Performance Studies on Exhaust Gas Recirculation diesel engine using Garcinia Gummi-Gutta Biodiesel with ceramic coating in direct injection

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Abstract

In today's digital environment, energy is the most essential for human survival. Its combustion surfaces were coated with ceramics to achieve total adiabatic operation, also called a low heat rejection engine (LHR). One of the best techniques to lower NO_x emissions in internal combustion engines is exhaust gas recirculation (EGR). The performance of an LHR with a delayed timing engine has been assessed using diesel and Garcinia Gummi-Gutta (GGG) biodiesel. GGG decreases CO, HC, and smoke emissions while improving brake thermal efficiency (BTE) compared to uncoated engines. The proportion of BTE (12.5%) and NO_x(18.5%) decreased as the EGR rate increased, whereas the percentage of HC (10%), CO (12%), and smoke (8.6%) increased. This indicates a complex interplay between EGR rates and emissions performance. Further research is necessary to optimise the EGR system settings to balance the benefits of reduced NO_x emissions with the potential increase in other pollutants, ensuring compliance with stringent environmental regulations while maintaining engine efficiency.

Keywords: Garcinia Gummi-Gutta**,** Low Heat Rejection, Exhaust Gas Recirculation, Brake Thermal Efficiency, Hydrocarbon , Carbon monoxide

1. Introduction

India's rapidly expanding economy is mainly reliant on oil. Currently, domestic output is around 34 million metric tonnes, whereas demand is over 146 million metric tonnes. S. Godiganur (2009) Biodiesel is derived from edible or non-edible oils or animal fats, and it is an alternative to petroleum-based fuels. Fuels made from raw vegetable oils suffer from poor atomisation, severe engine deposits, coking of injectors and sticking piston rings, and incomplete combustion that results in increased smoke density. Mohd Hafizil (2017). A nation's anxiety over such a large gap in supplies is understandable. The most practical method to fulfil this expanding need is to use renewable alternative fuels to replace fossil fuels. At the same time, alternative fuels must fulfil severe emission standards. Ladommatos (2004). Low heat rejection (LHR) engines are compression ignition (CI) engines with a ceramic coating on the combustion chamber (CC). The LHR engine can increase fuel efficiency by repurposing some heat energy that would otherwise be wasted as mechanical energy. For some biodiesel mixes, several studies employed LHR engines. Salim Mohamed (2003). Keeping the combustion temperature under control through exhaust gas recirculation can reduce NO emissions in the exhaust. EGR has a negative impact on the quality of lubricating oil and the durability of engines. Oil quality and engine durability are negatively affected by EGR. Due to sulphur oxide being directly proportional to the EGR rate, the amount of sulphur oxide in the oil is directly proportional to the EGR rate. An approach for reducing diesel engine NO_x emissions is to partially recirculate exhaust gases (EGR). It reduces NO_x emissions at higher loads but increases particulate matter emissions (PM). Agarwal (2005). On a 5.9 kW Kirloskar DAF 8 diesel engine, Baiju et al. (2009) investigated the methyl and ethyl esters of karanja oil mixes with fossil diesel. All other biofuels have lower BSFC with KOME (B20) and greater CO emissions with KOEE (B20). KOME (B100) produced the least amount of smoke. With all biodiesel mixes, there was a 10–25 per cent increase in NO_x emissions. Overall, methyl esters outperform ethyl esters in terms of performance and emission characteristics. Sivakumar (2012). Pradeep and Sharma (2007) investigated the NO_x reduction process in a 3.7 kW Kirloskar AV1 diesel engine that was fuelled with JOME using a hot EGR approach. There was a significant reduction in NO emissions when the engine ran at EGR levels of 6–24 per cent. The lowest CO, HC, and NO emissions, as well as a respectable BTE, were achieved with 15% of hot EGR. However, a greater amount of smoke was a disadvantage of the EGR technology. According to numerous studies, adding up to 10% diethyl ether to biodiesel-diesel blends significantly improved the diesel engines' combustion and emission performance characteristics. Only a small number of the thorough publications mentioned above discussed using non-food grain seeds as a feedstock to produce biodiesel in forests. Additionally, there hasn't been much research done on oxygenated additives to enhance base fuel and create ternary fuel blends that provide improved engine performance and lower emission characteristics.

