Türk Tarım ve Doğa Bilimleri Dergisi 9(2): 282–294, 2022
https://doi.org/10.30910/turkjans.1013070

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JOURNAL of AGRICULTURAL
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Research Article

Dizel ve Aspir Biyodizel Karışımına Eklenen Bazı Katkı Maddelerinin Motor Performansına Etkilerinin Belirlenmesi

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Received: 21.10.2021 Received in Revised: 09.02.2022 Accepted: 09.02.2022

Öz

Bu çalışmada, biyodizel (B_{100}) yakıtı ve hacimsel olarak farklı oranlarda motorin (M_{100}), biyodizel (B) ve n-bütanol (BÜ) veya n-pentanol (P) ihtiva eden alternatif karışım yakıtlarının (motorin/biyodizel/ n-bütanol ve motorin/biyodizel/ n-pentanol), yakıt özelikleri ve motor performans değerleri referans yakıt motorin (M_{100}) ile karşılaştırmalı olarak değerlendirilmiştir. Araştırmada ayrıca karışım yakıtlarına 2000 ppm konsantrasyonunda 2-etilhekzil nitrat (EHN) setan iyileştirici katkısı ilave edilerek EHN'nin yakıt özellikleri ve motor performans değerlerine etkileri incelemiştir. Tüm yakıt ve karışımlarına ait motor performans testleri, dört silindirli, dört zamanlı ve direkt enjeksiyonlu bir dizel motorda farklı hızlarda ve tam yük koşullarında gerçekleştirilmiştir.

Araştırma sonuçlarına göre motorin, biyodizel ve karışım yakıtlarına ait yakıt özelliklerinin, biyodizel ve motorin yakıtı standartlarıyla uyum içerisinde olduğu tespit edilmiştir. Tüm yakıtlar için motor performans sonuçları değerlendirildiğinde, maksimum motor gücü, maksimum motor torku ve minimum özgül yakıt tüketimi sırasıyla 63.3 kW (2100 min^{-1}), 339.65 Nm (1300 min^{-1}) ve 256.53 g kWh^{-1} (1600 min^{-1}) M_{100} yakıtında elde edilmiştir. Karışım yakıtları arasında motor performansı açısından M_{100} yakıtına en yakın sonuçlar $M_{85}B_{10}P_5$ + EHN yakıtından elde edilmiştir. Ayrıca n-pentanol içeren karışım yakıtları, n-bütanol içeren karışım yakıtlarına göre daha iyi performans sonuçları göstermiştir.

Anahtar kelimeler: Aspir, biyodizel, bütanol, 2-etilhekzilnitrat, 1-pentanol, motor performansı

Determination of the Effects of Some Additives in Diesel and Safflower Biodiesel Blends on Engine Performance

Abstract

In this study, fuel properties and engine performance values of biodiesel fuel (B_{100}) and alternative blended fuels containing different volumetric amounts of diesel (M_{100}), biodiesel (B_{100}) and n-butanol (BU) or n-pentanol (P) (diesel / biodiesel / n-butanol and diesel / biodiesel / n-pentanol) were evaluated in comparison to the reference diesel fuel (M_{100}). In addition, the effects of EHN on fuel properties and engine performance values have been examined by adding 2-Ethylhexyl nitrate (EHN) cetane improver additive to blended fuels at a concentration of 2000 ppm. Engine performance tests of all fuels and blends were carried out in a four-cylinder, four-stroke, and direct injection diesel engine at different speeds and full load conditions.

Fuel properties of diesel, biodiesel, and blended fuels have been determined to be in accord with the biodiesel and diesel fuel standards. When the engine performance results for all fuels were evaluated, the maximum engine power, engine torque, and the minimum specific fuel consumption values were realized in M_{100} fuel with values of respectively 63.3 kW (2100 min^{-1}), 339.65 Nm (1300 min^{-1}), and 256.53 g kWh^{-1} (1600 min^{-1}). Among the blended fuels, the closest results to M_{100} fuel in terms of engine performance were obtained from $M_{85}B_{10}P_5$ + EHN fuel. Besides, mixed fuels containing n-pentanol showed better performance results than blended fuels containing n-butanol.

Key words: Safflower, biodiesel, n-butanol, 2-Ethylhexyl nitrate (EHN), n-pentanol, engine performance.

Introduction

Instead of thinking about the amount and consumption of energy, people nowadays think about how to use it and how to provide it in more cost-effective ways. This new understanding predicts "healthy environment"," energy safety" and "energy diversity" policies. In today's world global warming and climate change cause many damages and these new policies help to lower the ecological and environmental harms (Güner and Turan, 2017).

Fossil-based (non-renewable) energy resources, such as oil, natural gas, and coal have a significant share in the imports of many countries. However, countries have turned to the production and use of renewable energy resources due to the instability in the prices of fossil-based energy resources, reducing their dependence on such energies, increasing their energy diversity, environmental problems ranging from air, water, and soil pollution caused by such energy resources to the destruction of vegetation and animals, and the understanding that they will be depleted soon (Anonim, 2012; Hiçdurmaz, 2019).

Biofuels, the general name of solid, liquid, or gaseous fuels that are produced by different methods from agricultural biomass, have standardized and commercial properties (Öğüt, 2007). Vegetable oils, biodiesel produced from these vegetable oils, and bio alcohols produced from biomass are the leading biofuels that can be used as an alternative to liquid fuels such as diesel and gasoline (Yılmaz and Atmanlı, 2016). Most of the studies on the improvement of fuel properties of vegetable oils consist of reducing the viscosity of these oils. Thermal and chemical methods are used to reduce the viscosity of vegetable oils. Chemical methods are defined as thinning, microemulsion formation, pyrolysis, and internal ester exchange (transesterification) (Çıldır and Çanakçı, 2006). The transesterification method is more preferred in biodiesel production because it is more suitable than other methods in terms of reaction time and efficiency. Transesterification is defined as the re-esterification of oils by reacting with alcohol in the presence of a catalyst (Öğüt and Oğuz, 2006).

Since alcohol fuels are produced as a result of anaerobic fermentation of agricultural waste biomass without being too dependent on food plants, it does not pose a problem with its availability (B. R. Kumar and Saravanan, 2016). Alcohols are considered a suitable diesel fuel additive because they are in the liquid phase and contain high levels of oxygen (S. Kumar et al., 2013). Alcohol fuels in the high alcohol group can provide additional advantages over low carbon alcohols when evaluated in terms of additives to diesel fuel. These advantages can be listed as follows; (Yeşilyurt, 2020).

- Energy content and cetane number values are higher.
- Due to their better blending stability, they can be mixed with diesel oil at high mixing ratios.
- Due to their weaker hygroscopic nature (low corrosive effect), they do not damage the transmission lines together with the fuel injection system.
- They are safer in terms of storage and use due to their higher flash points.
- During their production, energy consumption values are lower compared to low alcohols.

In this study, biodiesel (B_{100}) fuel and alternative blended fuels (diesel/biodiesel/n-butanol and n-butanol) containing diesel (M_{100}), biodiesel (B), and n-butanol (BU) or n-pentanol (P) in different volumetric ratios were investigated. Fuel properties and engine performance values of diesel/biodiesel/ n-pentanol, are aimed to be evaluated comparatively with the reference fuel diesel (M_{100}). In the study, the effects of EHN on engine performance were investigated by adding 2-Ethylhexyl nitrate (EHN) cetane improver additive at a concentration of 2000 ppm to the blend fuels. Linas variety safflower is a newly developed variety and there is no biodiesel study on this subject. High alcohol additives were used to improve the kinematic viscosity and cold flow properties of safflower biodiesel. Since it was recommended to use less than 20% of these high alcohols in previous studies, the rates were determined accordingly. Since high alcohol addition reduces the cetane number, the effect of the EHN additive as a cetane improver was investigated.

