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An Experimentally Investigation Of Usability Of A Blend Of Tallow Methyl Ester And Diesel Fuel Substitution Of Diesel Fuel In Diesel Engines

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ABSTRACT

Biodiesel fuels is one of the most attractive alternative fuels to reduce both emissions and petroleum based fuel consumption resulted from diesel engines. Therefore, the effects of biodiesel fuels on long-term engine operation and deposits in engine are considerably important, when biodiesel was evaluated as the alternative fuel for diesel engines. In this study, a 100 h engine test was performed on a single cylinder diesel engine using diesel fuel and tallow methyl ester as biodiesel fuel in order to compare the effects of the fuels on engine operation and deposits. The biodiesel was blended with 80 vol% diesel fuel and 20 vol % tallow methyl ester. Also, short-term engine performance and emissions were investigated and compared using both fuels. The test engine was disassembled before and after the experiment to determine the difference and clean carbon deposits. Experimental results were similar for both fuels in long-term engine tests, and indicated that the engine was satisfactorily operated for 100 hours with blend fuel. Deposits in engine at the end of the 100 h test were comparable in amount, but slightly different in color and adhesive, with the blend fuel when compared with those of diesel fuel. Besides, the blend fuel was comparable with the performance of diesel fuel and the exhaust emissions were lower than that of diesel fuel. It is concluded at the results of engine tests; the blend fuel can be a suitable alternative fuel for diesel engines to substitute diesel.

Key Words: Tallow methyl ester; Engine deposits; performance and emissions.

1. INTRODUCTION

The importance of renewable energy resources have been continuously increased with the increasing world demand for energy, diminishing petroleum reserves and growing environmental problems related to the combustion emissions of petroleum based fuels. Among the renewable energy resources biodiesel fuels derived from fats and oils are being considered for diesel engines. Biodiesel is one of the most attractive alternative fuels to reduce combustion emissions and petroleum based fuel consumption resulted from diesel engines.

Also, biodiesel have acceptable changes in the short-term engine performance and lower emissions also, it can be used without a significant engine modification. Nevertheless, the effect of biodiesel fuels on engine performance and emissions could be changed in long-term engine operation. For instance, an 80,000-km durability test was performed by Yang et al. on two engines using diesel and biodiesel (methyl ester of waste cooking oil) as fuel in order to examine emissions resulting from the use of biodiesel. They reported that, at 0 km, the emission changes of HC, CO and PM for B20 were lower than those for diesel.

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After running for 20,000 km and longer, B20 emission levels were higher than diesel. The viscosity of B20 (3.53 cst) is higher than that of diesel (3.15 cst) and results show that higher B20 viscosity is a factor causing higher emission after extended miles of engine operation [1]. Biodiesel fuels have comparable engine performance and exhaust emission levels for only short-term operation.

In addition, the number of reported studies related to the usability of biodiesel fuels for the long-term engine operation, especially for about the effect of animal fat based fuels are less although, the effects of biodiesel fuels on long-term engine operation are considerably important, when biodiesel was evaluated as the alternative fuel for diesel engines. Ali and Hanna [2] operated on a 80:13:7 % (v/v) blend of diesel fuel: methyl tallowate: ethanol for 200 hours in a Cummins N14-410 diesel engine and the study of their evaluated changes in engine performance and emissions also, engine oil was analyzed. They reported that engine performance and emissions were not considerably changed for 200 hours with blend fuel. Agarwal [3] investigated to long-term endurance tests in two identical engines fuelled by an optimum biodiesel blend (20 per cent LOME) and diesel oil. He reported that the performance of biodiesel fuel was found to be superior to that of diesel oil and the lubricating oil life was found to be longer while operating the engine on biodiesel. Pehan et al. [4] investigated the effects of biodiesel on engine tribology characteristics such as, carbon deposits on injectors and in combustion chambers. It was reported in their study that the carbon deposits in the combustion chambers was quite similar when using diesel fuel with biodiesel. By changing from diesel fuel to biodiesel only a redistribution of the deposits was observed. This was probably due to quite different injection characteristics resulting from high viscosity and high molecular weight of biodiesel. It was concluded by [5] that the wear of various vital parts has been reduced because of additional lubricity properties of biodiesel. The fuels of bio-origin are superior in wear performance, more environment-friendly, and do not add to global warming problems compared to petroleum based conventional fuels. Also, the carbon deposits for biodiesel- fueled engines are substantially lower than diesel-fueled engine. Çelik et al. [6], reported that engine parts were not damaged while using biodiesel as it has lubricant characteristics.

