Using waste animal fat based biodiesels–bioethanol–diesel fuel blends in a DI diesel engine

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HIGHLIGHTS
• The BSFC values of animal fat based biodiesels were higher than those of diesel fuel.
• Biodiesels showed higher MCP values than those of diesel fuel.
• Bioethanol blends showed retarded SOI timings compared with diesel fuel.
• Animal fat based biodiesels emitted lower CO and THC emissions than diesel fuel.
• Bioethanol fuel blends emitted lower CO₂ emissions than B20 blends.

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ABSTRACT
In this study, animal fat based biodiesels produced in the pilot plant were blended with certain amounts of diesel fuel and bioethanol. Neat biodiesels, diesel fuel and the blends were tested in a direct injection diesel engine and engine performance, combustion and exhaust emission characteristics were investigated. Engine tests were conducted at constant engine speed (1400 rpm) and four different engine loads (150 Nm, 300 Nm, 450 Nm and 600 Nm). The engine tests showed that the brake specific fuel consumptions (BSFC) of biodiesels were about 16% higher while those of the blends containing 20% bioethanol were about 15.7% higher than those of diesel fuel on average. The maximum cylinder gas pressures of biodiesels were about 1.2% higher than those of diesel fuel on average. The start of combustion of biodiesels occurred at earlier crank angles compared to diesel fuel, while the start of combustion occurred at later crank angles with increasing bioethanol amount in the fuel blends. According to brake specific emission results, biodiesels emitted lower carbon monoxide (CO) emissions but they emit higher carbon dioxide (CO₂) and oxides of nitrogen (NOₓ) emissions as compared to diesel fuel. THC emissions increased and CO₂ emissions reduced slightly for the blends containing bioethanol compared with B20 (20% biodiesel, 80% diesel fuel) on average.

1. Introduction
In today’s world, bioethanol and biodiesel are two of the most preferred alternative fuels. Production and consumption of these alternative fuels have been increased significantly each passing day. Bioethanol is a renewable fuel which can be derived from agricultural feedstock basically such as sugar beet, corn, wheat and sugar cane. It can be produced from agricultural wastes as well.

Biodiesel is another renewable fuel that can be produced from vegetable oils, animal fats and also from their wastes. Biodiesel is nontoxic, biodegradable and environmentally friendly diesel fuel. When bioethanol and biodiesel are produced from agricultural feedstocks and virgin vegetable oil, there will be a conflict with food production and this situation will cause an increase in the food prices. Therefore, the feedstocks of these renewable fuels should be agricultural wastes, waste vegetable oils or animal fats. Bioethanol is mainly used in gasoline engines due to having high octane number while biodiesel is an alternative to diesel fuel. However, renewability of bioethanol has shifted the researchers to use this fuel in diesel engines. As well known, viscosity of biodiesel is higher than that of diesel fuel. In addition, biodiesels produced...
from waste vegetable oils or animal fats may have higher viscosity compared to those produced from virgin vegetable oils [1]. Bioethanol has some advantages such as higher oxygen content and higher heat of evaporation which may reduce NO\(_x\) emissions in diesel engines [2] and has lower viscosity and distillation temperatures as well. One of the effective ways of using bioethanol in diesel engines is mixing it with biodiesel and diesel fuel. Thus higher viscosity of biodiesels may be lowered and will be approximate to that of diesel fuel. On the other hand, the disadvantages of using ethanol in diesel engine such as low lubricity and cetane number may be overcome by biodiesel addition to ethanol–diesel fuel blends. However, there are limited studies about the investigation of usage of biodiesel–ethanol–diesel fuel blends in the literature. Yilmaz et al. [3] investigated diesel emissions of ethanol–bioethanol–diesel fuel blends. In that study, the biodiesel was produced from waste cooking oil. They mixed ethanol with diesel fuel (DF) and biodiesel both at low and high concentrations (3%, 5%, 15% and 25%) while DF and biodiesel amount were maintained equal. The results showed that ethanol blends emitted higher CO and lower NO\(_x\) emissions at low loads while there were not significant differences in CO and NO\(_x\) emissions at high loads when compared to DF. Labeckas et al. [4] tested various ethanol–DF and ethanol–biodiesel (rapeseed methyl ester) – DF blends in a diesel engine with in-line fuel injection pump. They found that ethanol–DF blends had later injection timings than those of DF while the biodiesel–DF–ethanol blend containing 5% biodiesel had earlier injection timing. Maximum heat release rate (MHRH) increased with increasing the ethanol content in the fuel blends. Lu et al. [5] used biodiesel in a diesel engine with premixed ethanol by port injection. MHRH and ignition delay (ID) increased, cylinder pressure decreased with the increase in the injected ethanol amount to the intake port. Sayin and Canakci [6] worked on the engine performance and emissions of DF–ethanol blends containing 5%, 10% and 15% ethanol. Brake specific fuel consumption (BSFC) increased with increasing ethanol content in the fuel blends. He et al. [7] prepared DF–ethanol blends of low and high ethanol concentration (10% and 30% ethanol) to test them in a diesel engine. THC emissions of ethanol blends were higher than those of DF. In addition, they found that THC emissions increased with the increasing ethanol amount in the fuel blends.

