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JATROPHA OIL ESTER AND ITS EFFECT ON DIESEL ENGINE PERFORMANCE

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ABSTRACT

Diesel engine 26.12 kW was used to test Jatropha biodiesel and its blends. A pilot plant was designed and built for biodiesel production from different vegetable oils and used for this study. Five biodiesel ratio were tested and compared with diesel fuel. The engine performance was tested under different loads (10, 12.5 and 17.5 kW). The percent of specific fuel consumption increased from 2 to 20 % for B0 to B100 fuels. The brake thermal efficiency for biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions. The exhaust gas temperature increased with increase in load and amount of diesel. The highest exhaust gas temperature was observed as 370 °C for B100 among the three load conditions. The diesel gas exhaust temperature was observed as 420 °C at the highest load. The CO_2 emission was higher than biodiesel fuel B100 by about 11.5% at the highest load. The carbon monoxide reduction by biodiesel was 14, 21 and 12 percent at 10, 12.5 and 17.5 kW load conditions respectively. The NOx emissions from biodiesel was increased by 15, 16 and 17 percent higher than that of the diesel at 10, 12.5 and 17.5 kW load conditions respectively.

INTRODUCTION

Biodiesel is described as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. It is oxygenated, essentially sulfur-free and biodegradable (Yuan *et al.*, 2004). The use of non-edible oils compared to edible oils is very significant because of the increase in demand for edible oils as food and they are too expensive as compared with diesel fuel. Among the various non-edible oil sources, *Jatropha curcas* oil has added advantages like pleasant smell, odorless and can easily mix with diesel fuel. Jatropha oil cannot be used for food or feed because of its strong purgative effect (Corner and Watanabe, 1979). Pramanik (2003) found that the jatropha oil blending up to 40 to 50 percent with diesel fuel could be used in engine without modifications. In general, it has been reported by most researchers that if raw vegetable oils are used as diesel engine fuel, engine performance decreases, CO and HC emissions increase and Nox emissions also decrease accordingly (Sinha and Misra, 1997; Goering, *et al.*, 1992; Altőn, 1998 and Shay 1993). However, Acrolein is high toxic substance released from the engine due to thermal decomposition of glycerol present in the oils (Schwab *et al.*, 1987). The problems encountered in raw oils are solved by forming biodiesel, which is non toxic, eco-friendly fuel, and have similar properties of diesel fuel (Krawczyk, 1996). Biodiesel consists of Fatty Acid Methyl Esters (FAMEs) of seed oils and fats and have already been found suitable for use as fuel in diesel engine (Harrington, 1986). CO_2 emission by use of biodiesel in diesel engines will be recycled by the crop plant resulting in no new addition in to atmosphere (Peterson and Hustrulid, 1998). This study has been initiated to study the properties of jatropha oil to be used as diesel fuel substitutes, investigate the effect of fueling diesel engine with different concentrations of oil/diesel blends on diesel engine performance and compare their impact on gaseous and particulate exhaust emission levels relative to pure diesel oil as a trail to reduce the impact on air quality.

MATERIALS AND METHODS

Pilot Biodiesel Plant

A pilot biodiesel plant was manufactured at Research and Tractor Test Station in Sabahia – Alexandria for biodiesel production from different vegetable oils (Figure 1). The process used in the biodiesel plant was alkaline catalyst based biodiesel production. The biodiesel production capacity of the plant is 400 liters per day and the reaction time per batch is 2 hours. The pilot plant consists of processor with heater and agitating pumps, 1-chemical mixing tank, washing and drying tank.

