Applied Chemical Engineering (2024) Volume 7 Issue 3
doi: 10.59429/ace.v7i3.5549

ORIGINAL RESEARCH ARTICLE

Performance and emissions of a CI engine using a diesel, jatropha biodiesel and biodiesel adopting Al_2O_3 nanomaterial as fuel blend.

Nishant S. Thakar [1,*], Tushar M. Patel [2]

[1] *Research Scholar, Mechanical Engineering Department, Kadi Sarva Vishwavidyalaya, Gandhinagar, Gujarat-382015, India*

[2] *Professor, Mechanical Engineering Department, LDRP-ITR, Kadi Sarva Vishwavidyalaya, Gandhinagar, Gujarat-382015, India.*

***Corresponding author:** Nishant S. Thakar, nthakar.04@gmail.com

ABSTRACT

A nanocomposites of aluminum dioxide was employed as a fuel additive in a compression engine test. Nanoparticle stability in diesel was measured by their impact on the fuel's flash point, density, and viscosity. When compared to other forms of fuel, conventional biodiesel has superior qualities. Al_2O_3 was also put through its paces in terms performance of engine and pollution testing. The thermal efficiency of the engine's brakes may be improved by adding nanoparticles in to the jatropha biodiesel. Using Al_2O_3 nanoparticles has been shown to reduce brake-specific fuel consumption by 23%. In addition, this solution can cut hydrocarbon emissions by 19%.

Keywords: emission; biodiesel; blended fuel; performance; Al_2O_3 nanomaterial; CI engine

ARTICLE INFO

Received: 20 September 2024
Accepted: 22 October 2024
Available online: 25 October 2024

1. Introduction

A diesel engine is a specific variant of an internal combustion engine that operates solely on diesel fuel. The invention of the diesel engine, attributed to Rudolf Diesel during the latter part of the 19th century, has found extensive use across a wide range of industries. Its applications span several modes of transportation such as automobiles, trucks, ships, trains, as well as power generation systems. The current fuel problem is projected to exacerbate in the future as a result of a significant increase in the rate of fuel use in transportation during the preceding decades an area that warrants additional investigation is the deployment of enhanced engine design. This may encompass progressions in diverse elements, including turbochargers, intake and exhaust systems, and combustion chamber design, with the aim of enhancing fuel efficiency and overall performance. This upgrade improves the brake system's thermal efficiency, hence resulting in a decrease in pollutant levels. Consequently, the thermal efficiency of the engine will improve, leading to a decrease in environmental contaminants. The depletion of petroleum reserves necessitates researchers to explore essential energy alternatives that exhibit exceptional performance and minimal emissions. Numerous researchers have conducted experiments that indicate a projected surge in overall energy consumption by the year 2050, estimated to increase by more than 57 units compared to the current baseline.

Based on a significant study, it is projected that around 1.6 billion individuals will have access to electricity by the year 2035. The superiority of hydrogen fuel as a renewable energy source, which exhibits environmental favorability in the energy production process, is evident. Consequently, hydrogen is widely regarded as an ecologically and environmentally sustainable energy source. Please provide more context or information for me to assist you. Indeed, the practicality of utilizing hydrogen in a diesel engine is comparatively lower when compared to its application in a spark ignition engine. However, this issue can be addressed by the implementation of extensive engine operation strategies. One potential strategy to mitigate the aforementioned ambiguity is the incorporation of hydrogen into blends of diesel fuel[3]. The utilization of ethanol as a fuel source has been found to enhance engine performance, resulting in reduced levels of pollutant emissions and less ignition delay[4]. Nanoparticles are frequently included into lubricants, gasoline, and other carrier fluids. Numerous studies have shown that incorporating nanoparticles into lubricants increases bearing load capacity, decreases friction, and limits wear on tribosurfaces[5,6].

