PRODUCTION OF HAZELNUTOIL METHYLESTER, PERFORMANCE AND EMISSIONS ANALYSES AS A FUEL IN DIESEL ENGINE

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Abstract - In this study, briefly reviews as a fuel of hazelnutoil methylester use alternative fuel in pre-chamber diesel engines and compares to diesel fuel. For this purpose, a naturally aspirated, pre-chamber indirect injection, four cylinder diesel engine was used and without any modifications to the experimental engine. Hazelnutoil methylester test results were compared to test results of diesel fuel. Hazelnutoil methylester viscosity higher from diesel fuel, but hazelnutoil methylester density is lower from diesel fuels. Hazelnut oil methyl ester emissions compared to diesel fuel, CO, HC, and CO₂ emissions lower, but NOx and smoke emissions higher were observed. As NOx emissions, hazelnutoil methylester higher than diesel fuel and NOx emission was measured approximately 12% higher from the diesel fuel all engine rpm. It was observed: the specific fuel consumption increased, at low-speed 5%, medium speed 7%, high-speed 10%. The average increase in specific fuel consumption 8% determined. Hazelnut oil methyl ester compared to diesel fuel, engine torque and engine power performance are decreased 10% was observed. As a result, hazelnut oil methyl ester could be used as an alternative fuel in diesel engines.

Keywords: Alternative fuel; Diesel engine; Hazelnut oil; Methyl ester; Combustion; Emissions

I. INTRODUCTION

Diesel fuel is largely consumed by the highway transports sector. Due to increased environmental problems, sustainable energy and rapid depletion of fossil energy sources is demanding an urgent need to carry out research work to find out the sustainable alternative fuels. However alternative fuels have become increasingly important due to rapid decline in world oil reserves and increasing fuel prices and the impact of environmental pollution due to increasing exhaust emissions for diesel engines. The increase in alternative fuel investigations a rapid decrease in world petroleum reserves and important environmental concerns originating from exhaust emissions are two main factors. In many countries because of the world external dependence on energy supply, rising fossil fuels prices and emitted of fossil fuel emissions to the environment, researchers have focused on more environmentally fuels and new renewable energy sources. Fuel researchers have investigated the effect of many different types of biodiesel and biodiesel blended with ethanol or methanol on using in diesel engines[1, 2]. The fuels produced by transesterification of the oils are called biodiesel and the advantages of biodiesels as fuel are the minimal sulfur and aromatic hydrocarbons content, higher flashpoint, cetane number, lubricating property, biodegradability and not contain any metals or crude oil residues non-toxicity. Biodiesel cannot entirely replace diesel fuels, but biofuels and diesel fuel mixture can be used on diesel engines to achieve both environmental and renewable energy sources. Biodiesel has properties similar of traditional fossil diesel fuel and therefore it can be used for diesel fuel by little engine modification or no modification to engine. Studies, define that the using of biodiesel may potentially reduce the dependence on conventional diesel fuel and improve air quality. Especially, reduction in particulate emissions can be provided through the addition of biodiesel to diesel fuel. As a main source of biodiesel, vegetable oils have considerably higher
viscosity compared to diesel fuel. Despite lowering viscosity with transesterification, the viscosity of vegetable oil biodiesel has higher than diesel fuel. The viscosities of fuels have important effects on fuel droplet formation, atomization, vaporization, fuel/air mixing process and combustion process and viscosities of fuels effect the engine emissions and performance parameters. Many studies about the use of biodiesel fuels in diesel engines have been done and some of them have been summarized. Several studies have been studied for the purpose of alternative fuels and exhaust emission research using alternative fuels such as biodiesel or its blends in diesel engines by many investigators. It has been usually reported that there are NOx emissions increase while decreases in CO, HC and smoke emissions. By compared the emissions of biodiesel and biodiesel emulsified and fumigated methanol increased NOx emission was observed. Biodiesel has several superior combustion characteristics compared to fossil diesel fuel. Biodiesel fuel can effectively reduce engine-out emissions of particulate matter, CO, and hydrocarbons in modern four-stroke compression ignition engines. It has been considered that the oxygen content in biodiesel is the main factor for reducing pollutant emissions and increasing NOx as a result of better combustion[3, 4, 5, 6].

