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Research Article

INVESTIGATION OF THE EFFECTS OF DIESEL-BIODIESEL-BUTANOL AND DIESEL-BUTANOL MIXTURE ON ENGINE PERFORMANCE

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Abstract **–** The vast majority of the energy used in the world is obtained from fossil fuels. This situation increases external dependence in countries such as our country, which is constantly growing and developing. In addition, the fact that fossil fuels will end in the near future leads to price instability and environmental problems. These problems have pushed us to look for an alternative fuel, an alternative energy source. The low fuel consumption of the diesel engine and high compression ratios make the diesel engine very attractive for use in heavy duty vehicles. It is known that vegetable oils can be used as fuel in diesel engines without any processing, but when used for a long time, it causes clogging in the engine, fuel line, clogging of injectors, cold weather or difficulties in the first movement when the engine is cold. The conversion of oils into biodiesel by transesterification method is more suitable than the use of unprocessed oil. When we look at the fuel properties of biodiesel produced by transesterification method, although it is similar to diesel fuel, its viscosity value is higher than diesel. In this study, tests were carried out at various speeds to determine the characteristic properties of biodiesel, biodiesel - diesel fuel blend, biodiesel - butanol blend and biodiesel - diesel - butanol blends produced by transesterification method in a four cylinder four stroke direct injection diesel engine.

Keywords – Biodiesel, n-Butanol, Ternary Blend, Engine Performance, Transesterification

I. INTRODUCTION

Biodiesel is an alternative fuel that can be obtained from used waste oils of vegetable and animal origin and can be used directly in engines using diesel fuel. [1] The direct use of biodiesel fuel in internal combustion diesel engines or its use by making new mixtures with diesel in appropriate quantities will both reduce the negative effects of exhaust emissions released to the environment and contribute to the use of limited fossil fuels in an alternative way. Sunflower, canola, soya, peanut, peanut, cotton and used frying oils are generally used in biodiesel production, but experiments and applications on various biofuels are ongoing. The fact that biodiesel production costs are higher than diesel fuel requires the availability of an advantageous cost and highly efficient biodiesel feedstock. One of the most important technical conditions required for biodiesel production is the sunflower plant, which has a sufficient amount of vegetable oil, has a great potential due to its resistance to changing climatic conditions and very low costs. [2]

The basis of biodiesel production from unused sunflower oil is the reaction of vegetable oil with alcohol in the presence of a catalyst. A critical condition for biodiesel production is the correct selection of the catalyst. In the literature, it has been determined that the conversion rate of oil to biodiesel increases and the reaction time is shortened in biodiesel production by using basic catalysts. In biodiesel production by transesterification method, basic catalyst is about 4 thousand times faster than the same amount of acidic catalyst. When the optimum reaction temperature is compared, basic catalysts react at lower temperatures. According to the literature research, in the production of biodiesel by transesterification method, alcohol is recommended as 1 in 6 of the mole ratio of vegetable oil. In the transesterification method using basic catalyst, vegetable oil is esterified up to 98% during 90 minutes reaction time. After esterification, purification process can be applied with different methods. ([3],[4],[5],[6])

A. Biodiesel Fuel Production Methods

Biodiesel can be produced from animal, vegetable, waste and used oils, i.e. renewable resources. Biodiesel is the name given to mono acyl esters of long chain fatty acids. Biodiesel production, that is, making vegetable oils more usable in diesel engines, is carried out under two main headings: thermal methods and chemical methods. In thermal methods, it is generally carried out in order to reduce the viscosity of the oil to be burned in the engine by preheating it before combustion in the engine. Chemical methods are analysed under 4 sub-headings; ([7],[8],[9])

- Microemulsion
- Pyrolysis
- Dilution
- Transesterification

1) Microemulsion

Microemulsion methods are used to reduce the viscosity and improve the spraying properties of vegetable oils by creating microemulsion of oils by using short-chain alcohols. Microemulsions are spontaneous systems with very small particles (diameters between 1-150nm) formed by the combination of two thermodynamically stable liquids that are normally immiscible with amphiphilin. With the microemulsion method, an alternative diesel fuel completely independent from fossil fuels can be produced. Cetane numbers and volumetric heat values of microemulsions are lower than diesel fuel. ([10],[4],[11])

2) Pyrolysis

In pyrolysis method, also known as cracking, molecules are disintegrated into smaller molecules by breaking Carbon-Carbon and Carbon-Hydrogen bonds by heating the molecules to high temperatures and holding them at this temperature. Thanks to this method, the viscosity of oils is significantly reduced. We can think of pyrolysis as a heat treatment of organic materials. There are two different methods to obtain pyrolysis products in vegetable oils. The first method is to decompose the oil by heating in a closed container, and the second method is to decompose the vegetable oil by ASTM distillation by keeping it under the effect of thermal decomposition. Since the oxygen contained in the product obtained from the oil decomposed by the effect of heat is also removed by the effect of heat, its properties are very close to the properties of fossil fuels. ([4],[5],[12],[13])

3) Dilution

Dilution method, like the other two methods, is used to reduce the viscosity value of vegetable oils with high viscosity. In this method, solvent, ethanol or diesel fuel is mixed with vegetable oils to dilute the oil. It is important to keep the oil ratio in the mixture low in order to reduce the viscosity and not to lose the fuel properties of the fuel. ([14],[12],[6],[4])

