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Optimizing The Performance And Combustion Characteristics Of Single Cylinder LHR Based Diesel Engines Using Water Hyacinth Biofuel Blend

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Abstract
The growing demand for sustainable energy sources has prompted significant interest in biofuels as an alternative to conventional fossil fuels. Biofuels, derived from renewable organic materials, play a key role in reducing greenhouse gas emissions, promoting energy security, and supporting environmental sustainability. Among various biofuels, biodiesel blends, such as the water hyacinth B20D80 blend, have garnered attention due to their potential for improving engine performance while reducing dependence on fossil fuels. This study examines the impact of zirconia-based coatings on pistons in Low Heat Rejection (LHR) engines, focusing on their effects on performance and combustion characteristics when using the water hyacinth B20D80 biodiesel blend. The results show that the zirconia coating enhances thermal efficiency by minimizing heat loss, leading to improved energy retention within the engine. This reduction in heat dissipation results in better combustion characteristics, including more stable and complete fuel combustion. As a result, the engine demonstrates higher power output, more efficient fuel utilization, and reduced emissions. These findings highlight that zirconia-coated pistons in LHR engines significantly optimize performance and combustion efficiency when using the water hyacinth B20D80 blend, presenting a promising solution for enhancing engine performance with biofuels and contributing to sustainable energy solutions.
Key Words: LHR Engine, Water Hyacinth, Thermal Barrier Coating, Biofuel Blend and Automobile IC Engine.

1. INTRODUCTION.

Alternative fuels for internal combustion engines are the subject of extensive study due to the growing need for sustainable energy sources. Engines with low heat rejection (LHR) have become a potential technology to increase efficiency and lower emissions, especially when paired with mixes of biodiesel. The potential of water hyacinth, a plentiful biomass resource, as a feedstock for renewable biofuels has drawn interest. The goal of this project is to employ water hyacinth biofuel blends to optimize the performance and emission characteristics of a single-cylinder LHR diesel engine. The literature reviews that follow provide light on important facets of this study.

Mathur et al. (2022) emphasize how biomass, solar, wind, and biofuels may lessen reliance on fossil fuels and greenhouse gas emissions. The report highlights the technical obstacles, governmental assistance, and economic viability of widespread biofuel usage. Energy security may be improved by combining sustainable farming methods with alternative energies. This viewpoint encourages the use of water hyacinth biodiesel as a sustainable fuel [1].

According to Powar et al. (2022), microalgae's high oil output and capacity for carbon sequestration make it a viable biofuel. The research investigates engine combustion of biodiesel, lipid extraction, and cultivation. Scalability and manufacturing costs are obstacles that call for optimization techniques. Like algae, water hyacinth is a plentiful resource that has the potential to produce biofuel but has to be evaluated for economic feasibility [2]

Wiatrowski and Davis 2023 examine CAP for the generation of biofuel by combining fermentation, catalytic upgrading, and lipid extraction. Coproducts like polyurethane increase the economic viability of algae-based fuels, notwithstanding their continued high cost. A similar strategy may be used by water hyacinth biofuels, which would use coproducts to improve sustainability [3]

Using safflower biodiesel, Senthil et al. (2023) investigate the effects of EGR on an LHR engine, obtaining increased brake thermal efficiency and a decrease in NOx. The results demonstrate how well biodiesel and EGR combos reduce emissions. EGR may have comparable advantages when added to water hyacinth biodiesel blends [4]

The use of sunflower biodiesel in a turbocharged LHR engine with ceramic coatings is investigated by Has-imoglu et al. (2008). Transesterification was shown to improve fuel qualities and reduce pollutants. The research confirms the viability of water hyacinth biodiesel and supports the potential of biodiesel in LHR engines [5]

Paparao et al. 2023 demonstrate that oxy-hydrogen addition to biodiesel improves efficiency and reduces emissions. The study confirms that alternative fuels can enhance LHR engine performance. Investigating water hyacinth biodiesel with similar optimization techniques could further improve combustion efficiency [6]

According to Büyükkaya et al. (2006), ceramic coatings use improved injection timing to lower fuel consumption and NOx emissions.g. These results support LHR adjustments for biodiesel engines.s. Adding thermal barrier coatings to an engine that runs on water hyacinth biodiesel might increase efficiency.ns [7]. According to Ellappan et al. (2024), biodiesel blends with additives have improved efficiency and decreased emissions—with the exception of NOx. The research emphasizes the need of NOx management techniques for LHR engines powered by biodiesel. Similar NOx mitigation strategies could be needed for water hyacinth biodiesel blends [8]. According to Davies et al. (2013), water hyacinth briquettes have competitive combustion qualities when compared to traditional fuels. The findings support the feasibility of using water hyacinth as a substitute energy source. Its use as biodiesel might provide diesel engines a sustainable fuel source [9]

