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Research Article

Determination of effects of some alcohol blends on performance, emission, mechanical vibration and noise in diesel engines

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Abstract: The use of alcohol-derived fuels produced from renewable resources is an effective method to reduce dependence on petroleum. However, alcohols can improve the combustion process by changing the fuel chemistry. In this way, performance, emission, mechanical vibration and noise values can be improved in diesel engines. In this study; new fuel forms (D90E10, D90IB10, D80E10IB10, D77.5E10IB10DEE2.5, 75E10IB10DEE5) were formed by mixing ethanol, isobutanol and diethyl ether alcohols with diesel fuel in certain proportions. The fuels generated was used in experiments. The studies were conducted with four different loads (%25, 50, 75, and 100) at a constant speed (2800 rpm). The optimum fuel mixture was determined by examining the engine performance, exhaust emissions, mechanical vibrations and noise data obtained in the experiments. When the most important data output of the test results is evaluated; because D75E10IB10DEE5 fuel has a lot of oxygen in it and diethyl ether makes the cetane number go up, it was found that at full load, smoke emissions went down by 24.6% and mechanical vibrations went down by 14.2% compared to standard diesel fuel.

Keywords: Diesel engine, alcohol blends, performance, emissions, mechanical vibrations, noise.

1. Introduction

The majority of vehicles, which are indispensable to adapt to the fast flow of life, use petroleum-derived fuel. However, the limited amount of oil in the world threatens the future of vehicles. As a result, industries and academics are focusing on finding alternate energy sources. [1, 2]. This focus has led to a rise in the manufacture of electric vehicles in recent years. However, the inability to solve problems such as charging time, battery, and infrastructure of these vehicles stands as an obstacle to the transition to electric vehicles. Since it will take time to get over these challenges, internal combustion engines will be used for quite some time. [3-6]. Continuing the use of internal combustion engines requires solving the problems of these engines such as fuel, exhaust emissions, noise and vibration [7, 8]. The utilization of renewable biofuels, which can replace petroleum in internal combustion engines, is crucial for the resolution of these issues [9, 10]. The use of biodiesel, which is at the top of the biofuels, is widely used in diesel engines [11, 12]. In spark-ignition engines, the use of alcohol has become prominent. In addition, it is feasible to blend alcohols with diesel fuel and use the resulting mixture in diesel engines. This option is quite economical as it does not require significant modifications in diesel engines [13, 14].

When alcohols are introduced to diesel fuel, the fuel is changed, which has an impact on the combustion process. Improvements in engine performance, exhaust emissions, mechanical vibrations and noise emissions seem possible with the right choice of fuel mixtures [15]. Qudais et al. [16] investigated the impact of ethanol-diesel combination on engine performance and emissions. They determined that the optimum ethanol mixture is 20%. The researchers found a 7.5% increase in thermal efficiency and a 32% decrease in soot emissions with the ethanol mixture in the study. In another similar study, Bilgin et al. [17], conducted tests by adding ethanol to diesel fuel at volumetric ratios of 2%, 4%, and 6%. The trials revealed that 4% ethanol added to diesel fuel improved the engine's performance and efficiency. Mofijur et al.[18], in a review study on biodiesel-diesel-ethanol blends, stated that ethanol added to biodiesel-diesel blends reduced hydrocarbon, particulate matter, nitrogen oxide (HC, PM, NOx) and smoke emissions but slightly increased fuel consumption. In another experimental study examining alcohol blends, it was determined that the biodiesel-alcohol-diesel blend increased specific fuel consumption compared to pure diesel fuel. Additionally, it was found in the study that increasing the fuel's alcohol level increased the carbon dioxide (CO_2) and HC emis-

