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A COMBUSTION AND EMISSION STUDY OF DIESEL-BIODIESEL AND TIO_2 NANOPARTICLE BLENDS IN A SINGLE-CYLINDER FOUR-STROKE (DI) CI ENGINE AT DIFFERENT COMPRESSION RATIOS.

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Abstract: Research conducted an empirical investigation to examine the heat transfer characteristics occurring within a diesel engine. The methodology involves the utilization of a composite of biodiesel blends in conjunction with conventional diesel fuel. The present study investigated the impact of three distinct compression ratios (16, 17, and 18) on engine performance, with a consistent engine speed of 1500 revolutions per minute (rpm). The thermal energy required for efficiently converting biodiesel blends into brake power is similar to that of conventional diesel fuel. However, it has been shown that the thermal output generated by diesel fuel exceeds that of mixes containing biodiesel. The research findings indicate that the engine experiences a greater heat dissipation rate when employing diesel fuel than biodiesel mixtures. The analysis reveals that B20 exhibits higher levels of heat loss in both exhaust gas and radiation compared to the other fuels examined. The experimental study's findings demonstrate that using B20 biodiesel blends in an unmodified diesel engine leads to the highest thermal energy conversion into valuable work. This is supported by the observation of elevated values in Cylinder Pressure, heat release rate, and mean gas temperature compared to other biodiesel blends.

Keywords*:* TiO_2, Biodiesel, Blend, Heat Analysis, Temperature, Crank Angle

1. Introduction

Biodiesel is a chemical molecule including alkyl esters of fatty acids, synthesized via the transesterification process. The aforementioned reaction takes place when oils and fats undergo a chemical reaction with alcohol. The internationally recognized ASTM D6751-08 and EN 14214 standards require biodiesel to meet viscosity, density, cetane number, oxidation stability, heating value, cold flow properties, and other attributes. A compression ignition engine, commonly called a CI engine, is an internal combustion engine that utilizes diesel as its primary fuel. Initially conceptualized by Rudolf Diesel during the late 1800s, the diesel engine has experienced substantial adoption in diverse industries, including automotive, transportation, and industrial sectors. It has become a favored choice for various applications, encompassing automobiles, trucks, buses, marine vessels, and various machinery variants. The term "engine thermal efficiency" pertains to the efficiency of diesel fuel in converting its chemical energy into a mechanically useful output while concurrently minimizing waste heat generation. The concept of "generator thermal efficiency" refers to transforming the energy stored in diesel fuel into productive activity while simultaneously reducing energy dissipation as an unproductive byproduct. During the operational phase, generators have the potential to achieve a thermal efficiency ranging from 30% to 40% by employing optimization approaches under the given conditions. This indicates that an estimated range of 30% to 40% of the energy in diesel fuel is efficiently transformed into mechanical work, with the remaining portion released as thermal energy. The ongoing progress in science and engineering has yielded notable enhancements in the thermal efficiency of diesel engines, resulting in improved overall efficiency and reduced environmental impact. This research analyzes the thermal characteristics of a compression ignition engine running on a diesel and biodiesel blend. With this research, we will better understand how using biodiesel affects diesel engines' efficiency and pollution levels. Different aspects of engine performance, such as BTE,BSFC, and emissions of HC, NOx, and PM, have been studied about biodiesel blends. Canakci and Gerpen (2003) evaluated petroleum diesel fuel, yellow grease biodiesel, and soybean oil biodiesel for their engine performance and emissions [1]. PM, CO, UHC were found to be significantly reduced by both types of biodiesel fuels. The biodiesel mixes significantly increased the NOx emissions. The operational characteristics and environmental effects of a diesel engine were studied in depth by Khalaf et al. (2022)[2]. This study used an amalgam of Jatropha and fish oil as the biodiesel. According to the study, the study found hydrocarbon HC, CO, and smoke concentrations to be lower in the biodiesel blend than in regular diesel fuel. Mofijur et al. (2015) [3] looked into the effects of running diesel engines on the environment while using fuel blends containing biodiesel, diesel, and ethanol. According to the study's findings, using a composite mix in the engine significantly improved brake thermal efficiency compared to regular diesel fuel. When assessing the performance of an ICE powered by biodiesel-diesel blends, Falbo and Ramundo (2021) [4] developed a thermodynamic framework to make such assessments. The prediction model shows that employing fuel mixes with different percentages of biodiesel significantly increases brake thermal efficiency. Jagtap et al. (2021) [5] set out to determine how blending ethanol, biodiesel, and diesel affected the performance and pollution output of a compression ignition (CI) engine. Brake thermal efficiency (BTE) was lower when using biodiesel mixes than regular diesel fuel. Many measures of engine performance, including brake thermal efficiency (BTE) and specific fuel consumption, are shown to be significantly impacted by using biodiesel blends, according to the current empirical evidence. How much the composition of the fuel mixture and the engine's operating conditions affect emissions is a moving target. Carbon monoxide CO, HC, and PM emissions are effectively decreased using biodiesel mixes. However, some combinations may increase NOx emissions. Biodiesel blends' thermal efficiency and emissions depend on feedstock, blend ratio, and engine design. Academic study has examined methyl esters from vegetable oils [6,7] and ethanol [8–11]. The optimal performance of modern engines depends on accurate computational simulation of piston heat conduction mechanisms and cylinder combustion events. Prasad and Samria [12] studied transient heat transmission in a semi-adiabatic diesel engine's two-dimensional aluminum alloy piston. Researchers assumed border conditions were uniform across borders. Wu et al. [13,14] used an experimental arrangement to evaluate cylinder head temperature in a four-stroke spark-ignition engine. A novel heat transfer model was developed as a boundary condition for future spark-ignition piston heat conduction investigations. Heat Flow Analysis is essential for understanding engine performance, combustion efficiency, and emissions in diesel-biodiesel blends and biodiesel with Nanofuel TiO_2 in a four-stroke single-cylinder CI engine. This study uses Heat Flow Analysis to understand the thermal properties and enhance the operating efficiency of a single-cylinder Compression Ignition (CI) engine. Combining diesel and biodiesel fuels with TiO_2 nanofuel additives will accomplish the desired result. It also highlights minimizing emissions and improving internal combustion engine combustion. After testing different diesel-biodiesel mixtures, the combustion chamber temperature and pressure remained consistent. The diesel engine piston temperature profiles remained unchanged during transient and steady-state situations. Even with the same speed and torque, the results were consistent among combinations. Due to its lower heat value, biodiesel is more unstable than diesel. Users supplied numerical citations [15]. There is a lot of literature on how in-cylinder heat transfer affects internal combustion engine performance and exhaust pollutants. Heat transfer in the combustion chamber must be studied to improve fuel economy and environmental conservation—Hardenberg and Hase [19] modeled ignition delay. Comparing simulation results to experimental data showed a strong agreement, validating the simulation. The researchers used Eichelberg and Woschni models to compare the piston wall-combustion chamber heat transfer coefficient [20]. Temperature and combustion chamber composition were expected to affect combustion process temperatures. Diesel engine combustion has been studied using several models built for specific needs. These models can be categorized by complexity and computational system requirements. There are single-zone, quasi-dimensional phenomenological, and multidimensional computational fluid dynamics models. Utilizing these models could considerably decrease experimentation.

