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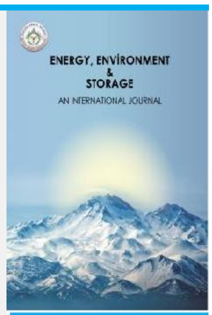

Investigation of the Effect of Stearic Acid Addition to Diesel on Combustion in a Compression Ignition Engine

Volkan Sabri Kül[1*], Mehmet Sarıtaş[2]

[1]Department of Mechanical Engineering, Erciyes University, Kayseri 38039, Republic of Turkey, volkanskul@gmail.com , ORCID:0000-0002-6412-6062

[2]Department of Mechanical Engineering, Erciyes University, Kayseri 38039, Republic of Turkey mehmetsaritas@erciyes.edu.tr ,

ORCID: 0000-0001-6576-689X

ABSTRACT. Stearic acid is a saturated fatty acid with the chemical formula CH3(CH2)16COOH. Stearic acid is used in the literature as a surfactant, plasticizer, reducer of flow resistance, water repellent (hydrophobic), reducing agent of hygroscopicity and dielectric film layer former. In addition, according to scientific studies, coating nanoparticles such as aluminium and boron with stearic acid increases their combustion stability. This study is a preliminary study for experimental studies on combustible solid particles. Due to the above-mentioned properties of stearic acid, it is desired to use it as a surfactant. However, the effect of stearic acid on combustion in a compression ignition engine needs to be investigated experimentally. For this purpose, stearic acid was used as an additive to diesel fuel in a compression ignition heavy-duty diesel engine. Stearic acid was added to the diesel fuel in the amounts of 125, 250, 500 and 1000 ppm by mass. Then it was mixed with a stirrer for 45 minutes. The test engine was operated at 700 rpm and 300 Nm load. Engine performance and emission data were examined.

Keywords: Stearic acid, diesel, surfactant, performance, emission

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1. INTRODUCTION

While increasing energy consumption pushes researchers to seek alternative fuels, efficiency studies on existing internal combustion engines are also of great importance. For this reason, many researchers are working on diesel fuel additives. Stearic acid is used in the literature as a surface active agent, lubricant, lubricator, coating material that reduces flow resistance, water repellent, moisture absorbent, and insulating film layer forming agent. In addition, according to scientific studies, coating nanoparticles such as aluminium and boron with stearic acid increases their combustion stability [1-4]. Especially aluminium powder has a strong explosion sensitivity. Therefore, the concern of explosion in the use of aluminium and similar materials has been stated in the literature [7-10]. In addition, elements such as aluminium, boron and magnesium oxidize very quickly during combustion, which can reduce the combustion efficiency of these materials [11, 12]. There are studies in the literature on surface coating methods to avoid these problems [13-15]. In the literature, studies have been conducted on materials coated with surface coating materials containing fluorine, such as fluorographene, fluoroalkyl silane, and polyvinylidene fluoride, although they have improved combustion, these materials have serious environmental damage [16, 17]. Therefore, stearic acid, a saturated fatty acid found in nature and in various oils, comes to the fore as a coating material for coating materials such as aluminium and boron. Stearic acid is a non-toxic fatty acid with hydrophobic properties. [18] and [1] have coated elements with high explosion sensitivity with stearic acid. As a result of their studies, they stated that the resistance of the materials coated with stearic acid to oxidation increased and a more controlled combustion reaction occurred.

