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AN IMPACT OF COMBUSTION CHAMBER GEOMETRY ON CHARARACTERSTICS OF A DIESEL ENGINE FUELLED WITH GARCINIA GUMMI-GUTTA METHYL ESTER (GGGME)

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Abstract. *Environmentally sustainable and renewable fuels present clear advantages over conventional petroleum-based fuels, offering improved energy utilization and helping to alleviate environmental and socioeconomic concerns. Their adoption in transport and power production supports cleaner energy transitions and assists in addressing emission-driven climate change challenges. In this investigation, combustion performance and emission characteristics were improved by redesigning the piston bowl geometry to intensify air–fuel interaction and in-cylinder turbulence. Three combustion chamber configurations were examined: a toroidal re-entrant combustion chamber (TRCC), a standard toroidal combustion chamber (TCC), and a shallow re-entrant combustion chamber (SRCC). The results obtained with diesel fuel were compared against those achieved using an optimized best fuel (BF) blend. The TRCC configuration exhibited the most favorable performance. It delivered a 4.85 % increase in brake thermal efficiency (BTE) and achieved significant emission reductions, including 41.6 % lower hydrocarbon (HC) emissions, 52.4 % reduction in carbon monoxide (CO), and 68.9% decrease in smoke opacity compared with diesel operation. These outcomes highlight the effectiveness of combustion chamber modification in enhancing engine efficiency while substantially reducing exhaust pollutants.*

Key words: *combustion chamber, geometry, Garcinia Gummi-Gutta methyl ester (GGGME).*

ВПЛИВ ГЕОМЕТРІЇ КАМЕРИ ЗГОРЯННЯ НА ХАРАКТЕРИСТИКИ ДИЗЕЛЬНОГО ДВИГУНА, ЩО ПРАЦЮЄ НА МЕТИЛОВОМУ ЕТЕРІ ГАРЦИНІЇ КАМБОДЖІЙСЬКОЇ (GGGME)

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Анотація. *Екологічно сталі та відновлювані види палива мають очевидні переваги порівняно з традиційним викопним паливом, адже дозволяють підвищувати ефективність використання енергії та сприяють зменшенню екологічних і соціально-економічних проблем. Їх використання у транспортній галузі й електроенергетиці забезпечує підтримку в процесі переходу до чистіших енергетичних систем і допомагає вирішувати проблеми зміни клімату, зумовлені викидами парникових газів. У цій роботі продемонстровано підвищення показників згоряння та зниження обсягів* *викидів завдяки зміні геометрії чаші поршня камери згоряння дизельного двигуна з метою інтенсифікації взаємодії повітряно-паливної суміші та турбулентності в циліндрі. У ході дослідження було проаналізовано три конфігурації камери згоряння: тороїдальну камеру згоряння з рециркуляційним виступом (TRCC), стандартну тороїдальну камеру згоряння (TCC) та неглибоку камеру згоряння з рециркуляційним виступом (SRCC). Результати, отримані під час роботи двигуна на дизельному паливі, порівнювалися з результатами, досягнутими при використанні оптимізованої суміші палива (BF). Найкращі показники продемонструвала конфігурація TRCC. У цьому випадку, ефективний термічний ККД зріс на 4,85 %, а також було досягнуто суттєвого зменшення викидів: обсяги викидів незгорілих вуглеводнів (HC) зменшилися на 41,6 %, оксиду вуглецю (CO) — на 52,4 %, при цьому також на 68,9% зменшився показник димності у порівнянні з подібним показником при роботі двигуна на дизельному паливі. Отримані результати підтверджують ефективність модифікації камери згоряння, що дозволяє підвищити ефективність роботи двигуна та істотно зменшити обсяги викидів забруднюючих речовин з відпрацьованими газами.*

Ключові слова: *камера згоряння, геометрія, метиловий етер олії гарцинії камбоджійської (Garcinia gummi-gutta) (GGGME).*

1. Introduction

Climate change and emission control remain pressing global challenges. The continuous rise in fuel demand and the widespread operation of internal combustion engines in transportation, agriculture, and industrial sectors have significantly intensified atmospheric pollution. Prolonged dependence on conventional diesel engines not only accelerates environmental degradation but also poses severe health risks to living organisms [1]. [2] performed experimental investigations on a direct injection diesel engine running at 2000 rpm, supported by CFD simulations. A standard combustion chamber (SCC) was compared with a modified combustion chamber (MCC). The modified design enhanced spray distribution within the piston bowl and improved evaporation characteristics. Consequently, noticeable reductions in NOx and CO emissions were achieved. When 7% hydrogen enrichment was introduced, higher in-cylinder temperature and pressure were observed. CO emissions decreased by 8.4%, while NOx showed a 2.5% reduction in diesel mode and nearly 28% variation with hydrogen supplementation. Enhanced flame speed and higher heat release rate (HRR) were also recorded with hydrogen blending. [3] optimized operating parameters in a Homogeneous Charge Compression Ignition (HCCI) engine. To prevent wall wetting, early split injections were adopted. The compression ratio was lowered from 18.0:1 to 15.5:1, and the spray cone angle was reduced from 150° to 65° to minimize wall impingement. Earlier injection timing improved brake thermal efficiency and advanced combustion phasing. A higher peak cylinder pressure was observed, while exhaust gas recirculation (EGR) helped reduce ignition delay and moderate combustion temperature. These combined modifications reduced NOx emissions and enhanced combustion stability. [4] studied the influence of re-entrant combustion chamber geometry on a diesel engine fueled with Pongamia oil methyl ester (POME). A toroidal re-entrant combustion chamber (TRCC) and a shallow depth re-entrant combustion chamber (SDRCC) of identical volume were compared with a baseline hemispherical combustion chamber (HCC). Experiments were conducted using B20 and neat POME. The TRCC with B20 demonstrated a 4.2% increase in BTE and a 3.8% reduction in BSFC. Emissions of PM, UBHC, and CO were reduced by approximately 22%, 18%, and 20%, respectively, although NOx emissions increased by 9%. Shorter ignition delay and higher peak pressure were observed for the TRCC design.

