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Performance of Diesel Engine using Jatropha Biodiesel Fuel Blends

أداء محرك ديزل بإستخدام خلطات ديزل حيوى مستخلص من الجاتروفا

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الخلاصة

في هذا البحث تم إستخدام خلطات وقود الديزل الحيوى المستخلص من ثمار نبات الجاتروفا بنسب خلط حجمية وهى20% , 40% , 60% , 80% و 100% مع وقود الديزل , لتقييم اداء محرك ديزل. تم إستخلاص زيت الجاتروفا من ثمار الجاتروفا وإستخدام تفاعل الأسترة لتحويل زيت الجاتروفا إلى وقود الديزل الحيوى. المحرك المستخدم رباعى الأشواط , ذو إسطوانتين , حقن مباشر , تبريد هواء يعمل على حمل كامل وسرعات مختلفة وهى500 , 750 , 1000 , 1250 و 1500 لفه/دقيقة. بينت الدراسة أن وقود الديزل الحيوى المستخلص من الجاتروفا المحلية يمكن إستخدامه كوقود بديل لوقود الديزل بدون اى تعديلات على المحرك, بينما إنخفض اداء المحرك عند زيادة نسبة الوقود الحيوى فى الخليط. حيث بينت النتائج إنخفاض كلا من القدره الفرملية الناتجه من المحرك بنسبة 16% , الكفاءة الحرارية الفرملية بنسبة 22% , نسبة الهواء للوقود بنسبة 17% (مما يدل على أن إستهلاك الهواء أقل فى حالة خلطات الوقود الحيوى مقارنة بوقود الديزل) و الكفاءة الحجميه بنسبة 11%. بينما إرتفع معدل الاستهلاك النوعى الفرملى للوقود عند زيادة نسبة الوقود الحيوى فى الخلطات بنسبة 31% وكذلك إرتفاع درجة حرارة غازات العادم بنسبة 34% مقارنة بوقود الديزل.

Abstract

In this study, jatropha biodiesel fuel blends were used by volumetric ratios of 20%, 40%, 60%, 80% and 100% with Diesel fuel to evaluate Diesel engine performance. Jatropha oil was extracted from jatropha carcass and converted to biodiesel fuel using transesterification reaction. Tests were performed on a four stroke, two cylinder, direct injection, air cooled Diesel engine at full load and different speeds, namely 500, 750, 1000.1250 and 1500 rpm. The present study reveals that, locally jatropha biodiesel fuel can be used as an alternative fuel for Diesel engines without any modifications. However, there was a decrease in engine performance with increasing biodiesel fuel percentage in the blends. The results showed a decrease in both of brake power by 16%, brake thermal efficiency by 22%, air to fuel ratio by 17% (which indicates that the consumption of air is less in case of biodiesel fuel blends compared to Diesel fuel), volumetric efficiency by11%. While there are increases in brake specific fuel consumption by 31% and exhaust gas temperature by 34% compared to Diesel fuel.

Keywords: Biodiesel fuel; Jatropha oil; Alternative fuel

1. Introduction

The term biofuel is referred to as liquid or solid or gaseous fuels, which are predominantly produced from biomass. The share of biofuel in the automotive fuel market will grow fast in the next decade [1]. A sustainable biofuel has two advantages which are its availability from renewable raw material and its lower negative environmental impact than that of fossil fuels. Vegetable oils are one of the renewable fuels; it is a potentially inexhaustible source of energy with an energetic content close to that of Diesel fuel. There are more than 350 oils bearing crops identified, among which jatropha, sunflower, safflower, soybean, cotton seeds, rapeseed and peanut oils are considered as potential alternative fuels for Diesel engines. Biodiesel derived from vegetable oils is the most promising alternative fuel to Diesel fuel due to the following reasons [2]:

1. Biodiesel can be used in the existing engine without any modifications.
2. Biodiesel is made entirely from vegetable sources; it does not contain any sulfur, aromatic hydrocarbons, metals or crude oil residues.
3. Biodiesel is an oxygenated fuel; emissions of carbon monoxide and soot tend to reduce.

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4. Unlike fossil fuels, the use of biodiesel does not contribute to global warming as CO_2 emitted is once again absorbed by the plants grown for vegetable oil/biodiesel production. Thus CO_2 balance is maintained.
5. Biodiesel is produced from renewable vegetable oils/animal fats and hence improves the fuel or energy security and economy independence.

The major problem with the direct use of vegetable oils as fuel into compression ignition (CI) engines is their higher viscosity. This problem can be overcome it by four methods, such as dilution (blending), heating (thermal cracking), emulsification and transesterification, but the transesterification method is the most common method and leads to mono-alkyl esters of vegetable oils and fats, now called biodiesel when used for fuel purposes [3].

