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COMBUSTION ANALYSIS OF 4-STROKE VCR DIESEL ENGINE FUELED WITH BIODIESEL DERIVED FROM FLAXSEED OIL

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Abstract: The research investigates the combustion characteristics of a 4-stroke VCR Diesel engine by adding zinc oxide nanoparticles and using flax seed oil as an alternate fuel. The experimental setup includes testing several fuel samples. These samples contain traditional diesel as well as the beneficial of adding zinc oxide nanoparticles (ZnO NPs) to B20-grade flaxseed oil biodiesel together with dispersion (Triton X) and surfactant (CTAB) additives. B20 with 50 ppm ZnO NPs (B1), B20 with 50 ppm ZnO NPs and 50 ppm surfactant (B2), and B20 with 50 ppm ZnO NPs and 50 ppm dispersant (B3) were the three different mixes that were made. A comprehensive evaluation was conducted to determine how various additions affected the stability and combustion properties of the biodiesel. While flaxseed oil biodiesel and zinc oxide nanoparticles were used, engine operating characters significantly improved. According to the performance parameters, after improvements were made to the combustion characteristics such as cylinder pressure (CP), Net heat release rate (NHRR), Mean gas temperature (MGT) rises by 1.2%, 2.98%, and 10.22%, respectively.

***Index Terms* – Flaxseed oil, VCR Diesel Engine, Zinc Oxide nanoparticles, Combustion Characteristics, Alternative fuels.**

I. INTRODUCTION

Worldwide, the transportation, residential, business, industrial, and agricultural sectors all depend heavily on energy. Fossil fuels are now a key source of energy supply due to their reliability, improved energy conversion efficiency, accessibility of handling facilities, and flexibility.[1] A significant scarcity of fossil fuels is inevitable since they can no longer be replenished and because the pace of usage is increasing. chinmoy Jit Sharma et al., [2] Examining the combustion of fossil fuels reveals it as the primary origin of harmful pollutants within the automotive sector, these pollutants contribute to the formation of smog, acid rain, greenhouse gases, and adverse climate changes. By changing the engine's architecture and enhancing the combustion process of the diesel engines.[1-2] within the engine, cleaning the engine's exhaust, and utilizing fuel additives made expressly to cut down on diesel combustion. Therefore, in order to address the fast-approaching energy scarcity and the hazards connected with environmental contamination, a different source of fuel has become necessary in the modern day.[3]Because biodiesel is extremely similar to tidy diesel, it is the most efficient and sustainable resource substitute for fossil fuels.[2-3] Biodiesels may be used in diesel engines without requiring major engine modifications. Biodiesel has been the subject of recent consideration as a possible alternative fuel due to its environmental friendliness, biocompatibility, non-flammability, and non-explosive nature.[4] Additionally, biodiesel has comparatively better combustion attributes than pure diesel.

