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Experimental Investigation on Performance, Emission and Combustion Characteristics of *Croton Megalocarpus* Biodiesel Blends In a Direct Injection Diesel Engine

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ABSTRACT

The emission, performance and combustion characteristics of croton biodiesel blends were tested in a direct injection (DI) single cylinder four stroke diesel engine. The physico-chemical properties of the biodiesel blends were all found to be within the standard ASTM values. The reduction in exhaust smoke emissions for the biodiesel blends ranged from 10% to 41% at maximum engine load of 10 Kg while a slight increase in NO_x emissions was observed with increase in concentration of biodiesel in the blends. Similar general increase in brake thermal efficiency (BTE), temperature of exhaust emissions and fuel flow rate was observed with increasing engine load for both petro-diesel and biodiesel blends. The difference between BTE for petro-diesel and biodiesel blends ranged from 2.04 to 5.03%. The brake specific energy consumption (BSEC) decreased with increasing engine load for both petro-diesel and biodiesel blends. An increase in both engine pressure and heat released was observed with increase in concentration of biodiesel in the blends. The difference in maximum engine pressure ranged from 1.05 bar at 0 Kg to 3.77 bar at 10 Kg load. The greatest difference in maximum engine pressure was recorded between petro-diesel and B50 blend. The observed difference in position of peaks for maximum heat released showed that there was slight delay in ignition of biodiesel blends as compared to petro-diesel. The results obtained in this study showed that higher blends of up to 50% biodiesel can be effectively used as an alternative to petro-diesel without compromising the engine performance.

Key words:*Croton biodiesel blends, Diesel engine, Emission and performance characteristics.*

1. INTRODUCTION

The limited supply of fossil fuels, increasing cost and concern of toxic emissions from internal combustion engines is making renewable green energy sources very attractive. The ever increasing world energy demands due to increased industrialization and population has made the limited fossil fuel reserves concentrated in particular regions of the world to reach the verge of their peak production [1]. Biodiesel is one of the fastest growing energy alternative fuels due to its advantages such as cleaner emission profile, ease of transport and use, mitigation of global warming and many other environmental benefits. Sustainable production of biodiesel, especially from non-edible and waste oils can allow this cleaner, renewable fuel help in combating the world energy crisis caused by the constantly increasing demand and price of petro-diesel [2]. Additionally, the by-product, glycerin can be purified and used in soap, pharmaceutical and cosmetic industries [3].

Biodiesel is receiving much attention as an alternative, non–toxic, biodegradable and renewable diesel fuel. Its properties depend on the source of oil feedstock and alcohol used for its production. Biodiesel can either be used as a blend with petro-diesel or as a direct substitute for petro-diesel [4]. Biodiesel has a higher cetane number, no aromatics, almost no sulfur, and contains 10% to 11% oxygen by weight. These characteristics leads to reduction in carbon monoxide (CO), Hydrocarbon (HC) and particulate matter (PM) in exhaust gas emission compared to petro-diesel. Despite its desirable properties, biodiesel from edible oils is not economically competitive with petro-diesel because of its higher cost [5]. However, provision of suitable subsidy for setting up processing plants and appropriate training can greatly improve production of biodiesel from non-edible and waste oil raw materials and hence make its cost lower than that of petro-diesel.

Schumacher *et al.*, [6] reported that use of biodiesel in internal combustion engines resulted in 4%, 47% and 66% reduction in HC, CO and PM emissions respectively, while Demirbas, [7] reported 42% and 55% reduction in CO and PM exhaust emissions respectively, relative to petro-diesel. Despite very positive environmental benefits associated with biodiesel use, it normally leads to higher nitrogen oxides (NO_x) emissions. However, reduction in NO_x emmisions can be achieved by modifications in combustion temperatures and injection timing [8]. Wang et al., [9] explained that shorter ignition delay for biodiesel resulted in slightly higher NO_x emissions from biodiesel than petro-diesel. They explained that levels of exhaust emissions were also influenced by oxygen content of biodiesel and combustion temperature.

