PERFORMANCE AND EMISSIONS OF AN ENGINE FUELLED WITH A BIODIESEL FUEL PRODUCED FROM ANIMAL FATS

by

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Oil reserves which are located around the world are declining day by day, so new alternative energy sources must be invented for engines of internal combustion and compression ignition, so biodiesel that is an alternative fuel source for diesel engines and it is a renewable energy resource. Biodiesel is a fuel made from vegetable oils, animals' fats, and waste oils. In this study, physical and chemical properties of biodiesel were analyzed and matched to the diesel fuel. In the experimental study, biodiesel was made from animal fats and compared to diesel fuel. Its effects on engine performance and emissions are studied. A single-cylinder, four-stroke, direct injected diesel engine with air cooling system are used as test equipment in different cycles. After the experimental study, it is concluded that the reduction of the emissions of CO and HC as biodiesel has the advantage of emission output. Environmentalist property of biodiesel is the most important characteristic of it. But the sight of engine performance diesel fuel has more advantage to biodiesel fuel.

Key words: *biodiesel, waste animal fats, engine performance, exhaust emissions*

Introduction

Oil reserves which are located around the world are declining day by day, so new alternative energy sources must be done for engines of internal combustion and compression ignition, so biodiesel is an alternative fuel source for diesel engines. The first of using vegetable oils as alternative fuel for diesel engines comes from Rudolph Diesel, the inventor of diesel engines [1]. In recent years, a wide range of studies has been carried out both on biodiesel production and the engine performance and emission characteristics of it. Initially, edible vegetable oils were used for biodiesel production, then waste vegetable oils or frying oils are used. However, different chemical properties of oils and fats are not appropriate for the engine. The researches have shown that one way to improve the fuel properties of oils and fats are their transesterification. The process of transesterification is a chemical reaction that converts a fatty acid to an acid ester. This process provides a fuel, called biodiesel, which can be used in unmodified diesel engines [2] and mixed, refined edible palm olein-soybean oil were used for biodiesel by using transesterification by Taymaz and Sengil [3].

Because of cost issues, waste animal fats are also good alternative for biodiesel production. Different animal fats are used for biodiesel production such as, pork lard, beef tallow, chicken fat, yellow grease, and brown grease [4]. On the other hand, the use of beef tallow for biodiesel production for Turkey has taken special interest, since it allows the use of waste materials from cattle slaughterhouses. The process of biodiesel production was studied using of beef

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tallow as raw materials with methanol and potassium hydroxide as catalyst [5]. At the same year, it is used inedible beef tallow [6]. Their fuel properties were mixture of diesel fuel and blends of them (5%, 20%, and 50% by volume). Biodiesel was obtained from pork lard using basic transesterification in consideration of the prevalence of animal husbandry [7].

