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# ENGINE PERFORMANCE OF BIODIESEL WITH N-OCTADECANE AND DIETHYLENAMINE ADDITIVE

[1] **Mahmut ÜNALDI**, [2,*] **Ayhan UYAROĞLU**

*Selçuk University, Cihanbeyli Vocational School, Motor Vehicles and Transport Technology Department, Konya, TÜRKİYE*
[1] munaldi@selcuk.edu.tr, [2] ayhan.uyaroglu@selcuk.edu.tr

## *Highlights*

- It is the first study fusel-biodiesel blends with additives.
- Biodiesel production from waste oils helps sustainability
- Fusel oil, which is the residue of sugar beet.
- Using fusel oil and waste oil reduce the biodiesel production cost.

***Corresponding Author:** Ayhan UYAROĞLU, ayhanuyaroglu@hotmail.com

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**ABSTRACT:** In diesel-fueled internal combustion engines (ICEs), a preferred method is to add small amounts of additives to the fuel to reduce the negative impact of harmful exhaust emissions without compromising engine performance. The main reasons for preferring this method are the laws and regulations that are made mandatory and its easy applicability. For example, as the sulphur content of diesel fuels has been drastically reduced by legal regulations, the use of lubricity enhancing in diesel fuel additives has become a necessity. In this study, an experimental study was carried out to increase the performance of the diesel engine and reduce the harmful emission values by adding 10% fusel oil, which is ethanol production residue, to biodiesel produced from domestic waste oils. In order to obtain the desired benefits, different amounts of cetane enhancer n-octadecane and lubricity enhancer diethylenamine were added to the fuel mixture. The effects of n-octadecane and diethyleneamine additives added in equal amounts (500, 1000, 1500 and 2000 ppm) to biodiesel fuel and fusel alcohol mixture (B90F10) on engine performance and emissions were investigated. Engine performance and emission values of these fuel blends were measured between 1400 to 2600 rpm at full load. It was experimentally determined that fusel alcohol can be used as a fuel blend, that the residual material can gain economic value, and a total of 2000 ppm n-octadecane and diethylenamine additive can be added to a mixture of B90F10 by volume at optimum values to reduce harmful exhaust emissions.

***Keywords:*** *Binary Blend, Diesel, Exhaust Emissions, Fuel Additives, Fusel Oil*

## 1. INTRODUCTION

In the past century, increase in temperature of Earth's atmosphere has been considerably higher than in previous centuries. This increase is caused by the burning of fossil fuels in power plants, increased use of vehicles and the emissions emitted from them. In addition, consumption of oil is increasing day by day due to its use as an energy source in the increasing number of electricity generation plants and vehicles. Compression ignition (CI) engines are widely used in passenger and freight transport in search of better mechanical and thermal efficiency, low fuel and energy consumption, and durability. Exhaust emissions from CI engines consist of nitrogen oxides (NOx), hydrocarbon (HC), carbon monoxide (CO), carbon dioxide ($CO_2$) and smoke (PM) [1, 2].

To comply with emission norms specified in regulations, harmful and hazardous components in the exhaust emissions of ICEs must be significantly reduced. Biodiesel fuel, produced from plant or animal sources, is an alternative fuel widely used in diesel engines in pure or blended form with diesel fuel. Although biodiesel has low $CO_2$, HC and PM emissions, it has disadvantages such as high viscosity, low volatility, low heating value and high NOx emissions. In order to overcome the aforementioned disadvantages and meet emission norms, additives that increase engine performance and reduce emissions have recently begun to receive more attention in scientific studies [2-4].

Some of the methods that are applied to improve the performance of an ICEs are engine, system and fuel modifications. In particular, the performance of a CI engine can be enhanced by making mechanical changes such as fuel injection timing, valve actuation timing, changing compression ratio, charge cooling,

***Corresponding Author:** Ayhan UYAROĞLU, ayhan.uyaroglu@selcuk.edu.tr

exhaust gas recirculation (EGR), and anti-wear coatings or linings for contact parts. However, engine mechanical modifications are not an easy option and also increase the cost of the engine. Fuel modification is the process of adding catalysts or additives to the base fuel to promote its chemical properties. Fuel additives can be added to improve engine performance and exhaust emissions, increasing the performance of a CI engine without making any changes to the engine [1, 3, 5-7].

Fusel oils, a mixture of several valuable alcohols, are by-products of the fermentation process and are the general name for organic substances with a high boiling point. About 60-70% of fusel oil is isoamyl alcohol, the rest is isobutyl alcohol, water and trace amounts of other compounds. Although the water content of fusel oil is high for use as a fuel additive, it is highly soluble in fuel. Detailed information on obtaining fusel oil and biodiesel production stages is given in the study conducted by Ünaldı and Uyaroğlu [8].

The amount and structure of fusel oil depend on the carbon type used in alcohol production, the fermentation process, the preparation - separation methods. The fusel oil as an alternative fuel can be considered as a new source of energy in CI engines. However, while the number of studies with gasoline blends of fusel oil in spark ignition engines has been increasing day by day, blends with diesel have only recently started to appear in the literature. In the findings from these studies in the literature, it has been reported that fusel oil increases CO and $CO_2$ emissions due to its water content and low cetane number, and reduces NOx emissions owing to the low thermal value [9-11].

