Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

Impact of Biodiesel Blends on Combustion and Endurance Characteristics of Diesel Engines

G. Balasubramanian[1] P. Balashanmugam[2] K. Kumaravel[3] S. Sivaprakasam[4]

[1]Asst. Professor/Research Scholar, Mechanical Engineering, Annamalai University, Annamalai nagar, Chidambaram, Tamil Nadu, India,*

[2]Associate Professor, Mechanical Engineering, Annamalai University, Annamalai nagar, Chidambaram, Tamil Nadu, India, [3]Associate Professor, Mechanical Engineering, Annamalai University, Annamalai nagar, Chidambaram, Tamil Nadu, India,

[4]Professor, Mechanical Engineering, Annamalai University, Annamalai nagar, Chidambaram, Tamil Nadu, India,

Abstract:- Biodiesel is a promising alternative fuel to run the automotive engine. However, its blends have not been properly investigated during idling as it is the main problem to run vehicles in a big city. In this study, the impact on CO, NOx and lubricating oil with various biodiesel blends was investigated to show the feasibility of biodiesel and various blends. The presence of more CO in exhaust gases indicates incomplete combustion. In terms of exhaust emissions, researchers agree that biodiesel produced fewer CO and NOx emissions in comparison with diesel fuel. Moreover, the reduction in emissions can be improved by optimizing the engine parameters such as engine speed and load. Accordingly, the research proposed the emissions of a diesel engine by using plastic pyrolytic oil, palm oil biodiesel and diesel. This discovered that CO emissions were reduced with increasing engine brake power at lower loads. However, the exhaust of NO_x emissions was still high with the use of biodiesel blends, mainly due to the oxygen content of biodiesel. NO_x formations are responsible for high oxygen content and high in-cylinder temperature. By controlling the engine load and ratio of biodiesel blends, NOx emissions can be maintained at a lower level. Combustion is one of the critical processes in engines that has a considerable on performance and emissions. The ignition delay, cylinder pressure, CD, and heat release rate are important parameters that indicate the efficiency of the combustion process. Combustion characteristics of biodiesel-butanol blends at different injection pressures are utilized in this study. Specifically, NO_x emissions are affected by combustion characteristics such as combustion duration (CD) and in-cylinder pressure. The increase in engine speed decreases the pressure due to the low burning rate of biodiesel during the ignition delay interval. The wear and friction mechanism was studied by analyzing the compositions and kinematic viscosities of the oil samples. . Engine performance, emission and combustion characteristics were investigated by operating the engine at full load conditions and varying engine speeds. The present work is implemented using Matlab software. Consequently, cylinder pressure is dependent on the combustion stage of fuel, so a higher calorific value will also give rise to higher cylinder pressure, and the combustion duration of the sample is improved.

***Keywords**:* Biodiesel Production, Blend Fuels, Plastic Pyrolytic Oil, Palm Oil Biodiesel, Diesel

1. Introduction

Technology advances are only one aspect of energy transitions, which are socio-technical processes. Energy transitions have a significant impact on society, the economy, and the environment, but their speed and scope are also influenced by social dynamics, such as how well-liked new technologies are. Despite this, with socioeconomic divides expanding globally, technocentric viewpoints have dominated transition discourses and social factors have frequently been ignored or instrumentalized. In light of this, initiatives have been made to make justice and equality the main emphasis of energy research [1-2]. Worldwide, the WHO estimates that excessive outdoor air pollution causes roughly seven million deaths each year. These estimated deaths are brought on by prolonged exposure to pollutant emissions that are harmful to human health. Common gaseous and particle pollutants that are extremely hazardous to human health at high exposure levels include hydrogen sulfide, ethyl benzene, ammonia, carbon monoxide, and others Optical damage, risk of stroke, cardiovascular disease, premature death, and morbidity are some of the serious diseases and health problems associated with the air pollution that people commonly experience [3-4]. And a wide variety of fuel uses have been documented in the transportation industry, where diesel serves as a "star fuel" to enable chemical energy to decompose and allow diesel energy to react more quickly to aid in power strokes [6].

Thus, search for substitute for diesel fuel, led many researchers to focus on bio-derived fuels. The development of biofuel from vegetable oils has also been influenced by the rising demand for alternative fuel due to the rapidly diminishing supply of petroleum diesel. The generation of biofuels from non-edible vegetable oils is favoured due to the greater cost of edible vegetable oils. Nowadays, there is virtually little study on using commercially available non-edible vegetable oils to replace petroleum diesel [5]. The fatty acid composition of the feedstock used in biodiesel production has a significant impact on the properties of biodiesel and its blends. Viscosity, density, heating value, flash point, and other physicochemical characteristics of biodiesel and its blends have a substantial impact on combustion behaviour, emissions and engine performance [14]. Additionally, biodiesel has poor cold-flow characteristics as fatty acid molecules may solidify and crystallize at low temperatures. In [7], mixing iso-butanol with biodiesel helped to address these flaws while also improving the fuel's characteristics. Renewable alcohols have been extensively studied as alternative fuels for diesel engines. One isomer of butanol that can be utilized as a partial alternative fuel for diesel engines is iso-butanol.

The lubricity of diesel-biodiesel blends with fuel additives (titanium dioxide (TiO2) and dimethyl carbonate (DMC)) and their impact on the tribological properties of a mineral lubricant were investigated and analyzed in [8]. Competitive, renewable, and environmentally benign biofuel technology is becoming widely embraced for sustainable development. Any type of fuel that obtains energy quickly from the biological carbon cycle is referred to as biofuel. E05B10 combination was created by adding 5% anhydrous ethanol to the ideal blend to increase biodiesel's use [9]. In [10], palm methyl ester (PME) and waste frying/cooking methyl ester (WFME) were produced by an alkali-catalyzed trans-esterification process, and the physicochemical characteristics of both the pure biodiesel and binary mixes between them were examined. In [10], waste frying/cooking methyl ester and palm methyl ester were produced utilizing an alkali-catalyzed trans-esterification technique and the physicochemical characteristics of the pure biodiesel as well as binary mixes between them were examined. Biofuels have been proposed as a technology aiding in the decarbonization of the sector, particularly in subsectors where scaling up electrification innovation is difficult. To provide insights and policy implications for future trajectories and decarbonization measures, [11] studies the historical evolution of the dominating regime transportation and the recent emergence of the biodiesel technical system using an integrated innovation systems framework.

In [12], a life cycle assessment was carried out in Malaysia to compare the greenhouse gas emissions of various forms of transportation, including buses, two-wheelers, and passenger automobiles with various types of powertrains. However, even without taking into account land use change, the greenhouse gas emissions of vehicles running on biodiesel are higher than those of vehicles running on gasoline. Four key production limitations are discussed in [13] for biodiesel as well as some sustainability standards for biodiesel. Water scarcity, food scarcity, feedstock availability, and crude oil pricing are the limiting variables. The model can predict changes in short-term energy security and emissions from light-duty diesel engines brought on by the use of biodiesel. To compare real-world emission rates and emission factors to those of petroleum diesel for three driving modes, namely low, medium, and high cruise speed, and transient conditions, experiments were conducted using a light-duty diesel vehicle filled with complete characterized 5%, 10%, and 20% volume ultra-low carbon intensity waste cooking oil biodiesel blends [15]. The impact on CO, NOx and lubricating oil with various biodiesel blends were investigated in this research to show the feasibility of biodiesel and various blends. By analyzing the compositions and kinematic viscosities of the oil samples, the wear and friction mechanism was studied. However, the engine performance, emission and combustion characteristics were investigated by operating the engine at full load conditions and varying engine speeds. The rest of the work is organized as follows, section 2 reveals the literature survey of the work, section 3 portrays the problem definition and motivation of the research, and section 4 illustrates the proposed research methodology. Section 5 exhibits the experimentation and result discussion, and section 6 portrays the research conclusion.