The current study investigated the effects of stearic acid on combustion when used with diesel fuel in a compression ignition engine due to these properties. It was evaluated whether stearic acid has a negative effect on combustion.This study aims to be preliminary for the studies to be carried out later on to use combustible metals coated with stearic acid in a diesel engine

*Corresponding author: volkanskul@gmail.com

Nomenclature

BSFC	Brake Specific Fuel Consumption	**CO**	carbon monoxide
BTE	Brake Thermal Efficiency	**NO**	nitrogen oxides
Nm	Newton meter	**D100**	Pure Diesel
rpm	revolution per minute	**St125**	125ppm Stearic acid + Diesel
g	gram	**St250**	250ppm Stearic acid + Diesel
mm	millimeter	**St500**	500ppm Stearic acid + Diesel
P_b	Brake power	**St1000**	1000ppm Stearic acid + Diesel
min.	minute	**LHV**	Lower Heat Value
ppm	Parts per million	**ṁ**	Mass flow
kWh	kilowatt-hour		

2. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Format

In this study, a compression ignition heavy-duty diesel engine was used as shown in **Figure 1**. The test engine has 11,670 cc engine volume and 6 cylinders (Table 1). The experiments launched with pure diesel (D100) and then continued with St1000, St500, St250, and St125, respectively in the current scrutiny. Pure diesel fuel (D100) was taken as a reference and efficiency and emission performances were compared by adding different amounts of stearic acid (St1000-1000ppm, St500-500ppm, St250-250ppm, St125-125ppm).

Figure 1 Test Engine

Table 1: Diesel engine which use at the experiment [19]

Engine Parameters	Specification
Bore and Stroke	133 mm, 140 mm
Number of cylinders	6
Displaced volume	11,670 cc
Max. Power and Speed	234 Hp, 2300 rpm
Compression ratio	16.5
Injection timing	16 'BTDC

A magnetic stirrer was used to ensure homogeneous distribution of the solution. Each fuel mixture was mixed for 45 minutes using 750 rpm and 40 degrees heat (**Figure 2**). A scale with 0.5 g sensitivity was used to measure liquid fuel consumption. Consumption was determined by 5-minute measurements. Emissions measuring was fulfilled with the Bosch-BEA60 emission analyzer. The technical specifications of the emission device are presented in **Table 2.**

Table 2 : Bosch BAE 60 gas analyzer

Components	Measurement Range	Precision
CO	% 0,000 – 10,00	% 0,001
CO_2	% 0,00 – 18,00	% 0,01
HC	0 - 9999 ppm	1 ppm
O_2	% 0,00 – 22,00	% 0,01
NO	0 - 5000 ppm	1 ppm

Figure 2 The Magnetic Stirrer

Experimental data were obtained thanks to the PCS performance measurement system. The data obtained with experiments were considered comparatively with each other, it was discussed in the section of results.
After the experimental setup, the experiments were first started with pure diesel fuel. The data obtained from the experiments conducted with pure diesel fuel were determined as the base values for comparison with other fuel types. Then, the experiments were continued with st125, st250, st500 and st1000 fuel types, respectively. Before the experimental data were obtained, the test engine was started and the engine speed was set to 700 rpm and the engine load was set to 300 Nm. After the test engine had run for at least 10 minutes under these operating conditions, a 5-minute period was started and the fuel consumption was measured. The same method was applied in the experiments conducted with each fuel type. In addition, at each fuel type change, the remaining fuel in the test engine fuel system was drained and the other fuel type to be tested was given to the system. The data obtained after the experimental procedure followed in this way were analysed and compared with pure diesel fuel.

3. RESULTS

BTE and BSFC are the most important performance indicators showing engine thermal efficiency and specific fuel consumption. BTE and BSFC are inversely proportional to each other as shown in **equation 1** (Equation 1 is derived from equations 2 and 3). It is logical that the engine with high thermal efficiency has low specific fuel consumption and vice versa [21, 22]. The BTE and BSFC graphs calculated in line with the data obtained in this study are presented in **Figure 4** and **Figure 5**, respectively. **Figure 4** shows the thermal efficiencies of D100 (pure diesel), st125, st250, st500 and st1000 fuels under 300 Nm torque. According to **Figure 4**, the thermal efficiencies of D100, st125, st250, st500 and st1000 fuels are 32.4, 31.0, 34.2, 34.9 and 33.5%, respectively. **Figure 5** shows the specific fuel consumptions of D100 (pure diesel), st125, st250, st500 and st1000 fuels under 300 Nm torque. According to **Figure 5**, the specific fuel consumptions of D100, st125, st250, st500 and st1000 fuels are 258.8, 269.8, 244.6 239.7 and 249.8 g/kWh, respectively. As can be seen from the graphs, the experiment in which the highest thermal efficiency was obtained was the experiment in which st500 fuel was used. Accordingly, the lowest BSFC value was obtained with ST500 fuel. When the BTE of St500, i.e. diesel with 500ppm stearic acid additive, was compared with the BTE of pure diesel, ST500 was observed to be 7.78% more efficient than pure diesel.