Moreover, using biofuels benefits the environment in a number of ways, such as lowering greenhouse gas emissions, improving air quality, and reducing pollution of the air, land, and water. However, there is still a long way to go until alternative bio sourced fuels completely replace fossil fuels on a broad scale. This is due to a number of disadvantages, including low productivity, increased manufacturing costs, limited flexibility, and so on[5] Because of this, and because there isn't a bio-based fuel that can fully replace diesel and is both widely accepted and economically practical, a lot of attention has been focused on an additive that can be added to diesel to enhance engine combustion while lowering emissions from exhaust.[4-5] By employing eco recycling methods, biofuels emerge as a sustainable energy source capable of improving combustion. This is exemplified by biofuel plantations utilizing it to fuel their growth and effectively acting as carbon sinks. The amount of carbon dioxide emitted by engines is overshadowed by the sustainable quantity absorbed by these plants.[6] Starting with first-generation biofuels made from mahua [2], sunflower, soybean oil[7], and jojoba oil[5] then moving on to second-generation biofuels such exploring third generation fuels extends beyond microalgae derived options to encompass alternatives such as neem, rubber seed, Karanja, jatropha, and rubber seed oil. The growing global demand for environmentally friendly and sustainable energy source has spurred extensive research into alternative fuels, particularly biofuels derived from renewable feedstocks. Samir J. Deshmukh et.al.,[8] examined the properties of a functional substance in all four distinct strokes, employing Wiebe's correlation as a baseline for investigating the power discharge rate pattern. Additionally, the study projected the heat transfer coefficient (HTC) using the Pflaum equation, in a similar vein, Battal Dogan et.al., contributed to this exploration.[9] investigations into enhancing biodiesel properties through research focus on the incorporation of unique additives in varying proportions into diesel-biodiesel fuel blends. Sundar kamalesan Pillai et al., conduct studies in this domain.[10] examining the performance and emissions of a single-chamber, four-stroke variable compression ratio (16, 17, and 18) engine, along with various blending ratios of jatropha oil (10%, 30%, 50%, 80%, and 100%) in comparison to diesel, is the focus of Navadeep Sharma Dugala et al., [11]A Viable approach to reduce Free fatty acids (FFA) in crude oil involves an appropriate pre-treatment process. the production of biodiesel from crude oil is influenced by factors such as reaction temperature, catalyst type, oil-to-alcohol ratio, and the purity of reactants. Biodiesel necessitates a slow, laborious, and environmentally challenging water washing process to eliminate excess catalyst. The disposal of catalyst-contaminated glycerine poses a challenging due to its limited value in the current market.[12] The goal is to create biodiesel is to help the rustic regions and empower the environmentally friendly power. Vital monetary angles to recognize for capital of biodiesel creation are the feed stock, which activity cost is 75-80%. [13]the production and utilization of energy and fuel derived from WCO align with economic, social, and environmental benefits, consistent with the sustainable development goals (SDGs) [14] In the pursuit of specific fuel characteristics and improved diesel engine performance, Basir Maleki et al. explore the use of aluminium oxide (Al_2O_3) in conjunction with B20 blended with watermelon seed oil, aiming to enhance engine control without substantial alterations.[15] In a related context, ZnO nanoparticles are synthesized through the sol-gel method by Basir Maleki et al.,[16] and their crystal size, morphology, and particle size are identified through XRD, SEM, and TEM analyses. Additionally, the incorporation of metal additives such as aluminium, silver, titanium oxide, manganese, copper, graphene quantum dots (GQD), cerium, magnesium, and iron enhances the catalytic activity of biodiesel, leading to improved engine performance and fuel combustion.[17] A study by F. Binhweel et.al., reveals that the higher content of Saturated Fatty Acids (SFA) in biodiesel negatively affects cold-flow properties, causing fuel blockages in the engine system and impacting overall engine performance.[18] Furthermore, the addition of nanoparticles in biodiesel, as studied by A. Prabhu[19] results in decreased ignition delay, accelerated combustion initiation, lower heat release rate, and cylinder pressure under full load conditions.