The cost-effectiveness of turning water hyacinth into bioethanol, biomethane, and biogas is discussed by Bote et al. 2020. The results demonstrate the plant's viability for use as biofuel. These observations are supported by research on its biodiesel potential in LHR engines [10]. Rezania et al. (2015) investigate the use of water hyacinth in wastewater treatment, biomass production, and biofuel generation. The research emphasizes how beneficial it is for the environment. Water hyacinth biodiesel promotes ecological sustainability in addition to being a renewable fuel [11]. In their 2019 study, Alagu et al. tested water hyacinth biodiesel in diesel engines and found that it lowered CO and hydrocarbon emissions while slightly increasing NOx emissions. This confirms that it may be used as a renewable fuel to optimize LHR engines [12]

Efficiency gains in a dual-fuel engine powered by hydrogen and water hyacinth biodiesel are shown by Bora et al. in 2023. Combining water hyacinth biodiesel with cutting-edge fuel technology may further optimize LHR engine performance, as seen by lower emissions and improved performance [13]. The economic viability of algae-based biofuels is examined by Wiatrowski et al. in 2022, with a focus on coproducts to offset expenses. Similar strategies might increase the marketing potential of water hyacinth biodiesel [14]

The effect of partly stabilized zirconia (PSZ) coatings on an ethanol-fueled direct-injection diesel engine was investigated by Balu et al. in 2021. When compared to a normal engine, the LHR engine showed a 30.18% boost in brake thermal efficiency. There were notable decreases in smoke opacity (8.33%), unburnt hydrocarbons (UBHC) (13.33%), and CO (24.8%). However, because of higher combustion temperatures, NOx emissions rose by 15.46%. The results back up using ethanol in LHR engines as a substitute fuel to increase efficiency and reduce pollution [15]. Solomon et al. (2021) used biodiesel made from leftover cooking oil to assess the performance of LHR engines. In tests, yttrium-stabilized zirconia (YSZ) coatings of different thicknesses (30μm, 40μm, and 60μm) produced the best results. In comparison to traditional diesel, the B20 biodiesel mix reduced NOx emissions and increased brake thermal efficiency. However, because of incomplete combustion, higher mixes (B50, B100) produced larger emissions of HC and CO. This research demonstrates how well LHR technology works to optimize engines that run on biodiesel [16]

The effects of Albizia lebbeck (AL) leaf extract as a natural additive in an LHR engine running on jamun biodiesel were examined by Ramalingam et al. in 2024. LHR technology increased NOx emissions even if it boosted combustion efficiency. According to the research, AL leaf extract decreased NOx emissions by 27% and also decreased emissions of smoke, hydrocarbons (HC), and carbon monoxide (CO). The results indicate that the performance of biodiesel engines may be improved while hazardous emissions are reduced by combining LHR technology with natural additives [17]. In 2022, Sarathbabu and Kannan investigated the combined impacts of Low Heat Rejection (LHR) and Low-Temperature Combustion (LTC) on a diesel engine that runs on biodiesel blends. Combustion efficiency was improved by the use of alumina-coated engine components and exhaust gas recirculation (EGR). The study found that brake thermal efficiency (BTE) increased by 3.48% and specific fuel consumption (SFC) decreased by 6.29%. The LTC strategy was able to effectively lower emissions despite a 1.2% increase in NOx. This research highlights how integrating LHR and LTC technologies might enhance fuel efficiency and pollution management [18]

The effect of thermal barrier coatings (TBC) on a six-cylinder turbocharged diesel engine was examined by Büyükaya et al. in 2006. Magnesium zirconate ($MgZrO_3$) was applied to the pistons, while calcium zirconate ($CaZrO_3$) was applied to the cylinder head and valves. The research discovered a 9% rise in NOx emissions and a 1–8% decrease in brake-specific fuel consumption (BSFC). Delaying injection time from 20° BTDC to 16° BTDC, however, decreased particle emissions by 40% and NOx emissions by 26%. This study emphasizes how TBC and injection timing modifications might improve fuel economy and emissions management [19].

Engine performance and combustion properties might be greatly improved by combining LHR technology with other biofuels, including water hyacinth biodiesel. Studies on LHR engines have shown better combustion, reduced fuel consumption, and increased brake thermal efficiency. utilizing knowledge from current developments in the area, this research attempts to maximize the performance and combustion properties of a single-cylinder LHR diesel engine utilizing a water hyacinth biofuel mix.

