

Transient Emissions Characteristics of a Turbocharged Engine Fuelled by Biodiesel Blends

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ABSTRACT

The effects of different biodiesel blends on engine-out emissions under various transient conditions were investigated in this study using fast response diagnostic equipment. The experimental work was conducted on a modern 3.0 L, V6 high pressure common rail diesel engine fuelled with mineral diesel (B0) and three different blends of rapeseed methyl esters (RME) (B30, B60, B100 by volume) without any modifications of engine parameters. DMS500, Fast FID and Fast CLD were used to measure particulate matter (PM), total hydrocarbon (THC) and nitrogen monoxide (NO) respectively. The tests were conducted during a 12 seconds period with two tests in which load and speed were changed simultaneously and one test with only load changing. The results show that as biodiesel blend ratio increased, total particle number (PN) and THC were decreased whereas NO was increased for all the three transient conditions. In addition, the largest PN transient spikes were observed for all the fuels in the test within the low-medium load speed change. Furthermore, the size of the spikes in PN decreased with the biodiesel blend ratio increasing. The duration of particulates transient recovery period was increased with the decrease of biodiesel blend ratio for all the engine transient tests due to the oxygen content in biodiesel. Moreover, compared to the diesel fuel, almost doubled NO and half reduced PN and THC cumulative emissions were observed during a 15 seconds time interval with neat biodiesel.

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INTRODUCTION

The emission characteristics of an engine during transient conditions have attracted the attention of researchers in recent years because of stricter exhaust emission legislations and the high frequency of occurrence of transients in daily driving. The limitations of laboratory engine control systems, exhaust gas analyzers and testing equipment have left the research of engine transients far behind steady-state engine studies. However, many researchers agree that engine performance during transient conditions are worse than the steady-state performance due to sudden changes in engine parameters [1, 2]. This problem is more pronounced in turbocharged diesel engines mainly because of the lag response of the turbocharger speed adjustment [3]. Hagen revealed that owing to the influence of turbocharger lag, both PM and NO_x emissions significantly increased in their V8 turbocharged engine when acceleration timing was shortened [4]. NO, smoke and noise emissions of a diesel fueled engine during transient conditions were also studied by Rakopoulos

et al. [5]. Their findings showed that harder acceleration could lead to a longer emissions transient period.

Biodiesel (referred to fatty acid methyl ester) properties like oxygen content, higher cetane number (CN) and viscosity can result in different engine performances and emissions. Many researchers have reported the performances and emissions of biodiesel engines under both steady-state and transient conditions. Chuepeng et al. researched the particulate matters of RME blends under various steady-state engine conditions and they found that the particle number increased at low air-fuel ratio conditions [6]. Other research studies on the gaseous emissions of biodiesel under steady-state conditions indicated that biodiesel emitted lower THC and higher NO_x [7, 8, 9]. The engine parameters with biodiesel operation were also investigated by Kawano et al. [10] and they researched the differences in required injection timing between biodiesel and mineral diesel. Their results showed that injection timing was not affected by the high bulk modulus of RME in common-rail diesel engines.

For transient biodiesel engine studies, Jaroonsathian et al. [11] investigated the performance of a diesel engine in accelerating transient mode running with palm methyl ester (PME). Their results implied that biodiesel had poor engine driveability especially at low speed and low load condition. Rakopoulos et al. studied the emissions of biodiesel and n-butanol blend during transient conditions [12]. They showed that NO peak values increased by approximately 52% and 35% and the smoke opacity decreased by around 40% and 73% respectively. Tesfa et al. have reported up to 17% higher NOx emissions and 52% lower THC emissions for their engine running with biodiesel during transient conditions [13]. Giakoumis et al. conducted a literature survey on biodiesel transient operations and they suggested that generally the PM and HC emissions tend to decrease whereas NOx emissions tend to increase as the biodiesel blending ratio increases [14].

This study investigates the engine performance under the conditions of acceleration and load increase at low and medium operating conditions. The experimental procedure and engine test bed set up is described in the next two sections. The engine emissions results and discussion based on the fuel properties and the engine parameters are then presented with a summary of conclusions at the end of the paper.

EXPERIMENTAL SETUP

Engine Test Cell

Engine and dynamometer

The engine used for this study was a Jaguar V6, 3.0L diesel engine. It was equipped with two variable geometry turbochargers and a common rail direct injection system. The engine specifications are listed in Table 1. An eddy-current water-cooled 230 kW dynamometer was connected to the engine to provide sufficient engine loads.

Table 1. Engine Specifications, Data given by Jaguar and Land Rover Motor Company

Type of the engine	Jaguar V6 3.0L Diesel
Bore	81.0 mm
Stroke	90.0 mm
Displacement volume	2993 cm ³
Maximum torque	600 Nm @ 2000 rpm
Maximum power	199.1 kW @ 4000 rpm
Compression ratio	16.1:1
Connecting rod length	160.0 mm

Control and data acquisition system

The engine load and speed changes were controlled and recorded by CP Engineering CADET software [15]. The engine parameters were observed by ETAS INCA software [16] which could record the engine ECU data. During transient conditions, the dynamometer was used to change the engine speed while the accelerator pedal was used to control the engine torque. The engine speed and load signals from CADET software were transferred to both the DMS500 input channels and a NI card. The latter was used to record the Fast FID and Fast NOx signals.

Particles and Gaseous Emissions Measurement

The real time particle number concentrations were detected by a Differential Mobility Spectrometer (DMS500) fast response instrument. Its specifications are listed in Table 2. Two diluters were applied in the DMS500. One was fixed in the heating sample line which was used to remove the water condensation. The second was a disc diluter inside the main control unit which was used to dilute the high concentration exhaust gas [17].

