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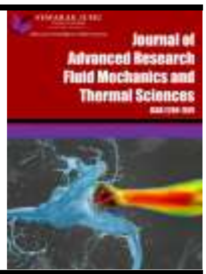

An Experimental Study using Diesel Additives to Examine the Combustion and Exhaust Emissions of CI Engines

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ABSTRACT

A single-cylinder diesel engine is used for an experimental inquiry utilizing diesel fuel (Di) and two different improver types: diethyl ether (DE) and bael oil (BO). The purpose of this research is to enhance fuel quality for improved engine efficiency in reduced emissions from engines by using diethyl ether and Bael oil. The fuel's cetane number was tested after 15% bael oil and 10% diethyl ether were added to commercial diesel. In order to assess engine performance and emissions, engine tests were conducted with the three fuels at progressively higher speeds, without load, and in the 1000–2500 RPM range with 250 RPM steps. The study's findings indicate that using diethyl ether and bael oil, respectively, improved the fuel cetane number from 48 to 52 and 54. Additionally, a notable rise in engine efficiency by 9.9% and 17.6% and a notable increase in engine brake power by approximately 15.9% and 26.8%, respectively, had been observed for the entire engine speed. At low and medium engine speeds, there was a notable decrease in specific fuel consumption of 19.7% and 36.6%, respectively. Furthermore, compared to commercial diesel, a discernible decrease in emissions has been noted for CO of 15.3% and 29.8%, CO_2 of 9.2% and 24.2%, and HC of 13% and 24.4%, respectively. Thus, it can be concluded that if you want to improve engine performance and lower exhaust emissions, you can use diethyl ether as a fuel additive with commercial diesel.

1. Introduction

A number of researchers have examined the efficiency and environmental effects of diesel engines, as well as their emissions and performance [1-6]. Modern two-stroke and four-stroke diesel engines with much better environmental behavior and thermal efficiency than those of previous decades have been developed by internal combustion engine manufacturers in collaboration with international research institutes and universities in recent years. These engines are intended for use in a range of industrial sectors. Global energy demand, depleting oil supplies, and strict transportation-related emission regulations encourage researchers to employ clean, alternative, and

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environmentally friendly fuels in automobiles. A 60% decrease in greenhouse gas emissions by 2050 is the goal stated in the European Union Commission's white paper report [7]. Between 2010 and 2011, the amount of renewable energy consumption failed to reach the target value, despite the European Union taking many efforts in this regard [7,8]. As is well known, diesel engines will need to be utilized in the transportation industry for the foreseeable future; yet, they release particulate matter and nitrogen oxides by Köse and Ciniviz [9], Liu *et al.,* [10], and Nieminen *et al.,* [11].

The 2011 emission measurement stations' limit values for NOx emissions were 42% higher, according to the Air Quality Report in Europe [8]. Additionally, the particulate matter emission values exceed the limit points by 43% [8]. The expense of catalyst materials is what drives up the price of after-treatment equipment. Consequently, several researchers start utilizing alternate fuels like biogas, LNG, CNG, ethanol, and LPG [12-22]. Hydrogen is a prominent and promising alternative fuel in the globe [22]. Due to limited battery capacity, driving an electric or hybrid car is not practical in the near future [23]. Using hydrogen or other clean, alternative gas fuels in diesel engines could be an option at this time [24]. Diesel fuel often contains additives to improve engine performance and reduce pollutants. Diesel engines commonly use a wide range of additives, such as dimethyl ether, naphthalene, acetone, camphor, benzyl alcohol, toluene, xylene, etc. [25-30].

According to Qi *et al.,* [31], adding 5% of diethyl ether to the blend of soybean biodiesel-diesel fuel (B30: 30% soybean+70% diesel) resulted in a small decrease in brake specific consumption of fuel. Additionally, in comparison to blended gasoline B30, CO emissions decreased with comparable NOx emissions. Similarly, ternary blends (alcohol-biodiesel diesel) with 5% diethyl ether show better combustion, emissions, and engine performance than blends without the addition [32]. In an alternative study, rubber seed biodiesel was mixed with a lower percentage of diethyl ether to increase engine performance and reduce emissions [33]. Diethyl ether is used with both jatropha and karanja biodiesel, showing the similar trend of improvement [34,35]. Conversely, while using the exhaust gas recirculation technology to run the engine, it is suggested that a ratio of 2% diethyl ether additive with fish oil biodiesel offered a superior reduction in all engine emissions [36].