The vegetable oils can be directly mixed with Diesel fuel and used for running the Diesel engines. The blending of vegetable oil with Diesel fuel were experimented successfully by many researchers. It has been proved that, the use of 100% vegetable oil was also possible with some minor modifications in the fuel system [4]. Emulsification with solvents such as methanol (also known as methyl alcohol, CH_3OH) and ethanol (also called ethyl alcohol, C_2H_5OH) have been used to solve the problem of high viscosity of vegetable oils. An emulsification is defined as the colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the range of 1-150 nm formed spontaneously from normally immiscible liquids [4]. Thermal cracking is the process of conversion of one substance into another, by means of heat or with the aid of catalyst. It involves heating in the absence of air or oxygen and cleavage of chemical bonds to yield small molecules. The thermal cracking of fats has been investigated for more than 100 years, especially in those areas of the world that lack deposits of petroleum [5]. The transesterification process is the reaction of a triglyceride (fats or oils) with alcohols to form esters and glycerol. Biodiesel is produced by transesterification which is a process of using either ethanol or methanol, in the presence of a catalyst, such as potassium hydroxide (KOH) or sodium hydroxide (NaOH) to chemically break the molecule of an oils or fats into an ester and glycerol [6]. The transesterification reaction is represented by the general equation as shown in figure (1).

A lot of research works has been carried out to use vegetable oils both in its neat form and modified form such as **Agarwal and Agarwal** [2] studied the effect of reducing jatropha oil's viscosity by increasing the fuel temperature. The results were found that heating the jatropha oil between 90 °C and 100 °C is adequate to bring down the viscosity in close range to Diesel fuel. Viscosity of jatropha blends (up to B30) was also close to Diesel fuel.

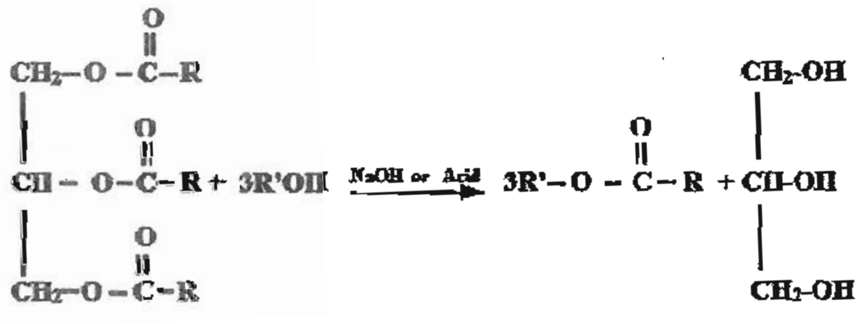

Fig. (1) Transesterification equation, R is a mixture of various fatty acid chains and R' = CH_3 [6]

From the experimental results obtained, jatropha oil is found to be a promising alternative fuel for Diesel engines. For blends, brake specific fuel consumption (BSFC) and exhaust gas temperature were found higher compared to Diesel fuel. Thermal efficiency was also found to be close to Diesel fuel for jatropha oil blends. The use of pure Jatropha oil/diesel fuel blends has been tested by **Pramanik** [7]. He found that, BSFC and exhaust gas temperature of the blends were found to be higher compared to Diesel fuel and tended to increase with increasing proportion of pure jatropha oil in the blend. The opposite applies for the brake thermal efficiency. However, blends of B30 and B40 showed BSFC and brake thermal efficiency close to the values of Diesel fuel.

Forson et al [8] studied the performance of jatropha oil blends in a Diesel engine. The jatropha oil was mixed with Diesel fuel in blends as B2.6, B20 and B50. The tests showed that, an increase in brake thermal efficiency, brake power and reduction of specific fuel consumption for jatropha oil and its blends with Diesel fuel in generally. But the most significant conclusion from the study is that the B2.6 produced maximum values of the brake power and brake thermal efficiency as well as minimum values of the specific fuel consumption. **Prasad et al** [9] showed higher BSFC for biodiesel use than for Diesel fuel use. Since the Heating value of biodiesel is lower than Diesel fuel, this observation implies that the biodiesel fuel consumption will be higher than Diesel fuel as well.

Sahoo et al [10] studied the effect of jatropha biodiesel fuel blends (B00, B20, B50 and B100) to the engine performance. Test data were generated under full/part loads for different engine speeds (1200, 1800 and 2200 rpm). The maximum increase in power is observed for B50 at 1500 rpm. BSFCs for all the biodiesel blends increase with blending ratio and decrease with speed.