[20] Recent advancement in biodiesel synthesis methods, such as the fluid phase plasma process for converting virgin oils entirely into biodiesel, are not covered comprehensively in previous reviews. Microwave technology, due to limited penetration depth and safety concerns, has been excluded from large-scale commercial biodiesel production.[21] Recent efforts have focused on the synthesis of novel Self-Healing Conductive Composites (SCCs) with unique electronic structures. For instance, adjusting the metal type and particle number of Mx can alter its geometrical topology.[22] Sambandam Padmanabhan et al.,[23] investigates a diesel engine fueled by a combination of plastic oil, castor oil, butanol and DEE as additives. The utilization of these blends results in improve combustion characteristics, showcasing biodiesel composites as alternative fuels to mitigate in diesel engines. Biodiesel can be coordinated from natural oil, animal oils or on the other hand fats, tallow, and extra cookery oil.[24] Rituparna devasan et al.,[25] researches the Central composite design (CCD) It is one of the most popular RSM response design experiments. This method has already been utilized to improve biodiesel yield from a wide range of feedstocks and catalysts. Doehlert Design (DD), Box-Behnken Design (BBD), and full factorial design are the types of design used for the RSM study, including CCD. making biodiesel and costs related with WCO assortment, transportation, and pretreatment as well as expenses bring about during the transesterification cycle.[26] Further components should be considered, for example, biomass transformation proficiency, air contamination because of emanations of gases from ignition, and effects on climate and wellbeing.[27] The conventional fuel assets get rolling down along with they created more discharge to the climate, which are prompts unsafe impacts to the living life forms and influence the climate attainability.

Flax seed oil, which is derived from the seeds of the Linum usitatissimum plant, is a viable option for the manufacture of biodiesel because of its easy accessibility and inexpensive cultivation. The search for unconventional and renewable resources becomes essential as the world tries to rely less on traditional fossil fuels. A workable answer to the environmental issues related to conventional fossil fuels is biodiesel, a renewable diesel replacement usually made from vegetable or animal fats. Because it is high in polyunsaturated fatty acids, flax seed oil provides an interesting option for biodiesel production. The process of converting flax seed oil into biodiesel, which is consistent with the ideas of sustainable and varied bioenergy production, not only offers a substitute fuel source but also helps to use non-food crops. In order to address the increasing need for energy while reducing its environmental impact, this study investigates the process of producing biodiesel from flax seed oil. Zinc oxide nanoparticles (ZnO NPs), surfactant (CTAB), and dispersant (Triton X) additives are also incorporated into the study to evaluate their effects on the general efficiency and combustion properties of flax seed oil biodiesel blends. A more environmentally conscious energy landscape and the advancement of sustainable energy solutions depend on comprehending and improving the flax seed oil biodiesel manufacturing process. Examining the literature currently available on biodiesel use, most studies agree that these alternative fuels work effectively to power combustion ignition engines. Studies have drawn attention to worries over biodiesel's possible detrimental effects on the thermal efficiency of diesel engines. Moreover, it has been shown that utilizing biodiesel in CI engines has negative effects on engine components increased fuel consumptions. Thus, the application of a wide range of fuel additives might lead to the creation of strategies for improving the fuel's combustion properties while using biodiesel. The use of nanoparticles (NPs) as additives in biofuel is a new technique to improving biofuel combustion and engine performance. A large dynamic surface for chemical reactions is produced by the nanoparticle additives' superior thermal properties and very high surface area per unit volume. Researchers found that adding a variety of nanoparticles improved the combustion characteristics like cylinder pressure (CP), Net heat release rate (NHRR), and Mean gas temperature (MGT). the characteristics of burning aluminium nanoparticles combined with hydro-processed vegetable oils at two distinct concentrations (0.5 and 1.0 weight percent) and sizes (40 and 70 nm). By concurrently increasing the concentration of nanoparticles and decreasing the particle size by up to 42.5% at 40 nm and 1.0 wt%, the biofuel's combustion rate was accelerated.

