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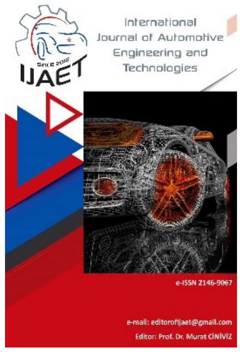

Original Research Article

Analysis of the effects of cetane improver addition to diesel on engine performance and emissions

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ABSTRACT

The high cetane number of the fuel used in diesel engines is extremely important as it provides some improvements in combustion in the cylinder. Therefore, the addition of cetane improver to diesel fuel has been highly preferred in recent years. In this study, the effects of 2-ethylhexyl nitrate (EHN) addition, a cetane improver, on compression ignition engine performance and emissions were analyzed at various engine loads. Four different fuels were used in the experiments as 100% diesel (D100), 99% diesel + 1% EHN (D99EHN1), 98% diesel + 2% EHN (D99EHN2) and 97% diesel + 3% EHN (D99EHN3). The results obtained from the experiments showed that the addition of 2-EHN positively affected the brake thermal efficiency (BTHE), hydrocarbon (HC) and carbon monoxide (CO) values, while the brake specific fuel consumption (BSFC), nitrogen oxide (NO_x) and smoke emission levels were negatively affected. With high engine load, 2-EHN supplement marginally rises NO_x emissions but significantly declines HC and CO emissions. EHN addition had small impacts on BSFC. Compared to D100 fuel, the highest BTHE value was obtained by D99EHN2 fuel, with an increase of 11.57% at 3000-Watt load value. With the D97EHN3 fuel, compared to diesel, HC emission decreased 60.61%, while CO emission decreased 31.25%. The results show that the 2-EHN cetane improver can be used successfully in a diesel engine.

Keywords: 2-ethylhexyl nitrate, cetane improver, diesel engine, performance, emission

1. Introduction

Nowadays, diesel engines are selected in many sectors due to their high economy, superior efficiency, and minimal fuel prices [1]–[3]. Diesel engines are one of the biggest consumers of fossil fuels in the world and emissions from these engines are one of the main suppliers of pollution in the environment [4]–[7]. With the environmental damage caused by the use of fossil fuels, insufficient reserves and the increase in demand for fossil fuel, the common perception worldwide is to find new fuels to reduce fossil fuel consumption or to minimize the negative effects of fossil fuel use [8]–[13]. Fuel additives have become interesting because biofuels are relatively costly to obtain and commercialize. The additives used in diesel engines are generally called cetane improvers. One of the main properties of diesel fuels is their cetane number which points out the ignition delay of the fuel in the process [14]. Therefore, additives that contribute to increase the cetane number of the fuel used are extremely important. Recently, various cetane improver additives such as alkyl-nitrates, 2-EHN and diethyl ether have been used in diesel engines to enhance the self-ignition quality of the fuel used [15]–[17]. Between the commonly employed cetane improver additives, 2-EHN is an industrial cetane improver, which presents the greatest performance in the most competitive way [18]. 2-EHN gives free radicals into the combustion space, accelerates oxidation activity, which enhances combustion attributes, and lowers flaming point and diminishes ignition delay [19]–[22]. The chemical formula is $C_8H_{17}NO_3$, with the main structure an ethyl hexane molecule with one of the hydrogen atoms substituted with an NO_3 nitrate radical [22], [23]. EHN is stable under room temperature situations and thus EHN only decomposes in the cylinder after injection and stays stable in the fuel injection system [24], [25]. Simsek and Uslu [15] formed a mixture of biodiesel obtained from different raw materials and added 2-EHN to this mixture and examined its effects. In addition, they applied RSM to determine the optimum 2-EHN ratio and biodiesel ratio at optimum engine load. They stated that the engine has ideal operation at 1515-W load, with 100% biodiesel rate and 1.1% EHN rate. Pan et al. [26] investigated the effects by adding different proportions of EHN to dimethyl carbonate / diesel mixtures in a four-cylinder turbocharged diesel engine. They stated that the use of EHN improves the performance and on the other hand increases the fuel consumption. Kuszewski [27] studied the effect of 2-EHN addition on the autoignition properties of an ethanol-diesel fuel mixture with 15% ethanol content. According to his results, he stated that as the 2-EHN ratio in an ethanol-diesel fuel mixture increased, the ignition and burning delay times decreased.

