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Original Article

Combustion and Performance Characteristics of a Lanthanum-Cerium Oxide Coated DI Diesel Engine Fueled with Lemon Grass Oil Methyl Ester and Di-Ethylene Glycol as Additives

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Abstract *- Biodiesel represents one of the alternate fuels that can be used in combustion engines due to its provenance that it has the ability to reduce emissions. Biodiesel is an eco-friendly, naturally occurring, renewable, and perishable fuel. Using biodiesel reduces the demand for imported fossil fuels, whose supply is rapidly depleting and whose price is being tested. An experiment assessed a diesel engine's combustion, emission, and performance with lemon grass methyl ester and its blends (20 percent diesel & 15 percent Di-Ethylene Glycol (DEG)). Biodiesel can find use in Low Heat Rejection (LHR) engines in a highly efficient and effective manner when the combustion chamber temperature is maintained by a thermal layer in the surface piston crown. In the current work, approximately 0.5 mm of ceramic material (La2Ce2O7) was plasma-sprayed onto the piston crown. The tests were directed in a Direct Injection (DI) diesel engine utilizing two different combinations of Lemongrass oil Methyl Ester (LGME) according to varying loads along with and without an adiabatic (Coated) piston. The findings indicate that B20 biodiesel with coating and additives increases Brake Thermal Efficiency (BTE) and reduces Brake-Specific Fuel Consumption (BSFC) by approximately 10 percent at 100% load. The LHR engine produced 20 percent more Nitrogen Oxide (NO) emissions than an uncoated diesel engine while at the same time lowering Carbon Monoxide (CO) and Hydrocarbons (HC). Both the pressure at its highest and the amount of heat release appeared substantially higher in the LHR engine than in a regular engine.*

Keywords *- Lanthanum–cerium oxide, Di-ethylene glycol, Transesterification, Emission, Lemon grass oil methyl ester.*

1. Introduction

Because of their long lifespan and their excellent capacity to make efficient use of heat, Compression Ignition (CI) engines find widespread application in the logistics and agriculture industries. Their study noted that despite its disadvantages, it produces more NO and smoke emissions, which are exceedingly hazardous to human health [1]. Consequently, smoke emissions must adhere to tougher regulations. Since vegetable oils have qualities similar to diesel and may be used in CI engines without alterations, they are often considered a good replacement for diesel.

Biodiesel is frequently blended with diesel instead of being utilized in its pure form. It has already been recorded and proved that the B20 blend of biodiesel and diesel is the most engine-appropriate combination [2]. According to biodiesel, it is a feasible natural alternative fuel source with positive environmental impacts [3]. Numerous research is currently being undertaken to establish the optimal quantity of biodiesel emissions for automotive use [4]. Oxygenated additives and Di-Ethyl Ether, which could be extra to diesel/biodiesel fuels to reduce NO emissions, were utilized to test the use of undiluted biodiesel, and they found higher NO levels [5].

Using a diesel engine set at a constant 1,500 rpm, researchers could examine the emission levels, performance, and combustion properties of 2nd generation Cooking Methyl

Ester (WCO-ME). The investigation for this study was carried out [6]. When compared with diesel according to final load, the usage of biodiesel resulted in a decrease of 6 percent in the brake efficiency rise of 24.9 percent in the amount of energy that had been consumed specifically by the brakes. This was due to the fact that biodiesel increased the amount of energy that was consumed by the brakes. In comparison to diesel, the emissions of CO, Unburned Hydrocarbons (UBC), NO, and smoke were all reduced by 43.3%, 52.7%, 23.0%, and 15.5%, respectively.

Incomplete combustion occurs in traditional CI engines because the combustion chamber contains insufficient oxygen molecules. To get over this problem in today's world, oxygenated chemicals are frequently mixed together with biodiesel. Nano additives [27], such as titanium oxide and zirconium oxide, were utilised in this study. They discovered that adding it to diesel fuel or using it as a pure additive can enhance engine efficiency, lessen the problem of cold starting, and reduce emissions. Research using a single-cylinder DI engine at constant state speeds (1200-3000 rpm) discovered that using biodiesel with a Lower Heating Value (LHV) decreased power by 1-4% and increased BSFC by 2-9% [8]. This occurred because the engine was running at a constant speed. These results are based on research into a diesel engine [9]. While Carbon Dioxide (CO_2) and Nitric Oxide (NO) emissions both went up (6.95-17.62%) with respect to the usage of biodiesel, Carbon Monoxide (CO) and Hydrocarbon (HC) emissions went down (28%-46%).

In order to discover how fuel affects the amount of heat produced, carried out a number of tests were carried out with rapeseed oil [26] and its methyl ester. Droplet ignition delay testing was the method that [10] utlize to control the ignition delay of a number of bio-esters. The combustion efficiency of biodiesels made from palm and coconut oil was analysed by [11, 12], which looked at how much fuel would be used, how the combustion process would change, etc., when oxygenated additives were added to diesel fuel, the overall efficiency, and the emissions. They focused on diesel engine smoke emissions ranging in size and dispersion from 5.6 to 560 nm.

Diglyme and Etil terbutil eter were added to diesel as oxygenated compounds. Seven different additives were added to the diesel fuel in increasing proportions, including 5 percent, 10 percent, and 15 percent oxygenated additions [13]. The investigations were conducted on VW Euro 4 2.0 TDI diesel engines under 9 stationary operation settings (1500, 2250, and 3000 min-1 at 15%, 30%, and 45% load, respectively [14]. They studied how adding additives to a mixture impacts NO, smoke emissions, and smoke opacity [15]. The addition of oxygenated additives reduces the total smoke opacity by a significant amount. The oxygenated addition to diesel fuel reduces the emissions of dangerous contaminants.