Agarwal et al., [10] reported that performance and emission characteristics of diesel engines fuelled with preheated Jatropha oil and blends were very close to those of petro-diesel. However at higher biodiesel blends, the performance and emissions were marginally inferior. Kumar and Nerella, [11] observed that for the same biodiesel blend, the concentrations of CO and SO_2 emissions decreased during on-road testing but increased for idle-engine testing. Kivevele et al., [12] reported that combustion characteristics in diesel engine were not influenced by addition of antioxidants to biodiesel. Agarwal and Rajamanoharan [13] reported that the thermal efficiency of Karanja biodiesel fuel blends except B100 were higher than that of petro-diesel. However on preheating the fuel samples, all the blends, including B100 showed higher thermal efficiency compared to petro-diesel. They explained that preheating fuel samples resulted in reduced viscosity and increased volatility which enhanced the atomization hence leading to improved fuel-air mixing. They also observed that thermal efficiency generally increased with increase of biodiesel concentration in the blends.

Although some investigations on physical properties and emission characteristics of croton biodiesel have been reported, certain parameters such as performance and combustion characteristics have not been adequately studied. More studies should be carried out to determine variation of performance and combustion parameters under different conditions. It is also important to carry out investigations to come up with more conclusive evidence and determine ways of making improvement. Moreover, large scale production of croton biodiesel has not been established in many developing countries such as Kenya where the plant grows readily. Since croton oil is non-edible, its use in large scale production of biodiesel will not interfere with food. In this work, a detailed comparative study was done on emission, performance and combustion characteristics of B5, B10, B15, B20 and B50 blends of croton biodiesel with petro-diesel to determine the suitability of the croton biodiesel blends as a replacement for petro-diesel.

2. MATERIALS AND METHODS

2.1. Materials

Croton biodiesel was prepared through a two-stage process using optimum reaction conditions reported by Osawa et al., [14]. Dried biodiesel was used to prepare B5, B10, B15, B20 and B50 blends with petro-diesel. The petro-diesel used for blending was purchased from Indian Oil Pump in Dehradun City in Uttarakhand State, India. All analytical grade reagents used from Merck or Rankem Chemicals were supplied by H. V. Technologies, India.

2.2. Physico-chemical properties of croton biodiesel

The physico-chemical properties of croton biodiesel blends with petro-diesel were determined using standard methods and equipment. The equipment used for determination of physico-chemical properties included Pensky Martins Flash Point Cup Apparatus (DM 93), density meter (DM 300), Pour and Cloud point apparatus, Fungilab viscometer (V300003) connected to thermostatic water bath and Bomb calorimeter.

2.3. Experimental set up for engine testing

The performance, emission and combustion characteristics of a test engine fuelled with different proportions of biodiesel blends with petro-diesel were separately investigated in a computerized four stroke single cylinder direct injection diesel engine test rig. The schematic experimental set up for engine testing is shown in figure 1(a) and (b) while the detailed specifications of the test engine used for the investigation are summarized in table 1.