In a subsequent study [5], ultra-low sulfur diesel (ULSD) blended with 20% POME was evaluated under varied injection timings and combustion chamber geometries. The optimized TRCC configuration achieved a 6.15% improvement in BTE and a 5.2% decrease in BSFC compared to conventional diesel operation. However, NOx emissions rose by about 13%, highlighting the efficiency–NOx trade-off. [6] experimented with a ternary fuel blend enriched with Al_2O_3 nanoparticles, referred to as high-performance fuel (HPF), in a single-cylinder diesel engine. TRCC geometry was tested with injection timings of 20°, 21°, 22°, and 23° bTDC. The highest BTE of 34.6% was obtained at 21° bTDC, compared to 32.9% for diesel in HCC mode. Lower BSEC values were recorded for HPF-TRCC21. HC and CO emissions decreased by 11.4% and 19.2%, respectively. Peak cylinder pressure reached 78.6 bar, with a maximum HRR of 88.7 J/deg CA. [7] further assessed TCC, TRCC, and SDRCC geometries using B20 POME without altering compression ratio. The toroidal combustion chamber (TCC) exhibited a 3.5% higher BTE than other geometries and reduced HC and CO emissions by nearly 17% and 15%, respectively. However, NOx emissions increased by 8%. Improved combustion characteristics were consistently observed under full-load conditions. [8] investigated spray structure, fuel motion, and emission behavior through combined experimental and numerical analysis. By modifying injection pressure and spray angle in re-entrant piston bowls, enhanced swirl and turbulence were achieved. Multi-swirl piston bowl (MSPB) and double-swirl bowl (DSB) configurations resulted in nearly 76% reduction in HC, CO, and soot emissions collectively. However, NOx increased by around 12% due to elevated combustion temperatures. [9] examined Calophyllum inophyllum methyl ester (CIME) in a diesel engine and identified B20 as the optimum blend under hemispherical combustion chamber conditions. A modified hemispherical combustion chamber (MHCC) was later introduced and analyzed using ANSYS Fluent simulations. The MHCC configuration improved BTE by 3.9% and reduced emissions compared with the conventional HCC. [10] developed a CFD model and validated it experimentally in a common rail direct injection (CRDI) engine. Various in-cylinder modification strategies, including optimized injection timing, multiple injection schemes, combustion chamber redesign, and EGR, were tested individually and in combination. The optimized combination reduced NOx by 21% and soot by 18%, while improving overall efficiency. [11] tested a ternary diesel–biodiesel–ethanol blend doped with Al_2O_3 nanoparticles (HPF) in TRCC, SDRCC, and TCC geometries. The TRCC configuration achieved a 13.2% increase in BTE and an 8.9% improvement in fuel economy compared with diesel baseline operation. CO emissions decreased by 35.8%, HC by 22–38%, and smoke by 16.5%. Increased HRR and peak pressure were attributed to superior atomization and enhanced air–fuel mixing within the re-entrant chamber. The present study aims to further enhance combustion performance using an optimized Best Fuel (BF) diesel blend combined with a toroidal re-entrant piston bowl geometry. Key combustion parameters, including in-cylinder pressure variation with crank angle, maximum rate of pressure rise, ignition delay, and emission characteristics, are evaluated and compared against diesel operation in a conventional hemispherical combustion chamber. This comparative assessment provides deeper insight into the impact of combustion chamber optimization on engine performance and emission reduction.

2. Materials and Methods

2. 1 Garcinia Gummi-Gutta Biodiesel Oil Preparation

The biodiesel derived from Garcinia gummi-gutta is obtained from the oil extracted from the seeds of Garcinia gummi-gutta (Malabar tamarind). Ripe fruits are harvested, and the seeds are separated, washed, and dried in the sun to evaporate the moisture. The dried seeds are crushed, and the oil is extracted either by expeller or solvent extraction using n-hexane. The extracted oil is filtered and heated to evaporate the remaining moisture. The raw oil has high viscosity; hence, it is converted to biodiesel through a transesterification reaction. In this reaction, the raw oil is heated to 55–60°C and mixed with methanol in the presence of a catalyst such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). The mixture is stirred for 60–90 minutes and left to settle, separating into two distinct layers: biodiesel (top layer) and glycerol (bottom layer). The biodiesel is separated, washed with warm distilled water to remove contaminants, and dried to produce clear FAME, which can be used in diesel engines or blended with conventional diesel fuel.

Table 1. Physical Properties of Garcinia gummi-gutta Biodiesel

Property	Diesel	Garcinia Biodiesel (Typical)	Effect on Engine
Density (kg/m³)	820–840	870–890	Higher density increases injected fuel mass
Kinematic Viscosity (mm²/s at 40°C)	2–4	4.5–5.8	Higher viscosity affects atomization
Calorific Value (MJ/kg)	42–45	36–39	Slightly lower → higher fuel consumption
Flash Point (°C)	50–70	150–170	Safer storage and handling
Cetane Number	45–50	50–55	Better ignition quality
Cloud Point (°C)	−5 to 5	8–15	Poor cold flow properties
Pour Point (°C)	−15 to 0	5–10	May cause cold-start issues

2.2 Combustion Chamber Modification

The piston crown is designed with a bowl-shaped cavity to promote efficient air–fuel blending, intensify in-cylinder swirl and turbulence, and thereby achieve more complete combustion. The configuration of this cavity plays a decisive role in governing spray behavior, flame development, and overall engine performance. For this investigation, four distinct combustion chamber geometries were analyzed: the conventional hemispherical combustion chamber (HCC), the toroidal re-entrant combustion chamber (TRCC), the toroidal combustion chamber (TCC), and the shallow depth re-entrant combustion chamber (SDRCC). These designs were selected to evaluate their influence on combustion efficiency and emission characteristics. A visual comparison of the different piston bowl configurations is presented in Fig. 1.

3. Experimental setup

The experimental investigation was carried out using a single-cylinder, four-stroke, air-cooled, direct injection stationary research engine. The engine was integrated with a range of measuring instruments to evaluate fuel performance, combustion behavior, and emission characteristics. Engine tests were performed under variable loading conditions using an electrical eddy current dynamometer. The load was applied from no-load (0%) to full-load (100%) in steps of 25% to ensure systematic performance evaluation. To measure in-cylinder pressure and to determine the heat release rate, a pressure transducer was mounted on the cylinder head in conjunction with a MICO fuel injector assembly. Exhaust emissions, including hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx), were quantified using a QRO-402 exhaust gas analyzer. Smoke opacity was measured with an AVL 437C smoke meter.