Although there are many studies in the literature regarding the use of 2-EHN in combination with biodiesel or some kind of alcohol in diesel engines [28-29], there are limited studies on the use of diesel fuel [30]. From this point of view, it has been deemed appropriate to conduct a study on 2-EHN / diesel mixtures. The aim of this study is to combine 2-EHN cetane improver with diesel to achieve improvement in performance and emission responses. For this purpose, the effects of 2-EHN additive on the performance and emissions of a compression ignition engine were examined and the advantages and disadvantages compared to diesel fuel use were compared.

2. Material and Method

The tests were performed with a single cylinder low power diesel engine and using four various fuels at several engine load (500, 1000, 1500, 2000, 2500 and 3000-Watt) values. Four different fuels were used in the experiments: 100% diesel (D100), 99% diesel + 1% EHN (D99EHN1), 98% diesel + 2% EHN (D99EHN2) and 97% diesel + 3% EHN (D99EHN3). The fuel characteristics of diesel and 2-EHN used in the experiments were obtained by testing in the energy and chemistry laboratory of TÜBİTAK Marmara Research Center according to TS EN 14214 standard and are displayed in Table 1. The experimental setup used is displayed in Figure 1. The experimental setup includes diesel engine, dynamometer, emission analyzer, load unit, load control unit and fuel consumption measurement unit. The properties of engine are shown in Table 2.

Table 1. Fuel properties

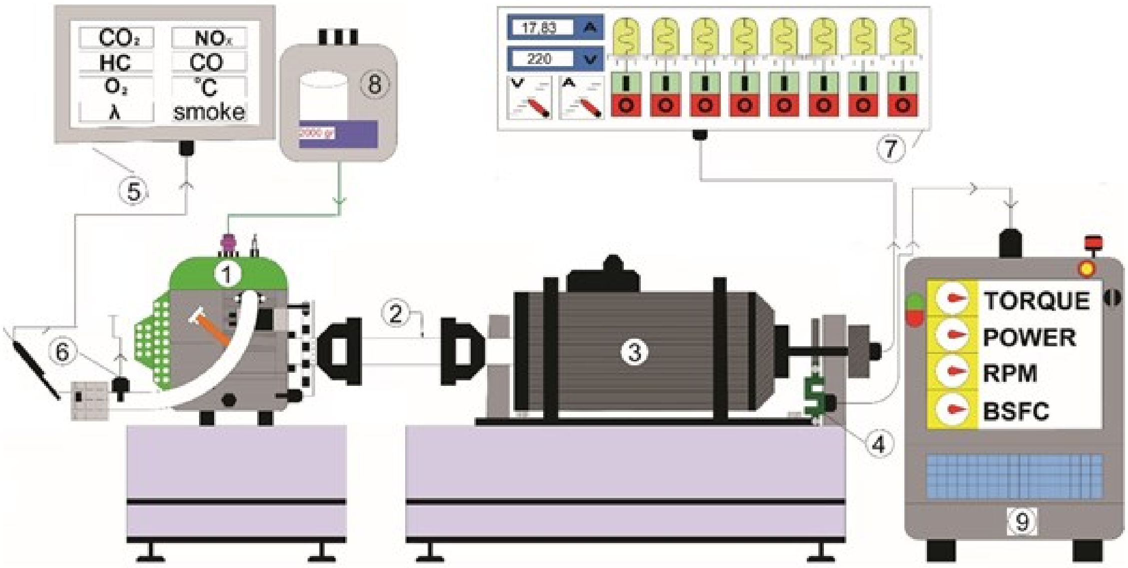
	Diesel	**2-EHN**
Chemical Formula	$C_{13}H_{28}$	$C_8H_{17}NO_3$
Oxygen Content (wt. %)	0	27.429
Lower Calorific Value (MJ/kg)	43.2	15.781
Density at 15 °C (kg/m^3)	883.6	963
Cetane Number	54	>76
Kinematic Viscosity at 40 °C (mm^2/s)	4.24	2.21