2. Materials and Methodology

The process of performing a heat flow analysis in a diesel engine, specifically one that operates using diesel-biodiesel blends and biodiesel with nanofuel TiO_2, involves the measurement and analysis of heat transfer occurring within the various components of the engine. This analysis aims to gain insights into the impact of different fuels and additives on the thermal characteristics of the machine. This study aims to conduct comprehensive research to explain the effects of various combinations of diesel fuel and biodiesel on the thermal performance characteristics of a diesel engine. The process of blending titanium dioxide (TiO_2) with biodiesel involves the integration of TiO_2 nanoparticles into biodiesel fuel, resulting in the formation of a nanofuel. This particular procedure optimizes biodiesel's properties and attributes, potentially leading to enhanced combustion efficiency and improved emissions performance. The controlled and measured addition of TiO_2nanoparticles is implemented into the biodiesel fuel. To achieve uniformity, the nanoparticles must be thoroughly dispersed within the power. The biodiesel and TiO_2 nanoparticles are meticulously combined to ensure a uniform and consistent blend. The achievement of nanoparticle dispersion uniformity may necessitate implementing mechanical motion or Sonication techniques. The nanofuel that is obtained should be subjected to a series of characterization and quality control examinations. These tests are essential in verifying the appropriate dispersion of nanoparticles and confirming that the nanofuel aligns with the desired specifications. It is imperative to evaluate the stability of the Nanofuel to ascertain the continued distribution of nanoparticles within the fuel throughout its lifespan. The accumulation of nanoparticles can impact the performance of the power. To achieve a homogeneous distribution of TiO2 nanoparticles within biodiesel, it is customary to employ a solvent to establish a stable suspension. Methanol or ethanol are frequently used as solvents in various applications. The measured TiO2 nanoparticles should be added to a laboratory flask or beaker containing an appropriate volume of the selected solvent. A sufficient quantity of solvent must be utilized to attain optimal dispersion. It is recommended to employ either a magnetic stirrer or an ultrasonic bath to facilitate the distribution of nanoparticles. Utilize either stirring or ultrasonicator techniques to achieve a state of uniform dispersion of the nanoparticles within the solvent. The achievement of adequate distribution may require several minutes for this process.

3. Engine and Experimental Setup:

The experimental setup was used for this evaluation. The practical design uses a 4-stroke, water-cooled, vertically-oriented single-cylinder diesel engine. The motor is securely mounted. Installing a counter-flow heat exchanger calorimeter at the exhaust site determines the exhaust gas mass flow rate. The brake dynamometer loads the engine. Integrating an orifice meter into the air supply line is done to measure the combustion air mass flow rate precisely. Calorimeters and cooling systems use water principally. The burette has a fuel tank to detect petrol mass flow specifically. Figure 1 shows the engine in line diagram.

The studies used diesel and diesel fuel mixed with biodiesel under different loading circumstances. Two experimental blends have been prepared for testing in addition to the conventional pure diesel fuel. One energy mix under consideration is B20, composed of a volumetric ratio of 20% biodiesel and 80% diesel. To evaluate the engine's performance, multiple important engine parameters were recorded, including the airflow rate, fuel consumption, engine speed, and temperatures at both the intake and exit of the water cooling system.

Table: 1 Test engine specification from engine manual

Particular	**Specifications**
Engine	1 cylinder, 4 stroke, water cooled engine
Bore and stroke	87.5mm by 110 mm
Rated power	3.5 kW at 1500 rpm
CR range	12:1 to 18:1
Dynamometer	Eddy current type, water cooled with load unit
Propeller shaft	With universal joints

Figure 1 Photograph of Experimental Setup

The engine's notable performances indicators, including brake power, specific fuel consumption, and brake thermal efficiency, were calculated after data acquisition. In table 1 indicated the engine specification from engine manual. Moreover, the energy analysis tools have devised an all-encompassing heat balance sheet for each scenario, considering the different blends. The engine is initially operated for thirty minutes to attain equilibrium. All measurements are recorded and logged during the engine's functioning without external load. A comprehensive dataset encompassed several loading scenarios, including a diverse array of fuel types, such as pure diesel and biodiesel fuel blends. A complete analysis was conducted on the engine's performance parameters, followed by a comparison with the observations made during the exclusive use of pure diesel fuel. In addition, a separate heat balance sheet was generated in conjunction with the performance analysis to assess the location with the highest level of energy dissipation. The utilization of energy analysis developed the heat balance sheet approach.

4. Results and Discussions

Experimental data regarding cylinder pressure, heat release rate, and mean gas temperature were analyzed for this study.