2. MATERIALS AND METHODS.

2.1 Materials:

An Eddy Current Dynamometer uses eddy currents created in a rotor to measure the torque, speed, and power of a rotating shaft. For high-speed applications, this non-contact measuring technique is precise and minimizes wear and tear. By shining a beam into the smoke and estimating the decrease in light transmission, a smoke meter determines the density or opacity of smoke. The amount of particulate matter in smoke is indicated by an electrical signal that is produced by the smoke meter's sensor from the light measurement. An emission analyzer uses a sampling method to quantify contaminants in exhaust gases, filters the sample to eliminate particulate matter, and uses a variety of sensors and detectors to evaluate the gas. Based on sensor data, the analyzer determines pollutant concentrations and presents the findings in quantities like ppm, mg/m^3, or %. The emission analyzer helps monitor and regulate emissions from automobiles, industrial operations, and other sources. Its operation is based on the identification of certain contaminants. Temperature, pressure, and gas composition are all measured by sensors in a combustion analyzer equipped with a Data Acquisition (DAQ) system. In order to compute combustion parameters such as air-fuel ratio, combustion efficiency, and emissions, the DAQ system gathers and analyzes data, transforming analog signals from sensors into digital data and evaluating it using software. By facilitating precise and trustworthy data collection and analysis, the DAQ system aids in the optimization of combustion processes in boilers, furnaces, and engines. Usually constructed of fiberglass, plastic, or metal, a fuel tank holds gasoline for engines, generators, and other devices. It has a venting mechanism to avoid pressure buildup, is poured into the tank by a fuel intake, and is tracked by a fuel gauge or float sensor. An engine control unit (ECU) regulates a fuel pump, which takes gasoline from the tank and delivers it to the engine. The fuel tank operates on the basis of a fuel supply that is either gravity-fed or pump-assisted. Engine cylinder exhaust gases are collected by an exhaust manifold, which then channels them into the exhaust system and away from the engine. The manifold, which is attached to the muffler and catalytic converter, is essential to preserving engine performance and cutting emissions.

By bringing air into the cylinder via the intake valve, compressing it with the piston, producing high pressure and heat, and then injecting fuel into the cylinder, a diesel engine employs compression ignition to burn fuel. High efficiency and torque are achieved via the engine's camshaft, which controls the intake and exhaust valves.

2.2 METHODS:

Using eddy currents created in a rotor within a magnetic field, an Eddy Current Dynamometer provides precise, non-contact measurements of torque, speed, and power. By detecting light transmission through exhaust gases, a smoke meter calculates the density or opacity of smoke, aiding in the evaluation of emissions and air quality. The Emission Analyzer uses sensors based on infrared absorption, chemiluminescence, and electrochemistry to collect and analyze exhaust gases for pollutants such CO, HC, NOx, and O_2. Using sensors to detect temperature, pressure, and gas composition, a combustion analyzer with DAQ monitors emissions and combustion efficiency in real time. With a gauge, venting system, and pump for a regulated supply to the engine, the fuel tank securely holds gasoline. By gathering and directing engine cylinder gasses, the exhaust manifold lowers backpressure and boosts efficiency. Compression ignition powers a diesel engine by injecting gasoline into very compressed air, which ignites on its own to power the crankshaft and piston. Eddy current probes are used to detect torque and speed; frequency denotes speed, while the amplitude of induced currents determines torque. The Smoke Meter analyzes opacity using the light extinction technique, which is based on the decrease of transmitted light. Emission analyzers ensure regulatory compliance by detecting particular contaminants. For process optimization, the Combustion Analyzer computes variables such heat losses and the air-fuel ratio. To effectively measure fuel levels, float sensors or electronic gauges are used. The exhaust manifold directs gases to the catalytic converter and muffler, which helps to lower noise and pollutants. Finally, compression ignition gives diesel engines their great efficiency and torque, which makes them perfect for heavy-duty applications. However, we have just utilized the configuration for performance and combustion characteristics in our experimental study.

3. Experimental Setup and Methodology

3.1 Engine Specifications and Test Fuels

Since a four-stroke, single-cylinder, air-cooled diesel engine is often used in both industrial and agricultural applications, it was selected for performance evaluation. Accurate power output and efficiency measurements were made possible by the engine's connection to an eddy current dynamometer. The experiment made use of the test fuels listed below. Pure diesel, or D100, serves as a standard by which all other diesel is measured. WH10, WH20, and WH30 are a blend of 90% diesel and 10% water hyacinth biodiesel (WHB), 80% fuel and 20% water hyacinth biodiesel, and 70% diesel and 30% water hyacinth biodiesel, respectively. Each fuel mixture was made by carefully balancing ordinary diesel with water hyacinth biodiesel. Prior to testing, key fuel properties such density, viscosity, calorific value, and cetane number were assessed to ensure consistency and reliability.