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sions while lowering the NO emissions. Lujaji et al. [19] found in their study with croton oil-butanol-diesel fuel blends that mixtures containing butanol exhibited higher in-cylinder heat and pressure release rate. Datta and Mandalı [20], in their study with croton oil-butanol-diesel fuel mixtures, they found that mixtures containing butanol exhibited higher in-cylinder pressure and heat release rate. In the study, determined that the addition of ethanol and methanol improved engine efficiency. The maximum in-cylinder pressure and heat release rate increased when butanol-ethanol-methanol mixtures were used with diesel fuel, according to Emiroğlu and Şen [21]. Additionally, they found that the addition of alcohol reduced smoke and CO emissions while increasing NO emissions. In a numerical study similar to this study, Temizer et al. [38] They examined the effects of ethanol and diethyl ether added fuel on performance and emissions at different speeds. In the study, it was determined that NO emissions decreased with alcohol additives. Overall, when the studies were evaluated, it can be concluded that using alcohols in combination with diesel fuel affects exhaust emissions. Especially, the high oxygen content in alcohols contributes to a more efficient combustion process, leading to reduced emissions.

Another important problem of diesel engines is mechanical vibrations and noise emissions [22-24]. These problems negatively affect driving comfort and harm people and the environment [25, 26]. When examining the literature studies in this regard, it is evident that research on biodiesel fuels generally predominates. The research on fuels made of alcohol and diesel has been found to be sparse. Focusing on this issue, Taghizadeh-Alisaraei and Rezaei-Asl [27] looked examined the impact of various ethanol mixture ratios on engine performance and vibration. According to the study, the addition of ethanol caused an increase in engine torque and vibration. Morgul [28], who examined the effect of butanol-diesel mixture on engine noise and vibration, determined that noise emissions decreased by 2-3 dBA and vibration values increased in his experiments with 10% butanol mixture. According to Karagöz [29], who investigated how introducing nanoparticles to the diesel-methanol combination affected engine vibration and noise, there was an increase in vibration and noise.

The main purpose of this research is to investigate the effects of alcohol fuels on the performance, emissions, mechanical vibration and noise emissions of the diesel engine. In line with this goal, an experimental study was carried out by applying different alcohol mixtures to diesel fuel. In the study; pure diesel (D100), 10% ethanol added diesel (D90E10), 10% isobutanol added diesel (D90IB10), 10% ethanol 10% isobutanol added diesel (D80E10IB10), 10% ethanol 10% isobutanol 2.5% diethyl ether added diesel (D77.5E10IB10DEE2.5) and 10% ethanol 10% isobutanol 5% diethyl ether added diesel (D75E10IB10DEE5) fuels were tested. The experiments were carried out at four different loads (25, 50, 75 and 100) and at a constant speed of 2800 rpm, which is the revolution at which the maximum torque occurs. In the tests, engine performance, exhaust emissions, mechanical vibrations and noise data were recorded and analyzed.

2. Material and Method

Figure 1 depicts the constructed system's schematic view. In the system; ANTOR AD320 model single-cylinder diesel engine, 49.3 kW ABB brand dynamometer for loading the engine, Bosch BEA 60-70 emission devices for emission measurements, fuel measurement system, PCE-VD3 vibration device was used to measure mechanical vibrations and GERATECH DT 8820 model noise device was used to measure engine noise values. The computer was wired to the vibration device, which was mounted to the engine's cylinder head. The device is capable of measuring