4.1 Cylinder pressure

The experimental data was collected at a rotational speed of 1500 revolutions per minute (rpm) under varying load conditions. The above data was utilized to accurately model the heat release rate curve during stimulation, with coefficients being changed accordingly. The mode exhibits a notable concurrence with the empirical data across all loads, particularly at a compression ratio of 18, primarily with the maximum pressure and the corresponding crank angle. The primary limitation of this model stems from the discovery that, within the area of diesel engine combustion, the optimal heat release rate exhibits two distinct curves: one for pre-mixed discharge and another for diffusion combustion. Therefore, employing an estimation of the heat release mechanism would have been a more appropriate strategy. It is paramount to recognize the inherent limitations in using data for simulation purposes and its inability to validate the model. This is because such data will provide substantial estimation regarding the simulation itself. Consequently, obtaining data for verification independently from the data employed for simulation is imperative. A properly calibrated (simulated) model will accurately replicate the results for any variations in load.

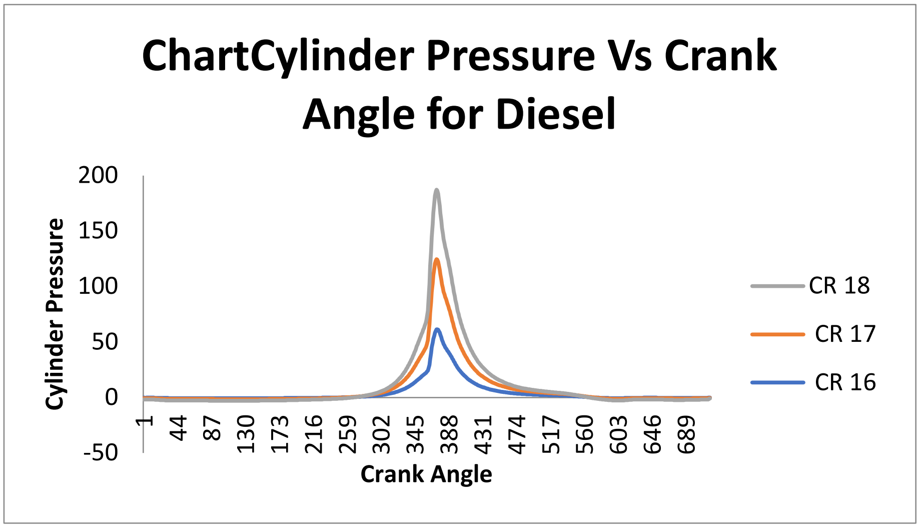

Figure 2: Cylinder pressure vs. crank Angle for Standard Diesel

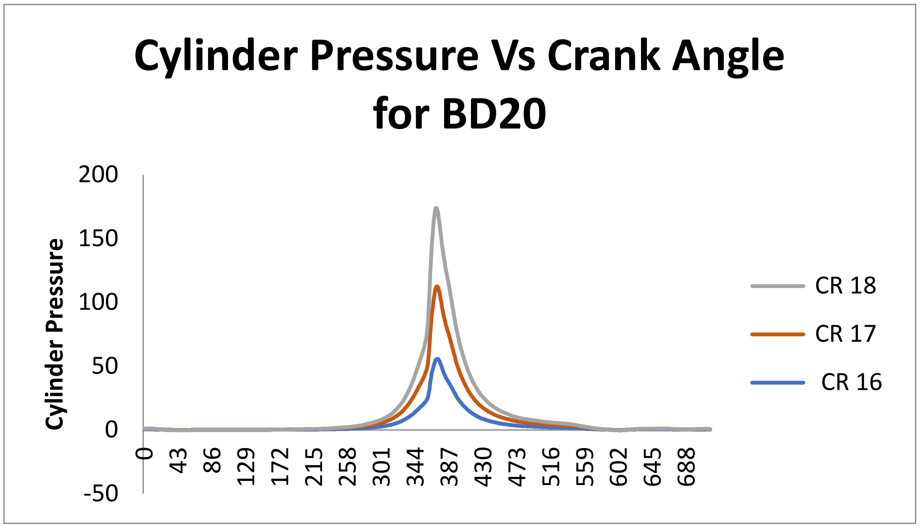

Figure 3: Cylinder pressure vs. crank Angle for BD20

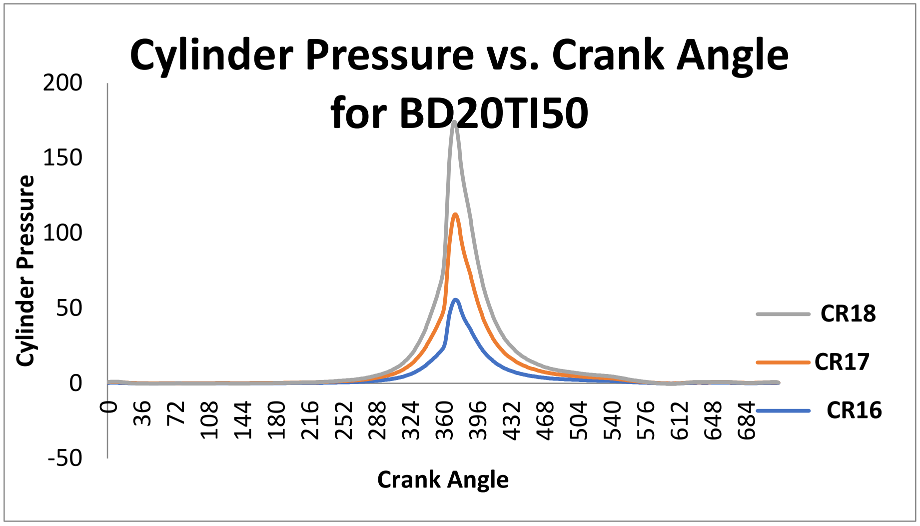

Figure 4: Cylinder pressure vs. crank Angle for BD20TI50

4.2 Heat Release Rate

Figures 6, 7, and 8 depict the heat release rate for different mixes. The elevated peak pressure observed during pre-mixed combustion can be ascribed to the heat release rate, which strongly correlates with the observed high heat release rate. The increased volatility demonstrated by diesel fuel enables improved air-fuel mixing. A significantly higher amount of thermal energy is emitted upon the piston's attainment of the top dead center (TDC). The heat release pattern demonstrates a lesser resemblance in engine load between diesel and biodiesel.