The main drivers of the hunt for alternative fuels today are the depletion of fossil fuels, rising energy consumption, environmental concerns, and fuel prices. Because they are inexpensive feedstock, the seeds of garcinia gummi-gutta trees grown in forests are utilised in this effort to produce biodiesel. Additionally, garcinia-gummi gutta seed by-products have a wide range of economic applications. Transesterification is used to change the fuel's characteristics to something similar to plain diesel fuel from crude oil extracted from garcinia gummi-gutta seeds.

Numerous studies have explored the use of biodiesel in CI engines, focusing primarily on feedstocks such as jatropha, soybean, and palm oil. Similarly, the application of ceramic coatings and exhaust gas recirculation (EGR) has been individually assessed for their potential in improving engine efficiency and emission control. However, there is a notable lack of research integrating non-conventional biodiesel sources such as Garcinia gummi-gutta with advanced combustion enhancement techniques. Furthermore, few studies investigate the combined effects of ceramic coatings and EGR on a direct injection diesel engine running on such biodiesel. This study addresses these gaps by evaluating the performance, combustion, and emissions characteristics of GGME-fuelled diesel engine under varying EGR rates and ceramic coating conditions.

Previous research has widely explored the use of biodiesel derived from conventional feedstocks such as Jatropha, Karanja, and Neem oil in combination with either thermal barrier coatings (TBCs) or exhaust gas recirculation (EGR) systems to improve diesel engine performance and emissions. For instance, Kumar et al. (2021) reported a 6% rise in BTE using Jatropha biodiesel in a ceramic-coated engine, while Ashok et al. (2020) demonstrated moderate NOx control with palm biodiesel using EGR. However, these studies often focused on a single modification (either biodiesel, EGR, or coating) and rarely addressed the combined impact of all three strategies. Furthermore, few works have evaluated non-traditional feedstocks with promising physicochemical profiles for biodiesel production.

To address these gaps, the present study investigates the combined effect of a novel biodiesel fuel—Garcinia gummi-gutta methyl ester (GGME)—with ceramic-coated combustion chamber components and varied EGR rates on the performance, combustion, and emission characteristics of a single-cylinder direct injection diesel engine. Unlike existing literature, this study not only utilizes a less-explored biodiesel source with high oxygen content and low viscosity but also integrates multiple engine optimization strategies simultaneously. The experimental results are critically compared with existing data to highlight the synergistic benefits of the GGME–EGR–TBC configuration. This comprehensive approach offers new insights into achieving enhanced thermal efficiency while controlling NOx emissions—contributing significantly to sustainable engine technology.

In this study the performance, combustion characteristics, and emission behavior of a ceramic-coated direct injection diesel engine fueled with Garcinia Gummi-Gutta biodiesel, incorporating exhaust gas recirculation (EGR), and to assess its feasibility as a sustainable alternative fuel solution.

2. Methods and Materials

2.1 A zirconia partially stabilized facility with low heat rejection

Figure 1: (a) During the research, the goal was to improve the engine's performance and increase the wear resistance of its parts. Plasma spray coatings are used to coat cylinder heads, pistons, and valves with thermal barrier coatings. The coating of ceramic reduces wear, friction,

corrosion, and oxidation in these parts. The combustion chamber temperature of ceramic-coated engines was higher than that of uncoated engines, allowing low-quality fuels to be used. Since the cooling system Balu (2023) removes less heat from the combustion chamber after compression, the gas in the chamber will be hotter than it was before the compression.