Materıal and Method

Biodiesel Production Facility

In the production of safflower (linas variety) oil methyl ester (biodiesel), PLC supported pilot production facility which was established within the scope of DPT 2004/7 project (Öğüt, H., et al., 2004) at Selçuk University Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering was used. It has a pilot production facility and a production capacity of 100 liters and consists of 10 different units.

Preparation of fuel blends

Blended fuels without EHN were prepared by homogeneously mixing diesel, biodiesel, and n-butanol and n-pentanol, which are in the high alcohol group, at certain volumetric ratios with a homogenizer. In addition, mixed fuels with EHN addition were obtained by adding 2000 ppm cetane developer 2-Ethylhexyl nitrate (EHN) to these blended fuels, which were re-prepared at the same volumetric proportions. Diesel fuel is symbolized as "M", safflower biodiesel "B", n-butanol "BU", n-pentanol "P", and 2-ethyl hexyl nitrate "EHN" for ease of use. The numbers added in the form of indices under the symbols represent the mixing ratios of the fuels.

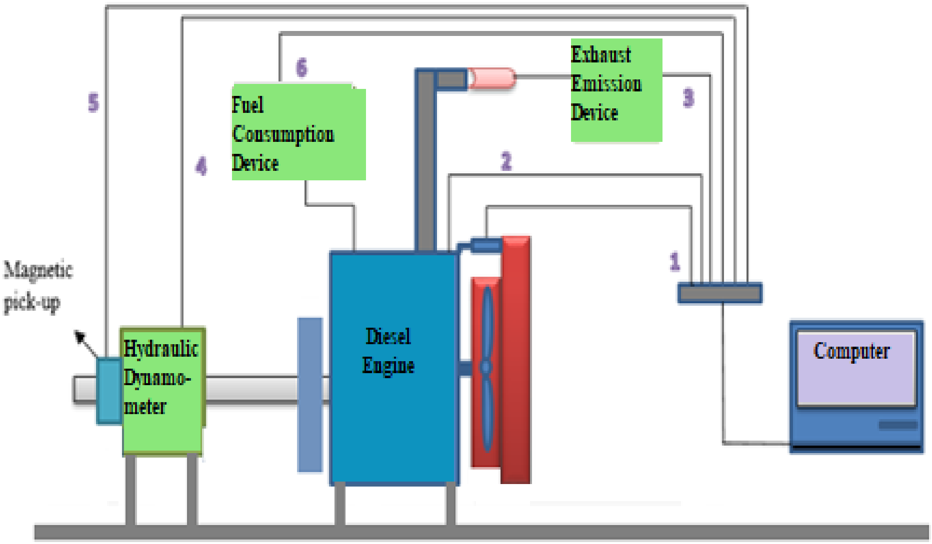
Engine Testing

The engine tests carried out to determine the engine performance values of diesel, safflower biodiesel, and blended fuels were carried out in the engine test set up within the Department of Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, Selçuk University. Engine performance tests of 26 different fuels were carried out in a 4-stroke, 4-cylinder, direct injection diesel engine with a turbocharger system. The test setup consists of engine, hydraulic dynamometer, magnetic pick-up, S type load cell, fuel meter, and control unit.

The engine speed, torque, and power values, as well as fuel consumption, engine oil pressure and temperature, coolant inlet and outlet temperature, engine coolant flow rate, and exhaust gas temperature values can be measured and the data can be recorded in real-time by the test setup and transferred to the computer automatically. The technical specifications of the engine used in the trials and the schematic appearance of the engine test setup are shown in Table 1 and Figure 1, respectively.

Table 1. Technical specifications of the diesel engine used in the research

Brand and model	Tümosan 4DT-39T-185C
Rated Power @2300 rpm	85 HP
Maximum torque	340 Nm
Total Engine Capacity	3908 cm^3
Diameter Stroke	104 mm x 115 mm
Number of Cylinders	4
Minimum Specific Fuel Consumption	160 g HPh^{-1}
Aspiration	Turbocharger
Number of Valves Per Cylinder	2
Compression Ratio	17:01
Combustion System	Direct Injection
Cooling system	Water Cooled



1-Engine water temperature measurement
2- Engine oil temperature measurement
3- Exhaust emissions measurement
4- Torque measurement
5- Speed measurement
6- Fuel consumption measurement

Figure 1. Schematic view of the engine test setup

Process Steps

The study consists of the following steps. These;

- Obtaining oil from safflower seeds,
- Production of safflower oil methyl ester (biodiesel) from the obtained crude safflower (Linas variety) oil by transesterification method,
- Procurement of alcohol fuels butanol and pentanol and cetane improver 2-Ethylhexyl nitrate (EHN) to be used in the preparation of mixture fuels from the market,
- Diesel, biodiesel (10% and 20%), and n-butanol in certain proportions by volume
- Preparation of mixtures ($M_{85}B_{10}BU_5$, $M_{80}B_{10}BU_{10}$, $M_{70}B_{10}BU_{20}$, $M_{75}B_{20}BU_5$, $M_{70}B_{20}BU_{10}$, $M_{60}B_{20}BU_{20}$) containing diesel, biodiesel (10% and 20%) and n-butanol (5%, 10% and 20%) by volume,
- Preparation of mixtures containing diesel, biodiesel (10% and 20%) and n-pentanol (5%, 10% and 20%) by volume $M_{85}B_{10}P_5$, $M_{80}B_{10}P_{10}$, $M_{70}B_{10}P_{20}$, $M_{75}B_{20}P_5$, $M_{70}B_{20}P_{10}$, $M_{60}B_{20}P_{20}$),
- Obtaining mixed fuels with EHN addition by adding 2000 ppm 2-Ethylhexyl nitrate (EHN) to all prepared fuel mixtures ($M_{85}B_{10}BU_5$+EHN, $M_{85}B_{10}P_5$+EHN, $M_{80}B_{10}BU_{10}$+EHN, $M_{80}B_{10}P_{10}$+EHN, $M_{70}B_{10}BU_{20}$+EHN, $M_{70}B_{10}P_{20}$+EHN, $M_{75}B_{20}BU_5$+EHN, $M_{75}B_{20}P_5$+EHN, $M_{70}B_{20}BU_{10}$+EHN, $M_{70}B_{20}P_{10}$+EHN, $M_{60}B_{20}BU_{20}$+EHN, $M_{60}B_{20}P_{20}$+EHN)
- Determination of fuel properties of reference fuel diesel, biodiesel, and blended fuels,
- Performing engine performance tests of reference fuel diesel, biodiesel, and blended fuels.

Results and Discussion

Fuel Properties

Tests were carried out to determine the compliance of the obtained safflower biodiesel with TS EN 14214 and diesel fuel with TS 3082 EN 590 standards, and the results of the analyzes were given in Table 2 and were determined that the fuel properties complied with the standards. The kinematic viscosity, density, calorific values, flash point values decreased in fuels containing butanol and pentanol. EHN contribution, on the other hand, was effective in increasing the calorific values and cetane numbers.