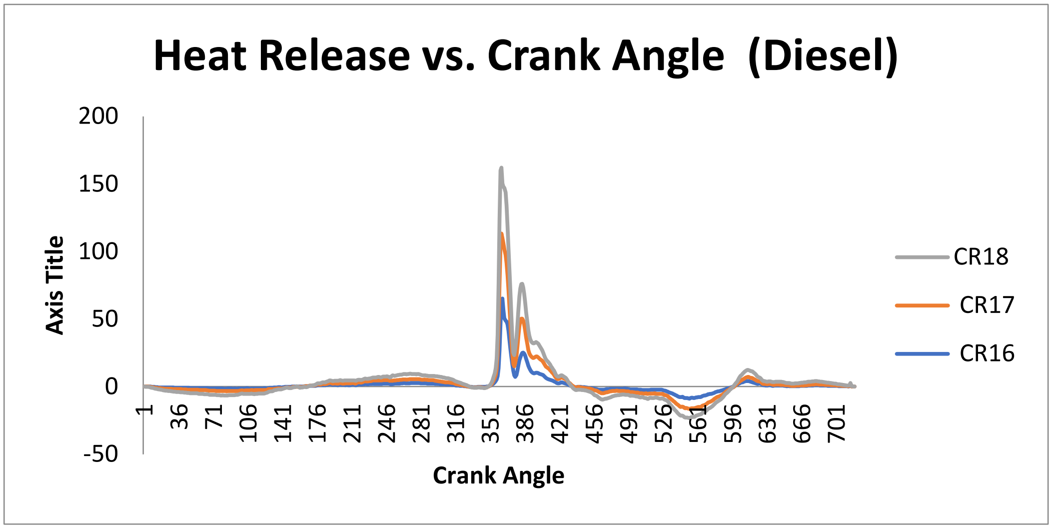

Figure 6: Heat release Rate vs. crank Angle for Standard Diesel

However, when exposed to higher loads, biodiesel blends demonstrated a noticeably increased heat release rate throughout mixing controlled combustion. This phenomenon can be ascribed to the diminished volatility and heightened viscosity. According to Figure 4, it can be observed that the Heat Release rate attains its peak value when subjected to a slight rotation of the crank angle. The

12-25 degrees Celsius temperature range was recorded throughout various load conditions. The graph illustrates a decrease in the heat release rate as the engine load decreases.

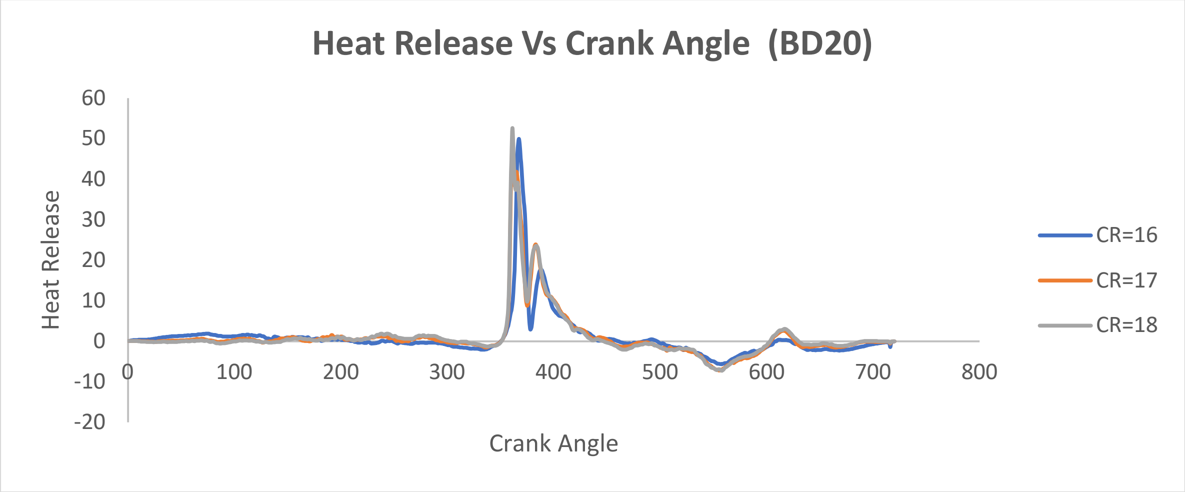

Figure 7: Heat release Rate vs. crank Angle for BD20

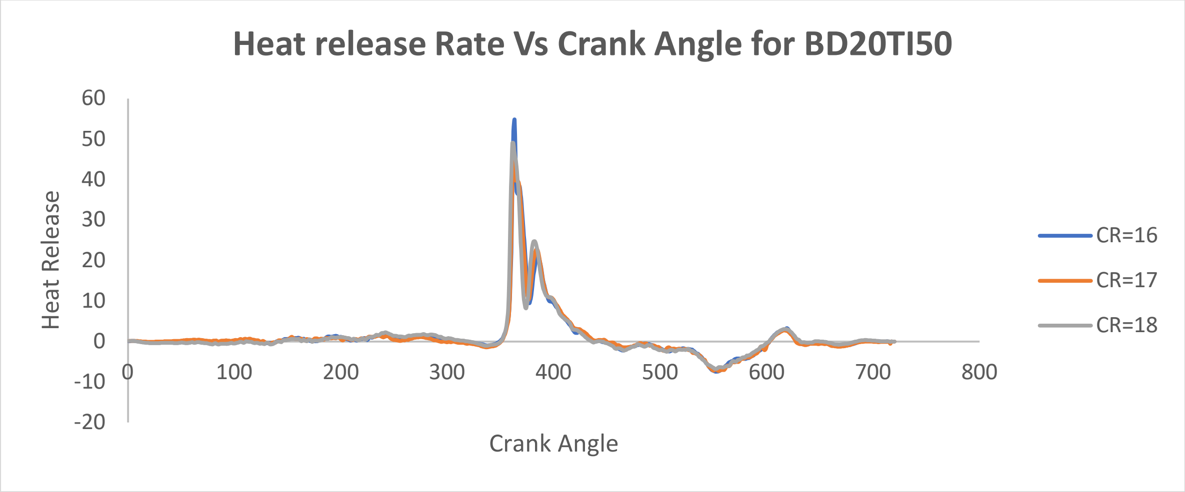

Figure 8: Heat release Rate vs. crank Angle for BD20TI50

4.3 Heat Transfer

Radiation and convection are the primary mechanisms responsible for heat dissipation through the cylinder wall. The Hochberg correlation is employed to compute heat transfer across the border of a cylindrical object. The relationship between the rate of heat loss from a cylinder and the temperature differential between its interior and exterior has been empirically established to be directly proportional. The finding suggests that the rate of heat loss reaches its peak at both 80% load and 60% load.