4) 1.1.4. Transesterification

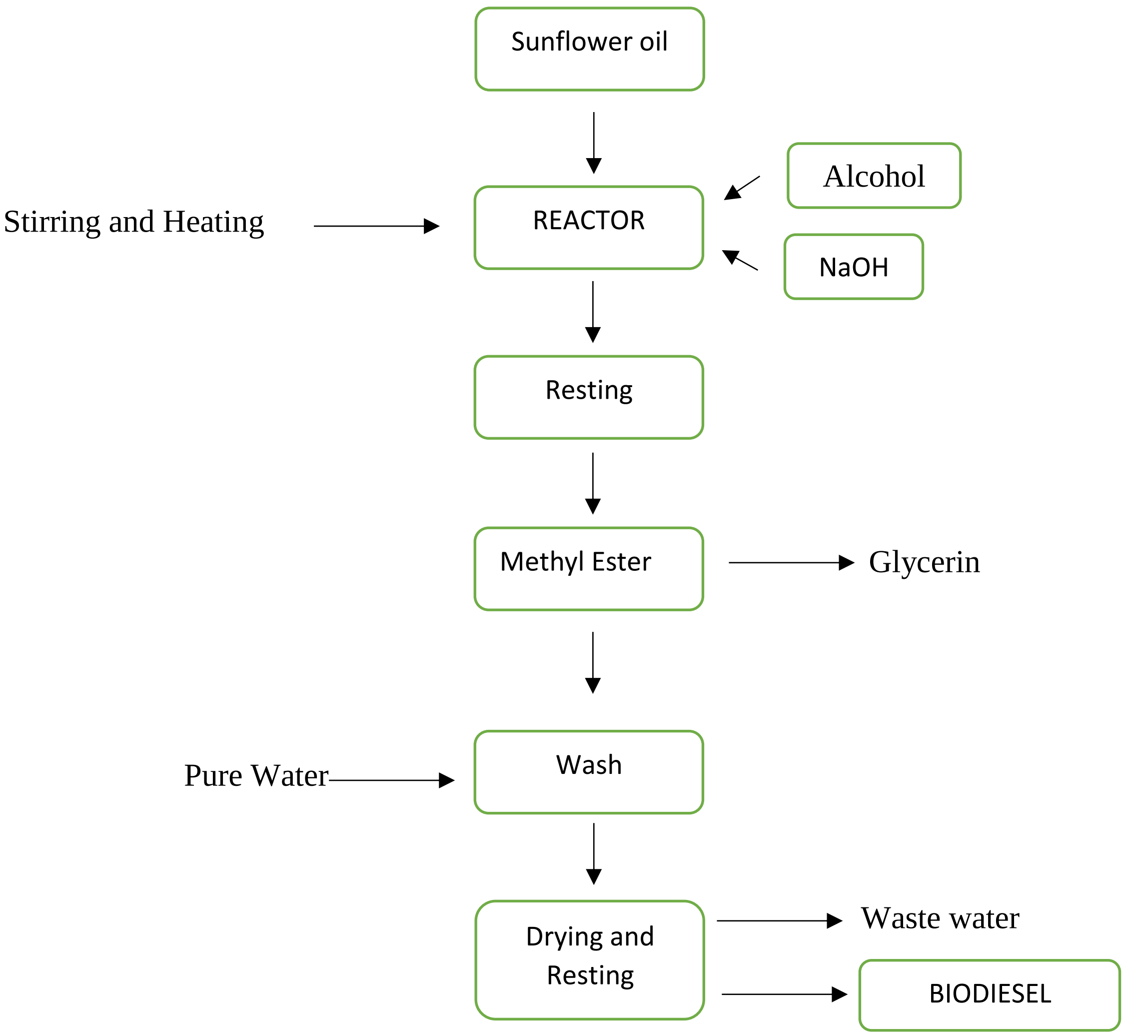
Transesterification method is the reaction of vegetable oil with alcohol (monohydric) with the help of a catalyst in order to use vegetable oil as an alternative fuel to diesel fuel in diesel engines, and as a result of re-esterification, glycerin and fatty esters are formed. The alcohol ester produced by this method, i.e. fatty acid methyl ester, is called biodiesel. Since the biodiesel fuel produced by the transesterification method is separated from the glycerin contained in the biodiesel fuel, the oil provides a finer structure. Transesterification method is the most effective method used to reduce viscosity.

Transesterification general equation

$$RCOOR^{I} + R^{II}OH \longleftrightarrow RCOOR^{II} + R^{I}OH$$

Ester Alcohol Catalyst Ester Alcohol

In biodiesel production, alkaline basic catalysts are usually used, such as potassium hydroxide or sodium hydroxide. Besides basic catalysts, acidic catalysts are also available. ([6],[4],[15],[13],[16],[17],[18],[19],[20])



Scheme 1.1. Biodiesel production scheme [21]

II. Materials and Method

Transesterification method was selected for biodiesel fuel production and biodiesel was produced by this method. The steps applied during biodiesel production are given in detail below. After the biodiesel production was completed, the test engine for engine performance parameter values was carried out in a diesel engine operated at standard values without any changes in the compression ratio, spray advance time and valve settings. Before

starting the experiment, necessary checks were made on the engine and no problems were observed. In order to obtain more accurate results in the experiment, the test engine was run until the test engine entered the regime, and then the measurement phase was started after reaching the desired engine operating temperature and the desired load position. The experiments were carried out at 1800, 2400, 3000 and 3600 rpm. In order to determine the standard values of the engine, it was first operated using pure diesel fuel and after the standard values were determined, pure biodiesel fuel was first tested under the same conditions. After B100 fuel, tests were carried out with D50B50, B95Bu5, B90Bu10, D47.5B47.5Bu5 and D45B45Bu10 fuel mixtures respectively. The engine performance values and exhaust emission values obtained were compared and analysed.