2. Literature survey

A study on the impact of biodiesel to diesel engine performance and emissions was given by Nghia *et al* [16]. With a simulation mode of 2200 (rev/min), at a rate of 25%, 50%, and 75% load, fossil diesel and biodiesel are blended with a replacement rate of 0% to 50%. The engine uses the least amount of fuel at these speeds. In particular, as the ratio of biodiesel mix grows, injection time tends to move closer to the top dead centre (TDC), propensity lower engine power, increase fuel consumption, and decrease CO and soot emissions. However, the increased usage of fossil fuels in the industry has resulted in pollution and climate change. As a result, Moringa oleifera biodiesel-diesel-carbon black water emulsion mixes are the subject of an investigation by Ramalingam *et al* [17]. The test was run on a typical diesel engine while under load. As standard diesel has identical combustion, emission, and performance properties to moringa oleifera carbon black water emulsion blends, these blends could aid in reducing air pollution without compromising engine performance, economy, or emissions.

Since there is a large demand for biodiesel production and this fuel has a higher production cost than ethanol, adding ethanol to the diesel/biodiesel blend to raise the renewable content of the additional fuel blend and decrease the amount of biodiesel could be a strategy. The performance and the composition of NOx, CO, and CO_2 exhaust emissions from a diesel engine running on blends of diesel, biodiesel, and ethanol were therefore investigated by Freitas *et al* [18]. However, in a vehicle application, this decline would only be noticeable at certain moments throughout the part-load regime, leading to significant losses in thermal efficiency. Puskar *et al* [19] analysed the effects of experimental diesel fuel mixtures containing varying amounts of bio-component on the unrestricted gaseous emissions produced by a diesel motor vehicle with a diesel engine using a direct fuel injection system as their main concern. The acquired results provide a complicated picture of how unrestricted emissions are produced based on operational circumstances and operational loading for the specified experimental engine.

By adopting a unique coordinated ultrasound-microwave reactor, Thakkar *et al.* [20] present an inventive single-step biodiesel synthesis method that is both energy-efficient and ecologically beneficial and avoids the oil extraction stage, which is a phase that consumes a lot of energy. For the in-situ generation of biodiesel, both regular and gamma-irradiated castor seeds are employed, and the optimal reaction conditions for each are determined using response surface methods. The adoption of Euro 5 fuel is desired because it is necessary to satisfy rising consumer demand and constrained government emission requirements. According to EU legislation, installing expensive special equipment is necessary to measure emissions. As a result, Sarwani *et al* [21] suggest a formula for converting volumetric emission % into specific emission (g/km).

Alternative fuels that can potentially reduce ICE emissions include biofuels made from renewable plant resources. Therefore, to support the use of various vegetable oils as a 10% ingredient in blended biofuel for diesel engines in commercial vehicles and agricultural machines [22]. Investigations were done on seven different vegetable oils. The fueling of a diesel engine using a blend of 90% petroleum diesel fuel and 10% vegetable oil has been used in experiments. The examination of currently available cutting-edge pollution control methods for reducing pollutant emissions while utilizing renewable, sustainable fuels in car tests as discussed [23]. This is carried out on a diesel demonstrator car that combines a 48V mild hybrid powertrain with dual-SCR and Lean NOx trap technology. To investigate the thermal performance of biodiesel extracts from used cottonseed oil for cooking mixed with diesel at 10%, 20%, and 30% by volume under various loading situations while maintaining a constant speed and compression ratio [24]. Additionally, it focuses on the combustion characteristics and emission metrics for biodiesel made from spent cottonseed cooking oil.

Patel *et al* [25] focused on the thermal, emission, and combustion performance of waste cotton seed biodiesel (WCOBD) blended in 10 and 20% by volume with diesel for a compression ratio of 17 at 1500 RPM engine speed. Under the same conditions, the engine was operated for a mixture of waste palm oil and waste cottonseed oil biodiesel blended with diesel, and the performance of both biodiesels was compared. In [26], the effects of the ethanol addition ratio on the spray, combustion, and emission performances of a diesel engine fuelled with biodiesel were investigated. A turbocharged common rail direct injection (CRDI) diesel engine was used to assess the combustion and emission performances while a high-speed camera and Malvern laser analysis were used to measure the spray characteristics.

3. Research Problem Definition and Motivation

Ever increasing drift of energy consumption due to the growth of population, transportation and luxurious lifestyle has motivated researchers to carry out research on biofuel as a sustainable alternative fuel for diesel engines. As the impetus to reduce diesel emissions continues, the need to develop more advanced or alternative-diesel fuels becomes more important. Two fuels that are being examined to meet these needs include biodiesel and ARCO Emission Control Diesel (EC-D). Biodiesel is renewable and can be produced domestically from sources such as vegetable oils, animal fats, restaurant grease, or other feedstocks. Several legislative measures have been passed promoting the increased use of biodiesel fuels, including a measure to allow fleets to meet alternative fuel vehicle acquisition requirements by using biodiesel added to conventional diesel at blends of 20% and higher. A wide range of feedstocks can be used for biodiesel production, with each type of feedstock introducing various social, economic, environmental, and technical challenges. Vegetable oils and animal fats are typically used in food production, and therefore useful in the fuel industry would encourage undesirable competition, referred to as the issue of “food vs. fuel”.

Other non-edible, algal or waste cooking oils (WCO) could be used; however, issues of affordability and ensuring sufficient supply to meet an ever-growing demand would need to be addressed. Impure feedstock such as WCO could potentially be both cheap and plentiful in supply, although high water and free fatty acid (FFA) content require resilient catalysts. In the literature, many studies have concentrated on investigating the effects of biodiesel and biodiesel blends on performance, combustion, and emission characteristics. The results obtained were attributed to adverse properties of biodiesel such as lower heating value, higher density and kinematic viscosity, and higher flash point in comparison with diesel fuel, resulting in poor atomization and combustion. In the mentioned approaches to improve engine performance and emission as using biodiesel, the use of additives and modified injection strategies are considered as efficient solution to enhance the fuel atomization and to promote the formation of a homogeneous mixture between biodiesel and compressed air, resulting in a more complete combustion process, thus increasing engine performance and reducing pollutant emissions.

4. Proposed Research Methodology

Two main aspects of the transportation industry are pollution of the environment and the depletion of fossil fuels. In the transportation industry, the pollution to the environment can be reduced with the use of cleaner fuel, such as gas-to-liquid fuel, to reduce exhaust emissions from engines. However, the depletion of fossil fuels is still significant. Biodiesel is a non-toxic, renewable, and biodegradable fuel that is considered an alternative resource to conventional diesel fuel. Even though biodiesel shows advantages as a renewable source, there are still minor drawbacks while operating in diesel engines. There is an urgent need to reduce global greenhouse gas emissions, yet to date, the decarbonization of the transportation industry has been slow and of particular difficulty. While fossil fuel replacements such as biodiesel may aid the transition to a less polluting society, production at the industrial scales required is currently heavily dependent on chemical catalysis. The core focus of the present investigation is on biodiesel production from industrial palm oil by applying a single-stage heterogeneous solid-catalyzed transesterification process to obtain a high yield of methyl ester.

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

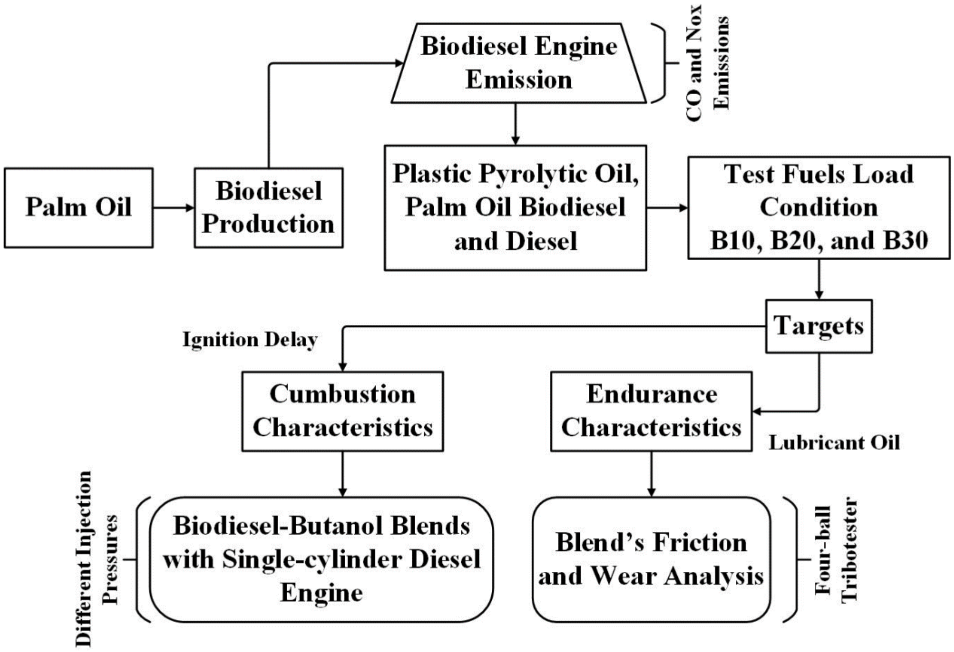

Figure 1: Flow Diagram of the Present Work

Figure 1 illustrates the flow diagram of the present work. To exhibit the feasibility of biodiesel and various blend, the research work studies the impact on carbon deposition and lubricating oil with various biodiesel blends. To explore the ignition and combustion characteristics, the research suggested biodiesel-butanol blends at different injection pressures. To explores the lubricant oil blend's endurance characteristics, the study analyses the wear and friction with the biodiesel derived from palm oil, waste cooking biodiesel-dieselblend, and Plastic Pyrolysis Oil (PPO).