2. Experimental Work

2.1 Biodiesel Fuel Preparation

A quantity of 65 kg of jatropha carcasses was obtained from jatropha plantation in Luxor-Egypt (harvest in May 2009), affiliated to the Egyptian Ministry of Agriculture. The carcasses were dried from its water contents in a stove at 70°C for 2hr. A quantity of 61.62kg of dry carcasses was shelled yielding approximately 40.5kg of the jatropha seeds. Then, a simple mechanical ram-press was used for the oil extraction from jatropha seeds. A quantity of 39.5kg of dough is produced after the milling process (1kg of dough was loosed through the milling process), which subsequently yielded 13.86 kg of jatropha oil representing an about 21.32% from dry and unshelled jatropha carcasses. Figure (2) shows oil extraction machine. The conversion of jatropha oil into methyl esters can be accomplished by the transesterification process using the following steps [11, 12]:

1. Methyl alcohol (CH_3OH) and the sodium hydroxide (NaOH) as catalyst are mixed in a tank (A specified amount of 450ml alcohol and 10gm sodium hydroxide per 1kg of jatropha oil).
2. Jatropha oil is added to the reaction vessel containing the mixture of alcohol/catalyst. The reactor was heated to about 65-70°C (a temperature which is much lower than the boiling point) to increase the reaction rate.
3. After about 3hr at a constant temperature of about 70°C, when enough jatropha oil was converted, the reactor was left for natural cooling for about 24hours. Two phases were distinct: a golden yellow liquid representing the esters (biodiesel) on top and the glycerol at the bottom, the biodiesel and the glycerine are separated by gravity.
4. The glycerin settled at the bottom of the reactor and the biodiesel was collected in a reasonable vessel.

2.1.1 Fuel Properties

Jatropha oil has a common molecular structure as other vegetable oils called triglyceride and has chemical formula of $C_{56}H_{101}O_6$. Biodiesel has been approximated as a single component of Oleic acid ($C_{18}H_{34}O_2$), based on the percentage composition of fatty acids [13]. Table (1) showing the fuel properties of Diesel fuel, jatropha oil and biodiesel blends [14].

2.2 Experimental Setup

2.2.1 Description of the Test Rig

A schematic diagram of the experimental test rig is shown in figure (3). It consists of a Diesel engine, AC alternator, Diesel and biodiesel fuel tanks, air and fuel flow meter, load bank, digital tachometer, stop watch and gas analyzer. The used engine is a naturally aspirated, two cylinders, four stroke, direct injection, air cooled **Deutz–F2L511** Diesel engine. The maximum power of this engine is 17 kW. It is typical engine widely used in the agricultural sector to drive water pumps. This engine is located in the combustion laboratory, Faculty of Engineering, Mansoura University. Specifications of the engine are reported in table (2).

The engine drives a 380V; three phase electrical AC alternator (of a fixed power factor of 0.8) uses two V-belts for loading the engine through a resistive load bank. The resistive load bank was prepared to consume the output engine power. The load bank consists of twelve electrical heating coils (1000 W of each one). These twelve heating coils are used as the full load of the engine of 12kW. An analogue voltammeter is used to measure the output voltage from the alternator, and analogue ammeter is used to measure the consumed current in the resistive load bank.

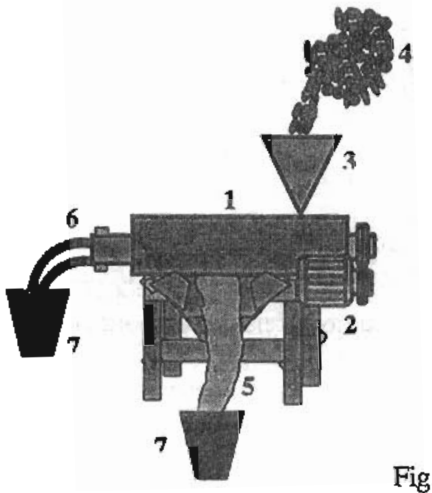

Fig. (2) Oil extraction machine

1- Screw press
2- Electrical motor
3- Hopper
4- Jatropha seeds
5- Jatropha oil
6- Jatropha pellets
7- Reservoirs

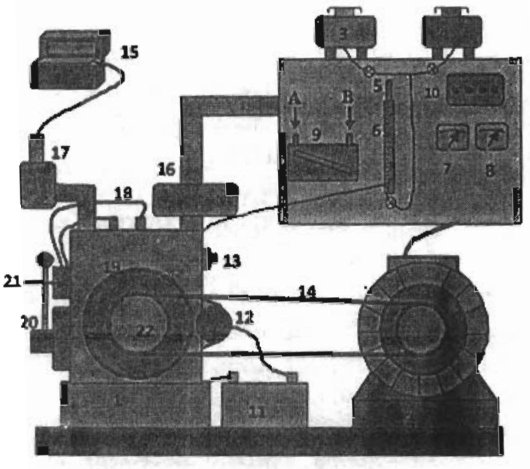

Fig. (3) Schematic diagram of the experimental test rig

1- Engine
2- AC Alternator
3- Biodiesel fuel tank
4- Diesel fuel tank
5- Fuel valves
6- Fuel burette
7- Ammeter
8- Voltammeter
9- Air flow manometer
10- Load bank buttons
11- DC Battery
12- Startup motor
13- Engine Start button
14- V-belts
15- Exhaust gas analyzer
16- Air filter
17- Exhaust pipe
18- Fuel injectors
19- Flywheel
20- Clutch handle
21- Fuel pump
22- Pulley
A- High pressure terminal (Before air flow meter viscous element)
B- Low pressure terminal (After air flow meter viscous element)