3.2 Diagram of the Experimental Configuration

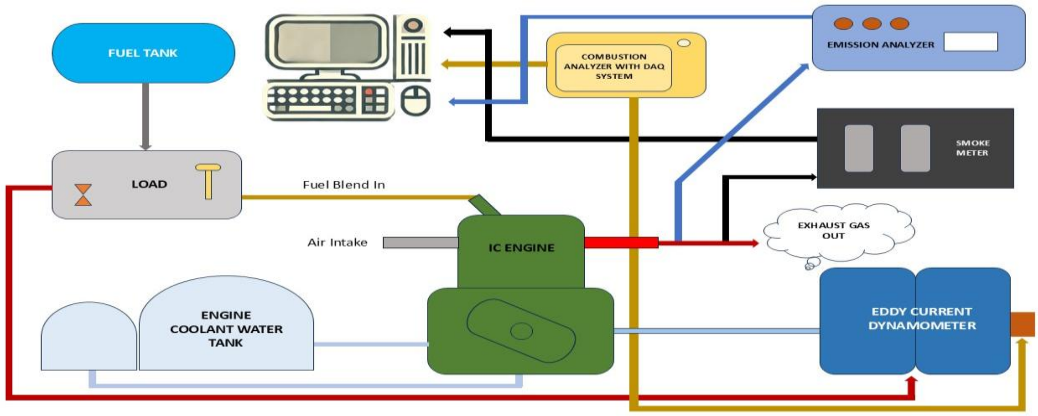

Fig 1. Experimental setup work

The experimental setup had many essential components needed to evaluate emissions and performance, As shown in Figure1. System of Fuel Supply Each blend was given its own gasoline tank to ensure smooth transitions between fuel types during testing. A fuel flow meter was included into the system to monitor gasoline use in real time. System of Air Intake and Exhaust The engine's air intake manifold regulated the ambient air supply for combustion. In order to measure contaminants, exhaust gases were collected via the exhaust manifold and transmitted to an emission analyzer. System for Combustion Analysis A combustion analyzer recorded real-time data on ignition delay, heat release rate, and cylinder pressure to provide information on each fuel mix's combustion characteristics. Unit of Emission Measurement An exhaust gas analyzer was used to measure the concentrations of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and carbon dioxide (CO_2) in the exhaust gases. Engine Loading System An eddy current dynamometer provided the engine with controlled loads in order to monitor torque and braking power (BP) under different operating conditions. Cooling and Lubrication System To prevent overheating, a water-cooled heat exchanger was used to regulate the engine's temperature. Engine oil levels and conditions were routinely monitored in order to minimize wear and ensure smooth operation.

3.3 Method of Testing

The engine testing was carried out in a controlled laboratory environment using the successive steps listed below.

Step 1: The engine was initially warmed up to achieve steady-state operating conditions by running on pure diesel (D100) for ten minutes.

Step 2: Fuel Blend Testing After that, the WH10, WH20, and WH30 blends were introduced one at a time to test the engine. After every new fuel mix, the engine was allowed five minutes to settle before data collecting began.

Step 3: Compiling Performance Data For each fuel blend, performance data was recorded at various engine loads (0%, 25%, 50%, 75%, and 100%). one of the crucial characteristics evaluated.

• Brake Power (BP): Determined by the dynamometer's torque sensor. Brake specific fuel consumption, or BSFC, is determined by the engine power output and fuel flow rate. breaking the engine's, braking force and the fuel's calorific value determine thermal efficiency, or BTE.

Step 4: Evaluation and the collected data were averaged across several test runs in order to improve accuracy and decrease measurement errors. Performance trends were investigated in order to assess how water hyacinth biodiesel mixing affected engine efficiency, fuel economy, and emission characteristics.

4 RESULT AND DISCUSSION

The study's findings on combustion characteristics provide important new information on the fuel's efficiency profile in different scenarios. With the use of the LHR Coated single cylinder diesel engine, the study demonstrates that improved fuel usage results from higher combustion efficiency as the temperature of combustion rises. The significance of improving combustion characteristics, such as the air-to-fuel ratio, is emphasized throughout the debate. Furthermore, the research indicates that sophisticated combustion methods like exhaust gas recirculation and staged combustion may be able to improve fuel economy while reducing the negative environmental consequences

4.1 Brake Thermal Efficiency (BTE).

The ratio of an engine's usable work output, or braking power, to the total energy provided by the fuel is known as brake thermal efficiency, or BTE. It is a crucial performance indicator for assessing internal combustion engines' efficiency. For all fuels, BTE rises with BP, indicating increased efficiency at larger loads. The greatest BTE is found in diesel, which is followed by B10, B20, and B30.B20 closely follows diesel efficiency, outperforming B10 and B30. The B30 consumes more gasoline since it displays the lowest BTE. The most efficient fuel is still diesel, but B20 provides an excellent balance between sustainability and efficiency. Because of its higher viscosity and lower calorific value, B30 has the lowest efficiency. Figure 2 illustrates that, when compared to diesel, the B20 mix offers near-diesel performance with the least amount of efficiency loss.