In the study they carried out [16], they found that one of the keys to improving combustion efficiency is cutting down on the amount of heat lost after the combustion chamber. By insulating the surfaces with a combustion chamber with materials that have high thermal resistance, it is feasible to cut down on the amount of heat that is lost from the chamber. Constructed low heat rejection engines [17, 28] by layer the inside of the piston crowned, and the inside of the cylinder head, the valve bodies, and the liner of the cylinder with a coating of partially stabilised zirconia with a thickness of 0.5 millimetres. Throughout the combustion process, a thermal barrier coating has been applied over the chamber of the engine in order to improve combustion performance and prevent heat loss to the air outside the engine. According to the possibility of pre-ignition and knocking in the combustion chamber caused by high temperatures prevents the use of thermal layer coatings in spark-ignited engines [18].

We looked at how an uncoated engine working on diesel and nerium methyl ester fared regarding pollutants and efficiency. Mostly Stabilized Zirconia PSZ-coated engines used less gasoline across the board thanks to the coating's insulating characteristics and enhancements to the combustion process. Braking thermal efficiency is 3.8% higher in a PSZ-coated MEON engine compared to an uncoated engine [19]. Because of its low thermal conduction and high thermal increase coefficient, Lanthanum Cerium Oxide ($La_2Ce_2O_7$) has been proposed as a new thermal barrier coating material. The PSZ-coated diesel engine had fewer emissions than the uncoated engine in all categories except for NO. Researchers found that biodiesel with cerium oxide nanoparticles added had a higher flash point and lower hydrocarbon and nitrogen oxide emissions. Numerous investigations [25] have been undertaken over the past two decades to determine the best alternative fuel source for autos [20].

After reviewing the relevant research, we can conclude that modifying diesel engines to run on Lemongrass oil Methyl Ester (LGME) under different loads and with or without an adiabatic coated piston ($La_2Ce_2O_7$) has not been effective. However, the effect that emissions have on the environment is a crucial aspect that has been overlooked. In the paper, this problem is examined in detail. DI engines have also benefited from efficient and effective Low Heat Rejection (LHR) engines, which use a thermal layer on the piston crown to keep the combustion chamber at a constant temperature.

The primary reason for this paper is to develop a semi-LHR engine with a combustion chamber that has great thermal shock resistance and increases combustion; the current study suggests coating the piston and internal chamber with 0.5mm of Lanthanum-cerium oxide using Atmospheric Plasma Spraying (APS). In the current investigation, 100 percent pure LGME ester and its 20 percent blend at varying loads with an oxygenated additive are utilized to improve the combustion, performance, and emissions of an experimental engine where a $La_2Ce_2O_7$-coated piston. The measured data are related to the diesel base engine and are analysed.

2. Materials and Methods

2.1. Preparation of Biodiesel (PME)

Citral is an odourless, pale-yellow liquid with a strong lemony fragrance. 65 to 85 percent of lemongrass oil is citral. Using steam distillation, citral is extracted from fresh leaves. The procedure of steam distillation was employed to isolate the lemongrass oils. Based on the optimal range, they were extracted individually from the lemongrass leaves and stems at a certain temperature and extraction time to generate a mixture of water and essential oil. Using dichloromethane, the aqueous layer and the essential oil were separated. The chemical process of transesterification reduces the size of the big, branching triglyceride molecules present in vegetable oils and fats to the size of the straight-chain molecules found in diesel fuel. The process begins when vegetable oil and alcohol react in the availability of a catalyst. Triglycerides, which are tri-esters of glycerol, constitute vegetable oil. Combining triglycerides and methanol produces biodiesel. Potassium methoxide is used as a catalyst to accelerate the exceedingly sluggish process. Lemongrass oil contains many unbound fatty acids [7].Consequently, biodiesel production involves a variety of stages. In order to get a high PFA ratio, the primary stage is an acid-catalyzed esterification process with 0.5% H_2SO_4 and a 6:1 molar ratio of alcohol. Reducing the acid content of lemon grass oil leads to the creation of methyl ester, followed by a transesterification catalysed by alkali [21].

To generate fatty acid ester, glycerol and the triglycerides in lemongrass oil must react in the occurrence of a catalyst with methyl alcohol throughout the transesterification process. In a flask with a flat bottom, one thousand milliliters (ml) of lemon grass oil, two hundred milliliters (ml), ten grams (g), and methyl alcohol were inserted.

The mixture was stirred until the production of esters commenced. After that, the mixture was heated to 70 degrees Celsius, where it remained while being swirled constantly for an hour until the temperature was maintained. After that, 24 hours passed without stirring the liquid while it cooled down. There were two distinct strata present. The uppermost layer was made up of an ester, whereas the lowermost layer was made up of glycerol [22]. Table 1 contains a listing of the characteristics of diesel, oil extracted from lemongrass, and methyl ester.