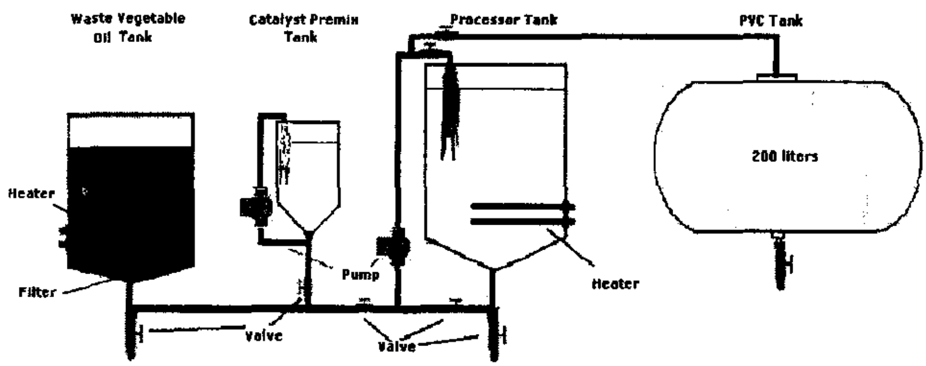

Fig. 1. Pilot biodiesel plant

Moussa, (2003). stated that the fatty acids of the vegetable oil exchange places with the OH group of the alcohol producing glycerol and the methyl ester.

Jatropha curcas and its fatty acids

Jatropha capsules had been brought from Luxor, threshed, oil extracted from seeds then biodiesel had been made by the transestrification process. Fuel structure and characteristics have been shown to have great influence on engine performance and emission behavior (Zumdahl et al.1995 and Goering et al.1982). Ordinary diesel fuel is a mixture of hydrocarbon molecules of differing lengths and structures. These molecules contain no oxygen atoms. They may have double-bonded carbons that cause the chains to bend. The characteristics of the hydrocarbons affect how they burn. Vegetable oils, on the other hand, are mixtures of fatty acids molecules that contain carbon, hydrogen, and oxygen atoms. The fatty acids may be saturated, monounsaturated, or polyunsaturated, length of carbon chains and number of double bonds in the fuel molecules affect low temperature suitability, spray formation and carbon residue Corinna1998.

Jatropha oil typically contains up to 9 different types of fatty acids. Different fractions of each type of fatty acid influence some of the properties of the fuel. Results of fatty acid content analysis of the tested oil are shown in table 1 and reveal the following;

Table (1): Fatty Acid Jatropha curcas oil seed

Oleic 18:1	Linoleic 18:2	Palmitic 16:0	Stearic 18:0	Palmitoliec 16:1	Linolenic 18:3	Arachidic 20:0	Margaric 17:0	Myristic 14:0	Saturated	Monounsat-urated	Polyunsatu rated
44.7	32.88	14.2	7.0	0.7	0.2	0.2	0.1	0.1	21.6	45.4	33

The greater the number of unsaturated double bonds, the more easily the compound reacts with oxygen from the air and deteriorates, while saturated fats turn solid at low temperatures and forms solid crystals plugging fuel lines. (Zumdahl et al.1995 and Goering et. al 1982)

The degree of saturation of the fatty acid governs the quantity of energy contained within. The presence of double bonds in unsaturated fat lowers the energy of the molecule, with respect to a saturated fat, which has only single bonds. The bond energy of a single bond is approximately 3.5 eV and that of a double bond is 6.4 eV. Therefore, the breakdown of two single bonds releases more energy than one double bond (7eV versus 6.4 eV) This confirms that a saturated fat has more energy than unsaturated fats. (Zumdahl et al.1995 and Corinna et al. 1998). Instability increases by a factor of 1 for every C=C bond on the fatty acid chain (Tyson 2001). Because oleic acid has only one double bond, it doesn't react with oxygen as readily as polyunsaturated oils. High levels of saturates (C14:0, C16:0, C17:0, C18:0, C20:0) in jatropha oil tend to improve stability and raise Cetane number (the higher cetane number the higher quality of fuel). (Reid et al 1989) found that some vegetable oil fuels produce injector nozzle cooking when burned in diesel engines with a corresponding 14% reduction in power output.

Manufacturer warranties cover engine problems related to any type of fuel including traditional petroleum diesel. Manufacturers state that fuel must meet certain criteria, which may differ slightly by manufacturer, but basically follow the standards set forth by the American Society for Testing and Materials (ASTM). The standard for diesel fuels is covered under ASTM D975, and for biodiesel under ASTM PS 121. ASTM, 1997.

Fuel Description

After Jatropha seeds were grinded, the powder squeezed to extract its oil, the oil collected and filtered from solid impurities. The Jatropha oil was transesterified using methanol in the presence of Potassium hydroxide in the pilot biodiesel plant. Five biodiesel levels were tested and evaluated in this paper, 20%, 40%, 60%, 80% and 100% of transesterified jatropha oil (B20, B40, B60, B80 and B100) compaed withdiesel fuel(Bo).

