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Combustion and performance characteristics of CI (compression ignition) engine running with biodiesel

B. Tesfa*, R. Mishra, C. Zhang, F. Gu, A.D. Ball

Computing and Engineering, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK

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ABSTRACT

Biodiesel is one of the alternative fuels which is renewable and environmentally friendly and can be used in diesel engines with little or no modifications. In the present study, experimental investigations were carried out on the effects of biodiesel types, biodiesel fraction and physical properties on the combustion and performance characteristics of a (compression ignition) CI engine. The experimental work was conducted on a four-cylinder, four-stroke, (direct injection) DI and turbo-charged diesel engine by using biodiesel of waste oil, rapeseed oil and corn oil and normal diesel. Based on the measured parameters, detailed analyses were carried out on cylinder pressure, heat release rate and (brake specific fuel consumption) BSFC. It has been seen that the biodiesel types do not result in any significant differences in peak cylinder pressure and BSFC. The results also clearly indicate that the engine running with biodiesel have slightly higher in-cylinder pressure and heat release rate than the engine running with normal diesel. The BSFC for the engine running with neat biodiesel was higher than the engine running with normal diesel by up to 15%. It is also noticed that the physical properties of the biodiesel affect significantly the performance of the engine.

1. Introduction

The invention of CI (compression ignition) engines and subsequent developments in engine technology has led to extensive exploitation of the petroleum reserves [1,2] which are being depleted at a rapid rate [3,4]. Currently, biofuels are being investigated in detail for application in CI engine with exciting potential opportunities to increase energy security and reduce gas emissions [5,6]. This could have significant effects on economic development and poverty reduction programmes throughout the world [7]. The main findings from the literature reviewed indicate that biodiesels, when used in engines, have comparable power, BSFC (brake specific fuel consumption) and brake thermal efficiency, as compared to engines running with diesel. Biodiesel also offers significant advantages of significant portability and although there is not at overwhelming agreement many studies have reported higher combustion efficiency with the biodiesel use [8–10]. Furthermore biodiesel offers lower sulphur and aromatic content, a higher cetane number and higher lubrication effects [11]. Moreover, it has unique advantage of being available around the world [5,12]. Currently, the biodiesel production processes have also been improved to increase the biodiesel yield to have continuous supply from process plants [13,14].

The performance of an IC (internal combustion) engine is represented by a number of different parameters. Some of the important parameters include: brake specific fuel consumption, brake effective power, thermal efficiency, in-cylinder pressure and heat release rate. Many researchers have investigated the performance characteristics of engines running with biodiesel and its blends and compared it against its performance when running with normal diesel [15–19]. In the following sections some important works have been reviewed to identify gaps in the knowledge in combustion and performance characteristics of the CI engine running with biodiesel blends to justify the present work.

1.1. Combustion characteristics

Combustion of fuels is one of the most important processes which affects the performance and emission characteristics as well as the engine durability [20]. The important parameters that signify the combustion process effectiveness are in-cylinder pressure, ignition delay, combustion duration, heat release and cumulative heat release rate [21,22]. In-cylinder pressure can be measured directly from the engine and the other combustion parameters can

* Corresponding author. Tel.: +44 0 1484 473532.
E-mail addresses: b.c.tesfa@hud.ac.uk, belachewmu@yahoo.com (B. Tesfa).

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be calculated from the in-cylinder pressure. The heat release rate is estimated from the first law of thermodynamics as given in equations (1) and (2) using the in-cylinder pressure and the geometry of crank and rod. The other important combustion parameters can be easily estimated from the (heat release rate) HRR variation over an engine cycle.

$$\frac{dQ}{d\theta} = p\cdot\frac{\gamma}{\gamma-1}\frac{dV}{d\theta}+\frac{1}{\gamma-1}V\frac{dP}{d\theta} \tag{1}$$

$$V(\theta) = \frac{V_d}{\gamma_c-1}+\frac{V_d}{2}\left[R+1-\cos\theta-\left(R^2-\sin^2\theta\right)^{1/2}\right] \tag{2}$$

where, $dQ/d\theta$ is rate of heat release (kJ/deg), P is the in-cylinder gas pressure (kPa), V is the in-cylinder volume (m^3), γ is the ratio of specific heats, V_d is the engine displacement (m^3), θ is crank angle (deg) and R is the ratio of connecting rod length (m) to crank radius (m).