II. MATERIALS AND METHODOLOGY

The manufacture of flaxseed oil biodiesel using zinc oxide (ZnO) nanoparticles comprises a transesterification procedure followed by the integration of ZnO nanoparticles to improve biodiesel characteristics. Methanol, flaxseed oil, and a catalyst (potassium hydroxide or sodium hydroxide) are combined in a reactor vessel. ZnO nanoparticles are added to the reaction mixture after being dissolved in methanol. Following the monitoring of the transesterification reaction, the biodiesel is separated from the glycerol. Next come measures for washing and purification, which include drying and separating the water. Biodiesel characteristics are evaluated by quality testing, and optional distillation can further refine the final product. ZnO nanoparticles in biodiesel must be thoroughly characterized using methods like TEM or SEM. After verifying that nanoparticles are properly included and that safety and environmental laws are followed throughout, the finished biodiesel is stored.

2.1 Biodiesel synthesis:

The synthesis of flax seed oil biodiesel was conducted using the well-established chemical technique of transesterification in 500 mL batches. Initially, 500 mL of raw flax seed oil was introduced into a round bottom flask and heated to 55 ◦C. Subsequently, a methyl solution composed of 150 mL of methanol ($CH3OH$) and 16 pellets of NAOH was added to the warmed oil. The mixture was agitated at 600 rpm for 1 hour. The methyl solution maintained a 4:1 methanol-to-oil ratio and 1 wt% NAOH relative to the oil weight. The resulting blend was then transferred to a separating funnel, allowing it to settle overnight. Upon settling, a distinct black glycerol layer formed at the bottom, while a lighter methyl ester layer (ME) developed on the top. The glycerol layer was separated, and the biodiesel underwent washing with distilled water at 90 ◦C to eliminate any residual methanol. After an hour of washing, the fuel was subjected to heating at 105 ◦C to eliminate moisture content, resulting in the production of dry flax seed oil biodiesel was obtained. Subsequent washing with water, drying and filtration steps removes impurities and residual catalyst. Quality testing assesses biodiesel properties, and optional distillation can be employed for further purification. The final biodiesel is stored in appropriate containers, adhering to safety guidelines and environmental regulations throughout the process. Adjustments may be made based on specific conditions is obtained.