As in many countries, Turkey is dependent on energy in the import and energy demand has increased rapidly with economic and social development year by year. Approximately 90% of Turkey's total energy consumption is provided from fossil fuels to be gasoline, natural gas and coal. In spite of Turkey's heavy dependence on fossil fuels, the country has a large potential large area of suitable agricultural land for the production of bio-fuel crops. Additionally, bio-fuels can provide an opportunity to avoid the dependency of Turkey to on foreign oil, create new employment opportunities and sustainable energy development. Turkey's bio-diesel production is only around 60000 tons per year. In the 2020s, it is estimated that gasoline consumption will remain at its current levels of around 2.5 million tones, but diesel fuel consumption is expected to increase[2, 7, 8]. Hazelnut, Turkey is the world's largest hazelnut producer and hazelnut oil biodiesel was selected for the study, because of its wide use in Turkey. The average yield of 2200 kg / ha per year includes 20 barrels of oil equivalent energy per hectare. Turkey can produce oil for biofuels from hazelnuts which do not qualify for the food industry[2]. The studies have been done about the use of hazelnut oil biodiesel fuels in diesel engines in Turkey. In the study, a four cylinder, turbocharged, direct injection diesel engine was used and the hazelnut oil methyl ester was tested as a fuel. CO, NOX, smoke density of hazelnut oil methyl ester and exhaust temperatures were lower than of diesel fuel was observed[9]. Biodiesel obtained from the mixture of waste hazelnut oil and waste sunflower oil was added to diesel fuel as different amounts of methyl ester and their effects on Diesel No.2 were investigated. The blend CO emissions higher at low speed and at high speeds, and CO2 emissions higher in the low and high speed ranges and NOx emissions increased due to the high combustion temperature and the presence of fuel oxygen with the blend was observed[8, 10]. Another study, the test fuel used in the experiments was produced under the optimum transesterification reaction conditions and reaction conditions of with respect to reaction temperature, volumetric ratio of the reactants, and catalyst, were investigated and blends similer with diesel fuel results[11]. In another similar study, the standard diesel, hazelnut oil methyl ester and rapeseed oil methyl ester blends used together as alternative fuel in existing diesel engines without any modification in diesel engines. In other study, the effects on engine performance and the exhaust emission characteristics the engine was fueled using COME–diesel blend of a diesel engine were experimentally investigated. Experimental results of this study, COME has similar physical-chemical properties and cED and compared to engine performance of cED to blend fuels. The aim of this experimental study is to investigate of biodiesel on combustion, performance and CO, CO2, NOx and soot emissions and an experimental comparison was performed with diesel fuel[12].
II. PRODUCTION OF HAZELNUT OIL METHYL ESTER

The transesterification is a widely applied, convenient and most promising method for reduction of viscosity and density of vegetable oils. Biodiesel are produces, from sunflower, rapeseed, cottonseed oil offers a great potential as the source of biodiesel cultivated area in Turkey[1]. In production of methylmester used hazelnut oil, it produced by Hazelnut Sales Cooperative Association. Transesterification is an effective method for converting high viscosity vegetable oil into a fuel with similar chemical properties to and low viscosity like diesel fuel. In the present study, base catalyzed transesterification NaOH is used to prepare biodiesel from hazelnut oil. The production of hazelnut oil methyl ester was made in Automotive Technology Program of diesel engines laboratory by using biodiesel production system. The transesterification process of hazelnut oil was performed using 1.25 liter methyl alcohol and 50 grams sodium hydroxide as catalyst per 5 liter pure refined hazelnut oil. Biodiesel production process, purity of 99.8% sodium hydroxide, 0.910 kg/l density of pure refined hazelnut oil, purity 99.5%, and 99.8% purity, density (at 25 °C) 0.793 kg/l.of methanol was used. First, the hazelnut oil was heated to about 65 ºC in a reactor with a capacity of about 8 liter. Methanol and catalyst were mixed in a separate glass containers. Then, the catalyst-methanol mixtures were to dissolve and added to the heated hazelnut oil in the reactor. The mixture was subjected to esterification reaction at a constant temperature of about 65 ° C during 1 hour. After the esterification process; the glycerol layer is separated in the lower part and the ester layer is separated in the upper part. A temperature of 65±1 ºC was maintained for 4 hours and the reaction products were allowed to settle under gravity for 6 hours in a separating funnel. By washing produced of biodiesel, the impurities, water and the residual catalyst are removed of essential for which may be harmful for combustion engines. The residue in the mixture was kept under gravity for a further 6 hours to settle the other wastes such as dust and water and the impurities in the lower layers were drained. After, produced biodiesel was heated at 100 ºC, for removing from the oil in the esterified hazelnut oil by evaporating. Finally, the produced hazelnut oil biodiesel was left to cool down. The production process of is shoved schematically in Figure 1. The flow chart of the biodiesel production process and production apparatus and the overall reaction is represented in Figure 2.