The properties of diesel fuel, jatropha biodiesel and its blends are shown in Table 2. ASTM standard procedures were adopted in this analysis.
A series of tests were performed to characterize the properties of the produced biodiesel in Miser Petroleum labs. These properties include Specific gravity (ASTM D 1298), kinematic viscosity (ASTM D 445), heating value (ASTM D 240), flash point (ASTM D93), and carbon residue(ASTM D524) . Biodiesel from jatropha oil was analyzed to determine, specific gravity, kinematic viscosity, calorific value, flash point and carbon residue. These characteristics were evaluated in accordance with ASTM procedures for petroleum products.

Table 2. Fuel properties of jatropha biodiesel and its blends

No	properties	Diesel	Jatropha Biodiesel				
		B0	B20	B40	B60	B80	B100
1	Specific gravity	0.8396	0.8437	0.8482	0.8530	0.8576	0.8621
2	Kinematic viscosity @ 40 °C, cSt	4.86	4.96	5.03	5.14	5.26	5.37
3	Calorific value MJ/Kg	44.42	43.25	42.072	41.139	40.174	39.174
4	Flash point, °C	51	55	76	98	109	174
5	Carbon residue, %	0.21	0.21	0.22	0.22	0.24	0.24

Engine specifications.

Technical specifications of the tractor diesel engine are a 3-cylinder, Helwan 35-IMT of maximum power 26.12 kW at 2200 rpm. The bore x stroke is 105 mm x 125 mm, where the compression ratio is 16:1, engine rated speed 1800 rpm.

Hydraulic dynamometer

The engine power was determined by using a hydraulic dynamometer. The tractor PTO shaft was coupled to the dynamometer for applying loads according to the ASAE Standard of tractor PTO performance at rated engine speed. Some characteristics for hydraulic dynamometer presented as in Table (3).
Torque was measured at rated engine speed and its power was calculated from the following equation:

$$P = \frac{2 \times \pi \times N \times T}{C}$$

Where:
P = Power, kW　　N = Speed of PTO shaft, rpm
T = Torque, N.m.　　C = Conversion constant = 1000

Table 3: The technical specification of hydraulic dynamometer.

Model	Maximum power	Maximum torque	Maximum RPM	Constant torque number
made in the UAS	220 kW	1360 N.m	3500	10

Methodology Adopted for Engine Testing

Engine and Equipment Details

Bio-diesel derived from jatropha oil and pure diesel fuels individually are used to operate an agriculture tractor. The tractor is coupled with hydraulic dynamometer to apply varying loads to engine at rated speed. The dynamometer is equipped with measurement facility of engine speed and brake torque. The five levels of jatropha biodiesel blending at 20, 40, 60, 80 and 100 percent (B20, B40, B60, B80 and B100) with diesel, diesel and biodiesel were used for engine testing. The diesel was tested at different loads by varying the loads 10, 12.5 and 17.5 kW.

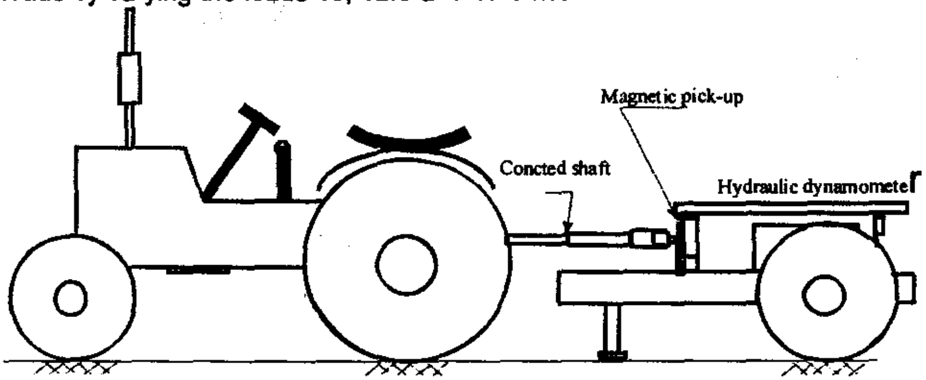

Fig.2: The tractor P.T.O was coupled to the dynamometer for applying loads

The engine speed was measured by a magnetic pick-up mounted to the vertical bar senses the rotation of toothed gear with 120-tooth gear which was attached to the dynamometer. The output signal from magnetic pickup converted to rpm through the daytronic data PAC model 10k4. A separate apparatus in Figure (3) was used to measure fuel consumption. It consisted of a secondary tank of 4.5 liters capacity with a level marked tube and bulb with volume 17 cm^3.