3. Experimental setup

A schematic representation of the experimental setup with an EGR is shown in Figure 1. (b). In this experiment, a CI engine was run at 1500 rpm at a constant speed. The system also monitors engine load, airflow using an anemometer, and gas temperatures using K-type thermocouples. In the exhaust gas analysis, hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) were detected. The non-dispersive infrared (NDIR) detection approach was used to detect CO and HC, while electrochemical sensors were used to quantify NO_x. In the C7112, combustion pressure is monitored inside the cylinder. In order to collect pressure readings, a data collection system was used. The average pressure values obtained from 20 consecutive combustion cycles were used to compute combustion pressure parameters. We calculated the net HRR and cumulative heat release (CHR) from the data. The current work used a compression ratio of 17.5:1 since, in the pilot run evaluation, the engine performed better with this ratio. Therefore, the same has been selected for more examination. Before starting the engine, the level of lubrication oil in the engine oil sump, the cooling water flow, and the gasoline level in the fuel tank were all checked. They started and warmed up the engine. The rated speed of the engine was maintained. The engine's power was determined by monitoring the voltage and current. To measure the temperature of the cooling water, a thermocouple with a digital temperature indication was employed. It was a Piezo electric pressure sensor that sensed the cylinder pressure. The QROTECH exhaust gas analyser was used to measure the exhaust emissions, which included CO, NOX, and HC. The smoke emission was measured using a TI Diesel Tune smoke meter. From no load to maximum load, the experiments were conducted again with different loads.

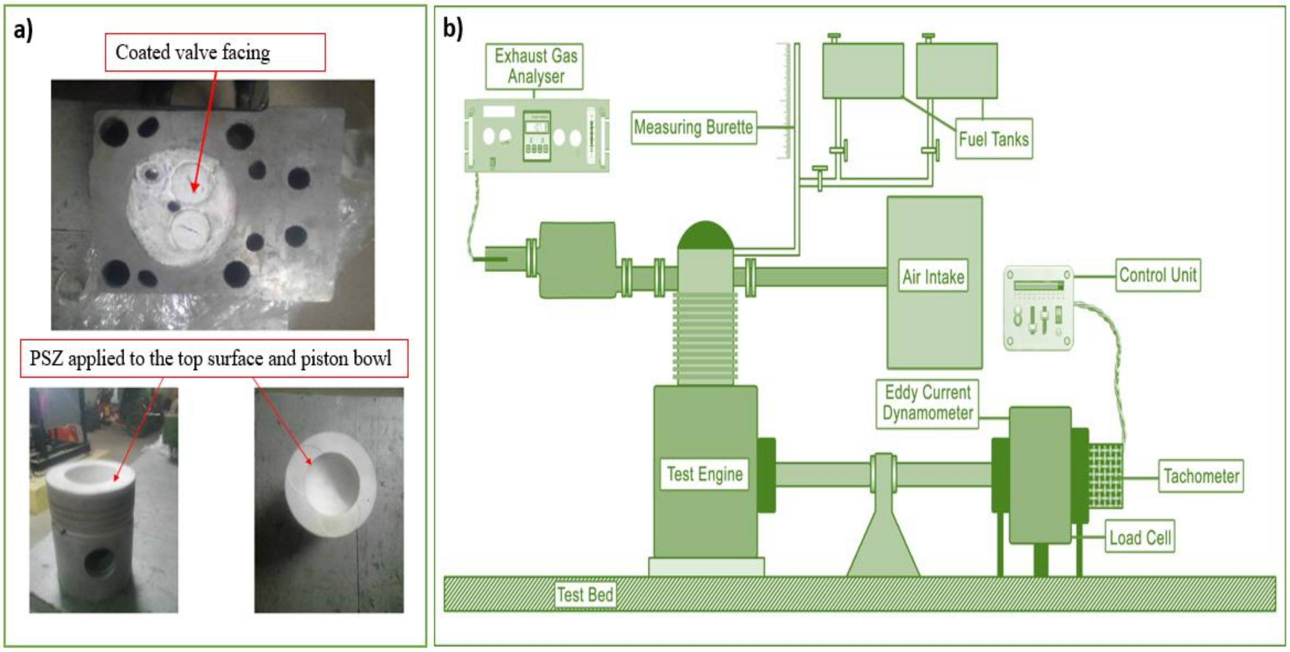

Fig. 1. a). Cylinder head and piston bowl; **b).** Experimental setup with exhaust gas recirculation.

