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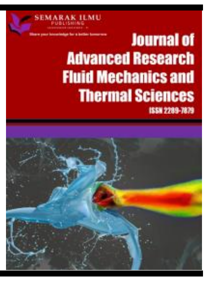

Rice Bran Oil as Emerging Green Fuels: Exploration on Combustion Behaviours of Single Cylinder Diesel Engine (Light-Duty Engine)

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ABSTRACT

In the current work, an experiment was conducted to examine the combustion properties of a single cylinder compression ignition direct ignition engine fuelled with rice bran oil at different engine loads. The investigation focused on the analysis of cylinder pressure and exhaust gas temperature as key factors in combustion. The fuel blends utilized in this study consist of various proportions of diesel and rice bran oil, including 100% pure diesel (RBO00), a blend of 25% rice bran oil and 75% pure diesel (RBO25), a blend of 50% rice bran oil and 50% pure diesel (RBO50), a blend of 75% rice bran oil and 25% pure diesel (RBO75), and 100% rice bran oil (RBO100). Comparisons are made between the results of an experiment using rice bran oil (RBO25, RBO50, RBO75, and RBO100) and a diesel engine (RBO00). RBO00 exhibits a greater heat output per unit mass compared to RBO25, RBO50, RBO75, and RBO100 blends because of the highest value of calorific value (CV) among others blends. Consequently, RBO00 demonstrated a higher measurement of exhaust gas temperature (EGT). One further contributing factor was the increased exhaust gas temperature (EGT), which led to an extended ignition delay, resulting in a lengthier fuel combustion process and the egress of combustion gas from the combustion chamber at higher temperatures. RBO100 achieved the highest cylinder pressure in both 50 % and 100 % engine load settings. The RBO100 blends fuel successfully achieved the optimal cylinder pressure in both 50 % and 100 % engine load conditions. The cylinder pressure for RBO00 (pure diesel) was the lowest at both half and full loads. The observed decrease in peak pressure can be attributed to the decreased cetane number (CN) and oxygen concentration found in RBO00 in comparison to the mixed fuels of RBOs. This will affect the completion of combustion such as wear and tear for the cylinder and piston. Under both 50 % and 100 % engine load condition, the cylinder pressure for RBO00 (pure diesel) was the lowest. In summary, rice bran oil showed superior combustion behaviour compared to pure diesel, and the mixture blends RBO75 and RBO100 can be thought of as ideal in terms of exhaust gas temperature and cylinder pressure.

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1. Introduction

Numerous investigations have been done recently to discover suitable alternatives for petroleum-based products [1]. The world's supply of fossil fuels is being used up at a rapidly increasing pace, hence it is crucial to discover effective substitutes because both the demand for and supply of these fuels are rising [2]. The transport sector is the leading cause of gasoline depletion due to the significant volume of automobiles present on the road [3]. Moreover, it is widely believed that the utilization of petroleum as well as other fossil fuels constitutes the primary factor responsible for the occurrence of air pollution and global warming [4]. The identification of suitable alternative fuels possessing similar characteristics is of utmost importance due to the fact that diesel engines were originally developed and implemented to operate using mineral diesel fuel [4-6]. Despite the numerous proposed methods for utilizing mineral diesel in engines powered by diesel, the issue of expensive engine modification remains a significant obstacle [7]. Biodiesel fuel is currently seen as a viable other fuel that can be employed in diesel engines, either with or without the need for modifications [8,9].

The wide range of biodiesel feedstock can be classified as regional commodities due to their widespread availability across various regions worldwide. Furthermore, due to their capacity to effectively retain substantial quantities of carbon dioxide (CO_2) and exhibit reduced engine emissions, these fuel variants provide the potential to mitigate the detrimental environmental effects associated with diesel engines [10-13]. According to the fuel standard recognized by the American Society for Testing Materials (ASTM), biodiesel derived from various feedstocks often exhibits dissimilar qualities. Blending biodiesel with pure diesel fuel is a widely adopted method for integrating biodiesel as a substitution fuel for diesel engines [14,15]. The maximum quantity of biodiesel that can be combined with pure diesel engines under the blending standard is determined by the property of the biodiesel source [16]. Hence, an analysis of the attributes of the fuel mixture implies significant importance in determining the optimal blend ratio [17,18].