Furthermore, the (cumulative heat release) Q_{cum} is calculated by the equation (3):

$$Q_{cum} = \int dQ = \int P\frac{\gamma}{\gamma-1}dV+\frac{1}{\gamma-1}VdP \tag{3}$$

Most of the researchers have reported that the engines running with biodiesel blends result in a hydraulic advancement in injection timing and the start of combustion as the biodiesel content in the blends increases [12,21,23–27]. Gao et al. [25] investigated the spray penetration, spray cone angle and spray tip speed characteristics using a high-speed camera for different biodiesel blends. The experimental result showed that as the ratio of biodiesel in the blends increased, the spray penetration and spray speed increased. They however observed that the spray cone angle decreased. They also reported that the Sauter mean diameter of blended fuels was observed to be greater than that of diesel under similar operating conditions. Furthermore, Zhang and Van Gerpen investigated the effects of blends of methyl esters of soya bean oil and diesel in a turbo-charged, four-cylinder and direct-injection diesel engine. They found that these blends gave a shorter ignition delay and similar combustion characteristics [28]. Yusuf and Milford [28] studied the in-cylinder pressure and heat release rate characteristics of a six-cylinder, direct-injection 306 kW diesel engine with blends of esters of methyl as a fuel. The peak rate of heat release, peak cylinder pressure, (indicated mean effective pressure) IMEP and charge of temperature for this blend were found to be lower than that of diesel. The combustion characteristics of a single-cylinder, four-stroke which is running with waste cooking biodiesel were investigated by Muralidharan et al. [29]. They found that the combustion characteristics of waste cooking oil methyl ester and its diesel blends closely followed those of standard diesel.

Recently, Gumus [21] reported results of an investigation into the combustion and heat release characteristics of biodiesel fuelling direct-injection compression ignition engines. The tests were conducted for different biodiesel blends and the in-cylinder pressure was measured. The combustion duration, heat release rate and cumulative heat release were calculated from the in-cylinder pressure values. It was concluded that the engine running with biodiesel did not show any significant deviation from the engine fuelled with diesel in parameters characterising combustion. However, as the biodiesel content in the blend increased, shorter ignition delays and premixed stage durations were observed. Gumus [21] also highlighted that a diesel engine can be modified by increasing the injection timing, compression ratio and injection pressure to make suitable for use with biodiesel.

1.2. Brake specific fuel consumption

BSFC is the ratio of the engine fuel consumption to the engine power output, as measured at the flywheel. Lapuerta et al. [18] and Xue et al. [19] carried out an extensive review of publications on the BSFC of engines using biodiesel and its blends. It is shown in Table 1 that from total reviewed papers on the engine running with biodiesel, 98% and 87.1% of them agreed that the engine running with biodiesel resulted in higher BSFC as per Lapuerta et al. [18] and Xue et al. [19] reports respectively. Chauhan et al. [16] carried out extensive tests on a Kirloskar make, single-cylinder, air cooled, direct injection, DAF 8 model diesel engine, to quantify performance and emission characteristics when running with Jatropha biodiesel, under steady state operating conditions. The brake thermal efficiency of Jatropha methyl ester and its blends with diesel were lower than diesel and brake specific energy consumption was found to be higher.

Dorado et al. [30] used transesterfied waste olive oil on a 3-cylinder, 4-stroke, water-cooled and direct-injection diesel engine. Their results revealed a slight increase in BSFC. Monyem and Gerpen [31] also tested several fuels including neat biodiesel, 20% blend, and a base diesel fuel on a John Deere 4276T turbo-charged DI diesel engine at a single speed of 1400 rpm, with 100% and 20% loads. The biodiesels used were both oxidised and un-oxidised. They reported that the oxidised and un-oxidised neat biodiesels resulted in 15.1% and 13.8% higher BSFC than the diesel fuel, respectively.

Ramadhas et al. [32] tested rubber seed oil on a four-stroke direct injection, naturally aspirated single-cylinder diesel engine at a speed of 1500 rpm under various loads. They reported that when the applied load increased, the BSFC decreased until the engine attained a 60–70% load condition. In the same analysis, it was seen that as the percentage of biodiesel increased the BSFC of the engine also increased. Lin C and Lin H [33] reported that the BSFC of fuels decreased with increasing speeds of the engine under a constant engine torque. It can be concluded from the reviewed literature that engines running with biodiesel result in a higher BSFC than when running with diesel, as the former has lower heating value and hence higher amount of fuel is consumed in order to maintain the same brake power [30,34]. These studies indicate that the fuel consumption is, on average, proportional to the loss of heating values, irrespective of whether heavy-duty or light-duty engines were tested. For example, Haşimoğlu et al. [35] obtained 13% higher BSFC with a biodiesel having LHV (lower heating value) 13.8% lower as compared to diesel on a 4-cylinder, TC (turbocharged) and DI (direct injection) diesel engine.

Armas et al. [36] found that the BSFC of B100 biodiesel, with a low heating value, 12.9% lower than that of diesel, had increased approximately by 12%, compared to the diesel on a 2.5 L, DI and TU, common-rail diesel engine operating at 2400 rpm and 64 N m.

Table 1
Estimated share of literature (in percentage of publications) on effect of pure biodiesel on engine performance and emission in comparison with diesel [18,19].

Parameters	Increasing trend number of papers (%)		Similar trend number of papers (%)		Decreasing trend number of papers (%)	
	Lapuerta et al.	Xue et al.	Lapuerta et al.	Xue et al.	Lapuerta et al.	Xue et al.
Power performance	0	7.4	2	22.2	96	70.4
BSFC	98	87.1	2	3.2	0	9.7
Thermal efficiency	8	NR	80	NR	4	NR

NR: not reported.