Table 2. Fuel properties of safflower biodiesel

	Kinematic viscosity ($mm^2\ s^{-1}$)	Density ($g\ cm^{-3}$)	Water content (ppm)	Calorific Values ($MJ\ kg^{-1}$)	Flash Point (°C)	CFPP (°C)	Cloud Point (°C)	Pour Point (°C)	Cetane Numbers	Copper Strip Corrossion
M_{100}	2.97	0.830	48	45.17	68	-22	-13.9	>-20	55.4	1a
B_{100}	4.57	0.8885	363	40.67	160	-11	-2.6	-15	53.6	1a
$M_{85}B_{10}BU_5$	2.81	0.8379	368	43.84	38	-13	-3.2	>-20	52.3	1a
$M_{85}B_{10}BU_5$+EHN	2.8	0.8377	358	44.01	39	-11	-2.1	>-20	54.9	1a
$M_{80}B_{10}BU_{10}$	2.66	0.8368	489	43.24	37	-12	-3.2	>-20	51.9	1a
$M_{80}B_{10}BU_{10}$+EHN	2.65	0.8365	470	43.43	38	-11	-2.2	>-20	54.7	1a
$M_{70}B_{10}BU_{20}$	2.54	0.8339	499	42.40	36	-12	-3.2	>-20	49.2	1a
$M_{70}B_{10}BU_{20}$+EHN	2.52	0.8337	425	43.21	37	-11	-2	>-20	49.7	1a
$M_{75}B_{20}BU_5$	2.81	0.8384	347	43.23	39	-13	-3.2	>-20	52.1	1a
$M_{75}B_{20}BU_5$+EHN	2.76	0.8382	325	43.86	40	-11	-2.5	>-20	55.3	1a
$M_{70}B_{20}BU_{10}$	2.79	0.8375	354	42.78	38	-12	-2.5	>-20	51.3	1a
$M_{70}B_{20}BU_{10}$+EHN	2.75	0.8372	347	43.31	39	-10	-1.4	>-20	53.4	1a
$M_{60}B_{20}BU_{20}$	2.62	0.8351	410	41.42	37	-12	-3.4	>-20	48.8	1a
$M_{60}B_{20}BU_{20}$+EHN	2.57	0.8348	406	42.10	38	-11	-2.3	>-20	49.3	1a
$M_{85}B_{10}P_5$	2.83	0.8388	332	43.91	50	-14	-3.3	>-20	52.5	1a
$M_{85}B_{10}P_5$+EHN	2.82	0.8382	326	44.10	51	-12	-2.4	>-20	55.8	1a
$M_{80}B_{10}P_{10}$	2.76	0.8375	350	43.50	49	-13	-3.3	>-20	52.2	1a
$M_{80}B_{10}P_{10}$+EHN	2.74	0.8373	333	43.96	50	-11	-2.6	>-20	55.4	1a
$M_{70}B_{10}P_{20}$	2.75	0.8347	384	42.68	48	-13	-3.5	>-20	49.5	1a
$M_{70}B_{10}P_{20}$+EHN	2.66	0.8342	363	42.77	49	-10	-2.7	>-20	50.4	1a
$M_{75}B_{20}P_5$	2.82	0.8383	426	43.84	51	-14	-3.5	>-20	52.5	1a
$M_{75}B_{20}P_5$+EHN	2.78	0.8381	397	43.96	52	-12	-2.2	>-20	55.6	1a
$M_{70}B_{20}P_{10}$	2.81	0.8379	439	43.64	50	-13	-4.2	>-20	51.5	1a
$M_{70}B_{20}P_{10}$+EHN	2.8	0.8375	403	43.84	51	-12	-2.9	>-20	53.9	1a
$M_{60}B_{20}P_{20}$	2.71	0.8367	493	42.49	49	-13	-4.2	>-20	49.3	1a
$M_{60}B_{20}P_{20}$+EHN	2.7	0.8362	461	42.88	50	-11	-3	>-20	50.7	1a

Engine Performance Test Results

Effective power

The variation of effective power (kW) values obtained depending on the engine revolution speed (min^{-1}) in the engine performance tests performed under full load conditions of diesel (M_{100}), biodiesel (B_{100}), and blended fuels (EHN additive- non-additive) are given in Figures 2, 3. and 4. The torque values of the engine speed at which the maximum power is obtained are shown in Figure 5.

If the effective engine power values of M_{100}, B_{100}, and blended fuels are examined in general depending on the engine speed, it is seen that the maximum engine power is obtained from M_{100} fuel with an average value of 63.3 kW (2100 min^{-1} engine speed).

When the effective engine power values of the B_{100} fuel are compared to the values of the M_{100} fuel, it has been determined that there is a certain decrease in engine power at all revolutions. At the engine speed which resulted in the maximum power(2100 min^{-1}), the effective power value of B_{100} fuel decreased by 5.94% compared to M_{100} fuel and was realized as 59.55 kW. This decrease in power value can be explained by the fact that the determined density and viscosity values of safflower oil methyl ester (B_{100}) are higher than that of diesel oil (M_{100}), and its calorific value is lower. İmal et al., (2017) and Erol (2019) stated that high viscosity and density values prevent the fuel from atomizing via the injector system and spraying as desired, which causes the ignition delay time that prolongs the combustion time and worsens the combustion.

It has been determined that, in the blended fuels containing the same proportion of butanol or pentanol by volume (with or without EHN additives), as the biodiesel ratio increases (by 10 and 20%), the power values of the fuels decrease at different rates. For example, at 2100 min^{-1} engine speed at which maximum engine power is obtained, the power values of all blended fuels containing B_{20} showed lower values on average by 0.66% to 4.75% compared to fuels containing B_{10}.

According to the research results; It has been determined that the power values of all blended fuels (with and without EHN additives) are lower between 1.46% and 15.72% compared to M_{100} fuel at 2100 min^{-1} engine speed at which maximum power is obtained. While the closest result to M_{100} fuel was obtained from $M_{85}B_{10}P_5$+EHN fuel with 62.38 kW value, the lowest result was obtained from $M_{60}B_{20}BU_{20}$ fuel with a 53.36 kW value. It is thought that these power reductions, which are detected at certain rates in all blended fuels compared to M_{100} fuel, are due to the lower energy contents (calorific value) of these fuels compared to M_{100} fuel. The results we obtained are similar to the studies conducted by (Atmanlı, 2016; Campos-Fernández et al., 2012; Yeşilyurt et al., 2018).

It was determined that fuels containing pentanol showed higher power values between 1.3% and 8.9% compared to fuels containing butanol. This result can be explained by the lower calorific value and higher cetane number of pentanol than butanol.

It has been determined that there is a certain (1.3% to 10%) decrease in the effective power values as the alcohol content increases in all blended fuels containing both butanol and pentanol. Campos-Fernández et al. (2012); Yeşilyurt et al. (2018) reported a similar relationship in their studies.

It has been determined that the EHN added to the blended fuels reduces the power values between 0.72% and 7.16%. Atmanlı (2016); İleri (2016) stated that fuels with EHN additives show effective power values close to diesel and EHN additive is effective in increasing power.