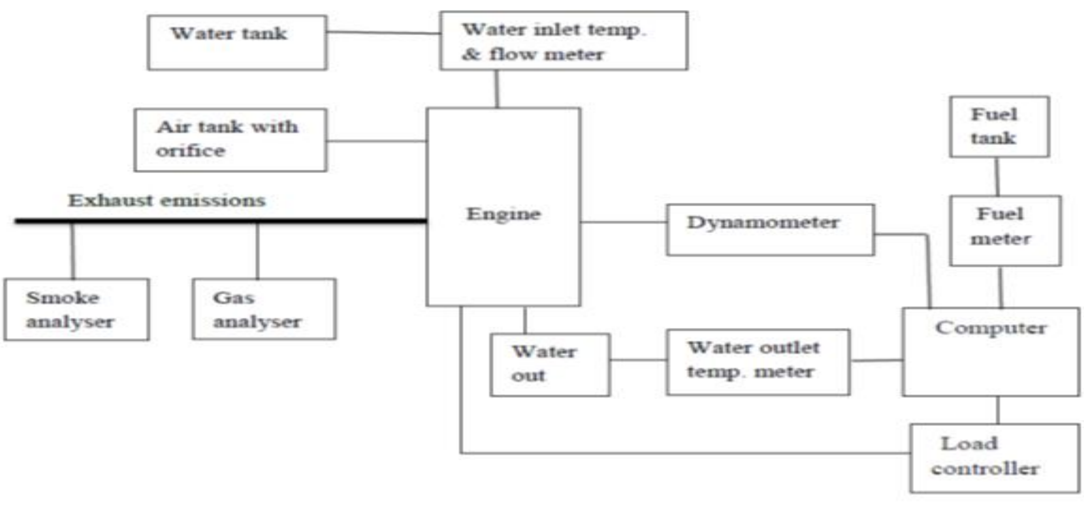

Figure 1(a). Schematic diagram of test engine arrangement

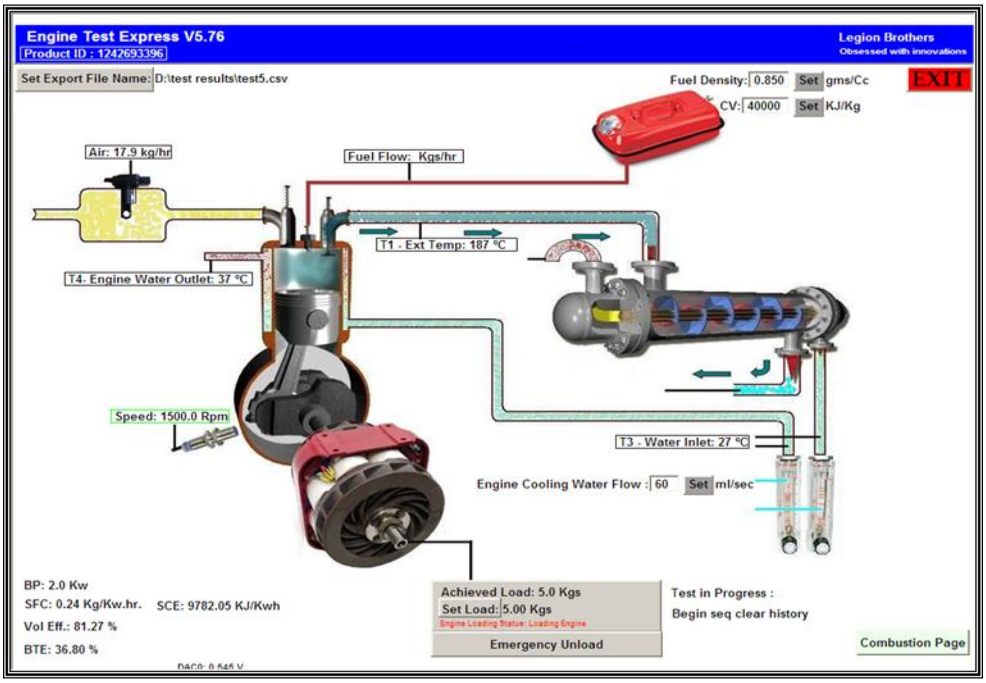

Figure 1(b): Display of engine layout and test parameters

Table 1: Test engine specifications

Particulars	Specifications
Engine Make	AV1 Kirloskar
Engine type	Direct injection single cylinder four stroke diesel engine
Engine weight without flywheel (Kg)	114
Weight of flywheel (Kg)	33
Bore diameter (metres)	0.08
Stroke length (metres)	0.11
Connecting rod length (metres)	0.235
Compression ratio	16.7:1
Engine cooling water flow (mL/sec)	60
Engine speed (rpm)	1500

The test engine, mounted on a stand was subjected to a load of 10 Kg (100%) at intervals of 2 Kg (20%) through dynamometer. The engine was operated at an optimum speed of 1500 rpm. The performance and combustion parameters such as fuel flow rate, airflow rate, exhaust gas temperature, brake power, brake thermal efficiency, heat release, crank angle and pressure at each load were determined electronically and the data stored in specific files in a computer. Each parameter was determined on loading and unloading of the engine and the mean values recorded.