Fuel meter installed and connected to the tractor fuel tank through hoses and two valves. The secondary tank was first filled with fuel to the mark on the top of the tape during the actual run. The tractor was first let go on its fuel from the main tank to measure the fuel consumption during a specific field operation, the secondary tank was utilized through the valves. At the end of the run, the valves were refilled off the secondary tank was refilled to the mark on the tube and amount of refuel was taken as the fuel consumption during the specific operation duration. The elapsed time to consume this amount of fuel was recorded.

Each blend was prepared by using a graduated cylinder 1 liter. After data for a given fuel had been obtained the engine was shut off and the fuel was bled from the fuel system. The engine fuel filter was replaced with a new one after each test. The engine was run for a long time to remove all residual of the previous fuel.

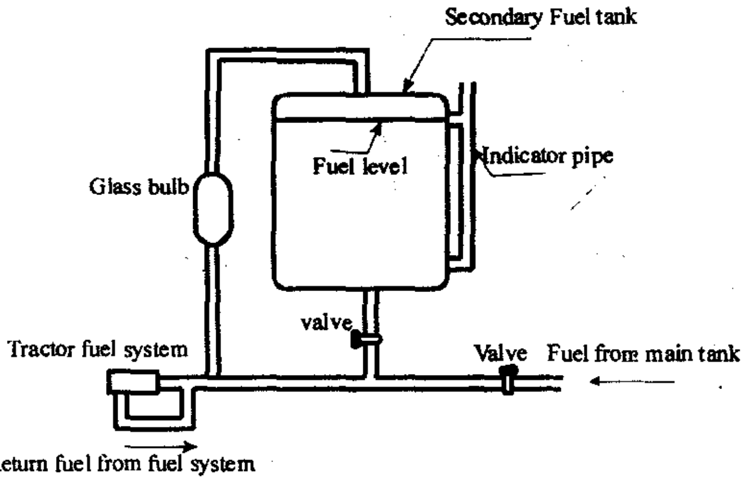

Fig. 3. schematic diagram for local manufactured fuel consumption meter

The emission stack measurement system consisted of a probe to sample gaseous emissions from the exhaust combustion effluents in the stack pipe at a rate of 2.8 L/min connected to a direct reading combustion gas analyzer IMR 1400 (IMR Environmental Equipment, Inc., USA). In each test series CO, NOx, CO_2 concentration, and exhaust gas temperature were recorded. all data were stored Fig. 4.

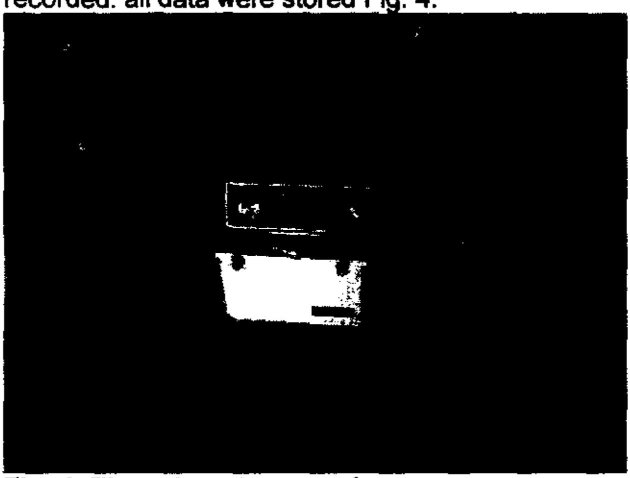

Fig. 4: The exhaust gas analyzer

Data were recorded at 30 seconds intervals during the last two minutes of each test. Baseline data were taken on diesel fuel at 100 percent before fueling with the vegetable oil/diesel fuel blends. The blends of 20, 40, 60, 80 and 100 % were selected for each test. Each blend was tested three times and the data were analyzed using a completely randomized design (CRD). Thermal efficiency was determined from the following formula.

$$Thermal\ Effieciency = \frac{BHP\,x\,60\,x\,60\,x\,75}{F.C\,x\,C.V\,x\,427}\,x\,100$$

Where:

BHP = brake horsepower,hp 427 = Thermal equivalent of fuel, kg.m/Kcal

C.V = Calorific value of fuel, kCal/kg . F.C = fuel consumption, kg/h

Engine Testing

The engine was tested with three load levels *viz.*, 10, 12.5 and 17.5 kW. The engine was started with diesel and changed over to the desired biodiesel blend. The exhaust gas was recorded at different loads.