Table (1) Fuel properties of Diesel fuel, jatropha oil and biodiesel blends [14]

Properties	Diesel fuel	Jatropha oil before Transesterification	Jatropha biodiesel (methyl ester) blends				
			B20	B40	B60	B80	B100
Chemical Formula	$C_{12}H_{23}$	$C_{56}H_{101}O_6$	-	-	-	-	$C_{18}H_{34}O_2$
Molecular weight, kg/kmol	167	869	190	213	236	259	282
AFR stoichiometric	14.60	12.37	13.95	13.44	13.03	12.70	12.42
Density at 15 °C, kg/m^3	840	910	843.7	848.2	853.0	857.6	862.1
Kinematic viscosity at 40°C, cSt	4.86	30	5.3	6.5	7.7	8.6	9.89
Heating value, MJ/kg	44.42	39	42.25	41.072	39.19	38.17	37.74
Flash point, °C	51	240	55	76	98	109	174
Cetane number	50	47	52	53	54	56	58

Table (2) Engine specifications

Engine model	Deutz F2L912
Number of cylinders	2
Compression Ratio	17:1
Cylinder arrangement	Vertical in-line
Borex Stroke (mm × mm)	100×120
Aspiration	Natural
Cycle	4 Stroke
Displacement (Liter)	1.88
Cooling system	Air-cooling
Speed Range (rpm)	500 to 2500
Rated Power at 1800 rpm (kW)	17

2.2.2 Instrumentation and Measuring Technique

Instrumentation includes devices for measuring both of air and fuel consumptions, engine speed, engine load and exhaust gases temperature. The fuel burette is used to determine the rate of fuel consumption by measuring the time through which 6 cc of tested fuel are fed to the engine. Fuel mass flow rate can be calculated using equation (1) as follow:

$$\dot{m}_f = \text{constant} * \rho V/t \quad (\text{kg/hr}) \qquad (1)$$

Figure (4) shows a sketch of air flow measuring system which consists of air filter, viscous element, air box and inclined tube manometer. Air is drawn through an air filter and then passed through a viscous element which consists of numerous small bores before entering the damping volume (air box). The size of the bores is chosen so that the Reynolds number (Re) is less than 2300, $Re = (\bar{u} * d/\nu)$. This ensures that an air flow through the viscous element is entirely laminar. The pressure drop is measured by an inclined tube manometer, which measures the pressure difference before and after the viscous element. The mass flow rate of air is given by equation (2). From air flow meter calibration curve can be obtained on the air flow rate in terms of pressure difference.

$$\Delta P = \text{constant} * \frac{\mu * \dot{m}_{air}}{\rho_{air}} \quad (\text{kPa}) \qquad (2)$$

An optical tachometer of **2IGI5** type is used to measure the engine speeds (rpm) with accuracy of 0.5rpm, it is easy and convenient to operate as a flashlight. The exhaust gas temperature with accuracy of ±2% of full scale and ambient temperature with accuracy of ±0.5°C are measured by **IMR 2800P** gas analyzer.

2.2.3 Engine Performance Parameters

The engine performance parameters are determined using the following procedures:

$B_p = \sqrt{3} \times I \times V \times \cos Ø$ (W) where,

cos Ø : Alternator power factor, cos Ø =0.8

$$BSFC = \frac{\dot{m}_f}{B_p} \ (\text{gm/kW.hr})$$

$$BMEP = \frac{B_p}{\left[V_d * \left(\frac{N}{60 * n_R}\right)\right]} \ (\text{kPa.})$$

where, n_R: Number of revolutions per cycle, for 4-stroke engine $n_R = 2$ rev./cycle

$$AFR = \frac{\text{actual air mass flow rate}}{\text{actual fuel mass flow rate}} = \frac{\dot{m}_{air}}{\dot{m}_f} \left(\frac{kg_{air}}{kg_f}\right)$$

$$\Phi = \frac{FAR_{act}}{FAR_{st.}}$$

where, FAR=1/AFR

$$\eta_{th,b} = \frac{\text{brake power}}{\text{energy supplied}} = \frac{B_p}{\dot{m}_f \times L.H.V}$$

$$= \frac{1}{BSFC \times L.H.V} * 100 \ (\%)$$

$$\eta_v = \frac{\dot{m}_{a,act.}}{\dot{m}_{a,th.}}$$

$$= \frac{\dot{m}_{a,act.}}{\left[\rho_{air} * V_d * \left(\frac{N}{60 * n_R}\right)\right]} * 100 \ (\%)$$

where,

$\rho_{air} = P_{air}/(R_{air} * T_{air})$ (kg/m^3)