The previous study conducted by Kose and Anivic[7] involved conducting experiments on diesel engines equipped with direct injection, varying the hydrogen amounts at 2.5%, 5%, and 7.5%. According to their assertion, the inclusion of hydrogen has the potential to mitigate the release of hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2) emissions. On the contrary, there is no significant reduction observed in the levels of NO_X (nitrogen oxides). Bari and Esmaeil (2019)[8] observed comparable results. The process of fuel formulation entails the incorporation of additives into diesel fuel in order to enhance its properties and optimize engine performance. Extensive research has been undertaken in this particular domain. These chemical additives enhance the lubricating properties of diesel fuel while simultaneously causing a slight reduction in viscosity. In a broad sense, the aforementioned compounds contribute to the reduction of carbon monoxide (CO) and hydrocarbon emissions, but do not effectively mitigate smoke emissions. The user has provided a numerical reference, indicating the presence of a citation or source[9]. The implementation of advanced engine design, utilization of alternative fuels, and development of efficient fuel formulations have the potential to greatly enhance engine performance while simultaneously reducing the emission of harmful exhaust pollutants. This enhances the thermal efficiency of the braking system and decreases the impact on the environment by reducing emissions. This study is novel in its exploration of an innovative fuel blend that combines jatropha biodiesel with Al_2O_3 nanomaterials, targeting compression ignition engines. It offers new insights into combustion characteristics, emissions profiles, and performance metrics, contributing valuable data for cleaner combustion technologies and sustainability efforts.

1.1. Formulation of fuel

Formulation of fuel is the term used to describe the procedure of creating a precise combination of elements in order to manufacture a fuel that possesses predetermined properties and characteristics. The process entails the selection and combination of various elements in precise proportions to meet certain requirements, such as energy density, combustion efficiency, environmental impact, and compatibility with intended applications. The increasing public apprehension around global warming and air pollution has led to a corresponding surge in the interest surrounding alternative fuel compositions. Fuel additives refer to chemical substances that are incorporated into a fuel blend with the aim of enhancing specific characteristics or resolving particular issues. The use of certain measures has the potential to enhance engine performance, optimize fuel efficiency, mitigate pollutants, prevent corrosion, and ensure fuel durability during storage.

Research is now being conducted on additives that are derived from metals. Ferric Chloride ($FeCl_3$) serves as a catalyst in the synthesis of biodiesel derived from palm oil, specifically for the utilization of coke waste. The findings indicate that the incorporation of FBC into biodiesel leads to a decrease in brake specific fuel consumption (BSFC) by 8.6%, accompanied by a corresponding increase in brake thermal efficiency of 6.3%.In comparison to diesel, the incorporation of fluidized bed combustion (FBC) in biodiesel production resulted in reduced emissions of oxide of nitrogen (NO_X), slightly increased emissions of carbon dioxide (CO_2), decreased emissions of carbon monoxide (CO), diminished emissions of total hydrocarbon (HC), and decreased emissions of smoke. Significant improvements in cylinder gas pressure, heat release rate, and ignition delay time were made as a result of the use of FBC biodiesel[10]. The user provided a numerical reference without any accompanying text. Ethanol's use resulted in enhanced engine performance, characterized by reduced emissions of pollutants and decreased ignition delay[11]. Diesel fuel parameters (viscosity, flash point, and fire point) were seen to vary with the addition of nanometal oxide. Diesel fuel improved little when nanometal oxide was added to it. There was a notable drop in pollutant emissions from diesel fuel treated with nanometal oxide[12].