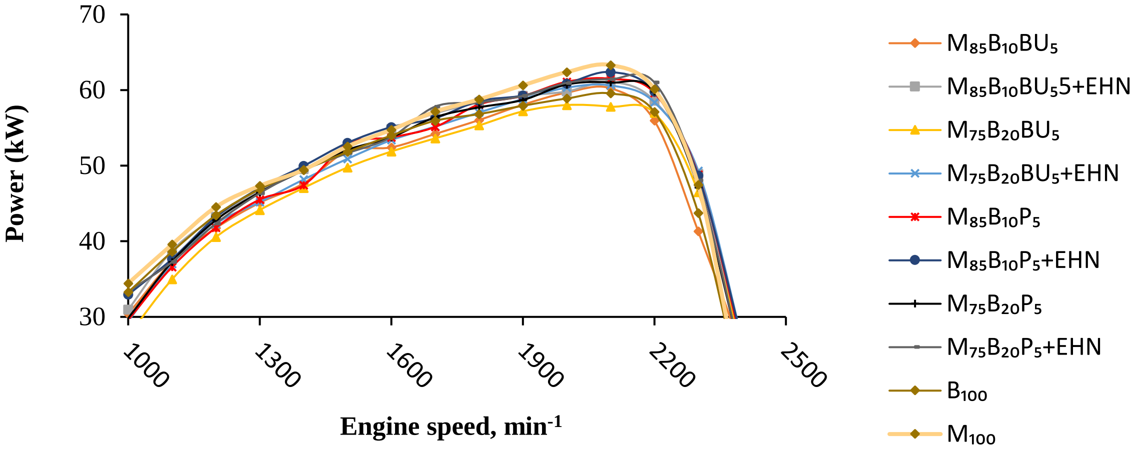


Figure 2. Change in engine power values of M_{100}, B_{100}, and blended fuels (containing 5% BU or P) depending on engine speed

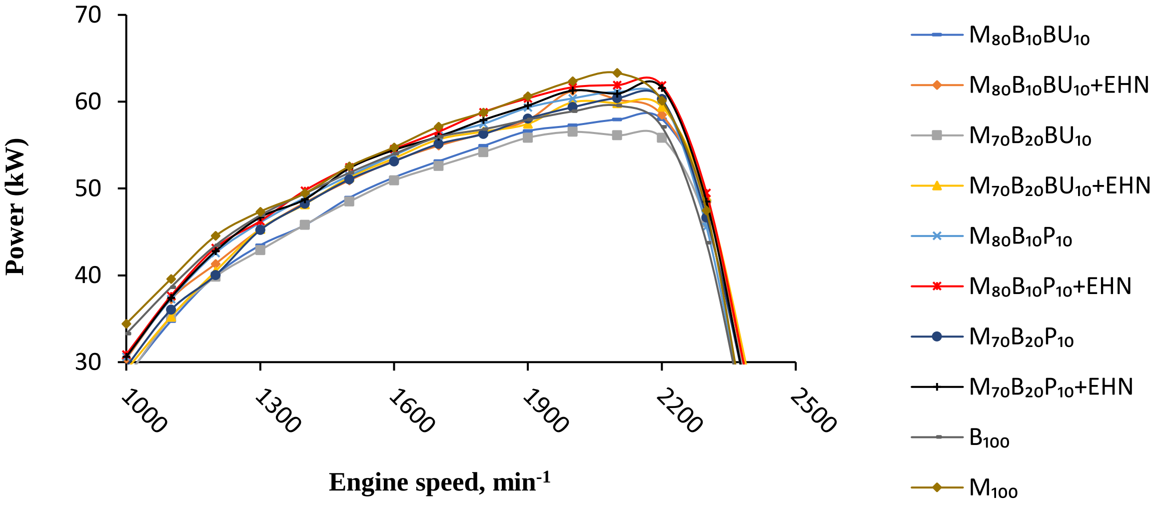


Figure 3. Change in engine power values of M_{100}, B_{100}, and blended fuels (containing 10% BU or P) depending on engine speed

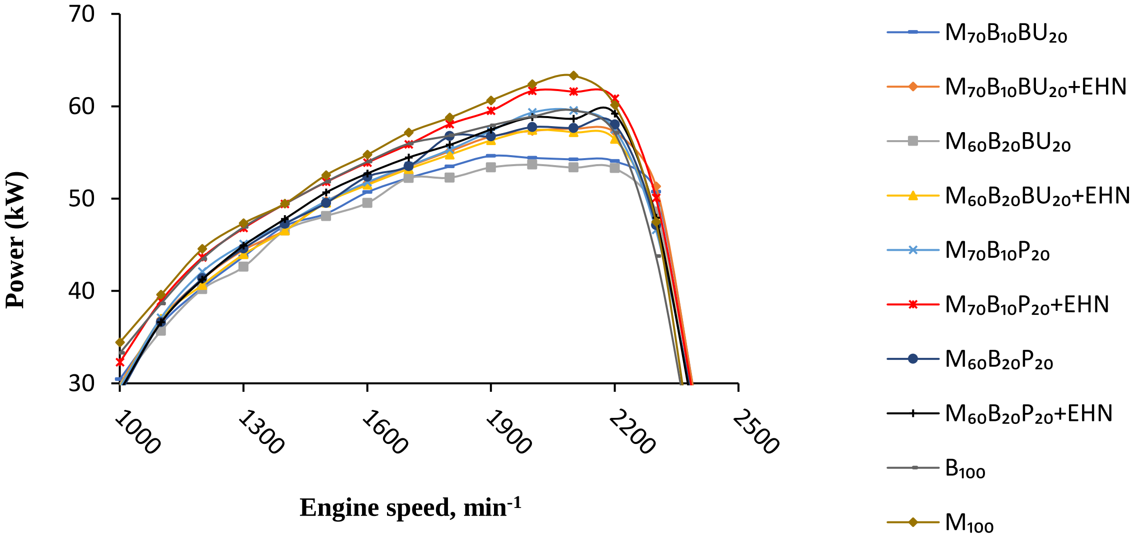


Figure 4. Change in engine power values of M_{100}, B_{100}, and blended fuels (containing 20% BU or P) depending on engine speed