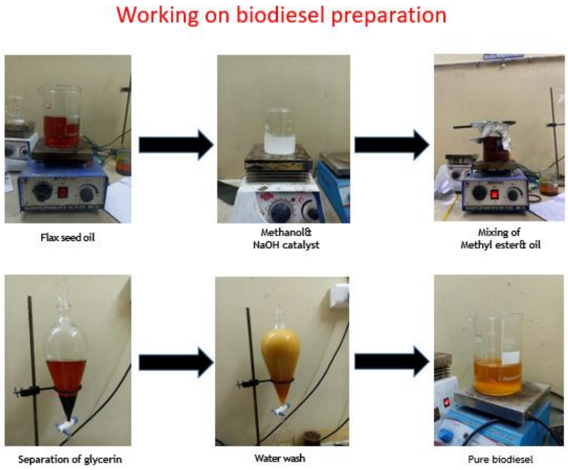

Figure 1 making of flaxseed biodiesel

2.2 Nanoparticle blend synthesis:

The synthesis of zinc oxide nanoparticles involved refluxing a precursor solution containing zinc acetate dehydrate (0.1M) in diethylene glycol at temperatures of 180°C and 220°C. The reaction time, with and without sodium acetate (0.01M), was altered, ranging from two to three hours before initiating reflux. Prior to refluxing, the solution was placed on a magnetic stirrer at 80°C for 1.5 hours. Post-reflux, the samples underwent centrifugation for 15 minutes at 8000rpm, followed by three subsequent washes in distilled water. Subsequently, it was subjected to drying at 80°C. The preparation of nanoparticle blends for flaxseed oil biodiesel involves creating three distinct formulations. In B1, a combination of 50 ppm ZnO nanoparticles is blended with a B20 mixture comprising 20% flaxseed oil biodiesel and 80% diesel. This initial blend ensures the incorporation of nanoparticles into the biodiesel matrix. Moving to B2, ZnO nanoparticles are introduced into the synthesis along with a surfactant (CTAB) at a concentration of 50 ppm. The analysis conducted by Jaikumar et al.[28] focused on assessing the impact of the surfactant on the stability and dispersion of nanoparticles in the biodiesel blend, particularly regarding the degree of vibration and noise for VCR diesel engines. Ultimately, in B3, ZnO nanoparticles in the B20 mix are combined with 50 ppm of Triton X, a dispersant. The objective of this formulation is to assess how the dispersant contributes to the improved stability and even dispersion of nanoparticles inside the biodiesel matrix. In order to attain homogeneity throughout the synthesis process, careful mixing is necessary. Subsequent analysis and characterization methods are advised in order to evaluate the characteristics of these blends of nanoparticles. Small-scale trials are the first step towards making alterations that are particular to the properties of the mixes' nanoparticles and biodiesel made from flaxseed oil.

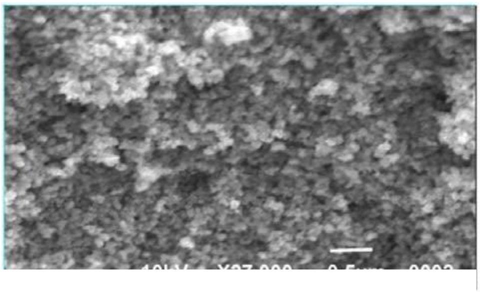

Figure 2 zinc oxide nanoparticles (ZnO)

2.3 Experimental setup:

The ongoing experiment employs a Kirloskar-assembled diesel engine. This engine follows a 4-stroke, single-cylinder, water cooled VCR arrangement, as illustrated in Figure 2. Detailed information regarding engine specifications and fuel constraints is presented in Table 3 and Table 4. The engine features a flexible configuration A top shaft is utilized to modify the pressure ratio by elevating and lowering the drag, which, in turn, raises and lowers the top of the engine. This variation is induced by a change in clearance volume. Connecting to the output shaft of the engine is a vortex eddy current dynamometer, linked through a tire coupling. The applied pressure is precisely determined with a load cell-style strain gauge positioned on the dynamometer's output shaft. To calculate the power balance during energy transformation, the exhaust gas is synchronized with an exhaust gas calorimeter. Numerous sensors are strategically mounted on the system engine to gauge the stream pace of air, fuel, speed and load. The combustion analysis system, part of the Legion Brothers package, comprising software, a combustion pressure sensor, and a CA encoder, was affixed to the engine. Piezoelectric sensors were employed to regulate both the infusion pressure and the fuel injection points. An enhanced piezoelectric sensor was integrated into the engine to monitor combustion pressure across an average of 20 cycles. A wrench point (CA) 11-piece 2050-stage encoder was attached to the camshaft for measuring motor CA. An engine with a data acquisition program is connected to a computer to track and analyze the data. A mobile gas Analyzer platform assesses exhaust gas emissions, calculating NOx, CO2, CO, HC, and smoke emissions. The Analyzer is inserted into the engine's exhaust pipe during measurements. Additionally, K-type sensors were strategically placed on the engine to monitor gas temperatures at various points. All sensor data is linked to the computer for result analysis.


Figure 3 engine test setup

Table 1 specifications of VCR engine

General details	4 strokes, water cooled, VCR engine, compression ignition
Compression ratio	5:1 to 22:1 (variable)
No. of cylinder	Single cylinder
Rated power	3.7 kw at 1500 rpm
Bore & stroke	80mm & 110mm
Loading	Eddy current dynamometer
Speed	1500 rpm (constant)
Connecting rod length	234mm
Swept volume	551 cc
Starting	Manual crank shaft
Air flow transmitter	Pressure transmitter
Load sensor	Strain gauge load cell
Rotameter	Pressure transmitter
Cooling	Water

III. RESULTS AND DISCUSSIONS

The study involved analyzing the combustion characteristics of a 4-stroke VCR engine using biodiesel blends, specifically flaxseed oil biodiesel (B20) and nanoparticle enhanced blends like B20+ZnO 50ppm (B1), B20+ZnO 50ppm+surfactant 50ppm (B2), and B20+ZnO 50ppm+dispersant 50ppm (B3), following the experimental procedure. The obtained results were measured and compared against neat diesel fuel. The combustion analysis included parameters such as Cylinder Pressure (CR), Net Heat Release Rate (NHRR), and Mean Gas Temperature (MGT) are assessed across different load conditions.