Cetane number increasing additives improve the ignition quality and combustion efficiency. In CI engines, ignition delay is defined as the time from the start of injection to the moment when the pressure or temperature change starts to show an exponential increase. Low cetane number is characterized by increased fuel consumption and engine noise due to incomplete combustion, as well as symptoms ranging from cold starting problems to increased emissions. To obtain high cetane number fuel or, better said, to achieve shorter ignition delay times, it is necessary to use diesel-biodiesel fuel blends and change the properties of the fuel by adding different cetane-enhancing additives such as nitrates, aldehydes, peroxides and tetra-azoles [3].

Lubricity improvers are additives that reduce wear of fuel injection equipment and extend the life of system components. The wear problem is caused by the removal of sulphur in diesel fuel and can be solved by adding lubricity enhancing additives to the fuel [1, 3].

Considering above discussion, the literature is reviewed to summarize concurrent studies about the mentioned fuels and additives.

Ickes, et al. [12] reported that cetane improvers, in addition to increasing the cetane number of the fuel, significantly improve cold start-up and reduce emissions such as particulates, NOx and hydrocarbons. However, it was emphasized that 2-Ethylhexyl Nitrate may have a negative effect on NOx emissions due to the nitrate ion found in all additives. However, this negative impact on NOx emissions is said to be very small compared to the benefits of reduced ignition delay and reduced duration of high temperature premixed combustion.

Hulwan and Joshi [13] conducted experiments with ethanol, diesel and biodiesel blends in a direct injection diesel engine. As a result, they emphasized that specific fuel consumption (SFC) increased significantly, thermal efficiency increased slightly, and smoke darkness decreased especially at high loads. While NOx changes occur under operating conditions, $CO_2$ emissions are reported to increase dramatically at low loads.

In the study conducted by Awad, et al. [14], a single cylinder diesel engine with five different speeds was used to determine the effect of fusel oil-diesel blends on engine performance and emissions compared to pure diesel. The impact of test fuels on engine power and torque, SFC, in-cylinder pressure, exhaust temperature and volumetric efficiency were investigated. In the article, which states that alcohols produced from a renewable source are among the important alternative fuels for ICEs, an experimental investigation of the performance and emissions in single cylinder CI engines operating on a fuel mixture of 20% fusel and 80% diesel (F20) and pure diesel (F0) fuel at five different engine speeds and 50% engine load was carried out. The experimental results showed that the power and torque of the engine decreased slightly at low speeds compared to pure diesel with F20. Furthermore, for the F20, in-cylinder pressure decreased at all engine speeds, increasing volumetric efficiency and fuel consumption. It was stated that $CO_2$ and CO emissions decreased owing to the low cetane number value of fusel oil, and the highest decrease in NOx emissions was at 1500 rpm.

The main purpose of the study conducted by Awad, et al. [15] was to determine the performance and emissions of a single-cylinder diesel engine operating with a fusel oil-diesel blend at 2100 rpm at different engine loads. The study was performed at constant engine speed, 17.7 compression ratio and various engine loads (0-25-50-75%). As a result of the experiments, engine power, torque and maximum cylinder pressure increased while ignition delay and emissions (CO, $CO_2$ and NOx) decreased.

A statistical analysis study was conducted by Awad, et al. [16] to reveal the significant relationship between the reduction of fusel oil moisture content and the change in fuel properties. In addition, a comparative study of the effect of fuel properties on combustion characteristics before and after the removal of moisture from the fusel oil was aimed to be carried out. As a result, the heating value and carbon content were found to increase by 13% and 7%, respectively, with the removal of moisture from the fusel oil and it was determined that there were statistically significant effects on the chemical properties of the fuel such as heating value, oxygen and carbon content as the fusel oil content increased in the test fuel, especially after the moisture content was reduced. It was also interpreted that braking power and brake SFC were improved by removing the moisture content with shorter combustion times.

Diesel fuel contains $Al_2O_3$, zinc oxide (ZnO), iron-II oxide ($Fe_2O_3$) and iron-III oxide ($Fe_3O_4$), copper oxide (CuO), cobalt oxide ($Co_3O_4$), titanium oxide ($TiO_2$), graphite oxide, cerium oxide ($CeO_2$), The effects of adding nanofluids such as manganese oxide (MnO), manganese dioxide ($MnO_2$), magnesium oxide (MgO), calcium oxide (CaO) have been studied by various researchers [1, 17-31].

In the study conducted by Çelik, et al. [32], organic-based manganese additive was added to diesel fuel at rates of 4-8-12-16 ppm and the effects of additives on combustion, performance and exhaust emissions were investigated. As a result of the experiments carried out in a single cylinder diesel engine at 5 different loads, the best results were obtained at 12 ppm blend rate. It was found that 12.48% increase in peak power and 8.17% decrease in SFC with 12 ppm added fuel.

The literature emphasizes that there is no perfect additive to reduce all exhaust emissions of ICEs at the same time. Due to the high oxygenated structure and low aromatic compounds of biodiesel, unburned HC, CO and smoke emissions of biodiesel blends are lower than diesel fuel, and the inclusion of biodiesel in diesel fuel negatively affects NOx emissions. It is stated that the source of the increase in NOx emissions is due to the higher oxygen content and lower compressibility of biodiesel fuel, resulting in higher NOx emissions in diesel engines running on biodiesel and its mixtures due to changes in injection characteristics and higher gas temperature [3].