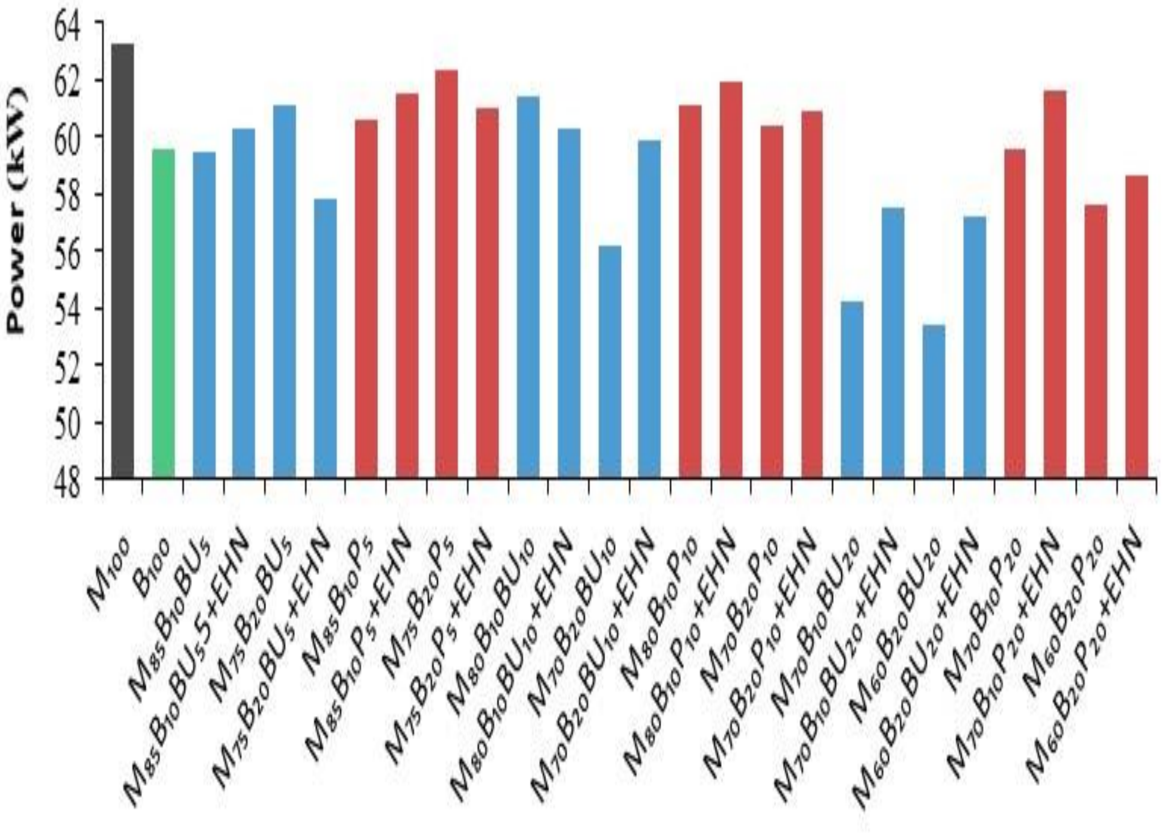


Figure 5. Effective engine power values of M_{100}, B_{100}, and blended fuels at the engine speed at which maximum power is obtained (2100 min^{-1})

Variation of moment values

The variation of torque (Nm) values obtained depending on the engine revolution speed (min^{-1}) in the engine performance tests performed under full load conditions of diesel (M_{100}), biodiesel (B_{100}), and blended fuels (EHN additive - non-additive) are given in Figures 6, 7, and 8. The torque values of the engine speed at which the maximum torque is obtained are shown in Figure 9.

If the effective engine torque values of M_{100}, B_{100}, and mixed fuels are examined depending on the engine speed; in general, it is seen that the maximum engine torque is obtained from M_{100} fuel with an average value of 339.65 Nm (2100 min^{-1} engine speed).

It has been determined that there is a decrease in the torque value of B_{100} fuel (333.08 Nm) compared to M_{100} fuel (339.65 Nm) at 1300 min^{-1} engine speed at which the maximum torque is obtained. This decrease in torque value can be explained by the fact that the determined calorific value and cetane number values of safflower oil methyl ester (B_{100}) show lower values than diesel oil (M_{100}). Özçelik (2011) reported that low calorific and cetane number values of fuels increase the ignition delay, the combustion performance deteriorates due to the increase in ignition delay, and as a result, the decrease in the maximum pressure in the cylinder causes the torque to decrease.

It has been determined that, in the blended fuels containing the same proportion of butanol or pentanol by volume (with or without EHN additives), the torque values of the fuels decrease at different rates as the biodiesel ratio increases (by 10 and 20%). For example, it has been observed that the torque values of the blended fuels containing B20, at 1300 min^{-1} engine speed at which the maximum torque is obtained, exhibit lower values between 0.29% and 2.77% compared to the blended fuels containing B_{10}.

It has been determined that the engine torque values of all blended fuels (with and without EHN additives) are lower, between 0.82% and 7.57%, compared to M_{100} fuel, at 1300 min^{-1} engine speed at which the maximum torque is obtained. This result can be explained by the fact that the calorific values of the blended fuels show lower values than diesel fuel (M_{100}) due to the biodiesel and higher alcohols (butanol, pentanol) they contain in certain proportions by volume. The low calorific value in fuels causes a decrease in the energy released as a result of combustion, and as a result, the pressure acting on the piston and its conversion rate to useful work decrease (Atmanlı et al., 2013).

When the torque values of the blended fuels containing the same proportion of butanol and pentanol by volume were compared at 1300 min^{-1} engine speed, where the maximum engine torque was obtained, it was determined that the fuels containing pentanol showed higher values between 1.07% and 4.55% compared to the fuels containing butanol. The obtained increases were reported by Yeşilyurt et al. (2018) show similarities with the results of their studies.

It has been determined that as the butanol and pentanol ratios increase in the blended fuels, there is a certain decrease (0.8% to 3.7%) in the torque values of the fuels. Results, Siwale et al. (2013); Tüccar, Özgür, and Aydın (2014); Yeşilyurt et al. (2018) show similarities with their studies.

It has been determined that the EHN added to the blended fuels reduces the torque values between 0.22% and 2.77%. It shows similarities with the studies of Alpaslan Atmanlı (2016); İleri (2016).

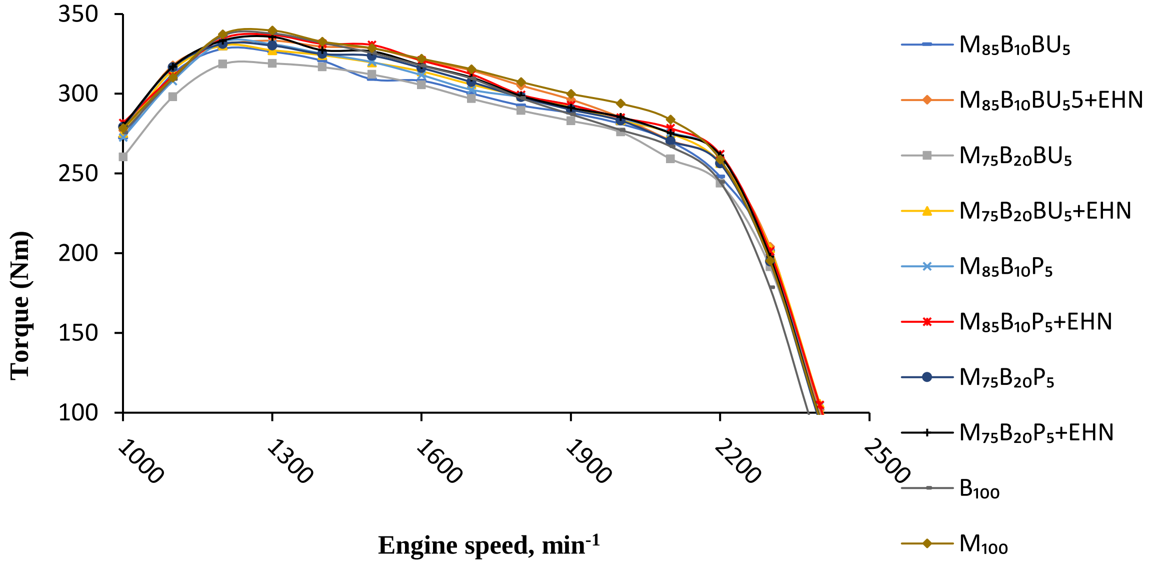


Figure 6. Change in engine torque values of M_{100}, B_{100}, and blended fuels (containing 5% BU or P) depending on engine speed