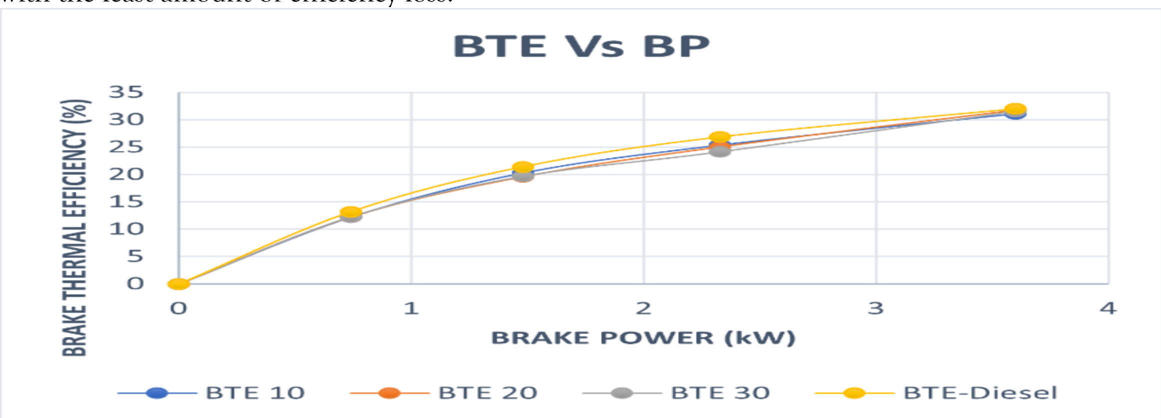

Fig 2. BTE of B20D80 Water Hyacinth Blend

The quantity of gasoline used to generate a given amount of power over a given length of time is known as specific fuel consumption, or SFC, and it serves as a gauge of an engine's fuel efficiency. For engines, it is often stated in grams per kilowatt-hour (g/kWh) units. Figure 3 Shows Better fuel economy is shown by lower SFC values, which signify that less fuel is needed to generate a given amount of power. Diesel is the most efficient, as shown by its lowest SFC. With just a little gain in SFC, B10 and B20 come in close behind. The largest SFC is shown by B30, indicating a decrease in efficiency as a result of its reduced calorific value. When it comes to energy use, diesel is still the most efficient fuel. B10 and B20 are good substitutes because of their encouraging efficiency. Because it uses more gasoline per unit of power output, the B30 is the least efficient.

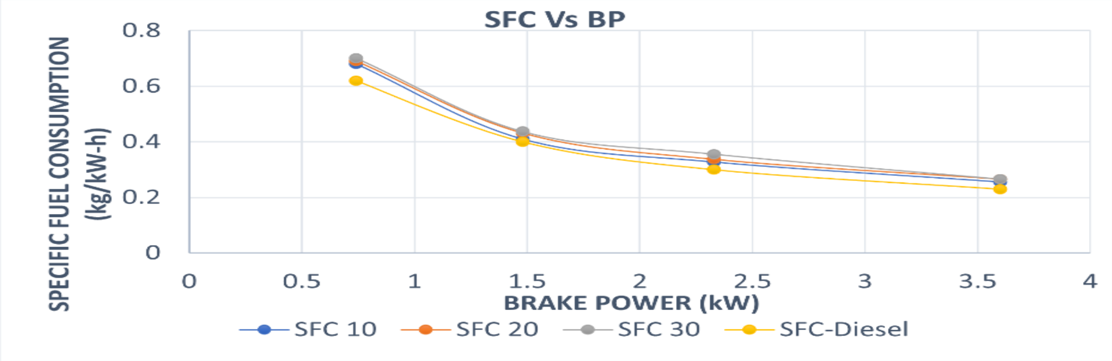

Fig 3. BSFC of B20D80 Water Hyacinth Blend

4.2 Total Fuel Consumption (TFC)

The entire quantity of gasoline used by an engine or system during a certain time period or for a specified amount of effort is known as total fuel consumption, or TFC. It is a crucial indicator for evaluating an engine's or combustion system's overall efficiency. The findings and discussion show that variables like engine load, operating time, and fuel type affect overall fuel usage. Since more energy is needed to sustain performance under heavier loads or longer operation, overall fuel consumption tends to rise. The most fuel-efficient choice is diesel, with B10 and B20 being good substitutes. B30 is the least efficient mix since it uses the most gasoline. With a modest rise in TFC and a sustainable substitute in Fig. 4, B20 provides the optimum balance.