Chauhan *et al.,* [37] concluded that adding 10% to 20% biodiesel to diesel fuel can be advantageous for long-term use in CI engines after analyzing the effects of several mixes of conventional diesel oil with various kinds of ethers and vegetable oils on the performance and emissions of CI engines. Moreover, a recent investigation, the effects of various additives, including oxygenated ones, on regulated and uncontrolled emissions from diesel engines were studied [38]. Apart from the assessments mentioned above, Giakoumis *et al.,* [39] examined the effects of various biofuel blends on burning-related noise pollution by utilizing both public and internal data. Furthermore, a comprehensive analysis of the relative impacts of various biodiesels on exhaust emissions during the transient operation of diesel engines has been conducted [40].

Very useful correlations for estimating the cetane number of biodiesels using different fatty acid compositions have also been discovered and published in a recent review [41]. In addition to previous experiments with different liquid and gaseous biofuels in CI engines, theoretical research has also been done with phenomenological simulations or multi-dimensional computational fluid dynamics (CFD) models of the operational efficiency and potential for pollution of CI engines using alternative oxygenated fuels. The impact of oxygenated Energies 2019, 12, 1547 3 of 36 fuels on CI engine operating and environmental behavior has been studied using detailed two-zone phenomenological models that were originally created for conventional CI engine efficiency and emission analysis as well as for EGR analysis [42,43]. These models have been appropriately modified and utilized for this purpose [44].

Moreover, the impact of the diesel/biofuel blending ratio and molecular structure on the efficiency and emissions of CI engines has been investigated using multi-zone models [45]. Lastly, the influence of oxygenated fuel characteristics on diesel spray combustion and soot generation has been evaluated using extensive CFD models [46]. Detailed simulation models have been used in the past to investigate the impact of fuel mix and characteristics on the transient operating and environmental performance of CI engines [47]. Labecki *et al.,* [48] investigated the effects of diesel and RME on the number-size distribution of soot particles released by high-speed DI diesel engines while taking different injection parameters and EGR rates into account. Klyus [49] looked into how different biofuels affected the technology of CI engines. Buyukkaya [50] examined the impacts of biodiesel type and content on the combustion parameters and emissions of pollutants from DI diesel engines. Using ordinary diesel oils and RME, Allocca *et al.,* [51] conducted experiments in a quiescent combustion chamber and in a EURO5 CI engine. Imran *et al.,* [52] demonstrated the beneficial effect of this biofuel on CI engine soot reduction and carefully investigated the effect of RME on CI engine performance and emissions at varied engine speeds and loads. The relative effects of RME on the performance and emissions of CI engines have been examined in previously published experimental investigations in comparison to other biodiesels, including bioethanol, gas-to-liquid (GTL), and soybean and palm oil methyl ester (SME) [34,53,54]. As is frequently the case, when RME combustion occurs in CI engines, NOx emissions decline in comparison to normal diesel operation.

Exhaust gas recirculation (EGR) has also been studied as a useful technique for reducing NOx emissions in CI engines that burn mixtures of regular diesel oil and RME [55]. Previous experimental investigations have also looked into the usage of RME and glycol ethers separately or in comparison to determine how each affects the performance metrics, pollutant emissions, and combustion properties of CI engines. In particular, Tsolakis *et al.,* [56] and Gómez-Cuenca *et al.,* [57] conducted engine tests using mixes of glycol ethers and standard diesel oil, and they showed that ethers had a favorable impact on the environmental behavior of CI engines. Furthermore, an experimental evaluation of the relative effects of glycol ethers and RME as diesel oil additives in a Ricardo/Hydra CI engine revealed that glycol ethers may have a greater soot reduction effect than RME [58]. Additionally, research on the addition of ethers to standard diesel fuels with increasing aromatic content has shown that diesel emissions of soot can be significantly reduced when the parental fuel has a low aromatic concentration and an increased glycol ether content [59]. The primary goal of this investigate is to experimentally investigate the effects of conventional diesel oil and its blends with diethyl ether and bael oil in order to evaluate each compound's influence on the combustion characteristics, fuel quality enhancement for enhanced engine efficiency, and emissions of CO, CO_2, and total unburned hydrocarbons (HC) from direct injection diesel engines.