Table 1 Detailed Kirloskar makes diesel engine specification

Type	**Four strokes, Direct Injection diesel engine**
Make	Kirloskar TAF – 1
Bore and Cooling type	87 mm and air-cooled engine
Stroke	112 mm
Compression ratio	17.5:1
Rated power and speed	5.2kW at 1500 rpm
Injection timing	23 deg before Top Dead Center (static)
Number of nozzles and spray hole diameter	3 and 0.3 mm
Piston geometry	Hemispherical
Swept volume	661 cc

Table 2. Uncertainty of various parameters

Parameters	Uncertainty (%
Load	0.2
Speed	0.3
Pressure	0.3
Temperature	0.3
Crank angle	0.2
Mass flow rate for hydrogen	0.3
Brake thermal efficiency	0.5
Brake specific fuel consumption	0.6
Oxides of Nitrogen	0.8
Carbon Monoxide	0.03
Unburnt Hydrocarbon	0.12

Table 3 effects on fuel properties of GGME and its blends

Test fuel properties	**Units**	**ASTM D6751**	**Diesel**	**Syzygium cumini**	**B20**
Density @ 15ºC	g/cm^3	0.858	0.831	0.886	0.837
Viscosity @ 40ºC	mm^2/s	1.9-6.0	3.2	5.14	3.9
Flash Point	ºC	Min.130	70	181	86
Cetane Number	-	Min.47	46	57	50
Higher heating value	MJ/kg	-	43.82	39.88	42.12

4. Results and Discussion

4.1 Performance characteristics

4.1.1 Brake Thermal Efficiency

Figure 2 depicts the relationship between BTE and brake power. A ceramic-coated retarded injection timing engine running on Garcinia Gummi-Gutta biodiesel had a BTE of 1.86 per percent and 5.73 per percent at maximum load. When recirculation ratios of 10 and 20% were used, exhaust gas recirculation was greater. The thermal efficiency of all fuels is reduced by EGR, according to the results. Saravanan (2020) suggests that it might be due to diluents lowering the flame temperature.

4.1.2 Brake Specific Energy Consumption

Figure 3 displays the load-dependent variation in the BSEC. Garcinia Gummi-Gutta Biodiesel has a BSEC of 13.06 MJ/kW-hr when run at maximum load in a ceramic-coated retarded injection timing engine. Additionally, the BSEC for ceramic-coated (LHR) retarded engines offers EGR rates of 10% and 20% and respective MJ/kW-hr values of 12.09 and 12.55. BSEC decreases in EGR as intake charge temperatures rise. The amount of fuel burnt per unit time decreases BSFC (Mani et al 2010).

4.3 Exhaust gas temperature

In Figure 4, exhaust gas temperature changes as EGR flow rates vary. As EGR amounts increase, the exhaust gas temperature decreases at all loads. A ceramic-coated retarded injection timing engine with Garcinia-Gum-Gutta biodiesel had an exhaust gas temperature of 403°C at maximum load and 438°C at minimum load. In this study, the exhaust gas recirculation rate was higher than in engines with a recirculation rate of 10% and 20%, respectively. In Pratap Kulkarni (2017), an increase in EGR within an engine cylinder causes a decrease in exhaust gas temperature.