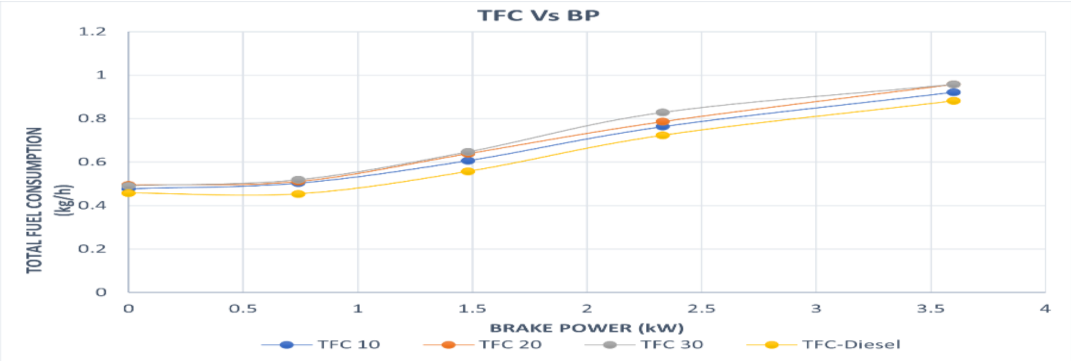

Fig 4. TFC of B20D80 Water Hyacinth Blend

4.3 Combustion Characteristics.

4.3.1 In cylinder pressure crank angle of B10 Blend.

From Figure 5. Peak Pressure: Shows efficient combustion and occurs close to TDC (~65–70 bar). Combustion phasing is characterized by a sudden drop in pressure after TDC and a rapid increase in pressure prior to TDC. Pressure Variability: Consistent combustion performance is shown by the little change between cycles. B10 WHB's effects include consistent pressure trends and good fuel-air mixing, which guarantee effective energy conversion. Peak pressure is close to TDC and the combustion is strong and consistent. Good fuel mix performance is shown by minimal cycle-to-cycle fluctuations.

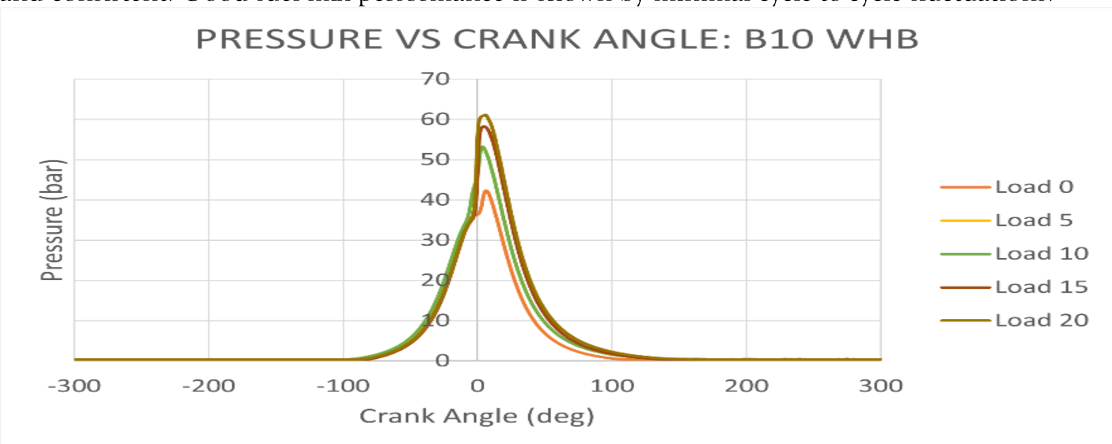

Fig 5. In cylinder pressure crank angle of B10 Blend

4.3.2 In cylinder pressure crank angle of B20 Blend.

Peak Pressure: A little higher than B10 WHB and close to TDC (~68–70 bar), suggesting better combustion. Combustion Phasing: a quick drop in pressure after TDC, followed by a rapid increase in pressure prior to TDC. Pressure Variability: Consistent combustion performance is indicated by little variations between cycles. Effect of B20 WHB: A higher percentage of biodiesel improves combustion but may have a little effect on ignition delay. Figure 6. has superior combustion smoothness but a lower peak pressure than B10/B20. Stable engine running is the outcome of optimal fuel-air mixing.