As seen in the literature, there are almost no studies especially about the engine tests of waste animal fat biodiesel–bioethanol–DF blends. Therefore, in this study, waste animal fat biodiesels such as chicken fat and fleshing oil biodiesels and their blends with DF and bioethanol were used as test fuels in a direct injection diesel engine and engine performance, combustion and exhaust emission characteristics of these fuels were investigated.

2. Materials and methods

In this study, waste chicken fat and waste fleshing oil based biodiesels produced in the pilot plant were used as test fuels. Detailed production process and the potential of these fuels can be found in the Ref. [8]. The fatty acid compositions of the oils and their biodiesels are given in Table 1. The chemical formulas of the biodiesels were calculated from the average of chemical formula and weight percent for each of the component esters determined by gas chromatography (GC). Bioethanol obtained from Pankobirlik Bioethanol Manufacturing Plant (Konya, Turkey) was derived from the wastes originated from sugar production process and DF was bought from a local petrol station. The fuel properties of DF, bioethanol, biodiesels and their blends were given in Tables 2 and 3. The prepared test fuels are DF, bioethanol (E), flexing oil biodiesel (FOB), chicken fat biodiesel (CFB), FOB20 (20% FOB, 80% DF), CFBE20 (20% CFB, 80% DF), FOBE5 (20% FOB, 75% DF, 5% E), CFBE5 (20% CFB, 75% DF, 5% E), FOBE10 (20% FOB, 70% DF, 10% E), CFBE10 (20% CFB, 70% DF, 10% E), FOB20 (20% FOB, 60% DF, 20% E), CFBE20 (20% CFB, 60% DF, 20% E). The phase separations of test fuels were checked two months ago before the engine tests. All fuel blends were stored in glass beakers to observe the phase separation. Significant phase separation was not observed for first several days. However, after one week, there was a phase separation in the fuel blends especially containing ethanol. Therefore, the test fuels were prepared daily and mixed before the each test. The test fuels were characterized in the Alternative Fuels Research and Development Center in Kocaeli University (AFRDC), Marmara Research Center-The Scientific and Technological Research Council of Turkey (MRC-TUBITAK) and Pankobirlik Bioethanol Manufacturing Plant (PBMP). The test methods used to determine the properties of the test fuels were given below (unless otherwise stated, the tests were done in AFRDC);

- Density (ASTM D4052), viscosity (ASTM D445), flash point (ASTM D93), sulfur content (ASTM D2622), water content (EN ISO 12937), iodine value (EN 14111), mono-, di- and triglyceride, total-free glycerin (EN 14105 – determined in MRC-TUBITAK), methanol content (EN 14110), cold filter plug point (ASTM D6371), acid value (AOCS Cd 3a-64), copper strip corrosion (ASTM D130) and heat of combustion (ASTM D240), cetane number (ASTM D613 – determined in MRC-TUBITAK), methanol content in ethanol (EN 13132 – determined in PBMP), fatty acid composition (IUPAC 2.301).

