Engine performance and emission of a diesel engine operating on waste cooking oil biodiesel

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In this research waste cooking oil from restaurants was used to produce pure biodiesel through transesterification, and this converted biodiesel was then used to prepare biodiesel/diesel blends. Experiments were performed on a four strokes, six cylinder, direct injection, and naturally aspirated diesel engine operating on 5%, 10%, 20% and 30% blends with Diesel fuel. The purpose of this research is to investigate the effects of waste oil biodiesel inclusion in diesel fuel on the brake specific fuel consumption (bsfc) of a high speed diesel engine, its brake thermal efficiency, emission concentrations changes and temperature of the exhausts. At a higher speed of 1800 rpm, the bsfc of the fully loaded engine for the B20 blend is nearly the same as that for diesel fuel, whereas B30 suggests that bsfc is higher by 11.65%. The bsfc of blend B5 appeared to be nearly the same as that of blend B10, both of them having lower bsfc by 2.9% relative to Diesel fuel. The brake thermal efficiency depends actually on both the biodiesel inclusion percent in the diesel fuel and the engine performance conditions. The results indicate that higher than 10 vol % of biodiesel in diesel fuel lowers the fuel energy conversion efficiency for the biofuel. Emissions of NOx appear to increase with increasing biodiesel concentration in the blend, and at the highest load point, the biggest CO emission of 0.08 % vol was measured for diesel fuel, and the lowest of 0.05 % vol was obtained for blend B30,indicating more complete combustion with increasing biodiesel concentration in the blend due to its oxygenated nature.

فى هذا البحث تم إستخدام زيوت نباتية مستعملة ناتجة من المطاعم لإنتاج الوقود الحيوى ناتج من عملية Transestrification وقد تم تجهيز وعمل خليط بنسب مختلفة من الوقود الحيوى مع وقود الديزل.تم إجراء تجارب على آداء محرك ديزل رباعى الأشواط ٦ أسطوانات مع خليط الوقود الحيوى بوقود الديزل بنسب ٥&١٠&٢٠&٣٠%.الغرض من هذا البحث هو إختبار تأثير الوقود الحيوى مع محرك ديزل على الإستهلاك النوعى للوقود والكفاءة الحرارية ونواتج العادم ودرجة حرارته. وجد من النتائج المعملية عند سرعة دوران ١٨٠٠ لفة فى الدقيقة للمحرك وعند الحمل الكامل أن الإستهلاك النوعى للمحرك عند خليط ٢٠% من الوقود الحيوى مساوى للإستهلاك النوعى لوقود الديزل.بينما عند إستخدام وقود مكون من ٣٠% وقود حيوى والباقى وقود ديزل وجد أن الإستهلاك النوعى أعلى بمقدار ١١,٦٥% من الإستهلاك النوعى لوقود الديزل.الإستهلاك النوعى للوقود عند ٥% نسبة خلط للوقود الحيوى لوقود الديزل تقريبا مساوى الإستهلاك النوعى للوقود عند نسبة خلط ١٠% وقود حيوى وكلاهما له إستهلاك نوعى للوقود منخفض بمقدار ٢,٩% مقارنة مع وقود الديزل.القيمة الحرارية للوقود تعتمد على نسبة الوقود الحيوى فى وقود الديزل وظروف آداء المحرك.كما أوضحت النتائج الأتى:الأكاسيد النيتروجينية تزداد بزيادة تركيز الوقود الحيوى فى وقود الديزل.عند أقصى حمل أعلى قيمة لأول أكسيد الكربون ٠,٠٨% (بالحجم) عند إستخدام وقود الديزل وأقل قيمة ٠,٠٥% (بالحجم) عند إستخدام وقود مكون من ٣٠% وقود حيوى مع وقود الديزل.أفضل إحتراق تام يكون عند زيادة تركيز الوقود الحيوى فى الخليط وهذا يرجع إلى وجود الأكسجينفى مكون الوقود الحيوى.