4.1. Biodiesel Engine Emission

The presence of more CO in exhaust gases indicates incomplete combustion. In terms of exhaust emissions, researchers agree that biodiesel produced fewer CO and NO_x emissions in comparison with diesel fuel. The research proposed the emissions of a diesel engine by using plastic pyrolytic oil, palm oil biodiesel and diesel. The blends are made in three different percentages, B10, B20, and B30, and performed in the diesel engine with various engine loads of 0 to 4 kW. They discovered that CO emissions were reduced with increasing engine brake power at lower loads. NO_x emissions were measured in three distinct loads. In low-load conditions, argemone biodiesel and its blends emit less NO_x than diesel fuel. Increasing the percentage of biodiesel in the blends resulted in reduced HC emissions, and this is due to the high CN and oxygen concentration of biodiesel blends.

Materials

The palm oil was bought from Pakistan's local marketplace. High-speed diesel and other chemicals including methanol, sulfuric acid, KOH, and dimethyl carbonate (DMC) were obtained from the local vendors. The chemicals utilized in this research were of analytical grade.

4.1.1 Biodiesel Production and Characterization

Single-stage heterogeneous solid-catalyzed transesterification process was utilized for palm oil processing to attain palm biodiesel. Before the conversion of palm oil into palm biodiesel, the acid value of palm oil was checked, the acid value of crude palm oil was 2.8 mg KOH/g (i.e., the FFA value of 5.6%) which was not appropriate for biodiesel production through the single-stage heterogeneous solid catalyzed transesterification process. However, the FFA value of any oil greater than 1% and 2 mg KOH/g acid value is not suitable for the production of biodiesel. Acid value has been reduced in a process known as the acid esterification process. Mineral acid H_2SO_4 and methyl ester were used along with other operating parameters of reaction speed of 500 rpm, reaction temperature 57 ºC, and reaction time of 2 h. The quantity of methyl ester in the acid esterification process plays an important role, the quantity of methanol has been selected as 2.25 x FFA and H_2SO_4 as 0.05 x FFA.

The acid value and FFA value of palm oil were determined using equations (1) and (2).

$$Acid\ Value = \frac{56.1 \times N \times V}{W} \tag{1}$$

$$FFA = \frac{Acid\ Value}{2} \tag{2}$$

Where, N represents KOH normality, V represents KOH volume and utilized palm oil weight is represented by W. Also, distilled water was employed for titration purposes.

Two step acid esterification process was employed. In the first step, palm oil acid value was decreased by 1.345 and further reduced in the second step up to 0.339. The acid-treated palm oil was converted into palm biodiesel via a single-stage heterogeneous solid catalyzed transesterification process at operating conditions of catalyst (KOH) concentration of 0.75 wt%, methanol to oil ratio of 60 V/V %, the reaction time of 38 min, reaction temperature of 60 ºC and 59% duty cycle. The utilized catalyst amount of the transesterification process has been calculated via equation (3).

$$Amount\ catalyst\ used = \frac{Catalyst\ concentration \times weight\ of\ palm\ oil\ used}{100} \tag{3}$$

Homogenous catalyst KOH was mixed with methanol and then poured into acid-treated palm oil and the reaction was started at the given operation parameters. On reaction completion, the mixture was poured into a separating funnel and left for 10 h to settle down the impurities present in the mixture. The mixture was divided into two layers; the upper layer was biodiesel and the lower layer was glycerin. The lower layer has been removed from the separating funnel and the remaining biodiesel was washed via hot distilled water for remaining impurities eradication. Water content was removed via a rotary evaporator and methanol impurities from washed biodiesel were. In the end, Whatman filter paper was used to eradicate any traces of catalyst present in evaporated biodiesel. Biodiesel yield has been recognized as an important factor and it can be calculated using equation (4).

$$Biodiesel\ yield = \frac{Quantity\ of\ biodiesel\ produced}{weight\ of\ palm\ oil\ used} \times 100 \tag{4}$$

A gas chromatography-mass spectrum technique was employed for palm biodiesel composition determination. GCMS analysis showed palm biodiesel consists of long-chain fatty acids methyl esters as mentioned in table 1.

Table 1: Composition of Long-Chain Fatty Acid Methyl Esters

Name of FAME	Formula	Structure	% (PME)
Methyl Decanoate	C9H19COOCH3	C10:0	0.0000
Methyl Hexanoate	C5H11COOCH3	C6:0	0.0000
Methyl Linoleate	C17H31COOCH3	C18:2	7.757
Methyl Tetradecanoate	C13H27COOCH3	C14:0	1.0931
Methyl Octanoate	C7H15COOCH3	C8:0	0.0000
Methyl oleate	C17H33COOCH3	C18:1	41.3787
Methyl Octadecanoate	C17H35COOCH3	C18:0	4.3144

4.1.2 Biodiesel Blends

Different biodiesel blends were prepared for the analysis of the performance, emission and combustion characteristics of diesel engines. Among these blends, three blends were B10, B20, and B30 without antioxidants. The antioxidant used in biodiesel blends was dimethyl carbonate. These samples were performed in the diesel engine with various engine loads of 0 to 4 kW and stirring speeds for 30 min to make a homogenous blend. Important fuel properties of these fuel samples before engine testing were measured like kinematic viscosity, dynamic viscosity, density, flash point, acid value and calorific value.

4.2 Combustion Characteristics

Specifically, NO_x emissions are affected by combustion characteristics such as combustion duration (CD) and in-cylinder pressure. Additionally, engine load, engine speed, biodiesel oxygen concentration, and biodiesel CN all have an impact on biodiesel NO_x emissions. A higher biodiesel blend ratio will have higher in-cylinder pressure. Furthermore, the in-cylinder pressure is also influenced by the engine load and speed. The increase in engine speed decreases the pressure due to the low burning rate of biodiesel during the ignition delay interval. The objective of the investigation is to explore the ignition and combustion characteristics of biodiesel-butanol blends at different injection pressures. A single-cylinder diesel engine was set up to attain tri-fuel emulsions combustion characteristics. The combustion characteristics were investigated to obtain the in-cylinder pressure reading.

4.2.1 Single-Cylinder Diesel Engine Setup

The objective of the study was to investigate the combustion characteristics of tri-fuel emulsions with secondary atomization attributes known as the micro-explosion phenomenon. In this study, alternative fuel for CI engines called tri-fuel emulsions was prepared using Hielscher Ultrasonic Processor UP400S. Three different samples of tri-fuel emulsion, namely E5B5D90 (5% ethanol and 5% biodiesel), E10B10D80 (10% ethanol and 10% biodiesel), and E15B15D70 (15% ethanol and 15% biodiesel) were selected to be further investigated based on selection criteria which the same authors previously published. The schematic diagram of the single-cylinder CI engine is presented in figure 2.