3.1 Combustion characteristics:

3.1.1-cylinder pressure

The pressure created within an engine’s combustion chamber during the combustion process is referred to as “Cylinder Pressure” in combustion analysis. It’s an important metric for assessing an engine’s effectiveness and performance. Fuel and air are combined and ignited within the cylinder during combustion. As the fuel-air combination burns, hot gases are produced that expand and push the piston downward, creating mechanical effort. This ignition causes a sudden increase in pressure. The force applied to the piston, which in turn controls the engine’s power production, is directly correlated with the pressure inside the cylinder. Through the examination of the pressure inside the cylinder during engine operation, to maximize engine performance, increase fuel efficiency, lower emissions, and guarantee dependable operations, this data is crucial. Utilizing specialized sensors and equipment, cylinder pressure analysis is frequently carried out and yields useful information for engine development, calibration, and diagnostics.

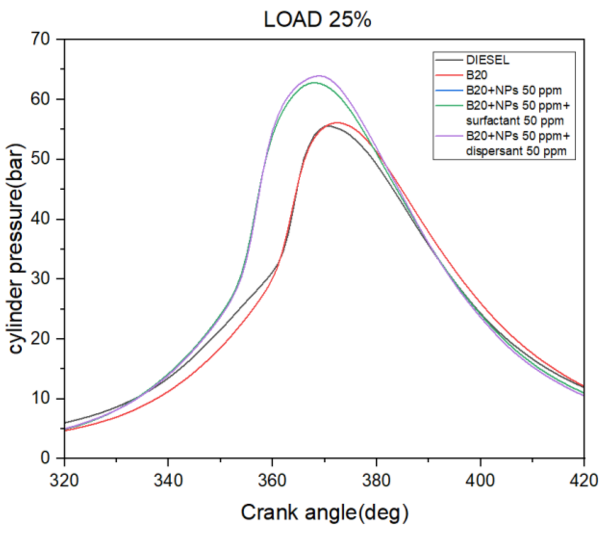

Fig 4: CP (bar) variation compared to crank angle(deg) at 25% load

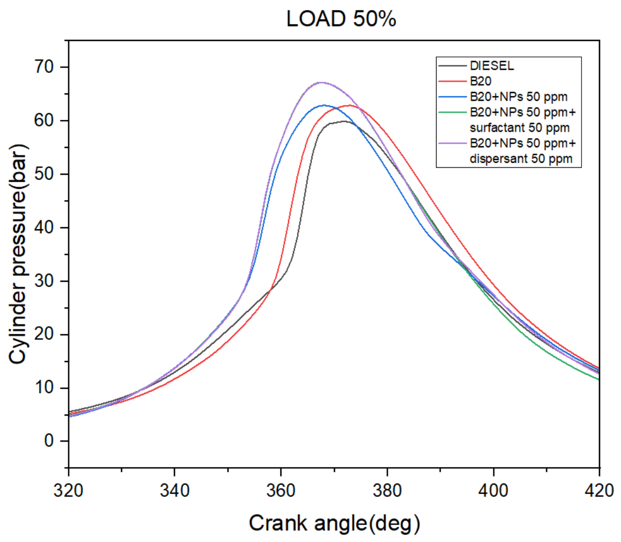

Fig 5: CP (bar) variation compared to crank angle(deg) at 50% load

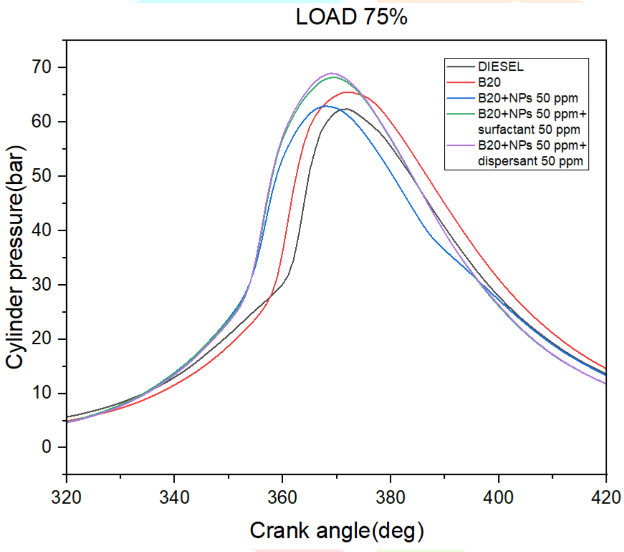

Fig 6: CP (bar) variation compared to crank angle(deg) at 75% load

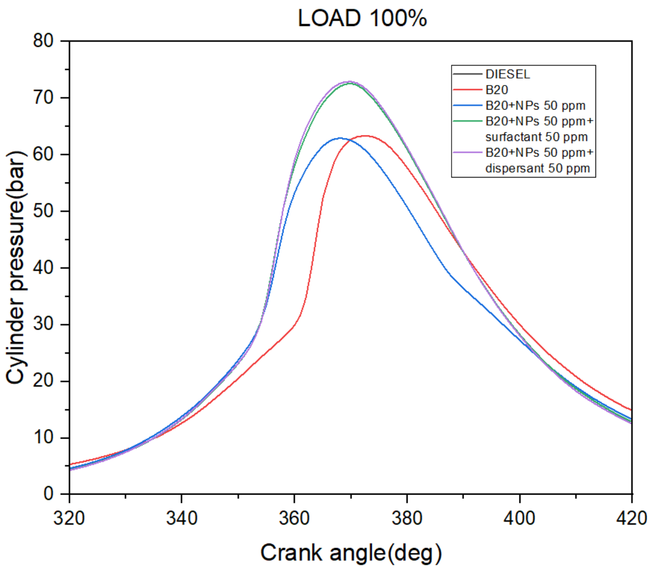

Fig 7: CP (bar) variation compared to crank angle(deg) at

100% load

Compared to the all-cylinder pressure variations at different loads to produce power. Fig 7 depicts the higher pressure increase and decrease within the cylinder for the B20, B1, B2, and B3 at a maximum load of 100%. The highest-pressure readings for 100% load are 0.42bar, 62.53bar, 72.57bar, and 72.92bar. The introduction of nanoparticles increases the cylinder pressure by 0.99%, 1.2%, 0.16%, 0.5% using B20, B20+ZnO50ppm(B1),B20+ZnO50ppm+surfactant50ppm(B2),B 20+ZnO50ppm+dispersant50ppm(B3) at 12kg load. Comparing with the diesel (D100) the test fuel B3 had better combustion characteristics than the other samples, a high cylindrical pressure was observed.

3.1.2 Net Heat Release Rate

In combustion analysis, the rate at which heat is released during the combustion process within an engine cylinder is known as net heat release rate (NHRR). It is an essential metric for comprehending engine's efficiency and combustion characteristics. Fuel and air react chemically to release heat energy during combustion. After that, this energy is transformed into mechanical labor, which powers the piston and eventually the car. The quantity of heat emitted during this operation per unit of time is represented by the NHRR. The timing and intensity of the combustion process, as well as other important aspects of combustion dynamics, may be better understood by analyzing the NHRR. Engineers may enhance engine fuel efficiency characteristics by tracking and fine turning the NHRR.