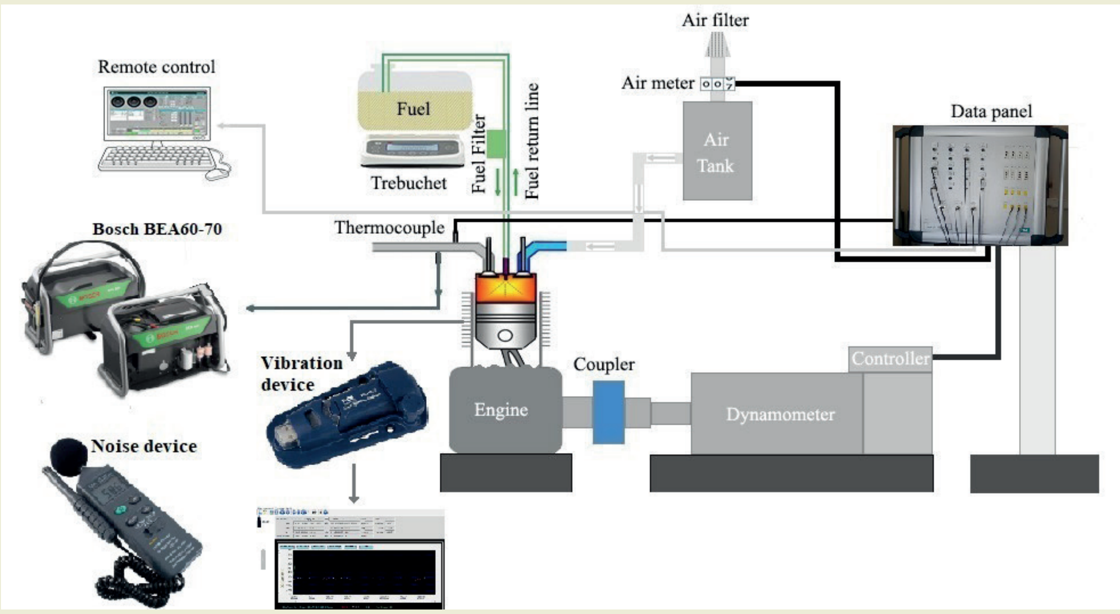

Figure 1. View of the test system schematically

in 3 axes (x, y, z) and can record data at 500 ms intervals through the computer interface, enabling the calculation of average values. The noise device determines values in decibels dB(A). Noise measurements were recorded according to ISO 362-1:2007 standard at a distance of 1.0 meter from the noise source [23].

2.1. Test Fuels

Table 1 lists the physical and chemical characteristics of the fuels utilized in the studies. The volumetric mixing ratios of the fuels are shown in Table 2. Mixture ratios of ethanol and isobutanol were determined based on literature review. However, the study of diethyl ether additive addition of these fuels is limited in the literature.

Table 1. Test fuels physical and chemical specialties [30, 31, 43-45].

Properties	Diesel	Ethanol	Isobutanol	Diethyl ether
Mol. formula	C_nH_m	C_2H_5OH	C_4H_9OH	$C_4H_{10}O$
Mol. wt. (Kg/kmol)	185-212	46.06	74.1	74.12
Density (kg/m³)	830-840	788	800-810	713
Cetane num.	45-52	5-15	-	128
Lower heating value (kJ/kg)	42500	26400	33000	36850
Viscosity at 40°C (m/s²)	0.0027	0.00012	0.0022	0.00023

Table 2. Volumetric fuel mixture ratios.

Fuel	Diesel (%)	Ethanol (%)	Isobutanol (%)	Diethyl ether (%)
D100	100	-	-	-
D90E10	90	10	-	-
D90IB10	90	-	10	-
D80E10IB10	80	10	10	-
D77.5E10IB10DEE2.5	77.5	10	10	2.5
D75E10IB10DEE5	75	10	10	5

Table 3 lists the experimental parameters. The tests were carried out at a constant speed of 2800 rpm with four different loads (2.7, 5.4, 8.1, and 10.8 Nm).

The full load (100%) of the AD320 model engine with mechanical fuel injector is determined to be 10.8 Nm. In preliminary tests, the motor can slightly exceed this load. However, due to the engine being air-cooled and considering the long duration of the experiments, 10.8 Nm load is set as the full load. Other loads are scaled based on this value. Prior to the experiments, preliminary tests were conducted to bring the engine to suitable operating conditions. During the operation, the engine was supported with a fan to maintain its temperature balance. Each test was repeated three times to reduce the error rates in the trials and the difference between the values remained below 3%.

