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The effect of diesel fuel-*Jatropha curcas* oil methyl ester blend on the performance of a variable speed compression ignition engine

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Abstract

The increase in crude oil prices, the problems associated with long term availability of conventional hydrocarbon fuels for automotive engines, and the continuous emission of combustion pollutants into the environment are cause for concern. These challenges have necessitated the need to investigate the performance of *Jatropha curcas* oil methyl ester as diesel fuel extender in compression ignition engines. A test rig of 2.43 kW, 165 F single cylinder -four stroke variable speed direct injection engine, and incorporated with a 1.25kVA Honda E 1500 A.C dynamometer manufactured by Ningbo Tri-circle Power Machinery Company, China and Honda Company, Japan, was used to conduct the engine performance tests on samples of fossil diesel fuel (DF), and diesel fuel containing 5%, 10%, 15%, and 20% by volume of *Jatropha curcas* oil methyl ester (i.e. B5, B10, B15, and B20 DF-JME blends) respectively. At maximum engine speed of 2600rpm, the brake power and brake mean effective pressure generated by DF-JME blends are somewhat comparable to fossil DF, with B10 and B20 samples exhibiting least engine power by the order of 1.80% and 2.72%. In terms of fuel consumption, B5, B10, B15 and B20 DF-JME blends are 1.63%, 3.06%, 0.030% and 0.514% higher than fossil DF. However, the lower break thermal efficiency could be attributed to the slow progress of combustion, lower heating value and combustion temperature of the DF-JME fuel mixture. Hence, it could be concluded from this study that transesterified *Jatropha curcas* oil is suitable for use as diesel fuel extender in compression ignition engines. To this effect, a deliberate investment in biodiesel production from Jatropha *curcas* oil will conserve crude oil reserve and improve Nigeria's energy security.

Keywords: Biodiesel; brake mean effective pressure; brake power; brake thermal efficiency; energy security; fuel consumption.

Abbreviations: B5_Samples of DF containing 5% by volume of JME; B10_Samples of DF containing 10% by volume of JME; B15_Samples of DF containing 15% by volume of JME; B20_Samples of DF containing 20% by volume of JME; DF_Samples of fossil diesel fuel; JME_*Jatropha curcas* oil methyl ester.

Introduction.

The rising world crude oil price, the growing environmental awareness and the fast depleting finite fossil fuel reservoirs has spurred renewed research interest and advances in alternative fuel development from agricultural feed stocks. At present, priority attention is being given to biodiesel derived from sources (such as; *Jathropha curcas*, waste vegetable oil, straw, and algae) that do not compete for food. This choice is informed by the argument that biodiesel produced from edible seed crops exacerbates global food crisis (Moore, 2008; Holmes, 2008; Ejilah et al. 2009). *Jathropha curcas* is a drought resistant oleaginous bushy shrub that belongs to the family *Euphorbiaceae*. It is a tropical and subtropical seed crop. The crops possess enormous industrial and export potentials, because their oils extracts are used in soap, dyes, insecticide, pesticide, illuminant, and alternative fuel production. The oil content is 35-40% in the seeds and 50-60% in the kernel. The crude oil contains 21% saturated fatty acids and 75% fueldiesel fuel blends produce remarkable results in fuel economy, brake power and minimal combustion chamber wear in compression ignition engines. Nonetheless, in longer term usage some engine durability problems such as clogging of fuel filter and coking of injector tips are evident (Engelman et al., 1978; Sims et.al 1981; Barsic and Humke, 1981; Worgetter, 1981; Sapaun et.al 1996; Ryan et.al 1984; Peterson et. al., 1990 and Reid, et.al (1989).). However, to surmount these challenges the transesterification of *Jatropha curcus* oil becomes necessary (Al Widyan and Shyoukh, 2002, and Demirbas, A. 2003). Furthermore, and in view of the fact that Nigeria's fossil driven economy is under severe pressure of over exploitation, an energy transition from crude oil to renewable energy has become imperative. Consequently, the search for alternative fuel, that promises harmonious relationship with sustainable development, energy conservation and efficiency, and environmental preservation, is being encouraged (ECN, 2005; Alamu *et al*., 2007; Bhattacharya *et al*. 2006). For these reasons, and also