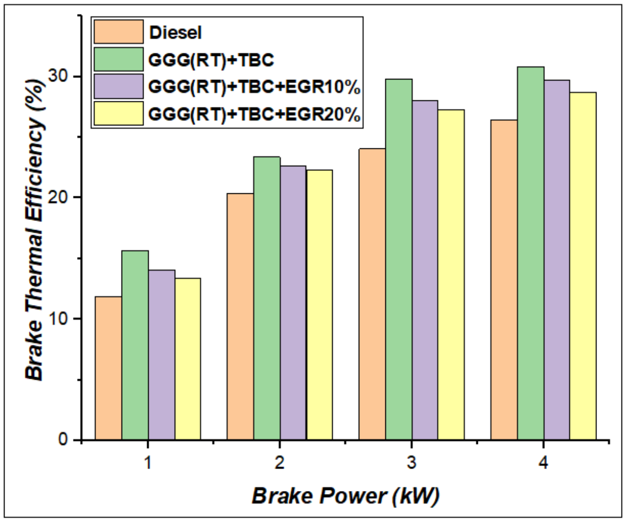

Fig.2. BTE vs BP

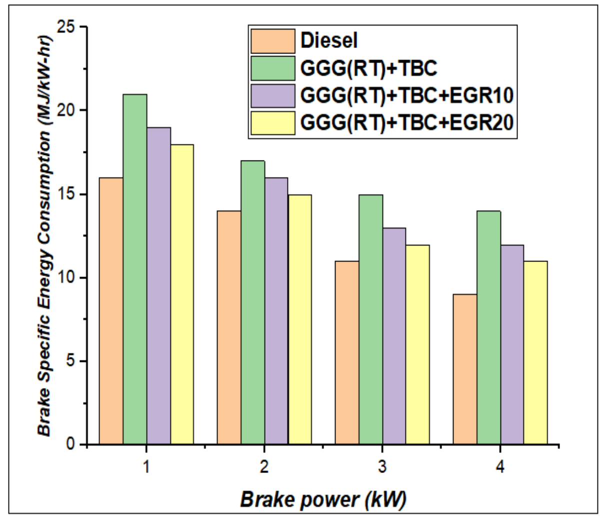

Fig.3.BSEC vs BP

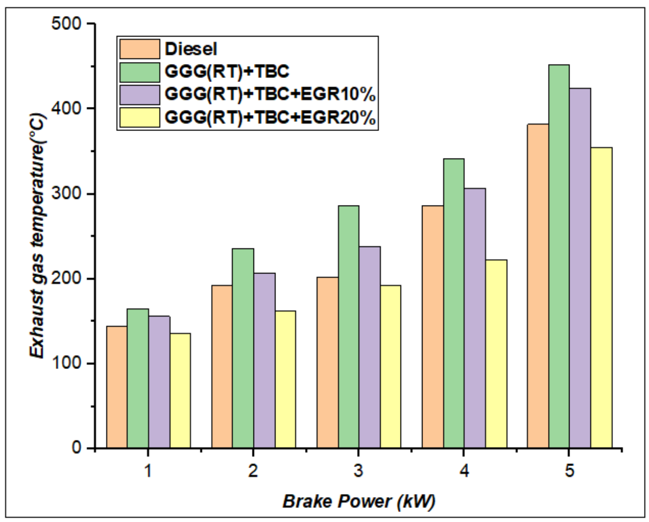

Fig.4.EGT vs BP

4.2 Emissions characteristics

4.2.1 Oxides of nitrogen emission

Fig. 5 shows the change in nitrogen oxide emission with load for various EGR percentages. On a biodiesel engine powered by Garcinia Gummi-Gutta, NO_x emissions were 13.5 grammes per kilowatt-hour at maximum load. For ceramic-coated (LHR) retarded engines with 10% and 20% EGR, there were 11.2 g/kWh and 10.1 g/kWh of NO_x emissions, respectively. Due to the presence of inert gases (CO_2 and H_2O), NO emissions decrease as the proportion of EGR increases. A combustion chamber's peak temperature is lowered, and oxygen is replaced by these gases by absorbing the energy generated during combustion. As the temperature and oxygen levels decrease, NO_x is reduced (Saravanan et al 2013).

4.2.2 Carbon monoxide emission

Figure 6 shows carbon monoxide emissions when Garcinia Gummi-Gutta biodiesel is used at different EGR percentages. This graph shows the CO emission rate of the ceramic-coated retarded injection timing engine at maximum load of 5.07 g/kWh. Similarly, CO emissions were 6.44 and 6.90 g/kWh for ceramic-coated retarded engines at ten and twenty percent EGR rates, respectively. As EGR rates rise, carbon monoxide emissions rise as well. Parlak (2003) suggests that incomplete combustion may be caused by the replacement of some oxygen in the input charge with recirculated exhaust gas.