Table 3. Experimental test procedure.

Engine Speed (rpm)	Engine Load (%)	Fuels
2800	25	D100
		D90E10
		D90IB10
		D80E10IB10
		D77.5E10IB10DEE2.5
		D75E10IB10DEE5
	50	D100
		D90E10
		D90IB10
		D80E10IB10
		D77.5E10IB10DEE2.5
		D75E10IB10DEE5
	75	D100
		D90E10
		D90IB10
		D80E10IB10
		D77.5E10IB10DEE2.5
		D75E10IB10DEE5
	100	D100
		D90E10
		D90IB10
		D80E10IB10
		D77.5E10IB10DEE2.5
		D75E10IB10DEE5

2.2. Test Engine

To perform the fuel tests, Figure 2 ANTOR AD 320 model single-cylinder CI engine, shown in. and technical specifications given in Table 4., was used.

Table 4. Engine specifications [34].

Brand/Model	ANTOR / AD 320
Number of cylinders	1
Cylinder volume	315 cm³
Cylinder diameter	78 mm
Stroke	66 mm
Compression ratio	17,5/1
Engine speed	3600 rpm
Max. torque	13.8 @2800 rpm
Crankcase oil capacity	1,2 lt
Injection timing	20 [°CA bTDC]
Injection pressure	220 [Bar]

2.3. Uncertainty analysis

The methods developed by Kline and McClintock have been widely employed for doing uncertainty analysis on test results due to their ability to yield more exact out-

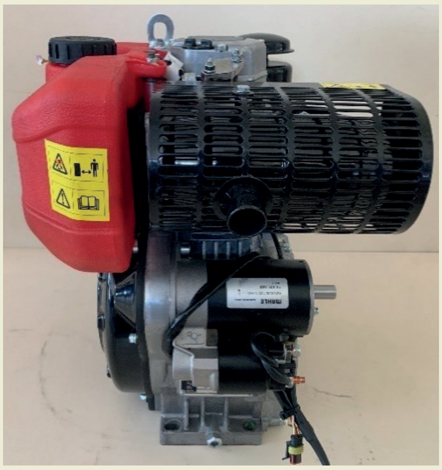

Figure 2. Test Engine.

comes. The uncertainty analyses of the calculated parameters were established by employing equation (1), as presented below [39,40]

$$W_R = \left[\left(\frac{\partial R}{\partial x_1}w_1\right)^2 + \left(\frac{\partial R}{\partial x_2}w_2\right)^2 + \left(\frac{\partial R}{\partial x_3}w_3\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n}w_n\right)^2\right]^{1/2} \quad (1)$$

Here; R represents the size to be measured or calculated, $x_1, x_2, x_3 \ldots x_n$ represents n independent variables affecting the size, $w_1, w_1, w_1, \ldots w_n$ represents the error rates for each independent variable, and W_R represents the total uncertainty of the magnitude of R.

3. Result and Discussion

3.1. Break thermal efficiency (BTE)

In internal combustion engines, thermal efficiency is an important evaluation criterion. The most significant factors affecting thermal efficiency are engine design and fuel chemistry. Changes in engine design require time and cost, whereas fuel changes are simpler. The thermal efficiencies of the fuels formed in Figure 3 at four different loads are given.

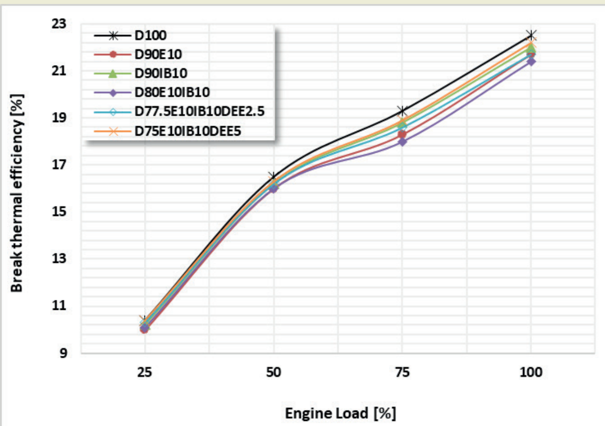

Figure 3. The calculated thermal efficiencies of fuels at 2800 rpm and various loads.