Engine tests were performed using a water-cooled, turbocharged-intercooled direct injection diesel engine. Engine specifications were given in Table 4. Four different engine loads (150 Nm, 300 Nm, 450 Nm and 600 Nm) and constant engine speed (1400 rpm – speed of maximum engine load) were selected for the engine tests. There were not any modifications on the diesel engine during the engine tests. A schematic diagram of the engine setup was shown in Fig. 1. The test engine was coupled to a hydraulic dynamometer to provide brake load. A magnetic pickup was fixed over the engine flywheel gear to determine the crankshaft position. A water-cooled cylinder pressure sensor (Kistler model 6061B) was mounted on the first cylinder head to measure the cylinder gas pressure. A pressure transducer (Kistler model 6005S) was installed in the fuel line of the first cylinder to obtain the fuel line pressure. A charge amplifier (Kistler model 5064A1) was used to produce output voltages proportional to the charge and then they were converted to digital signals. The cylinder gas and fuel line pressure signals were recorded by a computer using a digital device (Advantech PCI 1716 multifunctional data table).
acquisition board). The cylinder gas pressure data of 50 engine cycles were collected with a resolution of 0.25 ms acquisition board. The cylinder gas pressure data was analyzed with using single-zone thermodynamic model. The heat-release analysis was based on the changes of the cylinder gas pressure and cylinder volume during the cycle. The formula given below was used for all test fuels.

\[ Q_t = \frac{k}{k-1} P \frac{dV}{dt} + \frac{1}{k-1} V \frac{dp}{dt} + Q_{\text{wall}} \]

where \( k \) is the ratio of specific heats which was taken depending upon cylinder temperature, \( \theta \) is crank angle, \( P \) is cylinder gas pressure, \( V \) is cylinder volume, \( Q_{\text{wall}} \) is heat transfer from the cylinder wall. The details for heat release calculations can be found in Ref. [9].

### 3. Results and discussion

All fuels were tested at different engine conditions for three times and the results were averaged. It is indicated that low load means 150 Nm, medium loads mean 300 and 450 Nm, and high load means 600 Nm engine test conditions. Tables 2 and 3 show the fuel properties of the test fuels. As seen in the tables, biodiesels have lower heating values than that of DF and heating value decreases with increasing bioethanol amount in the blends. Similarly, viscosity of the bioethanol blends decreases with increasing bioethanol amount. Detailed comparison of the fuel properties can be found in the Ref. [8].

#### 3.1. Brake specific fuel consumption

BSFC is an important parameter to compare the performance of different fuels on an engine. Fig. 2 shows the BSFC results of the test fuels. As seen in the figure, the BSFC values decreased with increasing the engine load for all test fuels. The BSFC values of biodiesels and their blends with DF were higher than those of DF. As the bioethanol amount increased in the blends, the BSFC values increased as well. Zhu et al. [2], Gürü et al. [10] and Nadir et al. [11] presented also higher BSFC values for biodiesels, biodiesel–DF or bioethanol blends with DF as compared to DF. The increase in BSFC was expected since the lower heating value of biodiesel is about 13.7%, 14.1% and 39.4% lower than that of diesel fuel, respectively. This means that more fuel amount is required for the same work output.
FOB, CFB and bioethanol blends than that of DF. On the other hand, the BSFC values of the biodiesels were close to each other. Therefore, the results for the blends of FOB and CFB were close to each other as well.

3.2. Fuel injection line pressure and combustion results

The crank angle (°CA) at which the fuel injection line pressure reached the injector nozzle opening pressure was taken as the start of fuel injection (SOI). The SOI results were derived from the fuel injection line pressure data. The SOI timings were summarized in Table 6a. As seen in the table, each fuel had different injection line pressure values. The SOI timings of biodiesels and B20 (20% biodiesel–80% DF) blends were earlier than those of DF for all test conditions. Similar results can be found in the literature. Monyem [12] determined that the SOI timings of biodiesels were about 2°CA earlier than that of DF at full load. As well-known from
the literature [13], the bulk modulus of biodiesel is higher than that of diesel fuel. Higher bulk modulus shows lower compressibility of the fuels. It may be said that earlier SOI values of the biodiesels compared with diesel fuel caused from lower compressibility of the biodiesels. The SOI timings of FOB were about 0.75 °CA later than those of CFB. This means that CFB is less compressible than FOB. Higher viscosity of CFB as compared to FBO may be the reason of earlier injection. It is clear from Table 6a that the fuel injection timing was retarded with increasing bioethanol amount in the fuel blend. DF is less compressible than ethanol namely it has higher bulk modulus values. This property causes retarding in the fuel injection timing for bioethanol blends. Labeckas et al. [4] showed similar results for ethanol–DF blends. They found that the injection timings of E15 (15% ethanol-85% DF) were about 1 °CA later than those of DF on average at different engine speeds. The blends of FOB and CFB showed almost same results of SOI. On the other hand, the SOI timings of bioethanol blends were advanced up-to 2 °CA by the increment of engine load.