RESULTS AND DISCUSSION

Biodiesel Production

A pilot biodiesel plant was used to produce biodiesel from jatropha oil for reducing viscosity of raw oil through transesterification process. One hundred liters of jatropha oil was fed into the reactors and a reaction temperature was 55 °C. The chemical tank was used to prepare the Potassium methoxide by mixing of Potassium hydroxide with methanol and supplied to the reactor.

$KOH + CH_3OH \rightarrow KCH_3O + H_2O$

Stirring process was stopped after 1 hour. The reactants mixtures were allowed to settle, so that glycerol will settle at the bottom of the tank by gravity. The jatropha methyl ester was sent to the washing tank to get the pure biodiesel then dried. The fuel properties of the jatropha biodiesel and its blends are analyzed in Misr Petroleum Co.

Biodiesel specifications

In jatropha biodiesel blended fuels increase in amount of diesel fuel showed no effect on specific gravity of fuels. The kinematic viscosity of jatropha biodiesel blended fuels increased with increase in amount of biodiesel level. The viscosity of B20 biodiesel blended fuel was 4.96 cSt which was almost closer to desirable viscosity of diesel fuel (4.86 cSt). The calorific value of blended fuels was improved by addition of diesel fuel in the biodiesel blends. The blended fuels had effect in reducing the flash point of the jatropha oil blended fuels, which indicated the improvement in the volatile nature of the fuels. The flash point of blended fuels was increased with increase in amount of biodiesel in the fuels. Similar trend was observed for carbon residue of blended fuels. The fuel properties of jatropha biodiesel blended fuels met the diesel fuel and biodiesel standards.

Engine Performance

Specific Fuel Consumption

The specific fuel consumption was calculated by fuel consumption divided by the rated power output of the engine. Specific fuel consumption increased from 2 to 20 % for B0 to B100 fuels respectively. The range of increase in fuel consumption was found to be similar under all load conditions. Specific fuel consumption was increased by decreasing the amount of diesel fuel in the blended fuels.

The higher fuel consumption of bio-diesel can be related primarily to the lower-in average by 12.22%-net heating value of biodiesel. However, this is probably not the only reason that leads to the higher bio-fuels consumption in grams per unit energy developed. The lower bsfc can be related, reasonably, to the higher amounts of oxygen present in the considered blends. Fuel based oxygen, because of its indigenous property, accelerates reactions from within the extremely fuel rich spray patterns themselves, leading to more complete combustion, figure 5.

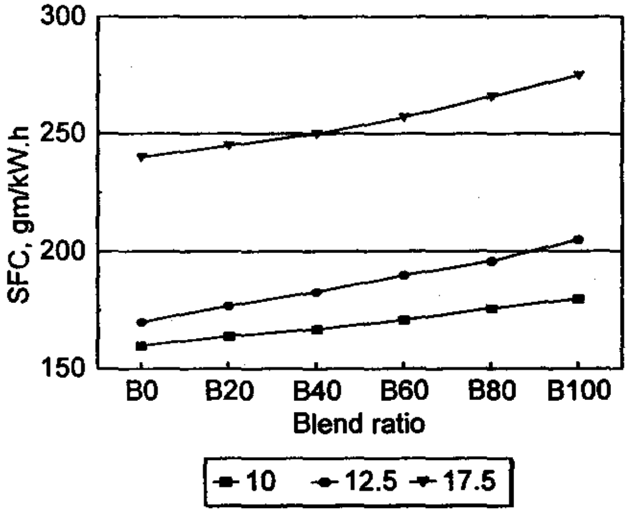

Fig.. 5. Biodiesel percentage as effecting on break specific fuel consumption at three different loads

Brake Thermal Efficiency

According to Canakci and Van Gerpan, (2001) brake thermal efficiency is defined as actual brake work per cycle divided by the amount of fuel chemical energy as indicated by lower heating value of fuel. Results indicated that the brake thermal efficiency with biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions. It varied from 28.6 to 33.0 percent for diesel fuel alone. There was no difference between the biodiesel and its blended fuels on efficiencies. The brake thermal efficiencies of engine, operating with biodiesel mode were 28.8, 30.6 and 33.1 percent at 10, 12.5 and 17.5 kW load conditions respectively.