$$\boldsymbol{BTE} = \frac{1}{\boldsymbol{BSFC*LHV}} \quad (\%) \qquad (1)$$

$$\boldsymbol{BTE} = \frac{P_b}{\dot{m}*LHV} \quad (\%) \qquad (2)$$

$$\boldsymbol{BSFC} = \frac{\dot{m}}{P_b} \quad (g/kWh) \qquad (3)$$

Although 125 ppm stearic acid added to diesel fuel has a negative effect on thermal efficiency, it has been concluded that diesel fuels with 250, 500 and 1000 ppm stearic acid added have higher thermal efficiency than pure diesel. In this context, it can be said that stearic acid generally has a positive effect on thermal efficiency. In this study, in order to find the optimum amount of stearic acid needed to be added, it was started with 125 ppm stearic acid added and continued by increasing it 2-fold in each experiment. At the end of the study, st500 fuel with the highest thermal efficiency showed that the optimum stearic acid added was 500 ppm.

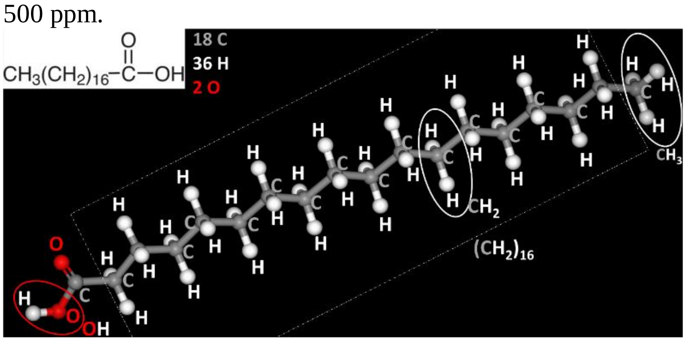

Figure 3 – Stearic Acid Crystal Structure [25]

Stearic acid has 18 carbons, 36 hydrogens and 2 oxygen in its structure. The crystal structure of stearic acid is a saturated fatty acid with an 18 carbon chain as shown in figure 3 [25, 26]. The reason why stearic acid has a positive effect on thermal efficiency can be attributed to the high hydrogen content as well as the fluidity enhancing feature, which ensures that the fuel is well atomized in the combustion chamber and provides more stable combustion [20, 1]. The presence of stearic acid, which is rich in hydrogen and oxygen in diesel fuel, has affected the ignition delay. Therefore, different efficiency values were obtained at different stearic ratios. 500 ppm stearic acid additive provided optimum ignition delay in the test engine. Therefore, it contributed to the highest thermal efficiency of St 500 fuel. The most important factor in obtaining different thermal efficiency values with different stearic acids is that stearic acid changes the ignition delay. As seen in **Figure 6**, st500 fuel significantly increased the ignition delay.