In this study, the effect of blend of 20 vol % tallow methyl ester and 80 vol% diesel fuel on long-term engine operation and engine deposits were investigated in a single cylinder, four stroke, direct injection diesel engine and compared with the findings of petroleum diesel fuel. In order to determine whether it is suitable for long term use or not in diesel engines the test engine was operated with both fuels for 100 h, and the results with the use of blend fuel were compared with that of diesel fuel. Also, the effect of blend fuel on engine performance and emissions was investigated in short-term engine operation. Animal fat based biodiesel fuels have more saturated fatty compounds than those from vegetable oils. Thus, they having some advantage and disadvantage such as higher cetane number and poor cold-flow properties. Nevertheless, tallow methyl ester from inedible animal tallow has lower pour point. Therefore, it can be a diesel fuel extender when blended with diesel fuel in cold weather conditions. In this study, we selected blend of 80% diesel and 20% methyl ester, biodiesel (B20), as the test fuel.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1. Test Engine and Experimental Setup

A Rainbow-LA186, single-cylinder, four-stroke, forced air-cooling, naturally aspired direct injection diesel engine was used as a test engine in both engine tests. The basic specifications of the test engine are shown in Table 1. This engine was coupled to a hydraulic dynamometer with a control system. A schematic diagram of the experimental setup is shown in Fig. 1. Tallow methyl ester was tested as 20% ratio blended with diesel fuel by volume. Experiments were started firstly with diesel fuel baseline datas were recorded after the engine reached the operating temperature. The diesel fuel and blend fuel were tested at a rated speed of 2000 rpm and full load conditions to determine the performance and emissions characteristics. The torque and power were recorded from digital indicator of the test ring. Fuel consumption by volume was measured with a burette and corresponding time was recorded by chronometer.

Green line 8000 brand 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 exhaust pipe, which is 1.5 m far away from exhaust manifold. BİLSA brand MOD 2100 model smoke meter was used for measuring smoke. Smoke measurements were carried out free engine acceleration conditions reaching a maximum engine speed of 3600 rpm. The final smoke results were obtained from the average of five measures. In the tests, CO (%), NO_x (ppm), and smoke K (m^{-1}) were measured by means of these instruments. The average of measured and calculated values was presented in Fig. 2 as percent variation with diesel fuel.

The engine tests for 100 h were performed in a single cylinder diesel engine which was used for engine performance and exhaust emissions tests. The test procedure was composed of four steps: start, warming up, acceleration and slowdown. After warming up, the engine was run at around maximum speed of 3600 rpm for about 10 h every day until the test equivalent of 100 h were accumulated. The test engine was disassembled before and after the experiment to determine the difference and clean carbon deposits. Combustion chamber and its elements were cleaned with gasoline before the engine was operated with both fuels. Also, injector and valves were removed from cylinder head and were cleaned. Engine lubricant oil was changed and engine connections were arranged then engine started with diesel fuel. These processes were repeated when other test fuel was used.

2.2. Fuel properties

Tallow methyl ester used in this study was produced by Altun [7]. The properties of tallow methyl ester and diesel fuel are presented in Table 2. The tallow methyl ester has higher density, kinematics viscosity and cetane number than that of diesel fuel by about 4%, 27% and 20%, respectively, but a lower flash point and heating value compared with diesel fuel by about 48% and 7%, as shown in Table 2. Also, tallow methyl ester has lower pour point. Therefore, it can not be used as a neat diesel fuel in cold weather conditions. Tallow methyl ester can be a diesel fuel extender when blended with petroleum diesel fuel in cold weather conditions. One of the most common and recommended blends of biodiesel contains 20 vol% biodiesel. The blend fuel (B20) has 3, 7650 mm^2/s viscosity and 846, 99 kg/m^3 density.

Table 1 Technical specifications of the test engine [22]

Items	Specification
Model	Rainbow - LA186
Operating principle	Four stroke, direct injection
Numbers of cylinder	1
Bore x Stroke	86x70 mm
Volume	406 cm^3
Compression ratio	18:1
Std. injection pressure	19.6±0.49 MPa

Table 2 Fuel properties of biodesel and diesel fuel.

Property	Diesel Fuel	Biodiesel
Heating value (kJ/kg)	42700	39858
Viscosity (mm^2/s) (at 40 ^0C)	3,6663	5,072
Density (kg/m^3) (at 15 ^0C)	843,51	877 (at 17^0C)
Cetane number*	47	58.8
Flash point (^oC)	58	30
Pour Point (^oC)	-	0

*Graboski et al.[8].