Exhaust Gas Temperature

The exhaust gas temperature gives an indication about the amount of waste heat going with exhaust gases. The exhaust gas temperature of the different biodiesel blends is shown in Figure. 6. The exhaust gas temperature of blended fuels and biodiesel at 17.5 kW load condition was 19 percent higher than that of 10 to 12.5 kW load conditions. The highest exhaust gas temperature was observed as 420 °C for diesel at load 17.5 kW load conditions. The raise in exhaust gas temperature of 17.5 kW load followed similar trend for blended fuels. The biodiesel fuel B100 mode exhaust gas temperature was observed as 370 °C at 17.5 kW load condition. Fuel structure and characteristics have been shown to have great influence on engine performance and emission behavior. Zumdahl (1995); and Goering et.al., (1982). Ordinary diesel fuel is a mixture of hydrocarbon molecules of differing lengths and structures. These molecules contain no oxygen atoms. They may have double-bonded carbons that cause the chains to bend. The characteristics of the hydrocarbons affect how they burn.

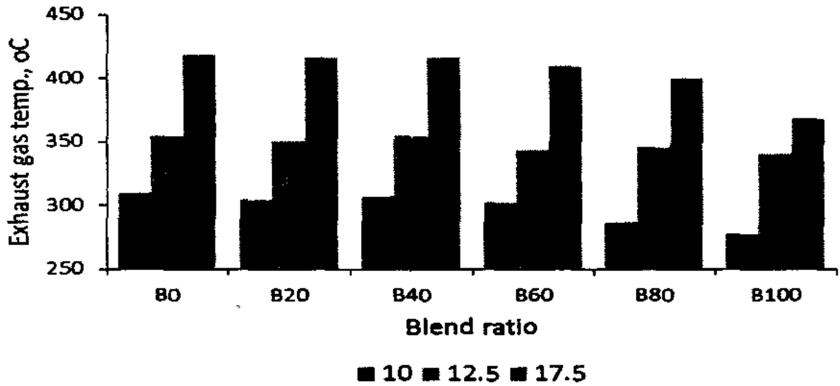

Fig. 6. Variation of exhaust gas temperature in diesel engine fuelled with different blended fuels

The exhaust gas temperature increased with increase in load and decreasing amount of biodiesel blends. The reason for raise in the exhaust gas temperature may be due to the higher relative density and lower energy density of B20. The net calorific value of the bio-diesel used is about 12.22% lower than that of diesel fuel where the exhaust temperature served as an indicator of the combustion temperature relating to heat release, which is related to fuel calorific value that would be lower in the case of bio-diesel. The exhaust gas temperature reflects on the status of combustion inside the combustion chamber (Nichaus *et al.*, 1986).

Emission profile

Carbon Dioxide (CO_2) Emission

The carbon dioxide emission from the diesel engine with different blends is shown in Figure 7. The CO_2 increased with increase in load conditions for diesel and for biodiesel blended fuels. The diesel followed the same trend of CO_2 emission, which was higher than in case of jatropha biodiesel. Burning biodiesel also produces CO_2, but in a full production-to-consumption system, plants recycle CO_2 to grow and produce more vegetable oils required as feedstock for biodiesel production. Therefore, much of the CO_2 production in biodiesel combustion is considered to be offset by CO_2 uptake by plants in the process of photosynthesis (Peterson et al. 2002).