Table 2: Basic Fuel Properties for Diesel, Biodiesel and Butanol and Ethanol

Fuel	Lower Heating Value (MJ/kg)	Density @20 ºC (kg/m3)	Viscosity @40 ºC (MPa s)	Flashpoint (ºC)	Cetane Number	Latent Heat at 25ºC (kJ/kg)
Ethanol	26.8	788	2.6	-	5-8	904
Butanol	33.1	808	2.63	35	25	582
Diesel	45.28	853.8	2.6	93	54.6	-
Biodiesel (PME)	41.3	867	4.53	165	67	-

However, a pressure transducer and crank angle encoder were used for combustion analysis. The relationship of the combustion pressure with that of the crank angle degree of the piston movement (pressure-crank angle degree) is provided by these two sensors. Digital data have been recorded in a computer by using a software name TFX engineering DAQ Combustion Analyzer. Alternative fuel like palm biodiesel and alcohol was bought from the local market. For the blending process of Alcohol (Butanol and Ethanol) with palm and diesel, the magnetic string process was used. The basic fuel properties of diesel, biodiesel, butanol and ethanol are shown in table 2. The engine was run mostly at room temperature with diesel fuel to maintain steady conditions and also run for a certain time to consume the alternative fuel from the remaining experiment which was conducted carefully and repeated 3 times. The experiment was conducted at room temperature.

4.3 Endurance Characteristics

In general, the endurance characteristics of an engine are determined by the lubricating oil, carbon deposits, and wear measurements of in-cylinder engine components. In terms of operation, the characteristic is to show the durability of an engine run on biodiesel. While diesel engines operated with biodiesel and blended fuel contributes to some findings, such as carbon deposition, lubricating oil dilution, deterioration, injector coking, fuel filter blockage, and engine wear issues. During the operation of the engine, the rate of dilution on lubricant with biodiesel was higher than diesel fuel due to the poor oxidation stability of the biodiesel, which increases lubricant viscosity. Subsequently, the study explores the lubricant oil blend's friction and wear with the biodiesel derived from palm oil, waste cooking biodiesel-diesel blend, and Plastic Pyrolysis Oil (PPO). Furthermore, the flash point of lubricant was decreased with the use of biodiesel mainly due to the increase in moisture content and free fatty acid. The test was conducted using a four-ball tribotester according to the ASTM D 4172.

4.3.1 Wear and Friction of Lubricant Oil Blends

The new steel balls, test-lubricant cup, and chuck assemblies were cleaned thoroughly with acetone and then rinsed with toluene to remove impurities and stained lubricant oil. The equipment was then wiped with tissue to ensure they were moisture-free. Three cleaned steel balls were placed in the test-lubricant cup and then locked with the nut at 68 ± 6m with a torque wrench. Another steel ball was placed into the ball chuck and mounted chuck into the chuck holder. The test fuel was poured into the cup until fully covered all three balls (approximately 10 mL). After that, the test-lubricant cup was assembled on the test apparatus to contact the fourth ball situated on the chuck holder. The experiments were conducted based on the Wear preventive characteristic of lubricating fluid (Four-ball method) according to ASTM D4172-94 with tests of 3600 s duration, at a temperature of 75 ◦C with a spindle speed of 1200 rpm and 40 kg for the load. After the test, the wear scar diameters of the three stationary balls were measured. The collected stationary balls were prepared for SEM and EDX analysis. For each set of test runs, four new steel balls were used.

4.3.2 Test Procedure

The proposed work is tested for frictional and wear evaluation, and flash temperature parameters. These evaluations are presented as follows.

Frictional and Wear Evaluation

The coefficient of friction was calculated by the multiplication of the mean friction torque and spring constant. Thus, the friction torque on the lower balls can be expressed as:

$$T = \frac{\mu \times 3W \times r}{\sqrt{6}} \rightarrow \mu = \frac{T\sqrt{6}}{3W \times r} \quad (5)$$

Where, μ is the coefficient of friction, r is the distance from the centre of the contact surface on the lower balls to the axis of rotation, which is 3.67 mm, T is the frictional torque in kg-mm; W is represented as applied load in kg. Then the wear scar diameter (WSD) was measured and analysed by DuCOM software with an installed image acquisition system.

Flash Temperature Parameter (FTP)

The flash temperature parameter is developed in terms of load, rotational speed and operating time using the response surface and design experiments.

Table 3: Test parameter for Four-Ball Wear Tests

Test Parameter	Unit	Value
Applied load	N	392
Rotation	rpm	1200
Fuel temperature	ºC	75
Test duration	s	3600

Table 4: Steel Ball Material

Steel ball	Unit	Description
Materials		Carbon-chromium steel (SKF)
Composition	%	10.2% C; 0.45% Si; 0.12% P; 0.07% S; 1.46% Cr; 0.42% Mn; 0.06% Ni; 2.15% Zn and 85.06% Fe

Diameter	mm	12.7
Hardness	HRc	62
Surface roughness	µm	0.1C.L.A

The FTP indicates the potential for lubricant film to break down. A high value of FTP indicates the high performance of the lubricant. For conditions existing in the four-ball test, the following formula is used:

$$FTP = \frac{W}{d^{1.4}} \tag{6}$$

Where, W is load in kg and d is mean wear scar diameter in mm which is represented in tables 3 and 4 for the test parameters and chemical composition of the steel ball.

4.4 Experimental Setup

The test was done Yanmar TF120M single-cylinder CI engine which was coupled with a positive displacement gear pump (model HGP-3A-F23) dynamometer. The idling condition (1200 RPM at low load was considered in this investigation. 5% and 20% (B10 and B20) blends of palm biodiesel with diesel and 20% of alcohols of butanol and ethanol (BU20 and E20) along with palm and diesel fuel have been used to run the engine. Also, to present the effect of idling, the engine was run at no load at low engine speed and measured data were compared with the diesel at idling condition.

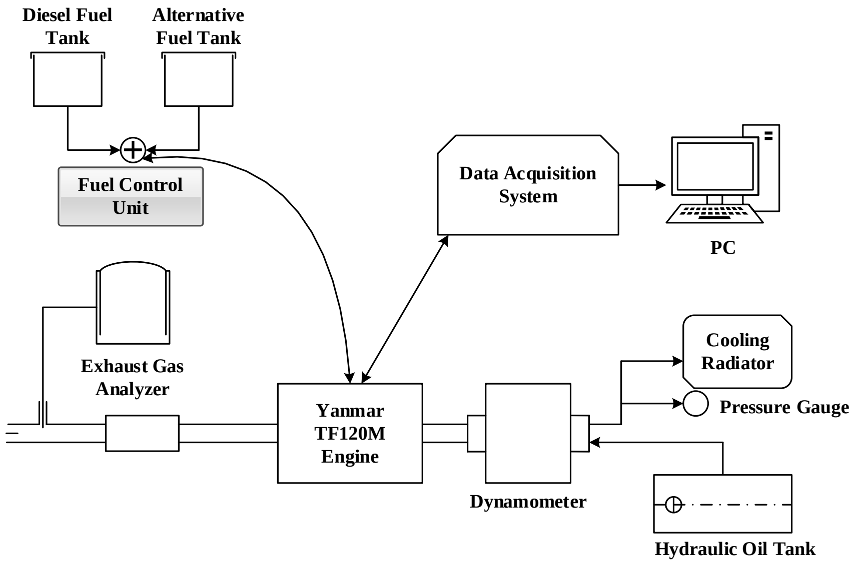

Figure 2: Schematic Diagram of the Diesel Engine

A schematic diagram of the utilized diesel engine is exhibited in figure 2 while the technical specifications of this engine are mentioned in table 5. Biodiesel blends were utilized to analyze engine performance characteristics. The fuel flow rate has been quantified by ascribing a graduate measuring cylinder along with the fuel tank.

Table 5: Specifications for Single Cylinder Engine

Description	Specifications
Engine model	TF120
Engine type	Horizontal, diesel 4 stroke
Combustion system	Direct injection
Number of cylinders	1
Bore x Stroke	92 mm x 96 mm
Displacement	0.638 L
Compression ratio	17.7:1

Maximum power	7.7 kW
Maximum engine speed	2400 rpm
Continuous output (HP)	10.5 HP at 2400 RPM
Rated output (HP)	12 HP at 2400 RPM
Cooling system	Radiator cooling

Engine performance characteristics including brake power, brake-specific fuel consumption, brake thermal efficiency and exhaust gas temperature, emission characteristics including carbon monoxide, unburned hydrocarbon and nitrogen oxide and combustion characteristics including in-cylinder pressure and heat release rate were investigated.