Keywords: Bio, Diesel, Transesterification-waste oil, Jatrophia curcas, Edible and non edible oils

1. Introduction

Biomass fuels- created by synthesis and obtained from recycled, plants or plants to be used again- is the fourth energy carrier in the world after oil, natural gas and coal. This fuel includes wood, straw, sugarcane residue, rice husks, municipal solid waste as well as edible and non-edible oil derived from seeds of vegetable plants. Biomass accounts for 3.2%of the primary energy consumption in US and 18% in Sweden, [1]. Globally, the usage of environment friendly fuel is being encouraged. Energy extracted from biomass is perhaps the oldest source of renewable energy. The most important bio-fuels generated from biomass are bio-diesel, bio-gasoline and bio-ethanol. Vegetable oil can be directly used in a diesel engine but only for short periods. It contains mixture of molecules with differing degrees of saturation that polymerize the engine oil. Engine performance problems encountered by using raw vegetable oil include poor atomization, chocking of nozzles, thermally unstable, higher viscosity, high amount of gum and wax, low heating value and make knocking and starting problems, [2]. Usta et al., [3] showed that tobacco seed oil methyl ester can be partially substituted for the diesel fuel at most engine operating conditions without any engine modification or preheating of the bio-diesel blended fuel. In Egypt, scientists are devoting good deal research effort to produce economical bio-diesel fuel from non edible vegetable plants as Jojoba, [4] and Jatrophia Curcas, [5], besides the source of waste vegetable oils.

The major chemically bounded oxygen component in the biodiesel fuel has the effect of reducing the pollutant concentration in exhaust gases due to better burning of the fuel in the engine [6]. Exhaust emissions of diesel engines operating on neat biodiesel and its blends with diesel fuel have been reported in numerous studies [7–14]. In many investigations, reductions in Carbon Monoxide (CO), Total Hydrocarbons (THc), and Particulate Matter (PM) emissions and smoke, along with increases in oxides of nitrogen (NO_x), have been determined in the exhausts. For example, Labeckas and Slavinskas [8] studied the effect of Rapeseed Oil Methyl ester (RME) on a four stroke, four cylinder, direct injection diesel engine operating on neat RME and its 5%, 10%, 20% and 35% blends with diesel fuel. Their results showed that maximum NO_x emissions increase with increased mass percent of oxygen in the biofuel and increased engine speeds. The carbon monoxide emissions and visible smoke emerging from the biodiesel overall load and speed ranges are lower by up to 51.6% and 13.5% to 60.3%, respectively. Carbon dioxide emissions, along with fuel consumption and gas temperatures, are slightly higher for the B20 and B35 blends and neat RME. Emissions of unburned hydrocarbons for all biofuels are low.

For the fully loaded John Deere 4276T engine[15], the Nitrogen oxides increase by 11.6% for the yellow grease methyl ester and by 13.1% for the soybean oil methyl ester, while the CO_2 emissions increase by 1.2% and 1.8%, respectively, along with significantly lower CO (17.8% and 18.2%), unburned HC (46.3% and 42.5%) and smoke (SN 0.38 and 0.41) [15]. Tests conducted in a John Deere 4276T four cylinder, four stroke, direct injection diesel engine operated on two different soybean methyl esters, one of which had been deliberately oxidized, and with their 20% blends with diesel fuel proved that the smoke number, CO and HC were decreased by 8% to 63%, 2% to 29% and 3% to 60%, respectively, while the NOx emissions increased by 0.5% to 18% [16].

In this study, wasted cooking oil from restaurants was used to produce neat biodiesel through transesterification, and this converted biodiesel was then used to prepare biodiesel/ diesel blends. Physical and chemical properties of oil are measured and compared with that of diesel fuel in Miser Petroleum labs are preseted in Table.1.The goal of this study was to compare the trace formation from the exhaust tail gas, and the engine performance of a four stroke ,six-cylinder, 4730 c.c. diesel engine using the different fuel type: biodiesel/diesel blends, and normal diesel fuels. Trace formation from the biodiesel fuel is compared to the trace formation of tradition petroleum diesel. The formation of HC, CO, CO2, NOx, SO2, and particulate matter are also investigated and discussed. The differences between trace formations from various engine speeds are also discussed.

2. Materials and methods

In this study wasted cooking oil from restaurants was used to produce pure biodiesel through transesterification, and this converted biodiesel was then used to prepare biodiesel/diesel blends. The production of the Methyl Ester of Waste Vegetable Oil [MEWVO] for use as a bio-diesel fuel has been studied. Experiments have been performed to determine the optimum conditions for the preparation of MEWVO, namely, room temperature 25 °C; 0.5-0.6 % sodium hydroxide catalyst by weight of waste vegetable oil; stirring time 60 minutes, agitation was not necessary after the reaction mixture became homogeneous, 60 min; absolute methanol was necessary for high conversion. 50% excess methanol with $NaOCH_3$ gave a maximum conversion.