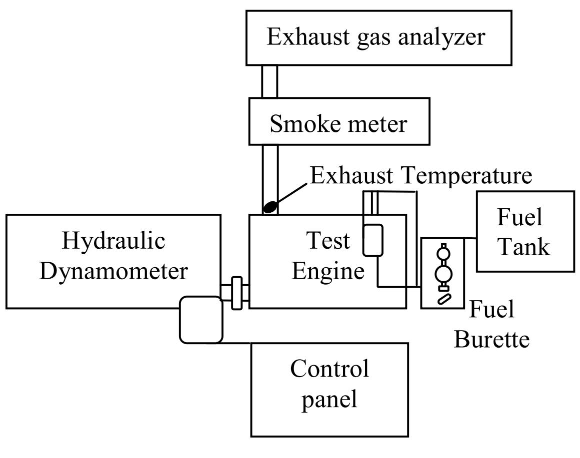

Figure 1 Schematic diagram of the engine setup.

3. RESULTS AND DISCUSSIONS

After 100 hours of engine operation with blend fuel and diesel fuel, engine was dismantled and deposit formed on the injector tip, cylinder head, combustion chamber, piston and valves were visually inspected. Some photographs as sample of these parts are shown in Figures 2, 3 and 4.

3.1. The results after 100 hours of engine operation

After 100 h of engine operation with tested fuels, when engine was dismantled it was found that the deposits was existed at the engine components. Fig. 2 shows carbon deposits on the piston head and cylinder wall with diesel fuel and blend fuel. It can be clearly seen that the areas between compression ring and TDC and combustion chamber were darker than other parts with both fuels. However, the amount in-engine deposits of blend fuel were similar to that of diesel fuel after 100 h operation. Namely, even though the combustion chamber was become sooty, a considerable soot layers were not formed in the chamber, as shown in Fig. 2. Fig. 3 shows carbon deposits on injector tip with diesel fuel and blend fuel after 100 h. The amount of carbon deposits on the injector tip of diesel fuel is higher than that of blend fuel, as shown in Fig. 3. The valve sticking or valve break was not coincided with diesel fuel and blend fuel operation. 20W-50 diesel lubricant oil was used in the test engine. No significant fault was found with lubricant oil. However, the micro-inspection of oil was not performed.

Nevertheless, there were two important differences between the soot formation of blend fuel and diesel fuel usage. First, the soot formation with blend fuel was more colorless than that of diesel fuel. In other words the diesel fuel one was dark-colored while that of blend fuel was smoke-colored. The difference in color of deposits can be clearly seen in Fig. 4. Second, the soot of blend fuel usage was a bit adhesive on engine components. Similarly, Clark et al. [9] stated that, engine deposits were comparable in amount, but slightly different in color and texture, with the soybean methyl ester engine experiencing greater carbon and varnish deposits on the pistons.

It is known that cetane number of fuel has effect on soot accumulation inside the combustion chamber. It can be considered that the higher cetane number of biodiesel fuel will accelerate the soot formation but, over 70 of cetane number has been increased soot and carbon deposits in engine, number of cetane up to 70 is improve combustion by shortening the ignition delay. It is clearly appears in results of this study that the higher cetane number of biodiesel was not increased carbon deposits. Besides, the unsaturation level of fuel also effects soot and deposits formation. It was revealed by Graboski and McCormick [8] that the higher unsaturation levels of biodiesel fuels causes more soot formation inside the combustion chamber. Similarly, Mittelbach [10; 11] pointed out that, unsaturation level of fuel cause to engine deposits and contaminate lubricant oil. Likewise, in the engine test made with vegetable oil based fuel which have high level of unsaturated fatty acids, it was indicated that engine deposits was much higher than that of diesel fuel [12, 13]. Besides, the higher viscosity of vegetable oil is also effect on the higher deposits in engine with vegetable oil. The lower unsaturated compounds so unsaturation level of animal fat based fuels than those of vegetable oil resulted the lower engine deposits and soot formation. Nevertheless, vegetable oil fuels caused carbon deposit buildups and sticking of piston rings after extended operation, as reported by Devan and Mahalakshmi [14] and Murayama et al. [15].

(a) **(b)** **(c)**

Fig. 2 The appearance of the piston head and cylinder wall after 100 h of engine operation, (a) cleaned (b) diesel fuel (c) blend fuel.