The complete arrangement of the experimental setup is illustrated in Fig. 2. SAE 100 grade lubricating oil was used to minimize friction and wear between the engine's moving components during operation.

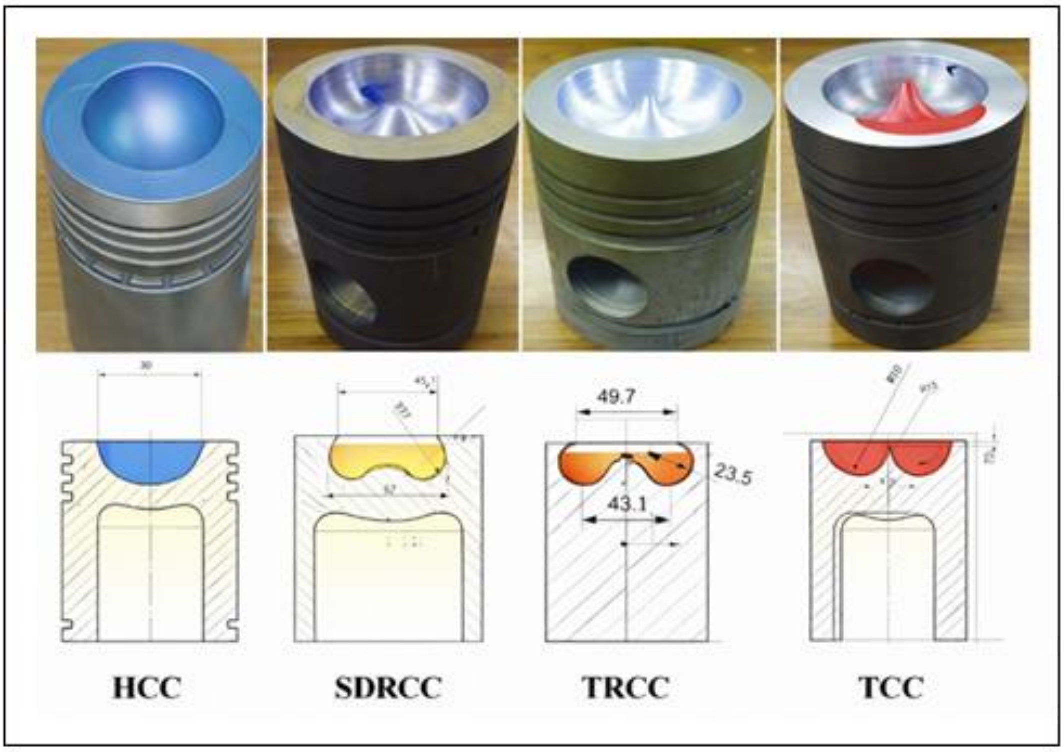

Fig. 1. Modified combustion chambers

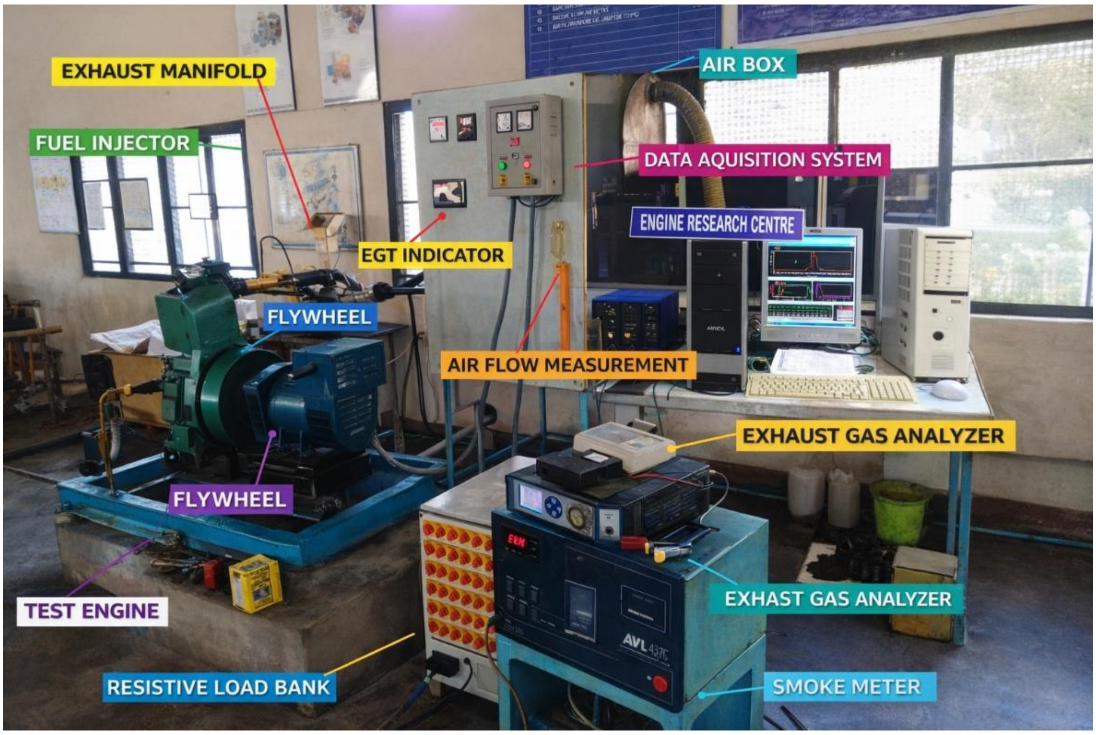

Fig. 2. Layout of experimental setup

4. Results and Discussion

The experimental study was carried out using redesigned piston bowl configurations, and the corresponding findings are presented in the following sections. In addition to the standard hemispherical combustion chamber, three alternative geometries were evaluated: the shallow depth re-entrant combustion chamber (SDRCC), the toroidal re-entrant combustion chamber (TRCC), and the toroidal combustion chamber (TCC). To ensure a fair comparison, the compression ratio was maintained identical for all combustion chamber designs. The photographic and schematic representations of these piston bowl configurations are provided in Fig. 1. The modified geometries enhance in-cylinder air motion and promote the recirculation of fuel-rich mixtures toward the active flame region, thereby supporting more efficient combustion. The Best Fuel (BF) blend was tested in each of these combustion chambers, and the resulting performance, combustion, and emission characteristics were comparatively analyzed.