Numerous investigations have been conducted thus far on a range of waste and unused crude oil feedstocks [19]. The cost reduction of biodiesel production has garnered significant attention, leading to a developing interest in rice bran oil (RBO) [20]. The report published by the Food and Agriculture Organization (FAO), the comprehensive production of rice whose amounted to 513 million tons, leading to the generation of substantial quantities of rice bran resulting in the huge production of rice bran as a secondary product [21]. The process of milling, whitening, and polishing rice results in the formation of a brown covering known as rice bran. Rice bran is predominantly utilized as a feed source for cattle or as a cost-effective solid fuel, commonly observed in countries such as Vietnam, China, India, Indonesia, and Bangladesh [22,23]. The weight percentage of rice bran varies between 16 and 32, depending on the milling process and the level of refinement applied to the rice [24]. Rice bran oil (RBO) has a notably higher concentration of free fatty acids, or FFA, compared to bran oil derived from other cereals, owing to the presence of an active lipase enzyme. Consequently, a significant proportion of RBO, ranging from 60% to 70%, poses potential hazards when consumed, particularly in the context of food consumption [25]. There has been a growing interest in the conversion of non-edible rice bran oil (RBO) into biodiesel, which has the potential to yield significant quantities of this byproduct [26,27].

The elementary objective of this study is to examine the impact of blending rice bran oil with diesel fuel at different ratios on the combustion characteristics of direct injection compression ignition (CI) engines. Specifically, the focus is on analyzing the impacts on the temperature of exhaust gases and cylinder pressure. The scope of the experiment is expanded to determine the most favorable values for the working parameters and their potential combinations. This investigation focused on examining the combustion features for the objective of research.

2. Sample Fuels and Procedures

2.1 Fuels

A local bio-oil producing company located at Selangor, Malaysia is supplier for rice bran oil (RBO). Samples of blended rice bran oil and pure diesel fuel were blended with an electric magnetic stirrer to produce RBO25 fuel (75% vol. pure diesel + 25% vol. rice bran oil), RBO50 fuel (50% vol. pure diesel + 50% vol. rice bran oil), RBO75 fuel (25% vol. pure diesel + 75% vol. rice bran oil) and RBO100 fuel (0% vol. pure diesel + 100% vol. rice bran oil).

2.2 Blends Preparation

The RBO blended fuels performed continuous stirring for a duration of one hour ensuring optimal blending before undergoing testing. Subsequently, there were left undisturbed for another hour to ensure its stabilization [9,10]. The utilization of rice bran oil in different blends has been found to yield several outcomes, including enhanced lubricity, reduced ignitability, reduced ignition delay, lowered volatility, and elevated cetane number [28,29]. The density of fuel samples was measured at a temperature of 15 °C by applying the Portable Density/Specific Gravity Meter (model DA-130N). The analysis of the viscosity of the test fuels was conducted by using a K23376-KV1000 model digital constant temperature kinematic viscosity bath, which maintained a consistent temperature of 40 °C ±0.01 [30]. Additional fuel qualities that have an impact on engine performance in the context of rice bran oil blends encompass energy content [16]. Consequently, a limited number of research have been conducted about energy content analyses, providing insufficient information regarding the instrumentation, equipment, and thorough techniques applied for analysis [31,32].

2.3 Sample Fuel Properties

The most essential factor for determining whether a particular fuel is suitable for use within the fuel standard is its attributes [33-35]. The evaluation of fuel properties holds significant importance in the evaluation of renewable energy sources prior to engine operation and the analysis of fuel combustion [14,36]. Table 1 shows the results of the RBO blends (fuel property) and the specified procedure for conducting tests on each property. The density of RBO fuel is frequently seen to be greater than that of diesel fuel, leading to an increased specific fuel consumption as the engine output remains constant [16,29,37]. This also resulting in notable effects on the production of fuel droplets and the penetration of sprays based on Table 1 [38,39].