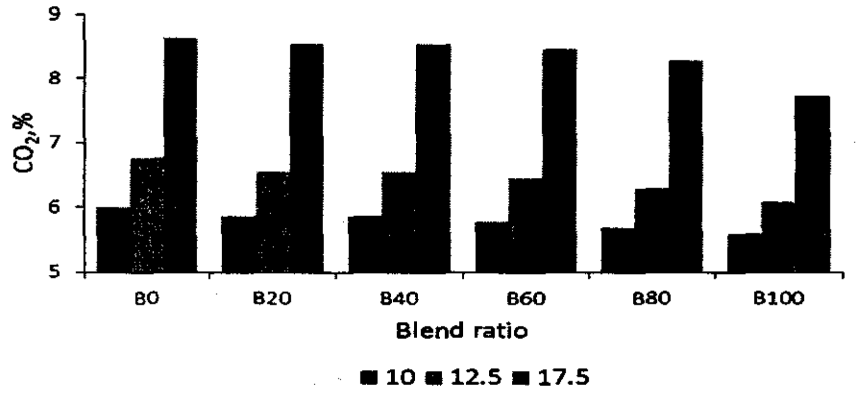

Fig. 7. CO_2 emission from diesel engine with different blended fuels

Carbon Monoxide (CO) Emission

The CO emission from the diesel fuel with biodiesel blended fuels and biodiesel is shown in Figure 8. The CO reduction by biodiesel was 16, 14 and 14 percent at 10, 12.5 and 17.5 kW load conditions respectively. With diesel fuel mode the lowest CO was recorded as 520 ppm at 17.5 kW load and as load decreased to 10 kW, CO also increased to 898 ppm. Similar results were obtained for biodiesel blended fuels and jatropha biodiesel with lower emission than diesel fuel. The amount of CO emission was lower in case of biodiesel blended fuels and biodiesel than diesel because of the fact that biodiesel contained 11 percent oxygen molecules. This may lead to complete combustion and reduction of CO emission in biodiesel fuelled engine.

NOx Emission

The NOx emission from engine with different jatropha biodiesel blended fuels and biodiesel is shown in Figure 9. The NOx emission increased for biodiesel by 15, 18 and 19 percent higher than diesel fuel at 10, 12.5 and 17.5 kW load conditions respectively. The percentage of increase in NOx concentration for blended biodiesel fuels were observed as 6.6 to 19 percent when compared with diesel fuel. The NOx emission increased with increase in biodiesel amount in the blended fuels and also found that NOx emission from the biodiesel fuel was higher than that of diesel. Probable reasons for increase in NOx concentration was due to higher oxygen level in the fuel and type of engine (Anonynous.,1993). Forgiel and Varde (1981) observed that the NOx concentration depended on the size of orifice. They reported that the NOx increased when the size of the orifice was reduced. Heywood (1988) reported that the NOx formation depended on combustion temperature and availability of oxygen. Fosseen and Goetz (1993) reported that the NOx concentration can be reduced by advancing the beginning of injection time by 0-3°. However, the increase in NOx concentration is the main problem in biodiesel and it can be reduced by making suitable change in the engine parameters.