When the studies in the literature are examined, it is noteworthy that the additives added to diesel and/or biodiesel fuels are generally nano-components, metallic additives, antioxidants and oxygenates. The n-octadecane and diethylenamine additives used in this study were added to improve the cetane number and combustion reactions, thereby reducing CO, NOx and smoke emissions. These additives have been used for the first time in scientific studies and have been included in the literature, as well as reducing the cost of biodiesel production, bringing waste frying oils into the economy and raising awareness about the development of environmental awareness in the people from whom the oils are supplied.

In the previous study conducted by the authors [8], the performance and emission values of the mixture obtained by adding fusel alcohol to biodiesel fuel obtained from domestic waste oil were examined and the best results were obtained with the fuel mixture coded B90F10. In this study, the effects of adding n-octadecane cetane improver and diethylenamine lubricant were investigated experimentally due to the fact that fusel alcohol added to biodiesel reduces the cetane number and lubricity of the mixed fuel. This study aims to contribute to the economy by producing fuel from waste materials. So that, biodiesel fuel produced from vegetable waste oil and fusel oil, which is the residue of sugar beet, were blended at 90% and 10% (B90F10) by volume and then n-octadecane and diethylenamine additives were added to this mixture in equal amounts (500-1000-1500-2000 ppm) and engine experiments were carried out. The engine experiments were investigated experimentally in terms of engine power and torque, SFC value, thermal efficiency, CO, HC, NOx and soot emissions at engine speeds of 1400 to 2600 rpm in increments of 200 at full load, in a four cylinder, four stroke, 17:1 compression ratio, turbocharged, 3.9 liters engine displacement, direct injection, CI engine.

## 2. MATERIAL AND METHOD

### 2.1. Fuels and Additives

The biggest obstacle to using vegetable oils as biodiesel raw materials is the cost of the oil [33]. Domestic waste frying oils were used for the biodiesel to be produced within the scope of the study. The study also contributed to the development of environmental awareness by informing the people interviewed for the collection of waste oils about the damage caused by waste oils to the environment and how they should be disposed of.

To give brief information about biodiesel production processes from waste frying oils; 0.45-0.50 wt% NaOH (Sodium hydroxide) as base catalyst, MeOH (Methanol) 6:1 alcohol/oil mole ratio, 55-60 °C temperature and transesterification process for 1 hour. The ester obtained at the end of the reaction was rested for 3600-4800 minutes to remove glycerine and then the esters were washed with 85 °C distilled water and dried at 120 °C for 30 min to produce biodiesel fuel [8]. The purpose of washing is to remove the unreacted alcohol, remaining fatty acids, Na+, K+ ions, catalyst material and glycerol that may remain during separation in the obtained biodiesel [34]. Biodiesel production processes and dehydration of fusel alcohol were described in the previous study by the authors [8].

It has been reported in the literature that fusel oil-biodiesel blends negatively affect engine performance on the grounds that the water containing [35, 36].

In order for fusel oil to be used as an alcohol type fuel additive, water must be removed from the fusel oil. The separation of mixtures formed as a result of mixing different liquids is possible by distillation. Although it is a simple process, it may sometimes need to be repeated several times to increase the degree of purity [37]. After the distillation process repeated twice, the water content in the fusel oil decreased from 2.2727 ppm to 0.7866 ppm.

Fuel cetane number increasing additives are additives that improve the ignition quality of the fuel. Low cetane numbers usually cause incomplete combustion, which is represented by different symptoms, from increased fuel consumption and high engine noise to cold start problems and increased emissions. To increase the cetane number, or better to make diesel-biodiesel fuel blends to achieve shorter ignition delay times, different cetane improving additives such as nitrates, peroxides, aldehydes and tetra-azoles can be added [3].

Lubrication improver additives are additives that reduce mechanical wear in fuel injectors and extend the life of fuel system components. Typical lubrication improvers include fatty acid esters (including FAME), unsaturated fatty acid dimers, aliphatic amines, and long-chain monocarboxylic acids [1, 3].

The fuel mixture obtained by blending biodiesel fuel obtained from waste frying oil and dehydrated fusel oil, which is the residue of sugar beet, at the rates of 90% and 10% is coded as B90F10. Equal amounts of n-octadecane and diethylenamine additives were added to this fuel mixture and four different fuel mixtures (1000-2000-3000-4000 ppm) were obtained. The proportions of the additives were determined by reviewing the literature [38, 39]. Some properties of the test fuels are given in Table 1.

**Table 1.** Properties of fuels and mixtures used in the experiment

| Fuels | Kinematic Viscosity ($mm^2/s$, at 40 °C) | Density ($g/cm^3$, at 15 °C) | Lower Heating Value (kJ/kg) |
|---|---|---|---|
| Diesel | 3.02 | 0.8342 | 43.524 |
| Biodiesel | 5.17 | 0.8831 | 37.953 |
| Fusel oil | 2.41 | 0.8356 | 26.83 |
| B90F10 | 4.79 | 0.8786 | 36.84 |

### 2.2. Engine and Test Equipment

The engine experiments were carried out at 1400, 1600, 1800, 2000, 2200, 2400, 2400 and 2600 rpm at full load in a four cylinder, four stroke, 17:1 compression ratio, turbocharged, direct injected CI engine with an engine displacement of 3.9 liters. The engine test rig is shown in Figure 1 and the specifications of the engine, hydraulic dynamometer and emission measurement devices are shown in Table 2, 3 and 4, respectively [40].