A series of tests were performed to characterize the properties of the produced biodiesel in Miser Petroleum labs, as shown in table 1. These properties include density (ASTM D 1298), kinematic viscosity (ASTM D 445), cetane number (ASTM D 976), pour point (ASTM D 5985), and gross heating value (ASTM D 240).

The biodiesel used in the fuel blended testing in this study was fuel produced from recycled cooking oil. The percentages of biodiesel that were tested were: 5% (B5), 10% (B10), 20% (B20), and 30% (B30). In addition, neat diesel fuel (B0) was tested to establish the 0% biodiesel blend point.

The experiments were carried out on a six-cylinder, four-stroke-cycle 4730 c.c. direct injection diesel engine (F Perkins LTD Peterborough). The engine characteristics are cited in table 2. The emission tests were performed at engine speeds ranging from 1000 to 2000 rpm, increasing in 200 rpm increments. The amounts of carbon monoxide CO (vol %) and dioxide CO_2 (vol %), nitric oxides NOx (ppm), residual content of oxygen O2 (vol %) in the exhaust, as well as the amounts of unburned hydrocarbons HC(ppm) emissions were measured with the techno-test emission analyzer model 488. The instantaneous speed (rpm) of a revolving shaft is measured with a tachometer of harding type, Heenab and Froude Ltd,with a maximum range of 4000 RPM, minimum range of 500 RPM, Sensitivity of 20 rpm ,and uncertainty of 0.5%. The rate of fuel consumption was measured by using calibrated burette and stop watch (±0.1 seconds). A fixed volume of fuel (50 c.c.) was consumed by the engine. The engine was coupled to a hydraulic dynamometer of the Froude type to measure the torque acting on the engine with a maximum load of 100 IB, minimum load of 0.5 IB, and uncertainity of 0.5%.

Table 1
Major properties of premium diesel and biodiesel used in the present study

parameter	Neat waste oil bio diesel (B100)	Diesel fuel	Test method
Relative density at 23 °C (g/mL)	0.8978	0.873	ASTM D 1298
Kinematic viscosity at 40 °C (cSt)	3.52	3.3	ASTM D 445
Cetane number	51.2	47	ASTM D 976
Pour point, °C	-3	2.8	ASTM D 5985
Heating value MJ/kg	42.66	45.819	ASTM D 240

Table 2
Engine specifications

type	4-cycle, water-cooled diesel
Combustion	Direct
Aspiration	Natural
Rated power	76 hP at 2000 rpm
Cylinders	6, V type
Ore x stroke	88.9 × 127 mm
Piston displacement	4730 c.c.
Compression ratio	15:1

3. Test results and analysis

Graphs of the brake specific fuel consumption (bsfc) in kg/kW.h as a function of load obtained during engine operation on B100, Diesel fuel and their blends at speeds of 1200 and 1800 rpm have been superimposed as shown in fig. 1. As is obvious from the figures, the bsfc values decrease gradually with the load to levels that depend on the engine rotation speed and the biofuel used, remaining at the highest level for B30. In spite of the different calorific values, the fuel blends B5 and B10 maintain, at low loads, about the same bsfc as that of diesel fuel, whereas the B20 and B30 blends recorded higher bsfc than diesl fuel. The higher fuel consumption of the B20 and B30 blends can be related primarily to the lower, on average by 4.25%, net heating value of pure recycled biodiesel (B100) table 1, whereas The blend B10 suggest the bsfc is lower by 5.5% at the higher load point. The lower bsfc can be related, reasonably, to the higher amounts of oxygen present in the considered blend. Fuel based oxygen, because of its indigenous property, accelerates reactions from within the extremely fuel rich spray patterns themselves, leading to more complete combustion at low speed.

At a higher speed of 1800 rpm, the bsfc of the fully loaded engine for the B20 blend is nearly the same as that for Diesel fuel, whereas B30 suggest the bsfc is higher by 11.65%. The bsfc of blend B5, which differs itself as having the lowest, amount of oxygen, appeared to be nearly the same as that of blend B10, both of them having lower bsfc by 2.9% relative to Diesel fuel. This result indicates a diminishing role of fuel oxygen at high speed and, hence high air–fuel mixture turbulence intensity, allowing residual air borne oxygen to be available at the final combustion stages. The higher fuel consumption of the blend B30 can be related primarily to the lower, on average by 4.25%, net heating value of pure recycled biodiesel (B100), table 1. The rapid increase in bsfc for highly concentrated bio diesel blends could possibly be reduced or eliminated after investigation of the effect of fuel injection timing advance, needle valve opening pressure and the spray parameters [8].