4.1 PERFORMANCE CHARACTERISTICS

The variation of brake thermal efficiency (BTE) with engine load for biodiesel fuel (BF) under different combustion chamber configurations is illustrated in Fig. 3. It is evident that combustion chamber geometry significantly influences engine performance characteristics. In addition to the standard hemispherical combustion chamber (HCC), three modified chamber designs demonstrated superior efficiency. The maximum BTE values recorded were 31.3% for the Shallow Depth Re-entrant Combustion Chamber (SDRCC), 31.5% for the Toroidal Combustion Chamber (TCC), and 31.6% for the Truncated Re-entrant Combustion Chamber (TRCC). The enhanced efficiency observed in the modified chambers can be attributed to improved in-cylinder air motion. The re-entrant configurations intensified squish flow and generated stronger swirl motion, thereby increasing turbulence intensity and promoting rapid mixing between air and fuel droplets. This improved atomization and vaporization process resulted in more complete combustion and higher thermal efficiency. Among the tested geometries, TRCC delivered the highest BTE, followed by TCC and SDRCC. The superior performance of TRCC is primarily associated with its optimized re-entrant profile, which facilitates greater swirl strength and improved air–fuel interaction. These findings are consistent with previously reported studies that highlighted the positive impact of re-entrant combustion chamber designs on engine efficiency [12].

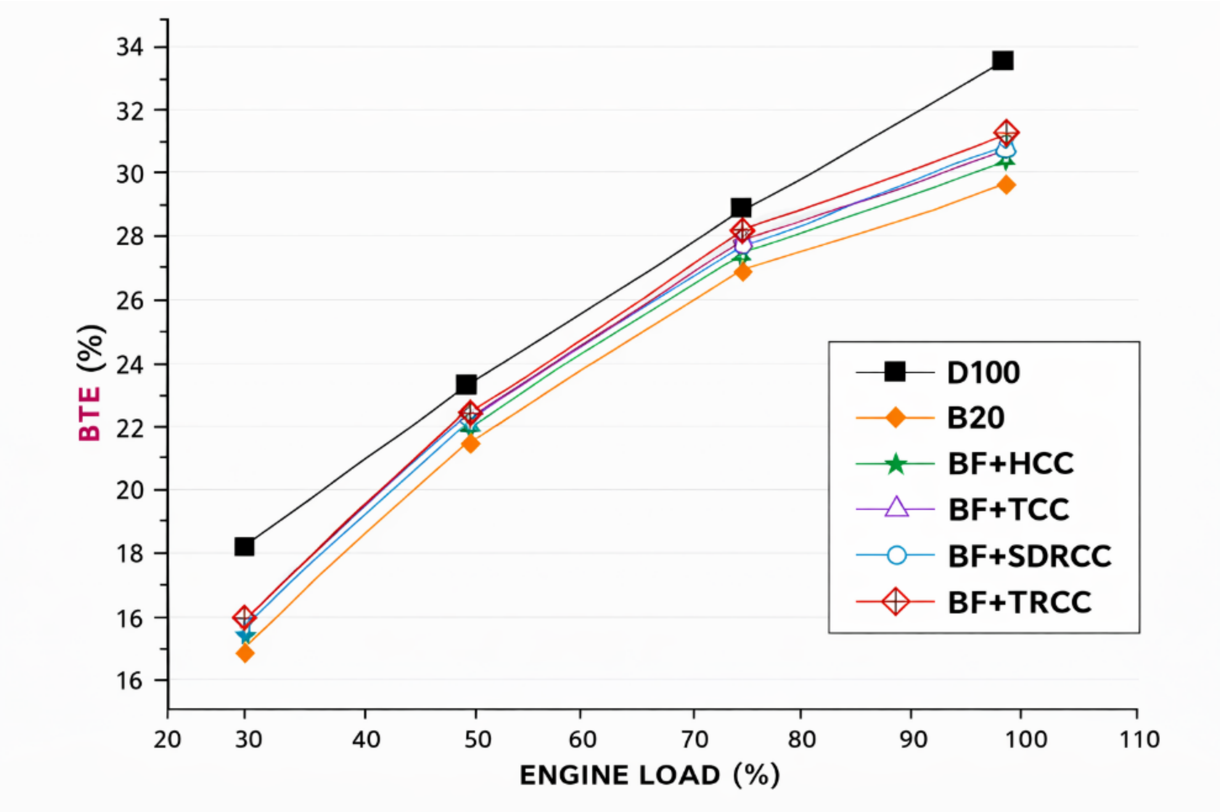

Fig. 3. BTE vs engine load

Brake specific fuel consumption (BSFC) exhibited a trend opposite to that of brake thermal efficiency, confirming their inverse relationship. The variation of BSFC for biodiesel fuel (BF) under different combustion chamber configurations is presented in Fig. 4. Among the tested geometries, the lowest fuel consumption at full load was observed with the Truncated Re-entrant Combustion Chamber (TRCC), followed by the Toroidal Combustion Chamber (TCC) and the Shallow Depth Re-entrant Combustion Chamber (SDRCC). The reduction in BSFC for the modified chambers can be attributed to enhanced in-cylinder air motion and improved charge circulation characteristics. The re-entrant design promotes effective recirculation of the air–fuel mixture toward the central combustion region, intensifying turbulence and facilitating superior mixing. This enhanced atomization and combustion efficiency lead to more complete energy conversion, thereby lowering the quantity of fuel required to produce the same power output. Based on fuel economy considerations, TRCC demonstrates the most favorable performance among the investigated configurations. The observed pattern aligns with findings reported in earlier experimental investigations, which highlighted the positive influence of re-entrant combustion chamber geometries on fuel consumption characteristics [13].

