Experimental investigations of Yttria-stabilized zirconia coated low heat rejection diesel engine with Jack fruit methyl ester and cashew nut shell methyl ester as fuels

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Abstract:

In this study the experimental analysis is conducted to examine the performance, emission and combustion parameters of YSZ(Yttria-stabilized zirconia) coatings (150,300 & 450 microns) over a Toroidal piston using Jack fruit methyl ester and cashew nut shell methyl ester as fuels. The chemical and physical properties of biodiesels are analyzed. The engine performance enhancement with Jack fruit methyl ester(JF) and cashew nut shell methyl ester(CS), the DI engine is tested with LHR and compared to a regular diesel engine. From the study it is observed that working with JF+LHR 300 shows higher brake thermal efficiency and lower specific fuel consumption at maximum load. Brake thermal efficiency is increased with JF+LHR 300 is 2.64 % more compared diesel. The carbon monoxide(CO) emissions are reduced by 9.3% with JF+LHR 300. The hydro carbon(HC) emissions are decreased by 20 % with JF+LHR 300. The combustion parameters also improved with LHR technique.

Keywords: Toroidal, Yttria-stabilized zirconia, Jack fruit methyl ester, cashew nut shell methyl ester, performance, emissions, Low heat rejection

1. Introduction

Fossil fuel sources are decreasing, and their prices have been steadily rising over the years. Furthermore, most nations rely on fossil fuel imports for their energy sector, putting a significant pressure on their economies [1]. Unburned hydrocarbons (HCs), Carbon monoxide (CO), particulate matter (PM), sulphur oxides (SOx), and nitrogen oxides (NOx) are the environmental pollutants and GHGs that are released during the fossil fuel energy extraction process, smog, acid rain, climate change, and other kinds of air pollution, and health issues are all possible outcomes. Countries must invest in sustainable and renewable energy sources to lessen their dependance on fossil fuels.

One of the renewable energy sources is biodiesel, which is formed by transesterification of animal or plant-based oils or fats. Because it produces the same amount of torque and power as traditional fossil diesel fuel and requires no adjustments to diesel engines, biodiesel has become a popular alternative fuel [3]. Biodiesel is primarily generated in various regions of the globe by crops such as mustard oil, sunflower, soybean, and others. Producing biodiesel from edible oil would be impractical given the country's scarcity of edible oils. However, first-generation technologies have problems in that they depend on feedstocks that are not readily available to meet the needs now provided by petroleum, and they rely on widely accessible edible feedstock fractions, so affecting food availability for people and animals. As a result, using non-edible feedstocks to convert biofuel may be a more sustainable option for meeting future energy needs. Furthermore, the nation has huge potential to generate tree-borne oilseeds for biodiesel manufacturing in order to meet the need for around 40% of total crude oil diesel requirements [4].

Besides reducing emissions, biodiesel offers advantages over diesel in areas like as lubricity, toxicity, and sulphur and aromatic chemical content. However, there are several limitations to the commercial use of biodiesel. Moisture absorption, oxidative instability, poor volatility, carbon deposition and corrosion, are some of the main downsides of biodiesel [5]. The experimental results revealed that, in comparison to the conventional engine using petroleum products, the SFC for Karanja oil methyl ester reduced by 7.4 %, and the brake thermal efficiency increased by 5.5 %[6]. The findings revealed that the oil output from Sandbox seeds was 47.77%, which is excellent, and the biodiesel yield was 86.49%, which is within acceptable range for worldwide norms. The best and greatest BTE was shown by B10, followed by D100, at all three torque settings (4 Nm, 6 Nm, and 7 Nm), with the lowest and most desired CO_2 emission[7].