For further analysis, the brake thermal efficiencies as a function of load for the diesel engine operating on diesel fuel and their blends have been superimposed as shown in fig. 2. At speed of 1800 rpm, during engine transition from part to full load operation, the brake thermal efficiency increases with load up to bp = 28 kW, reaching the top efficiency values of 0.231, 0.2404 and 0.2374 for diesel fuel B0 , B5 and B10 blends, respectively. Here are seen, probably, the most visible disadvantages of the B20 and B30 blends. Although those thermal efficiencies increase smoothly with load, they tend to converge to the one obtained under neat diesel operation. The latter indicate that higher than 10 vol% of biodiesel in diesel fuel lowers the fuel energy conversion efficiency for the biofuel.

In order to learn more about this situation, it was decided to test for the speed dependencies of the maximum brake thermal efficiency values as a function of percentage of biodiesel premixed into Diesel fuel. As it follows from the analysis of the curves in fig.3, the maximum values of the brake thermal efficiency increase with biodiesel concentration in the blend up to a degree that at every particular speed, tends to be a bit different. Test results indicate, evidently, that the fuel energy conversion efficiency starts to decline rapidly when the mass percent of biodiesel in diesel fuel exceeds 10% by volume, and this result is true for all loads and speeds tested. These results can be related to oxygen percent in the blend, where it loses its positive influence on the fuel energy conversion efficiency when the percent of biodiesel in Diesel fuel exceeds 10% by volume;and these results are matched with those obtained by Labeckas and Slavinskas [8]. Because of the different structures of biodiesel, its evaporation proceeds at much high temperatures than those of diesel fuel. The higher flash point, poor volatility and flammability may have an influence on the auto-ignition and combustion processes of biofuels.

This is especially important at high speeds where the extent of evaporation and the combustion processes actually play a key role. Because the operating conditions of the diesel engine could not have been optimal for all biodiesel blends at all loads and speeds, the fuel energy conversion efficiency in our tests appeared as rather being dependent on the content of biofuel premixed into the Diesel fuel [17].

The carbon monoxide CO emissions as a function of load (kW) for biofuels are presented in fig. 4. In spite of the overall fuel lean mixture, typical for the easy load operation, poor atomization and uneven distribution of small portions of fuel across the combustion chamber, along with a low gas temperature, may lead to local oxygen deficiency and incomplete combustion. That could be the answer as to why CO emissions tend to increase for the easy loaded engine.

At the highest load point, the biggest CO emission of .08 % vol was measured for Diesel fuel, and the lowest of .05 % vol was obtained for blend B30. Reduced CO emissions were maintained, probably, thanks to the oxygen inherently present in biofuels, which differs as having the highly acceptable feature of being right "on the spot", facilitating the combustion of big fuel portions. In contrast to air borne oxygen, the fuel based oxygen accelerates the combustion process from within the fuel rich spray patterns themselves.