4.4 Mean Gas Temperature

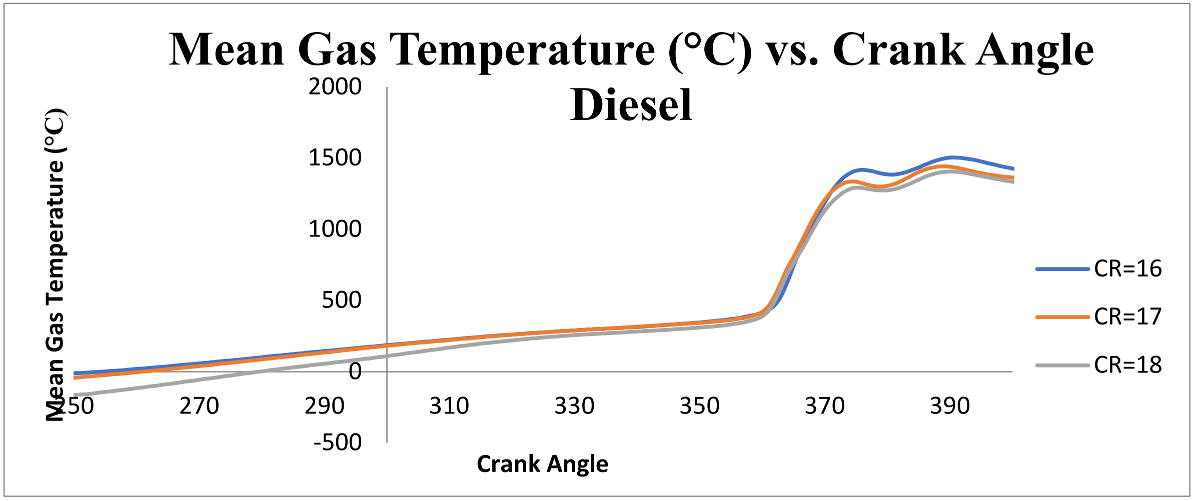

Figure 9: Mean Gas Temperature vs Crank Angle for Standard Diesel

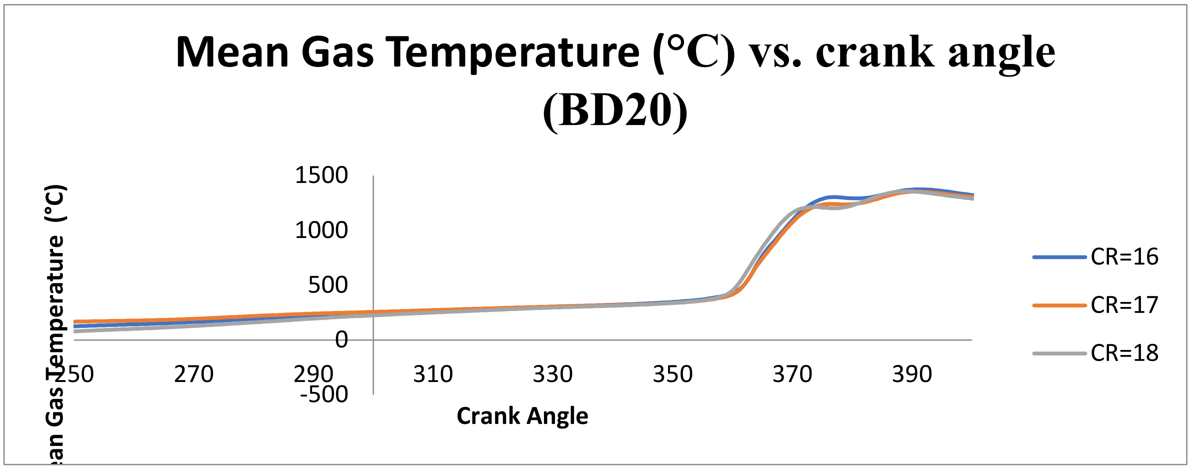

Figure 10: Mean Gas Temperature vs Crank Angle for BD20

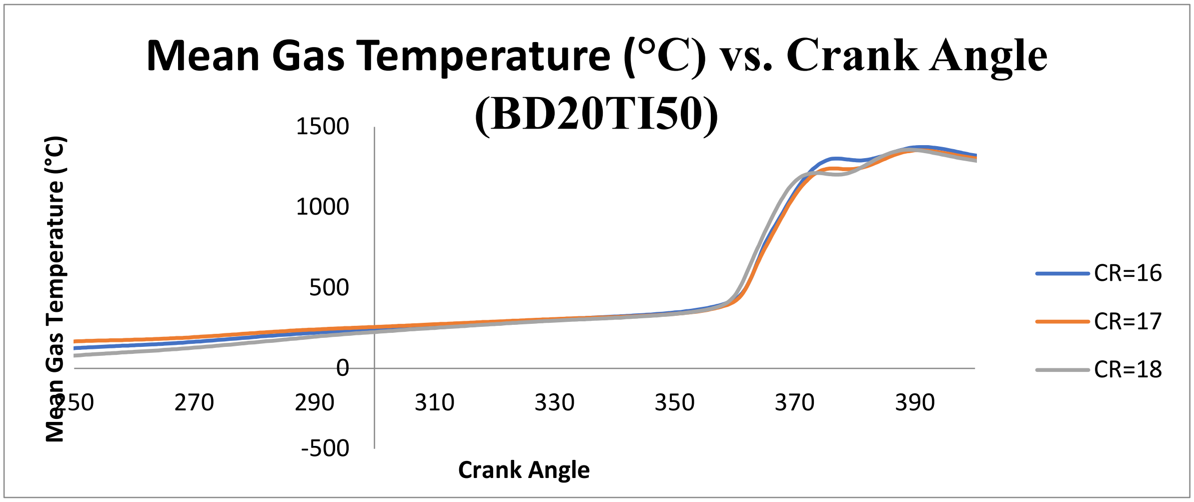

Figure 11: Mean Gas Temperature vs Crank Angle for BD20TI50

The figures 9, 10, and 11 present graphical representations that demonstrate the correlation between the average gas temperature and the crank angle in different types of diesel namely standard diesel, BD20 and BD20TI50. These figures offer valuable insights into the fluctuations in temperature occurring within the engine cylinder as the piston completes its operational cycle. In a normal diesel engine, the operational cycle typically comprises four separate strokes, namely intake, compression, power, and exhaust. The Mean Gas Temperature is calculated as the average of the temperatures during these four strokes. It's highest during the power stroke and lowest during the intake and exhaust strokes.