Diesel engines that operate on petrodiesel products also release additional toxic compounds including UHC, NO_X, soot, SO_X, particulate matters, etc., making the switch to biodiesel all the more important[8]. At full load, the findings showed a particular fuel consumption reduction of roughly 2.17 percent. While running at maximum throttle, emissions of both unburned hydrocarbons and carbon monoxide were cut by around 22.01% and 28.01%, respectively, compared to the baseline engine[9]. diesel, B20 (a biodiesel mix containing 20% palm oil), and BD1 (a biodiesel blend containing 20% palm oil and 1% di-tert-butyl peroxide) were utilized to the test. To raise the vehicle's cetane rating, DTBP was included. As a result of BSEC's efforts, both CO and NOx emissions were reduced by 13–15%. Similarly, a little improvement in UHC and BTE prevalence (between 2.5% and 3.5%) was also observed [10].

Biofuels are liquid fuels made mostly from transesterification process and simple chain alcohols (methanol or ethanol)[11]. Blends of jojoba biodiesel and diesel fuel, with 10% n-butanol added for oxygenation, were used in the experiments. Up to 80% less NOx, 80% less CO, and 65% less UHC were recorded, with a minor drop in the heat release rate, indicating a significant decrease in the GHG emissions[12]. According to the results, fuel cylinder pressure did not vary noticeably throughout the course of the investigation. Moreover, the blends achieved a 6.8% decrease in BTE, a 32% decrease in smoke, and a 50.4% decrease in carbon monoxide, but a 4.8% rise in BSFC and a 22.1% decrease in nitrogen oxides[13].

Antioxidants (BHT) were combined with Mahua oil extracted by the transesterification process at varying concentrations (5%, 10%, and 15%) for further research. When comparing the B85 blends to regular diesel fuel, it was discovered that the BTE was raised by 3.42 percent. Compared to mineral fuel, with more oxygen in the fuel and proper combustion, the B85 blend reduced HC emissions by 37.63% and smoke opacity by 2.66%. as opposed to diesel fuel, the B85 blend was shown to increase the percentage of NOx by 45.87% and Exhaust gas recirculation (EGT) by 27.33% [14].

In a experimental study by combining sunflower oil with soybean oil at a ratio of 50:50. In most cases, the diesel content is anywhere between 10% and 30%. When compared to pure diesel, the mixes' reduced CV and ID resulted in somewhat lower in-cylinder pressure and HRR. Better combustion and lower IT led to a 33.8% reduction in CO concentration compared to standard diesel fuel. Utilizing the B30 fuel blend resulted in lower HC emissions compared to using pure diesel fuel. When using fuel bend B30, the NOx and BSFC were 0.98 percent higher, 2.5 percent higher, and 11.4 percent higher, respectively, than when using plain base gasoline. It's because biodiesel has a longer ignition delay and less oxygen available[15].

Gas turbines and jet engines are two examples of industrial uses of thermal barrier coating, often known as TBC. In compression ignition engines, coating the walls of the combustion chamber, the head of the piston, as well as the intake and exhaust valves, is something that has been the subject of research from a number of angles. [16]. Due to their low volatility and high viscosity, vegetable oils are not ideal for main engines[17]. Internal combustion engines' thermal efficiency was increased with TBC by 37-41%. The experimental findings also shown a decrease in fuel consumption and an improvement in brake thermal efficiency for the LHR engine [18]. Pine oil (PO) has been shown to minimize fuel consumption compared to diesel fuel in coated and uncoated engines due to its chemical and physical features. Reduced emissions of hydrocarbons, smoke and carbon monoxide, were the outcome of employing a piston with a coating [19].

Engine testing with Ni-Cr and Al-Ti coatings SFC was concluded to be reduced by roughly 16.5% compared to the regular engine. At low and medium loads, the findings showed that coated piston engines performed better than the uncoated piston[20]. Researchers analyzed the exergy and energy of a 20% pomegranate methyl ester in a TBC engine under a different load and temperature conditions. In order to alter the working conditions of a single-cylinder DI engine running at 1500 rpm and 5.2 kW, water cooling was used. YSZ (Yttria Stabilized Zirconia) was used to coat the components of the combustion chamber. In comparison to the fundamental engine, the TBCE with B20, which contains 80% diesel and 20% pomegranate methyl ester, exhibited a superior level of thermal efficiency. It has also been shown that the methyl ester of B20 pomegranate seed oil is useful in lowering smoke emissions [21].