The nature and levels of exhaust gas emissions were determined using exhaust gas analyzer (AVL DIGAS 444) while PM (smoke) in the exhaust emissions was determined by a smoke meter (AVL 437). The exhaust gases analyzed included (CO), HC and NO_x. The exhaust emissions were recorded in triplicates on loading and unloading of the engine and the mean values determined.

3. RESULTS AND DISCUSSION

3.1. Properties biodiesel blends

The values of selected properties of croton biodiesel blends are shown in table 2.

Table 2

Property	Method	Diesel	B100	B50	B20	B15	B10	B5
Density (g/cm^3)	ASTM D15	0.8231	0.8858	0.8545	0.8347	0.8318	0.8293	0.8262
Kinematic Viscosity (40^{o}C, cs)	ASTM D445	2.87	4.51	3.63	3.14	3.08	3.03	2.97
Calorific Value (j/g)	ASTM D2015-85	44648	39179	40506	41445	42320	42957	43596
Cloud point (^{o}C)	ASTM D2500-91	4.0	-1.5	1.5	2.0	2.0	2.4	3.0
Pour point (^{o}C)	ASTM D97-94	-2.0	-6.5	-4.3	-3.0	-2.5	-2.3	-2.0
Flash point (^{o}C)	ASTM D93	64	>170	88	74.5	72	70	68
Acid number (mg KOH/g)	ASTM D664	ND	0.336	0.170	0.065	0.050	0.032	0.002

All the values of the selected physico-chemical properties were within the recommended ASTM values for biodiesel. The pour and cloud point of biodiesel blends were lower than that of petro-diesel hence making the blends more suitable for low temperature operations. The biodiesel blends also had higher flash points than petro-diesel, hence making them safer to transport and store.

3.2. Engine Performance

The performance of biodiesel blends was tested by comparing the effects of the blends on various engine parameters such as brake thermal efficiency, brake specific energy consumption, exhaust gas temperature and fuel flow rate with those of petro-diesel. The effects of load and concentration of biodiesel in the blends on the engine performance parameters are discussed below.

3.2.1. Exhaust gas temperature

Since the temperature of exhaust emissions are directly proportional to engine temperature, they can be used as an estimate of energy released during combustion in an engine. A general increase in temperature of exhaust gases was observed with increase in load applied to the engine due to increased fuel flow. A slight general increase in temperature was also observed for each load with increasing concentration of biodiesel in the blends. This could be attributed to improved combustion due to presence of oxygen in the biodiesel molecules. Figure 2(a) shows the variation of exhaust emission temperature with load for the biodiesel blends and petro-diesel.

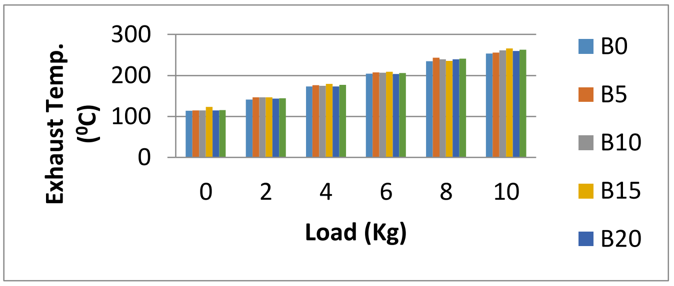

Figure 2(a): Variation in engine exhaust emission temperature with load.

3.2.2. Fuel flow rate

The engine fuel flow rate for both petro-diesel and biodiesel blends increased steadily with increase in load due to extra energy required to overcome the increased load. At maximum load, the fuel flow rate for the B50 blend was 9.75% higher than that of petro-diesel. Figure 2(b) shows the variation in engine fuel flow rate with increasing engine load.

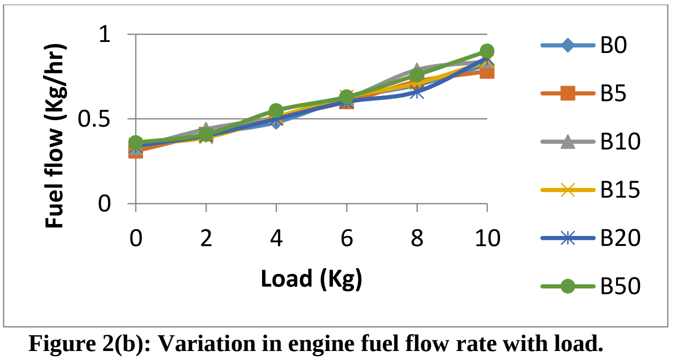

Figure 2(b): Variation in engine fuel flow rate with load.