Table 1. Properties of diesel, lemongrass oil methyl ester, and di-ethylene glycol

Properties	Diesel	LGME	DEG
Density (kg/m^3)	0.830	0.880	0.715
Kinematic Viscosity @ 40℃	3.2	6.4	0.15
Heating value (MJ/kg)	42.9	38.5	33.9
Cetane Number	46	53	>120
Ignition Temperature (℃)	265	465	165
Boiling Point (℃)	185-365	-	34
O_2(%)	0	11-13	22

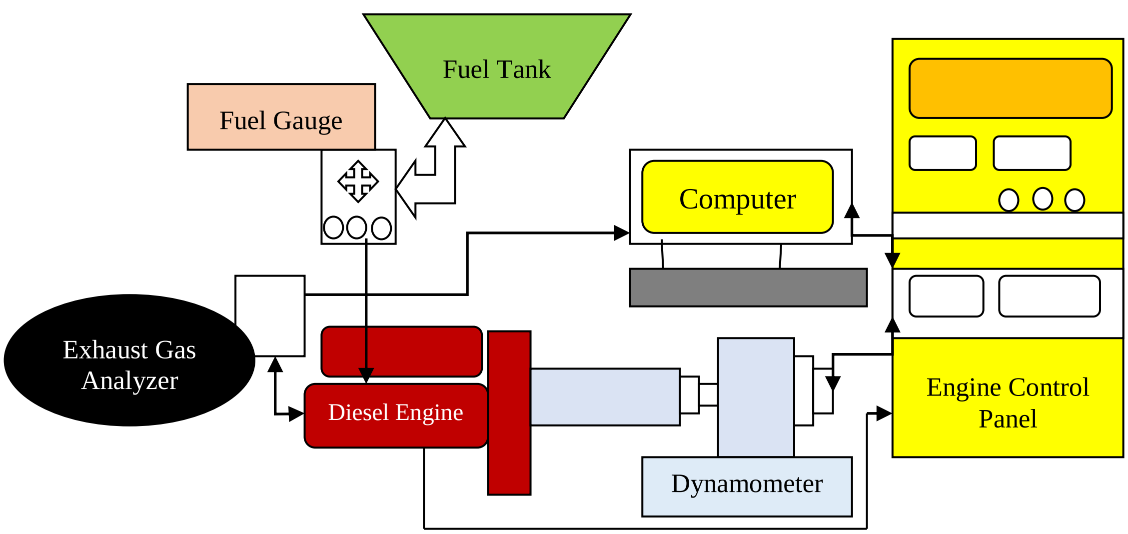

Fig. 1 Test engine setup

2.2. Experimental Setup and Procedure

As seen in Figure 1, an open ECU for a water-cooled diesel engine and a single-cylinder, four-stroke, multifuel VCR were utilized for the engine testing. The experiment's engine is hooked to an electrical eddy current dynamometer, generating the required braking load. The engine's performance was tested at 25 percent load intervals from idle to maximum load run at its rated speed of 1,500 revolutions per minute while utilizing diesel fuel and 20 percent methyl ester of lemongrass oil. The engine's rated speed is 1,500 revolutions per minute. Diesel fuel and lemon grass oil methyl ester were kept in separate fuel tanks.

For the purpose of determining the volumetric flow rates of air and fuel, respectively, a stopwatch-equipped burette with a capacity of $50m^3$ with a U-tube manometer was used. The amount of fuel used was estimated by measuring how long it took for a predetermined amount of gasoline to be ingested by the vehicle's engine. The AVL five-gas analyzer and the Bosch smoke analysis were used in order to quantify the emissions that were produced by the engine as well as the overall density of the smoke. Bosch manufactured both of these instruments. In order to obtain accurate readings of the combustion parameters, we made use of pressure sensors, TDC encoders, and computer-assisted data collecting.

3. Results and Discussion

The engine was run with diesel and 20 percent biodiesel under various loads. Monitored, analysed, and compared the cylinder pressure, HRR rate, ignition delay, BSFC, exhaust gas temperature, CO, NO and smoke emissions.

3.1. Combustion Analysis

When the piston approaches TDC, the peak pressure is reached; as a result, fuel injection is initiated, and self-ignition occurs. Figure 2 depicts the relationship between peak pressure and braking power at full load for various fuels, including diesel, LGME B20, coated engines, and Di-Ethyl Glycol. The peak pressure is determined by the amount of fuel engaged in unrestrained combustion. The figure reveals that compared to B20 LGME, the DEG's peak pressure is 4 bar greater, while diesel fuel's peak pressure is 1 bar lower. The maximum and minimum peak pressure values for additive mixed LGME are 60 bar and 55 bar, respectively.