Table 1
The Results of RBO blends (Sample Fuel Properties)

Properties	Testing Method	Diesel (RBO00)	RBO25	RBO50	RBO75	RBO100
Density (kg/m^3)	ASTM D1298	839.7	849.1	862.62	874.08	897.0
Kinematic Viscosity (mm^2/s)	ASTM D445-01	4.5	4.1	4.4	4.8	5.2
Calorific Value (MJ/kg)	ASTM D4809	45.7140	44.2210	43.8684	42.9456	41.1000
Cetane Number	ASTM D4737	48	50	52	54	55

2.4 Engine Setup and Description

The fuel blends used in the study are 100% pure diesel (RBO00), blends of 25% rice bran oil and 75% pure diesel (RBO25), blends of 50% rice bran oil and 50% pure diesel (RBO50) and blend of 75% rice bran oil and 25% pure diesel (RBO75) and 100% rice bran oil (RBO100). A single-cylinder, four-stroke diesel engine had been employed to conduct the experiment. The engine was coupled to a dynamometer that had been controlled by a Dynalec controller, which effectively monitored and controlled torque, engine speed and load. The test conditions and specifications of the engine are shown in Table 2 and Table 3, respectively.

Table 2
Engine specifications

Description	Specification
Type	4-stroke, Horizontal Cylinder, Air-Cooled Diesel Engine
Number of Cylinders	1
Combustion System	Direct Injection
Bore x Stroke	(70 x 55 mm)
Compression Ratio	20.1 +- 0.5
Maximum engine power	3.5 kW
Maximum torque	9.28 Nm

Table 3
Test conditions

Parameters	Test Condition
Type of Fuel	Diesel (RBO00), RBO25, RBO50, RBO75, RBO100
Engine Speed (rpm)	1500, 2000, 2500, 3000, 3500
Fuel Temperature	27 +- 1 °C
Air Temperature	30 +- 1 °C

The test engine's operational and performance parameters were evaluated through the utilization of several measuring devices, which were calibrated prior to measurement to ensure accuracy. Table 4 provides a comprehensive overview of the specifications pertaining to various measuring equipment.

Table 4
Instruments specifications

Particulars	Specifications
Speed measurement	Dynamometer
Temperature measurement	K-type thermocouples Range: 100˚C to 600 ˚C Digital temperature indicator
Fuel measurement	Burette and stop watch
Voltmeter	Range: 0-300 V Scale: Nonlinear type
Ammeter	Range: 0-30 A Resolution: 0.2 A
Anemometer	Type: Victor 816B

Exhaust gas composition was measured using QROTECH QRO-401. It measures CO, CO_2, HC, O_2, and NO_x in the exhaust, λ (air surplus rate) and air-fuel ratio (AFR). Table 5 provides information on the range of measurements and precision available from the QROTECH QRO-401 gas analyzer. Figure 1 depicts the schematic layout of the experimental equipment.

Table 5
Specification of QROTECH Model QRO-401

Gases	Measuring Range	Resolution	Measuring Method
CO_2	0 - 20 %	0.1 %	NDIR Method
HC	0 – 9999 ppm	1 ppm	
CO	0 – 9.99 %	0.01 %	
NO_X	0 – 5000 ppm	1 ppm	Electrochemical Cell
O_2	0 - 25 %	0.01 %	