Table 1. Technical specification of engine test rig

Model	165 F
Type	Horizontal single cylinder four stroke, air-cooled
Bore * Stroke	65 mm x 70 mm
Rated output	2.43 kW (3.26 h.p)
Rated speed	2600
S.F.C at rated output	<284.2 g/kW-hr
Method of cooling	Air cooling by blower
Lubrication method	Centrifugal lubrication, combined oil mist and splash
Starting method	Manual cranking
Compression ratio	20.5:1
Manufacturer	Ningbo Tri-circle Power Machinery Co. Ltd. China

for the purpose of expanding the energy supply mix, the development of alternative fuel from non-edible *Jatropha curcas* seed is a worthwhile venture. Hence, the objective of this paper is to report the result of the effect of diesel fuel-*Jatropha curcas* oil methyl ester (DF-JME) blends on the performance of compression ignition engines, with the aim of generating mechanical power, conserve the nation's fast depleting crude oil reserves, and reduce environmental pollution.

Materials and methods

Sample collection

The *Jatropha curcas* shrub found within the environs of the Federal Polytechnic, Bauchi, Nigeria was identified at the herbarium of the Biological Sciences Programme, Abubakar Tafawa Balewa University, Bauchi, Nigeria. The harvested and depulped *Jatropha curcas* seeds were collected, sun dried for seven days, and baked to prevent the growth of fungi. The baking process is controlled in a heat chamber at temperatures between 85^{o}C-90^{o}C to avoid charring the kernels. According to Fobil et al (2009), this condition could also reduce the fat content of the seeds. The baked kernels were then crushed and powdered in large wooden mortars. Subsequently, the powdered kernel was mixed with water and boiled. The resulting mixture was stirred continuously into a paste. The paste is allowed to settle with oil floating on top of the supernatant and eventually scooped-off, decanted, cooled and preserved in an air-tight plastic container at a room temperature of 33^{o}C.

Physico-chemical characterization

The physical and chemical properties of *Jatropha curcas* oil were determined according to standard procedure recommended by AOAC (1980); Pearson (1981), and Pa Qurt, (1979). The oil properties analyzed are: specific gravity, saponification, peroxide, iodine, free fatty acid and pH values respectively

Fatty acid determination

The fatty acid of the oil sample was determined in accordance to the method described by Atasie *et al. (*2009). In this case, about 2 grams of the oil sample was weighed, in a small beaker and dissolved in 50 ml of chloroform, transferred into a hundred volumetric flasks and diluted to the mark with chloroform. 1 mL of the unknown sample was transferred into a 10 ml screw top culture tube with a Teflon liner. Exactly, 1.00 mL of a standard solution of 0.814-mg/mL pentadecanoic acid was then added. The glyceride in

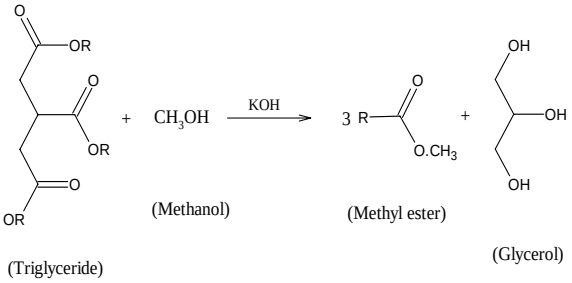


Fig 1. Methanolysis of triglyceride

the oil sample was esterified as well as the pentadecanoic acid standard. The efficiency for the esteri- fication of the standards is the same as that of the glycerides. Also, the response of the detector of each of the fatty acid methyl ester with the internal standard was the same. Hence, the amount of each ester in the fat was determined by comparing the integrated areas with the known concentration of the standard. Most of the chloroform was then evaporated under a stream of nitrogen until 100µl of the solution remained. 1 mL of interesterification reagent (25% volume of a 12% BF3 methanol solution, 20 % volume of benzene and 55 % volume methanol) was added. The tube was flushed with nitrogen, sealed and heated in a 100^{o}C water bath for 30 minutes – after which the methyl esters was extracted with hexane and water, the final mixture of the reagent, hexane and water were in the ratio 1:1:1 (adding 1mL each of hexane and water to the reaction mixture). The mixture was shaken thoroughly for 2 minutes. A stable emulsion was formed which was broken by centrifugation. Half of the top hexane phase was transferred into a small text tube for injection.