3.2.3. Brake thermal efficiency

The brake thermal efficiency (BTE) shows how well an engine converts heat energy from fuel to mechanical energy. There was a general increase in the BTE with increase in load for both petro-diesel and biodiesel blends. At intermediate load of 4 Kg, all the BTE values for biodiesel blends were higher than that of petro-diesel. However, at maximum load, the BTE of petro-diesel was the highest while that of the blend B50 was the lowest. A maximum difference of 4.93% was recorded between the BTE of petro-diesel and the B50 blend. The lower values of BTE for the biodiesel blends could be explained by their lower calorific values which result in poor atomization and poor combustion. Figure 2(c) shows the variation in BTE for biodiesel blends and petro-diesel with increasing engine load.

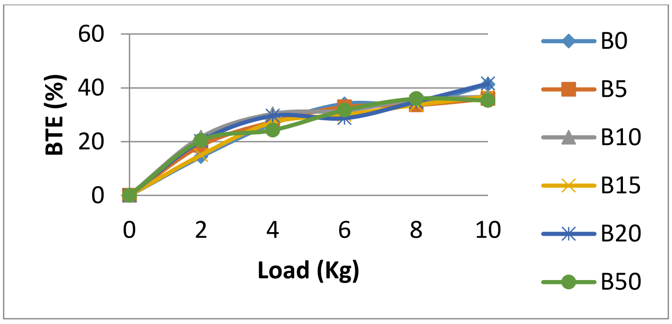

Figure 2(c): Variation in brake thermal efficiency with load.

3.2.4. Brake specific energy consumption

The Brake specific energy consumption (BSEC) is the mass of fuel consumed per unit power produced. The BSEC for both petro-diesel and biodiesel blends steadily dropped with increase in engine load. Deepali et al., [15] reported a similar trend in BSEC in a single cylinder four stroke diesel engine using biodiesel blends mixed with various quantities of n-butanol. Figure 2(d) shows the variation of brake specific energy consumption with load.

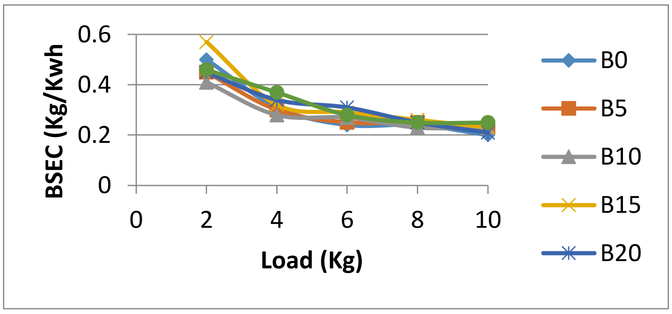

Figure 2(d): Variation in brake specific energy consumption with load.

3.3. Emission Characteristics

The nature and levels of exhaust gases and smoke emissions for petro-diesel and biodiesel blends were determined using exhaust gas and smoke analyzers respectively.

3.3.1. Carbon monoxide (CO)

The highest levels of CO exhaust emissions were recorded at lower engine loads but eventually reduced at moderate engine loads. At higher engine loads, there was lower difference in the levels of CO exhaust emissions for petro-diesel and the corresponding biodiesel blends. The slight increase in CO levels at higher engine loads could explained by the rich fuel/air mixture that is injected into the engine to overcome the extra loads. Figure 3(a) shows the variation of CO emissions with engine load.

