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Renewable Energy 33 (2008) 1791–1795
RENEWABLE ENERGY
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# The comparison of engine performance and exhaust emission characteristics of sesame oil–diesel fuel mixture with diesel fuel in a direct injection diesel engine

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Received 22 June 2007; accepted 29 November 2007
Available online 9 January 2008

## Abstract

The use of vegetable oils as a fuel in diesel engines causes some problems due to their high viscosity compared with conventional diesel fuel. Various techniques and methods are used to solve the problems resulting from high viscosity. One of these techniques is fuel blending. In this study, a blend of 50% sesame oil and 50% diesel fuel was used as an alternative fuel in a direct injection diesel engine. Engine performance and exhaust emissions were investigated and compared with the ordinary diesel fuel in a diesel engine. The experimental results show that the engine power and torque of the mixture of sesame oil–diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel. Hence, it is seen that blend of sesame oil and diesel fuel can be used as an alternative fuel successfully in a diesel engine without any modification and also it is an environmental friendly fuel in terms of emission parameters.


*Keywords:* Sesame oil; Alternative fuel; Exhausts emissions; Diesel engine; Engine performance

## 1. Introduction

Recently, the use of diesel engines has increased by virtue of their low fuel consumption and high efficiencies. Nowadays, diesel engines are used in transportation, electric power generation, farming, construction and in many industrial activities [1]. These wide fields of the usage lead to increasing requirement of petroleum derived from fuels. The depletion of world petroleum reserves and increasing demand also induce a steep rise in fuel prices. It is also known that exhaust emissions from diesel engines cause environmental pollution. Pollutants from diesel engines include carbon monoxide (CO), carbon dioxide ($CO_2$), sulfur oxides ($SO_x$), nitrogen oxides ($NO_x$), and particulate matter (PM) [2]. These emissions have hazardous effects on air, water and soil pollution as well as an global climatic change and human health. It is possible to reduce pollutant emissions in exhaust gases by using the different kind of fuels that are significant factors in the composition of exhaust gases. In diesel engines, alternative fuels are used for both reducing the consumption of petroleum-based fuels and pollutants in the exhaust gases.

Vegetable oils are alternative fuels and many researches are carried out on development of these fuels [3,4]. It is known that the original diesel engine designed by Rudolph Diesel ran with vegetable oil. Nowadays, vegetable oils are good alternative fuels to those derived from petroleum oils and can be used instead of the ordinary diesel fuel as fuel in diesel engines [5,6]. Vegetable oils have some advantages as follows: they are renewable energy as the vegetables that produce oil are renewable, heat release rate is similar to diesel, its emissions (CO, HC and PM) rate is relatively low [4,7–11], they do not contain almost sulfur element, and they can be used with simple or without modifications in

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0960-1481/$ - see front matter 
doi:10.1016/j.renene.2007.11.008

the engine [11–13]. These important advantages have led to several researches and development studies on vegetable oils.

While higher $NO_x$ emissions were found in some studies [10,11], several researchers found a slightly small reduction in $NO_x$ emissions when using biodiesel blends [14–16]. It is clear that the new fuel used in the diesel engine should not modify significantly the construction of the engine. Vegetable oils as fuel do not impose significant modification on engine and they cause a reduction in the exhaust emission rate [12,15,17].

The main problem of using neat vegetable oils as fuel in diesel engines is related to their high viscosity [15,18,19]. The high viscosity leads to the following problems in diesel engine; the blockage of fuel lines and filters, poor atomization of the fuel, incomplete combustion, severe engine deposits, injector coking with trumpet formation and piston ring sticking, gum formation and thickening of the lubricating oil [3,14,16,20–22]. To solve these problems caused by the very high viscosity of neat vegetable oils, the following usual methods are adopted: blending in small blend ratios with normal diesel fuel, pre-heating, micro-emulsification with methanol or ethanol, cracking and converting them into bio-diesel fuels [15,16,22,23]. The blending method has the advantages of improving the use of vegetable oil fuel with minimal fuel processing and engine modification [16]. Hence, mixing diesel fuel with vegetable oils with specific ratio reduces viscosity and consequently they can be used as alternative fuels in diesel engines.