5. Experimentation and Result Discussion

Engine parameters such as high engine load and high engine speed reduce the HC emissions, which are implemented in MATLAB software. The simulation system configuration of the proposed work is portrayed in table 6. The proposed technique is evaluated and tested under the Matlab R2021a software. The proposed work operates under windows 10 home and its memory capacity is 6GB DDR3. Additionally, it utilizes an Intel Core i5 @ 3.5GHz processor and the simulation time of the work is 10.190 seconds.

Table 6: Simulation System Configuration

Simulation System Configuration	
MATLAB	Version R2021a
Operation System	Windows 10 Home
Memory Capacity	6GB DDR3
Processor	Intel Core i5 @ 3.5GHz
Simulation Time	10.190 seconds

Various emission characteristics like CO emissions and HC emissions are presented in the following results. However, the Indicated Mean Effective Pressure (IMEP), Coefficient of Variable (COV) of IMEP, Heat Release Rate (HRR), and Ignition delay were also analyzed.

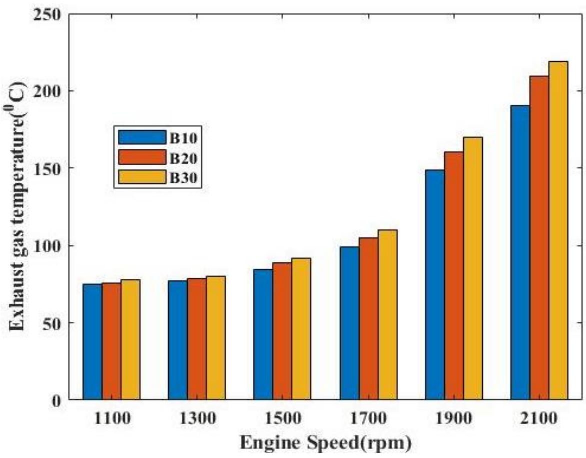

Figure 3: Exhaust Gas Temperature

Figure 3 represents Exhaust Gas Temperature (EGT) variation for different blends at various engine speeds along with full load conditions. Exhaust temperature is critical for combustion process indication and is a key factor of pollutant formation. Physicochemical characteristics including kinematic viscosity, density, and calorific value have a strong influence on EGT. According to observation, EGT values increase for all tested samples with increasing engine speeds. As the concentration of biodiesel increases, EGT tends to increase as well. The EGT reaches 75ºC, 76ºC, and 78ºC for blends B1, B2, and B3, when the engine speed is 1100 rpm. However, when the engine speed is 2100 rpm, the blend B1, B2, and B3 produce 190ºC, 210ºC, and 220ºC. This increment in EGT can be justified, due to the high viscosity of biodiesel blends which leads to poor atomization of fuel leading to the emergence of unburnt fuel in the premixed combustion phase in which they will continue to burn later in the diffusion combustion phase. Hence, the combustion of huge fuel amounts at one time will lead to higher EGT. However, the lower values of EGT represent the proper burning of biodiesel blends inside the compression ignition engine.

CO Emissions

CO is a toxic gas formed when incomplete combustion takes place in an engine when injected with any fuel. Several factors for the emission of CO are engine speed, air-fuel ratio, injection pressure and type of fuel used.

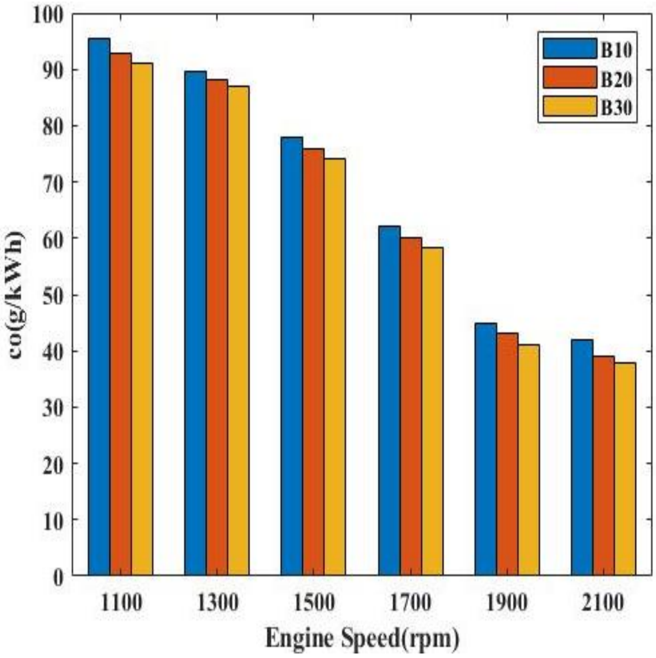

Figure 4: Effect of Engine Speed on CO Emissions

Figure 4 demonstrates CO emission variation when using different types of PME blends at varying engine speeds and full load conditions. It is observed for all samples that emissions of CO decrease with engine speed increment due to conversion rate increment of CO to CO2. At high engine speed both air to fuel ratio and combustion temperature inside the cylinder increase which escalates the conversion of CO to CO2. The CO emissions are also reduced with biodiesel concentration increments in biodiesel blends. Maximum values of CO emission for B10, B20, and B30 were recorded at 96, 93, and 91 g/kWh at 1100 rpm. The CO emissions are further reduced by increasing the speed of the engine. A significantly reduced CO emission was observed at 42, 39.5, and 38 g/kWh at 2100 rpm for B10, B20, and B30. All three biodiesel blends in the presence of DMC showed excellent CO emission decrement because of more oxygen content which leads toward complete combustion. The excess amount of oxygen in biodiesel blends and fuel additives tends to the oxidation of CO inside the combustion chamber which results in a reduction in CO emissions.

HC Emissions

HC emissions are dependent on fuel characteristics, engine operating parameters and atomization of fuel. HC emissions have been reduced with increasing engine speed and with increasing biodiesel concentration in blends.

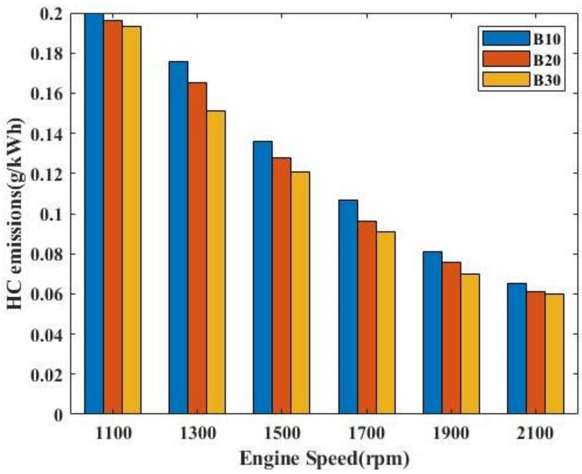

Figure 5: Graph for HC Emissions for Different Blends

Figure 5 denotes HC emission variations for different types of PME blends at varying engine speeds and full load conditions. The maximum values of HC emissions for B10, B20, and B30 were recorded as 0.2, 0.189, and 0.188 g/kWh respectively at 1100 rpm. Over the entire speed range from 1100 rpm to 2100 rpm, the average reduction of HC emissions for B10, B20, and B30 was observed as 0.063, 0.061, and 0.06 g/kWh, respectively. The main reason behind this significant HC emissions decrement is the higher oxygen content of biodiesel and oxygenated alcohol provided some good effects during the combustion process such as post-flame oxidation and higher flame speed which further enhances the oxidation of unburned HC. Furthermore, due to the high heat release rate and high temperature in the combustion chamber unburned hydrocarbons tends to oxidize.