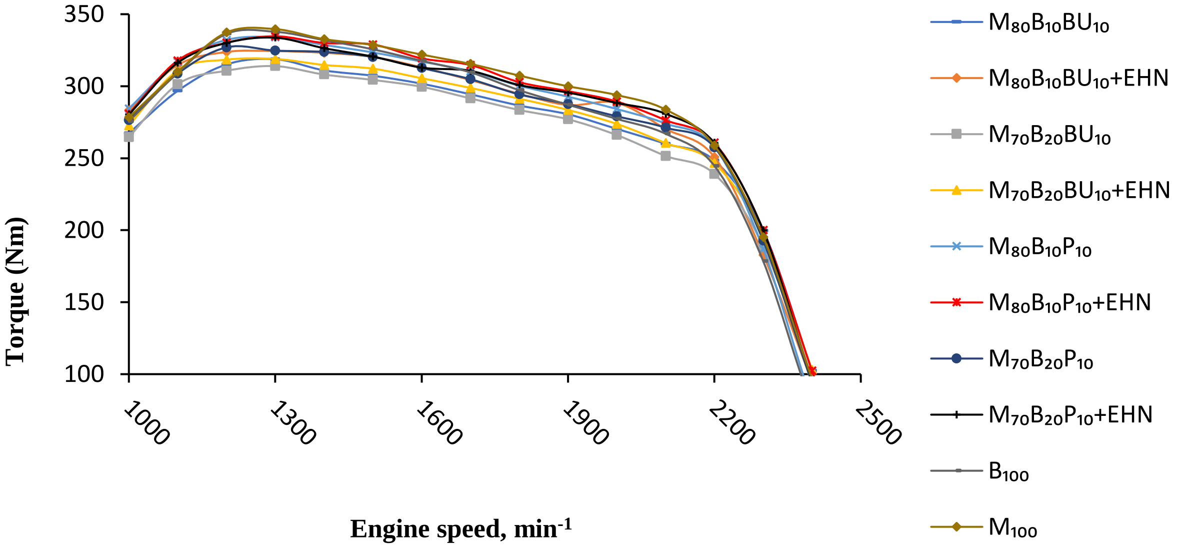


Figure 7. Change in engine torque values of M_{100}, B_{100}, and blended fuels (containing 10% BU or P) depending on engine speed

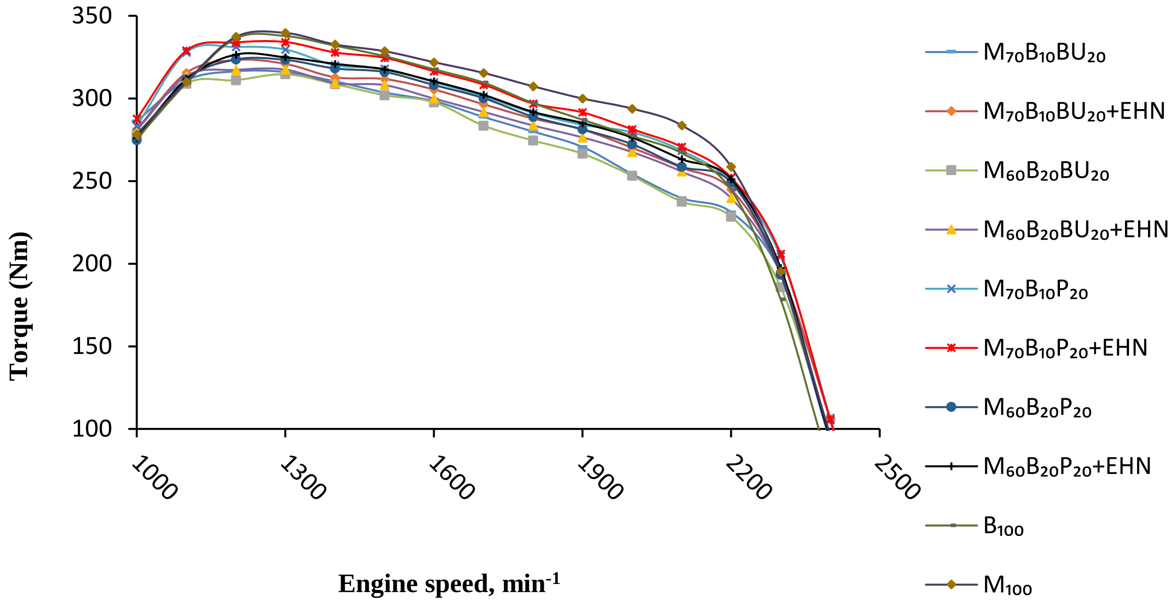


Figure 8. Change in engine torque values of M_{100}, B_{100}, and blended fuels (containing 20% BU or P) depending on engine speed

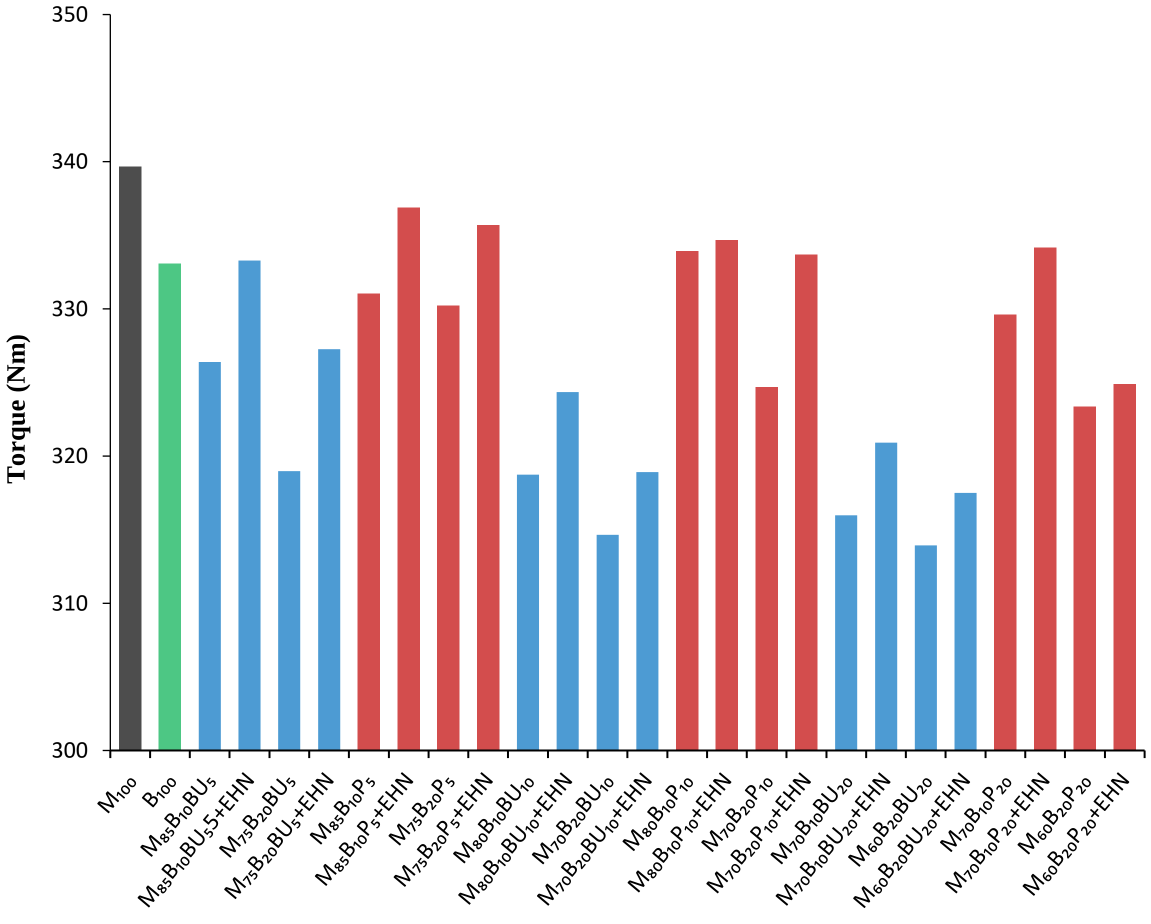


Figure 9. Engine torque values of M_{100}, B_{100}, and blended fuels at the engine speed at which the maximum torque is obtained (1300 min^{-1})