ρ_{air} : Air density (kg/m^3)

P_{air}: Atmospheric air pressure, $P_{air}=1.013*10^2$ (kPa)

R_{air}: Air gas constant, $R_{air} = 0.287$ (kJ/kg.K)

T_{air}: Atmospheric air temperature (K)

2.2.4 Experimental Procedure

The general testing procedure can be summarized as follows:

1. Check-up each of fuel level and lubrication oil level in Diesel fuel tank and lubrication oil reservoir, respectively. The clutch handle to be at the disconnected position (no load position). The start-up electrical motor is being connected to DC battery through turning starting switch at on mode.
2. The engine must be start-up with the Diesel fuel, and then left being run at no load for about ten minutes for warming up.
3. The required measurements to be performed at steady operating state for the engine at five different speeds, namely 500, 750, 1000, 1250, and 1500 rpm using Diesel fuel only. The engine is then loaded by changing the clutch handle position to required connected mode. At each speed the engine is loaded by full load. The engine was stabilized for four minutes before recording any data at the test speed and after loaded. After this, tests were conducted and repeated three times, in order to increase the reliability of the measuring results, and taking average value of the following items; air manometer reading, the time required for consumption of a 6cc from fuel burette, voltage and current measurements of the load bank instruments and recording the exhaust gas analyzer readings.
4. For biodiesel fuel blends experiments, the Diesel fuel valve was turned off and the biodiesel valve was opened while the engine was running after the warm-up duration. Tests of five cases of biodiesel/diesel fuel blends are carried out. Biodiesel is blended with Diesel fuel in 20%, 40%, 60%, 80% and 100% proportions by volume. The blends were prepared in laboratory just before the experiments. After insert the tested blends into biodiesel tank; waiting for about four minutes and then begin to execute data recording as mentioned above in step 3 for each blend at each speed.
5. After carrying out the tests with biodiesel, the engine is again switched back to Diesel before stopping the engine until the biodiesel is purged from the fuel line, injection pump and injector in order to prevent deposits and cold starting problems.

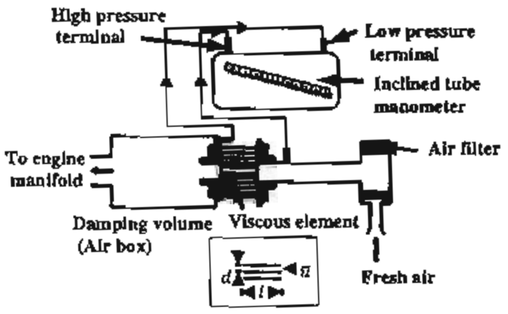

Fig. (4) Sketch of air flow measuring system

3. Results and Discussion

Obtained results of engine performance parameters, mainly Bp, BSFC, BMEP, AFR, $\Phi, \eta_{th,b}$, η_v and T_{exh} versus engine speed when operated at Diesel/jatropha biodiesel fuel blends, are illustrated in the following subsections.

3.1 Brake Power versus Engine Speed

Figure (5) shows the variation of brake power (B_p) using Diesel and biodiesel fuel blends versus engine speed. Generally, the engine output power increase with the increase in engine speed. This is due to that the output torque of the engine is constant as long as the engine load is maintained constant. Since the engine power depends on the output torque and engine speed, the engine power increases as engine speed increases. Also, the engine output power is gradually decreased as the biodiesel increases in the fuel blends. This may be due to increases in exhaust gas temperature for biodiesel fuel blends than Diesel fuel, that's leads to decreases volumetric efficiency of biodiesel blends. This means that, the volumetric efficiency of Diesel fuel higher than the biodiesel fuel blends and thus amount of B_p resulting from Diesel fuel higher than biodiesel fuel blends. The experimental results indicated that, the maximum decrease in output power is 16% (lower than Diesel fuel) for B80 at 750 rpm.

3.2 Brake Specific Fuel Consumption versus Engine Speed

Figure (6) shows the variation of brake specific fuel consumption (BSFC) using Diesel and biodiesel fuel blends versus engine speed. BSFC decreased with the increase in engine speed, reaches a minimum, and then increases at high speed. At low speed, the longer time per cycle allows more heat loss and BSFC goes up. At high speed, BSCF increases due to greater friction losses. BSFC increases with the increase in percentage of biodiesel fuel in the blends. This is maybe ascribed to reduction in heating value with increasing in biodiesel fuel in the blends. Therefore, higher rate of fuel should be injected to maintain the generated power. The test results show that, the maximum increase in BSFC is 31% for B100 at 1250 rpm. B20 is the optimum fuel blend as compared to the entire tests which has nearest values of BSFC of Diesel fuel as shown in figure (6).