According to Kegl[13], injection parameters and enhanced injection time tell biodiesel emigration and performance graphs. Except for NO_x, emigrations dropped. Energy blending, micro emulsification, and other colorful methods can convert crude oil painting into biodiesel, solving the above issues. Pyrolysis, esterification, and transesterification reduce energy density[14,16]. Biodiesel, along with colorful other indispensable energies, has garnered significant global attention[17]. BTE was improved and CO and HC emissions decreased by adding aluminum, iron, and boron nanoparticles to diesel fuel[18]. Enhancement results from complete combustion through quick oxidation, reducing ignition delay and burning time. Nano-additive increases surface area to volume ratio and catalytic activity[19]. High energy density nanoparticles can improve fuel oxidation and reduce ignition delay time through catalytic actions. The ignite probability of fuel mixtures with nanoparticles was significantly higher than pure diesel[20]. The presence of water in emulsified fuel reduces peak cycle temperature and NO_x emissions due to high latent heat of vaporization[21]. The water-diesel-nano fluid emulsion had lower carbon monoxide emissions than conventional diesel at all power outages. Nano particles in emulsified fuel shatter water molecules, allowing oxygen atoms to separate and complete oxidation of carbon atoms. Water diesel emulsion is a potential fuel for reducing smoke and NO_x emissions in diesel engines. Additionally, adding nanofluids to emulsified fuel can reduce hydrocarbons and carbon monoxide and increase engine performance. The optimization of biodiesel production is increasingly important for sustainable energy and environmental impact. Köse et al.[22] studied the viscosity of waste cooking oil biodiesel via transesterification, identifying optimal conditions for a minimum viscosity of 4.37 $g \cdot cm^3$ using response surface methodology (RSM). Towoju[23] emphasized the effects of fuel properties and combustion chamber geometry on compression ignition engines, highlighting how biodiesel blends can enhance efficiency and reduce emissions[23]. Aydoğan[24] explored ethanol/n-heptane blends in HCCI engines, noting improvements in thermal efficiency and emissions. Binboğa[25] reviewed the VECTO simulation tool for assessing fuel efficiency in heavy-duty vehicles, reinforcing the need for optimized fuels[25]. Kocakulak and Arslan discussed hybrid fuel cell systems as a clean energy alternative, aligning with biodiesel optimization goals[26]. Ardebili et al. demonstrated that adjusting fuel composition significantly improves HCCI engine performance[27]. Kumaran et al. found that Tomato Methyl Ester (TME) can enhance diesel engine performance while reducing emissions[28]. Celik, Bayındırlı, and Kuş investigated the effects of adding n-hexane to diesel and biodiesel fuels, finding that it improved fuel characteristics by decreasing cetane number, density, and viscosity while enhancing calorific value. Their experiments showed increased engine torque and power, alongside reduced CO and HC emissions, although NOx emissions slightly rose. This study underscores the potential of fuel additives to optimize engine performance and emissions in alternative fuel applications[29,30]. Modi and Patel (2024) develop a model using Response Surface Methodology (RSM) to enhance specific fuel consumption (SFC) in compression ignition engines fueled by plastic pyrolysis oils. The model evaluates critical engine parameters such as injection pressure, compression ratio, engine load, and fuel type, identifying load as the most crucial factor. Their model, validated by empirical data, has exceptional accuracy (R^2 = 99.35%), making it a potent tool for enhancing engine performance with alternative fuels[31]. Dubey et al. assessed biodiesel from waste cooking oil, optimizing the transesterification process to achieve a 92% yield under ideal conditions. Their economic analysis showed a production cost of 32.99 INR per liter, highlighting waste cooking oil's potential as a sustainable biodiesel source[32]. In 2022, Dubey et al. explored biodiesel-diesel blends with exhaust gas recirculation (EGR), achieving a 92% biodiesel yield from waste soybean oil. Their findings indicated that the B35 blend with 15% EGR reduced NOx and smoke emissions, leading to a 23.34% cut in operational costs, making it suitable for existing diesel engines[33]. A subsequent study Dubey et al., evaluated ternary blends of diethyl ether, waste soybean oil biodiesel, and ultra-low sulfur diesel (ULSD), identifying the DEE10B35EGR15 blend as optimal for performance and emissions, supporting green energy goals[34]. Dubey et al. confirmed the effectiveness of biodiesel-ULSD blends with EGR in reducing emissions, particularly NOx and smoke, while maintaining good engine efficiency, underscoring the benefits of biodiesel in diesel engines[35]. Usman et al. investigated a hydroxy gas (HHO) and compressed natural gas (CNG) mixture in spark ignition engines, demonstrating improved fuel efficiency and 10.59% lower NOx emissions compared to gasoline, with significant cost-saving potential[36]. Usman et al. analyzed acetone-gasoline blends, finding enhanced engine performance but greater lubricant oil degradation, indicating the trade-offs of alternative fuels[37]. Elkelawy et al. investigated diesel /WCO biodiesel/Cyclohexane blends in DI-CI engine and obtained results have been compared with the commercial diesel and B60D40 fuel blends [38]. Kumbhar et al. carried out statistical analysis of properties from fatty acid composition. They found that the predictive models for kinematic viscosity and heating value were ineffective and error between experimental and predicted values was sufficiently minimal for heating value[39]. Elkelawy et al. used nanoparticles of Mn (II) supramolecular complex in diesel-biodiesel blends for the Combustion and emission analysis. They found that the performance of the CI engine relies on the aid of the nanosized Supramolecular complex additive [40].