A. Fuel production Introduction of produced fuel

Biodiesel production was carried out using transesterification method, one of the biodiesel production methods. Biodiesel production by transesterification method can be carried out with two different catalysts, basic and acidic type. In this study, sodium hydroxide (NaOH), which has a basic characteristic structure, was selected as the catalyst. The reaction was carried out by keeping the temperature between 58 °C and 60 °C for 1 hour. Methyl alcohol was used as alcohol and personal protective equipment was used during the experiments.

1) Sunflower oil was heated and kept constant between 58 °C - 60 °C with the help of a thermostat for 90 minutes, which is the reaction time, and with the help of a thermometer, it was checked whether the thermostat was working correctly and it was understood that it was working properly, and finally the oil was mixed with the help of a mixer so that all sides of the oil could be heated evenly
2) In a separate vessel, 1/5 of the volume of methanol and 3.5 g of NaOH catalyst per litre of oil was added to the preheated oil for the reaction after dissolving the NaOH catalyst in the methanol with gentle stirring.
3) Provided that the temperature of the mixture was kept in the range of 58 - 60 °C during the reaction, it was mixed with the help of a mixer rotating 1400 revolutions per minute and the reaction was expected to take place for 90 minutes.
4) After the reaction was completed, the biodiesel fuel was placed in a holding vessel and kept for separation from glycerin. Then biodiesel and glycerin were separated with the help of a separating funnel.
5) Crude biodiesel was subjected to washing with pure water in order to remove residual alcohol and catalyst residues in the crude biodiesel. After the washing process, it was allowed to rest for 24 hours to allow the biodiesel fuel and pure water to separate from each other and then the biodiesel was separated with pure water. In order to remove the water that may remain in the biodiesel after separation, the biodiesel fuel was heated to 100 °C and the mixture was kept at this temperature for 45 minutes to evaporate the water and the biodiesel was left to cool at room temperature.

Figure 2.1. Biodiesel left to rest

Figure 2.2. (4 Hours) rested biodiesel

Figure 2.3 (36 Hours) rested biodiesel

B. Properties of the fuels produced

1) Characteristic

The kinematic viscosity, density, lower heating value, upper heating value and flash point values of sunflower oil methyl ester (AYME) obtained from sunflower oil by transesterification method were determined at MAM. The fuel properties obtained are as shown in Table 2.1.

Table 2.1 Characteristics of sunflower oil methyl ester

Features	**AYME**	**Method**
Density 15°C (kg/m^3)	876,8	TS EN ISO 12185
kinematic viscosity 40°C (mm^2/s)	4,581	TS 1451 EN ISO 3104
Upper Heating Value (Mj/kg)	39,71	ASTM D 240
Lower Heating Value (Mj/kg)	38,49	ASTM D 240
Flash Point °C	134,8	TS EN ISO 2719

Density and kinematic viscosity values are very important for biodiesel. One of the reasons for the high density and viscosity values is that glycerin is not sufficiently separated from biodiesel. The kinematic viscosity value of biodiesel is accepted in the range of 1.9-6.0 mm2/s at 40°C according to ASTM D 6751 standards and in the range of 3.5-5.0 mm2/s at 40°C according to EN 14214 standards. Table 6.1 shows that the kinematic viscosity value of LDPE is 4,581 mm2/s. It is seen that the viscosity value of AYME is within both ASTM D 6751 standard limits and EN 14214 standard limits.

The density value should be between 860 and 900 kg/m3 at 15 °C according to EN 14214 standard and between 875 and 900 kg/m3 according to DIN E 51606 standard. It is seen in table 6.1 that the density value of AYME is 876,8 kg/m3. It is seen that the density value of LDPE is within both EN 14214 standard limits and DIN E 51606 standard limits.

Flash point value plays an important role in the storage and transport of fuels. According to ASTM D 6751 standard, the flash point should be at least 130 °C and above, and according to EN 14214 standard, the flash point should be at least 101 °C and above. The flash point of AYME was measured as 134,8 °C at MAM.

Samples taken from the produced fuels and fuel mixtures were analysed at Marmara Research Centre and are given in Table 2.2.

Tablo 2.2. Characteristic properties of biodiesel and diesel fuel

Features	Diesel Fuel	Biodiesel
Kinematic viscosity (40°C)	3,1	4,581
Lower Heating Value (Mj/Kg)	43,5	38,49
Density 15°C Kg/l	835	876,8
Flash Point (°C)	59	134,8
Cetane index (calculated)	50	50

The formula in ASTM D976-91 standards was used to determine the cetane number of the obtained biodiesel fuel. ([6],[22])

$$454{,}74 - (1641{,}416 \times D) + (774{,}74 \times D^2) - (0{,}554 \times B) + 97{,}803 \times (\log B)^2 \quad (2.1)$$

D: Density value of biodiesel at 15 °C

B: The temperature at which half of the biodiesel is distilled

The determination of the distillation temperature of the biodiesel fuel sample was carried out at the Marmara Research Centre according to ASTM D-976 standards and the temperature value was found to be 342 °C. The cetane index of biodiesel was found by substituting the temperature and density values in the equation.

Engine performance experiments were carried out with 7 different fuel blends. The prepared fuel mixtures and their ratios are given in Table 2.3.

