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Characteristics of LPG-diesel dual fuelled engine operated with rapeseed methyl ester and gas-to-liquid diesel fuels

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ABSTRACT

A Liquefied Petroleum Gas (LPG)-diesel dual fuelled combustion experimental study was carried out to understand the impact of the properties of the direct injection diesel fuels, such as rapeseed methyl ester (RME) and gas-to-liquid (GTL), on combustion characteristics, engine performance and emissions. The experimental results showed that up to 60% of liquid fuel replacement by LPG was reached while keeping engine combustion variability within the acceptable range and obtaining clear benefits in the soot-NO_x trade-off. However, the amount of LPG was limited by adverse effects in engine thermal efficiency, HC and CO emissions. LPG–RME showed a good alternative to LPG-diesel dual fuelling, as better engine combustion variability, HC, CO and soot behaviour was obtained when compared to the other liquid fuels, mainly due to its fuel oxygen content. On the other hand, NO_x emissions were the highest, but these can be balanced by the application of EGR. LPG–GTL dual fuelling resulted in the highest NO_x emissions benefit over a wide range of engine operating conditions. The high cetane number and the absence of aromatic of GTL are the main parameters for the more favourable soot-NO_x trade-off compared to LPG–ULSD (ultra low sulphur diesel) dual fuelling.

1. Introduction

Liquefied petroleum gas (LPG) is considered as a promising alternative fuel and has been widely used in transportation due to its environmental and economic benefits [1–3]. Apart from being a lower pollutant, LPG is also desirable as it receives tax concession in Europe [1,4].

The high octane number of LPG makes it suitable for spark ignition engines. In contrast, the low cetane number (CN) of LPG makes it difficult to be used in large proportions in compression ignition engines, mainly due to high cyclic variation [5]. However, the addition of cetane enhancer can improve the performance of LPG fuelled diesel engine operation [5–7].

It has been reported that with the use of in-cylinder injected LPG, improvements in smoke and nitrogen oxides (NO_x) emissions are evident and in some cases carbon monoxide (CO) emission can be minimised, specifically in high engine load [8]. The presence of the LPG spray combined with diesel fuel into the cylinder promotes diesel atomisation, increasing the velocity of diffusion combustion, which in turn diminishes soot formation [9].

In dual fuel engine operation, the combustion characteristics are affected by both the pilot diesel fuel as ignition source and the primary premixed fuel. For instance, the differences in chemical and physical properties of the pilot fuel directly affect the emissions and performance of the engine mode [7,10,11]. Therefore, the high CN of GTL is expected to improve the engine performance and emissions of LPG-liquid fuel engine operation [12]. The use of high CN fuels could improve the auto-ignition characteristics and extend stable engine operation under LPG-diesel dual fuelling [5].

Similarly, the combustion of biodiesel fuel like rapeseed methyl ester (RME) shows emissions improvements mainly in terms of HC, CO, and soot. The oxygen content of RME (about 10.8%wt) improves fuel oxidation, inhibiting the formation of carbonaceous pollutant species and enhancing their oxidation [13–15]. However, changes in the injection and combustion patterns due to high biodiesel's bulk modulus and oxygen content have been reported which tend to raise NO_x emissions [10,11,13]. However, it is expected that this drawback can be minimised by the LPG combustion characteristics.

The objective of this work is to investigate the influence of three in-cylinder injected diesel fuels, ULSD, RME and GTL on the combustion characteristics and emission of the LPG-diesel dual fuelled engine. The influence of the exhaust gas recirculation (EGR) was also investigated.

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Table 1
Experimental engine specifications.

Engine specification	Data
Engine cycle	4-stroke DI
Number of cylinders	1
Bore/stroke	98.4 mm/101.6 mm
Connecting rod length	165 mm
Displacement volume	773 cm^3
Compression ratio	15.5:1
Rated power (kW)	8.6 @ 2500 rpm
Peak torque (Nm)	39.2 @ 1800 rpm
Injection system	Three hole direct injection
Engine piston	Bowl-in-piston

Table 2
Liquid fuel properties.