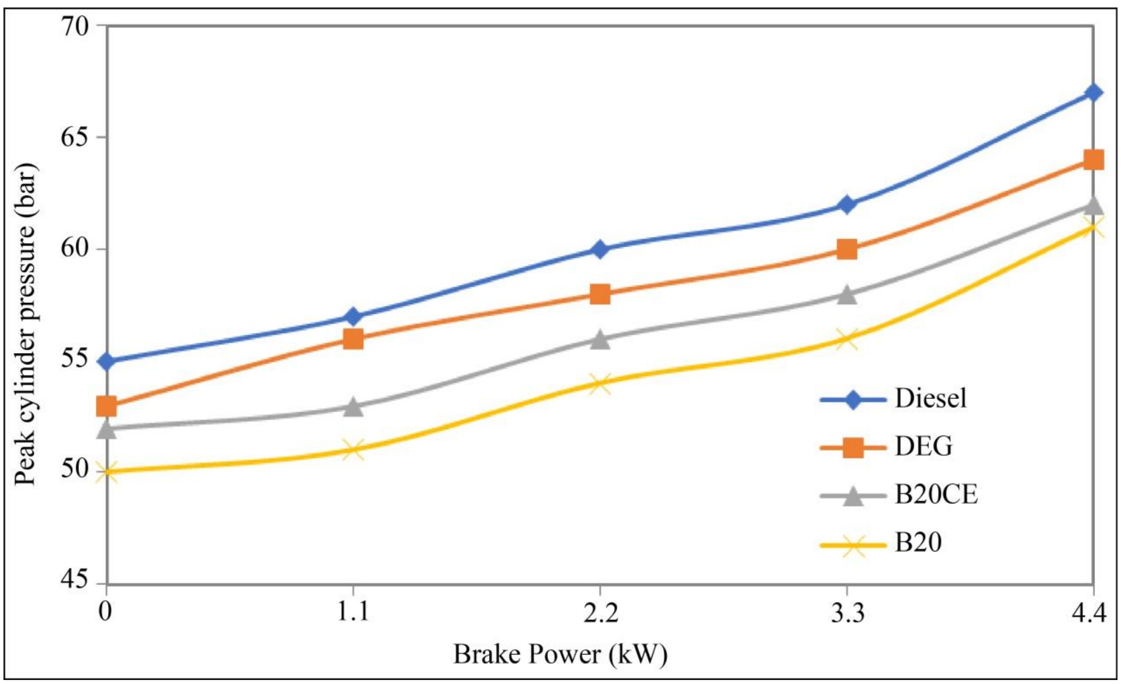

Fig. 2 Peak pressure with BP

Typically, instantaneous measurements of cylinder pressure utilizing precision pressure transducers are used to initiate HRR, which is then designed versus crank angle. Figure 3 depicts the extreme amount of heat released by the engine as the purpose of the crank angle. Compared to Di-Ethyl Glycol additive, LGME B20, and coated engines B20CE, the starting delay in diesel-prepared combustion is reduced, resulting in a longer combustion phase. For diesel, Di-Ethyl Glycol is 46 J/^{o}CA, B20CE is 44 J/^{o}CA, and LGME B20 is 42 J/^{o}CA. HRR equals 48 J/^{o}CA.

During a full load operation, the HRR of an additive mixed fuel engine increases by 2 J/^{o}CA, according to the experimental investigation [23].