2. Experimental Setup

Three various types of diesel fuel are employed in the experiment, together with two improvers called beel oil and diethyl ether, in an air-cooled single-cylinder diesel engine. In order to assess engine efficiency and emissions, engine tests were conducted with the three fuels at progressively higher speeds, without load, and in the 1000–2500 RPM range with 250 RPM steps. The YANMAR TF120M four-stroke, single-cylinder direct-injection diesel engine was used for the experimental test. Table 1 is a list of the test engine's specifications. The diesel fuel tank is part of the fuel control unit. A dynamometer of the hydraulic kind is used to put the engine under load. Every piece of information was gathered and handled using TFX Engineering used the DAQ to capture and process all of the data. In this experiment, particular fuel consumption, engine power, torque, and exhaust emissions were monitored and studied as parameters. Table 2 displays the chemical parameters for each kind of fuel. The fuel cetane number of the fuel samples was ascertained using the Shatox sx-100 portable cetane number analyzer. For more accurate findings, the apparatus has been calibrated using standard diesel fuel specimens in compliance with the manufacturer calibration protocols specified in the instruction manual. The fuel's cetane number test was conducted in triplicate in accordance with ASTM standard procedures, and the average value was taken into consideration for more accurate results.

Table 1
Technical specifications of the engine

Make and model	Kirloskar, TV-1
Method of cooling	Air cooled
Rated power	6.0(kW)
Number of cylinders	One
Fuel injection pressure	222 (bar)
Rated speed	2500 (rpm)
Combustion system	Direct injection
Bore and Stroke	87.6 and 111 (mm)
Engine displacement	0.7 (liter)
Compression ratio	17.6: 1
Fuel ignition Timing	°BTDC 22°
Loading device	hydraulic dynamometer

Table 2
The chemical properties of diesel fuel and additives [60]

Property Chemical	Diesel fuel (Di)	Diethyl ether (DE)	Bael oil (BO)
Structure	$C_{16}H_{34}$	$C_2H_5OC_2H_5$	$C_{18}H_{36}O_2$
Density (kg/m^3)	832	715	897
Auto ignition point (°C)	200-400	160	< 370
Cetane number	48	> 125	51.7
Lower heating value (MJ/kg)	42.8	33.9	36.3
Boiling point (°C)	182-332	36	299
Stoichiometric A/F ratio	14.8	11.2	12.5
Pour point (°C) 0	-20	-110	-5

3. Results and Discussion

This study involved experimental testing of engine efficiency, including specific fuel consumption, brake power and thermal performance, and emissions, including CO, CO_2, and HC, at engine speeds between 1000 and 2500 Rpm without any load. An essential measure of an engine's ability to efficiently transform fuel into mechanical power is its fuel consumption. The fuel usage trend as engine speed increases is depicted in Figure 1. Despite the fact that all fuels exhibit the same trend, it is evident that using 15% of Bael oil and 10% of Diethyl ether in combination with commercial diesel results in slightly lower specific fuel consumption at medium and low engine speeds—a significant decrease of 19.7% and 36.6%, respectively—than using gasoline fuel exclusively. This decline is the reason for this decline is due diethyl ether has a lower density than commercial diesel, as Table 1 illustrates [61]. Since fuel is measured by volume in the fuel measurement device, this increases the distribution of fuel spray and reduces the amount of fuel required for the same engine horsepower.