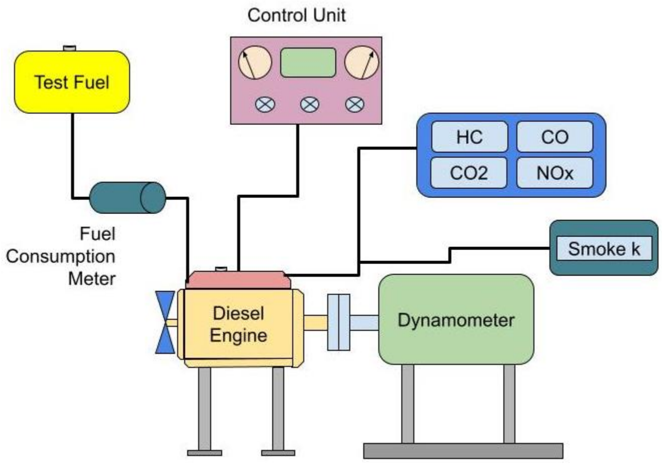


**Figure 1.** Engine test rig

**Table 2.** Technical specifications of the engine [40]

| Technical Specifications | Engine Features |
|---|---|
| Cylinder number | 4 |
| Cylinder Bore (mm) | 104 |
| Stroke (mm) | 115 |
| Total Cylinder Volume ($cm^3$) | 3908 |
| Compression Ratio | 17:1 |
| Max. Torque (Nm at 1600 rpm) | 295 |
| Max. Power (kW at 2500 rpm) | 62.5 |
| Max. Speed (rpm) | 2700 |
| Cooling System | Water Cooling |
| Injection Advance (°) | 18 |
| Injection Pressure (Bar) | 230 |
| Fuel Pump Type | Distributor |

**Table 3.** Characteristic features of the dynamometer [40]

| Technical Specifications | Dynamometer |
|---|---|
| Max. Braking Power (HP) | 160 |
| Max. Braking Torque (Nm) | 750 |
| Max. Speed (rpm) | 6000 |
| Required Water Amount ($m^3$) | 2.4 |
| Rotation Direction | Single |
| Motor Mounting Flange | Even |

Table 4. Specifications of the emission device [40]

| Emission | Measuring range | Accuracy |
|---|---|---|
| CO | 0–10 (% vol.) | ±0.01 |
| HC | 0–2000 (ppm) | ±1 |
| $O_2$ | 0–21 (% vol.) | ±0.01 |
| NOx | 0–5000 (ppm) | ±1 |
| k | 0–20 ($m^{-1}$) | ±0.01 |

Table 5. Flowmeter specifications [40]

| Flowmeter | Features |
|---|---|
| Measuring range ($m^{-1}$) | 0.005–1.5 |
| Max. pressure (bar) | 100 |
| Body, gear and shaft | AISI316 |
| Accuracy (±%) | 0.5 |
| Output signal | NPN |
| Voltage (VDC) | 5–24 |

Technical specifications of the Bass Instrument brand flow meter used in fuel consumption measurement are shown in Table 5. Two flow meters were used for fuel consumption measurement, one for the outgoing line and one for the return line. In the study, the engine power (Pe), specific fuel consumption (be) and thermal efficiency ($\eta t$) of the engine were measured and calculated as stated in the literature [8].

## 3. RESULTS AND DISCUSSION

According to the results of engine experiments performed on biodiesel-fusel fuel blends, a mixture of 90% biodiesel and 10% fusel oil by volume (B90F10) was determined as the optimum mixture. Additives of diethylenamine (lubricity improver) and n-octadecane (cetane improver) were added to the B90F10 blend in equal amounts as 500–1000–1500–2000 ppm respectively and experiments were carried out to determine the performance and emission values at engine speeds of 1400 to 2600 rpm in increments of 200 at full load [40].

The engine torque changes of the blends obtained with the additives added to B90F10 fuel are shown graphically according to the engine speed at full load (Figure 2). B100 fuel exhibited an average of 10% lower values compared to Diesel fuel data. The highest engine torque values were obtained in mixtures with 3000 and 4000 ppm additives, where the additives were also high, and torque values above 250 Nm were obtained in the 1600-2200 rpm range. The highest torque values at all speeds were obtained with the 3000 ppm blend while the lowest torque values were obtained with pure biodiesel (B100) fuel.