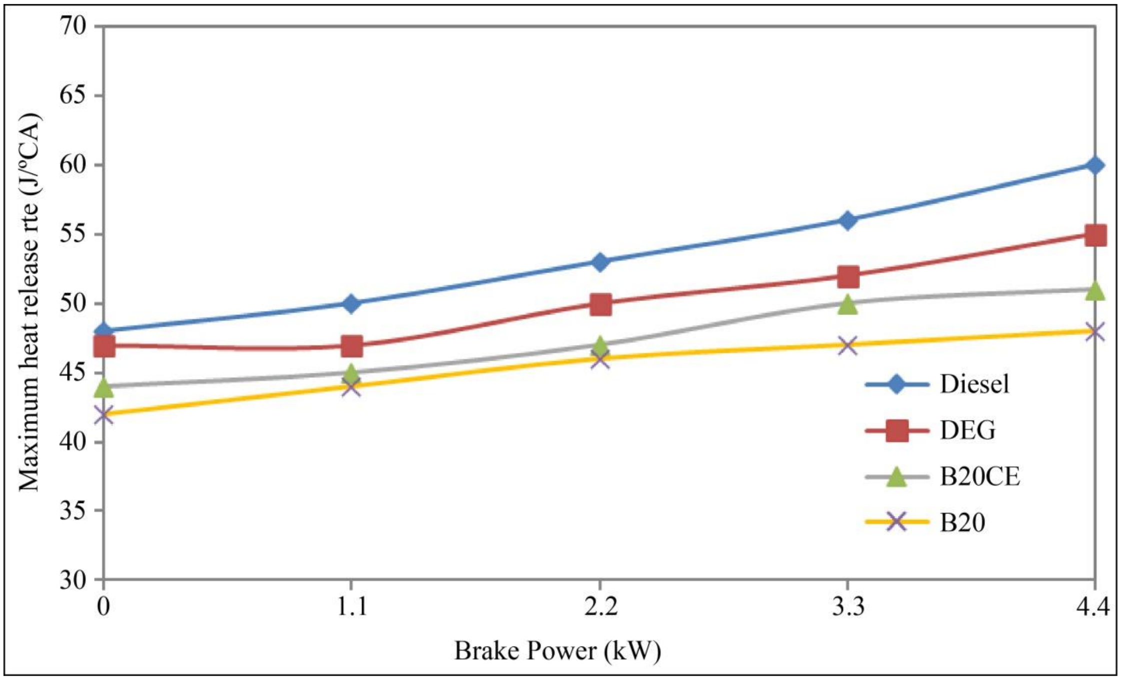

Fig. 3 HRR with BP

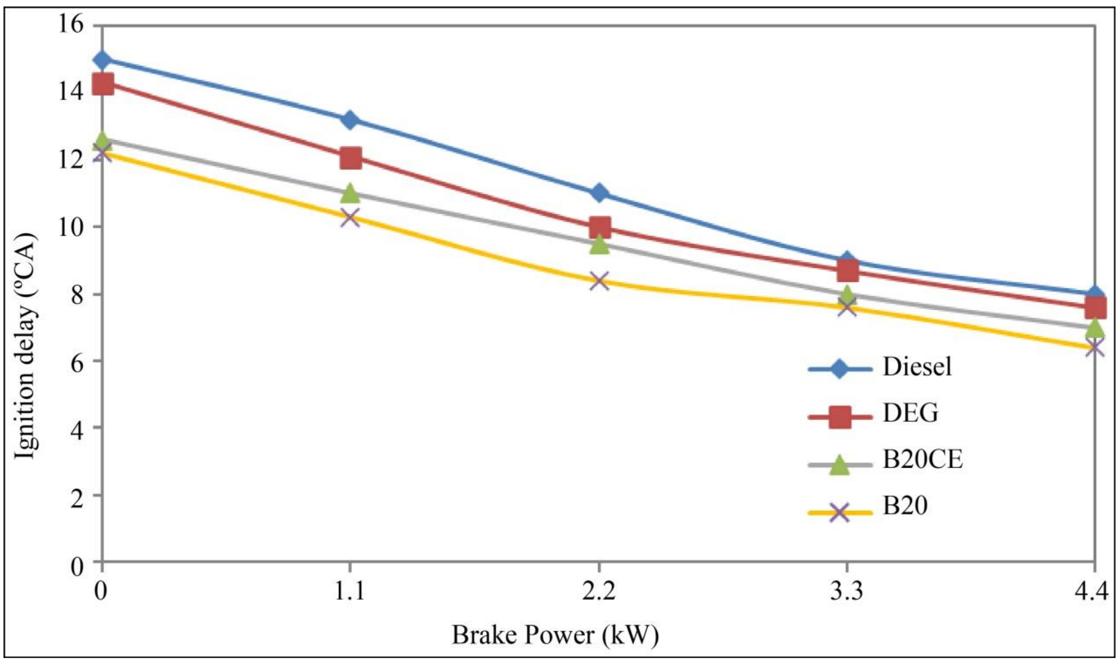

Fig. 4 Ignition delay with BP

Figure 4 illustrates the relationship between BP and ignition delay for diesel and LGME engines at 100% load conditions. The rate between the start of combustion and injection was measured. The ignition delay is shortened when the DEG is added to the emulsion. The ignition delay rises by about 7 and 14° CA per degree Celsius. Comparatively to coated engines, the ignition delay ranges between 8 and 15° CA. However, the ignition delay is significantly longer than diesel [24].

3.2. Performance Analysis

Figure 5 depicts the relationship between BTE and braking power for various fuel compositions, including DEG, B20CE, and B20 for diesel and biodiesel derived from lemongrass oil.

Die Ethyl Glycol has more advanced thermal efficiency for braking than the thermal coating engine due to the minor calorific value and greater vaporization capabilities. The graph depicts that the thermal efficiency of braking for diesel is 29%, DEG is 28%, coated engine B20CE is 27%, and B20 Lemon grass oil biodiesel is 26%, respectively. The relationship between brake thermal efficiency and braking power for a variety of fuel compositions, including DEG, B20CE, and B20 for diesel and biodiesel derived from lemongrass oil. Die Ethyl Glycol has higher thermal efficiency for braking than the layered engine due to its minor calorific value and better vaporization capabilities [29]. The graph depicts that the thermal efficiency of braking for diesel is 29%, DEG is 28%, coated engine B20CE is 27%, and B20 Lemon grass oil biodiesel is 26%, separately.

