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COMBUSTION ANALYSIS OF METHYL ESTER FOR SPLIT INJECTION WITH SQUARE AND TANGENTIAL PISTON WITH 0% AND 10% EGR

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ABSTRACT

This paper deals with a combustion analysis of a compression ignition (CI) engine. The engine was fueled with behada, chicken fat oil, and turmeric oil methyl ester along with diesel fuel. Before undertaking the experimental investigations, a thorough study of the fuels must be conducted on fuel properties for instance viscosity, and calorific value. These properties of the fuels may affect the fuel's droplet size, size distributions, spraying characteristics, fuel evaporation, pressure, and temperatures. The properties of the methyl ester were tested as per ASTM standards. Now a day's, diesel engines from low-power applications to heavy-duty applications are intended to use electronically control management (ECM) operated injection systems. The use of a solenoid injector and pressure control valve (PCV) in this system assists in strategically injecting fuel which helps for control and shortens combustion even for methyl ester. In this present study, the CI engine was operated with direct injection at high pressure and a split injection strategy. The split injection operated angles are pilot injection 14 deg before top dead center (bTDC) (27% mass share) and main injection 7 deg bTDC (73% mass share) at 600 bar fuel injection pressure. Also, the engine with maximum compression ratio (CR)18, piston geometry (square and tangential groove), exhaust gas recirculation (EGR 0% and 10%), and fuels (B00 and B20) are operated with a split injection strategy. The combustion characteristics like combustion pressure, rate of pressure rise, net heat release rate, and maximum mean gas temperature, combustion event time (duration, time, and angle) are studied.

This study provides a comprehensive model which might help in the design process by predicting the performances and emissions of CI engines running using diverse fuels, such as methyl ester & Diesel. The experimental investigation showed that the split injection strategy for both piston geometry is favored during combustion. A diesel engine with B00 fuel with a square piston is showing complete combustion, while B20 fuel with tangential piston geometry is favored. In addition, 10% EGR assists in controlled combustion and emissions.

Keywords: Split injection, tangential and square groove, combustion characteristics.

I INTRODUCTION

The world would need to examine alternate fuels, especially for roads, as oil & gas stocks dwindle & global warming due to emissions of carbon dioxide (CO_2) become increasingly obvious. There had been a lot of research on the possibility of using vegetable oils as a fuel for automobiles. Straight vegetable oils (SVO) are a kind of vegetable oil that has not undergone any chemical processing to change its molecular structure and is suitably used in diesel engines without any changes. Many different processes may be used to create chemical compounds with shorter chain lengths, this category is called biodiesel.

Diesel engines have become a necessity in today's world. But it is a major source of air pollution in the atmosphere. That new perspective might foresee a plan to lessen environmental damage & energy shortage by switching from fossil fuels to renewable resources. Given their renewable nature & potential for efficient generation in remote locations, microalgae oils have emerged as a significant diesel alternative. The availability of a particular kind of microalgae oil in large quantities is a key factor in determining whether this oil is chosen as an alternative engine fuel. Microalgal oils were diverse, and they were becoming evaluated as potential alternatives for petroleum-based fossil fuels in engines across the globe. Many researchers have looked at different ways to boost efficiency & cutdown on emissions. Considering that it is sustainable & could be readily produced in faraway places with an immediate need for modern energy sources. Microalgae oils are a highly promising alternative to diesel fuels. Diesel, which may be fueled by microalgae oils, will undoubtedly help the developing countries which adopt them immensely. These might seem like science fiction, but they believe this the use of diesel engines would show a crucial part in the near and far future. Several countries having strong economies & plenty of land resources are interested in developing microalgae oils as an alternative to diesel fuels. Climate, land availability, competing uses, etc., are typical considerations for deciding which microalgae oils are best for diesel. Microalgae oils are like diesel oils in many respects, but they also have their own unique properties. Microalgae oils are generally recognized for having low volatility. The inability to employ it in direct ignition engines is a major drawback. In general, diesel engines are thought to be better suited to microalgae oil because of their primary properties.[10]

Due to the high levels of toxic pollutants formed during the combustion of fuel, several government agencies were aiming to end their usage or perhaps prohibit them entirely in metropolitan zones. Several diesel engine drivers, however, also responded furiously, claiming they purchased their vehicles because they were the "green" alternative. Because of their ability to "lean-burn" more air & fewer fuels, diesel can match the performances of their gasoline counterparts while reducing emissions. Nitrogen oxides (NOx) are produced when engine air is heated; they include the hazardous Nitrogen dioxide (NO_2), the greenhouse gas nitrous oxide (N_2O), & NOx, which reacts using oxygen (O_2) to produce NO_2. Nitric oxide has been heavily restricted for a long time because of the knowledge that prolonged exposure may greatly increase the risk of respiratory problems. Diesel engines' generation of tiny particulate matter contributes to cancer & may exacerbate respiratory problems.

Vegetable oil used culinary oil, & even animal fat may all be processed into biodiesel, which is a diesel engine alternative fuel. Renewable, energy-efficient, non-toxic, & biodegradable, biodiesels also call for better diesel combustions & reduce diesel engine emissions of greenhouse gases. To be more precise, the combustion of biodiesel produces zero net CO_2 emissions. This research aims to clarify how changes in fatty acids make up influence biodiesel's combustions properties. Exhaust gas emissions & biodiesel fuels qualities were studied, Diesel engines were often seen in vehicles and are also employed in the power industry.

Scientists & engineers working on engines are constantly refining & perfecting the engine's architecture & trying out other fuels including biodiesel, hydrogen-enriched fuels, and kerosene. The emissions of pollutants may be reduced without sacrificing performance if several techniques, like EGR & biofuels, were combined & tested. Diesel engine designs & development might benefit from modeling the many events occurring inside the engine using techniques like a quasi-modeling method.[1]

II LITERATURE REVIEW

Rajaman et.al. (2012) studied the advanced heavy-duty combustion systems (AHDCS), which make use of a lower cone angle and deeper piston bowl with a smaller rake angle and just a wider cylinder’s width is still under discussion. Depending on this parameterized study, a knowledge of the phenomenology behavior of the spray-bowl interactions will pave the way for further optimization of the combustion systems. This paper will study parameterized the effect of piston bowls shape & nozzle features on combustions systems’ performances. Following validating the 3D simulation models with experimental data, a Designs of Experiments (DoE) approach must be used to examine a matrix of pistons bowls using parameterized changes in geometry. Moreover, the influence of the tip cross-section area, hydraulically ml/min, size of openings,and their combos must be determined by carefully altering the parameter for selected cylinder basic configurations[1].

Chinmaya Mishra et.al. (2014) explores the relevance of biodiesel using non-edible vegetable oils in India, whereedible oil output is inadequate. This paper examines the use of non-edible oils extracted from Kusum seed. High levels of free fatty acids in the oils necessitated a two-stage esterification and transesterification procedure to make Kusum biodiesel (KB). Significant physicochemical parameters were tested& determined to adhere to the applicable ASTM/EN specifications. Different experimental fuels were developed for such preflight by combining 10%, 20%, 30%, and 40% by the concentration of KB with diesel engine; these lubricants were called KB10, KB20, KB30, and KB40, correspondingly. Adding additive to the trial fuel lowered the efficiency of both the rotors at higher loads by 3.8%, to approach 17%. [2].