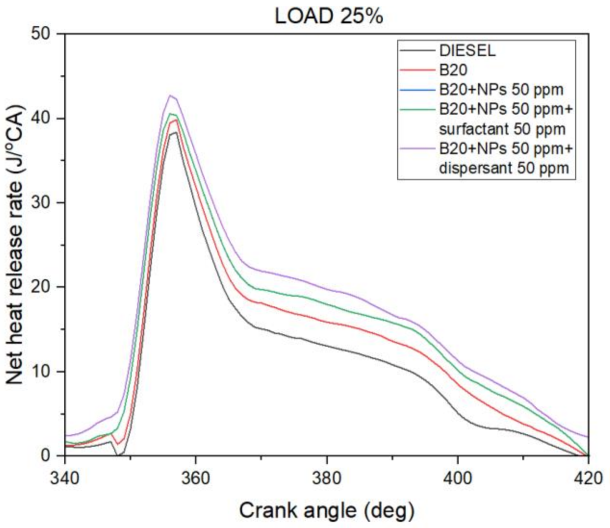

Fig 7: NHRR variation compared to crank angle at 25% load

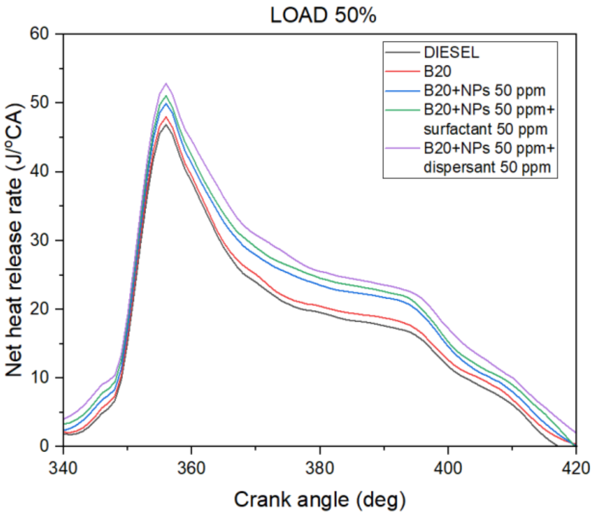

Fig 8: NHRR variation compared to crank angle at 50% load

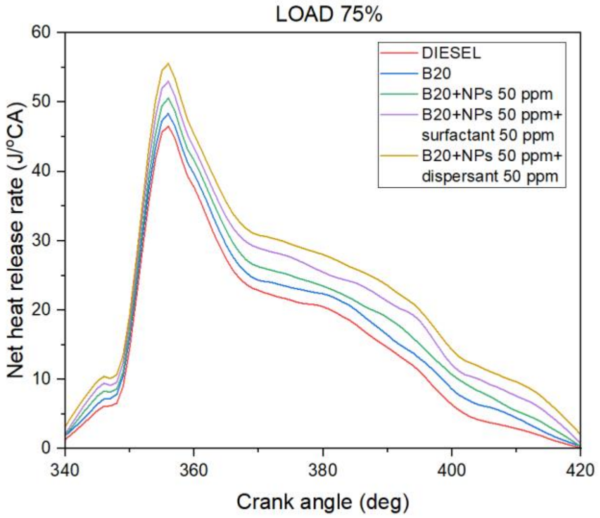

Fig 9: NHRR variation compared to crank angle at 75% load

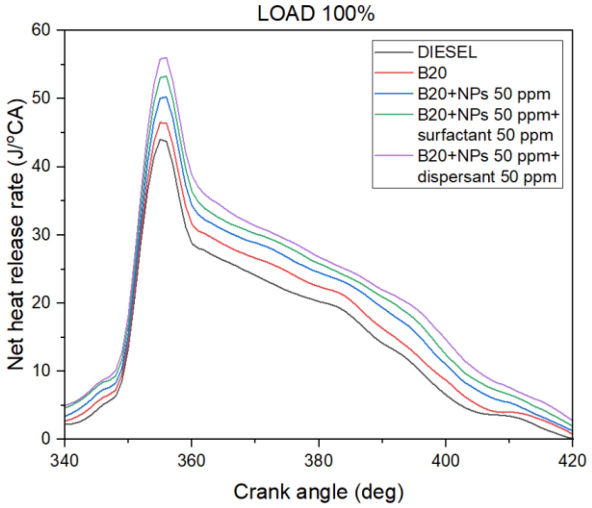

Fig 10: NHRR variation compared to crank angle at 100% load

The heat created by the combustion of the fuel samples, as shown in Figure 10, demonstrates the relationship between crank angle and NHRR. The fuels B20, B20+ZnO50ppm(B1), B20+ZnO50ppm+surfactant50ppm(B2), B20+ZnO50ppm+dispersant50ppm(B3) relative to the crank angle at the maximum 12kg load (100%). The results demonstrate that the B3 blend produces the most heat when compared to the other test fuels. At a load of 12kg, the maximal HRR values for B20, B1, B2, and B3 were 46.77J/^{O}CA, 50.83J/^{O}CA, 53.34J/^{O}CA, and 57.85J/^{O}CA. The inclusion of nanoparticles raises HRR values by 0.26%, 1.50%, 1.54%, and 2.98% utilizing B20, B1, B2, and B3 at 100% load, respectively. The ignition delay (ID) is the primary factor affecting the rate of heat release. In the case of nanoparticle blend biodiesel, the longer ID results in fuel build up and faster burning. The presence of nanoparticles lowers the cetane number and raises the ID. B3 has the highest Net heat release rate HRR compared to all engine loads.

3.1.3 Mean Gas Temperature

Mean gas temperature refers to the average temperature of gases inside an engine’s combustion chamber during the combustion process. it is an essential metric for evaluating engine longevity, emissions, and performance. Heat transmission, emissions production and combustion efficiency are all directly impacted by the combustion chamber’s gas temperature the fuel efficiency to air ratios, exhaust gas recirculation rates, and ignition time among other combustion strategy optimizations. In conclusion, mean gas temperature is a crucial variable in combustion analysis that offers information on engine longevity, emission production, and combustion efficiency. In relation to the research on zinc oxide nanoparticles and flaxseed oil biodiesel, understanding how mean temperature varies can be helpful in determining the fuel blend works in terms of optimizing combustion efficiency.