Table 2. Properties of engine

Engine Properties	
Type	Katana KM 178 FE
Maximum Horsepower	6.7 hp
Overall Volume	296 cm^3
Engine Speed	3000 rpm
Generator Properties	
Brand	Katana
Power	3.36 kVA
Voltage	230 V
Frequency	50 Hz
Phases	1

3. Result and Discussion

In internal combustion engines, it is desirable that the BTHE be as high as possible, which is



1. Diesel engine
2. Shaft connection
3. Dynomometer
4. Load cell
5. Emission analyzer
6. Temperature sensor
7. Load unit
8. Fuel consumption measurement
9. Load control unit

Figure 1. Experimental setup

an indicator of how much of the fuel supplied to the cylinder is beneficial. The cetane number is an expression of the ignition quality of a diesel fuel [31]. The ignition quality of the fuel with a high cetane number means it has a high ignition tendency. Therefore, high cetane number is a condition that improves the BTHE value. The variation of BTHE values obtained by using four different fuels with different engine loads is shown in Figure 2. It is clearly seen that BTHE increases with the use of 2-EHN. The maximum BTHE value was obtained with the addition of 2% 2-EHN, and with the addition rate of 3% BTHE tended to decrease. As the cetane number increases, the ignition delay decreases [32] and the BTHE increases. However, as the cetane number increases too much, the combustion rate increases, and the combustion is completed without shifting to the expansion period. This causes the BTHE to begin to decrease. The high cetane number shortens the ignition delay time while at the same time increasing the burning rate. For this reason, the completion of the combustion without shifting to the expansion period decreased the BTHE value. Compared to D100 fuel, the highest BTHE value was achieved with D99EHN2 fuel, with an increase of 11.57% at 3000-Watt load value. BSFC is described as the mass of fuel that the internal combustion engine must spend per hour to produce 1 kW of power [33]. BSFC is a parameter directly related to the lower calorific value of the fuel used [34]. When fuels with low calorific value are used, more fuel must be consumed in order to get the same power from the engine. Therefore, it is expected that the BSFC obtained with fuels with low lower calorific value will be high. Looking at Table 1, it is clear that the lower calorific value of 2-EHN is quite low compared to diesel. As expected, when looking at Figure 3, the BSFC value increased with the use of 2-EHN. Maximum BSFC value was found to be 1057.5 g / kWh at 500-Watt with D97EHN3 fuel. Compared to diesel, an increase of 8.47% was observed.

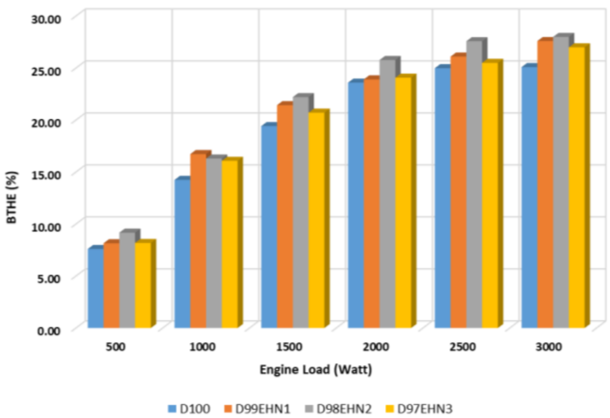


Figure 2. BTHE with different engine load

The main causes of NO_x emissions are high temperature in the cylinder and the presence of nitrogen atoms [35]. At high temperatures and high nitrogen content in the cylinder, NO_x is expected to increase. The presence of nitrogen atom in the content of 2-EHN, whose chemical formula is given in Table 1, is clearly seen.