In the current study, a plasma spray approach was used to provide a YSZ (Yttria-stabilized zirconia) over a Toroidal piston shape. In this analysis coating thicknesses of 150, 300, and 450 microns for thermal insulation were evaluated. The effects of diesel, Jack fruit methyl ester, and cashew nut shell methyl ester on an internal combustion engine were tested.

2. Materials and Methodology

A 5.2-kilowatt (4.55-kilowatt maximum load evaluated) single-cylinder, water-cooled, direct injection (DI) diesel engine was used for this research as shown in Fig.1. The Test engine shaft was coupled to the eddy current dynamometer. At a certain engine speed, it was subjected to varying loads. Various thermocouples and a pressure transducer were used to measure the temperatures and pressures. In this study, K-type thermocouples were utilized. An air flow sensor was used to determine the volume of air movement. The fuel flow rate was determined with the use of a u-tube manometer. The data collecting system was linked to various pressure temperature and sensors. A data acquisition system was attached to the complete testing apparatus. Initially, uncoated Toroidal pistons were used in studies running on diesel, Jack fruit Methyl Ester, and Cashew Nut shell Methyl Ester. Pistons with various YSZ coating thicknesses are shown in Figure 2. These thicknesses range from 150 microns to 450 microns. Table 1 and Table 2 describe the engine and fuel specifications respectively.

Fig.1-Test Engine

S. No.	Content	Specifications
1	Stroke length	110 mm
2	Stroke type	4
3	Rated speed	1500 rpm
4	Engine power	5.2 kW
5	Connecting rod length	235 mm

6	Speed type	Constant
7	No.of cylinders	1
8	Loading device	Eddy current dynamometer
9	Compression ratio	17.5:1
10	Cylinder bore	87.5 mm

Table1. Engine specifications

Parameters	**Jackfruit seed methyl ester**	**Cashew nut shell methyl ester**	**Diesel fuel**	**Standards**
Specific gravity	0.87	0.85	0.83	ASTM D 1298
Density - kg/m^3	889	883	831	ASTM D 1298
Heating value MJ/kg	38.81	38.10	42.5	ASTM D 5865
Kinematic Viscosity at 40 °C (cSt)	5.52	4.30	2.94	ASTM D 445
Fire point (°C)	183	148	61	ASTM D 92
Flash point (°C)	175	140	52	ASTM D 92

Table2. Fuel Properties

The tests were conducted while keeping the engine at constant speed of 1500 revolutions per minute. Common pollutants including CO, NO_X, HC, and CO_2 were assessed using a 5-gas analyser

Fig.2.1 LHR 150 TCC

Fig.2.2. LHR 300 TCC

Fig.2.3. LHR 450 TCC

3.Results and discussion

Fig.3 illustrates the variations of brake power with brake thermal efficiency(BTE). The main objective of the BTE is to covert heat energy into work, generally it is less than 45% due to heat losses to surroundings. With increase of BP the BTE increases for all LHR configurations with various fuels[22]. The BTE of LHRJF 300 (low heat rejection piston with Jack fruit methyl ester) is higher and is about 31%. The remaining all configurations pistons LHR JF 150, LHR JF 450, LHR CS 150, LHR CS 300 and LHR CS 450 brake thermal efficiency are lowered and are about 28.75 %, 24.7%, 25%, 22.28% and 22.98% respectively compared to LHR JF 300. The lesser brake thermal efficiency with biodiesel compared to standard diesel indicates that the lesser calorific value of biofuels. The more oxygen content and LHR gives whole combustion of biodiesel and minimize the heat losses from the engine.