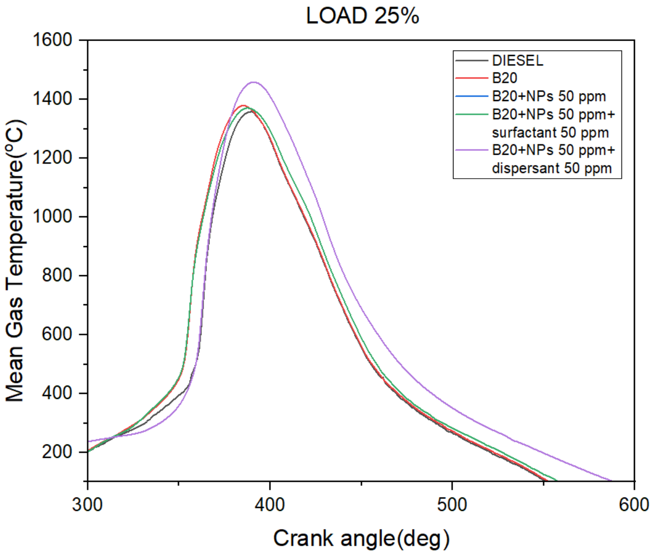

Fig 11: MGT against crank angle at 25% load

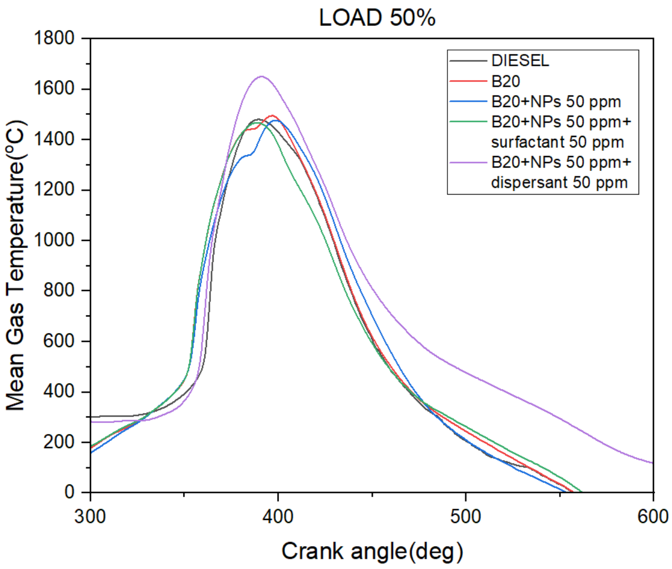

Fig 12: MGT against crank angle at 50% load

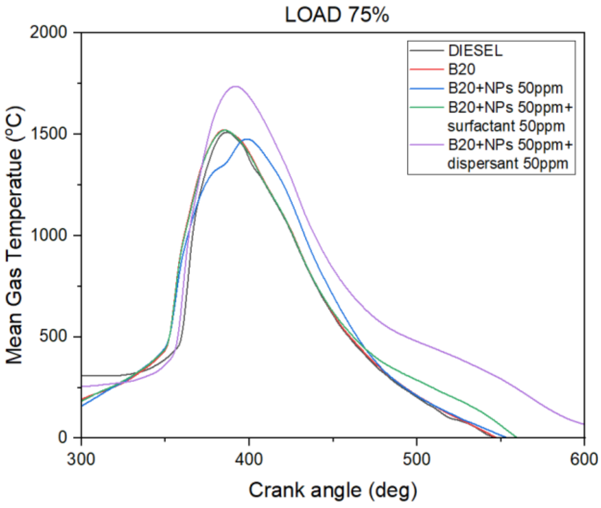

Fig 13: MGT against crank angle at 75% load

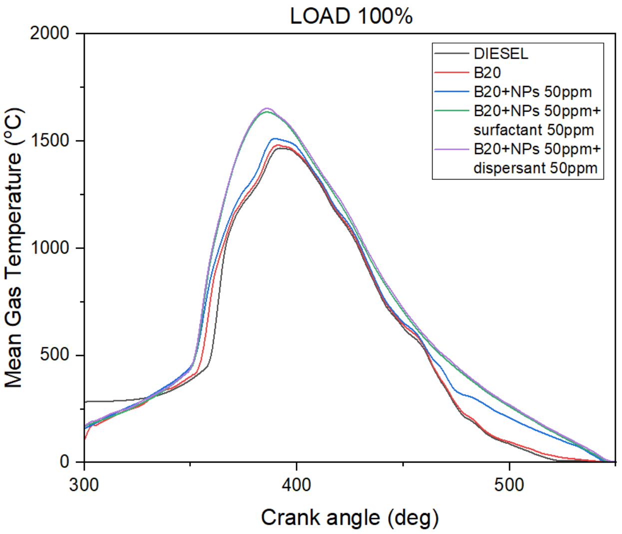

Fig 14: MGT against crank angle at 100% load

The temperature against crank angle like in Fig 14 shows a variation in mean gas temperature compared to diesel (D100). The values for B20, B1, B2, and B3 are 1410.39 ^{O}C, 1488.45 ^{O}C, 1636.34 ^{O}C, and 1668.07 ^{O}C respectively, at 100% load. The adding of nanoparticles the temperature improved by 2.43%, 5.28%, 8.30%, and 10.22% respectively. Considering the B3 blend had better combustion characteristics than the other fuel blends like i.e., B20, B1, and B2.

IV. CONCLUSION

The current study investigated the combustion characteristics behavior of utilizing fuels like diesel, B20, B20+ZnO50ppm(B1), B20+ZnO50ppm+CTAB50ppm(B2) B20+ZnO50ppm+TRITON-X50ppm(B3)
The outcomes lead to the following conclusion:

- The fuel properties of flaxseed oil biodiesel (B20) improve with the addition of Zinc oxide (ZnO) nanoparticles.
- The combustion characteristics like Cylinder Pressure (CP), Net Heat Release Rate (NHRR), and Mean Gas Temperature (MGT) were improved with test fuels B20, B1, B2, and B3 Represented by the following values on CP as 0.99%, 1.2%, 0.16%, and 0.5%. on NHRR as 0.26%, 1.50%, 1.54%, and 2.98%. on MGT as 2.34%, 5.28%, 8.30%, and 10.22% respectively, at a load of 12kg.

Overall, the study's conclusion suggests that incorporating zinc oxide (ZnO) nanoparticles into flaxseed oil biodiesel might be a practical strategy to improve the effectiveness and environmental impact of diesel engines.

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