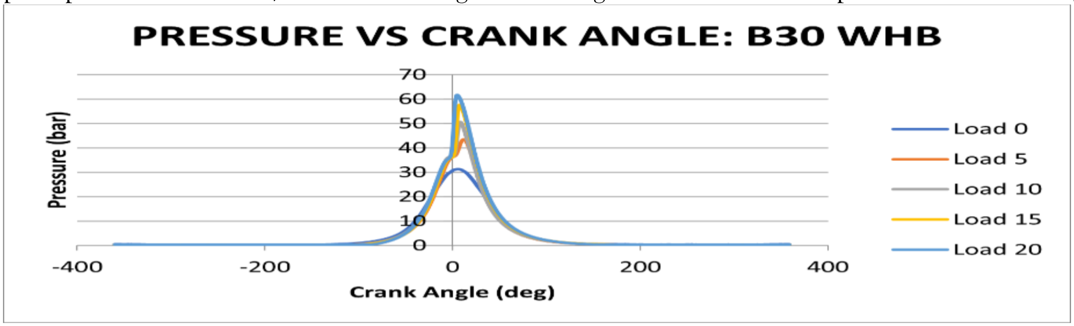

Fig 6. In cylinder pressure crank angle of B20 Blend

4.3.3 In cylinder pressure crank angle of B30 Blend.

In Figure 7. Peak Pressure: Lower than B10 and B20, around TDC (60–65 bar), suggesting smoother combustion. A gradual increase in pressure prior to TDC indicates a shorter ignition delay during combustion phasing. Pressure Variability: Consistent and steady combustion with little variations. Impact of B30 WHB: A higher amount of biodiesel increases combustion stability while lowering peak pressure. Better combustion smoothness but lower peak pressure compared to B10/B20. Stable engine running is the outcome of optimal fuel-air mixing.

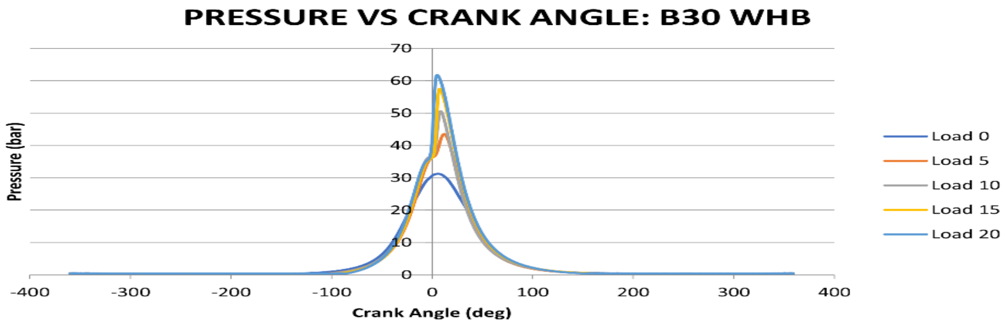

Fig 7. In cylinder pressure crank angle of B30 Blend

4.4 Heat Release Rate (HRR)

4.4.1 HRR for B10 Blend.

Better combustion efficiency is shown by the highest value around TDC (120 bar in Load 0 & 20). Combustion Phasing: Load 10 has a prolonged ignition delay; HRR rises quickly before TDC. Pressure Development: Fuel-air mixing and injection timing cause the pressure to peak at 120 bar (Load 0) and ~100 bar (others). Post-Combustion: Slow fall; slight oscillations indicate the presence of turbulence. Impact of B10 WHB: fluctuations brought on by operating circumstances, effective combustion, and excellent HRR alignment close to TDC. Excellent combustion, with a peak HRR close to TDC. In Figure 8, HRR variations show changes in fuel mixing and ignition delay.

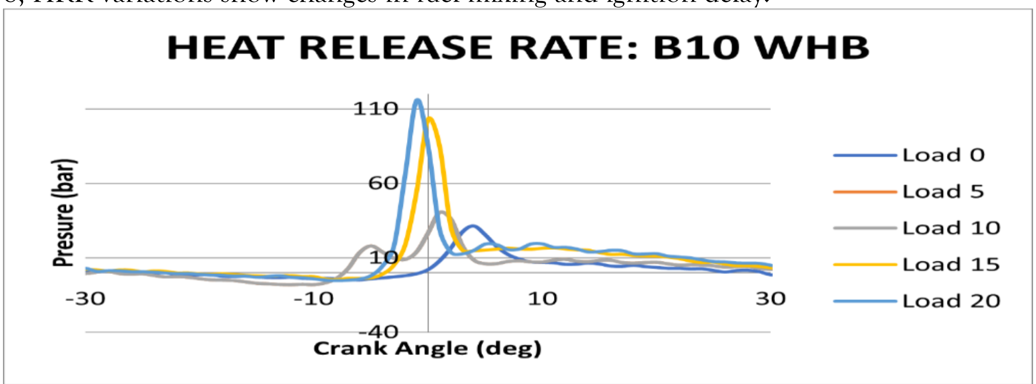

Fig 8. HRR for B10 Blend

4.4.2 HRR for B20 Blend.

Highest close to TDC (~1 in Load 0 & Load 15), suggesting intense combustion. HRR rises more quickly during combustion phasing, whereas HRR 3 indicates delayed combustion. Pressure and HRR Development: Variations because to air-fuel mixing and ignition delay, higher peak HRR than B10 WHB. HRR decreases after combustion, accompanied by oscillations that point to turbulence. from Figure 9. Impact of B20 WHB: Higher biodiesel content results in improved combustion but a longer ignition delay. sharper HRR peaks and stronger combustion than B10 WHB. Variations in HRR show turbulence effects and ignition delay.