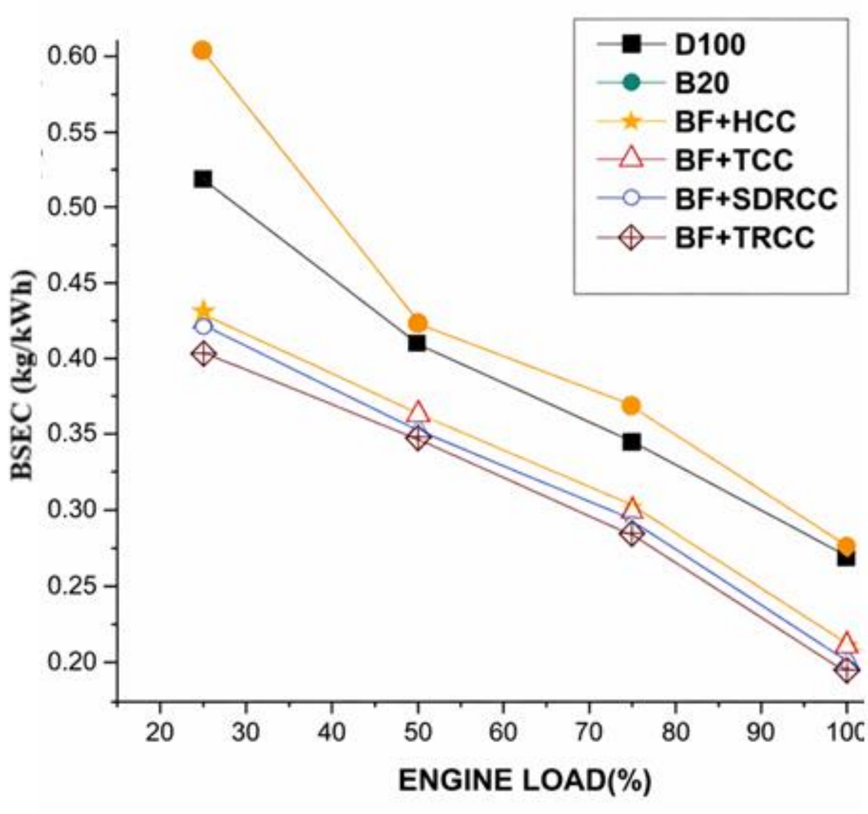

Fig. 4. BSFC vs engine load

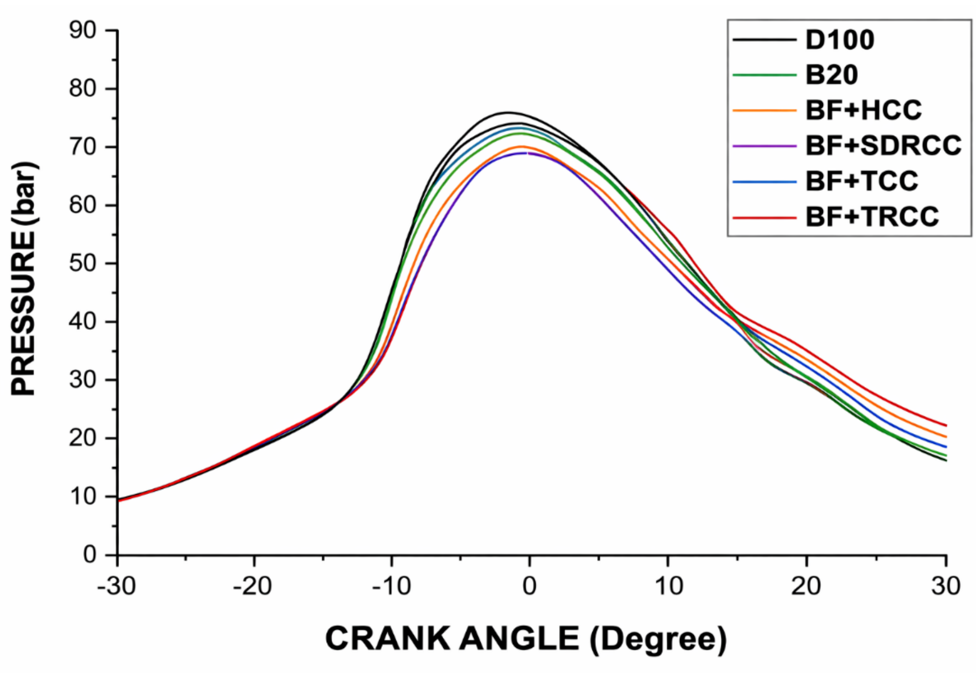

Fig. 5. Pressure vs crank angle

4.2 COMBUSTION CHARACTERISTICS

Fig. 5 illustrates the in-cylinder pressure characteristics of the test fuel under different combustion chamber geometries across varying engine loads. Among the configurations evaluated, the Truncated Toroidal Re-entrant Combustion Chamber (TRCC) recorded the highest peak pressure, reaching 78.2 bar. The modified chamber designs consistently produced higher maximum cylinder pressures compared with the baseline combustion chamber operating with biodiesel fuel. The improved pressure development in the modified geometries can be attributed to enhanced in-cylinder air motion and superior charge preparation. The re-entrant designs intensified swirl and tumble flows, promoting rapid fuel evaporation and improved spray dispersion. This strengthened turbulence level facilitated efficient atomization and more homogeneous air–fuel mixing, leading to a faster and more complete combustion process, thereby increasing peak pressure. In contrast, the comparatively lower peak pressure observed in the Toroidal Combustion Chamber (TCC) and Hemispherical Combustion Chamber (HCC) can be linked to weaker squish intensity within the piston bowl. Reduced squish limits turbulence generation near top dead center, resulting in comparatively slower combustion and lower maximum pressure rise. The overall trend observed in this study corresponds with previously reported experimental findings in the literature [14].