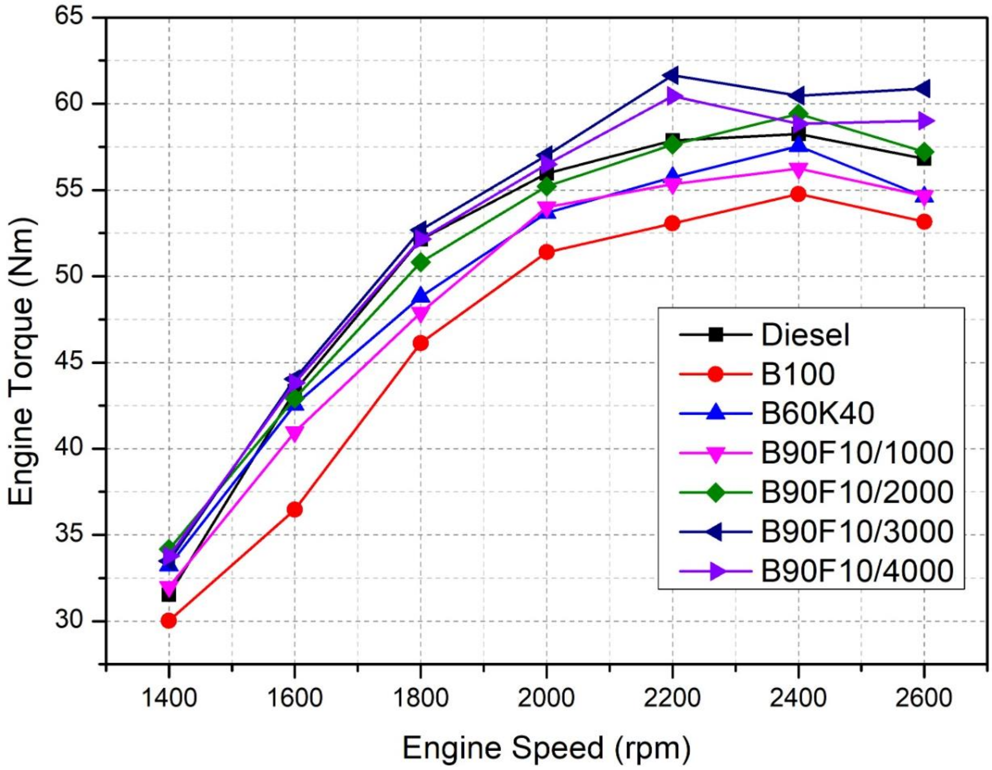


**Figure 2.** Engine torque variations according to engine speed

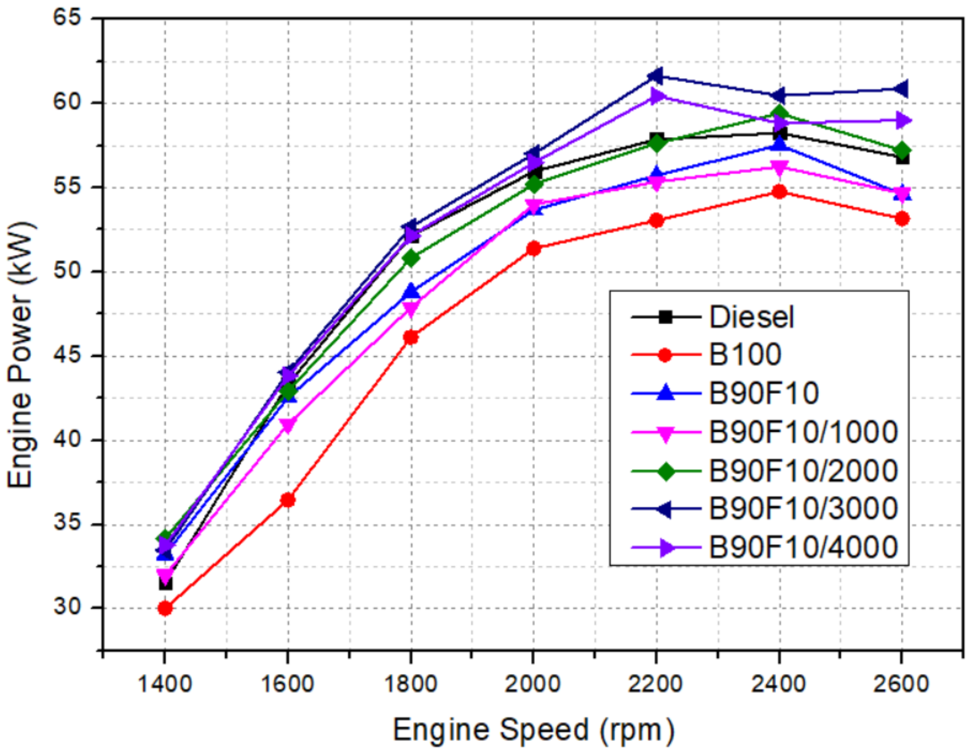


**Figure 3.** Changes in engine power

The engine power variations of Diesel, B100, and B90F10 blends with additives are given in Figure 3. B100 fuel exhibited approximately 10% lower values than Diesel fuel. In the engine power graph, where a similar change was observed as in the engine torque graph, the highest values were obtained with 3000 ppm additive mixture. The highest engine power value was obtained with B90F10/3000 blend with 61.64 kW at 2200 rpm, while the lowest engine power value was 30.03 kW at 1400 rpm with B100 fuel.

SFC is a value that is used to measure fuel economy. The specific fuel consumption of the internal combustion engines is desired to be low. The SFC (g/kWh) change graphs of the fuels are shown in Figure 4. According to the graph, the lowest SFC value is approximately 224 g/kWh in the 1600-2200 rpm range, while the SFC of B100 fuel with low calorific value is obtained at the highest values. B100 fuel exhibited about 20% higher SFC than diesel fuel. The SFC values of B100 fuel are 314.87, 306.28 and 292.1 g/kWh at 1600-1800 and 2000 rpm respectively.