The results of observations of diesel engines using biodiesels generally meet at the point of lower value for the torque and brake power output of an engine, while specific fuel consumption is higher compared with that of an engine using conventional diesel fuel. Many investigations of the combustion characteristics of biodiesel have demonstrated a reduction in CO and HC, along with increases in oxides of nitrogen NO_x in exhaust fumes [8-15]. The study of Lin *et al*. [16] is compared the exhaust emissions of neat biodiesel, a biodiesel/diesel blend, and normal diesel fuel in a four-cylinder, four-stroke cycle, with a water-cooled diesel engine. Their results showed that the B20 blend produced the lowest CO concentration at all engine speeds. On the other hand, NO_x emissions were higher for biodiesel and biodiesel/diesel blend fuels. Usta *et al*. [17] performed a study on a four-cylinder indirect injection diesel engine, with blends of 5, 10, 15, 17.5, and 25% hazelnut soapstock/waste sunflower oil biodiesel/diesel fuel. They found that using biodiesel/diesel blends increased NO_x emissions. They also reported that the CO emissions of the blend were higher than those of diesel fuel at lower speeds and loads of 75%, while they were lower than those of diesel fuel at higher speeds. Murugesan *et al*. [18] aimed to study the prospects of and opportunities for introducing vegetable oils and their derivatives as fuel in diesel engines. Their results showed that the use of biodiesel in a conventional diesel engine caused substantial reduction in unburned HC and CO. Ganapathy *et al*. [19] studied analytically and experimentally performance on non-edible jatropha feed biodiesel on diesel engine with single cylinder, four stroke, direct injection, air cooled. They reported the effects of injection timing, relative air fuel ratio, and compression ratio on the engine performance characteistics for diesel and jatropha biodiesel and their model were validated with experimental values for a reasonable agreement. Gumus and Kasifoglu [8] used apricot seed kernel oil methyl ester as fuel in a compression ignition engine and analyzed the performance and emission characteristics of the engine. The blends and neat methyl ester reduced CO and HC emissions but NO_x emissions increased slightly, resulting in the mixture having lower performance levels than diesel fuel. Taymaz and Sengil [3] used mixture of edible palm olein and soybean oil and processed with methyl ester and ethyl ester as fuel in single cylinder diesel engine and analyzed the performance and emission characteristics of the engine. They reported that performance values are generally the same when methyl ester and ethyl ester are compared, but the thermal efficiency of methyl ester is higher and it also has advantages with regard to CO, HC, and CO_2 emissions. The study of Tomić *et al*. [20] is compared the exhaust emissions of sunflower biodiesel, fossil diesel fuel, and a biodiesel/ fossil diesel blend in a four-cylinder, direct injection, with 48 kW rated power agricultural tractor engine. Their results showed that thermal efficiency increased as a result of more complete combustion of biodiesel and fossil diesel blends. The exhaust gas emissions implied that the addition of biodiesel reduced the content of CO_2 and CO, as well as the temperature of exhaust gases, but it increased the emission of NO_x.

The aim of this study is to carry out performance and emission testing on a single-cylinder, 4-stroke, diesel direct injection engine fuelled with biodiesels as methyl ester from waste animal fats and petroleum-based diesel. The emission data includes rates for CO, CO_2, HC, and O_2. This paper also reports on the production of methyl ester. Thus, this experimental study gives us the opportunity to compare methyl esters from animal fats and with diesel fuel.

Biodiesel production and specifications

In the experiments, petroleum-based diesel and waste animal fats and methyl esters were used as fuels. Animal fats from beef tallow were supplied by a private company in Turkey. Some properties of these fats can be seen in tab. 1.

It was produced methyl ester from beef tallow with formula 1000 ml of oil, 200 ml of methanol, and 4.9 g of KOH (as a catalyst). The catalyst was first dissolved in methanol. Meanwhile, the oil had been warmed to about 40 °C in another container for better mixing. Methanol and the dissolved catalyst were then added to the oil and stirred. The reaction was conducted close to the boiling point of methanol (55 °C) to show atmospheric pressure. After 60 minutes, of reaction time, the experiment was stopped and the mixture was allowed to form two

Table 1. Fuel properties of beef tallow methyl ester (biodiesel) and diesel fuel

Property	Diesel fuel	Biodiesel
Density, [gml^{-1}] (at 15 °C)	0.850	0.870
Heating value, [MJkg^{-1}]	42	38,2
Viscosity, [mm^{2}s^{-1}] (at 40 °C)	3.7	6
Cetane number	47	–
Flash point [°C]	55	196
Chemical formula	$C_{16}H_{28}$	$C_{53}H_{102}O_6$

Figure 1. General equation for transesterification of triglycerides

layers during the night. The mixture rapidly separated into a clear, golden liquid (ester) layer on the top and a light brown glycerin layer settling at the bottom. A general equation for the transesterification processes can be observed in fig. 1.
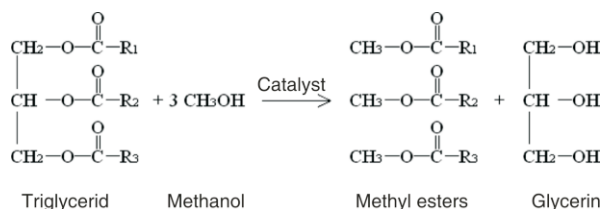
Glycerin was removed at the end of the settling process. The excess alcohol and residual catalyst were removed from the ester with water. The ester phase was put in a container and then water was added, representing half of the ester volume. An air stone was then placed at the bottom of the container and attached to the air pump. It started to bubble. The exact amount of bubbling time was 6-8 h. The wash water was changed and this process was repeated two times until the wash water was clear. Then, the wash water was drained off and the ester was heated to 100 °C to evaporate the remaining water residue.