Koli et.al. (2021) studied on biodiesels obtained using edible and non-edible oils. With the adjustment in fuel qualities suggesting an increase in the viscosity of the resulting biodiesels.Due to biodiesel's increased viscosity, the combustion mechanism was slowed, resulting in diminished performance metrics & increase engine emissions. To increase viscosity, preheating biodiesels before injections and identified enhanced performances, as shown by the rise in brake thermal efficiency, specific fuel consumption, and reliability [3].

Karthikeyan et.al. (2020) investigated the combustions properties of pilot-fueled engines were shown to be essentially identical to diesel. The ever need for energy causes an increase in dependence on fossil fuels. Lengthy energy protections are threatened by the decreasing nature of various energy sources & the increasing nature of power requirements. A major target of current research was to reduce pollutants and blend's higher viscosity. Chlorella Vulgaris oils with lesser viscosity added to turpentine oil will increase the fuel effectiveness of dual-fueled diesel. This paper details the results of an investigation done to examine the increase in burning and the attributes of diesel cars running on a mixture of Micro - algal oil and toluene oils. Data suggest the use of prototype fuels could also provide suitable in a normal diesel engine with no need for cylinder bending. The ideal fuel mixture for internal combustion engines was discovered to be a mixture of 50% microalgal oil with 50% Naphtha gas [4].

The purpose of an experiment conducted by Agbulut et.al. (2021) was to mitigate the deteriorated combustions and emissions of CI engines powered utilizing waste tyre pyrolysis oil-diesel mixture. In the tests, four fuels were evaluated. (1) diesel fuels, (2) 20% waste tyre pyrolysis oils 80% diesel fuels, (3) 10% pyrolysis oil & 80% diesel fuels with 10% waste biodiesel, & (4) 10% waste tyre pyrolysis oils & 80% diesel fuels with 10% waste fuel oil. These tests are performed using an engine speed of 2400 rpm and engine loads ranging between3 to 12 Nm in increments of 3 Nm. Using a mixture of waste tyre pyrolysis oils and diesel fuels reduces the thermal efficiency of the brakes by 9.13% compared to diesel fuels. However, that drop is mitigated by 7.50% &3.82%, respectively, when waste biodiesel & fuel oils were added to the blend [5].

The goal of studies conducted by Myo,et.al, (2008) was to assess the impact of concentration on the burning of biodiesel. In specifically, the fuels qualities & exhaust gas emissions of biodiesel were investigated, as well as theconstruction of a correlation program between fatty acids compositions & exhaust emissions. This research provides significant information on the characteristics of the combustion, fuel qualities, and Five varieties of methyl ester-type biodiesels, 5 kinds of pure fatty acids methyl esters (FAMEs), and 3 kinds of unsaturated FAMEs were analyzed for their exhausts [6].

Ranjithkumar et.al. (2020) aim to investigate the performances and emissions of direct-injections diesel engine powered by algae oils and Calophyllum Inophyllum oil (CIME). The viscosity of CIME & Algae oils was decreased by blending them with diesel fuel. The volumetric ratios of 20%, 40%, and 60% of CIME & Algae oil& Diethyl ether (DEE) were evaluated using diesel fuels. This whole universe faces 2 major crises: the depletion of fossil fuels & environmental deterioration. The decline in crude oil supplies & environmental concerns prompted the development of alternative fuels derived through a variety of bio-origin sources. CIME has garnered a great deal of interest lately due to its rapid growth rates and significant oil content [7].

The trials were led by Devan et.al. (2009) having the objective of determining the performances, emissions, & combustion powered by methyl ester of paradise oils (MEPS) & its diesel mixes. The emission research revealed that smoke & hydrocarbon emissions were significantly reduced by 33% & 22% for the MEPS 50 mix and by 40% & 27% for the MEPS 100 blending. There was a 5% & 8% rise in NOx emissions for MEPS 50 & 100, respectively. The thermal braking efficiency of MEPS & its diesel mixes is somewhat less than those of standard diesel [8].

Selim et.al. (2002) evaluated performances and combustions noises of indirect-injecting diesel engines running utilizing innovative fuels produced from jojoba oil, jojoba esters, and their mixtures with diesel oil. A compressed swirl engine was connected to monitor combustion pressures. & Its rising rate, in addition to other operational characteristics. Test settings were jojoba methyl ester concentration, engine speed, load, injection time, &compressing ratio. In terms of performance characteristics & combustion noise, the novel fuel obtained from jojoba was shown to be similar & a suitable alternative for gas oil in diesel under most operating situations [9].

Ethanol with jatropha methyl ester (JME) through port injections was studied by Kannan et.al. (2012) to regulate its outcome on the viscosity lessening & diesel engine performances. With viscosity change, its influence on combustion parameters like duration, ignitions delay, and emissions levels in diesel engines was investigated in depth. Because of the presence of excess oxygen in methyl ester, the chemical structures and physical properties, engine operating conditions, combustion parameters, and emissions levels are altered. However, by injecting just5% ethanol via port injections, diesel may be mixed using a total of 25% biofuels whilst retaining the properties of traditional diesel. However, experimental & theoretical investigations suggest that the addition of ethanol to JME-blended diesel increases fuel consumption & thermal efficiency was improved [10].

The consequence of injection pressure on the combustion, performance, and emissions characteristics of diesel having a piston that induces turbulence was examined by Lalvani et.al. (2014). Standard diesel & a 20% blend of adelfa biodiesel was employed throughout engine testing. Poor air-fuel mixing characteristics & the higher viscosity of the testing fuels led to a deterioration in the thermal effectiveness of the brakes in conventional engines utilizing the renewable fuels A20. This inspired an additional study aimed at enhancing turbulence for improved air- fuel mixing using a unique turbulence inducer piston. This experiment was conducted to examine the interactionbetween injection pressure & turbulence inducer pistons. Because of optimizing injection pressure, emissions characteristics such as hydrocarbon, carbon monoxide, and smoke were significantly enhanced. However, nitrogen oxide emissions are marginally greater than these of standard, unmodified engines. This engine having turbulence-inducing pistons demonstrates the potential for lowering the principal sources of pollution, hence ensuring environmental protection [11].

Gogoi et.al. (2013) focus on the exergy analysis of a single-cylinder, four-stroke, direct injections (DI) diesel engines utilizing 10% (B10), 20% (B20), 30% (B30), & 40% (B40) blends of Koroch seeds oil methyl ester (KSOME) with standard diesel fuels. This research focuses on steady-state engines functioning under varying load conditions. Exegetic performance metrics are tested for every fuel operation at different loads. At all engine loads, it was discovered that the KSOME fuel mixes produced greater exergy destructions than diesel fuel. Exergy destructions also rise with increasing biodiesel proportion in the mix, & it was much greater for B40 fueloperation at varied loads. In addition, the results indicate that the engine's exergy efficiency was lower while operating on biodiesel mixes. This investigation demonstrates the potential for significant engine performance improvements using biodiesel fuel blends, especially B40 & greater percentage blends [12].

Ileri et.al. (2013) aim to examine the effect of fuel injection times and engine speed on engine performance and exhaust emissions in diesel engines driven using canola oil methyl ester (COME). Transesterification was used to extract COME, which was then evaluated under full load by varying engine speeds by adjusting the fuel injection time in a turbocharged direct injection (TDI) engine. Response surface methodology (RSM), a well-known design of experimental techniques was used for predicting engines performances and exhaust emissions parameters from second-order polynomial equations acquired by modeling the relationship between fuels injection timing (t) and engine speed (n) [13].

