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Experimental Investigation of the Effects of Diesel–10 Number Oil Blends on Engine Performance and Emission Characteristics

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ABSTRACT

The increasing use of unauthorized fuels such as “10 number oil” raises serious concerns regarding engine performance, environmental safety, and public health. This study experimentally investigates the effects of diesel–10 number oil blends on the performance and emission characteristics of Mitsubishi Canter 4D31 diesel engine. Four blend ratios (D100, D50, D20, D10) were tested over a speed range of 1200–2700 rpm. Results show that increasing the proportion of 10 number oil reduces torque and power due to poor atomization and incomplete combustion, while specific fuel consumption increases, indicating lower efficiency. Emissions analysis revealed higher CO and NOx levels, whereas CO_2 decreased due to incomplete oxidation. At 2200 rpm, the D10 blend caused 3.64% decrease in torque and 2.30% increase in SFC, along with increases of 10.87% in CO and 20.55% in NOx. Overall, the findings highlight the negative impacts of 10 number oil on engine performance and emissions.

Dizel–10 Numara Yağ Karışımlarının Motor Performansı ve Emisyon Karakteristiklerine Etkisinin Deneysel Olarak İncelenmesi

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ÖZ

Yetkisiz yakıtların, özellikle “10 numara yağ”ın artan kullanımı; motor performansı, çevresel güvenlik ve halk sağlığı açısından ciddi endişeler doğurmaktadır. Bu çalışmada, dizel–10 numara yağ karışımlarının Mitsubishi Canter 4D31 dizel motorunun performans ve emisyon karakteristikleri üzerindeki etkileri deneysel olarak incelenmiştir. Dört farklı karışım oranı (D100, D50, D20, D10), 1200–2700 dev/dk aralığında test edilmiştir. Sonuçlar, 10 numara yağ oranının artmasının, kötü atomizasyon ve eksik yanma nedeniyle tork ve gücü azalttığını; özgül yakıt tüketimini ise artırarak verimliliği düşürdüğünü göstermektedir. Emisyon analizleri, CO ve NOx seviyelerinde artış, CO_2 emisyonlarında ise eksik oksidasyon nedeniyle azalma olduğunu ortaya koymuştur. 2200 dev/dk’da D10 karışımı, D100’e kıyasla torkta %3,64 azalma ve özgül yakıt tüketiminde %2,30 artışa neden olmuş; aynı koşullarda CO emisyonları %10,87 ve NOx emisyonları %20,55 oranında artmıştır. Genel olarak, bulgular 10 numara yağ kullanımının motor performansı ve emisyonlar üzerinde olumsuz etkiler yarattığını göstermektedir.

1. INTRODUCTION

The oil sector covers products with a wide range of uses. Especially the mineral-based oil sector has become popular in the global market with industrialization. The oil sector in industry and automotive is a dynamic field in constant search of development and innovation. It plays an important role in increasing the efficiency of engines and machines, reducing environmental impact and achieving sustainability goals. With the increasing use of diesel engines, which have an important place in the transportation sector, the exhaust emissions they cause greatly increase environmental pollution. For this reason, many researchers have started to search for alternative fuels that can be used in diesel engines [1].

Analyzing the oils used in machines is an important preventive maintenance practice for predetermining malfunctions, reducing repair and operating costs and efficient operation [2]. However, Oils that are not used for their intended purpose and known as illegal fuel oil in the market seriously threaten human and environmental health. These illegal fuels are called “Number 10 oil” in Turkey and may contain base oil and waste oil mixtures in their composition [3]. Recent studies have revealed that the use of such unauthorized fuels in diesel engines results in reduced engine efficiency, lower torque, and significantly increased levels of toxic components such as CO, NOx, and heavy metals in exhaust gases [4-6]. In addition, previous studies have reported that variations in fuel composition and physicochemical properties can significantly affect diesel engine performance and exhaust emission characteristics [7]. In particular, a study by Aliyu et al. [5] reported that dangerous levels of heavy metals such as lead, cadmium, and arsenic were detected in the exhaust gases of illegal fuels such as No. 10 oil. Furthermore, the literature emphasizes that such fuels pose serious safety problems, such as low flash points, uneven combustion, and fire risk [6]. Waste motor oil, burnt oil, unprocessed crude oil, smuggled diesel oil, vegetable oil, solvent, transformer oil and treated waste oils are commercialized by adding them into base oil [8].