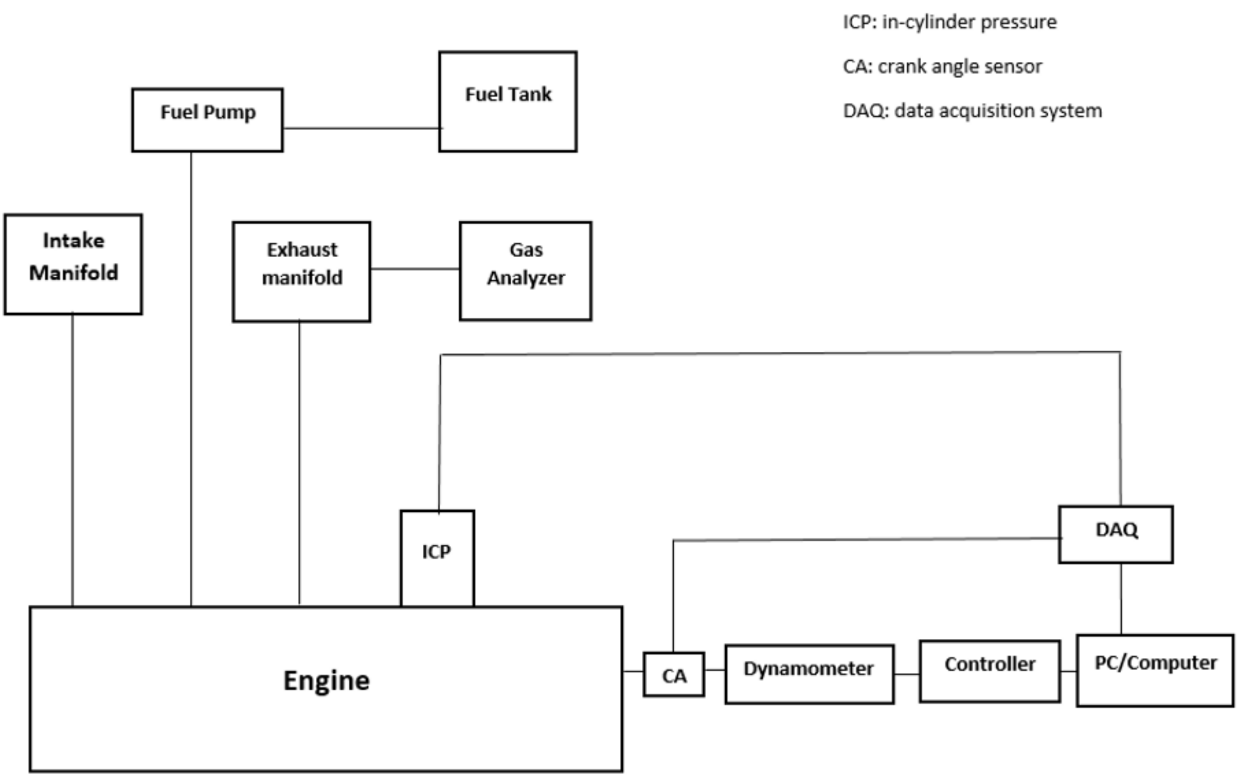

Fig. 1. Arrangement of experimental setup

2.5 Engine Test Procedures

All measurements were carried out on a 200 ml sample that had not been pre-treated. These mixtures were then put through their paces in an air-cooled diesel engine. A 200 bar was applied to an injection pressure in the engine [37]. The engine was initiated using a designated fuel mixture and thereafter allowed to reach operating temperature for a duration of 20 minutes. During this period, measurements were recorded for various incremental loads, spanning from idle to full load. All of the observations have been gathered [15]. The experimental procedure involved recording many parameters for each loading, including the input air flow rate, the time required for 30 cc of fuel consumption, the ambient temperature, the exhaust gas temperature, the flow rate of outlet cooling, as well as the readings from the ammeter and voltmeter. To guarantee the reliability of the results, the tests were repeated three times [29].

3. Combustion Analysis

The beneficial impact of utilized fuels in diesel engines is exemplified by performance evaluations, including brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and output power and/or volumetric efficiency, as well as combustion aspects including exhaust gas temperature and cylinder pressure. Additionally, elements such as the compression ratio, air-fuel mixing methods, cooling, and operating conditions have a direct impact on an engine's performance [40,41]. Innovative strategies and modern technologies have recently been developed to increase engine output power while lowering pollutant emissions [42-44]. Other methods, such as enhancing engine technical characteristics, the injection strategy, and others, have been employed independently or in combination with novel fuel compositions to optimize the combustion process and achieve the best efficiency [45,46].

3.1 Exhaust Gas Temperature (EGT)

The mean temperature of the exhaust gas discharge is commonly referred to as exhaust gas temperature (EGT). Figure 2 displays the EGT for various fuel mixtures and conventional diesel under different engine loads. Pure diesel fuel (RBO00), which functioned as the baseline, as well as blends like RBO25, RBO50, RBO75, and RBO100, were tested. The increase in engine load caused an increase in exhaust gas temperature (EGT) for the tested fuel, as more fuel was burned to provide the necessary torque to exceed the engine load, as shown in Figure 2 [47]. Due to limited dynamometer restriction which caused fuel to burn at the exhaust manifold area rather than in the combustion chamber, The thermocouple measurement obtained directly at the exhaust port was subject to external factors, resulting in elevated exhaust gas temperature (EGT) readings while the engine was not under any load [48]. Thus, due to that reason, the test started up with 20% engine load in this research. The major increment in Figure 2 is for RBO00, which are subsequently followed by RBO25, RBO50, and RBO100.