4.2.3 Unburned hydrocarbon emission

With various EGR quantities and loads, Figure 7 illustrates how unburned hydrocarbon emissions fluctuate. The UBHC emissions from ceramic-coated retarded injection timing engines are 0.492 g/kWh at full load, as shown in Figure 1. The emissions from a ceramic-coated (LHR) retarded engine with 10 and 20 percent EGR rates and 0.527 and 0.553 g/kWh, respectively, were also measured. Ekrem (2006) found that increasing the EGR rate results in higher levels of unburned hydrocarbons.

4.2.4 Smoke emission

Figure 8 illustrates how load affects smoke levels at varying EGR percentages. The ceramic-coated retarded injection timing engine's maximum smoke emission is depicted in the figure as 3.19 BSU. For ceramic-coated (LHR) retarded engines with 10% and 20% EGR rates, the corresponding smoke emissions are 4.63 BSU and 4.37 BSU, respectively. More smoke is produced as combustion becomes unstable as exhaust gases partially replace the air. According to Ramadhas (2008), EGR raises the volume of smoke.

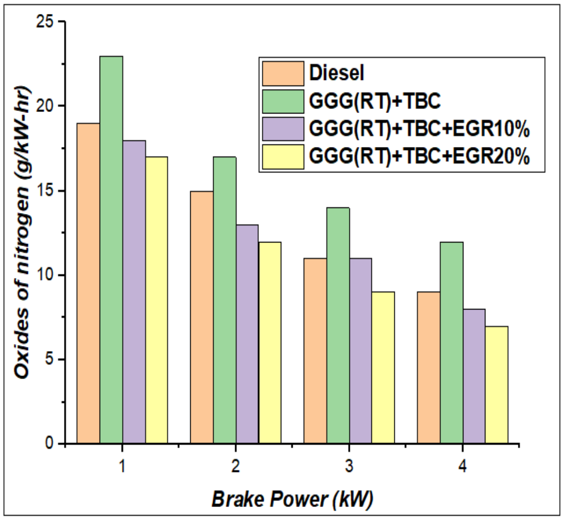

Fig.5.NOx vs BP

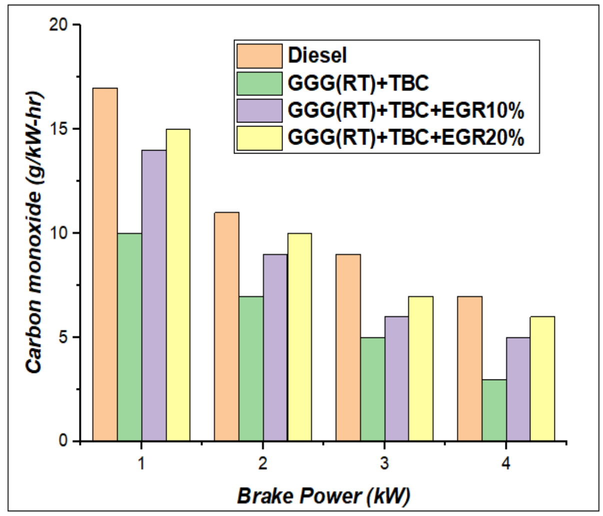

Fig.6. CO vs BP

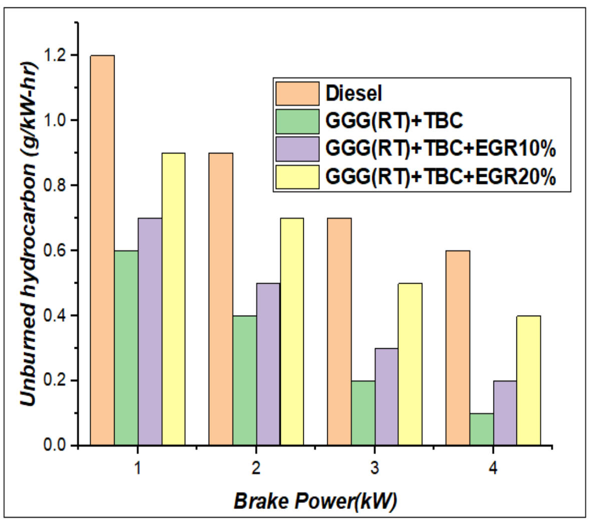

Fig.7. UBHC vs BP

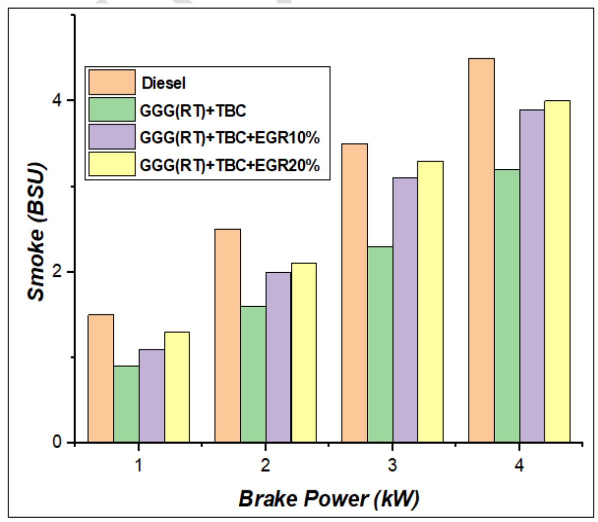

Fig.8. Smoke vs BP

4.3 Combustion characteristics

4.3.1 Ignition Delay