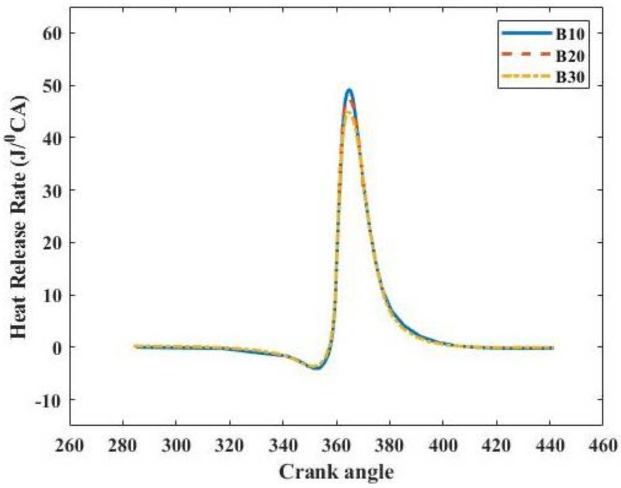

Figure 6: Heat Release Rate

Figure 6 demonstrates the heat release rate variation at varying engine speeds and full load conditions for biodiesel blends with and without antioxidants. From the graph data, it has been observed that the sample gives a higher peak heat release rate of 53.92 J/^{o}CA, 55.26 J/ ^{o}CA and 52.66 J/^{o}CA for B10, B20, and B30 respectively. Hence, it will further improve the calorific value of biodiesel. Since HRR is highly dependent on the calorific value of the sample as it is the rate at which the combustion process gives out energy, hence the sample with antioxidants will be higher. However, the SOC and EOC of samples added with antioxidants are close to each other. In other words, the combustion duration of the three samples becomes almost identical to each other. Consequently, it improves the combustion duration of the sample as well.

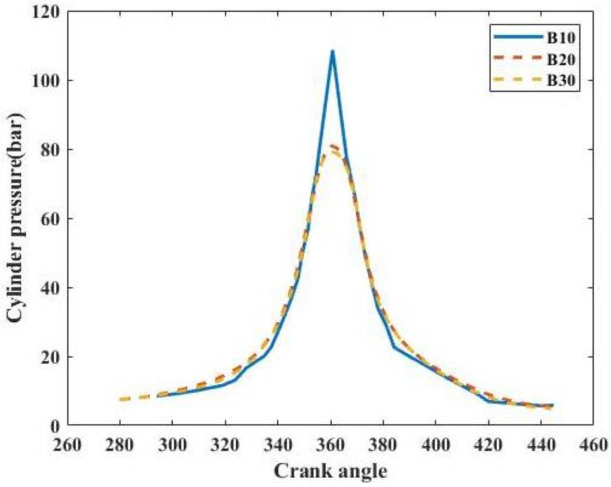

Figure 7: Variation in Cylinder Pressure for Different Biodiesel Blends

Figure 7 demonstrates in-cylinder pressure variation at varying engine speeds and full load conditions for biodiesel blends with and without antioxidants. The antioxidant used in this test is 10% DMC and is added to three samples (B10, B20 and B30). It has been observed that samples with antioxidants added to give a higher peak cylinder pressure at 109 bar, 80 bar and 79.5 bar for B10, B20, and B30 respectively. The reason for this raise in peak pressure is an oxygenated additive increasing the calorific value of PME blends when it is mixed together. A higher calorific value means the amount of heat produced from combustion will be higher as well. Since cylinder pressure is dependent on the combustion stage of fuel, so higher calorific value will also give rise to higher cylinder pressure.

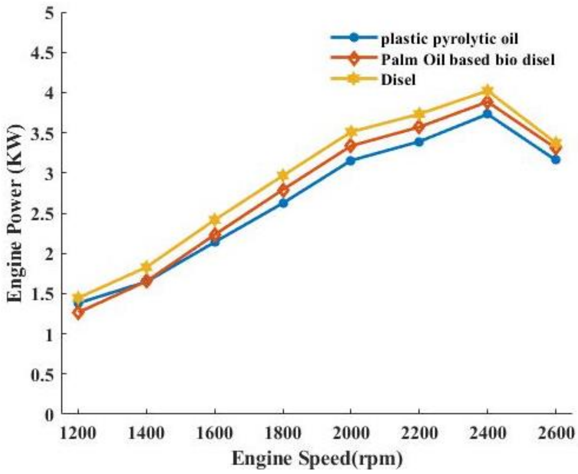

Figure 8: Variation of Engine Power to Engine Speed

Figure 8 shows the engine power fluctuation as a function of engine speed at full load. The power grows with rising engine speed until it reaches a maximum value, as indicated in the graph, and then falls with increasing engine speed. At the same time, engine power is increasing in response to the addition of biodiesel to the blend. The power increases initially when the biodiesel content in the mix is increased, reaches a maximum value, and then drops as the biodiesel percentage is increased further. Even though adding biodiesel to diesel reduces its heating value, more power was produced in the tests. There are several reasons for this. Firstly, biodiesel contains around 10% (by weight) oxygen, which may be utilized in combustion, especially in the fuel-rich zone. This might be the cause of more complete combustion, which would increase torque and power. Second, diesel fuel is poured volumetrically into the diesel engine cylinder, and the density of the plastic pyrolytic oil, and palm oil biodiesel is lower than that of diesel fuel. As a result, the engine receives a higher mass flow rate for the same fuel volume, resulting in increased torque and power. Meanwhile, the more viscous the blend, the less internal fuel pump leakage is visible. The torque and power are both increased as a result of this. The power rises with the addition of biodiesel content in the blend until it reaches a maximum value (4.01 kW) in the diesel. As the biodiesel concentration in the blend rises, the power falls below that of plastic pyrolytic oil (3.7 kW).

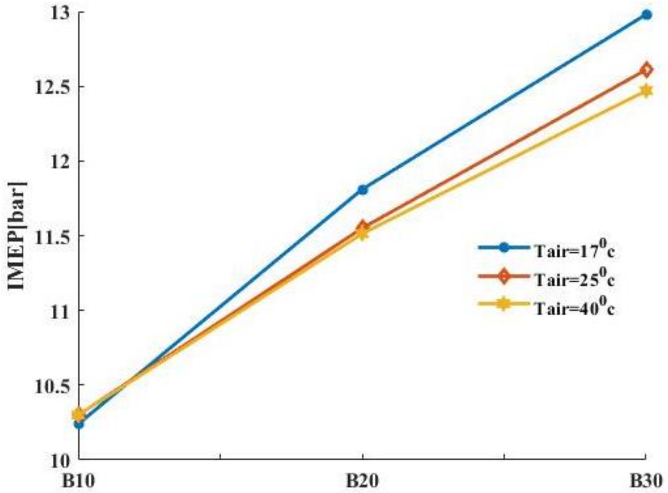

Figure 9: Indicated Mean Effective Pressure Graph VS Blend ratio

Figure 9 depicts the indicated mean effective pressure graph for the proposed method. The cycle-by-cycle variations are essential parameters for evaluating the combustion performance of spark-ignition engines. The CCV in the IMEP directly affects the drivability of an engine. It has been reported that an engine that is free of drivability has a COV in IMEP (COVIMEP) of < 3%. The IMEP exhibited for T_{air} as 17°C, 25°C, and 40°C, when the T_{air} is 17°C, the IMEP produces the highest values of 13 for B30, and 10.2 for B10. However, it produces the lowest values when the T_{air} is 40°C, ie. it produces 12.45 bar for B30, and 10.2 bar for B10, respectively.

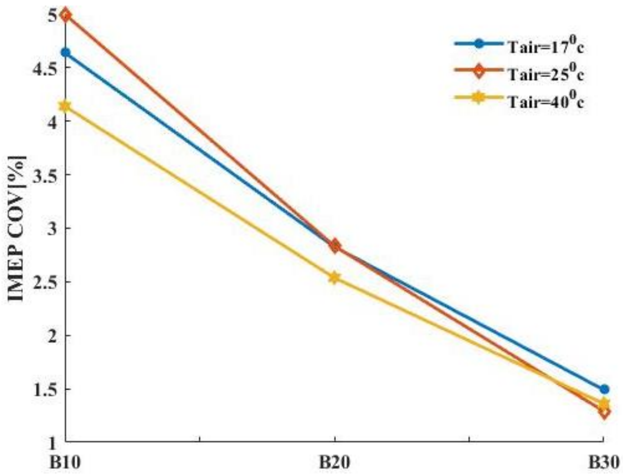

Figure 10: Coefficient of Variation for IMEP VS Blend ratio

Figure 10 reveals the COV graph for IMEP, it is measured for blend B10, B20, and B30 when $T_{air} = 17^{o}C, 25^{o}C, and\ 40^{o}C$. When T_{air} is 17°C and 25°C, the blend B10, B20, and B30 produces the highest values. For $T_{air} = 17^{o}C$, the blend B10, B20, and B30 has 4.7%, 2.8%, and 1.51%, however, when T_{air} is 25°C, the blend B10, B20, and B30 produces 5%, 2.8%, and 1.3%, respectively. Accordingly, when the T_{air} is 40°C, the COV produces a low value of 4.17%, 2.5%, and 1.43% for blends B10, B20, and B30, respectively.