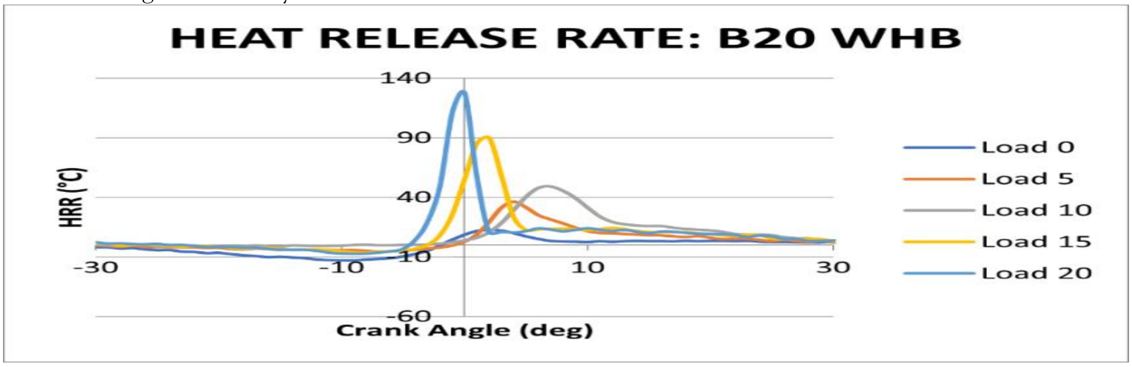

Fig 9. HRR for B20 Blend.

4.4.3 HRR for B30 Blend.

Better combustion efficiency is shown by the Peak HRR, which is at TDC (100–110 bar, Load 0 & Load 15) in Fig 10. Combustion Phasing: Shorter ignition delay and faster HRR increase than B10/B20. Pressure and HRR Development: Smoother energy release but less intense combustion, with a lower peak HRR than B10/B20. Post-Combustion: Improved fuel-air mixing and a more progressive HRR fall. Impact of B30 WHB: A higher ratio of biodiesel smoothes HRR, lowers peak intensity, and enhances stability. Better combustion stability but a lower peak HRR than B10/B20. minimized ignition latency and improved fuel-air mixing.

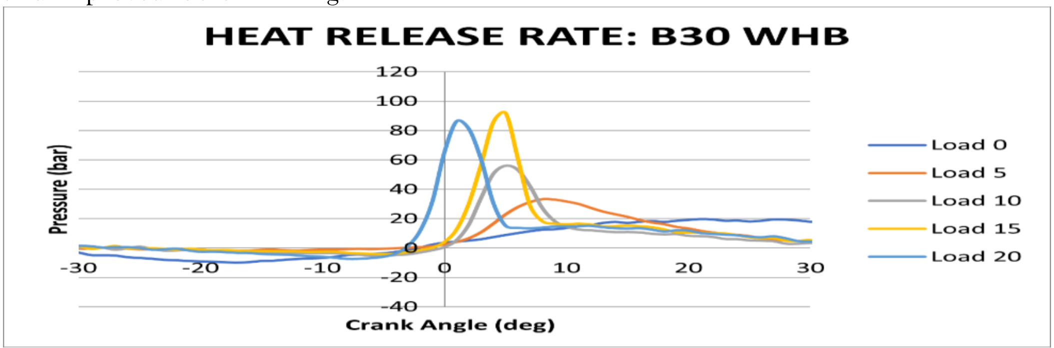

Fig 10. HRR for B30 Blend

5. CONCLUSION:

In conclusion, the water hyacinth B20D80 mix performs noticeably better thanks to the zirconia-based coating on the piston of the LHR (Low Heat Rejection) engine. When compared to other fuel mixes, the application of this coating produces enhanced thermal efficiency and optimum combustion characteristics. Because the zirconia coating significantly reduces heat loss, energy retention and engine efficiency are improved. Furthermore, the combustion process is more reliable and effective, which results in higher power production and lower emissions. A practical and sustainable alternative fuel for internal combustion engines, this research shows that the use of zirconia-coated pistons in LHR engines provides a feasible approach for enhancing the performance of biodiesel blends, notably the water hyacinth B20D80 mix, by 1.87%.

Conflict Of Interest

- The authors have no conflicts of interest to disclose.

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- No funding was received.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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