Especially number 10 oils, which are substituted for the diesel market, have very high fluidity and lower actual consumption. Number 10 oil is known to be produced from base oils such as SN100, SN150, SN500 in the literature [9]. These fake fuels are mostly preferred by heavy vehicle drivers. For this reason, It is sold in industrial zones, truck and bus garages and even in markets along the road, and it is quite easy to access the product in the market. In fact, number 10 oil, which caused widespread public outcry with its use in 2008–2012, is back on the agenda due to economic reasons, the increase in crude oil prices and tax increases [10].

The use of number 10 oils not only causes serious tax losses for the country, but also leads to unfair competition between companies and traders. The high difference between the tax burden on diesel fuel and the tax burden on the goods used in the production of Number 10 oil causes this phenomenon. Since the years when this problem was recognized by the tax administration, many legal arrangements have been made in the relevant legislation, but malicious taxpayers have always tried to continue the production and use of number 10 oil by developing new methods against them [11].

It also causes serious harm to human, public and environmental health due to the toxic and poisonous substances in its composition. On June 8, 2011, a bus crashed in Görele, Giresun and suddenly caught fire and burned down in a very short time, resulting in many deaths and injuries. The cause of this sudden fire was proven by an expert report to be a base oil-solvent mixed fuel oil product [12]. Exhaust pollutants are likely to include heavy metal pollutants such as arsenic, lead, cadmium and chromium, which are hazardous and harmful to human health.

Uyaroğlu et al. [13] examined two different engines that were known to have used number 10 oil and failed. In the study, it was stated that number 10 oil has a high ignition temperature (116-194 °C). For this reason, it was interpreted that the knocking increased with the extension of the ignition time and accordingly caused piston wear. In addition, it was also stated that the material strength was adversely affected due to the increase in pressure due to the delay in the ignition time but the fuel injection continued in the combustion chamber.

Eryılmaz et al. [14] investigated the performance of diesel fuel, waste vegetable oil and number 10 oil samples and the emissions that may occur as a result of their use. In their experiments, it was determined that the viscosities of waste vegetable oil and number ten oil were higher than diesel fuel. In terms of emissions, it was found that CO and SO_2 emissions were higher when number ten oil and diesel were used compared to vegetable waste oil.

Gedik and Yurdakul [15] investigated the chemical content of number ten oil. It was reported that the distribution of 19 metals (Ag, As, Ba, Bi, Cd, Co, Cr, Fe, Li, Mn, Mo, Ni, Pb, Rb, Se, Sr, Tl, V, Zn) in the samples collected from across Turkey ranged between 0.04-189 µg/g. It was concluded that the estimated metal emission values using measurement data and annual average base oil sales figures in Turkey are comparable or higher than the total metal emissions from diesel vehicles or industrial sources in different countries.

In this article, tests were carried out with a mixture of commercially available number ten oil and diesel at certain percentages and torque, sfc, CO_2, CO and NO_x values were investigated. Depending on these properties, power calculation was also made and a comparison between diesel and number ten oil was made.

2. MATERIAL AND METHOD

2.1. Evaluation of Diesel Fuel

Diesel has become more widely used in recent years due to its higher efficiency, higher torque and lower CO and HC emissions compared to gasoline engines [16]. Diesel fuel, which is widely used especially in light commercial vehicles, provides fuel economy for users [17]. Diesel vehicles are highly preferred in transportation and transportation sectors due to their low fuel consumption and high torque [18]. The sales data for diesel fuels, which are frequently used especially in transportation, from Petder (the Turkish fuel distributor) for December 2023 also confirms this [19].

Considering the increasing use of diesel oil in our country, a comparison of diesel and number ten oil was made in this study. Some important fuel properties of the diesel fuel used in this study are taken from studies in the literature [20].