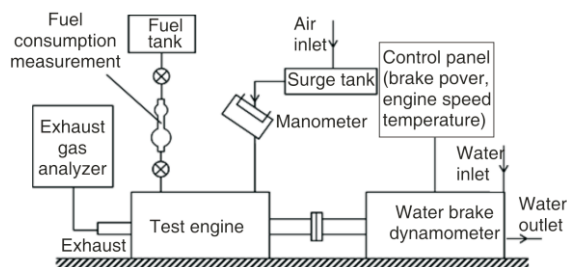### Experimental equipment and test procedure

The experimental set-up consists of a diesel engine, an engine test bed, and a gas analyzer. The schematic layout of the test system can be seen in fig. 2. A single-cylinder, four-stroke, direct injected diesel engine was selected for the tests. The technical specifications of the test engine are summarized in tab. 2. The diesel engine has air-cooling system. The engine test bed consists of a control panel, measurement instruments and a water brake dyna-

Figure 2. Schematic layout of the test system

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Table 2. Technical specifications of the diesel test engine

Engine	Property
Brand	Pancar motor
Model	E89
Type	Air-cooled, four strokes
Combustion	Direct injection
Number of cylinders	1
Cylinder diameter	90 mm
Stroke	105 mm
Compression ratio	21:1
Maximum torque	36.7 Nm at 1800 rpm
Maximum power	8.1 kW at 2300 rpm

Table 3. The uncertainties

Parameter	Unit	Uncertainty [%]
Engine speed	rpm	±1
BSFC	$gkW^{-1}h^{-1}$	±1
Torque	Nm	±0.5
Power	kW	±0.5

mometer. A water brake dynamometer is occupied by the diesel motor. The water brake is based on hydrokinetic construction or (torque absorption). The machine involves of an impeller (rotor) which accelerates water outwards by its rotation. The water has its velocity changed by a stator which causes the water to be returned to the inner diameter of the rotor. For given mass of water, this velocity change yields a corresponding momentum change – and the rate of change of momentum is proportional to a force. This force was measured by using weighing machine. The engine torque was calculated by using measured force. The fuel consumption is measured with a burette (10 ml volume) and a stopwatch. An oblique manometer was used to measure air consumption. The lubricating oil, fuel and ambient temperatures were measured by thermocouples and read from the digital screen of control panel. The uncertainties in the experimental results were then calculated. The results of the uncertainty analysis are tabulated in tab. 3.

The exhaust gas was emitted by a gas ventilation system. The emission measurements were measured with a Mobydic brand emission gas analyzer. The device was placed approximately 1 m away from the engine. The gas analyzer, having electrochemical sensors, was used to measure the CO, CO_2, and HC emissions. This apparatus can also measure the exhaust gas temperature.

The parameters were obtained during full load and variable speed performance tests. The engine ran on diesel fuel at first and then biodiesel fuel. After a standard warm-up procedure, the engine speed was increased to 2400 rpm as no load. Then, the engine loaded with water-brake and the tests and data collection were performed at nine different engine speeds: 800, 1000, 1200, 1400, 1600, 1800, 2000, 2200, and 2400 rpm. At each speed, the engine was stabilized and then the measurement parameters were recorded.

Results and discussion

Engine performance

Figure 3 shows the engine torque values according to the engine speed variations. The maximum torque with diesel fuel operation was 32.98 Nm at 1800 rpm. Biodiesel's maximum torque was 28.46 Nm at 1800 rpm. The maximum torque decreases for biodiesel was 13.7%.

The variations in engine power values in relation to the engine speeds are displayed in fig. 4. The maximum power of the diesel fuel operation was 6.67 kW at 2200 rpm. The observed maximum power values of the biodiesel fuel operations were less than the diesel fuel value. It was 5.78 kW for biodiesel fuel. The power differences between the diesel fuel and biodiesel fuel were about 13.3%.