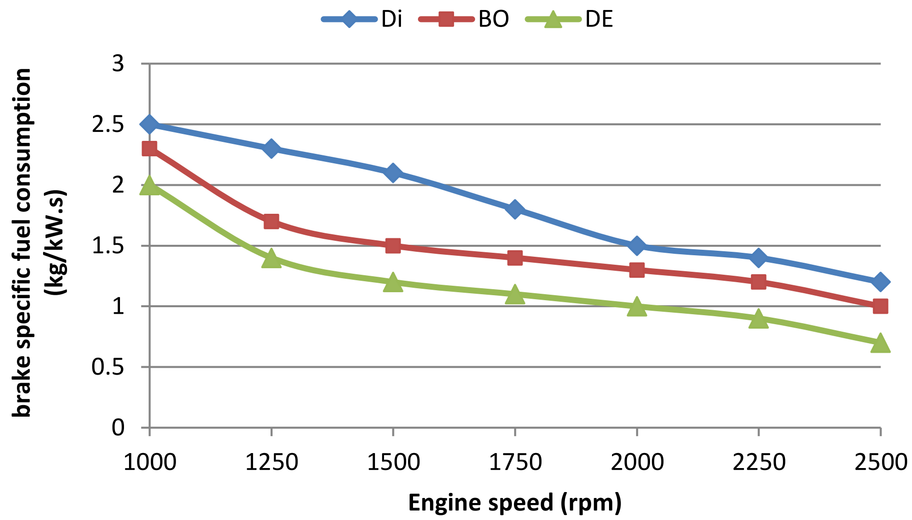

Fig. 1. Specific fuel consumption with increasing engine speed

Figure 2's engine test results demonstrate the tendency for engine power to rise with increasing engine speed for all three fuels: diesel, diesel + beel oil, and diesel + diethyl ether. Generally speaking, engine power rises as engine speed rises from 1000 RPM to 2500 RPM. Nonetheless, it is evident that at all engine speeds, the engine power obtained with 15% Bael oil and 10% Diethyl ether added to commercial diesel fuel is greater than that obtained with commercial diesel fuel without additive. These findings show that there is a large boost in engine brake power when diesel fuel is used, with 15% of the engine power increase coming from the usage of Bael oil and 10% from Diethyl ether. Nonetheless, it is evident that at all engine speeds, the engine power obtained with 15% Bael oil and 10% Diethyl ether added to commercial diesel fuel is greater than that obtained with commercial diesel fuel without additive. These findings demonstrate that, when compared to diesel fuel used in commercial engines, the average increase in engine power for diesel fuel utilizing 15% Bael oil and 10% Diethyl ether resulted in a considerable increase in engine brake power of roughly 15.9% and 26.8%, respectively. As indicated in Table 1, the high cetane number for diethyl ether has the impact of reducing ignition delay and improving fuel combustion, which results in an improvement in engine power. Additionally, it was discovered that the fuel cetane numbers with diethyl ether and bael oil improved from 48 to 52 and 54, respectively.