In parallel with the increase in load, the quality of combustion increased and increased the thermal efficiency. However, it was discovered that increasing the ethanol and isobutanol component of the fuel reduces the thermal efficiency. The main reason for this situation is that the heating values of alcohols are lower than diesel fuel. It was also found that the addition of diethyl ether caused a slight increase in thermal efficiency. With the addition of diethyl ether, the cetane number of the fuel increased, positively affecting the combustion efficiency.

3.2. Brake specific fuel consumption (BSFC)

A reduction in Brake Specific Fuel Consumption (BSFC) is desirable in internal combustion engines. However, especially in diesel engines, exhaust emissions have become more crucial than fuel consumption in recent years. Figure 4 shows the BSFC of the fuels at different loads. Table 4 illustrates the comparison of the used fuels with the standard diesel fuel, presented as a percentage. An upward arrow indicates an increase, while a downward arrow indicates a decrease.

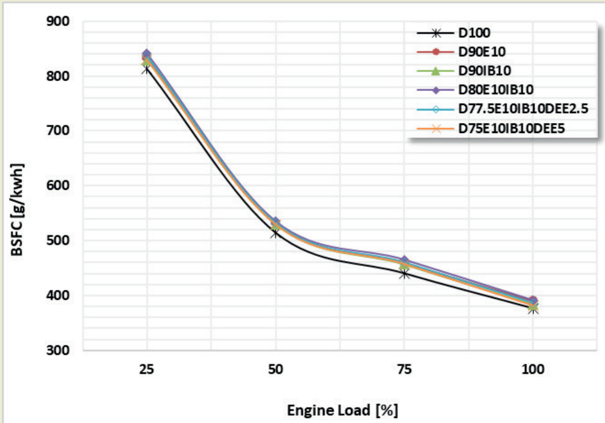

Figure 4. BSFC of fuels used at 2800 rpm and different loads.

As can be clearly seen in Table 6, the addition of ethanol and isobutanol increased the BSFC. The addition of diethyl ether to the mixture prevented the increase of BSFC somewhat. The reason for the increase in BSFC with increasing alcohol content in the fuel is the lower heating value of alcohols.

3.3. HC emissions

The basic fuel of internal combustion engines consists of hydrogen and carbon atoms. For this reason, incomplete combustion causes these atoms to be ejected from the exhaust without burning. Reducing HC emissions is an indication that fuel energy is used more efficiently [41]. Figure 5 shows the HC values of the fuels used at different loads. Table 7 shows the comparison of standard diesel and fuels used.

As seen in Table 7, HC emissions increased by 20% at full load when using D80E10IB10 fuel. In the use of D75E10IB10DEE5 fuel at the same load, there was a 5% increase in HC emissions compared to pure diesel fuel. In line with these results, it can be concluded that the ad-