Property	Method	ULSD	RME	GTL
Cetane number	ASTM D613	53.9	54.7	80
Density at 15 °C (kg/m^3)	ASTM D4052	827.1	883.7	784.6
Viscosity at 40 °C (cSt)	ASTM D455	2.467	4.478	3.497
50% distillation (°C)	ASTM D86	264	335	295.2
90% distillation (°C)	ASTM D86	329	342	342.1
LCV (MJ/kg)		42.7	37.4	43.9
Sulphur (mg/kg)	ASTM D2622	46	5	<10
Aromatics (%wt)		24.4	~0	0.3
O (%wt)		~0	10.8	~0
C (%wt)		86.5	77.2	85
H (%wt)		13.5	12.0	15
H/C ratio (molar)		1.88	1.85	2.10

2. Experimental setup

2.1. Engine

Tests were carried out using a naturally aspirated, single cylinder and mechanical direct injection compression ignition diesel engine. An electric dynamometer with a motor and load cell was coupled to the engine and used to motor and load the engine. A detailed engine specification is shown in Table 1 and the schematic diagram of the experimental setup is shown in Fig. 1.

2.2. Fuels

Three liquid fuels were used: ULSD, RME and GTL which were provided by Shell Global Solutions UK. The fuel properties are given in Table 2. LPG used in this experiment was provided in a gas cylinder. Propane and butane is generally the main component of LPG, but its actual composition varies widely among countries and depends on season and cost. In the UK, the quality specifications for LPG conformed to BS 4250 which is specified for commercial propane and butane. In this work the LPG used contains 100% propane, and its properties are given in Table 3.

2.3. Combustion and emissions facilities

Emissions measurements such as carbon dioxide, carbon monoxide, nitrogen monoxide, nitrogen oxides and gaseous hydrocarbons were carried out using an HORIBA 7100DEGR emission analyser. Particulate matter (PM) was evaluated using an HORIBA MEXA 1230 PM analyser. In this equipment soot was measured with a diffusion-charging (DC) detector and two flame ionisation detectors (FID) were used for soluble organic material (SOM) measurement. The emissions measurements were carried out three times and an average reading was taken.

The in-cylinder pressure was recorded by using a Kistler 6125B pressure transducer (1% measurement accuracy) mounted flush at the cylinder head and connected via a Kistler 5011 charge amplifier to a National Instruments data acquisition board. A digital shaft encoder was used to measure the crankshaft position. 200 consecutive engine cycles were performed in order to analyse the in-cylinder pressure and rate of heat release. Data acquisition and combustion analysis were carried out using the in-house developed LabVIEW-based software. Output from the analysis of consecutive engine cycles included peak in-cylinder pressure, indicated mean effective pressure (IMEP), coefficient of variation (% COV) of IMEP and peak in-cylinder pressure, rate of heat release (ROHR) and other standard combustion parameters. The COVs are used as criteria for combustion stability.

2.4. Engine operating conditions

A modification was made on the intake manifold to allow LPG and fresh air mixing, while the liquid fuel was injected directly in

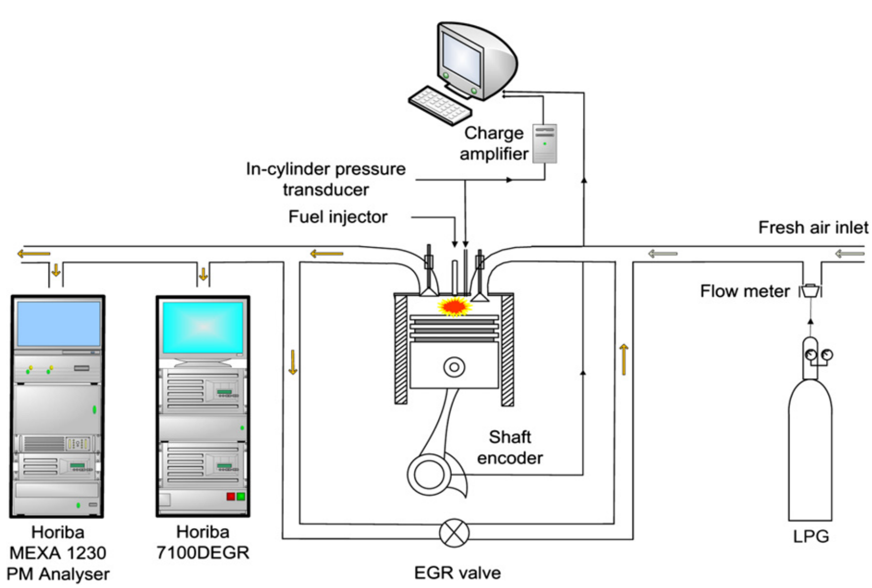

Fig. 1. Schematic diagram of experimental setup.