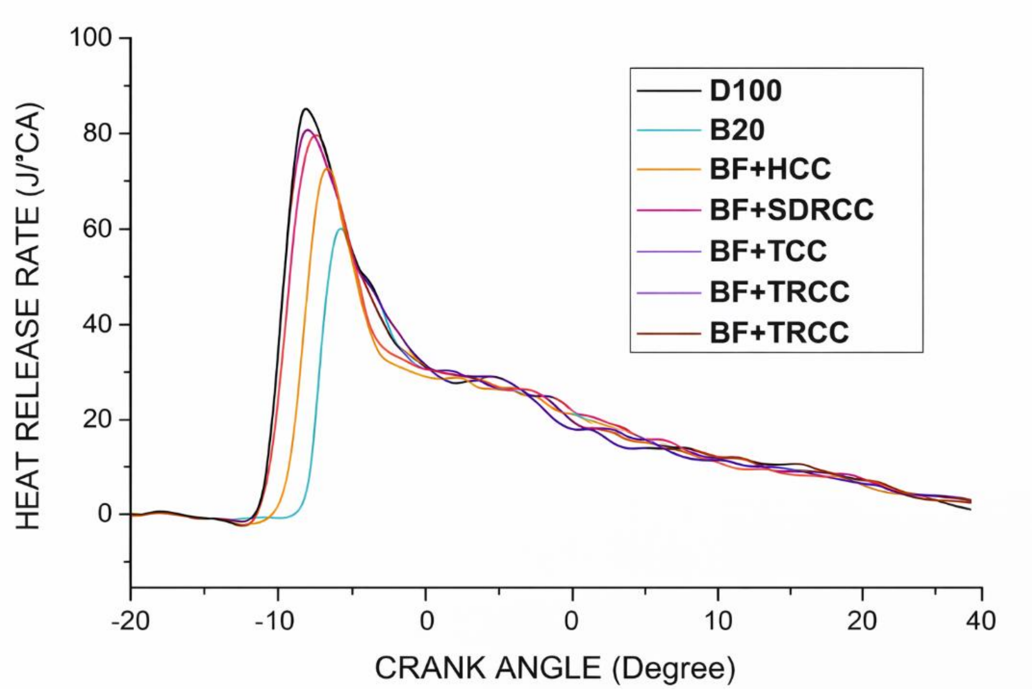

Fig. 6. HRR vs crank angle

Fig. 6 presents the heat release rate (HRR) characteristics of biodiesel fuel (BF) under different combustion chamber configurations at varying engine loads. Among the tested geometries, the Truncated Re-entrant Combustion Chamber (TRCC) exhibited the highest peak HRR of 80.25 J/°CA, followed by the Toroidal Combustion Chamber (TCC) with 79.3 J/°CA and the Shallow Depth Re-entrant Combustion Chamber (SDRCC) with 77.13 J/°CA. The elevated HRR observed in the modified combustion chambers is primarily attributed to intensified in-cylinder air motion. The re-entrant piston profiles enhanced swirl intensity along the direction of airflow, promoting rapid mixing between fuel droplets and air. This improved turbulence shortened the ignition delay period and accelerated the premixed combustion phase, resulting in a sharper and higher peak heat release. Furthermore, the favorable physicochemical properties of the biodiesel fuel, including optimized viscosity, higher cetane number, suitable density, and appreciable calorific value, contributed to efficient combustion behavior. These properties supported improved spray atomization, vaporization, and flame propagation, thereby increasing the rate of energy liberation during combustion. Consequently, the BF–TRCC configuration demonstrated superior HRR performance compared with the other chamber designs. The trend observed in this investigation aligns with earlier experimental findings reported in the literature.

4.3 EMISSION CHARACTERISTICS

Fig. 7 illustrates the hydrocarbon (HC) emission characteristics of biodiesel fuel (BF) when operated with different combustion chamber geometries, namely SDRCC, TRCC, TCC, and the conventional Hemispherical Combustion Chamber (HCC). The baseline HCC configuration exhibited comparatively higher unburned hydrocarbon emissions than the modified piston bowl designs. In contrast, all re-engineered combustion chambers demonstrated a noticeable reduction in HC levels across the operating range. Among the tested configurations, SDRCC, TCC, and TRCC produced lower hydrocarbon emissions not only compared to the conventional diesel operation but also relative to the B20 blend. The reduction in HC emissions can be attributed to two primary factors. First, the inherent oxygenated nature of the biodiesel fuel promotes more complete oxidation of hydrocarbons during combustion. Second, the re-entrant piston geometries, particularly in the TRCC design, intensified swirl and turbulence inside the cylinder. This enhanced air–fuel interaction improved atomization, vaporization, and mixture homogeneity, thereby minimizing the presence of unburned fuel fragments in the exhaust. The TRCC configuration, owing to its stronger swirl generation and improved in-cylinder charge motion, exhibited the lowest HC emission among the tested chamber designs. The overall emission behavior observed in this study is consistent with trends reported in earlier experimental investigations.