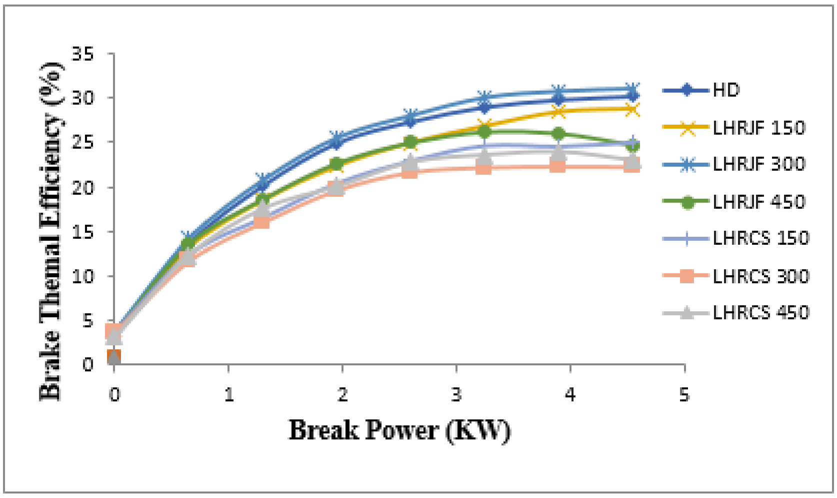

Fig.3 Brake thermal efficiency

Fig.4 demonstrates how SFV changes in relation to brake power. Brake specific energy consumption is mostly affected by density and viscosity. Inversely proportional specific fuel efficiency to brake power. When the brake power is increased from no load to full load, there is an initial rise in in particular fuel consumption, which is subsequently followed by a steady reduction. [23]. The lower brake specific fuel consumption is LHR JF 300 and is about 0.219 kg/kWh at peak load. The highest BSFC at full load condition for LHR JF 150, LHR JF 450, LHR CS 150, LHR CS 300 and LHR CS 450 are 0.269 kg/kWh, 0334 kg/kWh, 0.329 kg/kWh, 0386 kg/kWh and 0359 kg/kWh respectively. The average 6.6 % lower BSFC is observed for LHR JF 300 compared to diesel fuel.

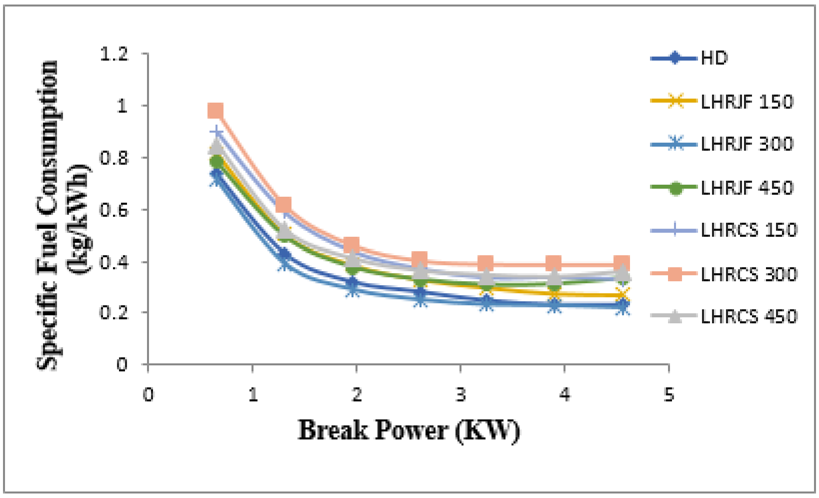

Fig.4 Specific fuel consumption

Fig.5 indicates the CO (carbon monoxide) emission vs brake power. The lower CO emissions are recorded from no load condition to half load conditions and thereafter CO emissions increased gradually upto full load condtion. The carbon monoxide emissions are affected by physical and chemical properties of biofuel/diesel. The lesser CO emissions are obtained due to self oxygenation property of biofuel. The higher CO emissions are obtained by biodiesel pre heating [24]. The lowest