Table 2.3. Percentages of fuel mixtures

Mixture Name	Diesel ratio (%)	Biodiesel ratio (%)	n-Butanol ratio (%)
D100	100	0	0
B100	0	100	0
B95Bu5	0	95	5
B90Bu10	0	90	10
D50B50	50	50	0
D47,5B47,5Bu5	47,5	47,5	5
D45B45Bu10	45	45	10

C. Calculation of Blend Fuel Properties

The lower heating value, density and cetane number of the prepared fuel blends were calculated according to Kay's mixing rule by utilising the known diesel biodiesel and n-butanol fuel properties. Kinematic viscosity values were calculated according to Arrhenius mixing rule. ([23],[24],[25])

1) Calculation of Lower Heating Value

The lower heating values of the mixtures were calculated according to the Kay mixture rule using the equation given in 2.2

$$Hu_k = \sum_{n=1}^{n}(x_n \rho_n Hu_n) \,/\, \sum_{n=1}^{n}(x_n \rho_n) \quad (2.2)$$

Hu_k: Lower heating value (Mj/kg)

Hu_n: Lower heating values of known fuels in the mixture

2) Density Calculation

The density values of the prepared mixtures were calculated according to the Kay mixing rule using the equation given in 2.3

$$\rho_k = \sum_{n=1}^{n}(x_n \rho_n) \quad (2.3)$$

ρ_k: Density of the mixture

ρ_n: Known density value of fuels in the mixture

x_n: Volumetric mixing ratio

3) Calculation of Cetane Number

The cetane numbers of the prepared mixtures were calculated according to the Kay mixing rule using the equation given in 2.4

$$SS_k = \sum_{n=1}^{n}(x_n SS_n) \quad (2.4)$$

SS_k: Cetane number of the mixture

SS_n: Known cetane numbers of fuels in the mixture

4) Calculation of Kinematic Viscosity Values

The viscosity values of the prepared mixtures were calculated using equation 2.5

$$\ln \eta_k = \sum_{n=1}^{n} x_n \ln \eta_n \quad (2.5)$$

η_k: Kinematic viscosity of the mixture

η_n: Known kinematic viscosity of the fuels in the mixture

5) Calculated Fuel Properties of Fuel Blends

The properties of diesel fuel were obtained from Petrol Ofisi, the properties of biodiesel fuel were obtained from MAM and the properties of n-Butanol were obtained from Mikro Teknik. Known values and calculated fuel properties are given in Table 2.4.

Table 2.4 Fuel properties of test fuels

Test fuels	Density kg/m^3	Viscosity mm^2/s	Lower Heating Value Mj/kg	Flash Point °C	Cetane Number
D100	832	3,1	43,5	59	50
B100	876,8	4,581	38,49	134,8	50
n-Butanol	810	2,6	34,24	35	24
D50B50	854,4	3,768	40,9293	96,9	50
B95Bu5	873,46	4,4526	38,2929	129,81	49
B90Bu10	870,12	4,3284	38,0943	124,82	48
D47,5B47,5Bu5	852,18	3,6987	40,6113	93,805	49
D45B45Bu10	849,96	3,6306	40,2918	90,71	47

D. Calculation of engine performances

As a result of the experiments, engine power, effective torque value, specific fuel consumption, thermal efficiency values were calculated using the following equations with the values obtained by measurement from the fuels burned in the engine.

$$P_e = \frac{2\pi . M_d . n}{60000} \quad (2.6)$$

P_e: Effective power (kW)

M_d: Rotation moment (Nm)

$$M_d = F \times l \quad (2.7)$$

F: Brake force (N)

l: Moment arm length (m)

$$ÖYT = \frac{m_y . 1000}{P_e} \quad (2.8)$$

ÖYT: Specific fuel consumption (g/KWh)

m_y: Fuel consumption (kg/h)

$$\eta_e = \frac{3{,}6 . 10^6}{ÖYT . H_u} \quad (2.9)$$

H_u: Lower heating value (kJ/kg)

η_e: Effective efficiency

III. Experimental Study and Results

In this study, firstly, biodiesel was produced from sunflower oil by transesterification method and the fuel properties of the biodiesel produced were analysed in Marmara Research Centre. It was compared with the biodiesel standards published in America and Europe. After proving its compliance with the standards, the biodiesel produced was tested in a diesel engine as blends with diesel and n-butanol at various ratios and its effects on performance and exhaust emissions were analysed.

A. Engine Performance Values

Values such as engine power, torque, amount of fuel consumed and engine temperature are called engine performance. Engine performance tests were carried out with the help of an electric dynamometer. Engine experiments were carried out with pure diesel fuel (D100) as reference, pure biodiesel (B100), 50% biodiesel 50% diesel (D50B50), 95% biodiesel 5% n-butanol (B95Bu5), 90% biodiesel 10% n-butanol (B90Bu10), 47.5% biodiesel 47. 5% biodiesel, 47.5% diesel, 5% n-butanol (B47.5D47.5Bu5), 45% biodiesel, 45% diesel, 10% n-butanol (B45D45Bu10) at 7 different fuels 4 different speeds: 1800 rpm, 2400 rpm, 3000 rpm, 3600 rpm at full load. Engine performance values obtained by combustion of these fuel mixtures are given in detail.

B. Effective Engine Power

Engine power and torque values vary depending on variables such as the physical and chemical properties of the fuel, the quality of the air-fuel mixture, air excess coefficient, ignition delay, heat dissipation rate. ([21],[26])

The effective engine power obtained as a result of performance tests with seven different fuels is shown in Figure 3.1. As can be seen in the figure, the power value increases as the speed increases in all test fuels.