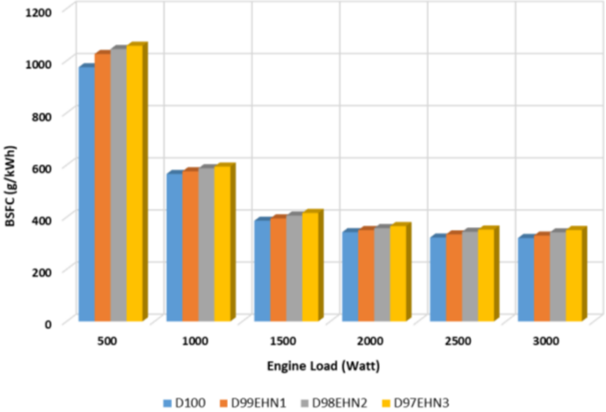


Figure 3. BSFC with different engine load

For this reason, as seen in Figure 4, it is thought that NO_x emissions increase with the addition of 2-EHN. On the other hand, NO_x emissions also increased as the increased engine load caused an increase in cylinder temperature. The maximum NO_x was achieved with D97EHN3 test fuel at an engine load of 3000 W. An increase as 42.68% was observed at the same engine load compared to the D100 fuel. Figure 5 shows the variation of smoke emissions depending on engine load. Smoke emissions are a type of emission that is adversely affected by the increasing cetane number. Therefore, increasing cetane number also increases smoke emissions. Since the cetane number of 2-EHN is higher than diesel, smoke emissions increased with the addition of 2-EHN. Figure 6 and Figure 7 show the variation of HC and CO emissions, respectively. Both HC and CO emissions are an incomplete combustion product [36]. Although there are many factors that cause incomplete combustion in internal combustion engines, the most effective one is insufficient oxygen [37]. For this reason, if there is enough oxygen in the cylinder, full combustion occurs and both HC and CO emissions decrease. When the fuel properties shown in Table 1 are examined, there is an oxygen mass of 27.429% in 2-EHN. Therefore, with the use of 2-EHN, HC and CO emissions decreased and continued to decrease with growing 2-EHN. While CO emission tended to decrease up to 2000 W engine load, it tended to increase again due to the increase in engine load. While there was enough oxygen for the fuel sent to the cylinder at low engine loads, insufficient oxygen due to the excess fuel sent to the cylinder at increased engine load caused this situation. With the D97EHN3 fuel, compared to diesel, HC emission decreased 60.61%, while CO emission decreased 31.25%.