Ramachander et.al. (2021) examine the effect of fuel injections pressure with ternary fuels (diesel + Mahua methyl ester + Pentanol) on the emissions, combustions, and performance characteristics of a single-cylinder, four-stroke,prevalent rails direct injections diesel engine operating at a constant speed and under different operating conditions. Due to its features & combustions characteristics, the use of ternary fuel led to an increase in NOx emissions (12.46%) & specific fuels consumption (SFC), as well as a reduction in brake thermal efficiency (BTE).The combustion process was impacted by the physical features of the mixed fuels, like volatility & viscosity,& the engine's performance was recorded as a result [14].

Jaichandar et.al. (2012**)** used Pongamia Oils Methyl Ester (POME) to evaluate the effect of re-entrant combustionchamber geometry on diesel engine emissions, performances, & combustions. Pistons with Toroidal Re-entrant Combustions Chamber (TRCC) & Shallow Depth Re-entrant Combustions Chamber (SDRC) were tested in four-stroke, single-cylinder DI diesel engine. This study utilized 2 fuels: a 20% POME and mix of diesel fuels (PBDF). When the tests for re-entrant combustion chambers fed using 20% POME & PBDFwere compared to it these of a baseline engine using a hemispherical open combustion chamber fueled with a PBDF & 20% POME mixture, the results showed that. These test findings revealed that the braking efficiency & specific fuel consumption of the TRCC engines were much greater than those of the standard engines fueled with20% POME. Compared to the others two, TRCC exhibited a significant decrease in particles, carbon monoxide (CO), & hydrocarbon (HC). However, more NOx was produced by TRCC. The combustions study reveals that the igniting delay for the TRCC engines was shorter than those of the baseline engines, 7 that the peak pressure at full loads is likewise greater [15].

Shameer et.al. (2018) examine prior research on the effects of suggested efficient tactics, involving variations in engine operating parameters such as fuel injection time & injection pressure, for increasing biodiesel combustion characteristics. This research concentrates on the improvements and retardation techniques of injection timing and injection pressure to handle engine combustions indicators such as tensions, peak cylinder pressures, heat release rates, ignition delay periods, and combustion durations. This paper concludes with the development of comparative assessments and a discussion of the relevant explanations for the variety of combustion characteristics. This study shows that advancing injection time & increasing injection pressures are optimal for enhancing biodiesel combustions phenomena. In the continuously expanding global energy demand, diesel engines perform a crucial role. The utilization of diesel fuels adds to the emission of dangerous air pollutants through the combustion chamber. Biodiesel derived using a variety of feedstocks has been researched and deployed during the last few decades to address those significant problems. Due to the differences in biodiesel's physiochemical properties, diesel and biodiesel mixes have dissimilar combustions characteristics. Numerous research having concentrated on insufficient biodiesel combustion profiles in CI engines [16].

Hasan et.al. (2016) aim to highlight the engine performance & emissions characteristics of Homogeneous chargescompressing igniting (HCCI) engines under various test situations, as well as the many issues connected to usingthose engines. Possible guidance to overcome those obstacles & increase engine performances & emissions characteristics is also presented. From the review, it could be deduced that HCCI combustions could be applied to current CI engines using changes, & the biggest notable impact of implementing those combustion techniquesis a reduction in NOx and soot emissions whilst almost maintaining the same effectiveness as CI combustion. HCCI engines use a relatively innovative combustion technique. Theoretically, neither a spark plug nor an injector was required to assist the combustion, since the mixture spontaneously ignites in several areas once it achieves its chemical activation energies. It is much faster than compressive ignitions and spark ignition combustions (SI). Modifying CI and SI engines, HCCI combustion modes increase thermal efficiency and maintain low emissions.In this technology, an extensive variety of fuels, fuel combinations, and alternative fuels might be utilized. It is important to overcome problems such as combustion phasing control, limited operating ranges, cold start, high noise levels, and uniform charging preparations for optimal operation of HCCI engines [17].

Alagumalai et.al. (2014) present a detailed analysis of the main concepts which govern the design & operation of internal combustion engines, as well as an elegantly arranged & simplified architecture of new-age engine technologies as a contribution to this pragmatic topic. Over the last decade or two, the engine industries have seen a huge increase in the research & development of cutting-edge technology. Despite the availability of vast information on modern engine technology, presenting these facts effectively is a difficult challenge. At this point,an attempt has been made to briefly outline the advantages & disadvantages of contemporary engine technology [18].

Tuan Hoang et.al. (2021) Added nanoparticles to biodiesel-based fuels to address the shortcomings of biodiesel, such as its large molecular mass, high viscosity, & pouring points, as well as its low calorific value, which has a substantial impact on spray, atomization, & combustions properties. Cerium oxide (CeO_2) nanoparticles were regarded to have the greatest potential to become an additive for diesel engines due to their flexible capability in valence change, huge oxygen storage, & excellent thermal characteristics. In fact, the manufacturing methods and physicochemical properties of biodiesel-based fuels including CeO_2 nanoparticles were exhaustively addressed in this paper. The effects of CeO_2 on the atomization & micro-explosion of spent fuels were also studied. In addition, the combustions behavior, performances, & emission characteristics of diesel-fueled using biodiesel containing CeO_2 nanoparticles was thoroughly examined. CeO_2 nanoparticles added to biodiesels were demonstrated to minimize harmful emissions (soot, smoke opacity, NOx, CO, & HC), enhance thermal efficiency & brake power, & reduce fuel consumption. Nonetheless, additional study into the effects of CeO_2 nanoparticles on particulate matter (PM) emissions, human health, & environmental conditions was required [19].

Bari et.al. (2020) intend to increase the performance of hydrocarbon volatile fractions (HVFs) by using technologies that were now inferior to diesel. Increasing the in-cylinder airflow characteristics may produce greater turbulence within the combustion chambers, allowing HVFs to break apart & better mix with the in-air, hence boosting engine performances. Many research shows that these tactics may also improve the performances of diesel engines fitted with HVFs, even though higher turbulence improves the performances of diesel engines running on diesel fuels. Using guiding vanes, throttling the intake manifold, and altering the combustions chamber & intake manifold, according to the literature, may enhance in-cylinder turbulence. The useof guiding vanes to create turbulence within the cylinders of HVF-powered engines improved engine efficiency by 1.3-2.8%. A number of studies have shown that increasing the air swirl within the combustion chambers results in a 12% reduction in brake-specific fuel consumption (BSFC). This article examines several methods for improving the in-cylinder airflow characteristics of IC engines, as well as a few articles that use

HVFs, to demonstrate that boosting in-cylinder turbulence may increase the performance of CI engines that use HVFs [20].
A quasi-dimensional model was created by Sindhu et.al. (2017) deriving the first law of thermodynamics & the equation for perfect gases Using phenomenological considerations, the models predicting heat release rates, heating transferring losses, ignition delays, the chemistry of combustions, NOx & soot forms were linked. Due to the restriction in the premixed phase of combustions of the second pulsed, split injections utilizing a smaller quantity of fuels injected in the first pulse were observed to significantly decrease NOx emissions. In contrast to increasing dilution rates with EGR & delaying injection time towards the top dead center (TDC), splits injections have been shown to successfully mitigate the piston work trade-off [21].