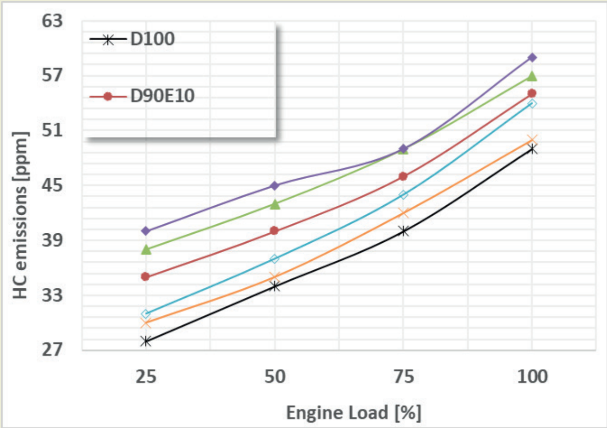

Figure 5. HC emissions measured at 2800 rpm and different loads

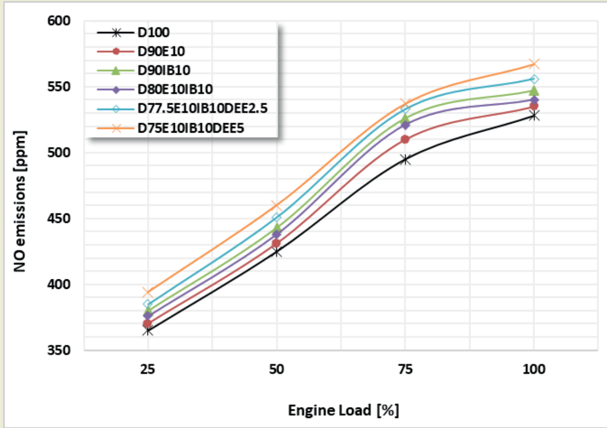

Figure 6. NO emissions measured at 2800 rpm and different loads

dition of ethanol and isobutanol increases HC emissions. it was also determined that the addition of diethyl ether decreased the HC emissions. The high cetane number of diethyl ether increases the cetane number of the mixture and causes a decrease in HC emissions.

3.4. NO emissions

In diesel engines, one of the significant emission issues is NO emissions [42]. Additional systems are being implemented in diesel engines to reduce these emissions. These systems negatively affect the engine performance and cannot work well for a long time. Figure 6 shows the NO values of the fuels used at different loads. Table 8 shows the comparison of the fuels used with the standard diesel.

As seen in Table 8, NO emissions rose as the alcohol concentration of the fuel increased. These experimental results are consistent with findings to other studies in the literature [32, 33]. The main reason for the increase in NO emissions is the low calorific value of alcohols. This increases the amount of fuel delivered to the cylinder as well as the temperature inside the cylinder. As a result, BSFC and NO emissions increase.

3.5. Smoke emissions

In diesel engines, another important emission is smoke emissions. Therefore, exhaust emission measurements focus on smoke emissions. The main cause of smoke emissions is the carbon atoms present in the fuel. Alcohols, due to their lower carbon atom count and the presence of oxygen, result in more efficient combustion, leading to a reduction in smoke emissions. Figure 7 illustrates the measured smoke emissions in the experiments. Table 9 shows the comparison of alcohol-blended fuels with the standard diesel fuel.

Table 6. BSFC change rates of the generated fuels compared to standard diesel.

Engine speed	Engine load (%)	D100 (g/kwh)	D90E10	D90IB10	D80E10IB10	D77.5E10IB10DEE2.5	D75E10IB10DEE5
2800 rpm	25	813	2.45%	1.97%	3.44%	2.83%	1.97%
	50	514	3.5%	3.11%	4%	3.5%	2.92%
	75	440	4.3%	3.86%	5.68%	4.55%	3.86%
	100	376	3.7%	2.12%	3.99%	2.66%	1.33%

Table 7. HC change rates of generated fuels compared to standard diesel

Engine speed	Engine load (%)	D100 (ppm)	D90E10	D90IB10	D80E10IB10	D77.5E10IB10DEE2.5	D75E10IB10DEE5
2800 rpm	25	28	25%	35%	42%	10%	7%
	50	34	17%	26%	32%	8%	3%
	75	40	15%	22%	22%	10%	5%
	100	49	12%	3.6%	20%	10%	2%

Table 8. NO change rates of generated fuels compared to standard diesel

Engine speed	Engine load (%)	D100 (ppm)	D90E10	D90IB10	D80E10IB10	D77.5E10IB10DEE2.5	D75E10IB10DEE5
2800 rpm	25	365	1.37%	4.1%	3%	5.48%	7.94%
	50	425	1.41%	4.23%	3%	6.1%	8.23%
	75	495	3%	6.26%	5.25%	7.67%	8.48%
	100	528	1.32%	3.6%	2.27%	5.3%	7.38%