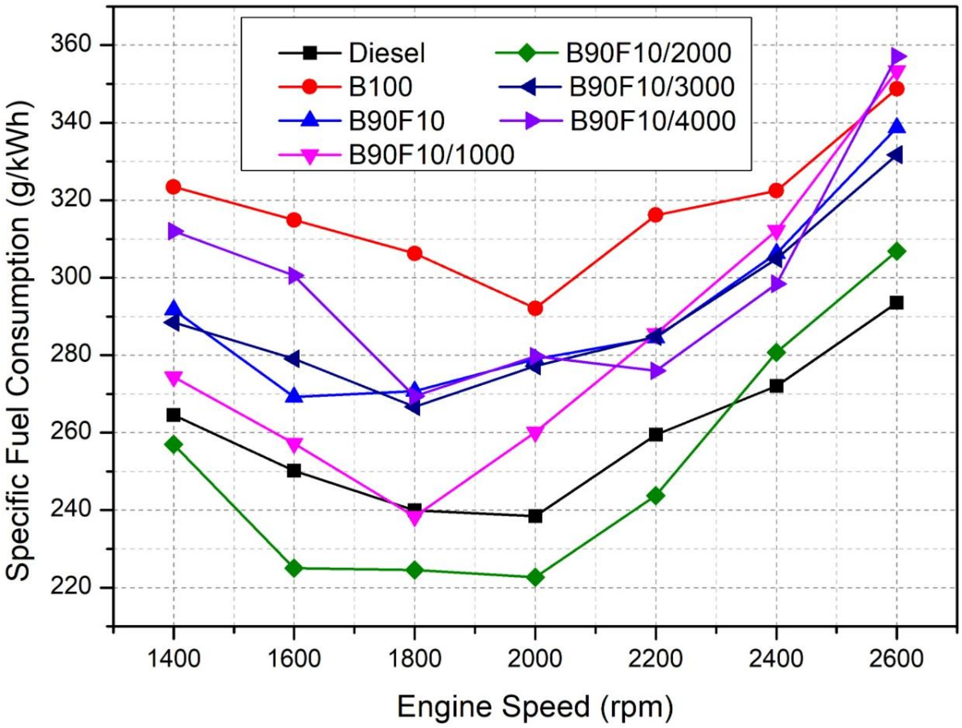

**Figure 4.** Changes in SFC value according to engine speed

The effect of different amounts of additives added to the B90F10 mixture on the thermal efficiency of the engine is shown in Figure 5. The maximal thermal efficiency value of 43% was obtained with B90F10/2000 blended fuel in the 1600-2000 rpm range, while the nethermost thermal efficiency value was obtained with B100 fuel with roughly 30%. The low values of thermal efficiency at 1400 rpm can be explained by the excess heat transfer to the cylinder walls. The increase up to 2000 rpm is due to the decrease in heat transfer to the cylinder walls and the turbulence effect due to the increase in piston speed. The decrease up to 2600 rpm can be explained by the shortening of the combustion duration and the deterioration of combustion due to the increase in speed.

In ICEs, the EGT value is a data that is controlled by one or more sensors and evaluated by the engine control unit to control the operation of the diesel particulate filter in order to repress fuel consumption and exhaust emissions. Figure 6 shows the EGT changes of the fuels graphically. The highest exhaust gas temperature was 495 °C with B90F10/4000 fuel at 2600 rpm, while the lowest value was 370 °C at 1400 rpm with diesel fuel. At high speeds, EGT increases as the combustion frequency increases. At low speeds, EGT is lower than at high speeds due to lack of turbulence and heat loss to the cylinder walls.