According to Michela Costa et.al. (2015) direct injection (DI) enables the flexible operation of to minimize fuel consumption & emissions of pollutants. Either experimental characterizations or computational fluid dynamics might be used to determine the optimal combinations of the many factors whichinfluence the energy conversion processes & environmental effects of particular engines (CFD). In these contexts, the objective of this study was to evaluate a CFD-optimization (CFD-O) process for the maximum performance of lean-operated DI engines with both single & double injection schemes accomplished throughout compressing [22].

Sarangi et.al. (2013) compare the impacts of split fuels injections at a level of 52% volumetric exhaust gas recirculating to these of single injection at levels of 52% and 62% volumetric exhaust gas recirculating. The results indicate that the combined effect of exhaust gas recirculation rates and splits injections could achieve near-zero nitrogen oxide emissions with excellent thermal effectiveness and substantially lesser total unburned hydrocarbons and carbon monoxide emissions than at 62% exhaust gas recirculation. Single injections at those locations produce substantial smoke, which may be reduced by greater than 75% using divided injections. Thosefindings were especially pertinent since they indicate extremely low nitrogen oxide emissions from a running engine having acceptable thermal efficiency & at levels of exhaust gases recirculating that were realistic [23].

Sundararajan Rajkumar et.al. (2014) developed a multi-zone zone phenomenology model for forecasting the combustion & emissions characteristics of split-injection & multiple direct common-rail diesel engines describedin this work. That model divides the immediate combustion area into two parts: sprayed zones & ambient air. The predictions of those models for combustions and emissions for split injections & numerous injections were evaluated using literature data for a variety of injection regimens. Comparisons show that the model can predict with moderate accuracy & that the multi-zone model can be used for multiple-injection common-rail direct- injections engines. As a result, the models were utilized in parametric studies to evaluate the influence of splits& multiple injections on the combustions & emissions characteristics of common-rail direct-injection diesel [24].

Tekgül et.al. (2022) used large-eddy modeling & finite-rate chemistry to examine the influence of alternative split injection techniques on ignition delay times (IDT) & heat release rates (HRR). Two independent injection pulses of n-dodecane are used to inject a diesel surrogate (n-dodecane) into a domain containing premixed methane & oxidizer. By settingthe quantity of total fuel mass, three distinct splits injections techniques were investigated: changing the time of the first injection and the second infusion [25].

III METHODOLOGY

In this research, the use of non-edible oils for biodiesel generation was to be examined. Seeds of behada were chosen for the biodiesel synthesis procedure. Chicken fat oil was added with the extracted behada oil along with turmeric oil as an additive. In the presence of a catalyst, transesterification or alcoholysis converts triglycerides of behada and chicken fat oil and turmeric oil into trinity oil methyl ester and glycerol as a byproduct. Experimentally, the properties of methyl ester and methyl ester blends were analyzed as per the standard values of ASTM 6751.

3.1 Experimental set-up and procedure

A single-cylinder, four-stroke, direct injection (DI), water-cooled, Kirloskar TV1 model diesel engine was used for the tests. The engine operates at a constant speed of 1500 rpm. The standard engine has a hemispherical combustion chamber (HCC) with overhead valve arrangements operated by push rods. This engine was conjugated to an eddy current dynamometer and equipped with an inline injection pump, which pressurizes and injects the fuel at an of pressure 600 bar. The cylinder pressure was measured by a piezoelectric pressure transducer fitted on the engine cylinder head and a crank angle encoder fitted on the flywheel. The engine combustion analyzer was used to evaluate and determine cylinder combustion characteristics.

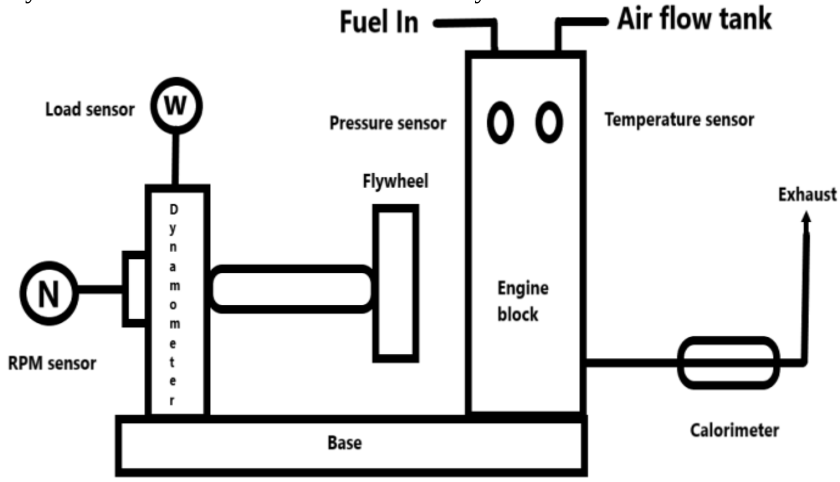
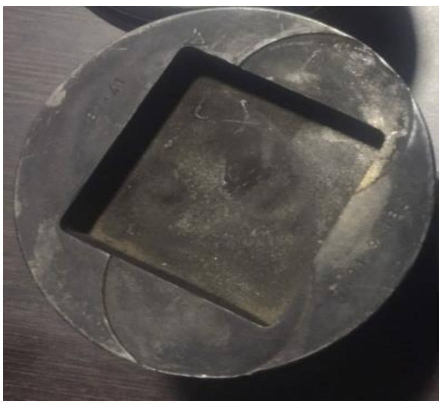


Fig. 1 Schematic diagram of the experimental set-up

The experimental tests are conducted by coupling with a water-cooled eddy current dynamometer fueledwith methyl ester blends. The engine speed was measured using a toothed sprocket and a magnetic pickup attached to the dynamometer and the engine torque was measured with a digital meter. The pressure crank angle diagram was obtained with the help of a piezoelectric pressure transducer, charge amplifier, crank angle sensor, and digital oscilloscope setup.

During diesel engine combustion, the air-fuel mixture was heterogeneous in the combustion chamber with fuel-rich and fuel-free zones. This heterogeneity affects the composition, fuel burning rate, temperature, and pressure. Hence, for the study split injection technology was used.

One useful approach to extend the CI engine's efficiency was changing the piston top geometry. In this experiment, the standard piston of the CI engine was modified and replaced by a square groove top piston shown in fig. 2A and a tangential groove top piston in fig. 2B. Ensuring all the electrical connections such as the sensor, battery, and power supply are disconnected. The flat piston of the regular diesel engine was detached manually by using a 9/16 spanner and fitted with the square and tangential groove top piston by using push rods.Connect the engine outlet water and exhaust connections to the engine block again. During the change of piston head, the compression ratio of the engine was modified and observed to 18 whereas injection pressure was maintained at 600 bar. The engine operating parameters are specified in Table 2.



(A) Square groove top

(B) Tangential groove top

Fig. 2 Square and Tangential groove top piston

3.2 Fuel properties analysis

Prior to conducting the experimental and numerical studies, a careful fuel analysis needs to be carried out. The fuel properties can influence the fuel droplet size, size distribution, spray characteristics, fuel evaporation, pressure, and temperatures during combustion. The details of the properties are checked as per ASTM standards and listed in table 1.