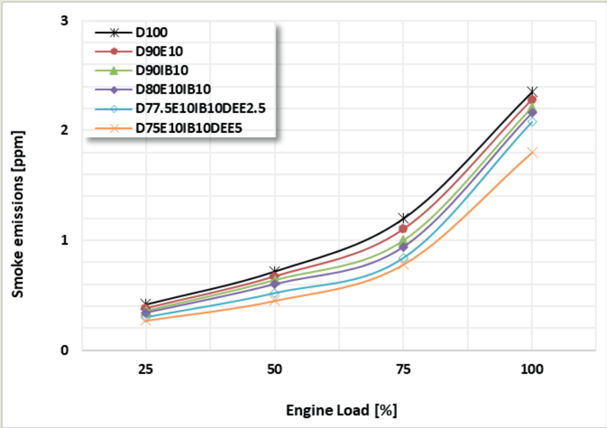

Figure 7. Smoke emissions measured at 2800 rpm and different loads

The addition of ethanol and isobutanol has resulted in a decrease in smoke emissions. Furthermore, the addition of diethyl ether has further contributed to the reduction of smoke emissions. The high-octane number of diethyl ether is the primary reason for this effect.

3.6. Mechanical vibrations

Since diesel engines have a high compression ratio, their end-of-combustion pressures are higher than those of spark-ignition engines. This causes diesel engines to generate a higher vibration. High vibration is undesirable for users and the engine. In Figure 8, the average vibration values occurring in the tests of fuels are shown as g (m/s^2). Table 10 shows the comparison of the generated fuel blends' vibration values with the standard diesel fuel.

The addition of ethanol and isobutanol has resulted in an average decrease of 4.4% in vibration values. Increasing the proportion of diethyl ether has been effective in reducing vibrations, providing a 12.2% decrease at full load. The high setan number of diethyl ether allowed the D75E10IB10DEE5 fuel to achieve minimum vibration values.

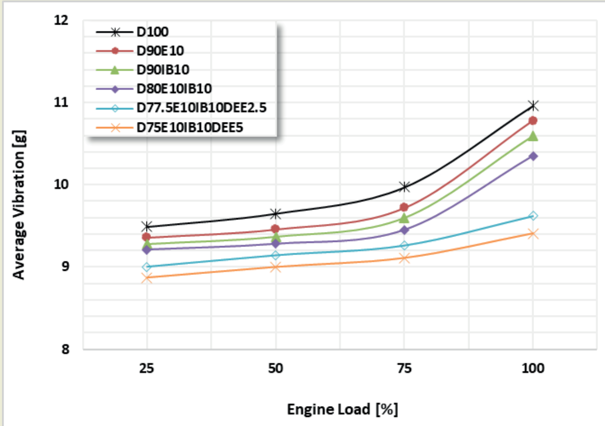

Figure 8. Mechanical vibrations measured at 2800 rpm and different loads

3.7. Noise

In diesel engines, noise caused by high cylinder pressure is an undesirable condition due to its negative effects. Furthermore, noise emissions must be restricted due to their negative influence on the environment and human health. Figure 9 shows the noise values obtained during the tests. Table 11 compares the noise levels of alcohol-blended fuels with the standard diesel fuel.