Specific fuel consumption is indicated one of the important performance parameters of an engine and defined as the consumption per unit of power within a unit of time. Test results showed that the minimum specific fuel consumption values obtained were close to the figures for the maximum torque area. As shown in fig. 5, the minimum specific fuel consumption values were 289.50 g/kWh with diesel fuel, 307.58 g/kWh with biodiesel.

The performance values of biodiesels exhibit some disadvantages of biodiesels in comparison with diesel fuels. These results may be due to the higher viscosity and lower heating values of biodiesels. Because of the higher viscosity, the spraying quality decreases in injectors as refrenced by Gumus and Kasifoglu [8]. So, this factor extends the time for fuel evaporating and burning. The fuel burning occurs at the point at which expansion occurs and cylinder performance decreases. These results are similar with other references [1, 21].

From the performance viewpoint, biodiesel has advantages at lower engine speeds. The advantage of biodiesel may be attributed to the higher fuel mass flow of its denser and more viscous structure. The denser structure of biodiesel can result in a larger mass flow for the same fuel volume and more viscous fuel means less internal leakage in the fuel pump [8, 12, 14, 15].

The trends depicted in fig. 6 for thermal efficiency indicate that the combustion process proceeded more efficiently with the biodiesels than the diesel fuel. It can be established that biodiesels possess a higher cetane number but the experimental fuel's cetane number is not known.
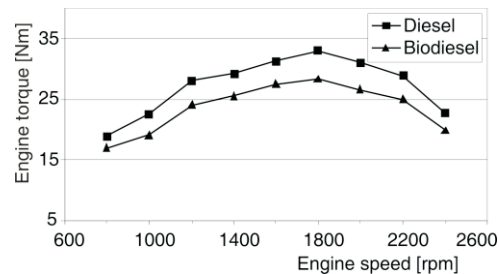

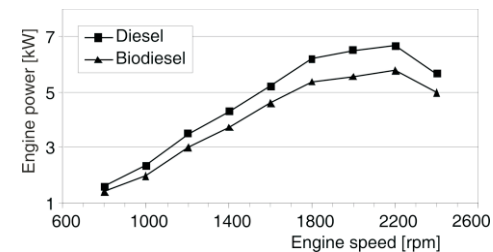Figure 3. Engine torque output *vs.* engine speed for the test fuels

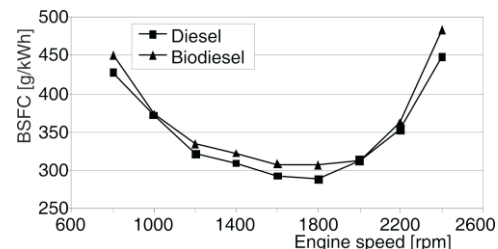Figure 4. Engine power output *vs.* engine speed for the test fuels

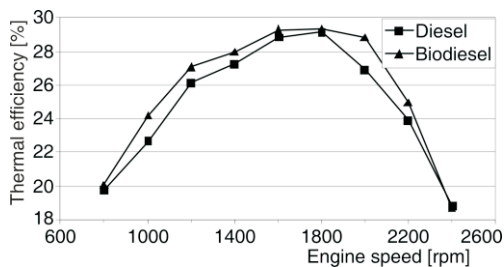Figure 5. BSFC *vs.* engine speed for the test fuels

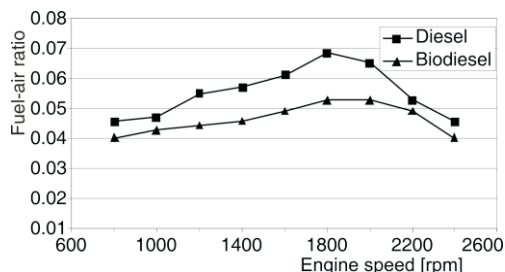Figure 6. Thermal efficiency *vs.* engine speed for the test fuels

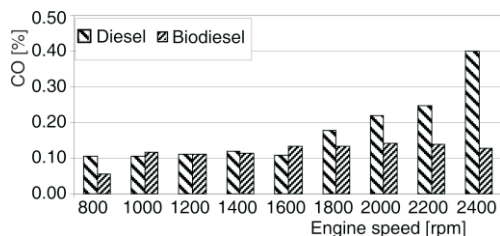**Figure 7. Fuel-air ratio *vs.* engine speed for the test fuels**