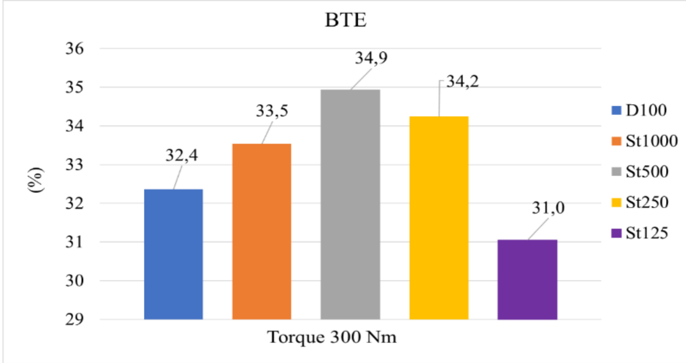

Figure 4 - BTE

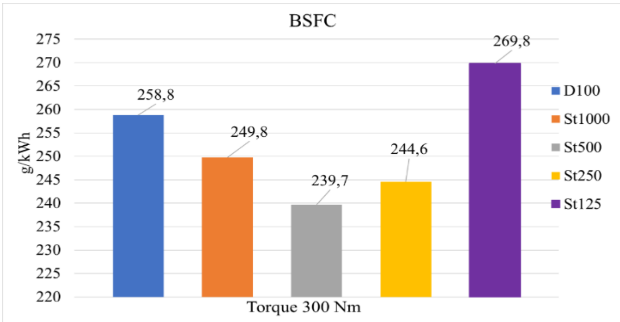

Figure 5 - BSFC

Table 3 shows Lambda values and **Figure 6** shows the in-cylinder pressure graphs. The graph shows the in-cylinder pressure values of D100, st125, st250, st500 and st1000 fuels in the 300-420 crank angle range in bar under 300 Nm Torque. Although the thermal efficiency of St500 fuel is the highest, the in-cylinder pressure is relatively lower than other fuels. High in-cylinder pressure is not a factor that affects thermal efficiency linearly. High pressure can often cause engine vibration and knocking combustion. In diesel engines, a flatter pressure graph at the top dead centre is desired rather than a very sudden pressure increase. 500 ppm stearic acid additive diesel fuel provided this situation and therefore thermal efficiency was higher than other fuels. In addition, the ignition delay of ST500 was observed to be longer than other fuels. This situation shows that the sudden pressure increase occurs at a more optimum crank angle degree compared to other fuels.

Table 3 Lambda

Fuel Types	Lambda
D100	3,063
St1000	2,979
St500	3,071
St250	2,976
St125	3,089

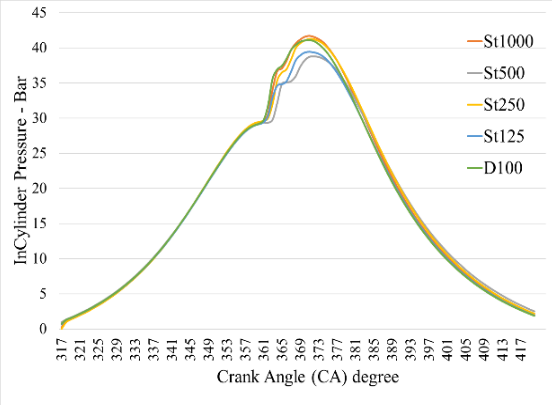

Figure 6 – In-Cylinder Pressure

The fact that stearic acid additive to diesel fuel does not generally affect thermal efficiency negatively is a positive data for future studies. Especially, the fact that more stable combustion is achieved with 500 ppm stearic acid additive sheds light on the ongoing studies of the authors of this study. Positive information has been produced that paves the way for the use of stearic acid as a surfactant in the use of elements sensitive to combustion such as Al, B and Mg as additives in diesel engines.

Nitrogen and oxygen atoms, which are broken down by high temperature and pressure, react and form nitrogen oxides [5]. Nitrogen oxide formation also depends on the length of the combustion period. A long combustion period, high oxygen density, and high combustion temperature result in the formation of high amounts of nitrogen oxides [6]. Nitrogen oxides are harmful gases that are not wanted in the atmosphere. **Figure 7** shows the NO emission graph. In the graph, the NO emission values of D100, st125, st250, st500 and st1000 fuels are 520, 483, 466, 487 and 546 ppmvol under 300 Nm engine load, respectively, and the pressure values are shown in bar. The NO graph provides information about the combustion temperature and air-fuel mixture quality [6, 23]. St500 has reached the highest thermal efficiency while showing a medium value in NO emissions. This situation shows that the additive amount is at the optimum level and that the combustion contributes to the maximum energy conversion without reaching high temperatures.