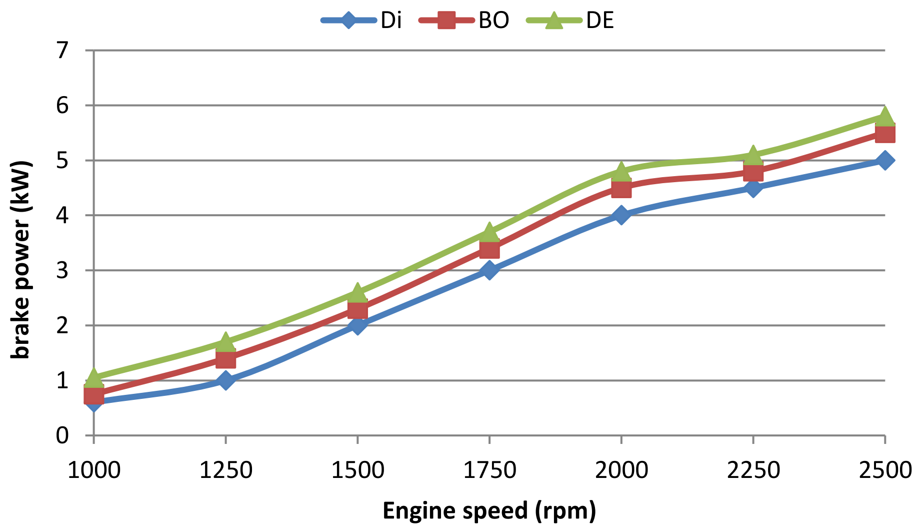

Fig. 2. Brake power with increasing engine speed

The ratio of gasoline and brake power consumption is known as the brake thermal efficiency. It displays the amount of energy transformed into usable energy [62]. An essential metric for engine performance while using the gasoline that has been tested is the brake thermal efficiency. It is more appropriate to use this measure to assess engine performance rather than brake-specific fuel usage because it accounts for the heating value of the gasoline being tested. As a result, it might be thought of as an engine's fuel conversion efficiency indicator. The engine brake thermal efficiency trend is depicted in Figure 3 as engine speed increases. Even though both fuels exhibit the same trend, diesel fuel with 15% Bael oil and 10% Diethyl ether had somewhat higher brake thermal efficiency than commercial diesel fuel at low and medium engine speeds by 9.9% and 17.6%, respectively. The increased cetane number of diethyl ether in comparison to commercial diesel, because this measure takes into consideration the heating value of the fuel being tested, it is more appropriate to use it to evaluate engine performance rather than fuel usage particular to the brakes. It might therefore be considered the fuel conversion efficiency indicator of an engine.

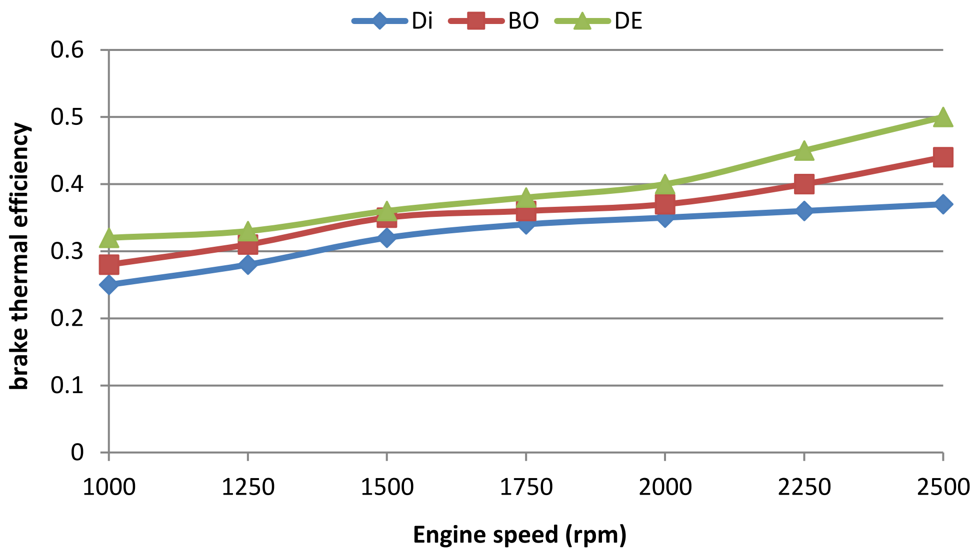

Fig. 3. Brake thermal efficiency with increasing engine speed

As a result of fuels based on petroleum not burning as efficiently as they should, internal combustion engines emit carbon dioxide (CO), a hazardous gas [63]. Incomplete combustion is the cause of carbon monoxide production during combustion [64]. The absence of oxygen during burning is the primary cause of CO emissions. Figure 4 illustrates the impact of improver addition on CO emission. The CO emission values were found to range from 0.02 percent to 0.1% vol, with a decrease of 15.3% when diesel fuel was used with 15% Bael oil and 29.8% when 10% diethyl ether was utilized. The air-fuel ratio affects the CO emission (AFR). Lower AFR causes less oxygen to be available, which raises CO emissions.