Table 1. Some important fuel properties of diesel fuel

Description	Unit	Diesel fuel
Density @ 15°C	kg/m³	835.7±0.2
Kinematic viscosity @40 °C	mm²/s	3.033±0.012
Upper calorific value	MJ/kg	45.360±0.12
Lower calorific value	MJ/kg	42.5383
Flash point	°C	68±1.5
Cetane number	-	Min.51

The properties of the diesel fuel provided in the table indicate that it is suitable for use as a reference fuel in experimental studies. Having physical and chemical characteristics within standard ranges enhances the reliability of comparative analyses with other fuel blends.

2.2. Number 10 Oil Analysis

According to the October 2012 report of PETDER, technical values of some samples taken from the tanks of vehicles using number 10 oil and from the cans sold as number 10 oil were analyzed. The number of samples analyzed in this study is 10, and the table below presents the average values.

Table 2. Number 10 Oil analysis results [21]

Tests	Truck using number 10 oil	Number 10 oil can	Ts En 590 specifications
Flash point, °C	24-82	42	Max. 55
Density @15 °C, kg/l	0.8447-0.8884	0.8611	0.820-0.845
Sulfur, ppm	2060-4000	4100	Max. 10
Viscosity, mm²/sn	4.32-9.41	30.9	2-4.5
Initial boiling point, °C	25-27	28	
%volume @250 °C	12-13	100	Max. %65
%volume @350 °C	40-41	100	Min. %85
Temperature at which 95% of the fuel is distilled (°C)	45-46	100	Max. 360 °C

When the table is examined, it is seen that the "flash point" values in the number 10 oil samples are lower than the standards and the "density" values are higher than the standards. The low flash point in the samples taken is an important indicator of the addition of substances such as solvents. A flash point below 55 °C will cause irregular and uncontrolled combustion in the engine. This may cause the vehicle to burn. The sulfur values indicate that, it is seen that they are much higher than standard fuels. The fact that the sulfur value is so high strengthens the possibility that the samples contain waste oils as well as mineral oils. When the "evaporation temperature" values are examined, it is seen that they are higher than standard fuels. It is seen that some of the samples examined completely evaporated before reaching 250 °C, while some of the other samples almost did not evaporate at all.

It is seen that especially the density and viscosity values are higher than diesel oil in the number 10 oil samples examined. Since the fuel is sprayed volumetrically from the injectors, the high density means that there is more fuel than there should be, especially in the combustion chamber where combustion will take place, and the fuel is not properly distributed in the combustion chamber. Mixing number 10 oils with fuel will also increase the viscosity of diesel fuel, causing the fuel sprayed into the combustion chamber to be sprayed poorly, resulting in inefficient combustion and smoke, soot and heavy odor from the exhaust.

In this study, Mitsubishi Canter 4D31 diesel engine was used to analyze the performance and emission parameters using variable RPM values. The nominal rpm value was selected as 1200 rpm and gradually increased up to 2700 rpm.

Table 3. Technical specifications of the test engine

Specifications	Description
Brand	Mitsubishi Canter
Model	4D31
Configuration	In-line 4
Type	Direct injection diesel with glow plug
Displacement	3298cc
Bore	100
Stroke	105
Power	91 HP @3500 rpm
Torque	223 Nm @2200 rpm
Oil cooler	Water-cooled