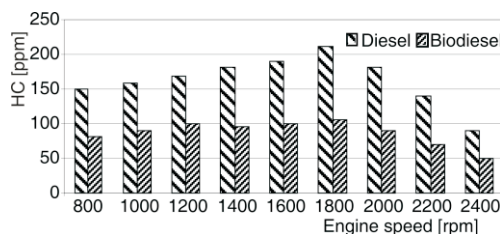**Figure 8. CO emission *vs.* engine speed for the test fuels**

Figure 9. HC emission *vs.* engine speed for the test fuels

The effect of higher thermal efficiencies of biodiesels was more than offset by operation at lower fuel air ratios than it had been with the diesel fuel. The lower fuel-air ratio in fig. 7 for the biodiesels may be partially explained by the fact that biomass-based fuels contain oxygen. These results are similar with another reference [22].

Exhaust emissions

In this section, the emissions of CO, unburned HC, CO_2, and O_2 in addition to NO_x, are examined and the results for all the test fuels are shown in figs. 8-11.

The use of biodiesel fuels resulted in the reduction of unburned HC and CO emissions. Figure 8 illustrates the CO emissions emitted for biodiesel were reduced. Figure 9 shows the reductions in HC emissions brought about by the use of biodiesel as similar with other references [21, 23].

Because of the lower fuel-air equivalence ratios of biodiesels, a poor mixture occurs in the engine and this may result in lower HC and CO emissions. Furthermore, since the lower cetane number of the diesel fuel may result in a less pronounced tendency to form an ignitable mixture, this results in the production of CO and unburned HC, which are the products of incomplete combustion. These results are similar with another reference [20, 22].

Figure 10 an 11 illustrate the O_2 emissions and CO_2 emissions in relation to engine speeds. O_2 emissions are higher than diesel at all speed range as shown in fig. 10. This situation is opposite to CO_2 emission. The levels of O_2 and CO_2 emissions can be explained by the detailed chemical structures of esters and burning reactions [21, 24]. This result was also obtained by Karaosmanoglu [25].
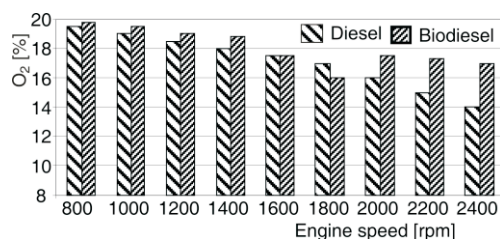

Figure 10. O_2 emission *vs.* engine speed for the test fuels
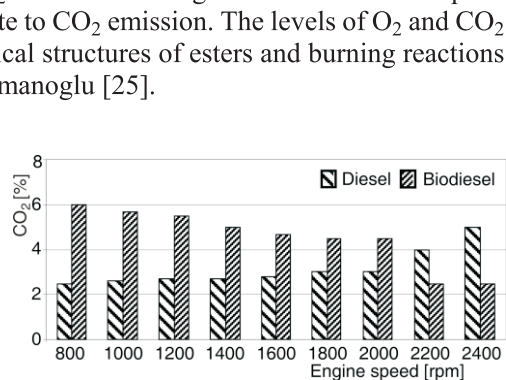

Figure 11. CO_2 emission *vs.* engine speed for the test fuels

Conclusions

The following conclusions can be drawn from this investigation of using esters as fuel for diesel engines.

- Compared with diesel fuel, a small amount of power loss occurred during biodiesel fuel operations, causing higher specific fuel consumption. However, the thermal efficiency of biodiesel fuels was higher.
- More O_2 is available for burning because of the oxygenated nature of biodiesel; this fuel produces decreased rates of unburned HC and CO emissions in the exhaust.
- The fuel that releases less CO_2 to the atmosphere is biodiesel; however, the fuel that releases the highest CO_2 emission to the atmosphere is diesel fuel in high engine speeds. The main advantage is that CO_2 emissions, in the case of use of biodiesel, can be regarded as carbon credit as it is a biofuel, produced by photosynthesis.
- This study has demonstrated that biodiesel fuels can be effectively used as an alternative fuel in diesel engines.

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