The main purposes of this study are to investigate the sesame oil and diesel fuel mixture as a fuel in a direct injection diesel engine and to determine engine performance and exhaust emissions characteristics. In the study, sesame oil is blended with diesel fuel at 50% ratio on volume basis in order to reduce the high viscosity of sesame oil. The experimental results are compared with those of ordinary diesel fuel.

## 2. Material and experimental procedure

The experiments are performed on a Lombardini 6 LD 400, one cylinder, four-stroke, air-cooled, direct injection diesel engine. The basic specifications of the engine are given in Table 1. A schematic layout of the experimental setup is depicted in Fig. 1. In the tests, ordinary diesel fuel sold commercially and sesame oil utilized for confectionery purposes especially as Tahini are used. Some properties of both the fuels are given in Table 2. As seen from Table 2, while the viscosity, flash point, and density of sesame oil are higher than that of diesel fuel, heating value and cetane number of sesame oil are slightly lower than that of diesel fuel. To solve the problem of high viscosity of sesame oil partly, it is not used alone; it is blended with diesel fuel, that is, the attenuating process is applied to sesame oil in this study.

Table 1
Technical specifications of the test engine

| Items | Specification |
|---|---|
| Model | Lombardini 6 LD 400 |
| Numbers of cylinder | 1 |
| Bore | 86 mm |
| Volume | 395 $cm^3$ |
| Stroke | 68 mm |
| Compression ratio | 18:1 |
| Standard injection pressure | 20 MPa |

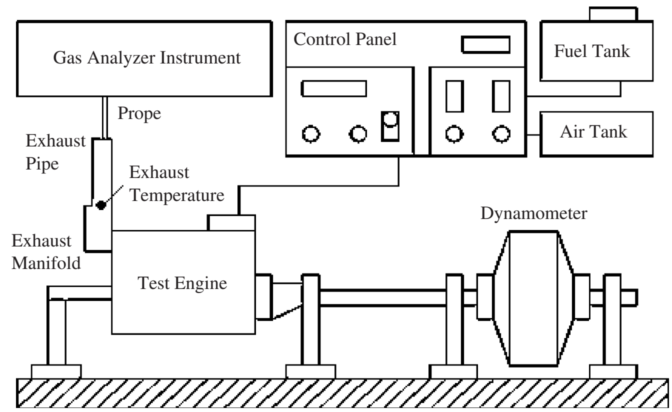


Fig. 1. The schematic diagram of the experimental setup.

Table 2
Some properties of fuels used in the experiments [24,25]

| Property | Diesel | Sesame oil |
|---|---|---|
| Heating value (kJ/kg) | 42 900 | 39 349 |
| Viscosity ($mm^2$/s) | 4.3 (at 27 °C) | 35.5 (at 38 °C) |
| Density (kg/l) | 0.815 | 0.913 |
| Cetane number | 47 | 40.2 |
| Flash point (°C) | 58 | 260 |
| Sulfur (%) | <0.01 | 0.01 |
| Carbon residue (% by weight) | <0.35 | 0.25 |

The test was firstly started with diesel fuel, and when the engine reaches the operating temperature, it was loaded with a Cussion brand electrical dynamometer. The engine was tested at full load and various engine speeds. The engine was loaded at six various speeds ranging from 1800 to 3300 rpm with 300 rpm period. The speed and load were recorded by digital indicator of the test ring. Engine torque and effective engine power were calculated from these values. An MRU Brand 95/3 CD model gas analyzer was used for measuring exhaust emissions. Before taking the measurements, the gas analyzer instrument was calibrated and its probe was inserted to the exit of the exhaust pipe, which is 1.5 m away from the exhaust manifold. By means of the instruments, temperature of exhaust gases (°C), ambient temperature (°C), $O_2$ (%), $CO_2$ (%), CO (ppm and mg/N $m^3$), $NO_x$ (ppm and mg/N $m^3$), $NO_2$ (ppm and mg/N $m^3$), air–fuel ratio and combustion efficiency (%) is measured.

## 3. Results and discussion

Engine torque, effective engine power, specific fuel consumption, and exhaust gases emission were investigated on the engine using diesel fuel and the blend of 50% sesame oil and 50% diesel fuel.