CO emission is observed for LHR JF 300 and is about 0.68 vol %. The remaining CO emissions for LHR JF 150, LHR JF 450, LHR CS 150, LHR CS 300 and LHR CS 450 are 0.9 vol %, 1.1 vol %, 0.99 vol %, 1.2 vol % and 1.3 vol % respectively. The average percent of CO emissions for LHR JF 300 is 17 % less compared to standard diesel.

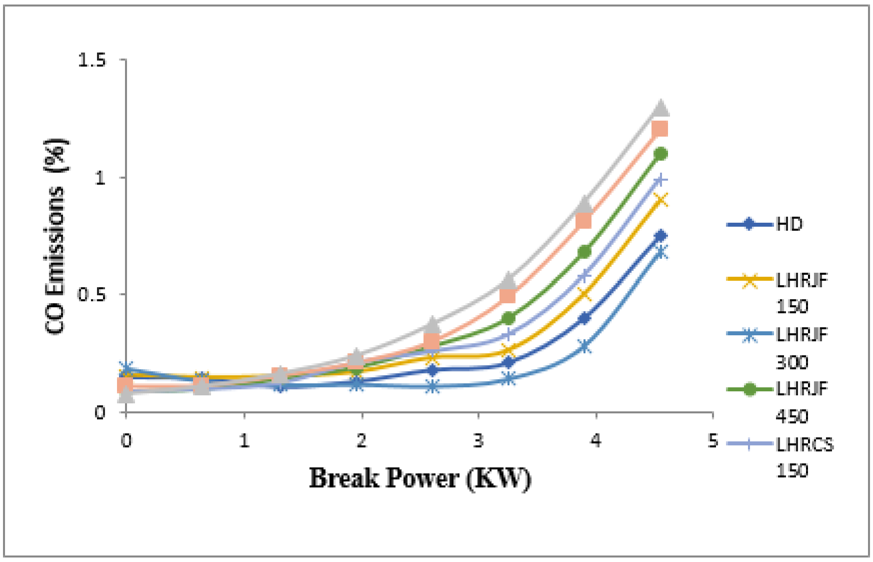

Fig.5 carbon monoxide

Fig.6 shows the emissions of unburned hydrocarbons (HC) with respect to brake power. The HC emissions increased for all parameters from no load to maximum load condition. These emissions are obtained for unstable and incomplete combustion of fuel [25]. An important and marginal variations are observed at 3.99 kW and 4.55 kW. An overall average of HC emissions are decreased by 23.65 % is observed for LHR JF 300 compared to diesel. The lowest 80 ppm and highest 145 ppm HC emissions are observed for LHR JF 300 and LHR CS 300 respectively. The other HC emissions like LHR JF 150, LHR JF 450, LHR CS 150 and LHR CS 450 are 90 ppm, 107 ppm, 120 ppm, and 135 ppm respectively.