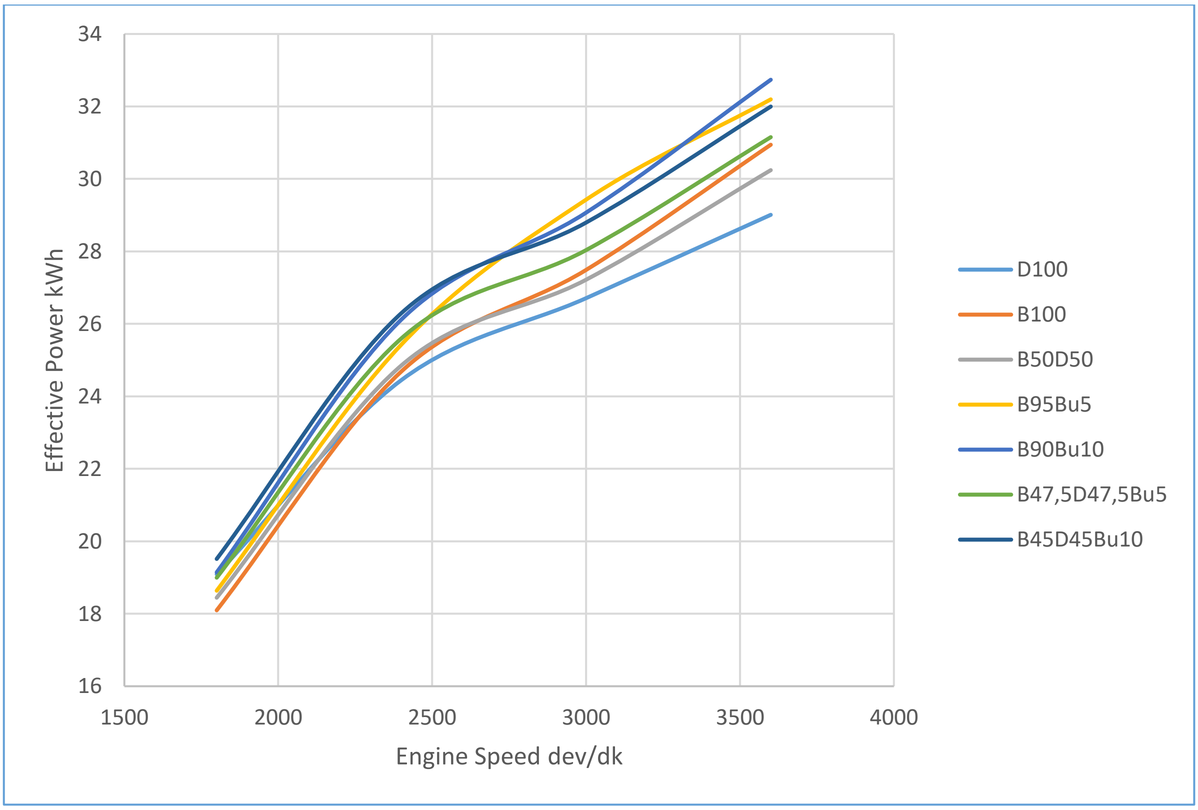


Figure 3.1 Effect of biodiesel, diesel, n-butanol fuel blends on effective engine power

Maximum power was obtained at 3600 rpm for all fuels used in the test. At 3600 rpm, the power value obtained in D100 fuel was calculated as 29.009 kW and the power value obtained in B100 fuel was calculated as 30.943 kW. Looking at the average of the values calculated as a result of the experiments, it is seen that B100 and D100 fuels are very close to each other. Compared to diesel fuel, the power values obtained at low engine speeds of biodiesel fuel were lower, while higher power values were obtained at high speeds. The biodiesel fuel produced has a lower calorific value compared to diesel fuel. In addition, when the density values are examined, it is predicted that the higher density value causes an increase in the amount of power obtained due to the higher amount of fuel sprayed per unit time. In addition, it is thought to have a positive effect on the high viscosity value of biodiesel fuel due to the increase in heat caused by the engine running at high speeds. In the experiment carried out with seven different fuels (D100, B100, B50D50, B95Bu5, B90Bu10, B47.5D47.5Bu5 and B45D45Bu10), the power values obtained at 3600 rpm were calculated as 29.009 kW, 30.943 kW, 30.242 kW, 32.195 kW, 32.737 kW, 31.152 kW, 31.997 kW respectively. With the addition of n-butanol to the fuel mixtures, some power increase was observed at all engine speeds. With the addition of butanol to the fuel mixtures, the viscosity and density values of the mixtures have improved. It has a positive effect on the spraying properties, resulting in better atomisation of the fuel and a more efficient combustion with the amount of oxygen contained in the butanol content, which manifested itself as a slight increase in the power values obtained as a result. The positive effect of the oxygen content and low viscosity of the butanol addition to the fuel mixtures (5% and 10%) is higher than the negative effect of the low calorific value and low cetane number.

C. Engine Torque

The changes in effective torque values at different speeds using seven different experimental fuels are shown in Figure 3.2.

As a result of the increase in friction losses in proportion to the increase in engine speed, there is a decrease in efficiency. With the effect of this decrease, it is seen that the effective torque value draws a gradually decreasing curve. The minimum torque value was obtained at 3600 rpm.