The cylinder pressure and heat release rate results were shown in Fig. 3 for all test fuels. As seen in the figure, maximum cylinder gas pressure (MCP) increased with increasing engine load for the neat fuels and the blends. MCP values of the biodiesels were higher than those of DF generally while MCP values of B20 fuel blends were close to those of DF. The pressure results of bioethanol blends showed that their MCP values were mostly lower than those of biodiesels and DF. Heat release rate results presented that maximum heat release rate (MHRR) increased with increasing bioethanol amount in the fuel blends. The MHRR values for DF were higher than those of biodiesels while the MHRR values of the B20 blends were similar to those of DF. The starts of increasing in heat release were different for the blends however ends of the heat release were close to each other. Labeckas et al. [4]. Shehata [14], and Hulwan and Joshi [15] presented similar results in their studies.

The injection and combustion characteristics of the test fuels were summarized in Tables 6a and 6b. When the results are investigated in terms of engine load, it is seen that start of combustion (SOC – derived from heat release rate profile) values were advanced with increasing engine load for all test fuels. The results showed that SOC of biodiesels occurred at earlier crank angles when compared to DF. The cetane number of DF is lower than that of FOB while it was higher than that of CFB. However, SOI of CFB was earlier than that of DF. This situation causes earlier SOC results for CB20 compared to DF although lower cetane number of CB20. Combustion results showed that FOB started to burn earlier than CFB due to higher cetane number of FOB although it was injected later than CFB. The SOC timings were retarded with increasing bioethanol amount in the fuel blends. The cetane number of bioethanol was much lower than that of DF and neat biodiesels. This property tended to retarded SOC timings for bioethanol blends when compared to DF, biodiesel and their blends. In addition, the later SOI timings of bioethanol blends were another factor for retarded SOC timings. Identical results were also mentioned in the literature [5,15].

The ignition delay (ID) is defined as the time between SOI and SOC. ID values of the DF, neat biodiesels and B20 blends decreased with increasing engine load. However, this tendency was different for the bioethanol blends due to differences in SOI timings. ID values were increased with increasing engine load and bioethanol amount in the blends at low engine loads. The results showed that the ID values of DF were shorter than those of CFB. Earlier SOI timings (about 2 °CA) of CFB caused longer ID although SOC values of CFB were earlier when compared to DF. The ID mainly depends on cetane number because the cetane number of a fuel shows the tendency of that to self-ignite. It is expected that higher cetane number of FOB provides shorter ID when compared to DF. However, there were not significant differences among the ID values of FOB and DF. These results indicated that the SOC was directly related with SOI timing and cetane number of the test fuel.

Combustion duration (CD) of the test fuels increased with increasing the engine load for all test conditions. The biodiesels had longer CD values when compared to DF. The bioethanol blends showed longer CD results than those of B20 fuels. As stated above, the end of heat release of the test fuels were close to each other for the same engine conditions. Therefore, SOC of the fuels were a dominant factor for CD. There were small differences in CD values of the test fuels.

### 3.3. Engine emissions

The exhaust emissions measured during the tests were carbon monoxide (CO), carbon dioxide (CO₂), total hydrocarbon (THC) and oxides of nitrogen (NOₓ). All emissions results were converted to the units of g/kWh, known as brake specific basis [16].

#### 3.3.1. CO emissions

As seen in Fig. 4, CO emissions decreased with increasing the engine load from 150 Nm to 300 Nm. However, CO emissions increased with increasing the engine load to higher values. As well known from the literature [17,18], the CO emissions increase especially for fuel-rich mixtures. More fuel was needed for higher engine loads and thus richer air–fuel mixture lead to more CO emissions.