3.3 Brake Mean Effective Pressure versus Engine Speed

Figure (7) shows the variation of brake mean effective pressure (BMEP) using Diesel and biodiesel fuel blends versus engine speed. BMEP increases with the increase in engine speed. BMEP is directly proportional to B_p that produced by the engine. At low engine speed, the fuel consumption increases. That leads to lower B_p consequently BMEP also decrease. At high speeds B_p increase, which lead to increase in BMEP. Also, BMEP decreases with the increase in percentage of biodiesel fuel in the blends. This may be due to bad fuel characteristics of biodiesel fuel as higher viscosity, higher density and poor volatility. That's mean that a poor atomization and combustion characteristic of biodiesel fuel blends. That leads to fuel consumption increase as biodiesel ratio increase in the blends. The test results show that, the maximum decrease in BMEP is 14% for B100 at 750 rpm.

3.4 Air to Fuel Ratio versus Engine Speed

Figure (8) shows the variation of air to fuel ratio (AFR) using Diesel and biodiesel fuel blends versus engine speed. Generally, the air flow rate enters to engine cylinder is roughly the same at the same speed for all fuel used. However, the fuel flow rate is increased with the increase in engine speed. This means that, the AFR is increased with the increase in engine speed. Also, the AFR is gradually decreased as the biodiesel increases in the fuel blends. This may be due to the oxygen content in fuel blends (about 11% of its contents) which lead to lower consumption in the amount of air. The experimental results show that, the maximum decrease in AFR is 17% for B80 at 750 rpm.

3.5 Equivalence Ratio versus Engine Speed

Figure (9) shows the variation of equivalence ratio (Φ) using Diesel and biodiesel fuel blends versus engine speed. Equivalence ratio increases with increase in engine speed. This is may be due to that the increase in engine speed requires a larger fuel flow rate and therefore an equivalence ratio must increase. Biodiesel fuel blends have the lowest equivalence ratio in comparison with the Diesel fuel. This may be due to lower fuel consumption rate and a higher heating value of Diesel fuel. Also, the stoichiometric AFR of biodiesel fuel blends less than stoichiometric AFR of Diesel fuel. Therefore the equivalence ratio depends on the stoichiometric AFRs, hence the equivalence ratio of biodiesel fuel must be less than of Diesel. The experimental results show that, the maximum decrease in equivalence ratio is 25% for B60 at 1000 rpm.

3.6 Brake Thermal Efficiency versus Engine Speed

Figure (10) shows the variation of brake thermal efficiency ($\eta_{th,b}$) using Diesel and biodiesel fuel blends versus engine speed. Brake thermal efficiency is increased with the increase in engine speed. This is maybe due to the reduction in heat loss and increase in power developed with increase in engine speed. Brake thermal efficiency decreases with the increase in percentage of biodiesel fuel in the blends. This drop in thermal efficiency can be attributed to the poor combustion characteristics of the blends due to their relatively high viscosity and poor volatility. Also, this may be due to increase of BSFC of biodiesel blends than that of Diesel fuel. The experimental results indicated that, the maximum decrease in $\eta_{th,b}$ is 22% for B100 at 1250 rpm.

3.7 Volumetric Efficiency versus Engine Speed

Figure (11) shows the variation of volumetric efficiency (η_v) using Diesel and biodiesel fuel blends versus engine speed. The volumetric efficiency decreases with the increase in engine speed. This may be due to flow restrictions presented by the air filter, intake manifold, and intake valves at high speed. This leads to decrease the amount of ideal air which must enters the cylinder. Volumetric efficiency decreases with the increase in percentage of biodiesel fuel in the blends. It may be noted that the volumetric efficiency curve is closely related to the exhaust temperature curves. Exhaust gas temperature is higher with all biodiesel fuel as compared to Diesel fuel. Also, the biodiesel fuel contains O_2 which lead to decrease the amount of air needed to occur the combustion. The experimental results show that, the maximum decrease in volumetric efficiency is 11% for B100 at 750 rpm.

3.8 Exhaust Gas Temperature versus Engine Speed

Figure (12) shows the variation of exhaust gas temperature (T_{exh}) using Diesel and biodiesel fuel blends, versus engine speed. The exhaust gas temperature increases with increase in the engine speed. This may be due to increases in fuel injected with increase in engine speed. Also, the exhaust gas temperature increases with increase in biodiesel fuel percentage in the blends. This may be due to shorter ignition delay (because higher Cetane number of biodiesel fuel blends), which resulted in increased of the afterburning combustion interval; longer afterburning results in higher exhaust gas temperature. The experimental results indicated that, the maximum increase in exhaust gas temperature is 34% for B100 at 1250 rpm.