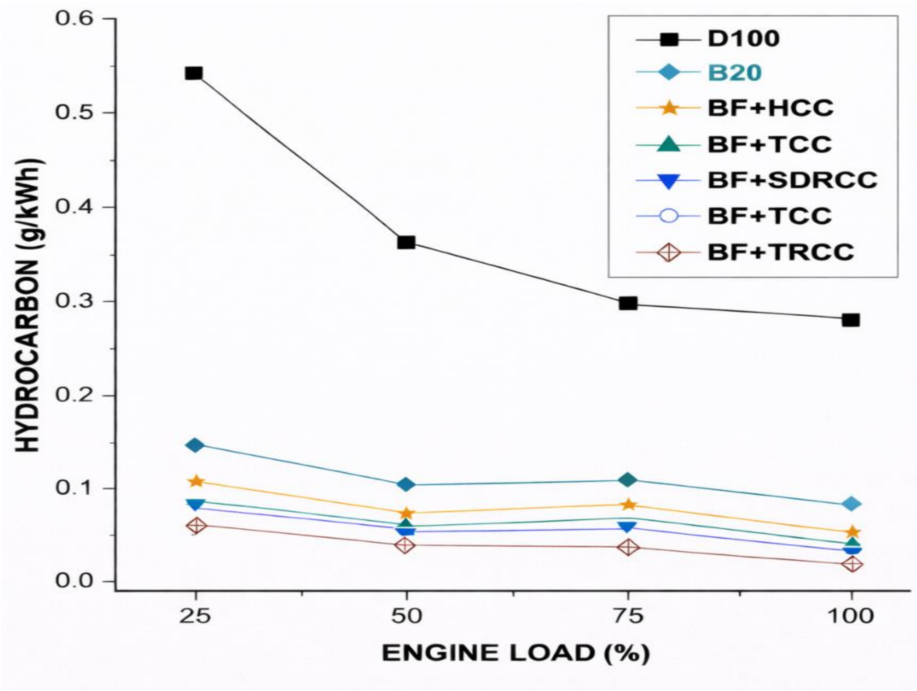

Fig. 7. HC vs engine load

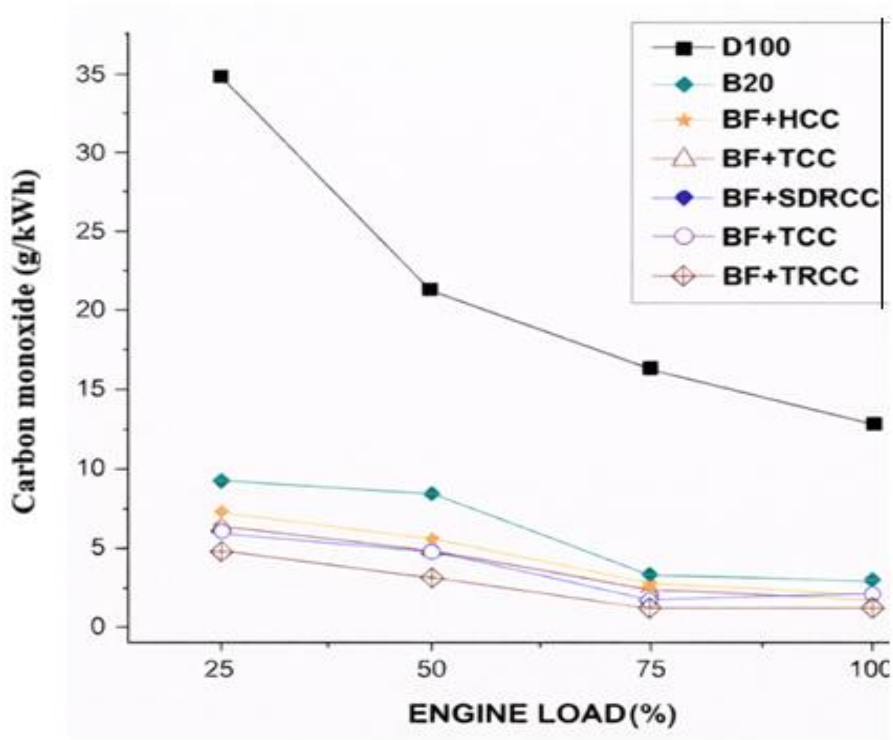

Fig. 8. Carbon monoxide vs engine load

Fig. 8 presents the carbon monoxide (CO) emission characteristics of biodiesel fuel (BF) under various combustion chamber configurations. The modified piston bowl geometries demonstrated noticeably lower CO emissions compared with the conventional chamber design. Among them, the Truncated Re-entrant Combustion Chamber (TRCC) recorded the minimum CO levels across the tested operating conditions. The reduction in CO emissions can be attributed to improved in-cylinder oxidation processes. Enhanced air–fuel mixing within the re-entrant chamber promoted more effective conversion of intermediate CO into carbon dioxide (CO_2), thereby limiting incomplete combustion products. In comparison with diesel operation, the SDRCC, TCC, and TRCC configurations operating with biodiesel showed a substantial decline in CO output. This improvement is primarily due to two factors: the inherent oxygen content present in biodiesel fuel and the intensified swirl and squish effects generated by the modified chamber geometries.

The re-entrant profile strengthened turbulent air motion near top dead center, shortened combustion duration, and facilitated more complete fuel oxidation. Consequently, incomplete combustion losses were minimized. The emission behavior observed in this study is consistent with trends previously reported in experimental investigations by other researchers.