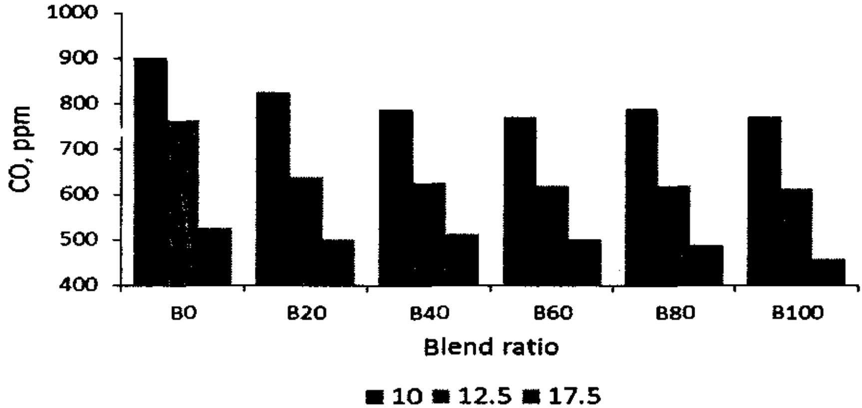

Fig. 8. CO emission from diesel engine with different blended fuels

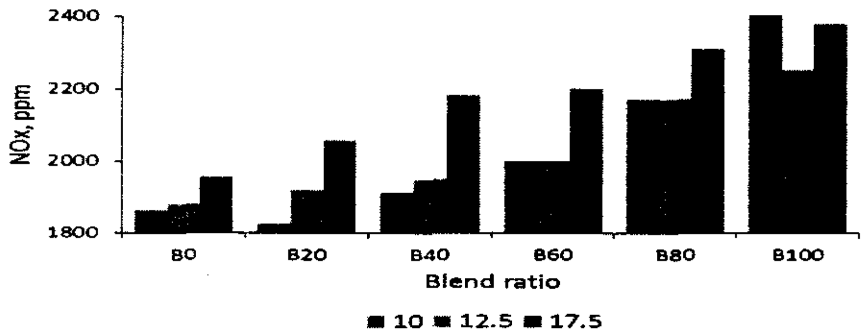

Fig. 9. NOx emission from diesel engine with different blended fuels

Conclusions

A 26.12 kW diesel engine with Dynamometer was used to test *Jatropha curcas* biodiesel and its blends and compared with conventional commercial diesel fuel. A biodiesel pilot plant was developed and used for biodiesel production from jatropha oil. The fuel properties of jatropha biodiesel were found to be similar to the diesel fuel. In the case of jatropha biodiesel alone. Specific fuel consumption increased from 2 to 20 for B0 to B100 fuels respectively. The brake thermal efficiency for biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions and there was no difference between the biodiesel and its blended fuel efficiencies. The exhaust gas temperature increased with increase in load and amount of diesel. The carbon monoxide reduction by biodiesel was 16, 14 and 14 percent respectively at 10, 12.5 and 17.5 kW load conditions. The NOx emission from biodiesel was increased by 15, 18 and 19 percent higher than that of the diesel fuel at 10, 12.5 and 17.5 kW load conditions respectively.

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تأثير الوقود الحيوي من زيت نبات الجاتروفا على اداء محرك الديزيل

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معهد بحوث الهندسة الزراعية – مركز البحوث الزراعية

استخدم جرار قدرته ٢٦.١٢ كيلووات لاختبار الوقود الحيوى المستخلص من زيت نبات الجاتروفاعند نسب خلط مختلفة مع وقود الديزل. صممت وحدة لإنتاج البيوديزل من الزيوت النباتية بمحطة ابحاث واحتبار الجرارات والالات الزراعية بالاسكندرية يسع لانتاج ٤٠٠ لتر من الوقود الحيوى يوميا. يتكون الجهاز من سخان كهرباء وطلمبة تقليب وخزان لخلط للمواد الكيميائية وخزان غسيل.استخدمت خمس مستويات من الوقود الحيوى المخلوط مع سولار بنسب ٢٠%، ٤٠%، ٦٠%، ٨٠%، ١٠٠% لاختبار الوقود الحيوى ومقارنتة بوقود الديزل بواسطة جهاز لختبار القدرة على عمود الإدارة الخلفي للجرارات الزراعية (هيدروليك ديناموميتر) عند احمال من ١٠، ١٢.٥، ١٧.٥ كيلووات .

نسبة الزيادة في معدل استهلاك الوقود الحيوى تتراوح بين ٢، ٢٠% أكثر من معدل استهلاك عند استخدام السولار. ووجد ان اقل زيادة لمعدل استهلاك الوقود كان عند نسبة ٢٠% من الوقود الحيوى. الكفاءة الحرارية للوقود الحيوى عند نسب الخلط المختلفة مع وقود الديزل زادت قليلا عن وقود الديزل منفردا عند الاحمال المختلفة.

درجة حرارة العادم زادت بزيادة الحمل وزيادة نسبة وقود الديزل. أعلي درجة حرارة لغازات العادم مع وقود البيوديزل ٣٧٠°م عند أعلي حمل. بينما درجة حرارة العادم في حالة وقود الديزل ٤٢٠ °م عند أعلي حمل. نسبة ثانى اوكسيد الكربون المنبعثة من احتراق الوقود الحيوى اقل من المنبعثة من احتراق وقود الديزل. بينما انخفضت نسبة اول اوكسيد الكربون عند استخدام الوقود الحيوى بنسبة ١٦، ١٤، ١٤ % عند احمال ١٠، ١٢.٥، ١٧.٥ كيلووات وزادت نسب اكاسيد النتروجين المنبعثة من احتراق الوقود الحيوى بمقدار ١٥، ١٨، ١٩% اكثر من احتراق وقود الديزل عند احمال ١٠، ١٢.٥، ١٧.٥ كيلووات على الترتيب.

قام بتحكيم البحث

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