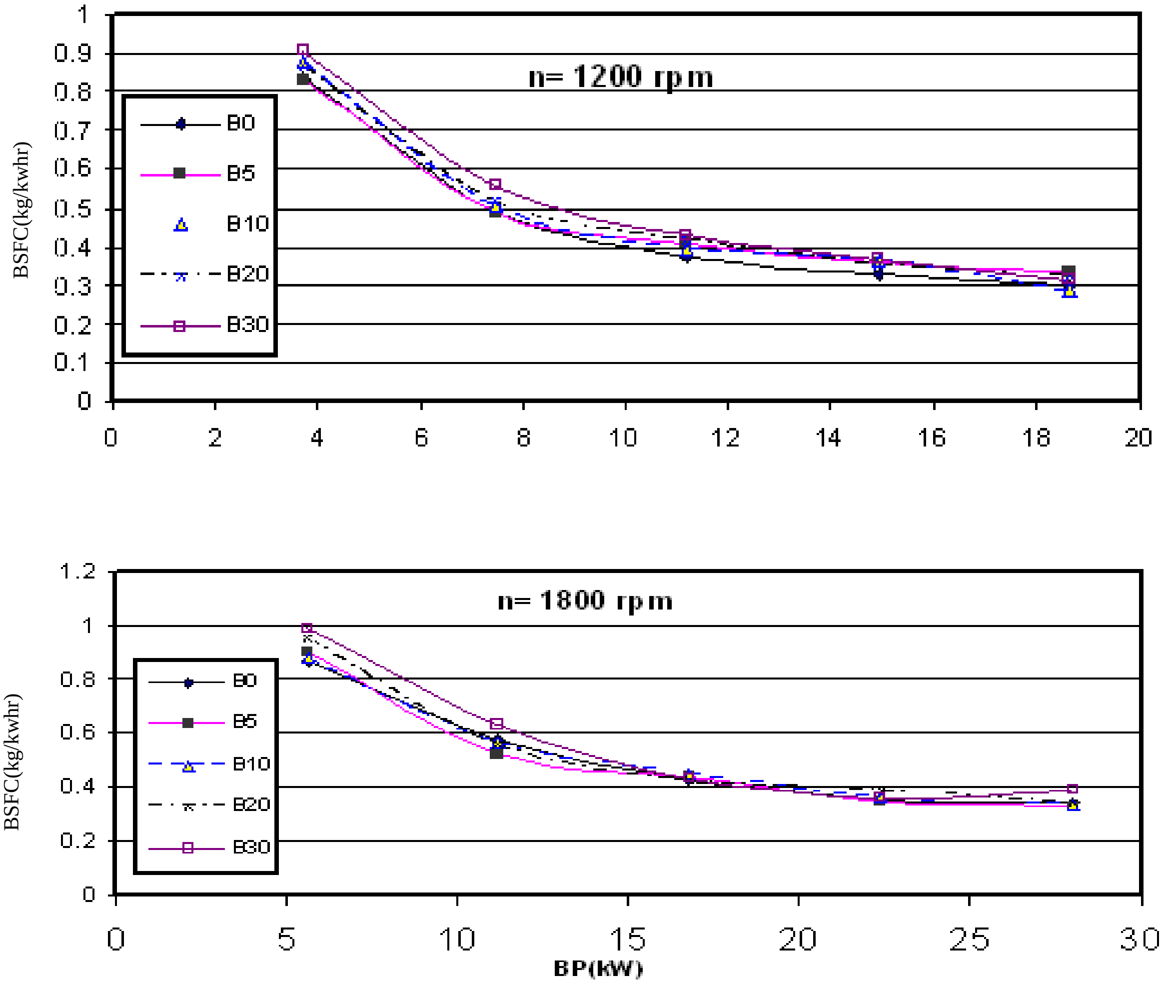

Fig. 1. The brake specific fuel consumption (bsfc) as a function of engine load (kW) at various rotational speeds (n).

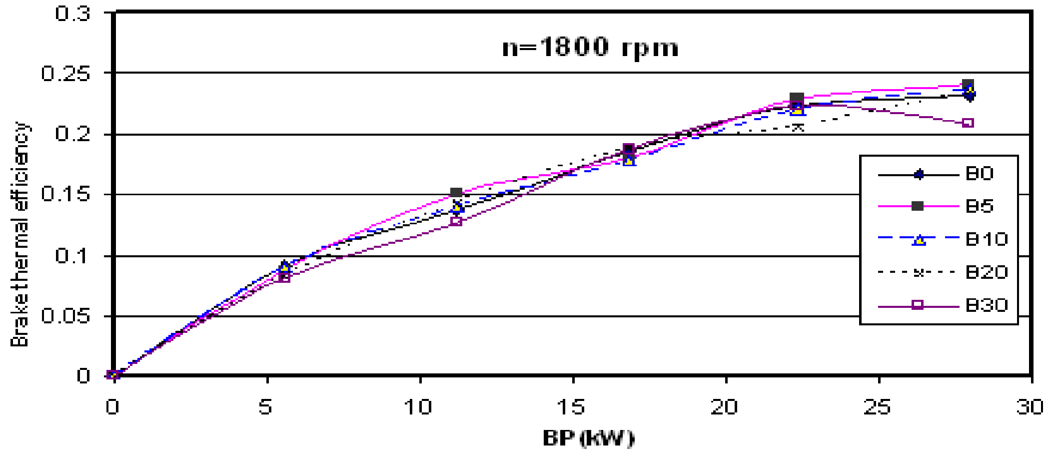

Fig. 2. The brake thermal efficiency as a function of engine load (kW).