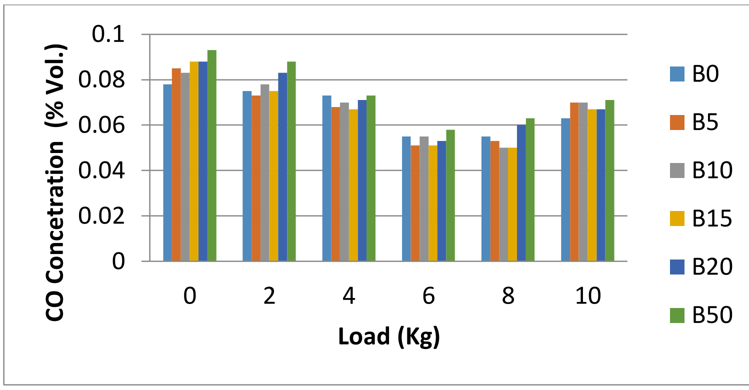

Figure 3(a): Variation in exhaust CO emission with load.

3.3.2. Nitrogen oxides (NO_x)

Nitrogen oxides are produced by the reaction between nitogen and oxygen at high temperature and pressure generated in the engines during combustion of fuel. A steady increase was observed in the levels of NO_x emissions with increase in load applied to the engine. A gradual increase in the levels of NO_x exhaust emissions was also observed for each particular engine load with increase in biodiesel concentration in the blends. These observations could be explained by the increased engine temperature and pressure which led to increased reaction between nitrogen and oxygen. The increased fuel flow into the engine and the fact that biodiesel molecules contain extra oxygen atoms which took part in the combustion process could also be a contributing factor to the increased NO_x emission. These observations were consistent to the results reported by Taher et al., [8]. Figure 3(b) shows the variation of NO_x emissions with load.

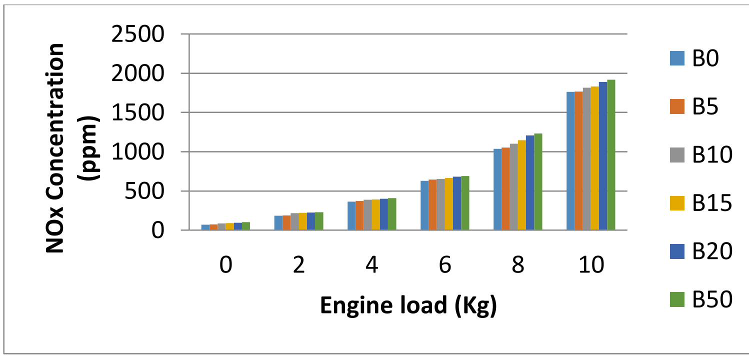

Figure 3(b): Variation in exhaust NO_x emission with load.

3.3.3. Hydrocarbons

The levels of hydrocarbon emissions initially decreased with increase in engine load for both petro-diesel and biodiesel blends. Further increase in load (>4 Kg) resulted to an increase in hydrocarbon emissions. It was also noted that at lower engine loads, an increase in concentration of biodiesel in blends led to an increase in hydrocarbon emission while at higher loads, an increase in concentration of biodiesel in the blends resulted to a decrease in hydrocarbon emission. These observations could be explained by the fact that at lower engine loads, the lower engine temperatures resulted in poor combustion of the biodiesel while at higher engine load, increased combustion of the biodiesel took place due to the higher engine temperature and pressure. The general increase in hydrocarbon emission at higher engine load can however be explained by the rich fuel/air mixture flow into the engine. Figure 3(c) shows the variation in hydrocarbon emissions. Kivevele et al., [12] observed a similar trend for petro-diesel and croton biodiesel blends.

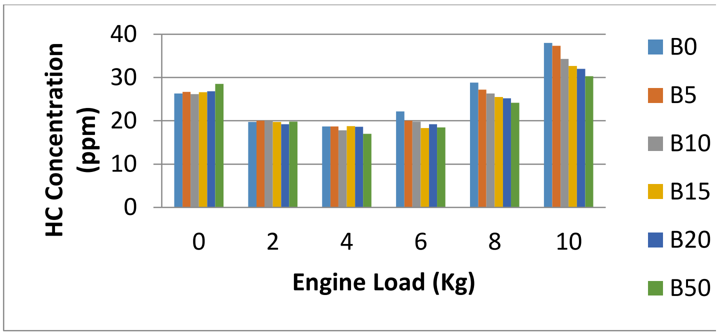

Figure 3(c): Variation in exhaust hydrocarbon emission with load.