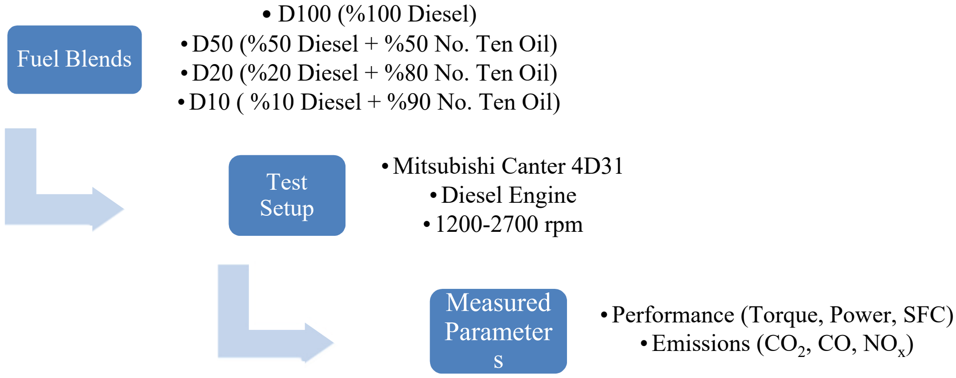
In this study, torque, sfc, CO_2, CO and NOx values were investigated by mixing number ten oil and diesel fuel at certain percentages. Depending on these properties, power calculation was also performed and the effect of diesel and number ten oil on engine and emission was compared.

3. RESULT AND DISCUSSION

3.1. Engine Performance Parameters

Emission assessment limits were applied in the same way when evaluating engine performance parameters.

Table 4. Overview of the experimental procedure



A gradual increase was observed between 1200 and 2700 rpm for all blend ratios. Torque and specific fuel consumption results were obtained experimentally and power calculation was calculated theoretically according to these results.

3.1.1. Torque

Engine torque data were obtained for D100–D50–D20–D10 ratio mixtures between 1200 and 2700 rpm. It is observed that the torque increases as the speed increases. When the torque is evaluated in terms of fuel, the torque values decrease as the number ten oil additive increases.

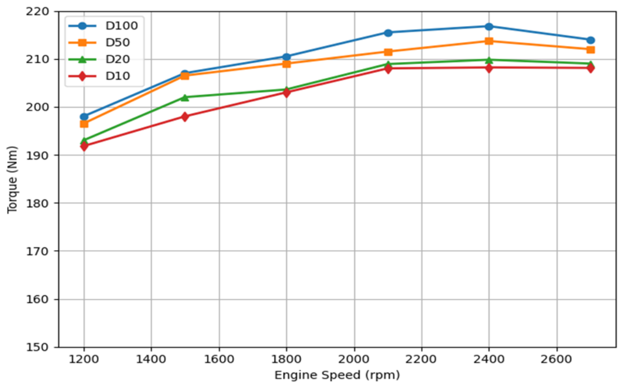


Figure 1. Engine torque according to number ten oil additive amount

As shown in Figure 1, number ten oil additive negatively affects engine performance. It has been shown in the experimental study that as the additive rate increases, the torque value decreases, that is, the traction power of the vehicle decreases. The decrease in torque with increasing number ten oil additive can be explained by the modification of the fuel's physical and combustion characteristics. As the additive ratio increases, the viscosity of the fuel blend becomes higher, which adversely affects spray formation, droplet atomization, and the homogeneity of the air–fuel mixture. Previous studies have shown that improved fuel atomization, achieved through higher injection pressures, significantly enhances engine torque and power output by promoting more efficient combustion [22]. Impaired atomization results in a slower and less efficient combustion process, leading to reduced in-cylinder pressure development. Since engine torque is directly related to the indicated mean effective pressure, any deterioration in combustion efficiency leads to a measurable decline in torque. Therefore, the observed reduction in torque at higher additive concentrations is primarily attributed to the decrease in combustion quality caused by the altered fuel properties.

3.1.2. Power

It is observed that the engine power increases as the speed increases with the same fuel mixture ratio. However, the engine power decreases as the number ten oil additive increases.