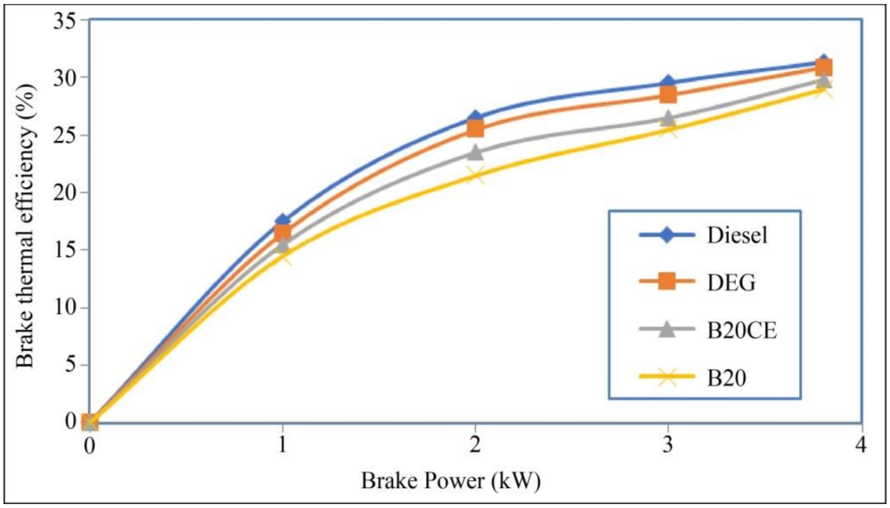

Fig. 5 BTE with BP

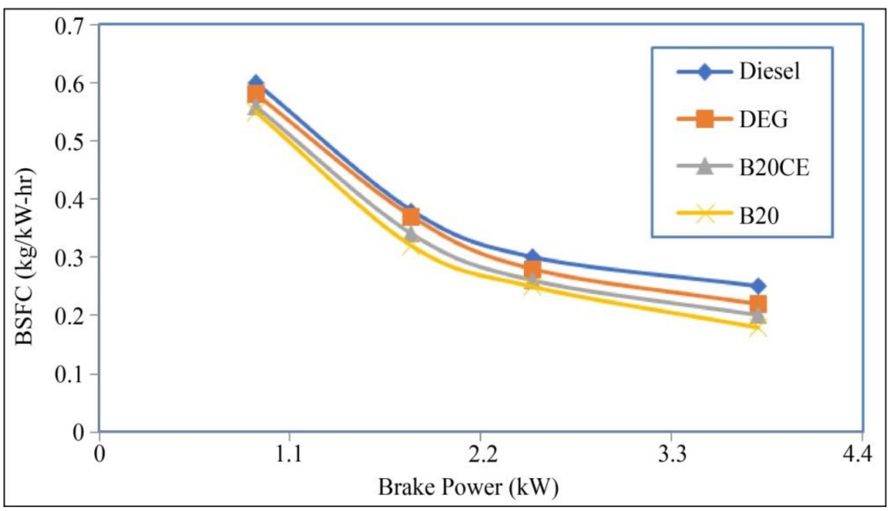

Fig. 6 BSFC with BP

The BSFC is an essential engine parameter. It computes the quantity of input energy essential to generate 1 kilowatt-hour of power. In Figure 6, the BSFC for diesel decreases from a maximum of 0.58 kW/hr to a minimum of 0.24 kW/hr. Adding Lemon Grass Biodiesel B20 reduces the BSFC from a maximum of 0.6 kW/hr to a minimum of 0.26 kW/hr. The BSFC value for coated engines B20CE ranges from a maximum of 0.63 kW-hr to a minimum of 0.28 kW-hr. Di-Ethyl Glycol is introduced as an additive, and the BSFC Value varies between 0.65 and 0.31 kW-hr. This depends on the LHR engine’s high oxygen molecule content and additive-mixed fuel [29 DEG significantly minimized CO emissions].

3.3. Emission Analysis

The link involving the thermal of the exhaust gases and the force of braking for a variety of restricted fuels is shown in Figure 7. When compared to a diesel engine, a DEG engine’s exhaust temperature is far more manageable. When utilizing 100% Lemongrass oil Biodiesel, the exhaust gas temperature is maximized by approximately 10%. The respective values for the standard engine with diesel exhaust gas range from 175°C to 300°C. The temperature range for Di-Ethyl Glycol is between 165 and 250 degrees Celsius. The range of 168°C to 280°C is suitable for the coated B20CE engine.

The variation in carbon monoxide emissions resulting from incomplete fuel burning is illustrated in Figure 8. Due to the lack of oxygen molecules in their atomic structure, it is more prevalent in petroleum-based fuels. It has been demonstrated that the alternate fuels utilized in the neat engine and DEG significantly minimized CO emissions [29]. Reduced in-cylinder heat transfer, extended combustion time, and a higher oxygen concentration in the biodiesel may all contribute to the DEG's lower CO emissions. The respective CO levels for the standard engine are 1.5% Vol and 6.2% Vol. For the coated engine B20CE, the observed range was between 2 and 6.6 percent Vol, whereas, for the die ethyl glycol, the observed range was between 1.75 and 6.5 percent Vol. Figure 9 depicts the variation in carbon monoxide for diesel fuel containing B20 percent, B20CE percent, and DEG when the engine works at its maximum capacity, also known as its rated load. Since the air-fuel ratio decreases as engine load increases, as it does in all conventional internal combustion engines, it is revealed that CO emissions are initially reduced with maximized engine load and then maximum with maximum engine load.

The CO_2 emission for diesel fuel begins at 0.07 percent, decreases to 0.04 percent, and then increases to 0.06 percent. The B20 value fluctuated between 0.06 percent and 0.04 percent before increasing to 0.05 percent. Similarly, the coated engine B20CE decreases from 0.05 percent to 0.03 percent and increases to 0.04 percent. After falling from 0.04 percent to 0.02 percent, the DEG value climbed to 0.035 percent. Using a lower percentage of biodiesel B20 and a biodiesel B20 CE-coated engine, the engine emits less CO than diesel fuel under load conditions.