3.3.4. Smoke

The levels of exhaust smoke emissions decreased with increase in concentration of biodiesel in the blends. This trend could be explained by the presence of about 11% oxygen in the biodiesel molecules [5] which result to improved combustion and hence less particulate matter (smoke). However, a general increase in smoke emissions was observed with increase in engine load due to increased fuel flow into the engine. At maximum load, a reduction of 41%, 31%, 26%, 15% and 10% reduction in smoke emissions were recorded for B50, B20, B15, B10 and B5 blends respectively. Prabhahar et al., [16] reported a reduction of 25% for B20 Pongamia biodiesel blend while a similar trend was reported for Croton biodiesel and its blend by Kivevele et al., [12]. Figure 3(d) shows the variation of smoke emissions.

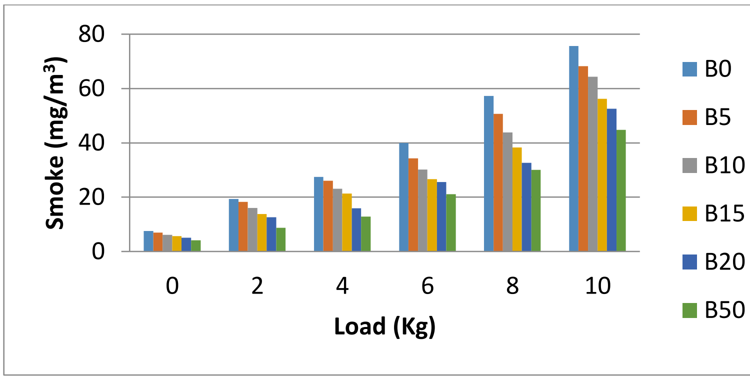

Figure 3(d): Variation in exhaust smoke emission with load.

3.4 Combustion

3.4.1 Pressure

There was minimal difference in maximum engine pressure for both petro-diesel and biodiesel blends at engine load of 0 Kg. There was however general increase in maximum pressure with increase in concentration of biodiesel in the blends as the engine was subjected to increased load. The maximum engine pressure at maximum load of 10 Kg for the B50 croton blend was 5.32% higher than that of petro-diesel. Figures 4(a) and (b) show the variation of pressure with crank angle around the ignition point at 0, 4 and 10 Kg engine loads respectively.

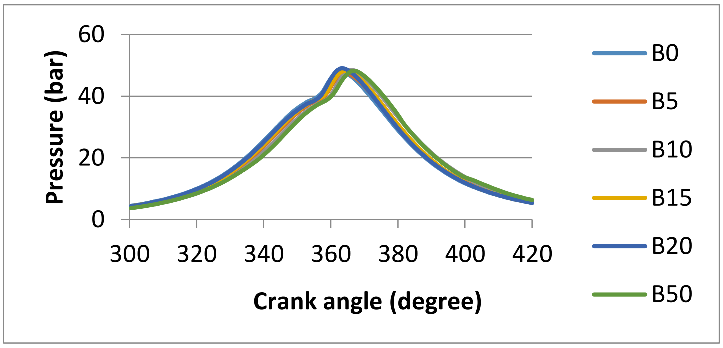

Figure 4(a): Variation in engine pressure against crank angle at 0 Kg load.

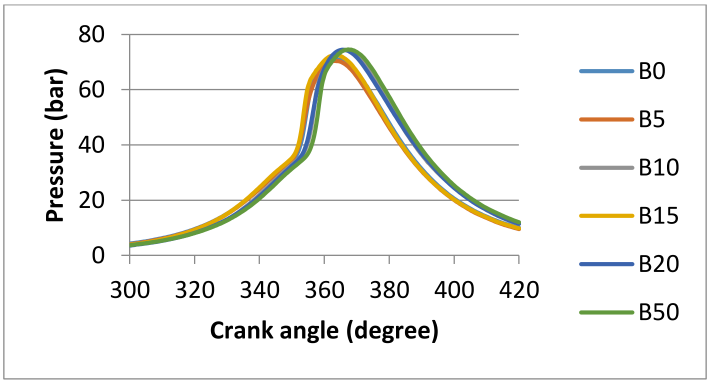

Figure 4(c): Variation in engine pressure against crank angle at 10 Kg load.