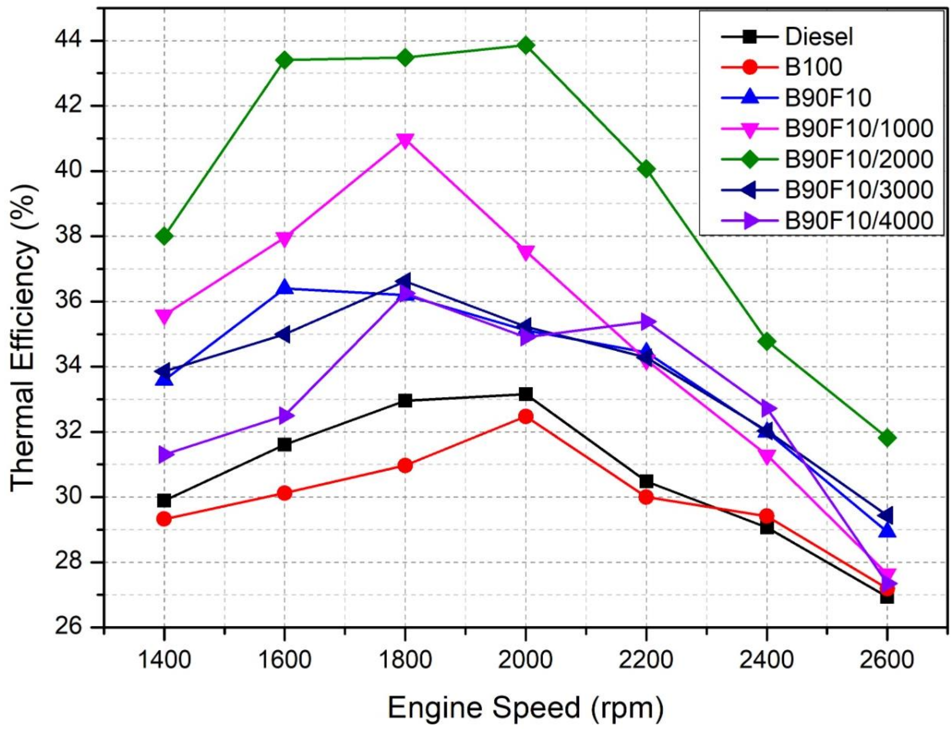


**Figure 5.** Thermal efficiency changes of B90F10 fuel with additives according to the engine speed

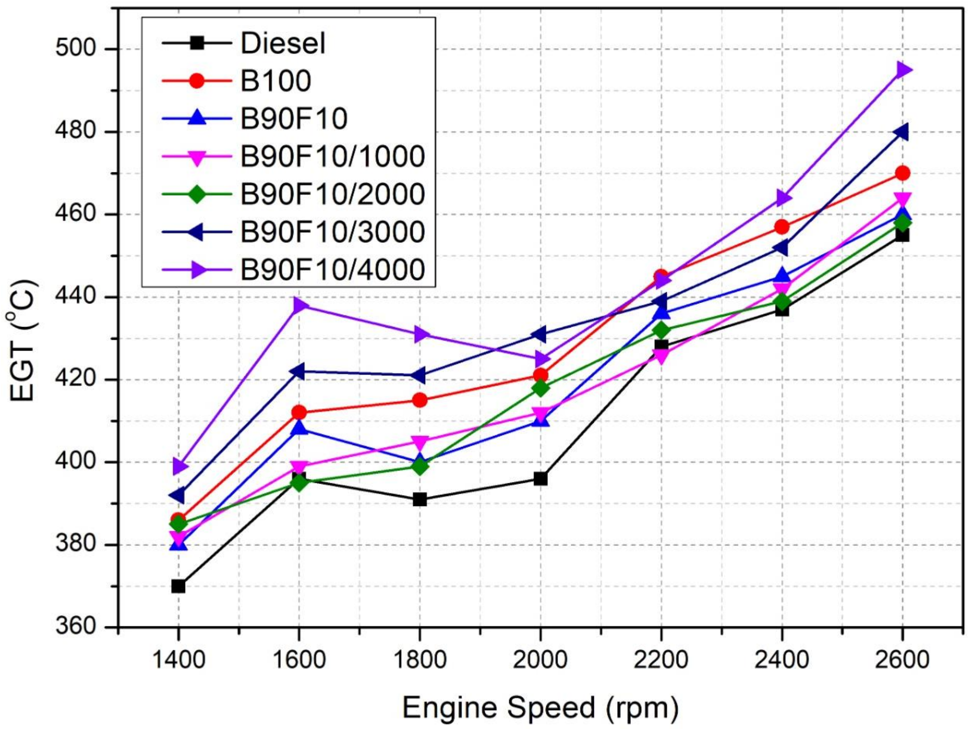


**Figure 6.** Exhaust gas temperature (EGT) changes of B90F10 fuel with additives according to speed

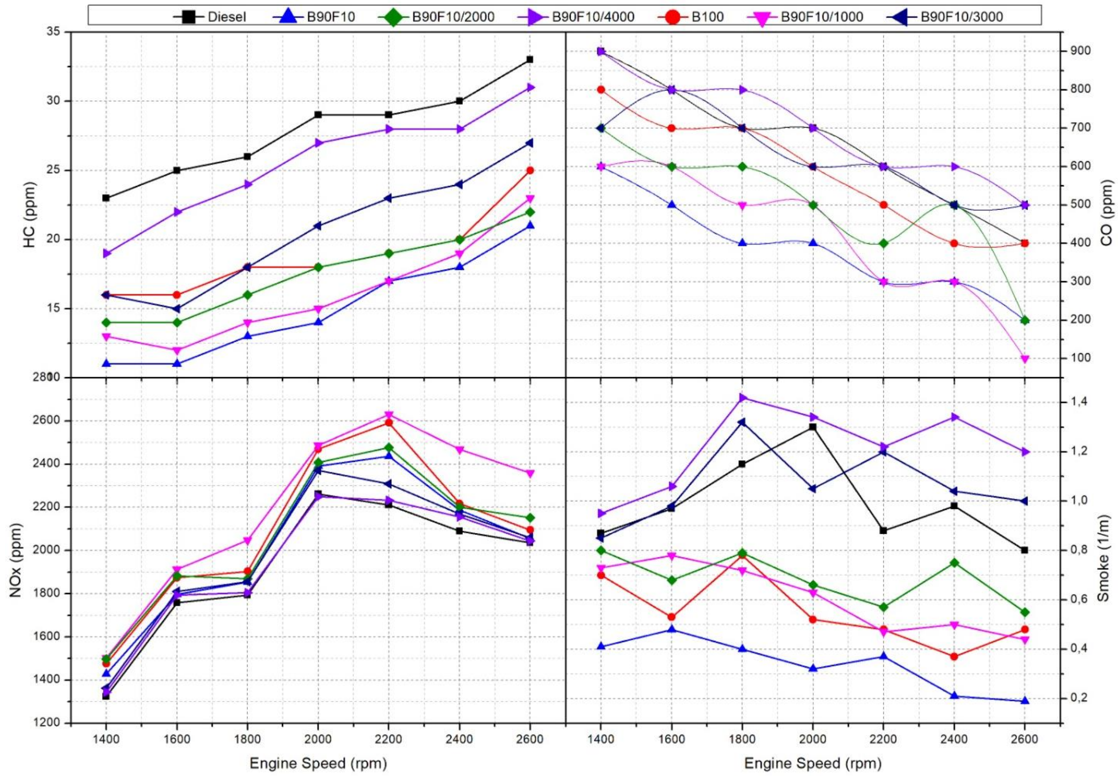


**Figure 7.** CO emission changes of B90F10 fuel with additives according to speed

The test results of HC, CO, NOx and soot emissions of biodiesel-fusel blend fuel and blend fuels with additives are given graphically in Figure 7. HC and CO gases are harmful emissions that are not wanted to be released in internal combustion engines. The changes in CO and HC emissions, which indicate a poor combustion reaction and high fuel consumption. Diesel and B90F10/4000 fuels had the highest CO emission values. By adding alcohol to biodiesel fuel, CO emissions decreased because combustion reactions occurred more smoothly. For this reason, the fuels with the lowest CO emissions were B90F10 and B90F10/1000 blends. Similarly, HC emissions were also low in B90F10 and B90F10/1000 blends, while the highest HC emission values were measured in diesel and B90F10/4000 fuels. Since diesel engines operate with excess air coefficient, that is, lean mixture, CO emissions are quite low. Since it is very low in this study, the change in CO emissions is not enough to draw a meaningful conclusion. Ağbulut et al. [41], found that fusel alcohol led to a decrease in CO emissions in their study.