Table 2. Parameters of Fast Response Equipments

Test Equipments	DMS500	Fast FID	Fast NOx
Time Response	200 ms	As low as 0.9 ms	As low as 2 ms
Acquisition Frequency	10 Hz		
Measurement Range	5 nm to 1000 nm	0-1000 ppm to 0-200,000 ppm	0-100 ppm to 0-5,000 ppm

The total hydrocarbon (C₃) and NO emissions were detected by a Flame Ionisation Detector (FID) HFR500 and a Chemi Luminescence Detection (CLD) CLD500 from Cambustion Ltd. Fast FID and Fast NOx detectors and probes were placed close to the sample point and the system was remote controlled. The NO emission was measured instead of NOx because the CLD500 required extra optional converters which could reduce the response time for the transient research.

All the three emission instruments were located at the exhaust manifold, upstream of the after-treatment system in order to achieve a rapid sample collection capability. A schematic diagram of the arrangement is shown in Figure 1.

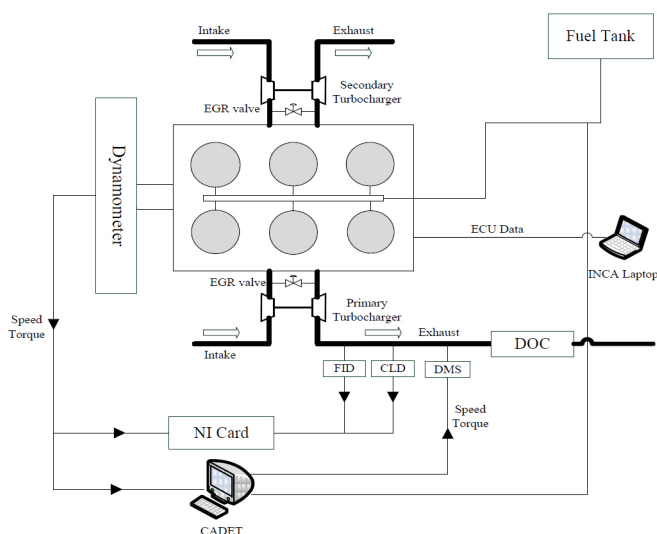


Figure 1. Schematic Diagram of the Engine Arrangement

Test Fuels

The test fuels used in this study were Rapeseed Methyl Ester (RME) in various blend ratios, B0, B30, B60 and B100. The Bxx means xx% neat biodiesel blend with mineral diesel by volume. The specifications of the four fuels are shown in the [Table 3](#).

Table 3. Fuels Specifications

	Diesel	RME30	RME60	RME100
Cetane Number	56.7	57.8	60.3	61.2
Density at 15°C (kg/m ³)	832.7	847.9	863.3	883.3
Viscosity at 40°C (cSt)	3.6	4.3	5.27	6.77
LHV (MJ/kg)	42.72	40.76	38.98	36.41
Oxygen Content (%)	0	4.6	7.8	10.8

EXPERIMENTAL PROCEDURE

Three engine transient tests were carried out with four different engine modes as listed in [Table 4](#). The test modes were selected from the engine map (provided by the Jaguar Car Ltd), which are the most representative conditions during the transient driving cycles. The data recording time of all the transient tests was 45 seconds, including purge (10 seconds), transient, and eventually stabilized stages. All the transient tests were conducted during a 12 seconds changing period or “recovery period” [18], with two tests in which load and

speed were changed simultaneously and one test with only load change. The mode of 1-3 represented the engine accelerating from low load low speed conditions to medium load medium speed engine operating conditions. The mode of 2-4 represented the acceleration for a higher initial/final engine operating conditions compared with the mode 1-3. The cumulative emissions of PM, NO and THC were calculated in a 15 seconds transient period, this being longer than the 12 seconds recovery period. The main purpose of this schedule is to give a reasonable time interval in order to obtain an accurate calculation of the total emissions during the transient changing period.

To ensure the repeatability and reliability of the results, the engine was completely warmed up for 20 minutes before each test. Moreover, the test cell temperature was maintained at 25 °C by a ventilating system. The fuel supply system filters were changed and lines were purged with each fuel change.

Table 4. Engine Test Conditions

Test mode	Initial Condition	Final Condition
1-3	750 RPM, 36 Nm	1500 RPM, 143 Nm
2-3	1500 RPM, 72 Nm	1500 RPM, 143 Nm
2-4	1500 RPM, 72 Nm	2000 RPM, 167 Nm

DATA PROCESSING

The mass flow rates of NO emissions were calculated by the following formula, [Equation 1](#) [4, 12],

$$\dot{m}_{NO} = 10^{-6} \times \frac{MW_{NO}}{MW_{exhaust}} \times C_{NO} \times (\dot{m}_{air} + \dot{m}_{fuel}) \quad (Eq. 1)$$

where MW_{NO} and $MW_{exhaust}$ are the molar mass of NO and the exhaust gas, C_{NO} is the detected concentration of the NO emission. $\dot{m}_{air}$ and $\dot{m}_{fuel}$ represents the intake air mass flow and mass fuel injection respectively. The unit of mass fuel injected from the INCA software was mg per cycle per cylinder, which had to be converted to g per second. The following formula was used,

$$\dot{m}_{fuel} = 5 \times 10^{-5} \dot{m}_{fuel1} \times v \quad (Eq. 2)$$

where v is the transient speed, rpm per min, and $\dot{m}_{fuel1}$ is the mass fuel injected in mg per cycle per cylinder. Therefore, the overall emissions of NO were derived by the following relation,