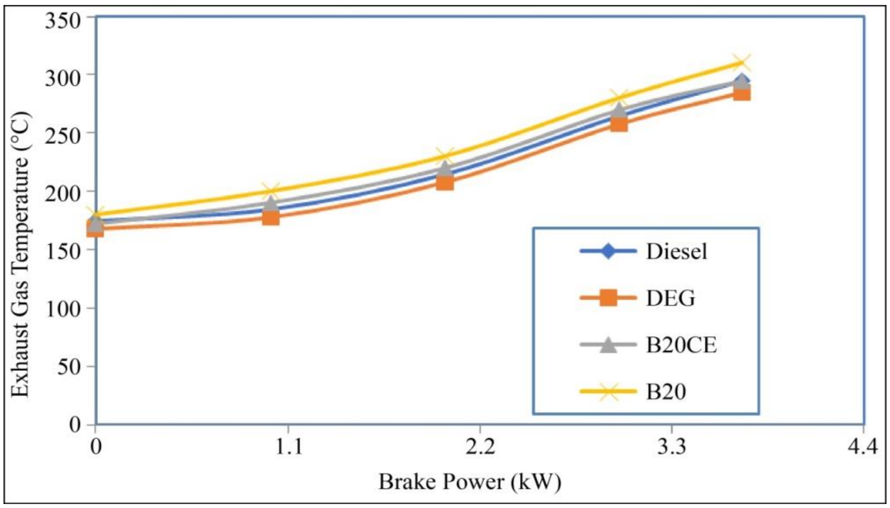

Fig. 7 Exhaust gas temperature with BP

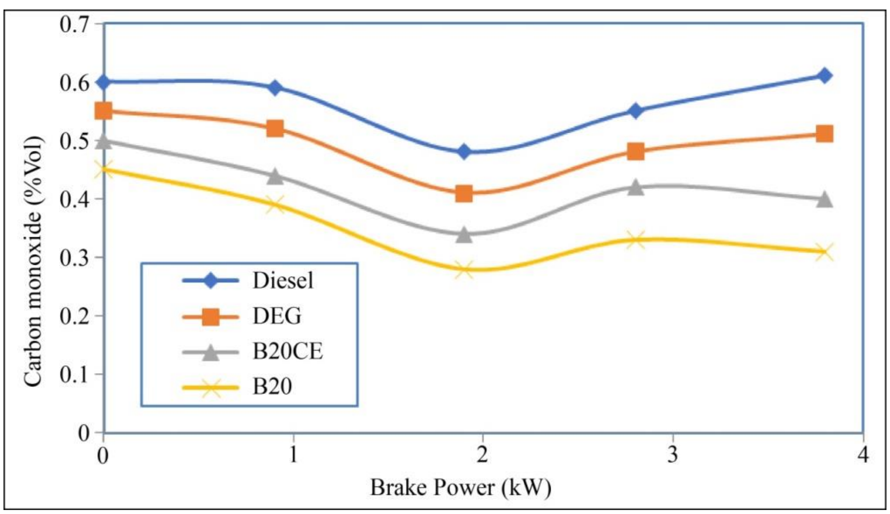

Fig. 8 CO emissions with BP

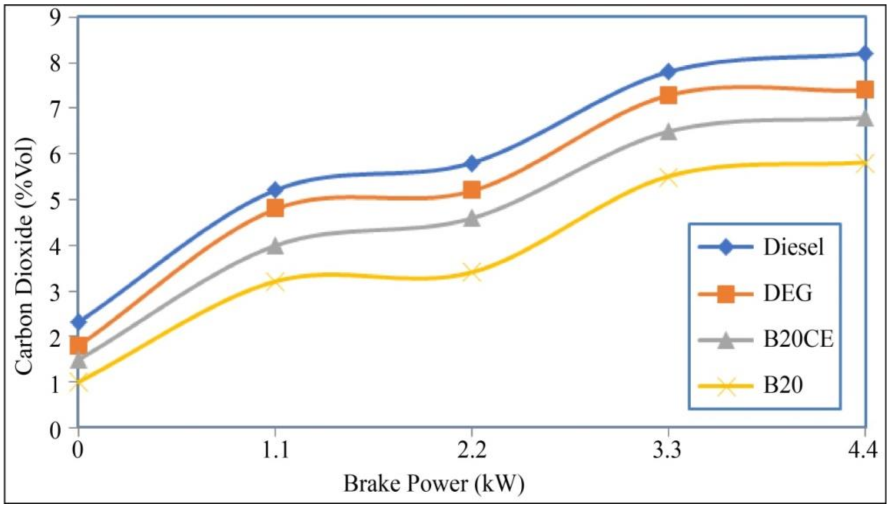

Fig. 9 CO_2 emissions with BP

The difference in HC emissions with diesel, biodiesel, coated engines, and Di-Ethyl Glycol additives are tested and plotted in Figure 10. An inverse relationship exists between the amount of biodiesel in a blend and the amount of hydrocarbon emissions. This decline may have something to do with the increased oxygen concentration of biodiesel, which enhances combustion quality.

The HC values range between 28 ppm and 35 ppm for diesel base engines, 33 ppm and 36 ppm for Di-Ethyl Glycol, and 36 ppm and 39 ppm for B20CE-coated engines. Figure 11 illustrates the relationship between NO and braking power. Diesel has fewer NO emissions than B20, B20CE, and DEG biodiesels. NO emissions increase as more biodiesel is utilized as a fuel in the blends B20, B20CE, and DEG. The fuel cost was 50, 90, 175, 250, and 410 dollars. The B20 value of lemon grass oil ranges from 75 to 110 to 210 to 270 to 430. The coated engine B20CE now produces 90, 130, 230, 310, and 450 horsepower.

Di-Ethyl Glycol concentrations in biodiesel additives are calculated to be 100, 150, 250, 325, and 475 parts per million. Because the oxygen in the fuel may provide additional oxygen to the production of NO, the oxygen level of biodiesel could result in a rise in NO emissions. This is because the oxygen in the fuel may provide additional oxygen to the production of NO.