CO emissions of biodiesels were lower than those of DF for all test conditions. One of the main reasons of this decrease in biodiesels’ CO emissions was their oxygen content. FOB and CFB contain about 11.2% and 11% oxygen on mass basis, respectively. CO emissions were also lowered by using B20 fuels compared with DF. Identical results were also given in the literature [19,20]. Maximum decreases in CO emissions were about 23% and 17%
Fig. 3. Comparison of cylinder pressures and heat release rates.
for FOB and CFB compared with DF, respectively. Maximum engine load of the test engine is 650 Nm and 600 Nm was selected for this study to compare the test fuels under the same test conditions. In these conditions, CO emissions of FOB and CFB fuels were about 21% and 12% lower than that of DF. Similarly, CO emissions of B20 blends of FOB and CFB fuels decreased about 10% and 11% compared with the result of DF.

In the fuel blends, it should be remembered that biodiesel content was constant (20%) and bioethanol amount was increased while decreasing DF amount. Namely, B20 fuels were taken as the reference fuel for the bioethanol blends. CO emissions increased slightly at 150 Nm and 300 Nm engine test conditions when compared to B20 blends with increasing bioethanol amount in the fuel blends. Di et al. [21] reported that CO emissions increased at low loads while CO emissions decreased at high loads with the addition of ethanol to ethanol–DF blends. In addition, similar results were given by Rakopoulos et al. [22] and He et al. [7]. Higher cylinder pressure and temperature at high loads compared with low loads provide better combustion and thus lower CO emissions for the bioethanol blends [21]. In addition, bioethanol fuel contains about 35% oxygen and lower carbon amount in its structure. These properties may cause to decrease in CO emissions for bioethanol blends when compared to B20 blends. Especially, CO emissions decreased significantly at high loads with using FOBE20 and CFBE20 fuel blends. CO emissions decreased about 46% and 41% for FOBE20 and CFBE20 at 600 Nm engine condition by comparison with DF, respectively.

### CO2 emissions

Main components of exhaust emissions built up by burning hydrocarbon fuels are CO2 emissions. Fig. 5 shows the CO2 emissions as a function of engine load at same engine speed for all test fuels. It is seen in the figure that CO2 emissions decreased with increasing engine load for all test fuels. The CO2 emissions of biodiesels were slightly higher than those of DF on average. This may be due to better combustion for biodiesels and their high carbon content in their structure. When compared to DF, CO2 emissions of FBO, CFB, FOB20 and CFB20 fuels increased by 1.1%, 2.5%, 0.9% and 0.1% on average, respectively. According to results, there were almost no differences in CO2 emissions of biodiesels and DF.

General trend was consistent with the study prepared by the researchers [20,23]. The CO2 emissions of bioethanol blends were lower than those of B20 test fuels for all test conditions. Randazzo and Sodre [24] and Ferreira et al. [25] presented similar results by adding ethanol to biodiesel–DF blends. At 600 Nm engine conditions, CO2 emissions decreased about 5.8% and 7.1% for FOBE20 and CFBE20 compared with DF. The reason of decrease in CO2 emissions is the low C/H ratio of bioethanol [7]. It was found that CO2 emissions, one of the most important greenhouse gases, can be reduced with using bioethanol as a blend with DF.

### THC emissions

The emissions of hydrocarbons (HC) are resulted from unburned fuel in the exhaust emissions. The HC emissions are divided into two categories which are total hydrocarbon (THC) emissions.
and non-methane hydrocarbons [17,18]. Fig. 6 shows the comparison of THC emissions of the test fuels. The results showed that brake specific THC emissions decreased with increasing the engine load.

Biodiesel fuels showed different trends in brake specific THC emissions compared with DF. The brake specific THC emissions of FOB were about 2.3% lower while the brake specific THC emissions of CFB fuels were about 9.2% higher than those of DF on average. Conversion of the emissions from the units of ppm to the units of brake specific basis (g/kWh) especially affects the THC emissions results. Before the conversion of emissions, THC emissions of CFB were lower than those of DF for all test conditions. However, higher carbon amount and fuel consumption caused low increases in brake specific THC emissions for CFB compared with DF. Similarly, conversion of emissions caused different change for B20 blends. The brake specific THC emissions of B20 blends were lower than their biodiesels and DF. The brake specific THC emissions of FOB20 and CFB20 were about 21.5% and 14.1% lower than those of DF on average.

Increasing bioethanol concentration in the fuel blends did not affect the brake specific THC emissions significantly. The brake specific THC emissions of bioethanol blends were close to B20 blends; however, there was a decrease for B20 blends when compared to bioethanol blends especially at higher engine loads.