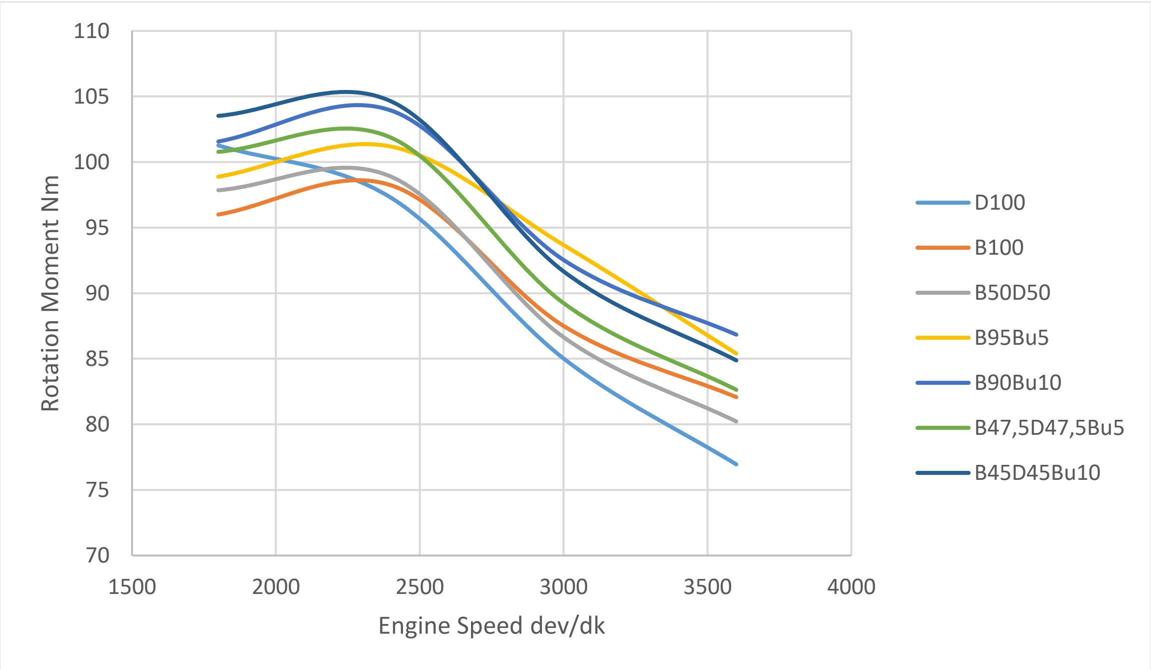


Figure 3.2 Effect of biodiesel, diesel, n-butanol fuel blends on torque

When the average effective torque values obtained as a result of the experiment with D100 and B100 fuels are analysed, it is found that the values of the two fuels are very close to each other. While higher torque is obtained at low revolutions with D100 fuel compared to B100 fuel, lower torque is obtained at high revolutions.

With the increase in engine speed, the efficiency decreases due to the inability to find the oxygen required for the combustion of the fuel in the combustion chamber. However, due to the oxygen contained in the biodiesel content, it provides an increase in engine torque as a result of some increase in efficiency at high revolutions. In addition, it is thought that increasing temperatures at high speeds have a positive effect on the viscosity and density values of the fuel. As a result of the addition of n butanol to biodiesel, an increase in engine torque was observed. The amount of oxygen in n butanol content improves the combustion of fuel in the combustion chamber, which is seen in increasing torque values. As a result of the experiments performed with D100, B100, B50D50, B95Bu5, B90Bu10, B47.5D47.5Bu5 and B45D45Bu10 fuels, the torque values obtained at 3600 rpm were calculated as 76.95 Nm, 82.08 Nm, 80.22 Nm, 85.40 Nm, 86.84 Nm, 82.634 Nm, 84.877 Nm, respectively. When the fuels are compared with each other, a torque increase of approximately 4.04% and 5.79% was obtained for B95Bu5 and B90Bu10 fuels compared to B100 fuel, respectively. When B47.5D47.5Bu5 and B45D45Bu10 fuels were compared with B50D50 fuel, a torque increase of approximately 3% and 5.80%, respectively, was obtained. Since the addition of n Butanol to the fuels prepared for use in the experiments caused an improvement in physical properties such as viscosity and density, the fuel mixtures also performed better combustion. Improvements as a result of the addition of 5% and 10% n butanol showed itself as an increase in engine torque in the experimental results.

D. Specific Fuel Consumption

It is desirable that the specific fuel consumption is low. The most important properties affecting the specific fuel consumption are viscosity, density and lower heating value of the fuel. The amount of specific fuel consumption is inversely proportional to the lower heating value, that is, more fuel must be burned in order to obtain the same amount of energy per unit time from a fuel with a high lower heating value and the same amount of energy per unit time from a fuel with a low lower heating value.

The variation of the specific fuel consumption calculated from the values obtained as a result of the experiment with seven different test fuels according to the engine speeds is as shown in Figure 3.3.