Specific fuel consumption values

The variation of specific fuel consumption (g kWh^{-1}) values obtained depending on the engine revolution speed (min^{-1}) in the engine performance tests performed under full load conditions of diesel (M_{100}), biodiesel (B_{100}), and blended fuels (EHN additive - non-additive) are given in Figures 10, 11, and 12. The torque values of the engine speed at which the minimum specific fuel consumption is obtained are shown in Figure 13.

As a result of the engine performance tests carried out with 26 fuels under full load conditions, the lowest specific fuel consumption was obtained from M_{100} fuel with an average of 256.53 g kWh^{-1} at 1600 min^{-1} engine speed.

The specific fuel consumption value of B_{100} fuel was determined as 291.33 g kWh^{-1} at an engine speed of 1600 min^{-1} where the minimum specific fuel consumption is obtained. This value is approximately 13.57 % higher than the specific fuel consumption value (256.53 g kWh^{-1}) obtained from M_{100} fuel. This is because the determined calorific value of B_{100} fuel is lower than that of M_{100}, and its density and viscosity values are higher. Zhang and Balasubramanian (2016) reported that the specific fuel consumption is expected to increase by 11.8-14.6% due to the lower calorific value of biodiesel compared to diesel.

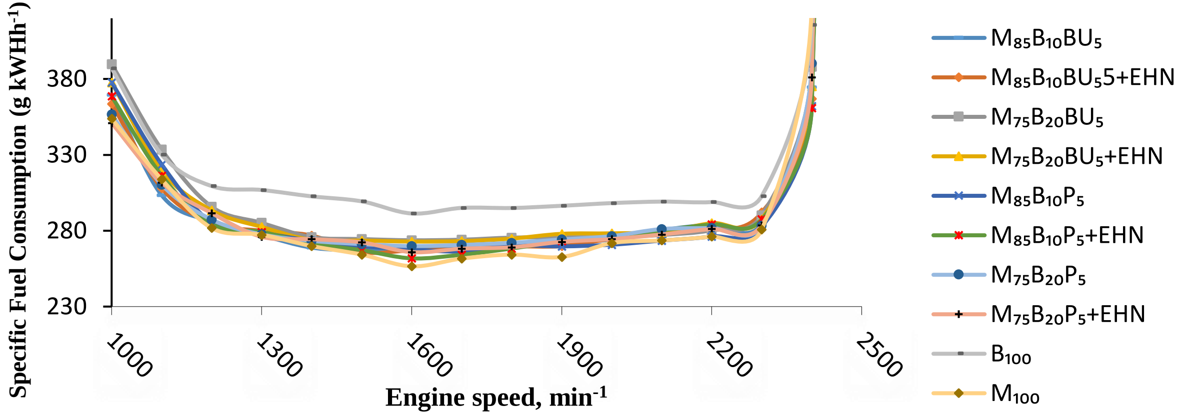


Figure 10. Change in specific fuel consumption values of M_{100}, B_{100}, and blended fuels (containing 5% BU or P) depending on engine speed

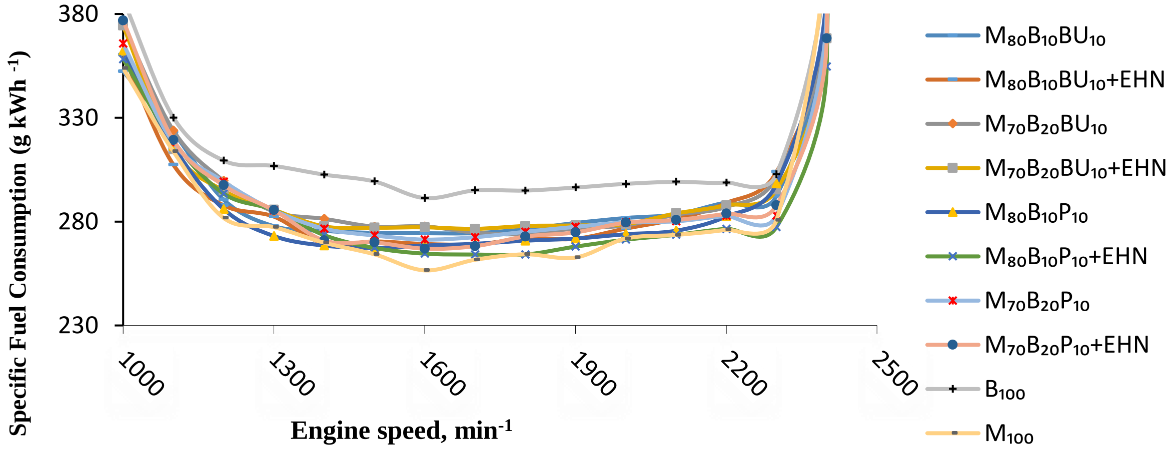


Figure 11. Change in specific fuel consumption values of M100, B100, and blended fuels (containing 10% BU or P) depending on engine speed

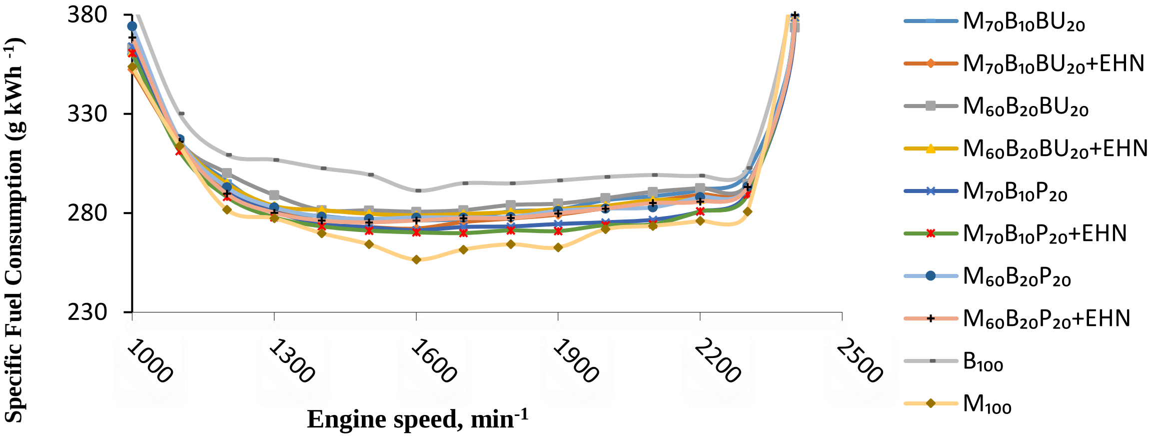


Figure 12. Change in specific fuel consumption values of M_{100}, B_{100}, and blended fuels (containing 20% BU or P) depending on engine speed