### 3.1. Engine performance

The variation of engine torque and effective engine power with engine speed are shown in Figs. 2 and 3, respectively. As seen from the figures, engine torque and power are low at low engine speed but when engine speed is increased, the engine power and torque increase. From Fig. 3, it can also be observed that when the power reaches its maximum value, then it decreases. The engine power and torque are generally slightly lower than the corresponding values using ordinary diesel fuel. The results of some thermophysical properties of the blends such as low heating value and high viscosity when compared with diesel fuel and not mixing air and fuel properly, which cause bad combustion, induce this situation.

### 3.2. Specific fuel consumption

Specific fuel consumption (SFC) varies depending on the engine power. For both fuels used in the tests, specific fuel consumption has high value at low speed, with increasing speed it decreases, and then it reaches high values (Fig. 4). In Fig. 3, engine power has high values in the range of 2400 and 3000 rpm. It is expected that SFC should be low in this range (Fig. 4). At high speeds, friction, heat loses and deteriorating combustion increases SFC. Although the blend gives the same power as diesel fuel, its SFC is higher than diesel fuel. This can be attributed to the fact that sesame oil has low heating value and high density when compared with diesel fuel.

### 3.3. Exhaust emissions

CO emission depending on many parameters such as air–fuel ratio and the engine temperature is one of exhaust gas emissions in the internal combustion engine. It is one of the toxic product of combustion due to the improper burning of hydrocarbon (HC) [26]. Fig. 5 shows the variation of CO emissions for both the fuels with engine speed. It is clear from Fig. 5 that CO emissions decreases with engine speed and the blend produces significantly lower CO emissions than that of diesel fuel. Wang et al. [16] also stated that only on the point of engine full load, the CO emission of the vegetable oil and vegetable oil/diesel fuel blends are all lower than that of diesel fuel. As seen from Fig. 5, CO emissions are high at low engine speeds. This is primarily due to the lower gas temperature in the

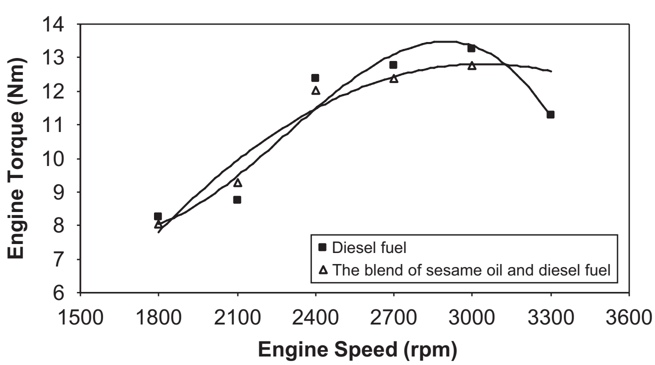


Fig. 2. The variation of engine torque with engine speed for diesel fuel and for the blend of sesame oil and diesel fuel.

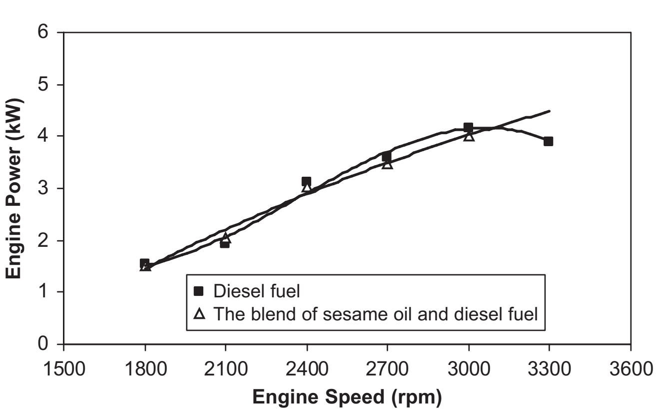


Fig. 3. The variation of engine power with engine speed for diesel fuel and for the blend of sesame oil and diesel fuel.

