vehicle drift over the course of the test programme to be evaluated. Testing on individual fuels was performed as part of a weekly testing schedule – this was designed to prevent any variation in results due to stranded

emissions tests being performed across weekends. At least triplicate New European Drive Cycle (NEDC) tests were performed on each test fuel; a fourth test was performed if there were any issues over repeatability of tests (Table 3).

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon
Preconditioning								
1st NEDC								
2nd NEDC								
3rd NEDC								
Road Load Accels								
Repeat NEDC								
Oil & Fuel Change								
Mileage Accumulation								am

Table 3: Weekly Test Schedule

Vehicle Preconditioning - the DPNR system was always regenerated prior to a set of emissions tests on each test fuel, to minimise the effect of unknown and variable degrees of trap sulphation or soot loading on the emissions measurements. The aftertreatment system was desulphated whilst driving on the track over ~100km driving distance at motorway speed, using a Toyota procedure initiated through the electronic control unit (ECU) via a Toyota Intelligent Tester, which is an electronic device for vehicle diagnosis and maintenance. A forced particulate regeneration was performed immediately prior to the emissions preconditioning procedure on the dynamometer, initiated through the ECU again by using the Toyota Intelligent Tester.

TEST RESULTS

PM REGENERATION EVENT OBSERVATIONS - Through examination of temperature data together with the downstream exhaust gas lambda value, it was possible to discriminate between the main types of regeneration, (desulphation, particulate, or NOx) during the 10,000km mileage accumulation phase.

The frequency of unforced desulphation and PM regeneration events which occurred during the initial 10,000km mileage accumulation were highly similar between the two vehicles used in Phases 1 & 2

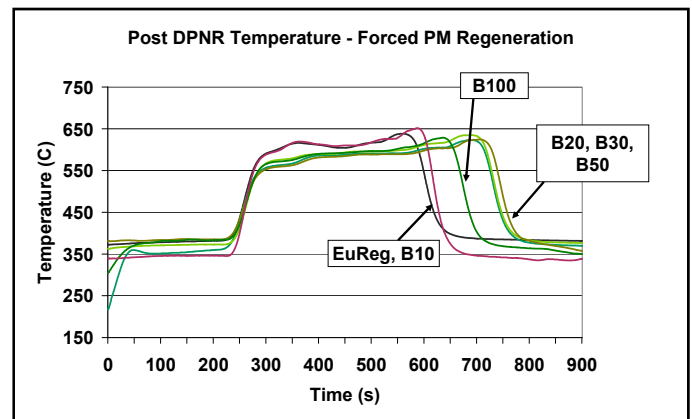


Figure 1: Post DPNR Temperature During Forced PM Regeneration