4.5 Result and Discussion of Emission:

The experiment with varying of compression ratio of 16, 17 and 18 full graphical and tabular comparison was analyzed.

Emission Parameters	**Fuel**	**Emission Range during experiment**	**BS-VI emission range [22]**	**Remarks**
HC (ppm)	1. Diesel	13-93	45	Only in overload, Out of range
	2. BD20	19-108		Only in overload, Out of range
	3. BD20TI50	22-106		Within range
NOx (% vol.)	1. Diesel	0.97-8.93	8.5	Only in overload, Out of range
	2. BD20	0.72-8.63		Only in overload, Out of range
	3. BD20TI50	1.41-8.53		Within range
CO (% Vol.)	1. Diesel	0.06-0.55	0.3	Only in overload, Out of range
	2. BD20	0.05-0.53		Only in overload, Out of range
	3. BD20TI50	0.04-0.50		Within range

Figures 12, 13, and 14 show the correlation between hydrocarbon emissions and engine load in a vehicle or engine while considering different compression ratios. The term "engine load" generally pertains to the level of power generated by the engine, while hydrocarbons are a specific category of air pollutants discharged by internal combustion engines.

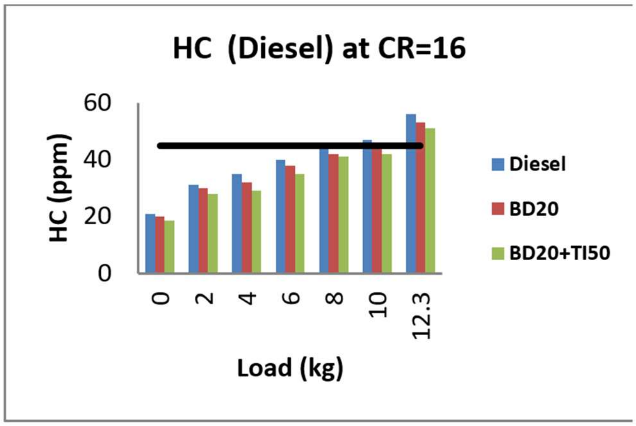

Figure 12 HC vs Load for Diesel for CR=16

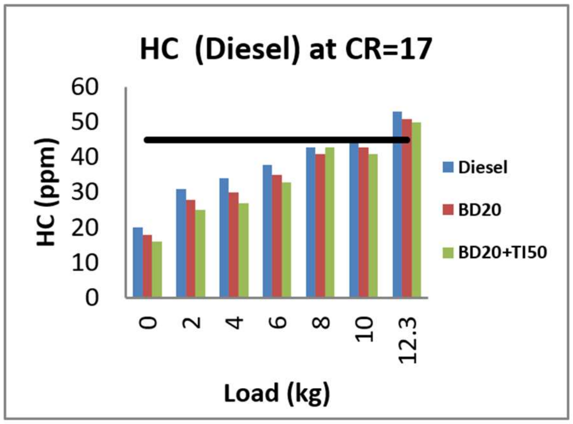

Figure 13 HC vs Load for Diesel for CR=17

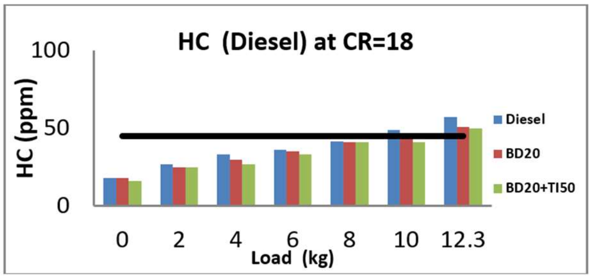

Figure 14 HC vs Load for Diesel for CR=18

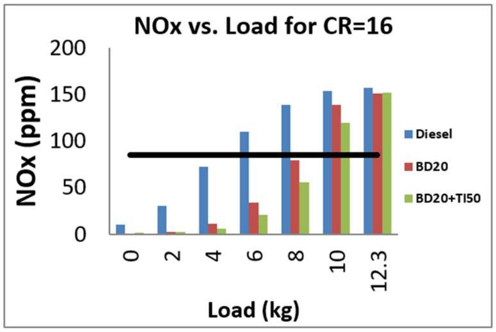

Figure 16: NOx vs Load for Diesel for CR=16

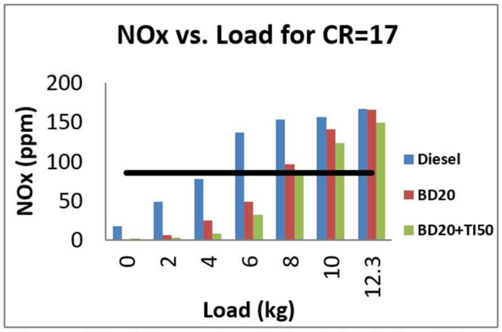

Figure 15: NOx vs Load for Diesel for CR=17

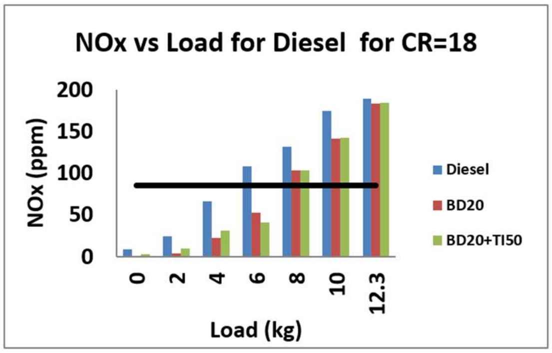

Figure 17 NOx vs Load for Diesel for CR=18

The graph facilitates the examination of hydrocarbon emissions fluctuations across various engine load circumstances, hence offering valuable insights. The implementation of Bharat Stage 6 (BS6) range guidelines in India in 2020 signifies adopting a comprehensive set of emission limits for automobiles. The requirements above are comparable to the Euro 6 standards implemented in Europe, and they enforce rigorous restrictions on a range of pollutants released by cars, such as HC,NOx, CO, and PM. The graph illustrates the variations in hydrocarbon emissions in response to fluctuations in engine load while also considering the necessity of adhering to the BS6 emission standards. The parameters above delineate the uppermost permissible levels of hydrocarbon emissions under different load scenarios. It is imperative to maintain emissions data within the prescribed limits. Conduct a comprehensive data analysis to discern any patterns or trends in hydrocarbon emissions when the engine load changes. As an illustration, emissions can exhibit a rise under high-load situations or a drop during idle periods. It is imperative that the graph accurately represents adherence to the BS6 regulations across the whole spectrum of loads. If emissions are above the established thresholds, it would signify a state of non-compliance. Analyze the graph to get inferences regarding the emission performance of the engine across different load conditions. This information is valuable in optimizing engine and vehicle design to comply with pollution laws. Manufacturing