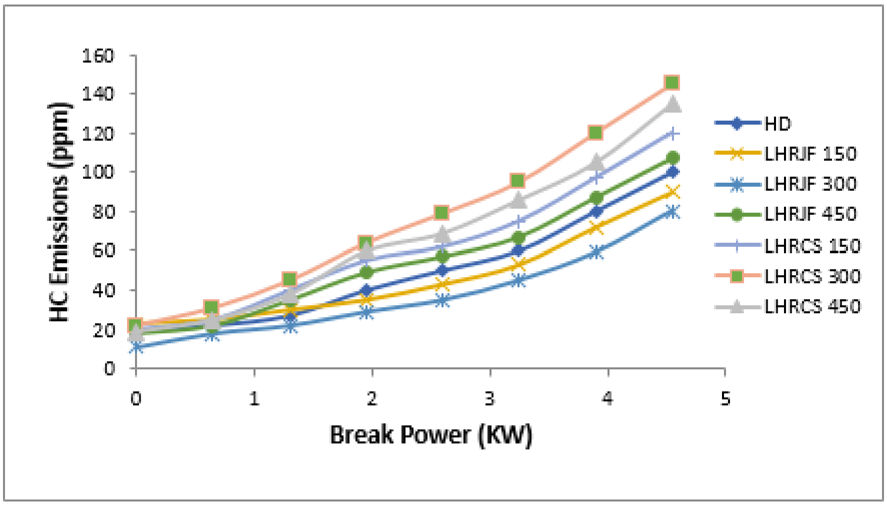

Fig.6 HC Emissions

Fig.7 demonstrates the oxides of nitrogen(NOx) vs brake power. The higher NO_x emissions are observed for all parameters compared to diesel fuel.The higher NO_x obtained due to maxium peak pressure and oxygenation property of biofuel [26]. Marginal and significant variations are observed from no load to full load condition. On an average 35.8 % higher NO_x emissions are recorded for LHR CS 300 compared to diesel. The highest NO_x 1200 ppm and the lowest NO_x 1040 ppm for LHR CS 300 and LHR JF 300 respectively. The other NO_x emissions for LHR JF 150, LHR JF 450, LHR CS 150 and LHR CS 450 are 1070 ppm, 1130 ppm, 1180 ppm and 1090 ppm respectively.

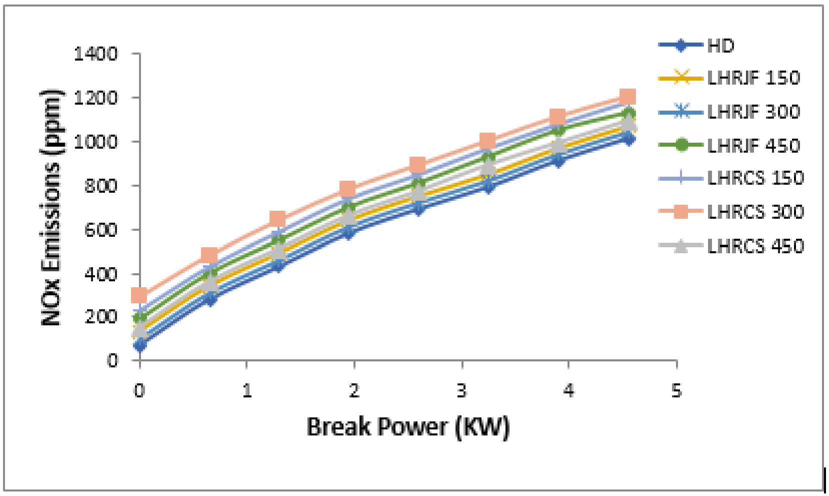

Fig.7 oxides of nitrogen

Fig.8 represents the cylinder pressure vs crank angle. In CI engines in-cylinder pressure indicates the combustion efficiency. The cylinder combustion is influenced by chemical and physical properties of biodiesel such as density and viscosity[27]. The highest peak pressure is obtained for LHR CS 300 is 57.3 bar and lowest peak pressure obtained for diesel and is about 48.6 bar. The cylinder pressure for the remaining parameters like LHR JF 150, LHR JF 300, LHR JF 450, LHR CS 150 and LHR CS 450 are 52.43 bar, 54.21 bar,55.31 bar,56.31 bar, 56.81 bar respectively.