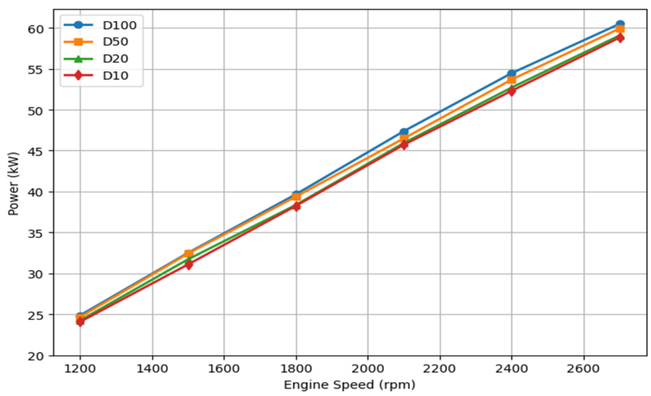


Figure 2. Power values according to number ten oil additive amount

The increase in engine power with rising engine speed at a constant fuel mixture ratio is an expected behavior, as higher speeds generally enhance the rate of combustion events per unit time. However, the observed decrease in engine power with increasing number ten oil additive is primarily related to the deterioration of fuel atomization and combustion efficiency. As the proportion of the additive increases, the viscosity of the fuel blend rises, leading to poorer spray breakup, reduced evaporation rate, and a less homogeneous air–fuel mixture. These effects result in slower and incomplete combustion, which lowers the in-cylinder pressure and consequently limits the engine's ability to produce power. Therefore, the reduction in engine power at higher additive concentrations can be attributed to the negative impact of the altered fuel properties on combustion quality.

3.1.3. Spesific Fuel Consumption

Engine specific fuel consumption data of D100-D50-D20-D10 ratio mixtures between 1200-2700 rpm. It is observed that the specific fuel consumption decreases with increasing speed up to 2400 rpm, but above 2400 rpm, the specific fuel consumption starts to increase again. When evaluated in terms of fuel mixture, as the additive ratio of number ten oil in the mixture increases, the specific fuel consumption increases.

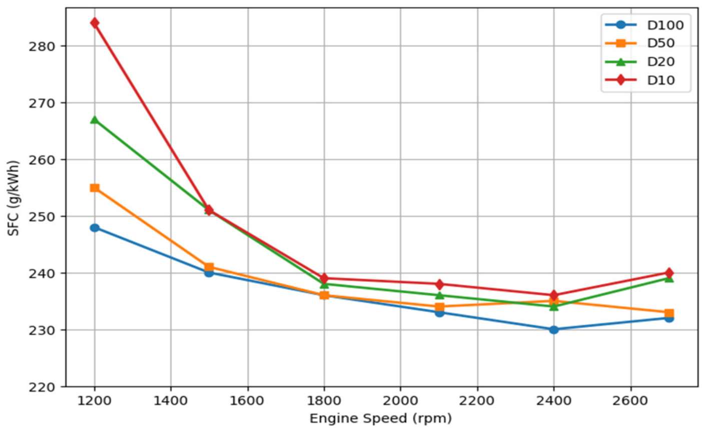


Figure 3. Specific fuel consumption according to number ten oil additive amount

Figure 3 shows that, it is evident that the number ten oil additive has an adverse effect on specific fuel consumption (SFC). The experimental results clearly show that as the additive ratio increases, SFC rises, indicating that the engine consumes more fuel to produce the same amount of power. This trend is primarily due to the reduction in combustion efficiency caused by the additive.

As the proportion of number ten oil increases, the viscosity of the fuel blend becomes higher, which impairs spray atomization, reduces evaporation, and leads to a less homogeneous air–fuel mixture. Consequently, the combustion process becomes slower and less complete, resulting in lower in-cylinder pressure. To compensate for this loss in effective pressure and maintain power output, the engine requires a higher amount of fuel, which is reflected as an increase in SFC.

This finding is also consistent with previous studies in the literature, which report that higher-viscosity fuel additives generally deteriorate combustion characteristics and consequently increase fuel consumption. In summary, the rise in SFC with increasing additive ratio is a direct outcome of diminished combustion quality and reduced fuel–energy utilization efficiency.

3.2. Engine Emission Parameters

While evaluating engine emission parameters, there is a gradual increase between 1200-2700 rpm. Diesel-number ten oil mixture ratios were determined as (100%-0%), (50%-50%), (20%-80%), (10%-90%) respectively. The "D" ratio shown in the graph and table indicates the percentage of diesel fuel in the mixture.

3.2.1. Carbon Dioxide (%)

CO_2 (%) emission results of D100-D50-D20-D10 ratio mixtures between 1200 and 2700 rpm. It is observed that the amount of CO_2 decreases as the number ten oil additive increases at the same speed, while the amount of CO_2 increases as the speed increases at the same number ten oil additive.