titanium dioxide commonly involves the utilization of high-temperature methodologies, such as the sulfate or chloride process. The processes above may necessitate the utilization of fuel combustion, such as natural gas or coal, to produce the requisite thermal energy. Combustion operations can potentially emit NOx emissions into the environment, predominantly in nitrogen oxides (NO and NO_2). It is crucial to acknowledge that the influence of titanium dioxide production on nitrogen oxide (NOx) emissions can exhibit variability contingent upon the distinct procedures, technologies, and energy sources manufacturers employ. Regulations and emission control devices can greatly influence the level of NOx emissions related to the manufacture of titanium dioxide. To address the potential environmental consequences associated with releasing NOx emissions during titanium dioxide manufacturing, manufacturers have the opportunity to employ a range of strategies. These strategies encompass using cleaner energy sources, implementing emission control systems, and adhering to established environmental norms and standards. The emission impact of titanium dioxide on nitrogen oxides is ultimately indirect and contingent upon multiple factors associated with its manufacturing and utilization. Managing and reducing emissions in industrial operations necessitates incorporating environmental factors and adherence to regulatory compliance.

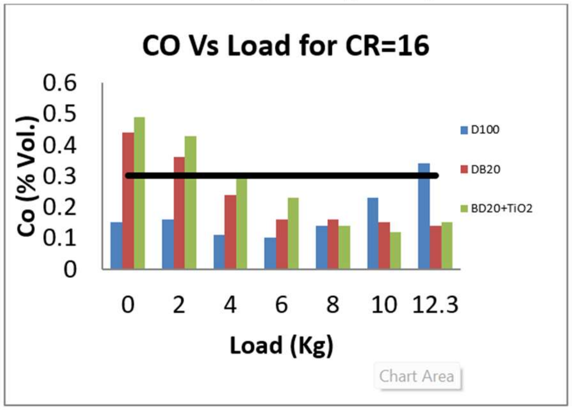

Figure 18: CO vs Load for Diesel for CR=16

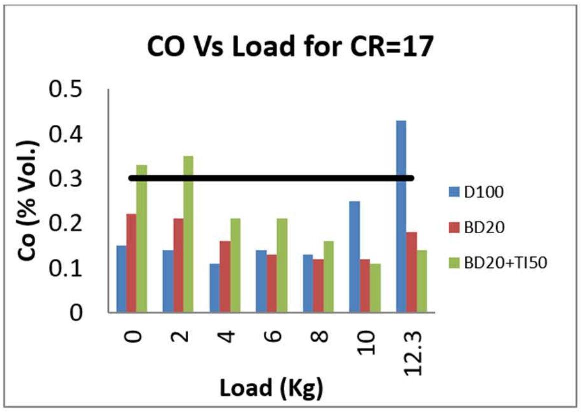

Figure 19: CO vs Load for Diesel for CR=17

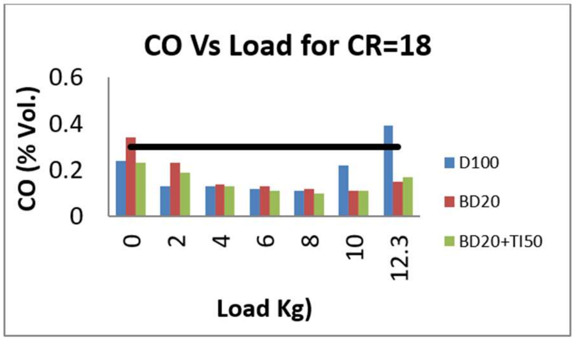

Figure 20 : CO vs Load for Diesel for CR=18

Figure 18, 19,and 20 illustrate the variations in carbon monoxide (CO) emissions in relation to load for diesel, BD20 and BD20+TI50.Carbon monoxide (CO) is sometimes generated during the process of combustion due to incomplete combustion. Insufficient preparation of air mixture and a deficiency in oxygen supply. As the load increases, there is a corresponding increase in the quantity of carbon monoxide. Recent findings have revealed that high-density diesel comprises chemical constituents possessing a greater carbon count in comparison to conventional fuel sources. The combustion of these carbon-rich molecules necessitates a greater amount of oxygen for complete oxidation. The efficiency of a turbocharger is significantly reduced during part loads compared to full loads. The insufficiency of air can be attributed to the increased carbon content in the fuel mixture. Additionally, the highest carbon monoxide (CO) emission is seen while employing low-density of BD20 operating at maximum capacity of 100% load. When low-density BD20+TI50 is utilized as a fuel source, it exhibits the lowest average carbon monoxide (CO) emissions in comparison to alternative fuels. Conversely, the highest CO emissions are observed when diesel and BD20 employed as a fuel. When the compression ratio (CR) is 18, the emission of carbon monoxide (CO) is the lowest among all fuels when compared to the average values of lower compression ratios.