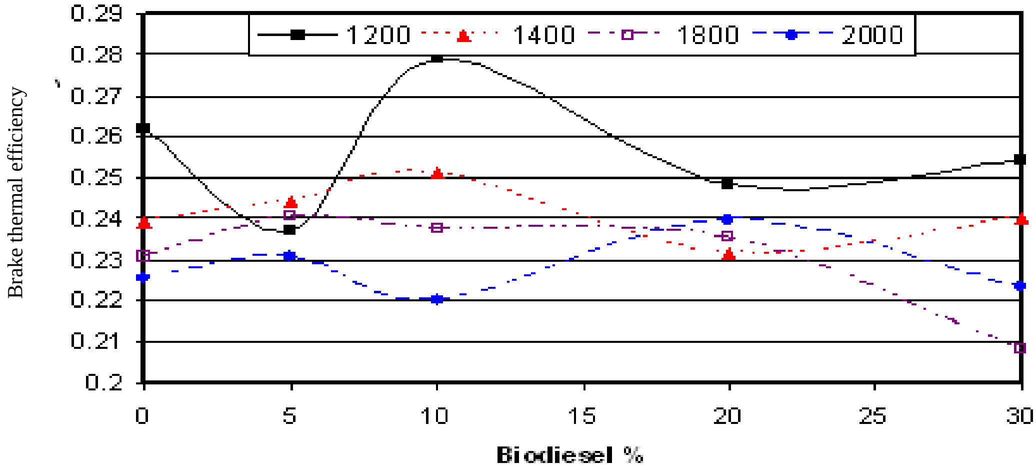

Fig. 3. Dependencies of the maximum brake thermal efficiency on percentage of biodiesel premixed into diesel fuel at various engine speeds.

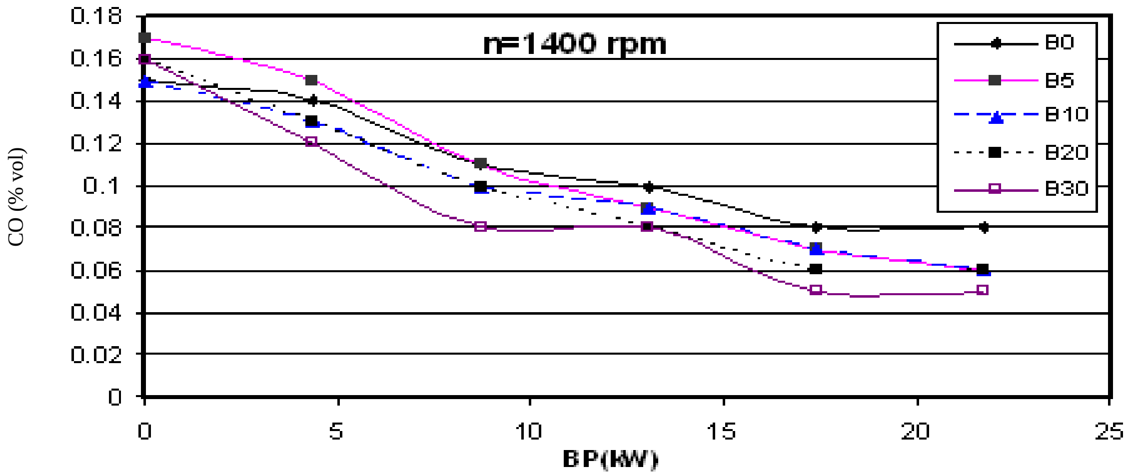

Fig.4. Carbon monoxide emissions as a function of load (kW).

At high revolutions and high radial turbulence intensity in the combustion chamber, the mixing of the fuel rich portions with ambient air should improve. On the other hand, the duration of the combustion process expressed in units of time becomes limited too, which results in only a slight CO emission decrease with Diesel speed. At high speed, the positive effect of biodiesel blends on CO emissions remains, without undergoing significant changes.

Fig. 5 shows that the emission of unburned hydrocarbons HC for all blends is lower than that of diesel fuel except for B10, increasing slightly with load and proportion of fuel injected. This is primarily due to the fact that biodiesel contains more oxygen, which helps to oxidize these combustion products in the cylinder.

The results obtained at constant-speed operation showed that the diesel fuel operation recorded lower exhaust temperatures than all blends at all loads as shown in fig. 6. This behavior may be related to the oxygenated nature of biodiesel which will lead to more complete combustion and so higher exhaust gas temperature at low speeds. At higher speeds the exhaust temperature of all blends decrease than diesel fuel as shown in fig.6. This may be related to the higher relative density and lower energy density of biodiesel, where the oxygen content loss its positive effect at high speeds, and the effect of heating value is the dominant because the volumetric efficiency at higher speeds is greater than that at low speeds, where the engine used was natural aspirated direct injection, and the air flow was controlled by means of a throttle valve.