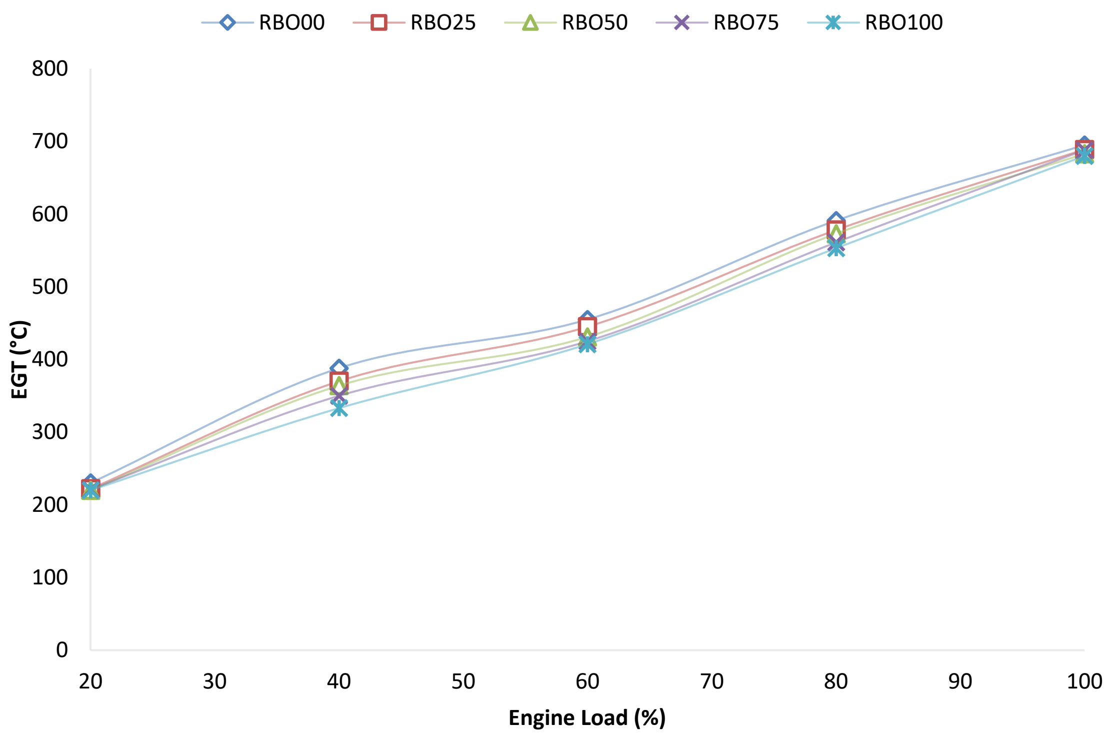

Fig. 2. EGT for RBO blends versus engine load

The RBO00 blend had the highest calorific value compared to the RBO25, RBO50, RBO75, and RBO100 blends. Consequently, the RBO00 blend generated more heat per unit mass. This observation was further supported by the high exhaust gas temperature (EGT) measurement obtained for the RBO00 blend. Another significant element was the prolonged ignition delay of RBO00 blends, which lengthened the fuel-burning process and raised temperature of the combustion gas leaving the combustion chamber (CC). This also clarifies that RBO100 blend with a short ignition delay have the lowest exhaust gas temperatures (EGT), as combustion proceeds more quickly and the exhaust gas temperature (EGT) exhibits a slight decrease prior to exiting the combustion chamber [49].