HC emissions, on the other hand, increased in parallel with the increase in speed. Because the amount of fuel sent to the cylinder increases with the increase in speed and the mixture becomes richer. Both rich mixture and shortening of combustion duration cause combustion to deteriorate, resulting in high HC emissions.

As a result of the combustion reaction in diesel engines, smoke emissions are also released, which have a high negative impact on nature and consist mostly of carbon and a small amount of hydrogen and oxygen [42]. Soot emissions, like NOx emissions, are closely related to the air-fuel ratio and combustion temperature (more than 1600 K). In addition, studies in the literature have stated that soot emission formation is largely dependent on fuel composition, that oxygenates have a positive effect in reducing soot formation, and that preventing the formation of overly rich regions in the cylinder is important for soot formation processes [43-45]. Smoke emissions tend to increase with increasing speed. As speed increases, the mixture becomes richer and combustion worsens, resulting in increased smoke emissions. The changes in NOx and soot emission values of fuels depending on engine speed are seen on the right and left at the bottom of the graph in Figure 7. The NOx emissions were lowest with diesel fuel and highest with B100 and B90F10/1000 fuels. The highest soot emissions according to engine speed were obtained with B90F10/4000, B90F10/3000 and diesel fuels. Çiftçi et al. [46], said that fusel alcohol led to a reduction in NOx emissions.

Since NOx emissions are mostly formed by the effect of temperature, as the amount of fuel entering the cylinder increases, NOx emissions increase due to the increase in the temperature inside the cylinder. However, after 2400 rpm, NOx emissions decrease despite the increase in fuel. The reason for this can be interpreted as the incomplete combustion due to the lack of oxygen in the cylinder due to the enrichment of the mixture in the diesel engine and the shortening of the combustion period. The increase in HC emissions also supports this phenomenon. The use of catalytic converters and particulate filters reduces nitrogen oxide (NOx) and particulate matter (PM) emissions in diesel engines, but negatively affects engine performance and fuel economy [47].

## 4. CONCLUSIONS AND RECOMMENDATIONS

In order to decipher the effects of diesel, biodiesel and B90F10 fuels with added additives on engine performance and exhaust emissions, experiments were executed at engine speeds of 1400 to 2600 rpm in increments of 200 at full load on a 17:1 compression ratio, four cylinders, four stroke, turbocharged, 3.9 liter, direct injection CI engine.

The engine power values of B90F10/4000, B90F10/3000 and diesel fuels with high thermal value and viscosity were higher than the other fuels. Similar results were obtained for engine torque and power. When the SFC changes of the fuels are analysed, high values are obtained with B100, B90F10/4000 and B90F10/3000 fuels, while relatively low values are obtained with diesel and B90F10/2000 fuels due to viscosity, thermal and density values. Since the end of combustion temperature values increase on the grounds that the presence of oxygen in B100 fuel, exhaust gas temperature values also increase and the addition of fusel as alcohol to biodiesel fuel also causes an increase in exhaust gas temperatures.

CO and HC formation increases in exhaust emissions due to insufficient temperature and oxygen in the combustion chamber environment. Oxygenated fuels reduce the possibility of CO and HC emissions as well as soot emissions. The negative side of having oxygen in the fuel is that it increases the end-of-combustion temperature and causes NOx emissions.

When the engine performance and exhaust emission results of biodiesel and diethylenamine and n-octadecane blended fuels were examined, it was observed that the B90F10/2000 blend showed values close to diesel fuel in terms of SFC, engine power, engine torque and thermal efficiency, and had satisfying emission values in terms of emissions. In this context, it was concluded that it is possible to recycle biodiesel fuel obtained from waste cooking oils and fusel oil, which is sugar beet residue, and to use this fuel in existing CI engines without any problems by adding a total of 2000 ppm diethylenamine and n-octadecane additive to the B90F10 mixture.

In the next stage, it can be investigated whether there will be changes in engine performance and emissions by adding additives at different rates instead of adding them at equal rates. Residual cooking oils can be categorized according to the places where they are supplied or their intended use, and the changes in the properties of biodiesel fuels to be obtained from them can be investigated.

## DECLARATION OF ETHICAL STANDARDS

The authors declare that they have carried out this original study in compliance with all ethical rules, including authorship, citation, data reporting and publishing original research.

## CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mahmut ÜNALDI: Project administration, Conceptualization, Investigation, Methodology, Writing – review & editing, Validation.

Ayhan UYAROĞLU: Investigation, Writing – review & editing, Formal analysis, Methodology, Resources.

## DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## DATA AVAILABILITY

Data supporting the findings of this study can be obtained from the corresponding author with requests to assist in scientific studies.

## 5. REFERENCES

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