![Flow Chart of Biodiesel Production Process and Production Apparatus](image-url)
Produced hazelnut oil biodiesel, hazelnut and diesel fuels properties are given as a comparison of in Table1. As shown in Table 1, the differences specific gravity and thermal values is observed for vegetable oils and diesel fuel. Viscosity of hazelnut oil is more than about 10-12 times from diesel fuel and hazelnut oil has about 27% lower heating value. Hazelnut oil biodiesel viscosity is higher 1.75 times of from diesel fuel and hazelnut oil biodiesel has about 14% lower heating value. Despite the differences between these values, from the technological point of view, as a fuel hazelnut oil and hazelnut oil biodiesel seems to meet the fundamental requirements of a diesel engine.

![figure2.png](image)

**Figure 2. The transesterification of triolein (glycerol trioleate) to methyl esters[14]**

| Property           | Hazelnut oil methyl ester | Hazelnut oil | Diesel oil |
|--------------------|---------------------------|--------------|------------|
| Density (kg/L)     | 0.88                      | 0.91         | 0.86       |
| Flash point (°C)   | 50-170                    | 245          | 60         |
| Cetane             | 45-50                     | 41–43        | 50 min     |
| Sulfur (%)         | 0.00-0.0024               | 0.030        | 0.050      |
| Heating value (kJ/kg) | 38724                  | 33028        | 45390      |
| Colour             | Light green               | Amber yellow | –          |
| Kinematic viscosity (mm² s⁻¹) | 3.1-5.6            | 30.97        | 2.9        |
| Ash (%)            | 0.01-0.02                 | 0.004        | 0.001      |
| Density (kg/L)     | 0.82                      | 0.91         | 0.86       |
| Flash point (°C)   | 112-170                   | 245          | 60         |
| Cetane             | 45-50                     | 41–43        | 50 min     |

### III. EXPERIMENTAL STUDY, EQUIPMENTS AND TEST PROCEDURE

Figure 3 shows the schematic structure of the experimental system. The experimental setup consists of a naturally aspirated pre-chamber diesel engine of Mercedes-Benz OM 616, an engine test bed, gas analyzers and thermocouples. The experiments were performed with a 2403 cm³ displacement, four cylinders, four-stroke, water cooled, compression ratio 21:1 pre-chamber diesel engine. The engine catalog values are maximum torque was 138 Nm at 2400 rpm, and the maximum engine power was 44 kW at 4200 rpm. In the study, at the conventional diesel engine not modification of structure is unnecessary as has been confirmed. A hydrokinetic dynamometer was coupled to the engine and the engine’s power was measured. A simple mechanism has been attached to the engine rpm by controlling the throttle position and the engine was tested different rpm at partial and full loads. To ensure standard test conditions and thus for increasing the credibility, comparing the measured values, each fuel at the experimental engine, it was possible to keep constant test process operating parameters of the engine circuits, the oil and cooling water temperatures.

The procedures repeated, for two type fuels by keeping the same engine operating conditions. By working with traditional diesel fuel and hazelnut oil biodiesel are engine torque and engine power performances values and exhaust emission parameters measured from the basic operation of the
engine taken and compared. The tests were made by using of 2 type fuels with the engine working at a different speeds and static fuel injection advance of was determined as 240 crank angle before TDC for the test engine. The fuel pipe system used to prevent the mixing of the fuels tested three separate pipelines for diesel fuel and nut oil biodiesel used, and the engine run for about 10 minutes to stabilize each fuel change in its new state. At the beginning of the study, engine performance and diesel fuel emission characteristics were determined by using diesel fuel. In the second stage of the study, hazelnut oil methyl ester used as fuel, for engine torque and power performance and exhaust emission values were determined. Thermocouples and sensors installed to determine the pressure, temperature, fuel consumption values, cooling water inlet and outlet temperature, intake air pressure and temperature, exhaust gas temperature, test laboratory temperature values of the lubricating oil. Pressure gauges used to measure the intake manifold pressure, atmospheric pressure and humidity. For measureof engine speeds, tachometer and speed sensors connected to test system. A Bosch ETT008.55EU model and Bosch BEA370 gas analyzer used to measure the CO, CO\textsubscript{2} in percentages by volume, NOx, and HC ppm by volume. Smoke measured with Bosch 3.011 exhaust-gas measuring module for diesel engine emissions. The initial data taken after the stabilization of the engine in running. The test results of this study pre-combustion chamber diesel engine have indicated that hazelnut oil biodiesel can employed as a substitute for diesel fuel.