Table 1. Properties of methyl ester

Description	Reference Standard ASTM 6751	Reference Unit	Blend ID	
			B00	B20
Density	D 1448	gm/cc	0.830	0.833
Calorific Value(CV)	D 6751	MJ/Kg	43.50	42.89
Cetane Number	D 613	--	49	49.52
Viscosity	D 445	mm^2/sec	2.70	2.84

The blend used for experimentation was B00 and B20. B00 indicates pure diesel fuel and B20 represents 20% methyl ester (behada + chicken fat oil+ turmeric oil) and 80% diesel fuel. This combination of the blend was fed to the compression ignition engine. The EGR technology was used up to an extent of 0% and 10%.

Table 2. Engine operating parameters

BLEND	RUN	CR	Injection of pressure (IOP)	Piston type	Load (Kg)	EGR
B00	1	18	600	Square Piston	0,4,8,12.3,15	0% EGR
	2	18	600	Square Piston	0,4,8,12.3,15	10% EGR
	3	18	600	Tangential Piston	0,4,8,12.3,15	0% EGR
	4	18	600	Tangential Piston	0,4,8,12.3,15	10% EGR
B20	5	18	600	Square Piston	0,4,8,12.3,15	0% EGR
	6	18	600	Square Piston	0,4,8,12.3,15	10% EGR
	7	18	600	Tangential Piston	0,4,8,12.3,15	0% EGR
	8	18	600	Tangential Piston	0,4,8,12.3,15	10% EGR

IV RESULTS AND DISCUSSION

1. In-cylinder combustion pressure characteristics

In this combustion study, the compression ratio CR18 was fixed. Two fuels (B00 and B20), piston shape geometry (square groove and tangential groove), and with and without 10% EGR are studied. The injection of directly injected fuel was operated with a split injection strategy. The pilot injection was done at 14 deg bTDC with a mass of pilot injection 27% and main injection fuel of 73% mass at 7 deg bTDC timing. In-cylinder combustion pressure vs crank angle shows combustion behavior, combustion flame propagation, cylinder pressure peak hit, and combustion duration.

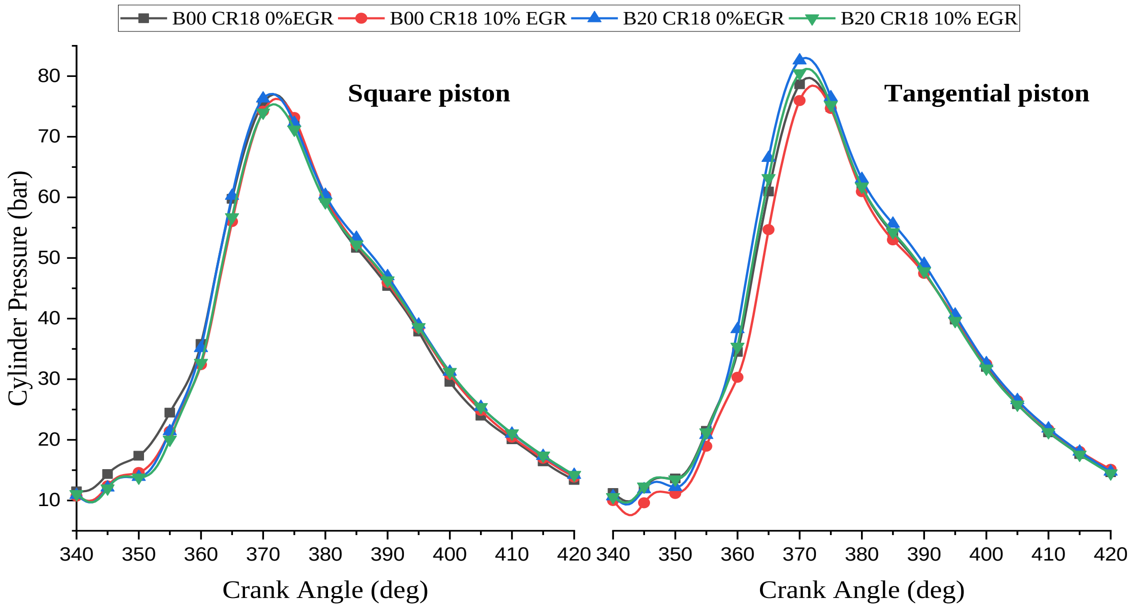


Fig. 3 In-cylinder combustion pressure with crank angle behavior

It can be seen in fig. 3 B20, and the tangential groove piston shows a steep slope withmaximum cylinder pressure of 83 bar followed by 10% EGR of B20 fuel of 81 bar. Further, B00 with 0% EGR and 10% EGR have shown inferior results compared to the former. Also, the effect of the split injection strategy with B20 and 10% EGR has improved combustion with rapid premix, re-burning of fuel and oxygenated fuel combustion of B20 fuel.

Figure 4 shows that the rise in maximum cylinder pressure increases with an increase in load. However, at part load to full load, the tangential groove piston has shown a 70 bar to 84 bar maximum cylinder pressure range. This peak cylinder pressure was 10-12% higher compared to the respective cylinder pressure of square groove geometry at a higher load. Conversely, at low load operation square pistons are 8% better at higher cylinder pressure values. Hence, at part load square piston geometry seems better whereas full load tangential groove seems better.