(a) **(b)** **(c)**

Fig. 3 The appearance of the injector nozzle after 100 h of engine operation with (a) cleaned (b) diesel fuel (c) blend fuel.

(a) **(b)**

Fig. 4 The appearance of the valves after 100 h of engine operation, (a) diesel fuel (b) blend fuel.

3.2. The comparison of performance and emissions

The engine performance and exhaust emissions with blend fuel and diesel fuel was evaluated in terms of engine torque and power, specific fuel consumption, carbon monoxide (CO), oxides of nitrogen (NO_x), and smoke K (m^{-1}). The change as percentage in the performance and exhaust emissions of the blend fuel compare to the diesel fuel presented in Fig. 5. The engine torque and power for blend fuel was less than that of diesel fuel by about 2-3%. As shown in Fig.5, the specific fuel consumption for blend fuel was higher than that of diesel fuel by about 4%. The lower heating value of biodiesel requires that a larger amount of fuel be injected into the combustion chamber to produce the same power [16]. Besides, the density of biodiesel was higher than that of diesel fuel, which means the same fuel consumption on volume basis resulted in higher fuel consumption on mass basis in case of blend fuel which the specific fuel consumption was calculated on mass basis. Yücesu and İlkılıç has been also reported that the increase in specific fuel consumption were due to the lower heat capacity and higher density of biodiesel [17]. As seen in the Fig. 5, the blend fuel was produced lower CO and smoke compared with diesel fuel and the these emissions were decreased by 28.5% and 27% with use of the blend fuel, respectively. In the literature, many studies reported that the CO and smoke decreased for the biodiesel fuels due to oxygen content of them [18-20]. The change of NO_x emission compared with diesel fuel is presented in Fig.5. The NO_x emissions for blend fuel were less than that of diesel fuel by about 7%. The reduction in emissions of NO_x can be explained by means of the biodiesel have higher cetane number as compared to diesel fuel. It has been reported by İçingür and Altıparmak that NO_x emission decreases about 10% when the fuel cetane number is increased from 46 to 61 [21]. Lower NO_x emissions with blend fuel can be also attributed to the higher saturation level of tallow methyl ester.

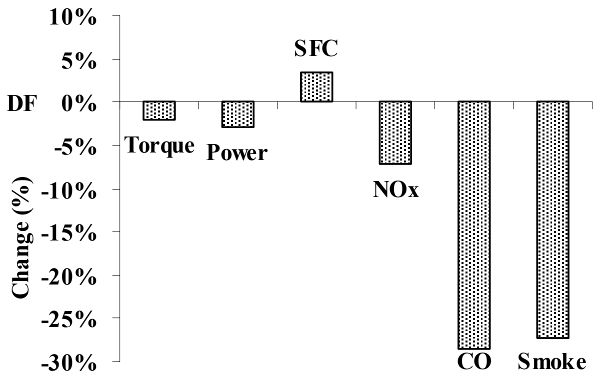

Fig. 5 Percentage change in the performance and exhaust emission of the blend fuel compared to the diesel fuel (DF).

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, the effect of blend of 20 vol % tallow methyl ester and 80 vol% diesel fuel on engine performance, emissions and engine durability were investigated in a single cylinder, four stroke, direct injection diesel engine and compared with the findings of petroleum diesel fuel. Based on the experimental results, the following conclusions can be drawn:

1. No abnormalities were occurred during 100 h operation period and the cold starting problems was not encountered as well.
2. Deposits in engine were comparable in amount when compared with those of petroleum diesel fuel. The biodiesel has higher cetane number and saturated fatty compounds that these can be caused normal engine deposits. However, it was observed slightly different in color and adhesive with the blend fuel compare it with diesel fuel.
3. The more residues were clustered around the exhaust valve both with diesel fuel and blend fuel operation yet no breakage of valve was happened.
4. The residues collected at the vicinity of injector nozzle did not impede engine run.
5. A carbon deposit was not found at the stalk of intake valve. Carbon formation was not found at intake manifold.
6. No scratches were found at the cylinder surface. The area between compression ring and TDC was darker than other parts.
7. It was found that blend of tallow methyl ester with diesel fuel reduced emissions such as CO, NO_x and smoke on an average of 28.5%, 7% and 27%, respectively. Besides, the engine performance run by blend fuel was comparable with the performance run by diesel fuel.

The results have been sufficiently encouraging the further investigation, including: a study of engine wear; a detailed analysis of exhaust emissions and lubricating oil contamination with extended endurance tests.

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