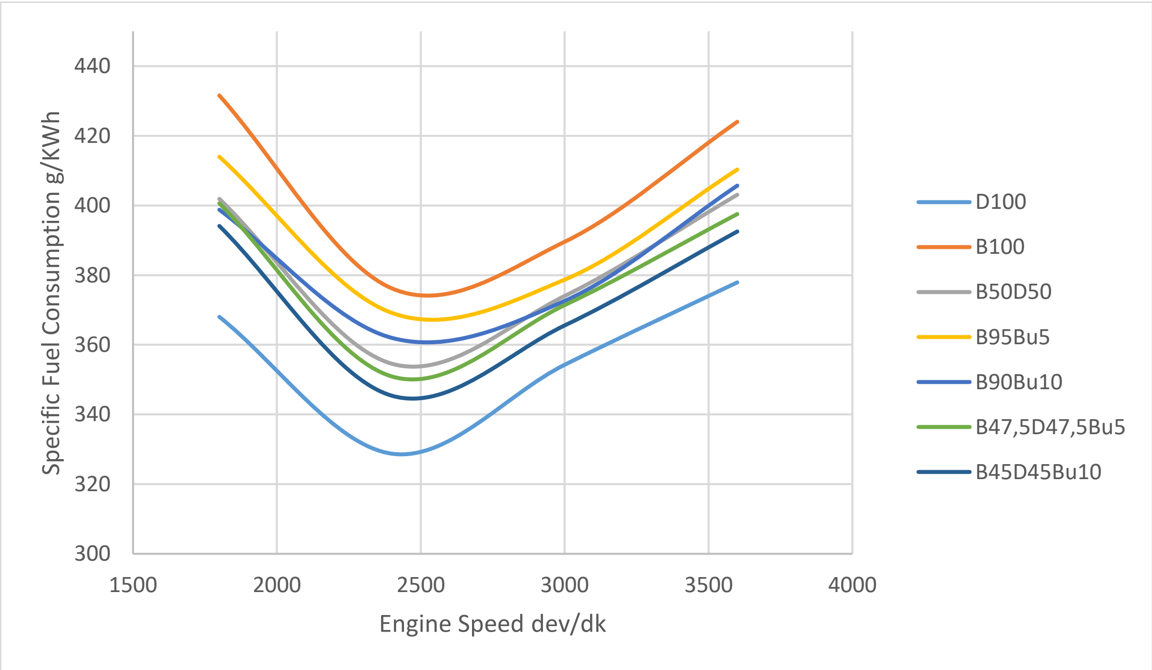


Figure 3.3 Effect of biodiesel, diesel, n-butanol fuel blends on specific fuel consumption

In the experiments carried out with all test fuels, the lowest specific fuel consumption value was obtained at 2400 rpm. As the engine speed increases, the specific fuel consumption decreases until 2400 rpm. When the engine speed increases above this value, the increase in the amount of fuel supplied to the engine leads to an increase in the specific fuel consumption. Among the fuels used in the experiment, the fuel with the lowest specific fuel consumption was measured as D100. The main reason for this is that the lower calorific value of D100 fuel is higher than the other fuels. As a result of the experiment with the test engine with seven different fuels, the approximate average fuel consumptions were calculated as D100 357.25 g/kWh, B100 405.34 g/kWh, B50D50 387.70 g/kWh, B95Bu5 393.02 g/kWh B90Bu10 384.74 g/kWh, B47.5D47.5Bu5 380.10 g/kWh B45D45Bu10 374.39 g/kWh. Although the lower calorific value of biodiesel fuel is low, an increase of 13.46% was observed compared to diesel fuel due to the higher density and viscosity values than diesel fuel. When fuels with 5% and 10% n Butanol addition were compared with B100 and B50D50 fuels, B95Bu5 3.03%, B90Bu10 5.08%, B47.5D47.5Bu5 1.96%, B45D45Bu10 3.43% improvement was obtained respectively.

This improvement observed in butanol added fuels is thought to be due to the more efficient combustion realised by increasing the amount of oxygen in the fuel mixtures and the lower density and viscosity values of the mixtures.

E. Effective Efficiency

The efficiency expresses how much of the heat energy resulting from the combustion of the fuel is converted into work. The efficiency is calculated by Equation 2.9. The effective efficiency values calculated as a result of the experiment with seven different fuels are as shown in Figure 3.4.

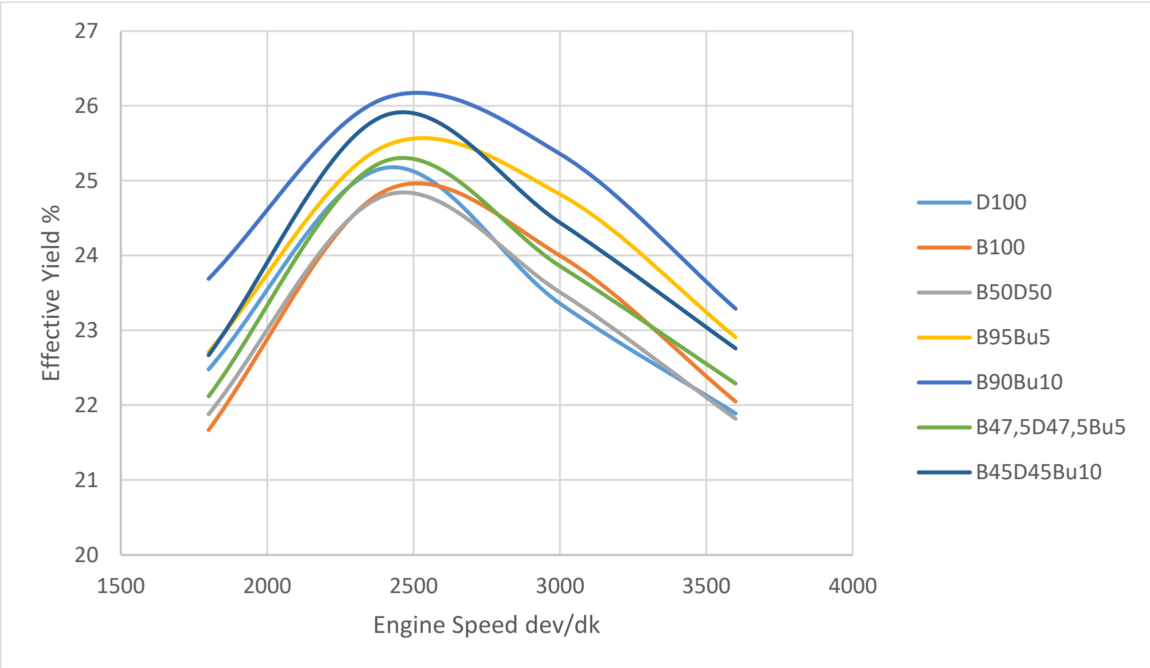


Figure 3.4 Effect of biodiesel, diesel, n-butanol fuel blends on effective efficiency