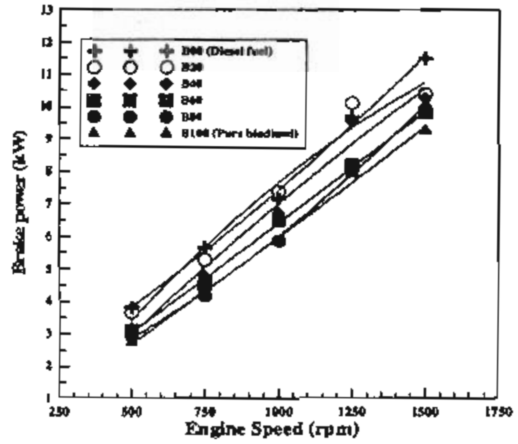

Fig. (5) Brake power versus engine speed

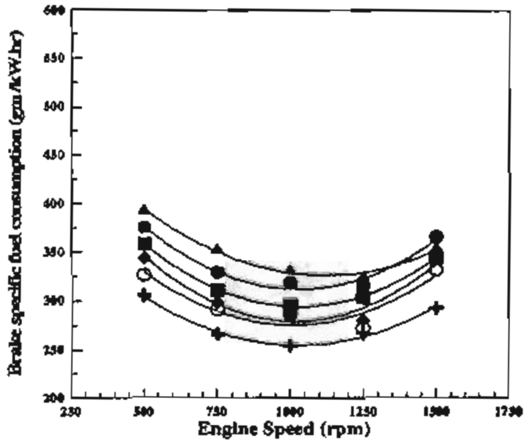

Fig. (6) Brake specific fuel consumption versus engine speed

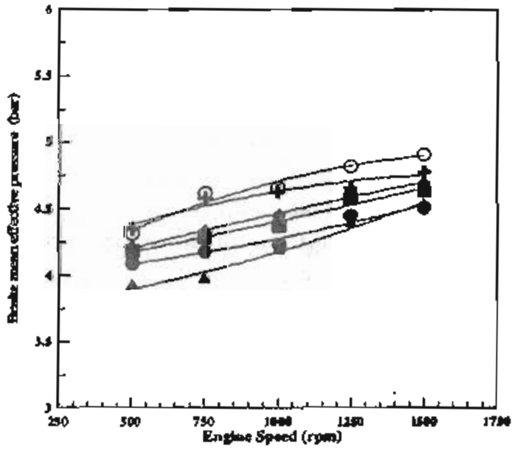

Fig. (7) Brake mean effective pressure versus engine speed

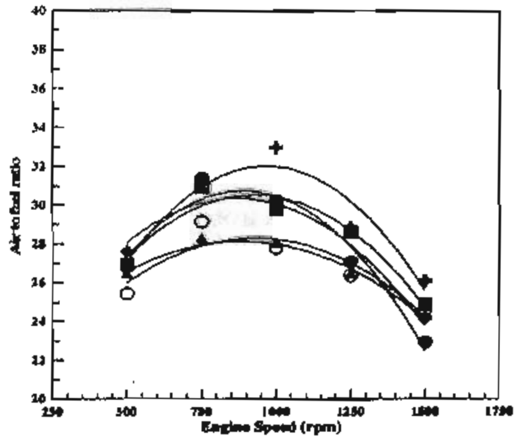

Fig.(8) Air to fuel ratio versus engine speed

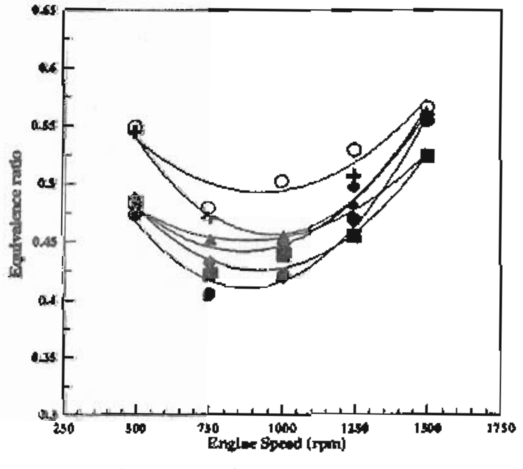

Fig. (9) Equivalence ratio versus engine speed

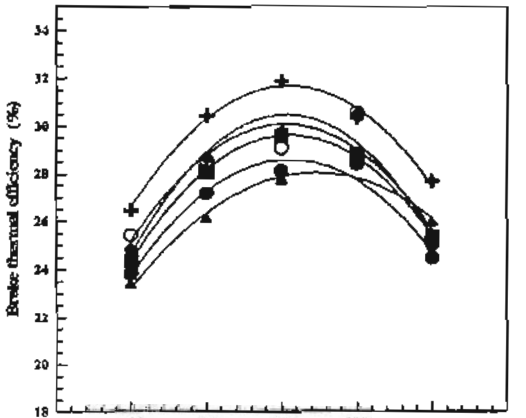

Fig. (10) Brake thermal efficiency versus engine speed

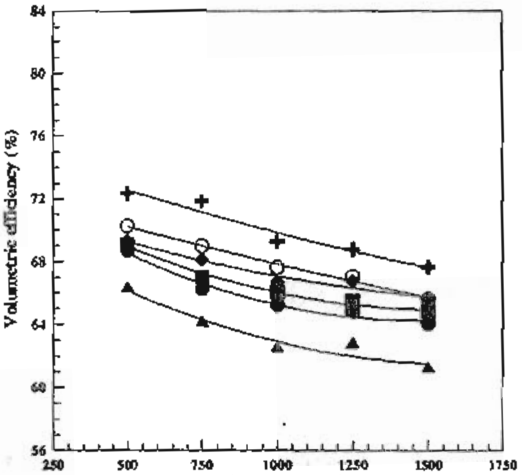

Fig.(11) Volumetric efficiency versus engine speed

4. Conclusions

A 17kW, naturally aspirated, two cylinder, four stroke, direct injection, air cooled Diesel engine with alternator was used to evaluate the performance of Diesel engine using biodiesel from jatropha. The engine was operated successfully using methyl esters of jatropha oil only or at its blends. The following conclusions are made based on the experimental results.

1. Pure biodiesel from jatropha and its blends as a new biofuel can be used in Diesel engines without any engine modifications.
2. Engine works smoothly on jatropha biodiesel with performance comparable to Diesel operation.
3. Biodiesel blends results in a decrease in brake power, the maximum decreases occur for B80 at 750 rpm by 16% as compared to pure Diesel fuel.
4. Using of biodiesel blends leads to a decrease of air to fuel ratio and equivalence ratio by 17% and 25% as compared to Diesel fuel, respectively.
5. Using fuel blends leads to a decrease of brake thermal efficiency by 22% and increase brake specific fuel consumption by 31% which observed for B100 at 1250 rpm, compared with that of neat Diesel fuel.

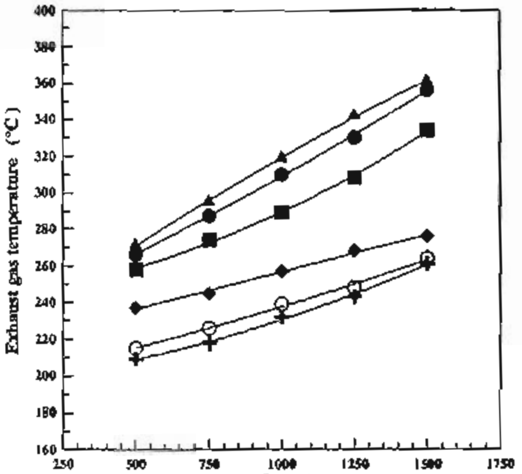

Fig. (12) Exhaust gas temperature versus engine speed