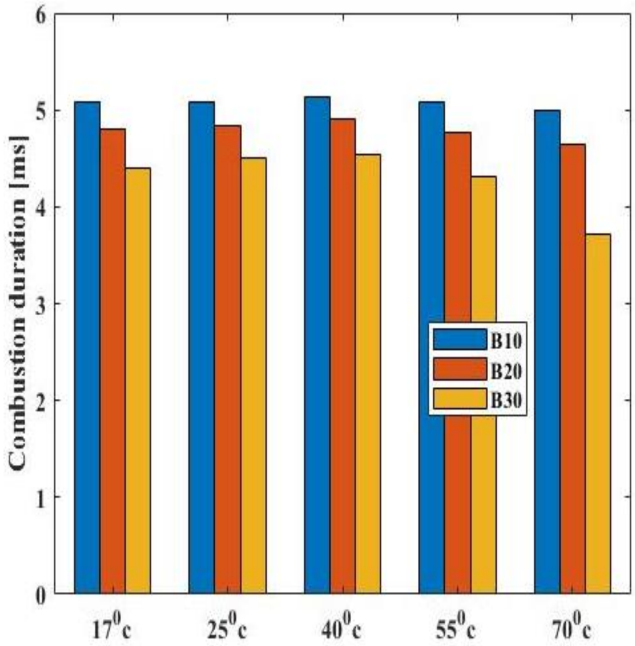

Figure 11: Combustion Duration Graph for Different Blends

The combustion duration graph for the proposed work is presented in figure 11. It is presented for different blends as B10, B20, and B30 at various air temperatures as 17°C, 25°C, 40°C, 55°C, and 70°C. The blend B10 produces higher combustion duration than the other blends. Accordingly, when the temperature is 17°C, the combustion duration for B10, B20, and B30 are 5.08 ms, 4.85 ms, and 4.4 ms. However, when the temperature is 70°C, the combustion durations for B10, B20, and B30 are 5 ms, 4.7 ms, and 3.8 ms, respectively.

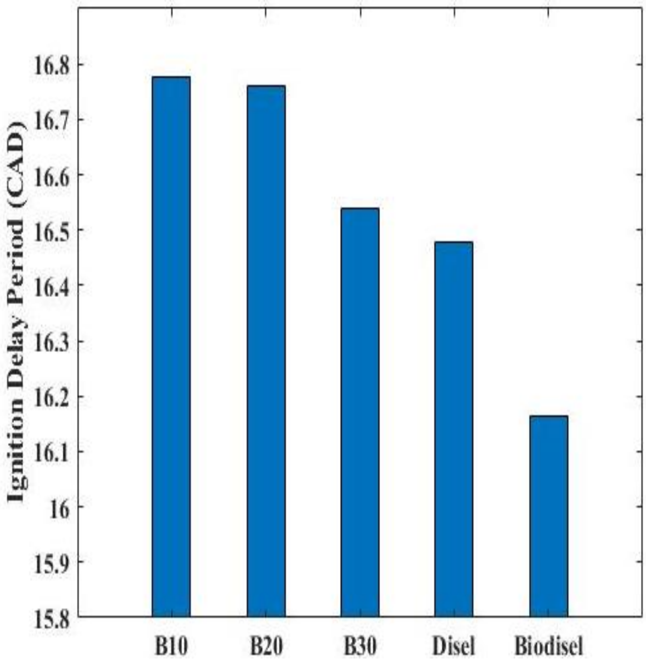

Figure 12: Ignition Delay Period Graph

Figure 12 illustrates the Ignition delay period of the different types of fuels under idling conditions. By definition, the ignition delay period is cumulated from the moment injection starts till the moment combustion begins to initiate. It is presented for B10, B20, B30, Diesel, and Biodiesel. It is widely accepted that volatile compound responds much faster than the rest during combustion and as a result, a shorter ignition delay value is produced for biodiesel.

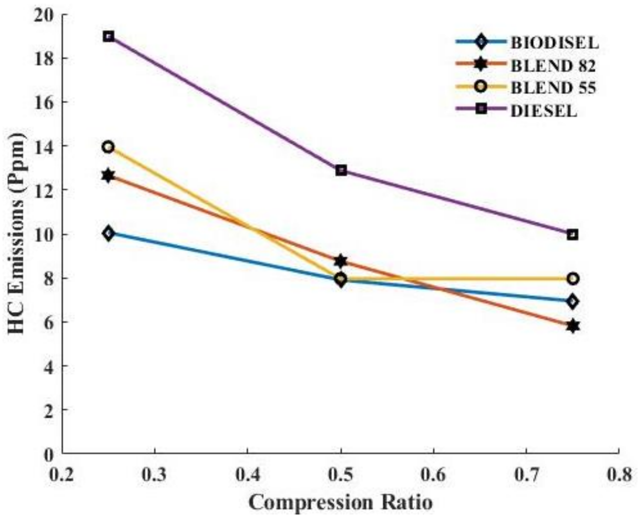

Figure 13: CO Emission Variation with Different Fuels

Figure 13 depicts the CO exhaust emission fluctuation for all fuels used in the experiment at various compression ratios and 50% load. Compared to the fuels used in existing work, biodiesel produces low HC emissions. When comparing all biodiesel blends to diesel, figure 1 demonstrates that CO emissions dropped as the compression ratio increased.

6. Research Conclusion

Biodiesel or biodiesel–diesel blend fuel is the current fuel used to power transportation engines. Contamination of lubricating oil is a common issue due to leakage or extensive use of engines. The research work studies the impact of biodiesel production from industrial palm oil by applying a single-stage heterogeneous solid-catalyzed process with a methyl ester. The study proposed the emissions of a diesel engine by using plastic pyrolytic oil, palm oil biodiesel and diesel. Increasing the percentage of biodiesel in the blends resulted in reduced HC emissions, and this is due to the high CN and oxygen concentration of biodiesel blends. The increase in engine speed decreases the pressure due to the low burning rate of biodiesel during the ignition delay interval. The objective of the investigation is to explore the ignition and combustion characteristics of biodiesel-butanol blends at different injection pressures. During the operation of the engine, the rate of dilution on lubricant with biodiesel was higher than diesel fuel due to the poor oxidation stability of the biodiesel, which increases lubricant viscosity. Subsequently, the study explores the lubricant oil blend’s friction and wear with the biodiesel derived from palm oil, waste cooking biodiesel-diesel blend, and plastic pyrolysis oil (PPO). The proposed work is implemented using the Matlab software and the findings as below.

- The EGT of the proposed work is 75ºC, 76ºC, and 78ºC for blends B1, B2, and B3, when the engine speed is 1100 rpm. However, the blends B1, B2, and B3 produce 190ºC, 210ºC, and 220ºC when the engine speed is 2100 rpm.
- Engine performance, emission and combustion characteristics were investigated by operating the engine at full load conditions and varying engine speeds from 1100 rpm to 2100 rpm.
- Minimum values of CO emission for B10, B20, and B30 were recorded at 42, 39.5, and 38 g/kWh at 2100 rpm. However, the minimum values of HC emissions for B10, B20, and B30 were recorded as 0.063, 0.061, and 0.06 g/kWh respectively at 2100 rpm.
- The heat release rate of the work is produced as 53.92 J/ºCA, 55.26 J/ ºCA and 52.66 J/ºCA for B10, B20, and B30 for the given samples, and it will further improve the calorific value of biodiesel.
- The COV of IMEP produces 5%, 2.8%, and 1.3% for blend B10, B20, and B30 during the $T_{air} = 25°C$.

Higher CN, oxygen content, and biodiesel blend percentage lead to improved combustion and, as a result, decreased HC emissions. The reduction in CO with biodiesel can be explained by a few factors: an increase in engine speed, high load conditions, more oxygen molecules, and less carbon content. Accordingly, the result found that fatty acid contained in the biodiesel and the low viscosity of biodiesel significantly reduced the frictional coefficient of the lubricating oil and worked as wear prevention. This study indicated that biodiesel produced from palm oil blended with B10, B20, and B30 shows better lubricity and can be used as an additive to biodiesel-based lubricants for better automotive engine performance, respectively.