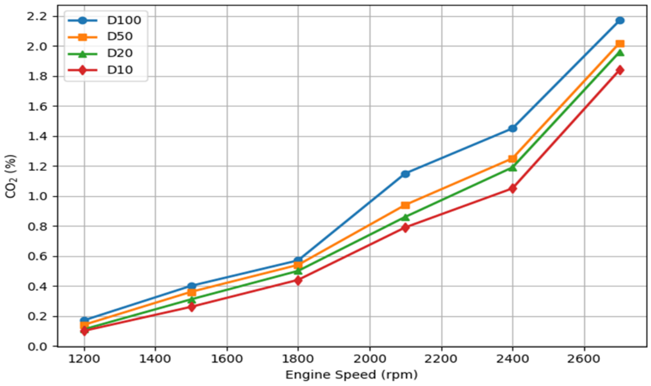


Figure 4. CO_2 emissions by number ten oil additive amount

Figure 4 illustrates the variation of CO_2 emissions (%) with respect to engine speed and the number ten oil additive ratio. In general, CO_2 levels tend to increase at higher engine speeds because the combustion process becomes more complete as the engine operates under greater airflow and improved mixing conditions. However, as the proportion of number ten oil additive increases, a decrease in CO_2 emissions is typically observed. This reduction is attributed to the deterioration of combustion quality caused by the higher viscosity of the fuel blend. Poor atomization and inadequate mixing lead to incomplete combustion, resulting in a shift from CO_2 toward intermediate or partially oxidized species such as CO and unburned hydrocarbons. Therefore, the trends observed in Figure 1 are consistent with the expected relationship between fuel properties, combustion efficiency, and emission formation.

3.2.2. Carbon Monoxide (Ppm)

CO (ppm) emission results of D100-D50-D20-D10 ratio mixtures between 1200 and 2700 rpm. It is observed that the amount of CO increases as the number ten oil additive increases at the same speed, and similarly, the amount of CO increases as the speed increases at the same number ten oil additive.

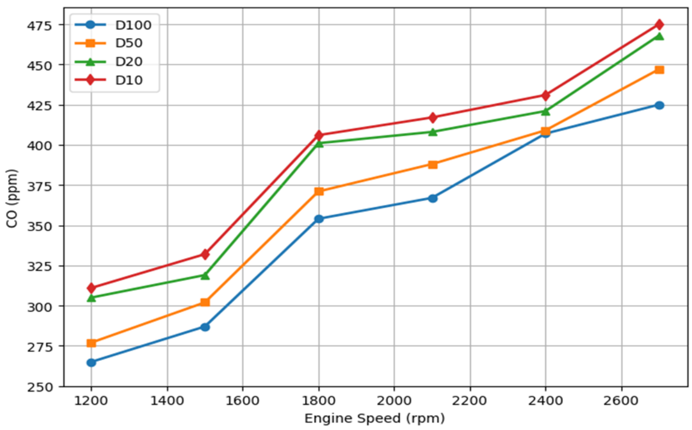


Figure 5. CO (ppm) emission according to number ten oil additive amount

Figure 5 presents the variation of CO emissions (ppm) as a function of engine speed and the number ten oil additive ratio. Typically, CO emissions decrease with increasing engine speed because higher speeds enhance air–fuel mixing, promote more complete combustion, and reduce the formation of partially oxidized species. However, as the number ten oil additive ratio increases, CO emissions exhibit a noticeable rise. This increase is primarily attributed to the deterioration of fuel atomization caused by the higher viscosity of the additive-enriched blend. Poorer atomization and insufficient mixing lead to incomplete combustion, causing a greater portion of the carbon in the fuel to be released as CO rather than fully oxidizing to CO_2. Therefore, the increase in CO concentrations with higher additive ratios is a direct indication of reduced combustion efficiency and incomplete oxidation processes.