![Figure 3. The Experimental apparatus.](image)

**IV. CALCULATION OF THE ENGINE PERFORMANCE PARAMETERS**

Experiments carried out without any changes to the engine and referring to the diesel fuel setting values. For each fuel testing, the volumetric flow rates of air and fuels were measured and based on which the mass consumption rates of the fuel were calculated. The air/fuel ratio was calculated, based on the stoichiometric air/fuel ratio and the actual air/fuel ratio. According to in the experimental study results, engine torque, engine speed, mass consumption rate of the fuel, the brake power, the brake specific fuel consumption, the brake thermal efficiency, the brake mean effective pressure were determined by using the following equations. The brake power, \( P_e \) (in kW);

\[
P_e = \frac{Me \times ne}{9549} \tag{1}
\]

The brake mean effective pressure, \( bmep \) (in bar),

\[
bmep = \left(\frac{4\pi Me}{VH}\right) \times 10^5 \tag{2}
\]

As known, \( VH \) (in m\textsuperscript{3}) the engine total (i.e. of all four cylinders) displacement volume. The brake specific fuel consumption, \( be \) (in g/kWh),
\[
B_f = \frac{m_f \cdot \rho_f \cdot 10^{-3} \cdot 3600}{Pe}
\]  \hspace{1cm} (3)
\[
b_e = \frac{3600}{H_u \cdot \eta}
\]  \hspace{1cm} (4)

Where, \( \dot{m}_f \) is the mass consumption rate of the fuels in kg/s; \( H_u \) is the amount of heat produced by a completed combustion of fuel and it is measured as a unit of energy per unit mass or volume of substance in kJ/kg. The primary evaluation calculated for burning of diesel fuel and hazelnut oil biodiesel is its thermal efficiency(\( \eta \)). The relationship between thermal efficiency \( \eta \) and specific fuel consumption (\( b_e \)) is represented by equations 3-4. For made easy and understand, the specific fuel consumption used as an estimate of the thermal efficiency and, on account of the inverse relationship between them, a decrease in specific fuel consumption would reflect an increase in thermal efficiency. Thus, in the following tests, specific fuel consumption was taken as the main evaluation parameter.

V. RESULTS AND DISCUSSION

Engine performance, diesel fuel and hazelnut oil methyl ester were used in various loads, braking power (PE), brake specific fuel consumption (bsfc) and exhaust emissions (CO, CO\(_2\), HC, NO\(_x\) and O\(_2\)) values were compared.

5.1. Engine performances

The results are made by using 100% diesel fuel and hazelnut oil biodiesel under different engine conditions and engine load conditions and the engine performance values are compared for both fuels. For test fuels, the torque variations with engine speed were show with Fig. 5(a), the maximum torque values were observed around 2350 rpm of engine, the maximum torque values are similar for diesel fuels and hazelnut oil biodiesel but the hazelnut oil biodiesel torque is lower from torque of diesel fuel. Fig. 5(b) shows that the values of brake power variations of the test engine for two fuels. It is clear from the Fig. 5(b) that the power of diesel fuel was found higher than hazelnut oil methyl ester fuels. It was observed that the engine torque and power values increased with the increase in engine speed, but after the engine's medium speeds, the engine torque values of both fuels started to decrease. The first of these two main reasons, the higher calorific value of diesel fuel is higher than hazelnut oil biodiesel. Secondly, the viscosity of hazelnut oil biodiesel is higher approximately 2 times than the viscosity of diesel fuel, and this high viscosity negatively affects in the combustion process. The maximum torque values for diesel fuel 138 Nm, and for hazelnut oil methyl ester 130 Nm were measured respectively at 2350 rpm. The lowest torque value was obtained for hazelnut oil fuel for all engine speeds. The maximum engine power values for diesel fuel 42 kW, and for hazelnut oil biodiesel 39.2 kW were measured respectively at 4400 rpm and the lower power was obtained for hazelnut methyl ester for all speeds of engine.