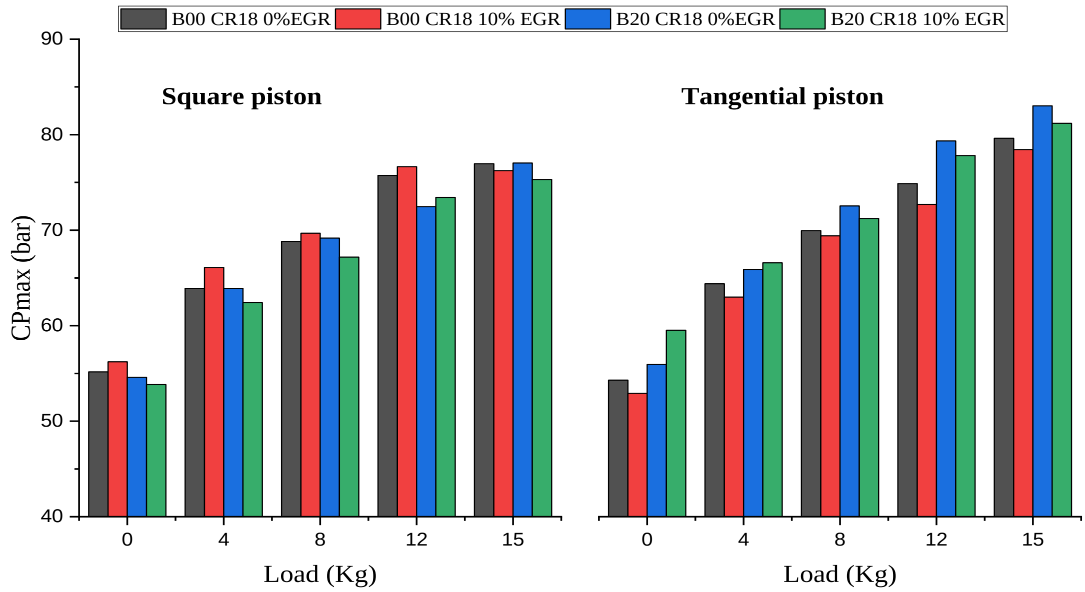


Fig. 4 In-cylinder maximum combustion pressure with load behavior

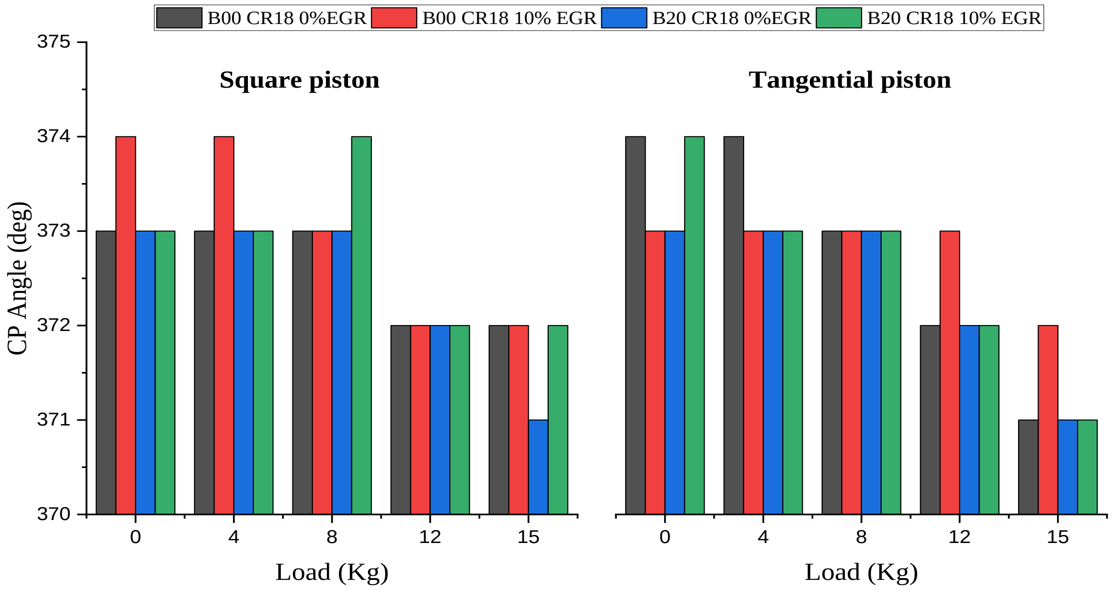


Fig. 5 Combustion pressure angle with load behavior

EGR operation has reported considerably lower cylinder pressure compared to without EGR operation. However,B20 fuel has reported more cylinder pressure for tangential groove piston and B00 fuel showed more cylinder pressure for square groove piston geometry. Further, tangential grooves piston geometry with B20 fuel has reported nearly the same and highest cylinder pressure maximum values for 0% and 10% EGR. It shows that B20 fuel with 10% EGR and tangential groove piston geometry has the highest in-cylinder combustion behavior and promising result.

In-cylinder combustion pressure angle sheds light on how fast combustion traveled as shown in fig 5. In-cylinder maximum, cylinder pressure can be expressed as combustion propagation in terms of combustion (time) duration or crank angle. As expected B20 fuel and EGR 0 and 10% with tangential groove piston has shown the least crank angle 11 deg after top dead center (aTDC) or 44ms milliseconds. However, a square piston with B00 and 10% EGR has reported 56ms of time to reach peak pressure shown in fig. 4 and 5.

2. Rate of pressure rise (RPR)

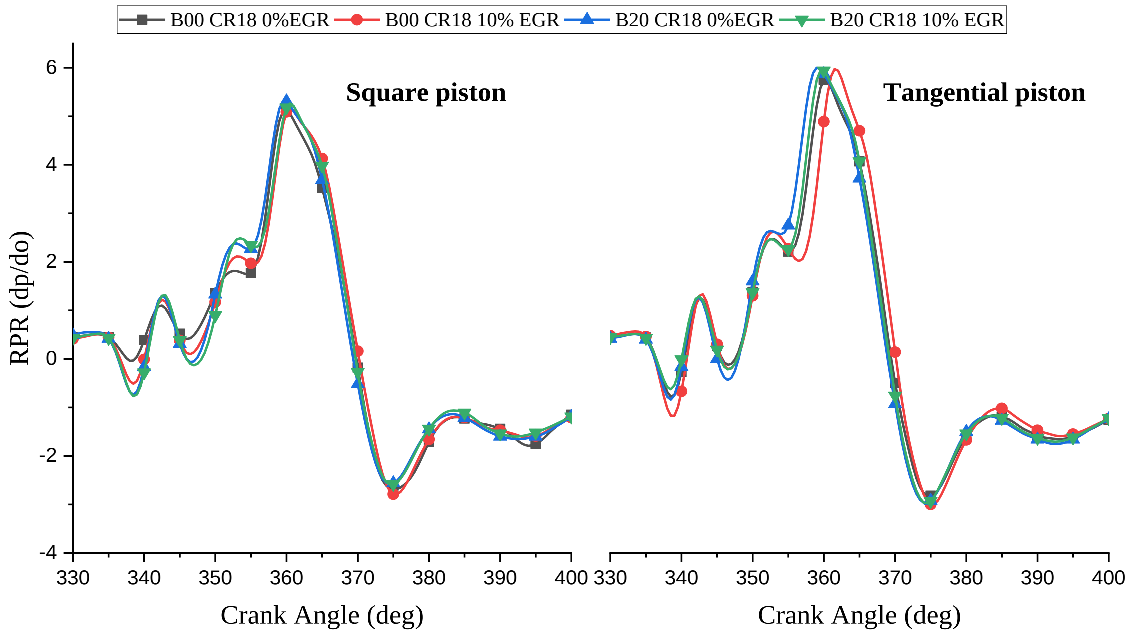


Fig. 6 Rate of pressure rise (RPR) with crank angle behavior

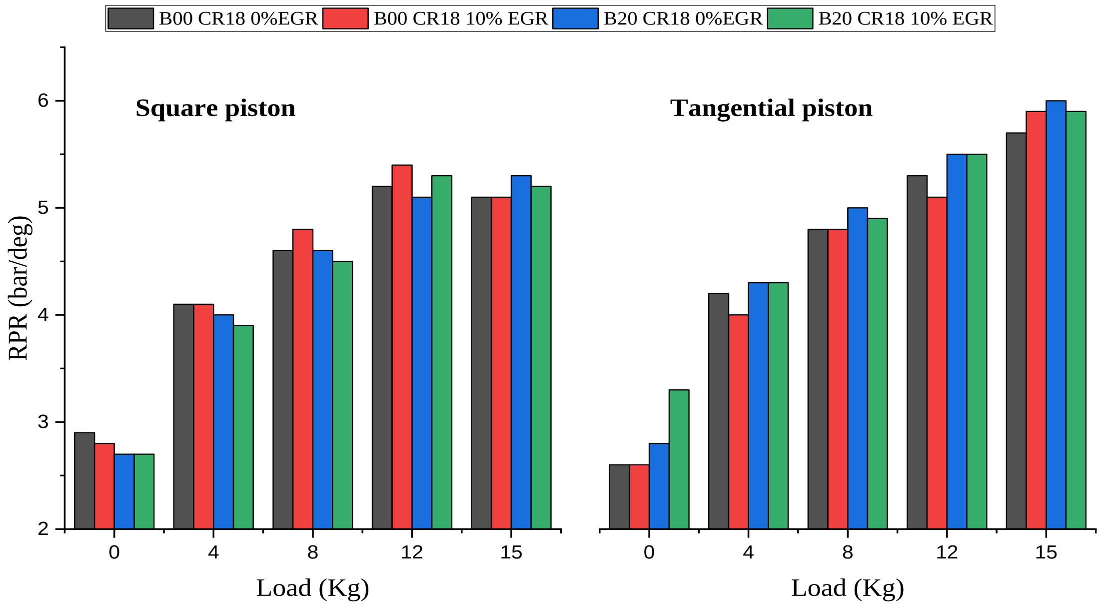


Fig. 7 Maximum rate of pressure rise (MRPR) with load behavior

One of the major CI engine's limitations was heterogeneous and uncontrolled combustion. It can be measured withdetonation into a cylinder or more rate of pressure rise. Hence, RPR quantifies the combustion process. Also, the rate of pressure rise was the change in cylinder pressure rate per degree change in crank angle.