Cooling effect and latent heat of vaporization of ethanol tends to slow the vaporization and mixing of fuel and air, this results leaner and incomplete combustion and higher THC emissions [7,26].

3.3.4. NO\textsubscript{x} emissions

During the combustion process, oxygen and nitrogen reacts with each other at high temperatures and this reaction causes NO\textsubscript{x} emissions. Main part of NO\textsubscript{x} emissions consists of NO emissions while NO\textsubscript{2} emissions are the small part of NO\textsubscript{x} emissions. The rest trace amount of NO\textsubscript{x} emissions are composed of other oxygen–nitrogen combinations. The emissions of NO\textsubscript{x} emissions are mainly due to oxygen in air. However, some diesel fuels may have trace amount of nitrogen molecules in their structure but the nitrogen content in the fuel have little effect on NO\textsubscript{x} emissions. The emissions of NO\textsubscript{x} depend on cylinder temperature, pressure, air–fuel ratio and combustion duration. In addition, some fuel properties such as viscosity and bulk modulus also affect the NO\textsubscript{x} emissions [7,13,17,18,27–31]. Humidity has an important effect on NO\textsubscript{x} emissions. An increase in air humidity causes a reduction in NO\textsubscript{x} emissions [32]. Therefore, humidity values were measured to do humidity correction during all engine tests. The oxides of nitrogen were calculated as assured in the Ref. [33] according to humidity measurement results.
The brake specific emissions of NOx decreased with increasing engine load generally. Biodiesel emitted higher NOx emissions when compared to DF. The maximum increase in NOx emissions for FOB and CFB are 15.2% and 16.0% with regard to DF results, respectively. Yilmaz and Sanchez [34] also found higher NOx emissions results with using biodiesel compared with DF. The reason of higher NOx emissions may be the oxygen content of biodiesel. Moreover, it is clearly seen in Table 6a that biodiesels have earlier start of fuel injection timings and higher cylinder pressures than those of DF generally. These parameters may be other reasons for the increase in NOx emissions. On the other hand, the NOx emissions of CFB were slightly higher than those of FOB. This may be also due to earlier fuel injection timing for CFB. When using B20 blends, the NOx emissions also increased with regard to the results of DF on average.

As stated above, B20 test fuels were considered as reference fuels for bioethanol blends. The results showed that bioethanol blends emitted lower brake specific NOx emissions with reference to B20 blends on average at lower engine loads. However, the brake specific NOx emissions were close to each other for B20 and bioethanol blends at higher engine loads. Increasing bioethanol amount in the blends did not affect the brake specific NOx emissions significantly. Xingcai et al. [35] showed that the NOx emissions decreased at low engine load while the NOx emissions increased at high loads when the engine was fuelled with DF–ethanol blends compared with DF. Di et al. [21] obtained similar results for DF–ethanol blends. The results from this study showed that the trend in NOx emissions changed with respect to engine load. Cooling effect and latent heat of vaporization properties of bioethanol caused lower NOx emissions at low engine loads [7,20,35].

4. Conclusion

The main aim of this paper is to present the performance, combustion and exhaust emission characteristics of animal fat based biodiesels, DF and their blends with bioethanol in a direct injection diesel engine. According to the performance and combustion results, the BSFC values decreased from low to high engine loads. The BSFC increased with increasing bioethanol concentration in the fuel blend. The MCP values of all test fuels increased with increasing engine load. Biodiesels generally showed higher MCP values than those of DF. The MCP values of bioethanol blends were mostly lower when compared to neat biodiesels and DF. The SOI timings of neat biodiesels and their B20 blends with DF were earlier than those of DF while bioethanol blends showed retarded SOI timings. The combustion started at earlier crank angles for neat biodiesels with regard to DF. The SOC values retarded with increasing bioethanol amount in the blends due to lower cetane number. CD values were impressed by the SOC values rather than the end of combustion. The exhaust emissions results showed that FBO and CFB emitted lower CO and higher CO2 and NOx emissions when compared to DF. When compared to B20 blends, bioethanol blends had different trends in CO and NOx emissions with respect engine load. Bioethanol fuel blends provided lower CO2 emissions than those of B20 blends. The results showed that biodiesel–bioethanol fuel blends performed well and animal fat based biodiesels and bioethanol as a fuel blend with DF could be used in diesel engines.

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