Trans-esterification of Jatropha curcas oil

1.0 g of KOH was weighed on a digital beam balance and dissolved in a beaker containing 100 ml of distilled water (H_2O) to give 1% of KOH solution. 282 g of *Jatropha curcas* oil was weighed and preheated to 45^{o}C to 50^{o}C. Furthermore 102.2 g of methanol was also weighed and poured into the preheated *Jatropha curcas* oil in a plastic container to maintain 6:1 alcohol to oil molar ratio. 1.0 g of KOH was weighed on a digital beam balance and dissolved in a beaker containing 100ml of distilled water (H_2O) to give 1% of KOH solution. 1% of KOH solution was then introduced into the methanol in the plastic container and gently swirled. The preheated *Jatropha curcas* oil was then added and stirred for 5-10 minutes, and then heated to a temperature of 60^{o}C -80^{o}C in a water bath to initiate the transesterification reaction (Lele, 2009; Belsor and Hedlund, 2007). The mixture was then poured into a separating funnel and allowed to settle for about 7-8 hours for the complete separation of glycerol from *Jatropha curcas* oil methyl ester (JME). The glycerol which is denser settles at the bottom of the funnel is drained off leaving behind JME as biodiesel. The tranesterification reaction chemistry is presented in Fig. 1. To remove impurities(such as; excess methanol, soap, glycerin and catalyst) from the biodiesel, two 2-litre PET bottles were used in succession, with half- litre of tap water added for each of the four washes carried out. A small 2mm orifice was pieced in the bottom corner of each of the two bottles and covered securely with duct tape. Biodiesel was poured into one of the wash bottles. Half–litre of fresh water

Table 2. Dynamometric specification

Type	HONDA Model E 1500
Maximum operating capacity A.C	220V, 50Hz, Single phase
Maximum operating capacity D.C	12V, 8.3A
Maximum speed	4000rpm
Torque arm radius	130mm
Manufacturer	Honda motor, Tokyo, Japan

was added and the cap screwed on tightly. The bottle was turned on its side and rolled about until oil and water were well mixed and homogenous. After washing and settling, the water was drained off from the bottom of the bottle by removing the duct tape sealing the orifice. The hole was blocked again when it reached the biodiesel. The biodiesel was transferred to the second wash bottle. The first wash bottle was then cleaned and the duct tape replaced. The process was repeated four times (Alamu *et al.* 2007; Belser and Hedlund, 2007).

Blending of Jatropha curcas oil with Diesel fuel

25ml of JME and 475ml of diesel fuel were measured with a 500ml measuring cylinder and poured into a 500ml beaker and stirred thoroughly to produce B5 DF-JME blended fuel. The mixture was allowed to settle for 4-6 hours for miscibility and homogenous consistency. The procedure was repeated for B10, B15, and B20 DF-JME blended fuel respectively.

Determination of Fuel Properties.

Physical properties of JME and DF were conducted in accordance with standardized ASTM test procedures and these include; ASTM D97-93, ASTM D2015-85, ASTM D 93-94, ASTM D D613, ASTM D 445 for density , higher heating value, flash point, octane number and kinematic viscosity respectively(ASTM, 1993).