It was discovered that as the alcohol component in the fuel mixture increased, the noise levels decreased. It was determined that the addition of ethanol and isobutanol

Table 9. Smoke emissions change rates of generated fuels compared to standard diesel

Engine speed	Engine load (%)	D100 (ppm)	D90E10	D90IB10	D80E10IB10	D77.5E10IB10DEE2.5	D75E10IB10DEE5
2800 rpm	25	0.42	9.53%	14.3%	19%	28.5%	36%
	50	0.72	7%	10.12%	17%	27.8%	37.5%
	75	1.2	8.4%	16.7%	22%	30%	35%
	100	2.35	3%	6%	8%	21.5%	24.6%

Table 10. Change rates of mechanical vibrations of the generated fuels according to the standard diesel

Engine speed	Engine load (%)	D100 (g)	D90E10	D90IB10	D80E10IB10	D77.5E10IB10DEE2.5	D75E10IB10DEE5
2800 rpm	25	9.49	1.4%	2.8%	3%	5.2%	6.55%
	50	9.65	2%	3%	3.85%	5.3%	6.5%
	75	9.97	2.5%	3.7%	5.2%	7.2%	8.7%
	100	10.96	1.65%	3.3%	5.7%	12.3%	14.2%

Table 11. Noise change rates of the generated fuels compared to standard diesel

Engine speed	Engine load (%)	D100 (dBA)	D90E10	D90IB10	D77.5E10IB10DEE2.5	D75E10IB10DEE5
2800 rpm	25	100.9	0.2	0.3	1.1	1.4
	50	101.1	0.1	0.3	1	1.3
	75	101.3	0.2	0.3	1.1	1.4
	100	101.9	0.2	0.4	1.3	1.6

reduced noise emissions by 0.7 dBA at full load. In addition, although the diethyl ether ratio is low, it has been found to be more successful in reducing noise values. It was determined that the noise emissions were reduced by 1.7 dBA with the addition of 5% diethyl ether at full load. Increasing the cetane number of the fuel with diethyl ether additive reduced the knocking process and reduced vibration and noise emissions.

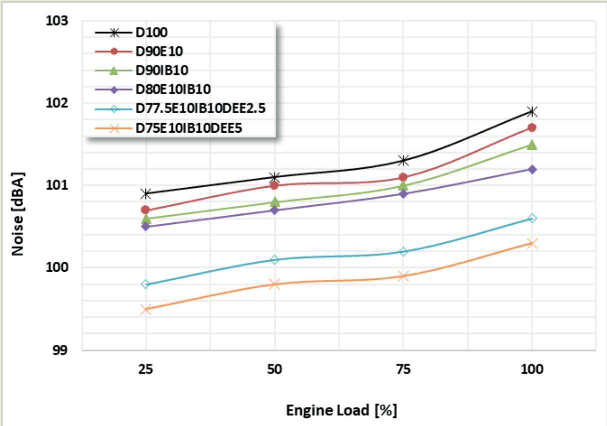

Figure 9. Noise measured at 2800 rpm and different loads

4. Conclusion

Different alcohol mixtures; When the data obtained in this study, which examined the effects on engine performance, exhaust emissions, mechanical vibrations and noise, the following results were determined.

- The increase in alcohol rates reduced thermal efficiency. This drop has been determined to be less at low loads and more at high loads.
- An increase in the alcohol blending ratio has reduced the thermal efficiency. However, the addition of diethyl ether has somewhat mitigated this decrease in thermal efficiency.
- NO emissions obtained from alcohol-blended fuel tests are higher than those from standard diesel fuel. This is due to the higher fuel injection resulting from the lower calorific values of the blends. The experimental results are in line with the studies in the literature [37,38].
- It has been found that alcohols are effective in reducing smoke emissions. At half load (50%), D75E10IB10DEE5 fuel has shown a 37.5% reduction in soot emissions compared to standard diesel. These results are supported by studies in the literature [35,36].
- Increasing the alcohol percentage effectively reduces mechanical vibrations. When compared to ethanol and isobutanol blends, the addition of diethyl ether was found to be more successful in minimizing mechanical vibrations.
- The use of alcohols has been effective in reducing noise emissions. It has been determined that diethyl ether is the most effective alcohol in reducing noise emissions.
- Future research could contribute to the usage of alcohols in diesel engines by exploring the effects of different alcohol blends and motor changes on engine performance.

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