In Garcinia Gummi-Gutta Biodiesel oil and diesel, Fig. 9 demonstrates the fluctuation of ignition delay with an optimal EGR of 20% at full load. At maximum load, ceramic-coated retarded injection timing engines had an ignition delay of 3.54 percent and 7.33 percent, respectively. The exhaust gas recirculation rate was higher than those with 10 and 20%. During higher braking power, fuel vaporisation was increased due to higher temperatures inside the cylinder, resulting in a short chemical delay.

4.3.2 Cylinder pressure crank angle diagram

The change in pressure for Garcinia Gummi-Gutta biodiesel and diesel is shown in Fig. 10, with an optimal EGR of 20%. In comparison to engines with 10% and 20% exhaust gas recirculation rates, respectively, the peak pressure produced by a delayed timing LHR engine running on GGG fuel is 43.7 and 8.12 percent greater. Serio (2017) reports that recirculated exhaust gases lower combustion chamber temperatures by absorbing heat during combustion.

4.3.3 Heat release rate

Figure 11 shows that, with retarded timing, the highest heat release rate of the Garcinia Gummi-Gutta Biodiesel-powered LHR engine with retarded timing is 94 J/°CA, which is 7.63 percent and 14.27 percent higher than peak pressure observed with 10% and 20% EGR on the same engine. The peak heat release rate of EGR clearly illustrates this. As CO2 concentrations increase when EGR is incorporated, ignition delay is reduced significantly (Narayana Reddy et al 2006).