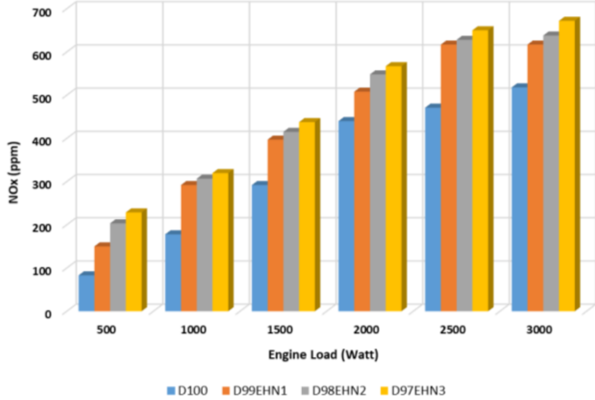


Figure 4. NO_x emission with different engine load

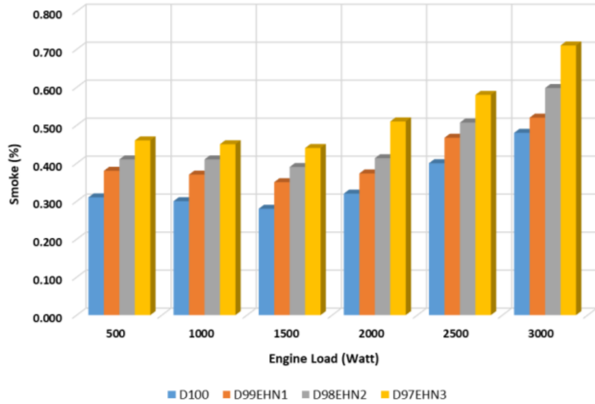


Figure 5. Smoke emission with different engine load

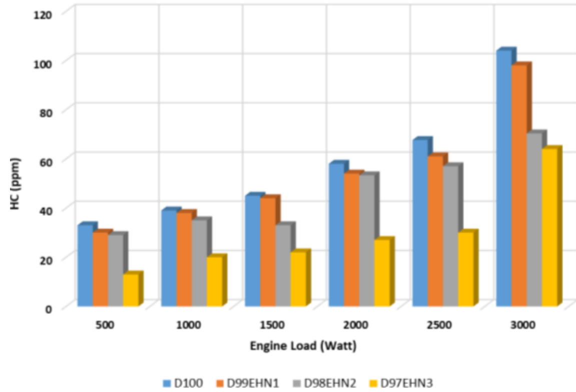


Figure 6. HC emission with different engine load

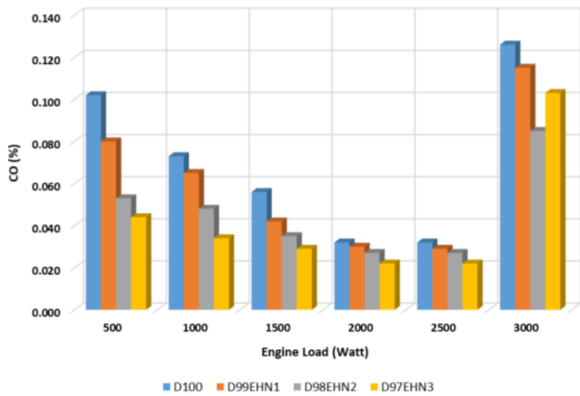


Figure 7. CO emission with different engine load

4. Conclusion

In this study, the effects of adding 2-EHN to diesel fuel at different rates were investigated at different engine loads. The main results obtained at the end of the study are as follows;

- ✓ The addition of 2-EHN up to 2% increased the BTHE values at all loads. Due to the very high cetane number, BTHE tended to decrease with the addition of 3% 2-EHN. The maximum BTHE value was achieved with D99EHN2 fuel as 27.99% at 3000 W load. An increase of 11.57% compared to D100 was observed at the same load.
- ✓ BSFC values increased at all loads with the addition of 2-EHN. The lowest BSFC was obtained with D100 fuel at 3000 W load as 319.78 g / kWh.
- ✓ NO_x and smoke emissions increased with the addition of 2-EHN. The highest NO_x and smoke emissions were obtained with D97EHN3 as 672 ppm and 0.710%, respectively.
- ✓ HC and CO emissions reduced with the use of 2-EHN. With the D97EHN3 fuel, compared to diesel, HC emission decreased 60.61%, while CO emission decreased 31.25% compared to diesel at same load.

As a result, the use of 2-EHN increased NO_x, smoke and BSFC values, but reduced BTHE, HC and CO. It can be said that the use of 2-EHN as an additive in the diesel engine is successful, depending on the output requested from the engine.

Nomenclature

BSFC	: brake specific fuel consumption
BTHE	: brake thermal efficiency
CO	: carbon monoxide
D100	: 100% diesel
D99EHN1	: 99% diesel + 1% 2-ethylhexyl nitrate
D98EHN2	: 98% diesel + 2% 2-ethylhexyl nitrate
D97EHN3	: 97% diesel + 3% 2-ethylhexyl nitrate
EHN	: 2-ethylhexyl nitrate
HC	: hydrocarbon
NO_x	: nitrogen oxide

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