Figure 6 indicates RPR for tangential groove piston with B20 fuel and EGR 0 and 10% has given a significant approach. As RPR was 5.8 bar/deg at TDC hence can be approached as availability or energy. However, for CR18 B00 and 10% EGR for tangential groove, it acts as exergy as RPR was observed in the afterburning combustion phase. Tangential groove piston has shown more RPR compared to square groove piston geometry it can be used as energy because it happens bTDC. The maximum RPR reported by the B20 tangential groove piston without EGR was 5.8 bar/deg and it was 13% higher than the respective value with square groove piston geometry.

Figure 7 shows load increases RPR increase. MRPR was observed to be 3 to 6 bar/deg from no load to full load operation. Also, it can be noted that for square pistons from 0 to 80% load, B20 fuel has reported low MRPR compared to B00 fuel. This may be due to oxygenated fuel like B20 has got sufficient swirl to penetrate the fuel spray. Hence, more homogeneous, and controlled combustion was achieved. However, B20 with and without EGRhave reported more MRPR with tangential groove piston geometry before TDC. A split injection strategy for all operations has made more atomization, reduced ignition delay, and combustion duration for all fuel. It can be viewed as an approach toward controlled and rapid combustion as not much difference in the combustion phase.

Tangential groove piston geometry has shown the dual positive effect of MRPR. It was observed that more MRPR at bTDC and low MRPR after TDC compared to square groove piston geometry. This may be due to more swirl, air penetration to fuel sprays, and fine atomization causing homogeneous combustion. Hence, the Tangential groove piston with 10% EGR and B20 fuel gives controlled and homogenous combustion from the RPR characteristics.

3. Net heat release rate (NHR)

Two major peaks are observed in the net heat release rate noted in fig 8 and 9. The first peak was due to the pre-mixed and rapid combustion phase while the second peak was a result of the controlled combustion phase. Figure 8 gives the net heat release rate expressed in J/deg CA (crank angle). For the square piston and tangential piston groove geometry, the first peak of NHR was observed at 360-365 deg CA. Hence, piston geometry has not much affected NHR also the split injection strategy of fuel injection at 600 bar and pilot and main fuel injection has caused NHR to peak at the same duration. However, tangential groove piston geometry with B00 fuel has reported MNHR 60 J/deg CA at full load operation.

It can be observed that B00 have shown more for all operation more NHR compared to B20. This may be because even though biodiesel has more oxygenated fuel it cannot produce more energy than diesel. Heat release rate doesnot depend on only one-factor oxygen content it also depends on calorific value, carbon-hydrogen(C-

H) value, and latent heat of vaporization. As B20 has a low calorific value compared to diesel lower NHR by B20 was reported.

The control of the rate of NHR was one method that promises improvement in emission as well as in combustion. The B00 and B20 with 10% EGR have shown 5% more NHR than those without EGR at all load operations. This may be due to the rapid mixing of EGR acts as a pre-mixed charge and more NHR. Also,due to the EGR oxygen content of the mixture was reduce hence, more fuel may be burnt to achieve power. B00 and tangential groove pistons have reported 5% more NHR compared to B20 and square piston operation demonstrated in fig. 8 and 9.