5. Conclusion

A simulation utilizing a zero-dimensional single-zone combustion model has been conducted to forecast the performance of a single-cylinder constant-speed diesel engine, with the compression ratio being varied. This analysis combines modeling and combustion analysis techniques. The current study focuses on doing experimental calculations and simulations to determine the Rate of Heat Release and pressure for a diesel engine operating on a fuel blend consisting of 20% biodiesel and biodiesel combined with titanium dioxide nanoparticles. The following is the analysis done:

1. Using biodiesel-diesel blends at lower concentrations enhanced engine performance, as the increased maximum combustion temperature and pressure. These findings are visually represented in the accompanying graph.
2. The pressure and temperature variations within the cylinder were determined by employing combustion correlations that yielded simulated results consistent with experimental findings.
3. The simulation presented in this work efficiently facilitates heat loss investigation. If required, adjust the equations to enable their use across a broader spectrum of velocities and loads.
4. The use of MATLAB software for simulations on models has several advantages, including enhanced ease of use and a broad range of applications for conducting micro-level analyses of engine performance.
5. The findings of the current models exhibit a strong concurrence with the experimental outcomes.

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6. Nomenclature

D100	Standard Diesel / Regular Diesel
BD20	Biodiesel 20% + Petroleum diesel 80%
BD20TI50	Biodiesel 20% + Petroleum diesel 80%+TiO_2 (50 ppm)
CR	Compression Ratio
CO	Carbon Monoxide
HC	Hydrocarbons
NOx	Oxide of Nitrogen
PM	Particulate Matter
UHC	Unburned Hydrocarbons

7. References

1. Canakci, M., Gerpen, J. (2003). Comparison Of Engine Performance and Emissions For Petroleum Diesel Fuel, Yellow Grease Biodiesel, And Soybean Oil Biodiesel. Transactions of the Asae, 4(46). https://doi.org/10.13031/2013.13948
2. Falbo, L., Ramundo, E. (2021). Performance Analysis Of a Biodiesel-fired Engine For Cogeneration. E3S Web Conf., (312), 08013. https://doi.org/10.1051/e3sconf/202131208013
3. Jagtap, S., Pawar, A., Lahane, S. (2021). Effect Of Ethanol-biodiesel-diesel Blend On Performance and Emission Characteristics Of A DI Diesel Engine. IJHT, 1(39), 179-184. https://doi.org/10.18280/ijht.390119

4. Khalaf, M., Abdel-FadEel, W., Abdelhady, S., Esmail, M. (2022). Performance and Emissions Of A Diesel Engine Fueled With A Biofuel Extracted From Jatropha Seeds. International Journal of Applied Energy Systems, 0(0), 0-0. https://doi.org/10.21608/ijaes.2022.130246.1008
5. Mofijur, M., Rasul, M., Hyde, J. (2015). Recent Developments On Internal Combustion Engine Performance and Emissions Fuelled With Biodiesel-diesel-ethanol Blends. Procedia Engineering, (105), 658-664. https://doi.org/10.1016/j.proeng.2015.05.045
6. Qi DH, Chem H, Geng LM, Bian YZH, Ren XCH. Performance and combustion characteristics of biodiesel-diesel-methanol blend fuelled engine. Appl Energy2010;87:1679–86.

7 Aydin H, Cumali I. Effect of ethanol blending with biodiesel on engineperformance and exhaust emissions in a CI engine. ApplThermEng2010;30:1199–204.

8 He B-Q, Shuai S-J, Wang J-X, He H. The effect of ethanol blended diesel fuels on emissions from a diesel engine. Atmos Environ 2003;37:4965–71.

9. Caro PS, Mouloungu̇ia Z, Vaitilingomb C, Berge JC. Interest of combining andadditive with diesel–ethanol blends for use in diesel engines. Fuel 2001;80:565–74.
10. Hansen AC, Zhang Q, Lyne PWL. Ethanol-diesel blends – a review. BioresourTechnol2005;96:277–85.
11. Li D, Zhen H, Xingcai L, Wu-gao Z, Jian-guang Y. Physico-chemical properties ofethanol-diesel blend fuel and its effect on performance and emissions of dieselengines. Renew Energy 2005;30:967–76.
12. Prasad R, Samria NK. Transient heat transfer in an internal combustion engine piston. ComputStruct 1990;34(5):787–93.
13. WuYY, Chen BC, Hsieh FC. Heat transfer model for small-scale air-cooled spark ignition four-strokes engines. Int J Heat Mass Transfer 2006;49:3895–905.
14. Wu YY, Chen BC, Hsieh FC, Ke CT. Heat transfer model for small-scale spark-ignition engines. Int J Heat Mass Transfer 2009;52:1875–86.
15. Marcelo J. Colaçoa,,Cláudio V. Teixeira.Thermal analysis of a diesel engine operating with diesel–biodiesel blends.Fuel 89 (2010) 3742–3752.
16. Borman G, Nishiwaki K. Internal combustion engine heat transfer. ProgEnergyCombust Sci1987;13:1–46.
17. Compression and expansion. ASME J Heat Transfer 1994;116:536–42.
18. Singh VP, Upadhyay PC, Samria NK. Some heat transfer studies on a diesel engine piston. Int J Heat Mass Transfer 1986;29(5):812–4.
19. Hardenberg HO, Hase FW. An empirical formula for computing the pressurerise delay of a fuel from its cetane number and from the relevant parameters ofdirect-injection diesel engines. SAE paper 790493. SAE Trans; 1979. p. 88.
20. Ramos JI. Internal combustion engine modeling. HPC; 1989.

21. BORDET Nicolas, CAILLOL Christian, HIGELINPascal, “A Physical 0D Diesel Combustion Model UsingTabulated Chemistry with Presumed Probability DensityFunctionApproach:For engine pre-Mapping, InstitutPRISME - University of Orleans, France, FISITA2010-SC-O-26.
22. Modi MA, Patel TM, Experimental investigation of emission parameters of diesel engine fueled with various plastic Pyrolysis oils, International Journal of Engineering, Science and Technology Vol. 15, No. 3, 2023, pp. 1-10, © 2023 Multicraft Limited.