In the experiments carried out, the highest efficiency value of all fuels was 2400 rpm. Increasing friction losses with increasing engine speed cause the efficiency to decrease. The average effective efficiency values were calculated as D100 23.22%, B100 23.14%, B50D50 23.01%, B95Bu5 23.97%, B90Bu10 24.61%, B47.5D47.5Bu5 23.38%, B45D45Bu10 23.93% respectively. When D100 and B100 fuels are analysed, it is seen that the average efficiency values between the two fuels are quite close to each other. In addition, when the graph is analysed, it is clearly seen that the efficiency of D100 fuel is higher than the efficiency of B100 fuel at low and medium revolutions, but it is seen that the difference closes as the engine speed increases. At high speeds, the efficiency of D100 fuel decreases as a result of deterioration of combustion and incomplete combustion. On the other hand, thanks to the amount of oxygen in the content of B100 fuel, it is thought that the effective efficiency has improved slightly due to some improvement in the combustion event.

Viscosity value and surface tension of the fuel play a role in determining the atomisation degree of the fuel. In addition, the high volatility of the fuel accelerates the formation of the mixture and ensures more efficient combustion of the fuel. [28]

It was determined that the effective efficiency increased at all test speeds with the addition of alcohol to biodiesel fuel. This increase in effective efficiency can be attributed to the better mixing of the air-fuel mixture taken into the cylinder thanks to the high volatility of alcohol and the oxygen molecules in the alcohol content are directly proportional to the improvement of combustion in the cylinder. In other words, thanks to the -OH group in the alcohol content and as a result of the weakening of the C-C bond during combustion at high temperatures, a faster combustion occurs. This leads to an increase in efficiency. ([21],[27])

IV. Result

Biodiesel is produced from sunflower oil, which is very easy and widespread in Turkey. Biodiesel fuel was used as a blend with diesel and n-butanol and its effect on purple performance characteristics was investigated. Transesterification method was selected as the biodiesel fuel production method and produced by this method. Seven different fuels were prepared to be tested in the experimental engine. Fuels were named as D100, B100, B95Bu5, B90Bu10, B50D50, B47,5D47,5Bu5, B45D45Bu10. The prepared fuels were tested in a four-stroke four-cylinder diesel engine at 4 different speeds.

In the tests, it was understood that B100 fuel had better engine power and torque values at high speeds and worse values at low speeds compared to D100 fuel. Considering the calculated average values, it was seen that the fuels were quite close to each other. Although the lower calorific value of B100 fuel is lower than D100 fuel, the power and torque values obtained have increased due to the high amount of fuel sprayed into the combustion chamber per unit time due to its high density value. In addition, it is predicted that the heat released as the engine speed increases has a positive effect on the high viscosity value of biodiesel fuel. The addition of n-butanol to the fuel blends had a positive effect on the viscosity and density values of the blends. It had a positive effect on the spraying properties and provided better atomisation of the fuel mixtures and provided more efficient combustion of the fuel thanks to the oxygen in its content and caused a slight increase in engine power and torque values at all engine speeds. It was found that the positive effect of the oxygen in the content of n-Butanol, which was added to the fuel mixtures by maximum 10%, was higher than the negative effect of the lower calorific value of the mixture and the low cetane number.

Abbreviations and indices

ASTM American Society for Testing and Materials

NaOH Sodium hydroxide

AYME Sunflower Methyl Ester

MAM Marmara Research Centre

DIN Deutsches Institut für Normung e.V.

EN Europen Norm

D100 Pure Diesel

B100 Pure Biodiesel

B95Bu5 95% Biodiesel 5% n-Butanol fuel blend

B90Bu10 90% Biodiesel 10% n-Butanol fuel blend

B50D50 50% Biodiesel 50% Diesel fuel mixture

B47,5D47,5Bu5 47.5% Biodiesel 47.5% Diesel 5% n-Butanol fuel blend

B45D45Bu10 45% Biodiesel 45% Diesel 10% n-Butanol fuel blend

D Density value of biodiesel at 15 °C

B The temperature at which half of the biodiesel is distilled

Hu_k Lower heating value (Mj/kg)

Hu_n	Lower heating values of known fuels in the mixture
ρ_k	Density of the mixture
ρ_n	Known density value of fuels in the mixture
x_n	Volumetric mixing ratio
SS_k	Cetane number of the mixture
SS_n	Known cetane numbers of the fuels in the mixture
η_k	Kinematic viscosity of the mixture
η_n	Known kinematic viscosity of the fuels in the mixture
P_e	Effective power (kW)
M_d	Rotation torque (Nm)
F	Brake force (N)
L	Moment arm length (m)
ÖYT	Specific fuel consumption (g/KWh)
m_y	Fuel consumption (kg/h)
η_e	Effective efficiency
Mj/kg	Megajoule per Kilogram
kW	Kilowatt
Nm	Newton metre
N	Newton
m	Metre
g/KWh	Grams per kilowatt hour
kg/h	Kilogram per hour

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