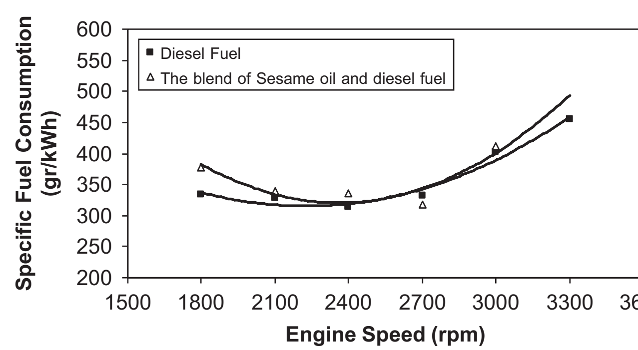


Fig. 4. The comparison of specific fuel consumption of the blend with ordinary diesel fuel.

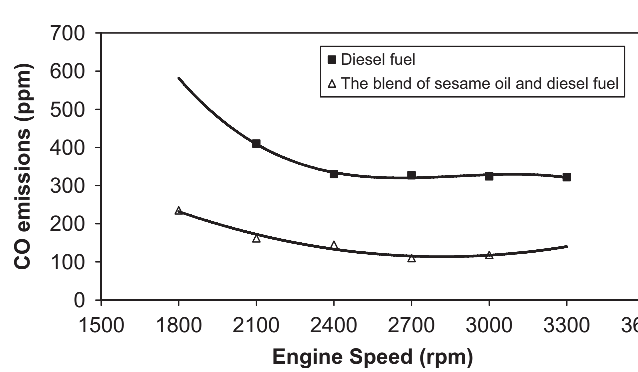


Fig. 5. Comparison of CO emissions of the blend of sesame oil and diesel fuel with those of neat diesel fuel.

engine cylinder at lower engine speeds, which prevents the CO component from effectively converting to $CO_2$ [2].

$NO_x$ emissions are very important in polluted air [14]. Diesel engines operate with an excess air ratio on full load and higher values on lower loads. Diesel engine combustion generates large amounts of $NO_x$ because of high flame temperatures (>1800 K) in the presence of abundant oxygen and nitrogen in the combustion chamber [10]. The variation of $NO_x$ emissions for both the fuels with engine speed is shown in Fig. 6. The $NO_x$ emissions decrease with the increase in engine speed. This is primarily due to the increase in volumetric efficiency and gas flow motion within the engine cylinder under higher engine speeds, which leads to a faster mixing between fuel and air, and a shorter ignition delay. As a result, a large mass flow of the fuel and air inducted into the engine cylinder at larger engine speed could cause an increase of the volumetric efficiency. The reaction time of each engine cycle was thereafter reduced so that the residence time of the high gas temperature within the cylinder was shortened. This led to the lower $NO_x$ emission under higher engine speed [2]. To reduce $NO_x$, the temperature in the cylinder should be reduced. The $NO_x$ emissions increased with the engine load, due to a higher combustion temperature. This proves that the most important factor for the emissions of $NO_x$ is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture. From Fig. 6, it can be seen that within the range of tests, the $NO_x$ emissions from the mixture of sesame oil and diesel fuel are lower than that of diesel fuel. The reduction of $NO_x$ emissions is possibly due to the smaller calorific value of the blend [16].

Cetane number is also effective in $NO_x$ emissions. Cetane number of the sesame oil is smaller than that of the diesel fuel. The smaller the cetane number, the longer the ignition delay and the burning . This causes lower temperatures inside the cylinder and low $NO_x$ emissions in the exhaust gases. Although some researches found that $NO_x$ emissions were found to be insensitive to ignition delay [9], others stated that ignition delay could be a reason of increased $NO_x$ emission [6].

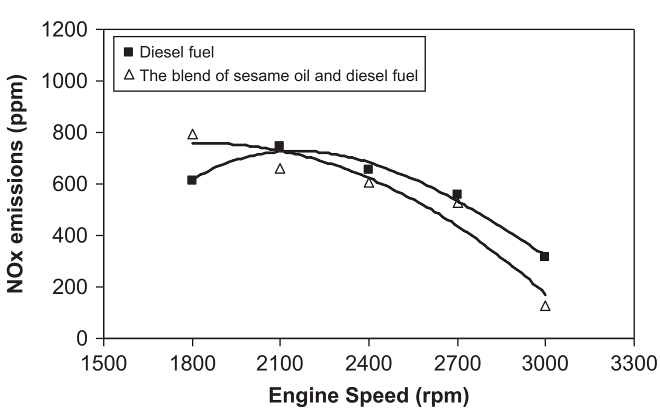


Fig. 6. Comparison of $NO_x$ emissions of blend of sesame oil and diesel fuel with that of an ordinary diesel fuel.