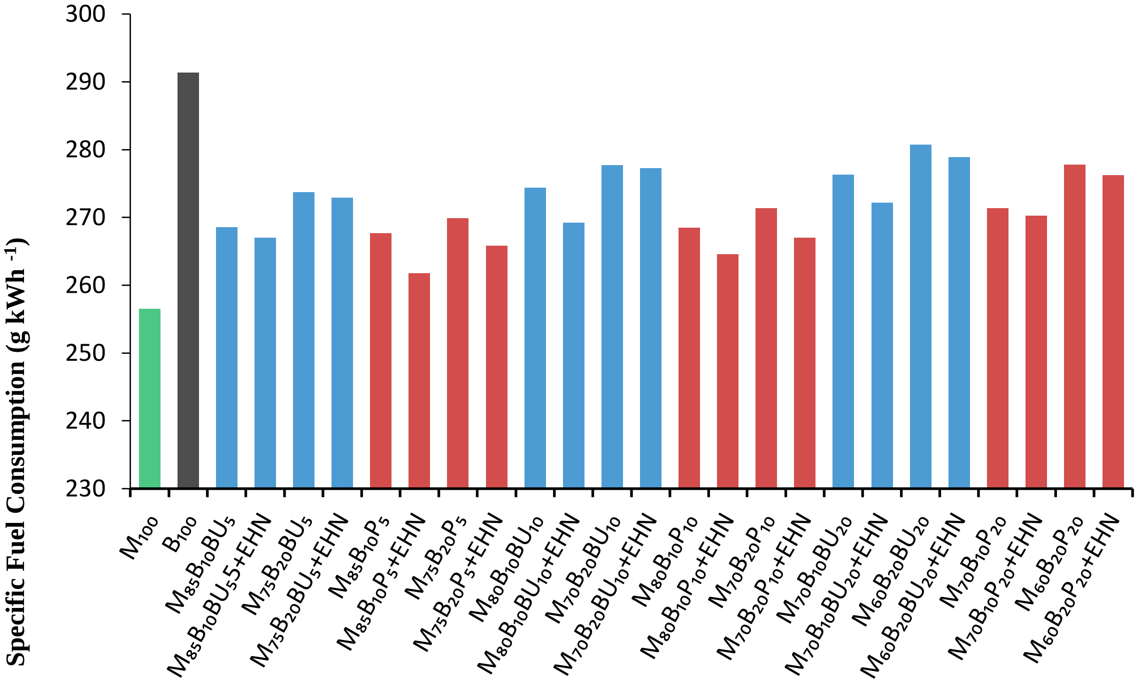


Figure 13. Specific fuel consumption values of M_{100}, B_{100}, and blended fuels at the engine speed at which the minimum specific fuel consumption is obtained (1600 min^{-1})

It has been determined that as the biodiesel ratio increases (by 10 and 20%) in the blended fuels (with or without EHN additives) containing the same proportion of butanol or pentanol by volume, the specific fuel consumption values of the fuels increase by 0.83% and 3%.

It was determined that the specific fuel consumption values of all blended fuels (with and without EHN additives) increased by approximately 2.05% to 9.42% compared to M_{100} fuel at an engine speed of 1600 min^{-1} where the minimum specific fuel was obtained. While the closest results to M_{100} (256.53 g kWh^{-1}) fuel were obtained from $M_{85}B_{10}P_5$+EHN fuel (261.78 g kWh^{-1}), the worst results were obtained from $M_{60}B_{20}BU_{20}$ fuel (280.7 g kWh^{-1}). The increase in the specific fuel consumption values of the blended fuels compared to the M_{100} can be explained by the lower energy content of these fuels compared to the M_{100}.

When the specific fuel consumption values of the blended fuels containing the same proportion of butanol and pentanol by volume at the same engine speed were compared, it was determined that the specific fuel consumption values of the blended fuels containing pentanol showed lower values varying between 0.32% and 3.71% compared to the fuels containing butanol. The main reason for this situation is that pentanol has a higher calorific value and lower latent heat of vaporization than butanol. Atmanlı (2016) and Nanthagopal et al. (2018) reported that the rate of increase in specific fuel consumption values of pentanol blends, which have a higher energy content compared to butanol, is less than diesel.

It has been determined that there is a certain increase (0.8% to 3.9%) in the specific fuel consumption values of the fuels as the alcohol content increases (5, 10, and 20%) in all blended fuels containing both butanol and pentanol (with or without EHN additives). The decrease in the energy content (calorific value) and cetane number values of the blended fuels due to the increase in alcohol concentration can be shown as the reason for this increase. Karabektas and Hosoz (2009); Yeşilyurt et al. (2018); Zhang and Balasubramanian (2016) reported that the specific fuel consumption values increased due to the increase in high alcohol content in fuels.

It has been determined that the EHN added to the blended fuels reduces the specific fuel consumption values between 0.16% and 2.2%. A similar relationship was also reported by Atmanlı (2016) and İleri (2016). Researchers have reported that due to the high volatility of EHN, fuel vapor can disperse in the combustion chamber and this will help increase the combustion process and decrease fuel consumption.

Conclusion

When the engine performance values of all blended fuels are evaluated in general;

- The highest effective power value was obtained from M_{100} with 63.3 kW and $M_{85}B_{10}P_5$+EHN fuel with 61.43 kW from the blended fuels at 2100 min^{-1} where maximum power is obtained. The lowest effective power value was found in $M_{60}B_{20}BU_{20}$ fuel with 53.36 kW.
- The highest torque value was obtained in M_{100} fuel with 339.65 Nm at 1300 min^{-1}, where the maximum torque is obtained, and in $M_{85}B_{10}P_5$+EHN fuel with 336.88 Nm among mixed fuels. The lowest torque value was determined with 314.65 Nm in $M_{60}B_{20}BU_{20}$ fuel.
- The lowest specific fuel consumption value was obtained at 1600 min^{-1} from M_{100} fuel with 191.37 g kWh^{-1}, and $M_{85}B_{10}P_5$+EHN fuels with 261.78 g kWh^{-1} from the mixed fuels. The highest specific fuel consumption value was determined at $M_{60}B_{20}BU_{20}$ fuel with 209.4 g kWh^{-1}.

The production of high alcohol fuels (butanol, pentanol, etc.) using domestic resources will reduce the cost and contribute to the economy of the countries. The fuels used in the study can also be examined in terms of thermodynamics, environmental and economic aspects. The effects of blended fuels on engine parts and fuel systems should be investigated by conducting long-term tests in different engine types. Biodiesels obtained from different raw materials should be mixed with diesel, butanol, and pentanol fuels at different ratios by volume and compared. The usability of other fuels in the high alcohol group in diesel engines should be investigated. As a result of long-term tests of diesel/biodiesel/butanol or pentanol blended fuels, the effect on engine oil should be examined.

Acknowledgments

&: Determination of The Effects on Fuel Properties, Engine Performance, and Emission Values of Some Additives Added to Diesel and Safflower Biodiesel Blends is a part of Ph.D. Thesis by Seda ŞAHİN (2021). This study was supported by the Scientific Research Projects Coordination Unit of Selçuk University with project number 18101007.

Conflict of Interest Declaration: The authors have no conflict of interest concerned to this work

Contribution Rate Statement Summary: The authors declare that they have contributed equally to the article.

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