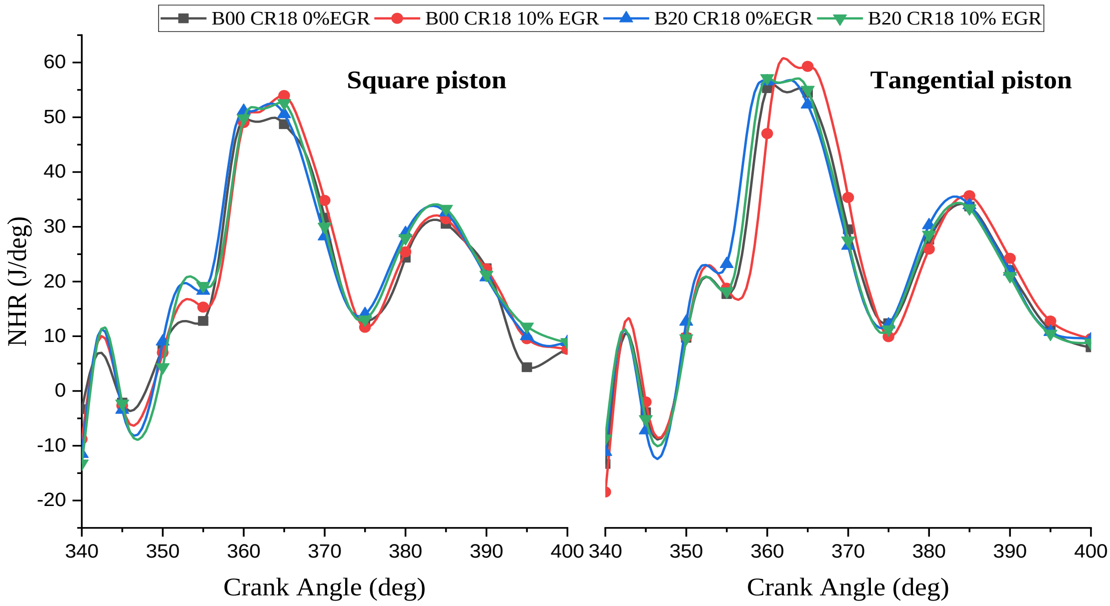


Fig. 8 Net heat release rate (NHR) with crank angle behavior

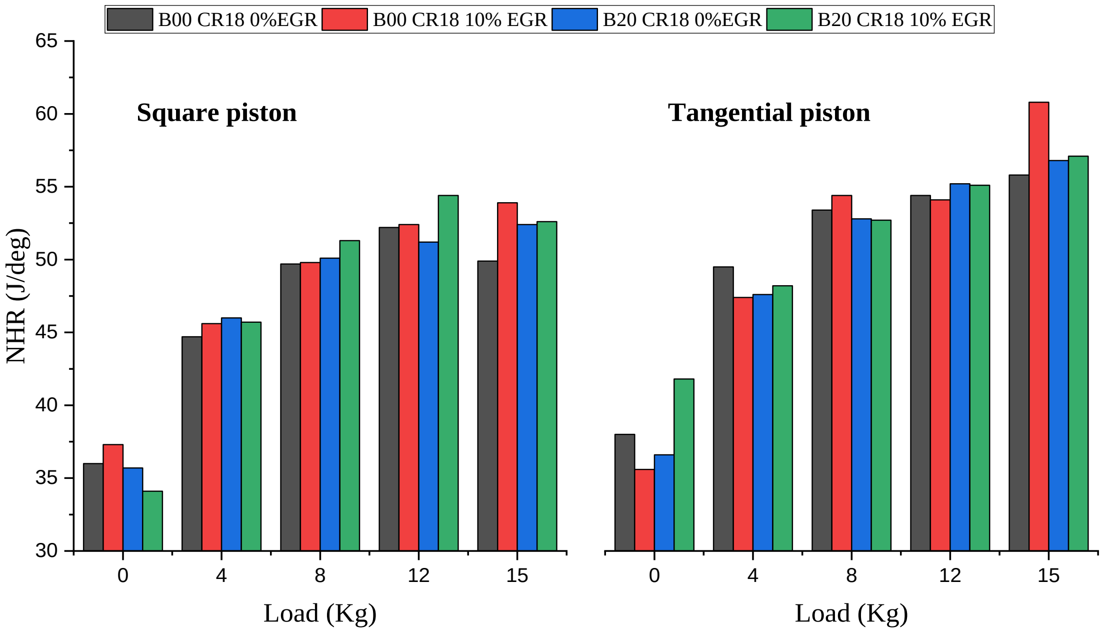


Fig. 9 Maximum net heat release rate (MNHR) with load behavior

As seen from fig 9 MNHR increases with the increase in load operation. It was observed that 35 J/deg to 60 J/deg was NHR from no load to full load operation. Also, 10% EGR operation with both fuels and square piston geometryhas shown more NHR compared to tangential piston both fuels operation. Because the split injection strategy at 600 bar has reduced NHR for all load operations due to more atomization of fuel and air fuel spray penetration.

4. Mean Gas Temperature (MGT)

Mean gas temperature is the average gas in-cylinder combustion temperature given in degrees Celsius. It can be seen from fig. 10 and 11 MGT remains higher for B20 and B00 fuel without EGR. Also, MGT was reported more at controlled combustion without EGR while MGT remains higher in the afterburning phase of combustion for 10% EGR.

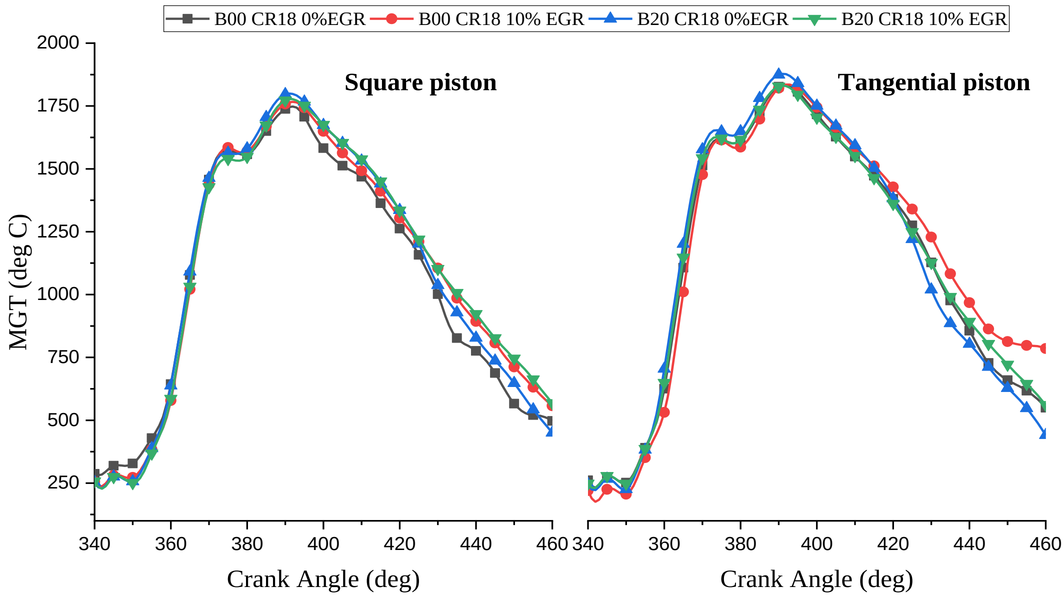


Fig. 10 Mean Gas Temperature (MGT) with crank angle behavior

It can be noted that MGT with 10% EGR for both fuel and piston geometry was 5% less compared to MGT without EGR. This may be due to the EGR oxygen content in the combustion chamber being reduced and due to which combustion temperature may reduce. As expected with an increase in load MGT increases for all fuel blends and piston groove geometry.

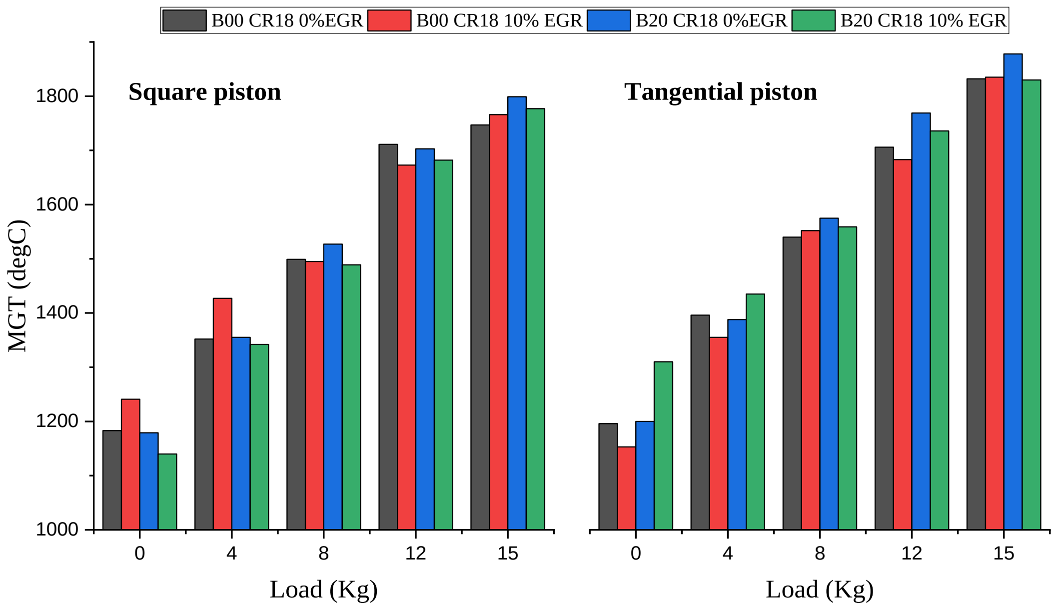


Fig. 11 Mean Gas Temperature (MGT) with load behavior

V CONCLUSION

Experimentation shows that the cylinder pressure curve for fuel B20 and the tangential groove piston was a steep slope with maximum cylinder pressure of 83 bar. For B20 blend with 10% EGR was recorded as 81 bar. Further, B00 with 0% EGR and 10% EGR have shown inferior results compared to the former. Also, theeffect of the split injection strategy with B20 and 10% EGR has improved combustion with rapid premix and burning of fuel because of oxygenated fuel combustion of B20 fuel.

B00 and B20 with 10% EGR have shown a 5% rise in NHR than without EGR at all loads. This may be due to the rapid mixing of EGR acts as a pre-mixed charge and more NHR. Also, due to the EGR oxygen content of the mixture being reduced hence, more fuel may be burnt to achieve power. B00 and tangential groove pistons have reported 5% more NHR compared to B20 and square piston operations.

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