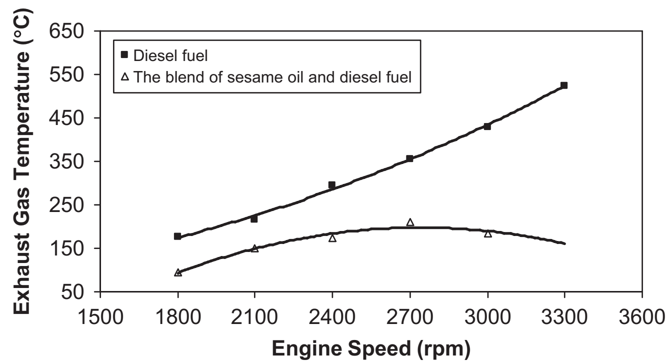


Fig. 7. Exhaust gas temperatures versus engine speeds for the blend and diesel fuel.

Exhaust gas temperatures of the blend are lower than those of the diesel fuel due to the lower heating value of the blend. It is proved that the lower temperature causes low $NO_x$ emissions when compared with diesel fuel. The variation of exhaust gas temperatures of the fuels used in this study is shown in Fig. 7. While the exhaust gas temperatures rise with the increase of engine speed for ordinary diesel fuel, the exhaust gas temperatures of the blend increase with engine speed but then at high speed, it shows a downward trend. Exhaust gas temperatures of the blend are lower than those of the diesel fuel due to the lower heating value of the blend. The higher flash point temperature and viscosity of sesame oil compared with diesel fuel have adverse effects on combustion. These factors also cause low-exhaust temperatures. Lin et al. [2] also stated that the burning of diesel fuel has high-exhaust gas temperature due to its high heating value.

Soot and smoke emissions are the main problems in diesel engines. In this study, smoke measurement was not carried out for sesame oil–diesel fuel mixture due to the lack of a smoke meter. But smoke emissions were visually observed and appeared notably higher than diesel fuel. A significant soot formation was also detected in the combustion chamber and especially on the exhaust valve. To prove the quality of this fuel, however, long-term engine tests at different proportions of sesame oil are required. Therefore, soot and smoke emissions will be measured in future work.

## 4. Conclusions and recommendations

In this study, the effects of sesame oil–diesel fuel mixture as an alternative fuel on engine performance and exhaust gas emissions are investigated experimentally. Based on the experimental results of this study, the following conclusions can be drawn:

1. The mixture of sesame oil and ordinary diesel fuel can be used as fuel without any modification in direct injection diesel engines successfully.
2. Although the power produced by the blend of the sesame oil and diesel fuel is close to that by the ordinary

diesel fuel, specific fuel consumption of the blend is higher than that of the ordinary diesel fuel. This is attributed to the lower heating value of the blend compared with the ordinary diesel fuel.
3. It is seen that the blend emits low CO values and slightly low $NO_x$ values when compared with an ordinary diesel fuel.
4. In the short term, it can be deducted that sesame oil cannot be used instead of diesel fuel, due to its relatively high cost. The cost of sesame oil is increasing generally due to growing and harvesting of sesame crop based on handwork (not mechanized), its low yield and limited sowing areas for growing. Therefore, sesame oil cannot compete with diesel fuel or other vegetable oils today. If vegetable oils are used in diesel engines, it is expected that growing sesame production will be raised.
5. It is seen that exhaust emissions of the sesame oil–diesel mixture are lower than that of ordinary diesel fuel and it can be used as an alternative fuel in view of the environmental pollution.
6. The blend of sesame oil and diesel fuel at various grades can be tested in engines and the improvements on its fuel characteristics can be investigated.

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