Engine Performance Analysis

A 3.26 hp single cylinder four stroke 165F compression ignition engines incorporated with a 1.25kVA Honda E 1500 A.C dynamometer with technical specification presented in Tables 3 and 4 respectively was used to conduct the performance analysis. The engine performance characteristics was monitored within the speed range of 1400rpm and 2600rpm, and varied incrementally by 400rpm after every interval of two hours. A control test was carried out on diesel fuel for a period of 8 hours after which similar test procedure was carried out on B5, B10, B15 and B20 DF-JME fuel samples. The brake power, brake mean effective pressure, specific fuel consumption, and brake thermal efficiency were monitored during each respective test.

Results and discussion

The fatty acid profile of Jatropha oil in Table 3 presents the composition of palmitic acid as 12.6%, stearic acid as 3.9%, oleic acid as 41.8%, linoleic as 41.8%, and linolenic acid as 7.8% respectively. The fairly high percentage of fully saturated fatty acid, and poly-unsaturated linoleic and linolenic acids predisposes the oil sample to oxidative

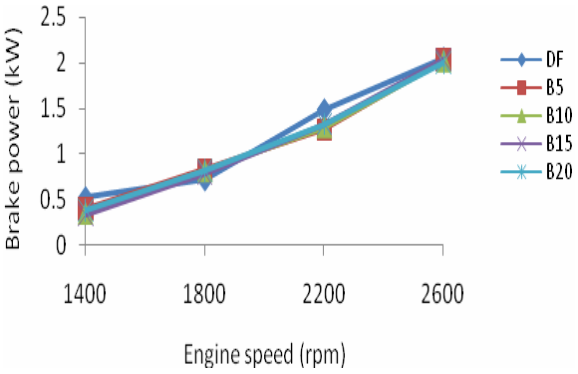


Fig 2. Brake power of DF and DF-JME fuel samples

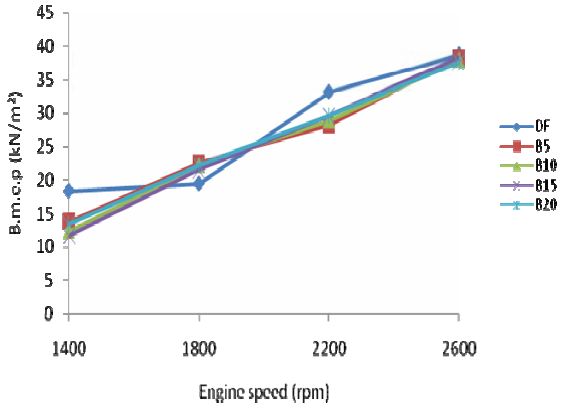


Fig 3. B.m.e.p. of DF and DF-JME fuel samples

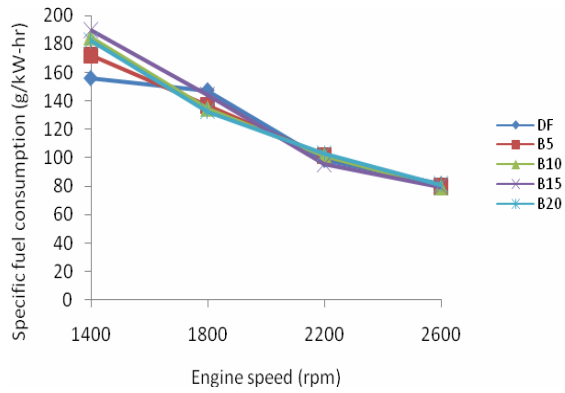


Fig 4. Specific fuel consumption of DF and DF-JME fuel samples

instability and shorter shelf life (Asadauskas and Perez, 1997). In addition, it could be seen from the physico-chemical properties of *Jatropha curcas* oil in Table 3 that; the oil's show high relative density (0.917), and saponification value (198 mg/KOH/g). This explains the oil's propensity for soap formation. However, according to Halling (1989), the formation of soapy film provides adequate boundary lubrication and reduces engine wear. Similarly, the iodine value of 112.5 g/100g shows a high degree of unsaturation, and is classified as a semi drying oil by Remington and Wood (1918). While, an acid value of 38.2 mg KOH/g indicates the percentage of fatty acid