The mechanism of NO_x formation from atmospheric nitrogen has been studied extensively and it is accepted that it is highly dependent upon temperature, due to the high activation energy needed for the reactions involved. Hence the most significant factor that causes NOx formation is high combustion temperatures. Nitrogen oxides (NOx) emissions during test cycle are shown in fig. 7, where an overall increase can be observed as load increase. This is probably due to the increase in the combustion temperature inside the cylinder. As shown, almost every biofuel produced higher amounts of NOx than conventional diesel, which has been well documented [17, 18]. It has been proposed that certain injection systems suffer an unexpected advance of fuel injection timing caused by the higher bulk modulus of compressibility in the fuel blends containing biodiesel. This increases the speed of sound, causing a faster transference of the pressure wave from the injection pump to the nozzle, thereby advancing the needle lift. It is well known that advancing injection timing causes an increase in NOx emissions [19, 20].

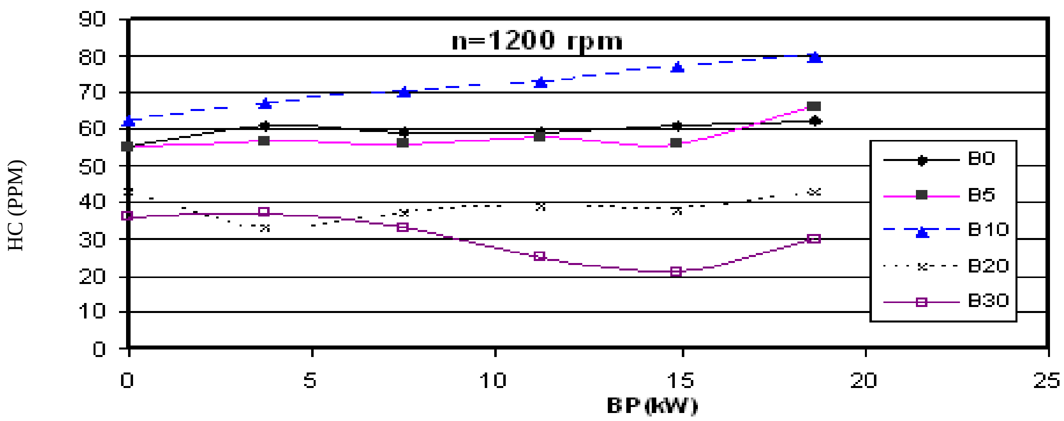

Fig. 5. Hydrocarbons emissions in Diesel exhausts as a function of load (kW).