6. Biodiesel blends results in a decrease in volumetric efficiency, the maximum decreases occur for B100 at 750 rpm by 11% as compared to Diesel fuel.
7. The exhaust gas temperature is increased with the biodiesel fuel blends by 34% (over than Diesel fuel) is observed for B100 at 1250 rpm.

5. Recommendations

The investigation can be extended to cover the following aspects:

1. Study the influence of changing the injection pressure on the engine performance.
2. Study the influence of heating the fuel on the engine performance.
3. Study the influence of changing the compression ratio on the engine performance.
4. Examination of lower cost feed stock materials for manufacture of esters, including studies of the transesterification process applied to these feeds.

Nomenclature

Symbols

d	Viscous element tube diameter	(m)
I	Current	(A)
l	Viscous element tube length	(m)
$\dot{m}$	Mass flow rate	(kg/hr)
N	Engine rotational speed	(rpm)
n	Number	
P	Pressure	(kPa)
R	Universal gas constant	(8.3143 kJ/kmol. K)
T	Temperature	(K)
t	Time	(s)
$\bar{u}$	Average air velocity	(m/s)
V	Voltage, Volume	(V), (m^3)

Subscripts and superscripts

air	Air	
act.	Actual	
a.act.	Actual air	
b	Brake	
d	Displacement	
exh.	Exhaust	
f	Fuel	
P	Power	
R	Revolution	(rev./cycle)
st.	Stoichiometric	
th,b	Brake thermal	
v	Volumetric	

Abbreviations

AC	Alternative current	(A)
AFR	Air/fuel ratio	(kg_{air}/kg_f)
BMEP	Brake mean effective pressure	(bar)
BSFC	Brake specific fuel consumption	(kg/kW.hr)
B_P	Brake power	(kW)
DC	Direct current	(A)
FAR	Fuel to air ratio	(kg_f/kg_{air})
L.H.V	Low heating value	(MJ/kg_f)
rpm	Revolution per minute	(rpm)

Greek Symbols

Φ	Equivalence ratio	
ρ	Density	(kg/m^3)
ν	Kinematic viscosity	(m^2/s)
μ	Dynamic viscosity	($N.s/m^2$)
Δ	Difference	
η	Efficiency	(%)

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