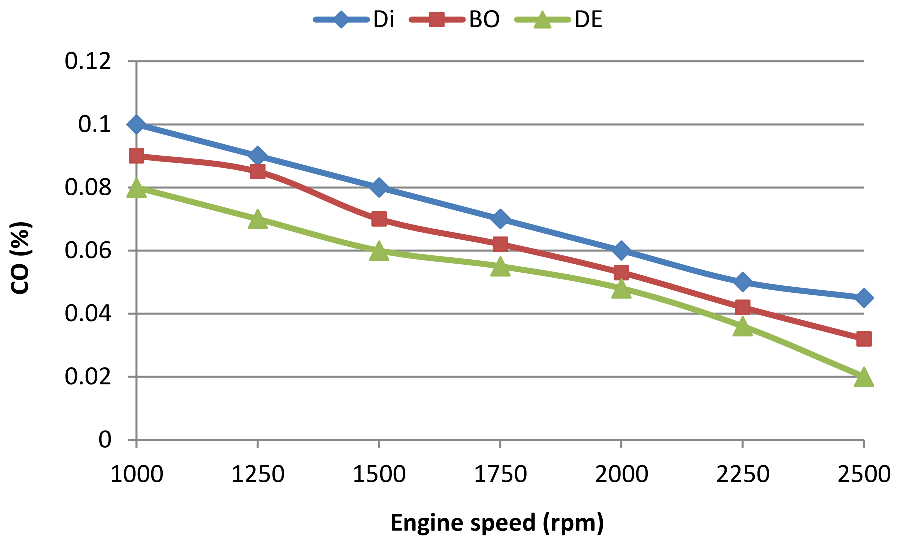

Fig. 4. CO with increasing engine speed

The complete burning of fuel produces CO_2 emissions, which play a major role in global warming. [65-68]. Figure 5 illustrates that, at all engine speeds, the CO_2 emission from using improvers was more than that from diesel. The CO_2 emission values range found from 3.4 %vol to 12 %vol with decreasing of 9.2 % for using diesel fuel with Bael oil used at 15% and 24.2 % for using 10% diethyl ether.

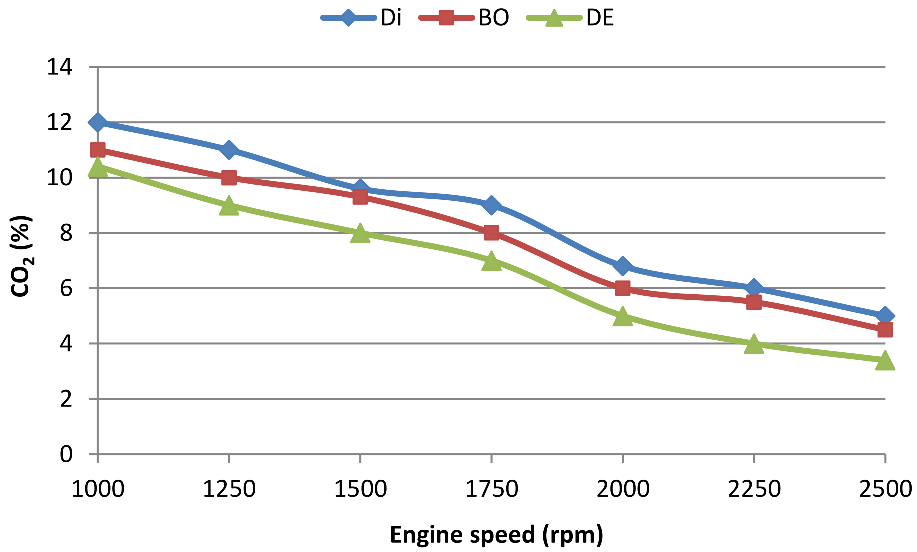

Fig. 5. CO_2 with increasing engine speed

Figure 6 shows the variation in the amount of hydrocarbon emissions without load for diesel fuel and its mix with improver. Figure 6 makes it evident that when engine speed rises, HC emissions for all test fuels decrease. This results from fuel-rich mixes decreasing at higher engine speeds. Fuels with a larger percentage of diesel will emit more hydrocarbons (HC) at lower engine speeds. It could be because of the larger diesel dispersion in the combustion chamber and the lower viscosity of the fuel with higher percentages of diesel. Diesel fuel use, however, produced the most HC emissions. It is acknowledged that improvers reduce HC emissions.

The range of HC emission levels was found to be 30 to 84 ppm, with a decrease of 13% when diesel fuel was used with 15% Bael oil and 24.4% when 10% diethyl ether was used. Improvers have been added to the blend, significantly reducing the amount of unburned hydrocarbon. Higher combustion temperatures and the oxygen present in improvers encourage the oxidation of hydrocarbon emissions, which is the cause of this.