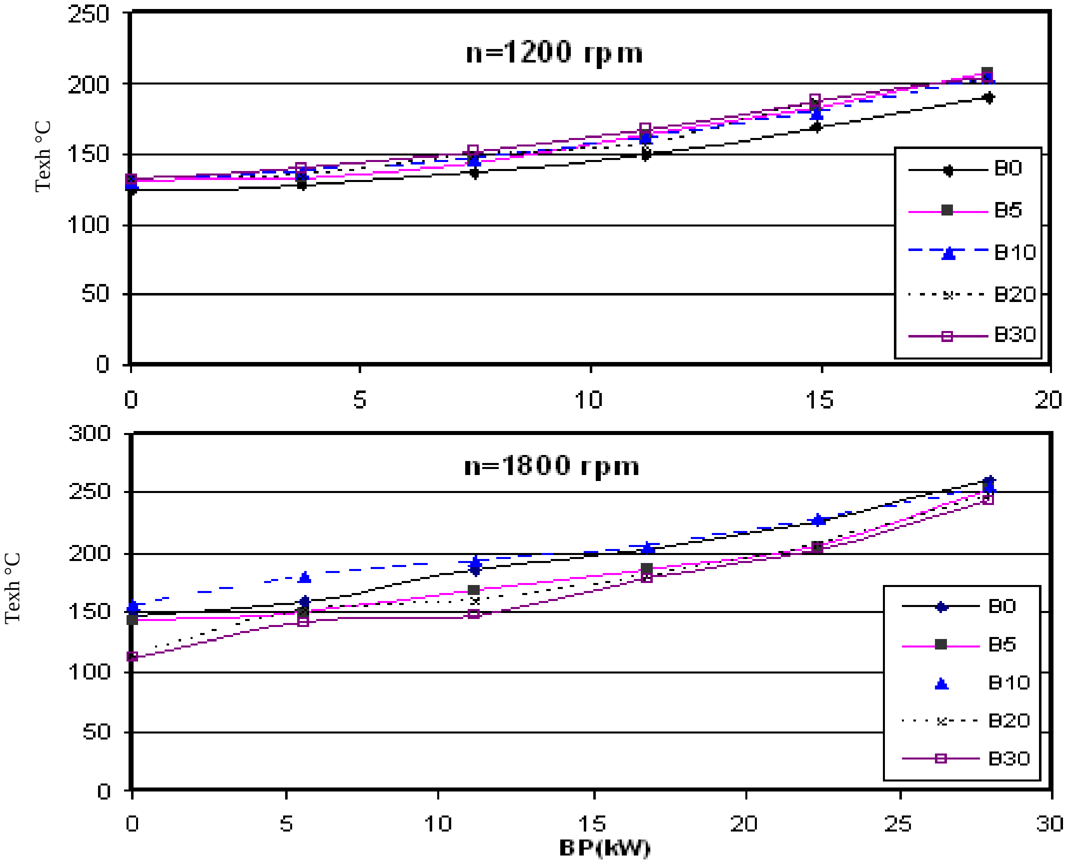

Fig. 6. Comparison of exhaust temperatures at various rotational speeds (n).

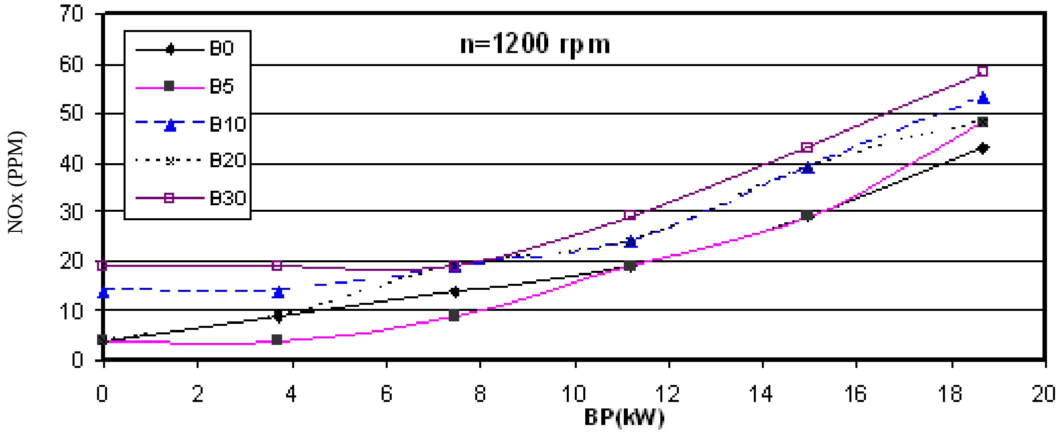

Fig. 7. NOx emissions in Diesel exhausts as a function of load (kW).

4. Conclusions

1. Experiments have been performed to determine the optimum conditions for the preparation of MEWVO, namely, room temperature 25°C; 0.5-0.6% sodium hydroxide catalyst by weight of waste vegetable oil.

2. At low speeds, in spite of the different calorific values, the fuel blends B5 and B10 maintain, at low loads, nearly the same bsfc

as that of diesel fuel, whereas the B20 and B30 blends recorded higher bsfc than diesl fuel. At a higher speed of 1800 rpm, the bsfc of the fully loaded engine for the B20 blend is nearly the same as that for diesel fuel, whereas B30 suggest the bsfc is higher by 11.65%. The bsfc of blend B5 appeared to be nearly the same as that of blend B10, both of them having lower bsfc by 2.9% relative to Diesel fuel.

3. The brake thermal efficiency depends actually on both the biodiesel inclusion percent in the Diesel fuel and the engine performance conditions. The results indicate that higher than 10 vol% of biodiesel in Diesel fuel lowers the fuel energy conversion efficiency for the biofuel.

4. Emissions of NOx increase with increasing biodiesel concentration in the blend.

5. At the highest load point, the biggest CO emission of .08 %vol was measured for Diesel fuel, and the lowest of .05 %vol was obtained for blend B30, indicating more complete combustion with increasing biodiesel concentration in the blend due to its oxygenated nature.

This paper has shown that the biodiesel can be used as blended with conventional diesel or as alone in diesel engines without major modifications to the engine for blends up to B20 with performance nearly the same as diesel fuel.

Nomenclatures

MEWVO	Methyl Ester Waste Vegetable Oil,
B20	Blend of 20% biodiesel and 80%, diesel fuel,
IB	Bound, and
Hp	Horse power.

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