3.2 Cylinder Pressure

In the context of the development and measurement processes of compression ignition (CI) engines, the acquisition of data pertaining to the monitoring and assessment of in-cylinder pressure is anticipated to be highly valuable. The graphs depicting in-cylinder pressure offer valuable insights, encompassing key parameters such as peak pressure, indicated mean effective pressure, effective pressure for fuel delivery, the duration of combustion, and ignition delay [37]. Furthermore, supplementary parameters, including mass flow rate of air, combustion evaluation, and oxide of nitrogen emissions, can be evaluated and predicted using the equations derived from the first law of thermodynamics for an ideal gas [50]. In compression ignition (CI) engines, the effect of fuel proportion during the premixed combustion phase, also known as the starting combustion stage, has an important effect on maximum in-cylinder pressure [21]. Peak pressure often rises in response to rising engine loads, and the Pressure-diagram (P-diagram) could be used to show how in-cylinder pressure and crank angle are related. Two possible patterns for changes in engine cylinder pressure during blended RBO combustion are as follows: (i) Peak pressure increased because RBO and its blends have higher cetane numbers (CN) and oxygen contents than petroleum-based diesel fuel; (ii)

Peak pressure decreased as a result of RBO's higher viscosity and lower low heating value (LHV) compared to pure diesel fuel.

Figure 3 and Figure 4 indicate cylinder pressure for RBO blends versus crank angle, specifically illustrating the effects of 50% as well as full load circumstances, respectively. RBO100 achieved the highest cylinder pressure in both 50% and 100% engine load settings. The cylinder pressure for RBO00 (pure diesel) was seen to be the lowest under both 50% and 100% engine load circumstances. When the engine is functioning at maximum efficiency, the pressure within the cylinder experiences an increase while the ignition delay is reduced. Cylinder pressure determines whether mixed fuel may ignite when it combines with air. The RBO's higher oxygen concentrations are what cause their high pressures for both half and full load conditions. Under half load condition, the RBO100 blend had the highest peak pressure, which was followed by the RBO75, RBO50, RBO25 and RBO00 blends, with values of 74.67, 70.53, 69.9, and 68.48 bar, respectively.