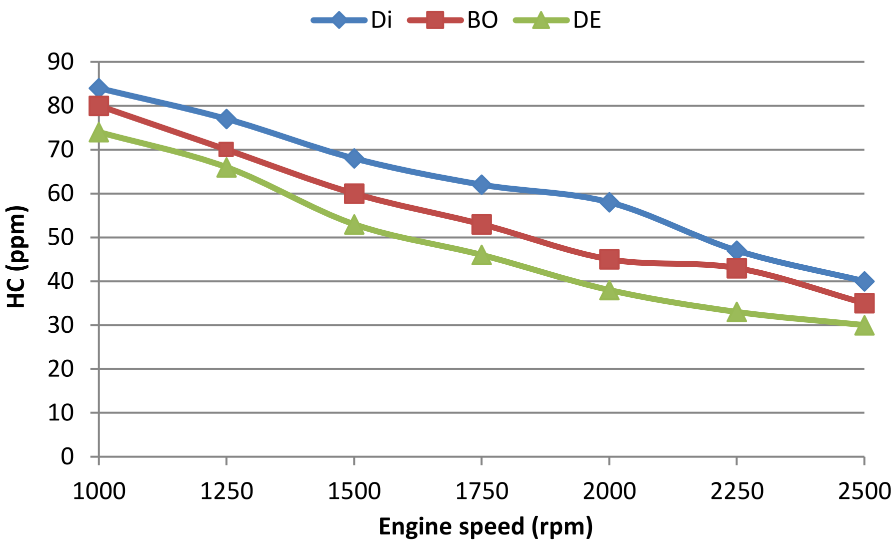

Fig. 6. HC with increasing engine speed

4. Conclusion

In this work, engine values related to brake thermal performance and CO, CO_2, and HC emissions were examined experimentally. A four-stroke, naturally aspirated, air-cooled, single-cylinder diesel engine was tested at 1000–2500 RPM with a 250 RPM step and without a load. Diesel fuel and two enhancers, called Bael oil, were put through experimental testing in a compression ignition test engine at 15% and 10% diethyl ether. the obtained findings are provided as

i. The specific fuel consumption decreased by19.7 % and 36.6 % respectively with addition of Bael oil used at 15% and 10% diethyl ether compared to use diesel fuel only.
ii. There was an approximate 15.9% and 26.8% increase in engine brake power. respectively with addition of Bael oil used at 15% and 10% diethyl ether compared to use diesel fuel only.
iii. The brake thermal efficiency increased by 9.9 % and 17.6 %, respectively with addition of Bael oil used at 15% and 10% diethyl ether compared to use diesel fuel only.
iv. CO emissions decreased by 15.3 % and 29.8 %, respectively with addition of Bael oil used at 15% and 10% diethyl ether compared to only use of diesel fuel.
v. CO_2 emissions decreased by 9.2 % and 24.2 %, respectively with addition of Bael oil used at 15% and 10% diethyl ether compared to only use of diesel fuel.
vi. HC emissions improved by 13 % and 24.4 % respectively with addition of Bael oil used at 15% and 10% diethyl ether compared to only use of diesel fuel.

5. Future Direction

About 25% of the electricity in the world is produced by internal combustion engines using fossil fuel oil. and as a result, they generate 10% of the global emissions of greenhouse gases (GHGs). Engine manufacturers and researchers have long sought to reduce emissions and fuel consumption. It's true that tremendous advancements have been achieved, making the modern IC engine a marvel of technology. Internal combustion engines' reputation has been seriously harmed by previous pollution scandals, raising concerns about the technology's ability to continue significantly reducing emissions in the transportation industry. In an attempt to further reduce fuel consumption, pollution, and greenhouse gas emissions from automobiles, ideas have been made to convert internal combustion engines (IC engines) to electric drives in vehicles by Reitz *et al.,* [69], Berkeley [70], and Auto Tech Review [71]. Given its market value, which is estimated at trillions of dollars, and the fact that there is still a long way to the technology of electric cars and renewable energies, the motor industry has a bright future despite the technological revolution in the fields of renewable energies and the uses of electric motors. Future practical uses requiring further research will necessitate the development of new materials and technologies to improve engines. Furthermore, because they have a significant impact on heat dissipation and increase the heat and mass transfer and improve them using various types of technology, improving the properties of fluids and the heat transfer also has a major impact on increasing the effectiveness of various machines and devices [72-77]. One of these techniques is the use of nanofluids, which are still in their infancy and require further investigations because there are so many different kinds of nanomaterials by several authors [78-82].

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