Table 3. Fatty acid composition (%) and chemical structure *Jatropha curcas* oil

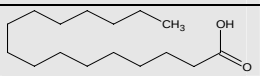
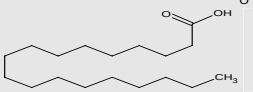
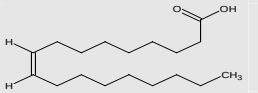
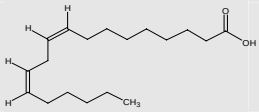
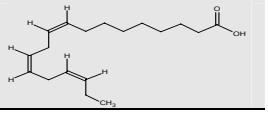
Name	Composition (%)	Structure
Palmitic acid	12.6	
Stearic acid	3.9	
Oleic acid	41.8	
Linoleic acid	41.8	
Linolenic acid	7.8	

Table 4. Physical and chemical properties of *Jatropha curcas* oil and diesel

Properties	Jatropha oil	Jatropha methyl ester (JME)	Diesel oil
Viscosity (cp)@35^{o}C	40.4	3.57	3.6
Specific density@35^{o}C	0.917	0.8809	0.841
Cetane value	51.0	58.4	47.8
Flash point (^{o}C)	274	174	52
Carbon residue (%)	0.64	0.024	< 0.05
Sulfur (%)	0.13	-	< 1.0
Acid value	38.2	0.38	-
Saponification value	198	-	-
Iodine value	112.5	-	-
Calorific value	39,862	39,340	45,457

present in the oil that could possibly influence oxidation. Nonetheless, it is pertinent to mention, that poor oxidation stability causes fuel thickening, gums and sediments formation, fuel filter clogging and injector fouling. From Table 4, it could be seen that the specific gravity of JME sample is slightly heavier than conventional DF. While, the viscosity of JME is comparable to DF. It was also noted that beside the function of fuel injection system lubrication, fuel viscosity also controls the diesel fuel droplet size and spray characteristics originating from the fuel injection system (Lele, 2009). Furthermore, it was also observed that the heating value of JME is lower than DF. The lower heating values of JME fuel sample in Table 5 suggest that oil density exert some influence on the calorific value of fuel samples (Atasie *et al.*, 2009).The flash point of the JME fuel samples are also higher than DF samples. However, the flash point of biodiesel fuel blend is dependent on the flash point of the base diesel fuel used, and increase with percentage of the biodiesel in the blend respectively. The advantage of this behaviour is found in safe storage and usage as biodiesels are less flammable than conventional diesel (Lele, 2009). It was also observed that JME fuel sample exhibited higher cetane number than conventional DF sample, and as such provide smoother combustion and higher combustion efficiency accordingly (Lele, 2009). The result of engine performance analysis in Table 6 show that engine temperature of B5, B10, B15 and B20 JME fuel blends are 16.10%,13.79%, 15.54% and 16.68% higher than their DF counterpart. The increased exhaust gas temperature is attributed to the rise in peak cylinder pressure resulting in higher peak combustion temperature as reported by Ecklund, (1984). However at maximum speed, B5, B10, B15 and B20 DF-JME fuel blends exhibit 0.87%, 1.80%, 0.87% and 2.72% lower brake power than the DF sample. According to Meiring *et al.* (1983) the marginally lower brake power generated by DF-JME fuel blends could be credited to their lower calorific (heating) value, and increase in ignition delay of JME blends as they combines with conventional DF to burn (refer toTable 5). The b.m.e.p (i.e. the calculated mean pressure that would act upon observed power output, in the absence of any mechanical losses) behaves in a similar manner as the brake power. The results on b.m.e.p agrees with the opinion of Wirawan *et al.* (2008) and Knothe *et al.* (2004) which claimed that the higher engine power rating exhibited by biodiesel blends is no doubt affected by lower viscosity profile, higher fuel injection and combustion of the tested pure biodiesel. On the other hand, high fuel viscosity reduces fuel injection efficiency and atomization, and this lead to poor fuel combustion and power losses in engine(s). It has also been reported that with increase in concentration of biodiesel in the fuel blends, the adsorption layer on metal surface in relative motion to one another (such as, injector system, pistons, rings and sleeves) become better lubricated, and initiate a declination of frictional horse power. Hence, this improved lubrication conditions enhances engine power output and b.m.e.p respectively (Masjuki and Maleque, 1996; and Sabeena *et.al.*, 2004). The engine performance results illustrated in Figs 2 to 5 shows that the brake power, b.m.e.p , and brake thermal efficiency of tested fuel sample increase with engine speed, while specific fuel combustion