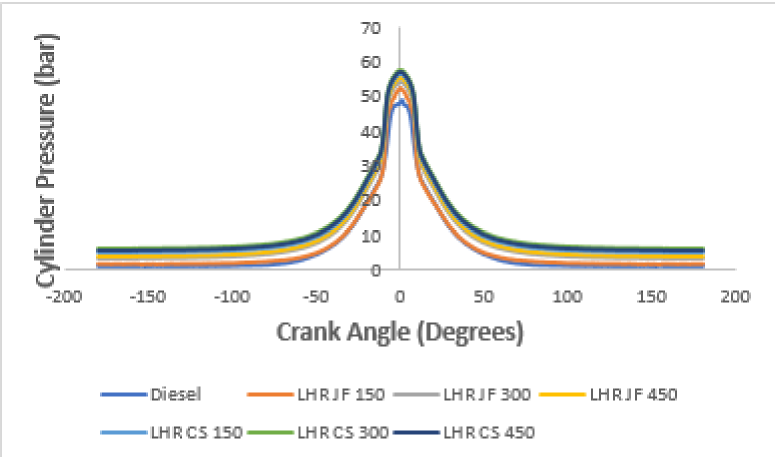

Fig.8 cylinder pressure

Fig.9 demonstrates how HRR varies as a function of crank angle. When investigating combustion and ignition characteristics, the HRR in a CI engine is crucial. The combustion parameters like ignition delay, nature of combustion and combustion duration are determined with HRR curve[28]. The highest and lowest HRR are recorded for LHR CS 300 and diesel are 123.4 J/deg and 110 J/deg respectively. The heat release rate obtained for remaining parameters like LHR JF 150, LHR JF 300, LHR JF 450, LHR CS 150 and LHR CS 450 are 117.4 J/deg, 116.3 J/deg, 121.4 J/deg, 119.2 J/deg and 120.2 J/deg respectively

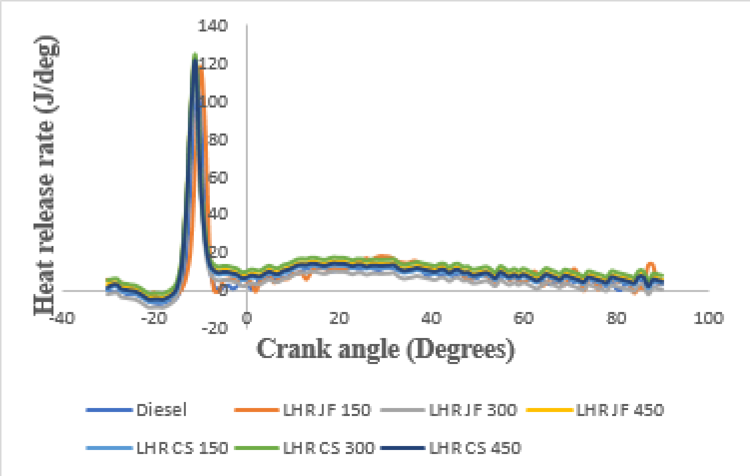

Fig.9 Heat Release Rate

4 Conclusions

The Combustion, emission and performance parameters of YSZ piston coated diesel engine using jack fruit methyl ester and cashew nut shell methyl ester is analyzed.

- The chemical and physical properties of jack fruit methyl ester and cashew nut shell methyl ester are found.
- LHR jackfruit methyl ester 300 brake thermal efficiency is 2.9% higher compared to diesel. This is because thermal barrier coatings function as insulation, resulting in less heat loss.
- The SFC of LHR jackfruit methyl ester 300 is 5.19% less compared to standard diesel. This is because the complete combustion in engine cylinder.
- The ME for LHR jackfruit methyl ester 300 is 8.6% more compare to diesel.
- The lowest CO and HC emissions obtained for LHR JF 300 are 0.68 vol % and 80 ppm respectively.
- The NO_x emissions are increased for all biodiesel compared to diesel fuel.
- The highest cylinder pressure and Heat release rate are obtained for LHR CS 300 is 57.3 bar and 123.4 J/deg respectively.
- Based on the study it can be concluded that Jack fruit and cashew nut methyl esters used as substitute fuel in diesel engines. Further it is observed that YSZ (300 microns) piston coated material is recommended.

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