3.2.3. Nox (Ppm)

NO_X (ppm) emission results of D100-D50-D20-D10 ratio mixtures between 1200 and 2700 rpm. It is observed that the amount of NO_x increases as the number ten oil additive increases at the same speed, similarly, the amount of NO_x decreases as the speed increases at the same number ten oil additive.

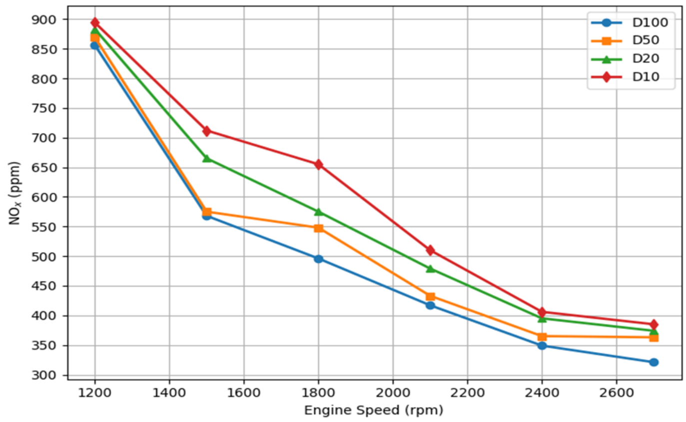


Figure 6. NO_x emissions according to the amount of number ten oil additives

When the graph is examined, it is observed that the amount of NOx increases as the number ten oil additive ratio increases at the same engine speed. This trend can be explained by the fact that higher additive ratios tend to cause local increases in combustion temperature due to poorer atomization and the formation of fuel-rich regions. These locally richer zones can result in delayed but more intense heat release, which raises peak combustion temperatures—conditions that strongly promote thermal NOx formation according to the Zeldovich mechanism.

Conversely, at the same additive ratio, NOx emissions decrease as engine speed increases. At higher speeds, the residence time of the gases in the high-temperature zone is reduced, and the combustion duration becomes shorter. Since the formation of NOx is highly dependent on both temperature and residence time, the shortened exposure to peak temperatures limits NOx production. Additionally, incomplete mixing at high speeds can further suppress peak flame temperatures, contributing to the reduction in NOx levels.

4. CONCLUSION

In today's developing automotive industry, the environmental friendliness of the vehicle is as important as vehicle performance and efficiency. Encouraging the increased use of sustainable energy sources is in line with the parallel goal of reducing the greenhouse gas effect on the world and naturally reducing the emission rates in vehicles. For this reason, in this study, the effects of mixing diesel fuel with illegal number ten oil at certain ratios on engine performance and emission values were investigated. When evaluated in terms of emission; it was found that emission release at the same speed or at the same fuel mixture ratio increased with the increase in the number ten oil additive compared to diesel fuel. Considering the ongoing policies to reduce the greenhouse gas effect all over the world, the negative impact of number ten oil use on the environment and human health is an inevitable fact.

When evaluated in terms of engine performance, number ten oil, which users turn to for economic reasons, is actually not advantageous, and the amount of fuel consumed to generate power in the engine is higher than diesel. Considering that engine torque also decreases, there is no positive contribution of number ten oil to engine performance and efficiency.

The policy recommendations developed against all these negative effects of number ten oil can be listed as follows;

- Road inspections (at Ministry of Transportation checkpoints) and deterrent law enforcement
- License revocation for businesses selling number ten oil through facility inspections,
- Incentive practices for users in tax applications,
- Practices informing citizens such as workshops, advertisements, brochures

As a result of the study conducted, it is inevitable that number ten oil, which is used even though it is not legal, should be considered as a problem and characterized as illegal because it causes environmental pollution and threatens environmental safety and human health. While non-governmental organizations and professional organizations support the solution of the problem, the key role will be played by the effective coordination and supervision of all relevant institutions and organizations. If the problem is approached with a holistic perspective and a systematic structure can be established, both economic, social and environmental security and honest competition will be ensured, the trust and competitiveness of honest companies in the sector will increase, and on the other hand, the system will not allow malicious companies. These findings may provide a scientific basis for regulatory monitoring and future experimental investigations.

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