References

[1] Rokhum, S.L., Agrawal, P. and Belkhode, P., 2022. Sustainability in Biofuel Production Technology. JohWiley & Sons.

[2] Dall-Orsoletta, A., Ferreira, P. and Dranka, G.G., 2022. Low-Carbon Technologies and Just EnergyTransition: Prospects for Electric Vehicles. Energy Conversion and Management: X, p.100271.

[3] Ogunkunle, O. and Ahmed, N.A., 2021. Overview of biodiesel combustion in mitigating the adverseimpacts of engine emissions on the sustainable human–environment scenario. Sustainability, 13(10), p.5465.

[4] Singh, T.S., Rajak, U., Verma, T.N., Nashine, P., Mehboob, H., Manokar, A.M. and Afzal, A., 2022. Exhaust emission characteristics study of light and heavy-duty diesel vehicles in India. Case Studies in Thermal Engineering, 29, p.101709.

[5] Balasubramanian, D., Hoang, A.T., Venugopal, I.P., Shanmugam, A., Gao, J. and Wongwuttanasatian, T., 2021. Numerical and experimental evaluation on the pooled effect of waste cooking oil biodiesel/diesel blends and exhaust gas recirculation in a twin-cylinder diesel engine. Fuel, 287, p.119815.

[6] Kanimozhi, B., Alsehli, M., Elfasakhany, A., Veeman, D., Balaji, S., Kumar, T.P. and Sekar, M., 2021. Effects of oxyhydrogen on the CI engine fueled with the biodiesel blends: A performance, combustion and emission characteristics study. International Journal of Hydrogen Energy.[7] Xiao, H., Guo, F., Wang, R., Yang, X., Li, S. and Ruan, J., 2020. Combustion performance and emissioncharacteristics of diesel engine fueled with iso-butanol/biodiesel blends. Fuel, 268, p.117387.

[8] Mujtaba, M.A., Masjuki, H.H., Kalam, M.A., Noor, F., Farooq, M., Ong, H.C., Gul, M.,Soudagar, M.E.M., Bashir, S., Rizwanul Fattah, I.M. and Razzaq, L., 2020. Effect of additivized biodiesel blends on diesel engine performance, emission, tribological characteristics, and lubricant tribology. Energies, 13(13), p.3375.

[9] Jagtap, S.P., Pawar, A.N. and Lahane, S., 2020. Improving the usability of biodiesel blend in low heat rejection diesel engine through combustion, performance and emission analysis. Renewable Energy, 155, pp.628-644.

[10] Çamur, H. and Alassi, E., 2021. Physicochemical Properties Enhancement of Biodiesel Synthesis from Various Feedstocks of Waste/Residential Vegetable Oils and Palm Oil. Energies, 14(16), p.4928.

[11] Nikas, A., Koasidis, K., Köberle, A.C., Kourtesi, G. and Doukas, H., 2022. A comparative study of biodiesel in Brazil and Argentina: An integrated system of innovation perspective. Renewable and Sustainable Energy Reviews, 156, p.112022.

[12] Kosai, S., Zakaria, S., Che, H.S., Hasanuzzaman, M., Rahim, N.A., Tan, C., Ahmad, R.D.R., Abbas, A.R., Nakano, K., Yamasue, E. and Woon, W.K., 2022. Estimation of Greenhouse Gas Emissions of Petrol, Biodiesel and Battery Electric Vehicles in Malaysia Based on Life Cycle Approach. Sustainability, 14(10), p.5783.

[13] Chong, C.T., Loe, T.Y., Wong, K.Y., Ashokkumar, V., Lam, S.S., Chong, W.T., Borrion, A., Tian, B. and Ng, J.H., 2021. Biodiesel sustainability: The global impact of potential biodiesel production on the energy–water–food (EWF) nexus. Environmental Technology & Innovation, 22, p.101408.

[14] Thakkar, K., Kachhwaha, S.S., Kodgire, P. and Srinivasan, S., 2021. Combustion investigation of ternary blend mixture of biodiesel/n-butanol/diesel: CI engine performance and emission control. Renewable and Sustainable Energy Reviews, 137, p.110468.

[15] Martínez-Martínez, S., de la Rosa-Urbalejo, D., Rua-Mojica, L.F., Hernández-Altamirano, R. and Mena-Cervantes, V.Y., 2022. Experimental analysis of real-world emissions using ultra-low carbon intensity biodiesel for a light-duty diesel vehicle in Monterrey metropolitan area. Fuel, 317, p.123408.

[16] Nghia, N.T., Khoa, N.X., Cho, W. and Lim, O., 2021. A study the effect of biodiesel blends and the injection timing on performance and emissions of common rail diesel engines. Energies, 15(1), p.242.

[17] Ramalingam, S., Dharmalingam, B., Deepakkumar, R. and Sriariyanun, M., 2022. Effect of Moringa oleifera biodiesel–diesel–carbon black water emulsion blends in diesel engine characteristics. Energy Reports, 8, pp.9598-9609.

[18] Freitas, E.S.D.C., Guarieiro, L.L.N., da Silva, M.V.I., Amparo, K.K.D.S., Machado, B.A.S., Guerreiro, E.T.D.A., de Jesus, J.F.C. and Torres, E.A., 2022. Emission and Performance Evaluation of a Diesel Engine Using Addition of Ethanol to Diesel/Biodiesel Fuel Blend. Energies, 15(9), p.2988.

[19] Puškár, M., Živčák, J., Král, Š., Kopas, M. and Lavčák, M., 2021. Analysis of Biodiesel Influence on Unregulated Gaseous Emissions of Diesel Motor Vehicles. Applied Sciences, 11(10), p.4646.

[20] Thakkar, K., 2022. Development of Process Intensive in-Situ Biodiesel Production Technique Using Non-Edible Oil Bearing Feedstock; Process Optimization and Performance Studies (Doctoral dissertation, Pandit Deendayal Energy University, Gandhinagar).

[21] Sarwani, M.K.I., Fawzi, M., Osman, S.A. and Yahya, W.J., 2022. Calculation of Specific Exhaust Emissions of Compression Ignition Engine Fueled by Palm Biodiesel Blend. Journal of Advanced Research in Applied Sciences and Engineering Technology, 27(1), pp.92-96.

[22] Markov, V., Kamaltdinov, V., Devyanin, S., Sa, B., Zherdev, A. and Furman, V., 2021. Investigation of the influence of different vegetable oils as a component of blended biofuel on performance and emission characteristics of a diesel engine for agricultural machinery and commercial vehicles. Resources, 10(8), p.74.

[23] Demuynck, J., Dauphin, R., Yugo, M., Mendoza Villafuerte, P. and Bosteels, D., 2021. Advanced Emission Controls and Sustainable Renewable Fuels for Low Pollutant and CO2 Emissions on a Diesel Passenger Car. Sustainability, 13(22), p.12711.

[24] Prajapati, P.A. and Sadanand, N., Thermal Performance Analysis for Single Cylinder Diesel Engine using Biodiesel from Waste cooking Cottonseed oil and Diesel.

[25] Patel, A., Comparative Assessment of Thermal, Emission and Combustion for Biodiesel Extracted from Waste Cottonseed Cooking Oil with a Mixture of Waste Palm Oil and Waste Cottonseed Oil Biodiesel.

[26] Geng, L., Bi, L., Li, Q., Chen, H. and Xie, Y., 2021. Experimental study on spray characteristics, combustion stability, and emission performance of a CRDI diesel engine operated with biodiesel–ethanol blends. Energy Reports, 7, pp.904-915.

[27] Kosai, S., Zakaria, S., Che, H.S., Hasanuzzaman, M., Rahim, N.A., Tan, C., Ahmad, R.D.R., Abbas, A.R., Nakano, K. and Yamasue, E., 2022. Estimation of Greenhouse Gas Emissions of Petrol, Biodiesel and Battery Electric Vehicles in Malaysia Based on Life Cycle Approach. Sustainability 2022, 14, 5783.