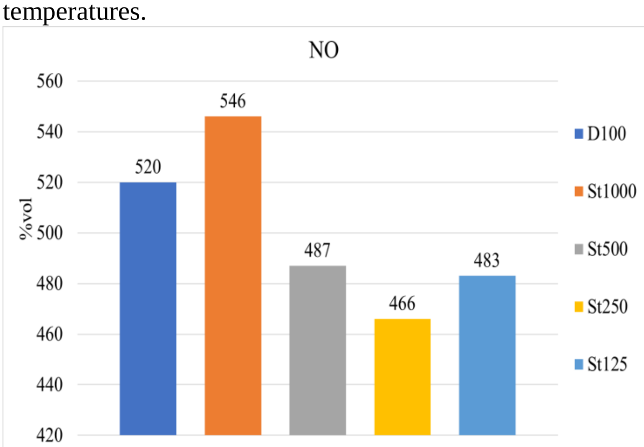

Figure 7 - Nitrogen Oxide

Figure 8 shows the graph of CO emissions. In the graph, the CO emission values of D100, st125, st250, st500 and st1000 fuels are 0.021, 0.018, 0.019, 0.012 and 0.015 ppmvol, respectively, under 300 Nm engine load. The amount of CO emissions is an important factor that helps us understand how efficient the combustion is [24]. Low CO emissions indicate that the fuel is approaching complete combustion and high combustion efficiency. According to the graph, D100 has the highest CO emissions, which indicates that the combustion is not good and the combustion efficiency is low. St500 has both low CO emissions and the highest thermal efficiency in the BTE graph. This shows that the St500 additive level optimizes combustion, producing maximum work from the fuel's energy, and the engine is operating more efficiently.

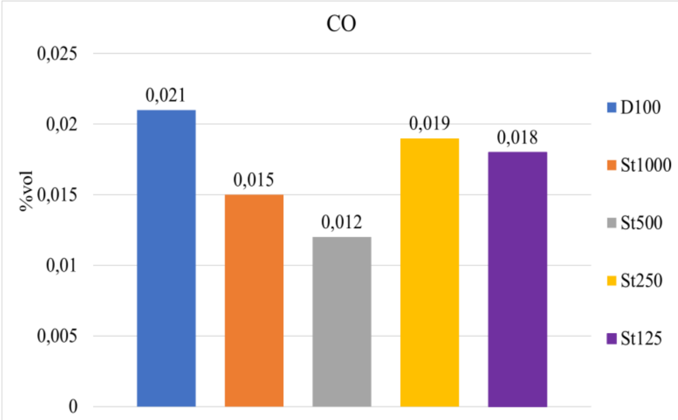

Figure 8 - Carbon monoxide

4. CONCLUSION

In this study, the effects of stearic acid on combustion due to these properties when used with diesel fuel were investigated in a compression ignition engine. Experiments were conducted at 300 Nm torque and 700 rpm constant engine speed by adding 125, 250, 500 and 1000 ppm stearic acid to pure diesel fuel. It was evaluated whether stearic acid had a negative effect on combustion. This study is preliminary for the studies to be carried out later on the use of flammable metals coated with stearic acid in diesel engines.

1- Stearic acid additive to diesel fuel generally has a positive effect on thermal efficiency. Thermal efficiency decreased relatively at 125 ppm stearic acid additive. However, thermal efficiency increased at 250, 500 and 1000 ppm stearic acid additives. The optimum stearic acid additive reached as a result of the experiments is 500 ppm. Because st500 fuel was observed to have 7.78% higher thermal efficiency than D100 fuel.

2- Stearic acid additive generally reduced NO emissions except st1000 fuel. CO emission value of all stearic acid additive fuels is lower than pure diesel. Stearic acid improved CO emissions.

3- Stearic acid additive generally did not have a negative effect on thermal efficiency and emissions. Positive information was produced that it can be used as a coating material in the authors' ongoing studies with elements sensitive to combustion.

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