3.4.2 Heat

A general increase in maximum heat released by the engine was observed with increase in concentration of biodiesel in the blends. The peaks for maximum heat released by engine fuelled with biodiesel blends occurred after that fuelled with petro-diesel implying that there was delay in ignition of the biodiesel blends as compared to petro-diesel. The delay in ignition of the biodiesel blends was probably due to poor atomization of the fuel. The effects of delay in ignition of the biodiesel blends could be minimized by adjusting the injection time (angle). The variation in heat released against the crank angle around the ignition point for 0 and 10 kg engine loads are shown in figures 5(a) and (b) respectively.

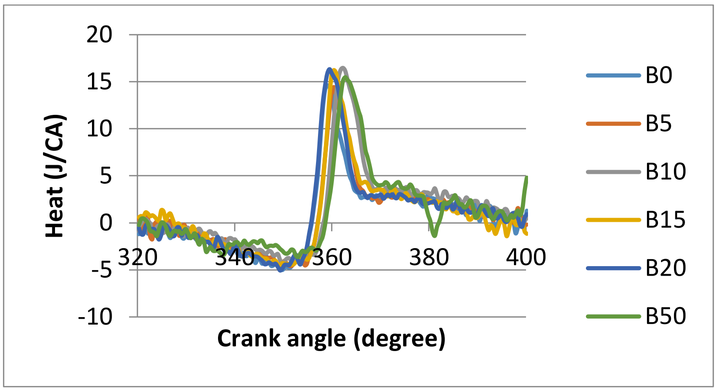

Figure 5(a): Variation in heat released against crank angle at 0 Kg load.

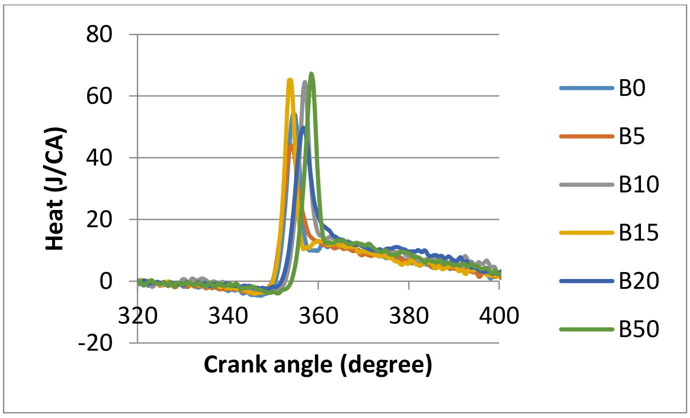

Figure 5(b): Variation in heat released against crank angle at 10 Kg load.

4. CONCLUSIONS

The levels of exhaust smoke emissions decreased with increase in concentration of biodiesel in the blends due to improved combustion. The slight differences observed in the performance parameters such as Brake thermal efficiency, Brake specific energy consumption and fuel flow rate showed that the engine performance characteristics of croton biodiesel blends were similar to those of petro-diesel at all engine loads. A significant decrease in exhaust smoke emissions ranging from 10% to 41% was recorded while a slight increase was observed in the NO_x emissions with increase in concentration of biodiesel in the blends. A general increase in engine pressure and heat released was observed with increase in concentration of biodiesel in the blends. The results from this study showed that higher blends of croton biodiesel of up to B50 displayed similar engine performance as petro-diesel and could therefore effectively act as an alternative to petro-diesel. Since *Croton megalocarpus* readily grows in many parts of Kenya, the non-edible plant seeds can be readily used for large scale production of biodiesel. Due to the good emission and performance characteristics of croton biodiesel, the government should encourage improved production and use of biodiesel blends. However more studies should be done to determine any effect on long term use of different compositions of croton biodiesel blends and ways of mitigating any effect that may arise.

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