Table 5. Heating values and specific gravity of fuel samples

Properties	DF	DF-JME blends			
		B5	B10	B15	B20
Heating values Mj/kg	45.59	45.27	44.96	44.64	44.33
Specific gravity at 35^{o}C	0.840	0.837	0.835	0.834	0.831

Table 6. Engine performance of DF and DF-JME blends at 2600 rev/min

Performance Characteristics	Manufacturer's Specification	DF	DF-JME blends			
			B5	B10	B15	B20
Exhaust Temperature (^{O}C)	-	125	149	145	148	150
Brake power (kW)	2.43	2.06	2.04	2.02	2.04	2.00
Brake mean effective pressure (kN/m^2)	-	8.68	38.33	37.97	38.33	37.62
Specific fuel consumption (g/kW-h)	< 284.2	81.64	80.31	79.14	79.16	81.22
Brake thermal efficiency (%)	-	32.23	32.77	33.25	33.24	32.39

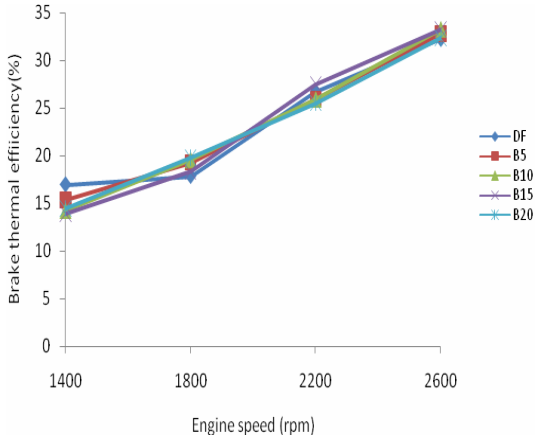


Fig 5. Brake thermal efficiency of DF and DF-JME fuel samples

decrease with engine speed and reach a minimum level at 2600 rpm. The specific fuel consumption values in Table 6 also show that B5, B10, B15 and B20 DF-JME fuel blends are lower than DF benchmark by 1.63%, 3.06%, 0.030%, and 0.514%. However, the fuel economy characteristics of the blended fuel samples could be ascribed to improved miscibility, better fuel atomization characteristics and combustion. According to Wirawan *et al*, (2008), higher fuel viscosity reduces the quality of fuel atomization, and this could result in higher gas emission and fuel consumption. Table 5 show that the brake thermal efficiency of B5, B10, B15 and B20 DF-JME fuel blends are 1.64%, 3.06%, 3.04% and 0.49% higher than DF samples. The decrease in brake thermal efficiency could be partially explained by the slow progress of the combustion, gradual drop in heat value, and lower combustion temperature in the fuel mixture (Pathak, 2004; Asokan, 1990, Bhattacharya *et al*., 2001 and Uma *et al*. 2004).

Conclusion

The results of the study on the performance characteristics of a variable speed compression ignition engine run on DF-JME fuel blends at maximum engine speed shows that: DF-JME fuel blends generated marginally lower brake power, and b.m.e.p. than diesel fuel. Secondly, the specific fuel consumption of DF-JME fuel blends is slightly lower than DF samples. Finally, the brake thermal efficiency of B5 and B20 DF-JME blends is slightly higher than DF samples, and B10 and B15 blended fuel samples exhibit much higher values. Hence, it could be concluded from this study that DF-JME fuel blend are suitable diesel fuel extender in compression ignition engines.

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