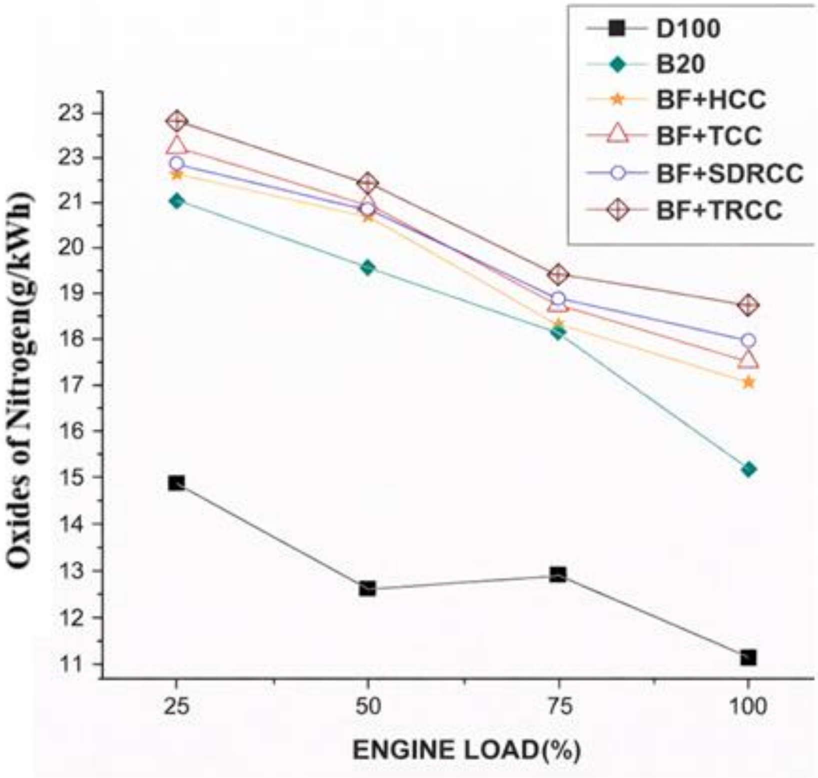

Fig. 9. Oxides of Nitrogen vs engine load

Fig. 9 illustrates the variation of nitrogen oxides (NOx) emissions for biodiesel fuel (BF) under different combustion chamber geometries across varying engine loads. The modified chamber configurations generally produced higher NOx levels compared to the baseline design, with the TRCC configuration exhibiting the maximum NOx emission among the tested geometries. The SDRCC also showed relatively elevated NOx values, while the TCC demonstrated comparatively lower NOx formation than the other modified chambers. The increased NOx observed in the TRCC configuration can be attributed to intensified swirl motion and higher turbulence levels within the cylinder. These enhanced in-cylinder flow characteristics promote rapid combustion and elevated peak temperatures, which favor thermal NOx formation. In contrast, the relatively weaker swirl intensity in the TCC geometry limits peak combustion temperatures and reduces the availability of high-temperature zones, thereby resulting in comparatively lower NOx emissions. Furthermore, the physicochemical properties of biodiesel fuel including its inherent oxygen content, higher cetane number, and lower viscosity contribute to improved combustion efficiency and elevated in-cylinder temperatures. While these properties enhance oxidation and overall combustion quality, they also create conditions conducive to increased NOx formation. The emission trends identified in this investigation are consistent with previously published experimental findings reported in the literature.

Fig. 10 presents the variation of smoke opacity with increasing engine load for the different combustion chamber configurations. The modified piston bowl geometries exhibited noticeably lower smoke emissions compared with conventional diesel operation. Among them, the TRCC configuration showed the most significant reduction, followed by TCC and SDRCC. The decline in smoke formation can be attributed to improved in-cylinder charge motion and enhanced combustion efficiency. The re-entrant chamber profiles intensified swirl and turbulence, promoting finer fuel atomization and more uniform air–fuel distribution. This improved mixture preparation minimized locally rich zones within the combustion chamber, thereby suppressing soot formation. The TRCC design, owing to its stronger swirl intensity and efficient combustion characteristics, achieved the lowest smoke opacity among the tested geometries. The emission behavior observed in this study is consistent with findings reported in earlier experimental investigations, which highlighted the effectiveness of optimized combustion chamber designs in reducing particulate and smoke emissions.

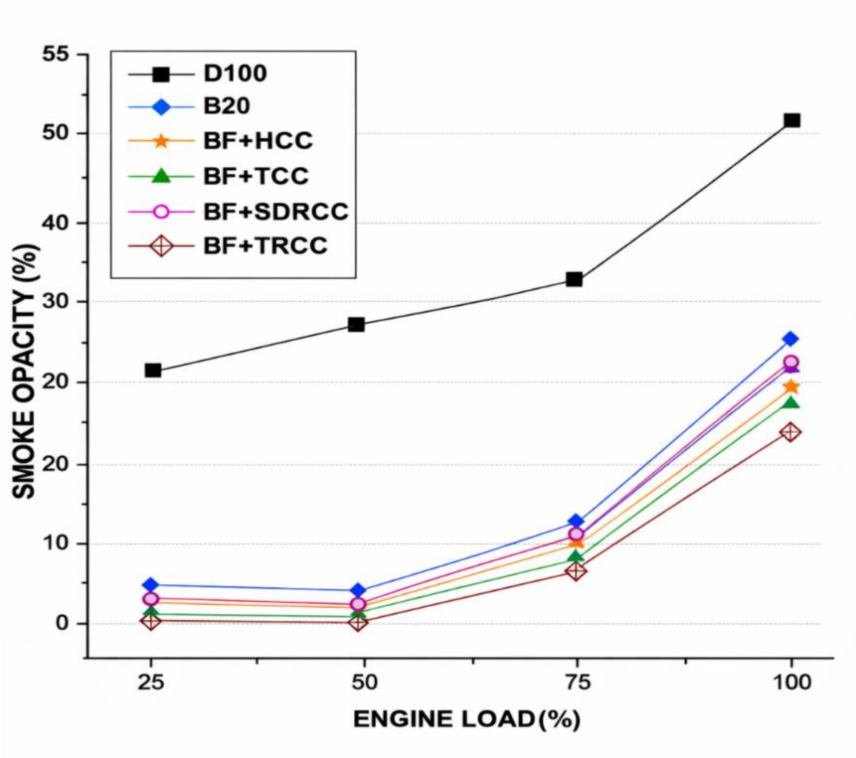

Fig. 10. Smoke vs engine load

Conclusions

Experimental investigations were carried out using three modified combustion chamber (CC) geometries: SDRCC, TCC, and TRCC, and their performance was evaluated while operating with biodiesel fuel (BF). All modified chamber designs demonstrated improved results compared with the conventional hemispherical combustion chamber.

- Among the tested configurations, the TRCC geometry delivered the most favorable performance characteristics. A noticeable improvement in brake thermal efficiency (BTE) was accompanied by a corresponding reduction in brake specific fuel consumption (BSFC). The enhanced performance can be primarily attributed to intensified in-cylinder swirl motion, which promoted superior air–fuel interaction and more efficient combustion.
- In terms of emission characteristics, the TRCC configuration also showed improved exhaust behavior when fueled with BF. A significant reduction in hydrocarbon emissions was observed compared with diesel operation. This improvement is associated with improved spray development, minimized wall wetting, and reduced fuel impingement on the combustion chamber surfaces, all of which contribute to more complete combustion.
- Based on the overall assessment of performance and emission parameters, the suitability of the combustion chamber geometries for biodiesel operation can be ranked in descending order as:

TRCC > TCC > SDRCC > HCC

This ranking confirms the effectiveness of re-entrant piston bowl modifications in enhancing biodiesel combustion characteristics.

Availability of data and materials

No datasets were generated, collected, or subjected to independent analysis as part of this study. Therefore, data sharing provisions are not applicable to the present work.

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Conflict of Interest

The authors certify that there is no conflict of interest.

Authors' contributions

Vinothkumar A. – Investigation**, Balu P.** – Supervision, **Saravanan C., Sokolovskyi O.** – Conceptualization, **Navaneetha Krishnan P.** – Visualization.

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