![Figure 4(a) Engine torque and (b) engine power parameters versus engine speed for two fuels.](image-url)
5.2. Specific fuel consumption

Figure 5(c) shows the engine torque values for the most appropriate fuel consumption for both fuels to all engine speeds and engine loads. As curves indicate; With the increase in medium engine speed, there is a decrease in the specific fuel consumption (be) for both fuels. Hazelnut oil methyl ester consumption increased roughly in proportion with engine speed under engine loads conditions. The main reasons for this is that the diesel has the highest heating value from the hazelnut oil methyl ester fuels and needs the lowest fuel consumption rate to achieve the same engine brake horsepower output as other fuels. Results from the tests hazelnut oil methyl ester indicated that specific fuel consumption is approximately 11% higher than that diesel fuel. For the lower heat values of hazelnut oil methyl ester more fuel has to be injected to obtain the same power output.

![Figure 5(c) Specific fuel consumption parameters versus engine speed for two fuels.](image)

5.3. Exhaust gas emissions

Fig. 5(d) shows the CO emissions for the two alternative fuels under different engine speeds. The minimum CO emissions were obtained with hazelnut oil methyl ester from diesel fuel all engine rpm. Depending on the increase in engine load, the fuel mixture is enriched and more CO emission is produced. Owing to the high viscosity of hazelnut oil methyl ester, the size of the atomization particles in the fuel/air mixture has a negative effect on combustion. This situation is typical for a homogeneous charging engine as CO emission is usually affected by fuel viscosity and combustion quality. The increase in the CO levels is same for the same increase of the supplied hazelnut oil methyl ester diesel fuel at maximum engine rpm region. In addition, hazelnut oil methyl ester were found to emit significantly lower CO concentrations compared with diesel fuel. The hazelnut oil methyl ester is contain 10% oxygen on a mass base and have lower carbon content than the diesel fuel. Because of the oxygen content in the biodiesel enhances, thereby reducing the formation of CO emission in combustion process. Therefore, the hazelnut oil methyl ester can be replace as a fuel clean and lower carbon content alternative fuel to fossil fuel for diesel engines. As it is clear from the figure that the curves of CO emissions for hazelnut oil methyl ester remain under the curve of diesel fuel all engine speeds.
Fig. 5(e) shows that the HC emissions of for two fuels are lower in partial load and decreases at medium engine speed but to increases at higher engine speed and loads. HC emissions in hazelnut oil methyl ester is higher than the diesel fuel at all engine speeds. The high viscosity of hazelnut oil methyl ester were caused to deterioration, the combustion tend to generate high levels of unburned hydrocarbons. Factors causing combustion deterioration (such as high latent heats of vaporization) could be responsible for the increased HC production. Although HC emission of hazelnut oil biodiesel was higher but CO emission lower than diesel fuel. This is because of better combustion of hazelnut oil methyl ester inside the combustion chamber due to oxygen content in biodiesel.

Fig. 5(f) shows O$_2$ concentrations respectively, for diesel fuel and hazelnut oil methyl ester. The hazelnut oil methyl ester O$_2$ emissions values are show that almost the same when operating with diesel fuel. It can be observed that oxygen concentration available for reactions decrease the engine speed and O2 emissions are higher than diesel at all engine rpm. It can be said that O$_2$ concentration was high in the exhaust gazes and similar for fuels. The reason for the high oxygen concentration can be explained by the oxygen content of the hazelnut oil methyl ester and the excess air in combustion. This is due to the lack of oxygen resulting from the operation at higher air/fuel ratios.
Fig. 5(g) shows, the NOx emissions for the all fuels under varied engine speeds and engine torques. The hazelnut oil methyl ester was produced a higher amount of NOx, while diesel fuel produced the low amount of NOx emissions at these engine speeds. The formation of NOx depends on a large extent on the flame temperature, high compression ratio and excessive air in the combustion. This situation is probably, the relatively higher oxygen content of hazelnut oil methyl ester, which produced a higher NOx formation from diesel fuel. Finally, it is seen that the hazelnut oil methyl ester operations usually yield higher approximately 10-14% NOx emissions at all engine test speeds compared to diesel fuel.

![Figure 5(g) Variations NOx emissions versus engine speed for fuels](image)

Fig. 5(i) shows CO$_2$ emissions, respectively, for all test fuels under varied engine speeds. The CO$_2$ emission is increased with increasing engine speed for two fuels. Diesel fuel produced the highest amount of CO$_2$ than hazelnut oil methyl ester for all engine speeds. This is probably due to the fact that this hazelnut oil methyl ester has the lowest air/fuel ratio and also the fact that CO$_2$ emission concentration decreases with the air/fuel ratio. The burning of the hazelnut oil methyl ester appeared to emit the lowest CO$_2$ emission, primarily owing to its having the lowest carbon content from diesel fuel. Generally, the amount of carbon dioxide is proportional to the amount of fuel burned and the CO$_2$ emissions increase by increasing engine speed and the mass of fuel. It is an indication of efficient combustion of the hazelnut oil methyl ester due to its oxygenated nature.