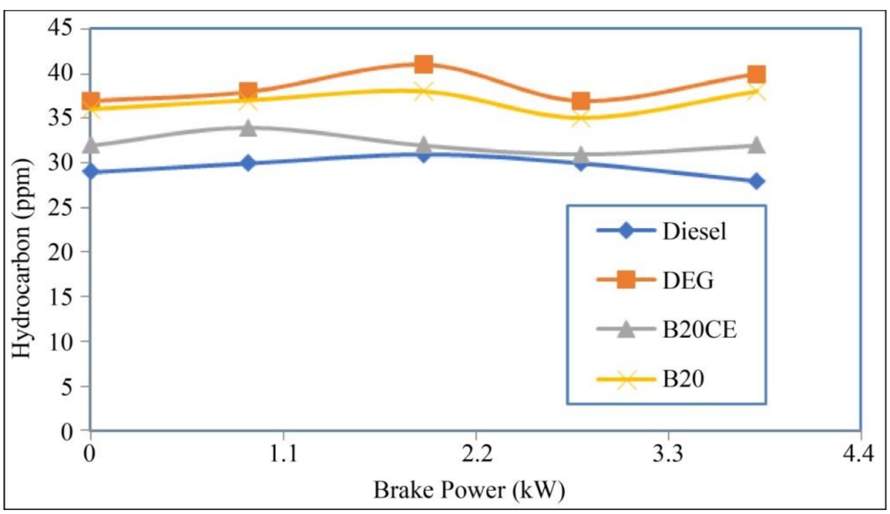

Fig. 10 HC emissions with BP

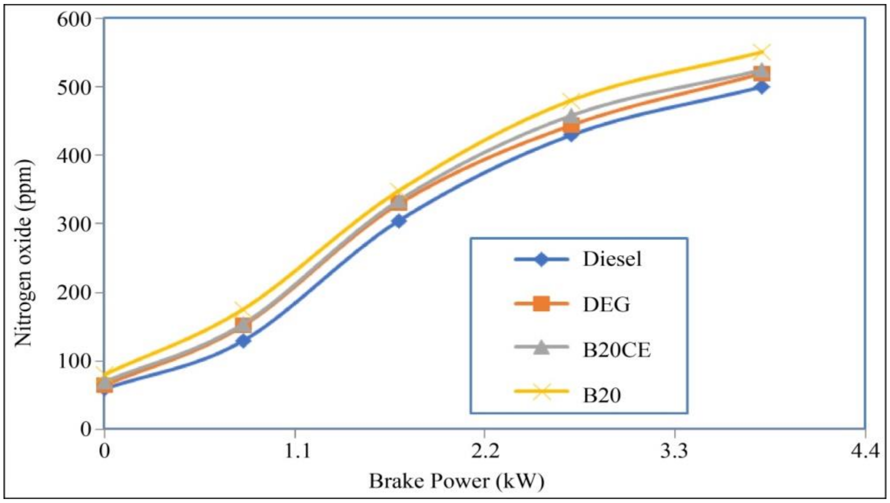

Fig. 11 NO emissions with BP

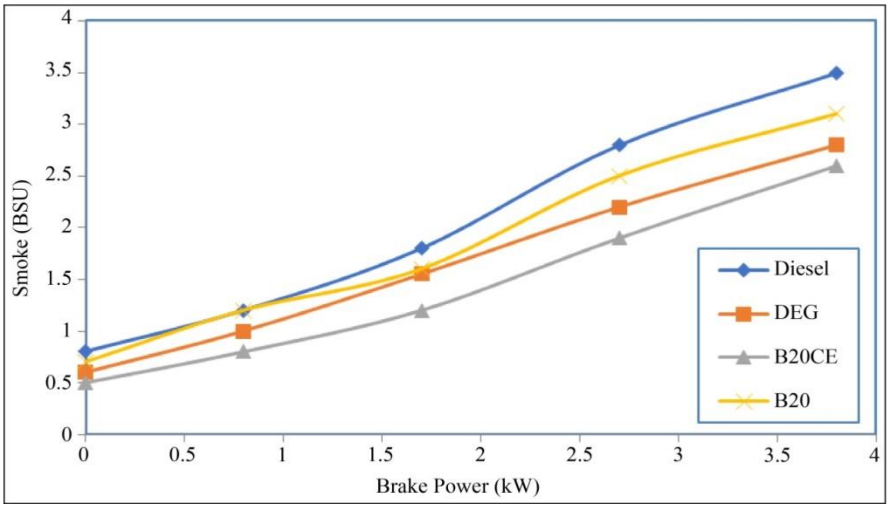

Fig. 12 Smoke emissions with BP

Figure 12 depicts the fluctuating smoke density of the engine. Di Ethyl Glycol and coated engines are foreseeable. The base engine would create more smoke than the lemongrass B20CE. This is due to a rise in temperature-holding gas and the combustion chamber wall.

The smoke densities for DEG and B20CE decreased from 3.2 BSU to 0.4 BSU and 3.4 BSU to 0.5 BSU, respectively. However, lemongrass oil biodiesel creates less smoke than diesel. Higher oxygen levels may account for the reduced smoke density of lemongrass oil Biodiesel. The normal diesel engine's smoke value ranges from 3.8 to 0.8 BSU.

4. Conclusion

This research work created a semi-adiabatic engine by coating the combustion chamber piston crown and cylinder head controllers with 0.5 mm of partially stabilized $La_2Ce_2O_7$. The results of this experimental investigation have led to the following conclusions.

- According to the study, the peak pressure for the DEG-infused biodiesel is 4 bar higher than that of B20 LGME and 1 bar lower than that of diesel fuel. For additive mixed LGME, the maximum and minimum peak pressure values are 60 bar and 55 bar.
- Regarding diesel, DEG has a heat release rate of 46 J/^{o}CA, coated engines B20CE have a rate of 44 J/^{o}CA, and LGME B20 have a rate of 42 J/^{o}CA. According to the experimental investigation, an additive mixed fuel engine's HRR increases by 2 J/^{o}CA while operating at full load.
- According to the study, B20 Lemon grass oil biodiesel has a brake thermal efficiency of 26%, DEG is 28%, coated engine B20CE is 27%, and diesel has a thermal efficiency of 29%.
- The BSFC value for coated engines B20CE ranges from a maximum of 0.63 kW-hr to a minimum of 0.28 kW-hr depending on the presence of Lemon grass oil biodiesel. Di-Ethyl Glycol is added as an addition, and the BSFC Value ranges from 0.65 kW-hr to 0.31 kW-hr. The LHR

engine's high oxygen molecule content and additive-mixed fuel are to blame.
- When we employed coated engines, the CO, CO_2, and HC emissions were greatly decreased. After adding DEG additives, a further drop in the readings was evident. However, the NO emission marginally increased by up to 10% compared to diesel engines.

$La_2Ce_2O_7$ ceramic coating was successfully applied in this investigation without requiring significant engine modifications.

It has been noted that a biodiesel engine with ceramic coating may have higher thermal efficiency. The study finds that adding DEG to coated engines improves thermal efficiency and reduces hazardous emissions.

4.1. Future Research

The following suggestions may progress the efficiency and reduction of the diesel engine emissions that use LGME as fuel.

- The effects of varying the compression ratio of an LGME diesel engine to improve its performance can be studied.
- Diesel engines using LGME can benefit from studying the effects of piston crowns coated with thermal barrier materials like Titanium Dioxide (TiO_2) and Phosphor Bronze (PSZ) on engine performance.

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