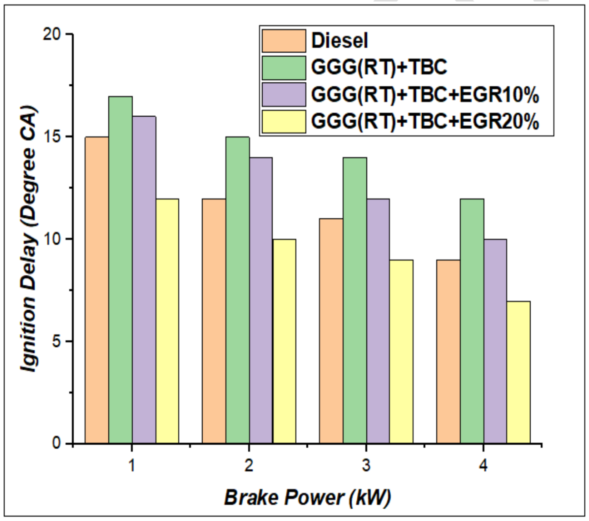

Fig.9. Delay Period vs BP

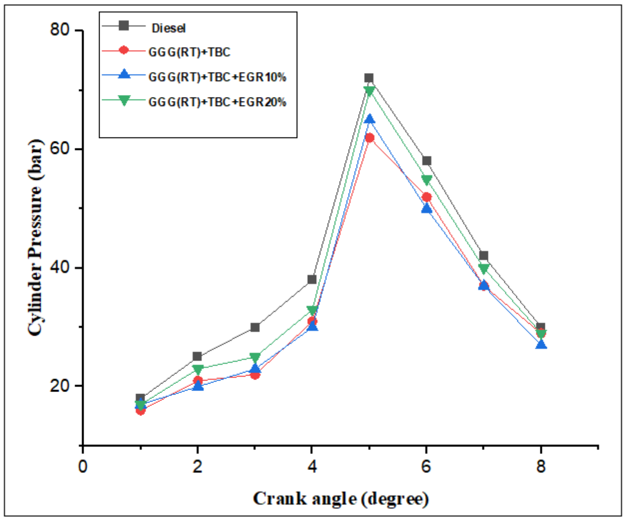

Fig.10. Cylinder Pressure vs Crank angle

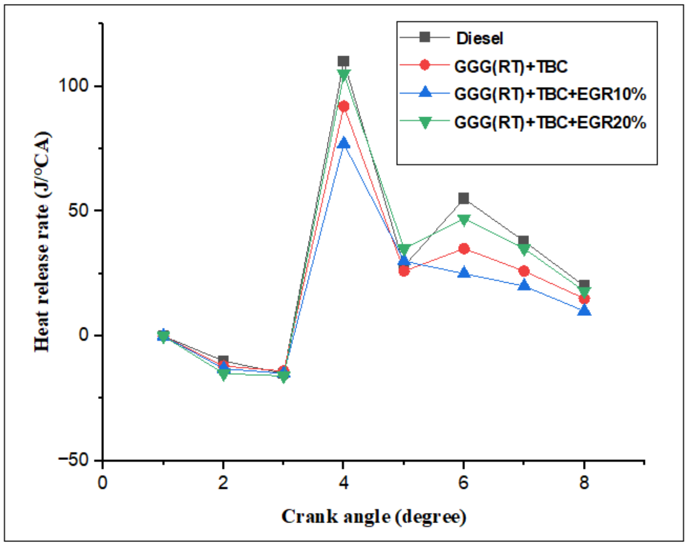

Fig.11.HRR vs Crank angle

Conclusion

The following are the key findings from the experiments using diesel and Garcinia Gummi-Gutta biodiesel oil, both with and without EGR:

- Without EGR, the brake thermal efficiency of a Garcinia Gummi-Gutta biodiesel-fuelled LHR engine with delayed timing ranges from 13% to 29%, compared to 14–26% with 20% EGR. With increased EGR flow rates at full load, brake thermal efficiency decreases due to high EGR percentages that result in more air replacement.
- Without EGR, Garcinia Gummi-Gutta Biodiesel emits 15.24 to 9.07 g/kWh of emissions, compared to 11.27 to 9.07 g/kWh with 20% EGR. Along with decreased peak combustion temperatures brought on by the presence of gases with greater heat capacities, NO_x emissions fall as the EGR percentage rises.
- In a Garcinia Gummi-Gutta Biodiesel LHR engine, the maximum heat was released. A 10% EGR rate produced 7.63 percent more peak pressure than a 20% EGR rate, which produced 14.27 percent more peak pressure. A decrease in fuel heat release behaviour is caused by burnt gases. In our situation, this also reduces heat release.

Further research and experimentation are necessary to validate these findings and optimize the blend composition for maximum performance and emission benefits. Additionally, the long-term durability and compatibility of the biodiesel blend with leaf extract additives should be investigated.

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