![Figure 5(i) Variations CO$_2$ emissions versus engine speed for fuels.](image)

Fig. 5(h) shows the smoke values versus to engine rpm and the hazelnut oil methyl ester is produces less smoke than the diesel fuel at 2000 rpm engine speeds of approximately. The smoke of hazelnut oil methyl ester is lower than that of the diesel fuel under 2000 rpm engine speed. But in higher speed, hazelnut oil methyl ester is produced significantly higher smoke than diesel fuel. It can be
explained that the hazelnut oil methyl ester has higher viscosity than diesel fuel and this situation caused to deterioration of combustion and incomplete combustion.

![Graph showing smoke concentrations versus engine speed for fuels](image)

**Figure 5(h) Variations smoke concentrations versus engine speed for fuels**

Fig. 5(j) shows the exhaust gas temperatures changes depending on engine rpm for two fuels. It can be seen that exhaust gas temperatures of hazelnut oil methyl ester lower than diesel fuel for all of the engine speeds. The highest value of diesel fuel exhaust gas temperature was measured 535 °C at 4400 rpm with full load, but the corresponding value with the hazelnut oil methyl ester measured to 495 °C. The reason for this change in the exhaust gas temperature, hazelnut oil methyl ester has a low calorific value and has a low of the cetane number than diesel fuel. It can be explained that hazelnut oil methyl ester of combustion temperature is lower, because of the high cetane number and the ignition delay shortening for diesel fuel.

![Graph showing exhaust gas temperature versus engine speed for fuels](image)

**Figure 4(j) Variations the exhaust gas temperature versus engine speed for fuels**

VI. CONCLUSIONS

The experiments were made for diesel fuel and hazelnut oil methyl ester at various loads and following conclusions may be drawn from the this study:
- It was shown that hazelnut oil methyl ester as an alternative fuel can be used with pre-chamber diesel engine successfully without modifications.
- Specific fuel consumption of hazelnut oil methyl ester is higher approximately 10-12% for all engine rpm than diesel fuel.
- Hazelnut oil methyl ester emissions are higher HC, NOx, O₂ but CO and CO₂ is lower than compared with diesel fuel emissions.
- The hazelnut oil methyl ester NOx emissions are higher 10-14% for all engine loads compared to the diesel fuel.
- Hazelnut oil methyl ester physical and chemical properties are similar and hazelnut oil methyl ester heat value close to diesel fuel heat value but it is lower.
- For all engine rpm, specific fuel consumption increased on by an average rate of 11% was determined.
- Hazelnut oil is more expensive than diesel fuel, and possible to use hazelnut oil biodiesel produced from oils obtained from hazelnuts that cannot be used as food.
- Turkey is the biggest producer of hazelnuts in the world’s, hazelnut oil methyl ester may potential alternative fuel for internal combustion diesel engines.

**Nomenclature**

| Symbol | Description                  |
|--------|------------------------------|
| IDI    | Indirect diesel injection    |
| % vol. | Percentages of volume        |
| NaOH   | Sodium hydroxide             |
| CO     | Carbon monoxide              |
| CO₂    | Carbon dioxide               |
| HC     | Hydrocarbon                  |
| O₂     | Oxygen                       |
| NOx    | Nitrogen oxides              |
| Kg     | Kilogram                     |
| Rpm    | Rotation per minute          |
| PPM    | Parts per million            |
| ne     | Engine rpm                   |
| Me     | Effective Torque, Nm         |
| Pe     | Brake power kW               |
| Dₚ     | Density, kg/m³               |
| BSU    | Bosch Smoke Unit             |
| L      | Liter                        |
| °C     | Degree Centigrade            |
| Nₘ     | Newtonmeter                  |
| kW     | Kilowatt                     |
| rpm    | Revolution per minutes       |
| be     | Specific fuel consumption, kg/kWh |
| bte    | Brake thermal efficiency,%   |
| bmep   | Brake Mean Effective Pressure|
| mf     | Mass flow of fuel, kg        |
| Hu     | Lower heating value, kJ/kg   |
| η₂     | Thermal efficiency,%         |
| cED    | Conventional Euro Diesel     |
| COME2  | Blends obtaining from volume basis 2% mixing. |
| COME5  | Blends obtaining from volume basis 5% mixing. |
| COME10 | Blends obtaining from volume basis 10% mixing. |

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