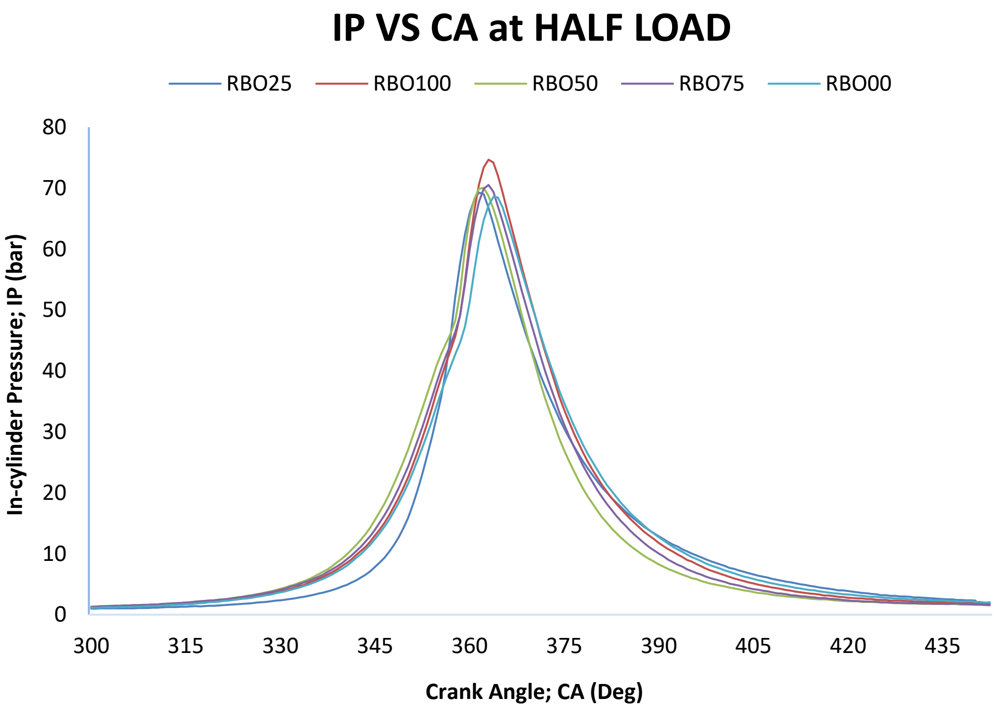

Fig. 3. Cylinder pressure for RBO blends versus crank angle at 50 % engine load

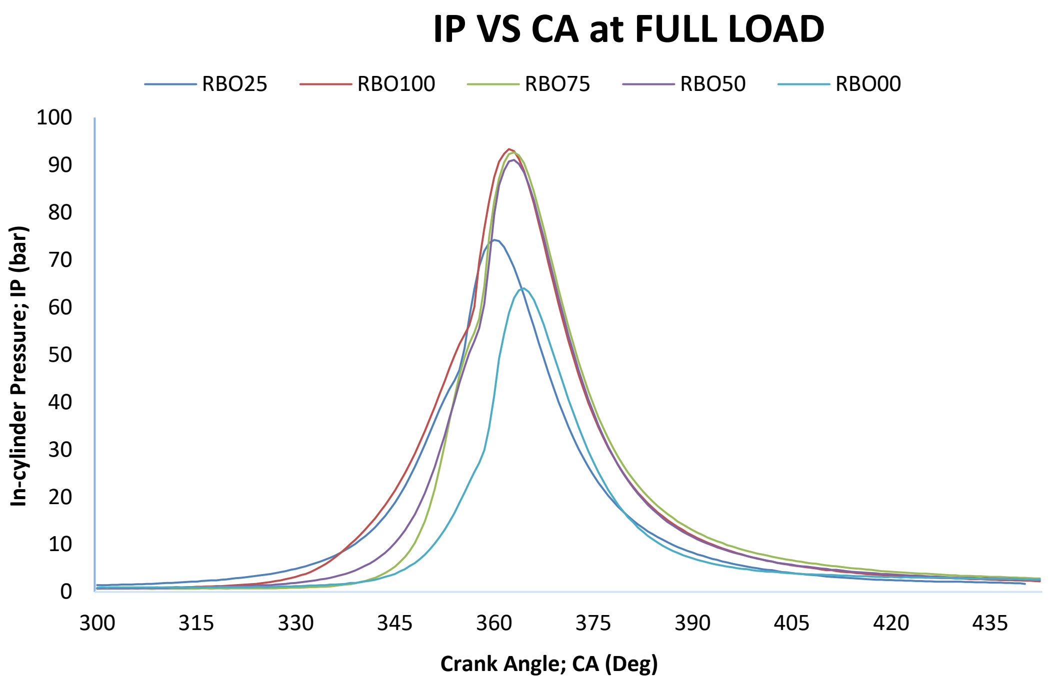

Fig. 4. Cylinder pressure for RBO blends versus crank angle at 100 % engine load

The trend is the same for under full load condition. The RBO100 blend had the maximum peak pressure, which was followed by the RBO75, RBO50, RBO25 and RBO00 blends, with values of 92.65, 91.06, 90.18, 79.58 and 64 bar, respectively. In conjunction of this, the cetane number (CN) is an essential aspect in determining cylinder pressure. The fuel with the highest cetane number and the most oxygen is rice bran oil [21]. The RBOs blend with a higher cetane number also often has a rapid premixing process and a reduce igniting delay for absolute combustion [37].

4. Conclusion

Experimental research is done on the combustion behavior in compression ignition (CI) or diesel engines running on RBO blends with pure diesel fuel. The following explanation can be stated to sum up the study's findings

i. Compression Ignition (CI) or Diesel engines can use RBO25, RBO50, RBO75, and RBO100 without any modifications.
ii. RBO00 produced more heat per unit mass than RBO25, RBO50, RBO75 and RBO100 blends which resulted in RBO00 having a high EGT measurement. This is because RBO00 has the highest value of CV. High EGT causes a longer ignition delay, leading to the fuel burn for longer and produces combustion gas leave the chamber at a higher temperature. This is also another explanation, was another contributing cause.
iii. RBO100 managed to reach the optimum cylinder pressure under both half- and full-load circumstances. The cylinder pressure for RBO00 (pure diesel) was the lowest at both half and full loads. This is because the RBO00 blend fuel has the lowest cetane number (CN) and oxygen level compared to the RBOs blend fuel. This caused the peak pressure to be low. This will affect the completion of combustion such as wear and tear for the cylinder and piston.

In a nutshell Rice Bran Oil (RBO) is currently identified as a highly promising option for alternative fuels because of their wide resource availability and high-performance standards. For the best optimization, more study on the dynamics of combustion utilizing RBO as a fuel is necessary.

Declaration of Competing Interest

The authors indicate that they do not possess any identifiable conflicting financial interests or personal relationships that would have potentially influenced the findings presented in this research article.

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