In summary, this research emphasizes the significant potential of alternative biofuels to enhance diesel engine performance and mitigate emissions. By optimizing fuel blends and utilizing exhaust gas recirculation (EGR), efficiency and sustainability can be markedly improved. However, further investigation into the long-term impacts on engine performance and lubricant health is essential. The literature also highlights the importance of optimization techniques, such as response surface methodology (RSM), in advancing the development of biodiesel and alternative fuels. Future research should focus on the combined effects of these fuels and innovative additives to further enhance engine efficiency and emissions reduction.

2. Experimental method and engine set up

The inclusion of nanoparticles to biodiesel is being studied to improve its performance. **Table 1** quantifies diesel, jatropha biodiesel, and nanoparticle-infused biodiesel fuel properties. Small particles, commonly 1 to 100 nanometres, are called nanoparticles. Nanoparticles in jatropha biodiesel may improve fuel performance. These nanoparticles can increase fuel combustion, emissions, stability, lubrication, and filterability. Clogging or filter blockage can occur in biodiesel due to impurities or higher particulate matter levels than petroleum fuel. Nanoparticles, specifically alumina (Al_2O_3), in a fuel mixture at 50 ppm improve engine combustion. This could improve biodiesel filterability, reduce clogging, and optimize fuel flow. This study examines biodiesel additive nanoparticles made of Al_2O_3. Experimental measurements determine dispersion chemical properties such focus point, viscosity, density, and calorific value. Biodiesel and biodiesel with Al_2O_3 nanoparticles are tested in a compression ignition (CI) engine. Ultrasonicates create nano emulsions and precisely manipulate their properties. GT Sonic ultrasonicators blend nanoparticles with biodiesel-surfactant mixtures. Nanoparticles were added to biodiesel at specified concentrations and static for 30 minutes at 45 KHz. **Figure 1 and 2** shows the schematic diagram of engine inline view and photographic set up of an engine respectively.

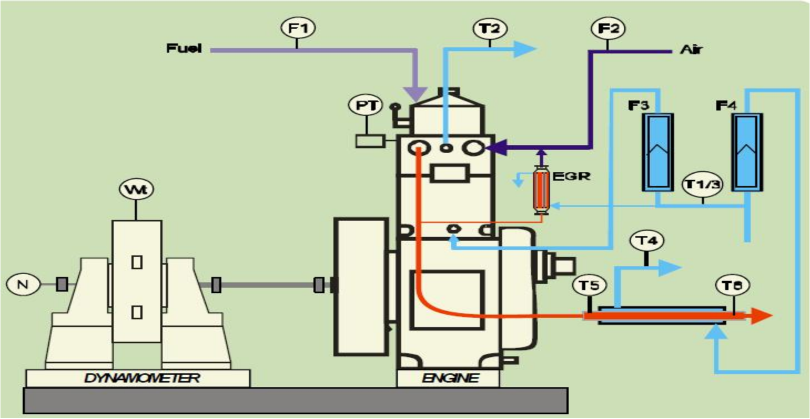

Figure 1. Schematic diagram of engine inline view.

Figure 2. Photographic set up of engine.

This study uses an eddy current dynamometer and a single-cylinder, four-stroke CRDI-VCR engine as a load. An innovative tilting cylinder block provides 18 compressions without halting the engine or changing combustion chamber shape. The ECU controls fuel injection timing, angle, and ignition dependent on speed and air mass pressure. The configuration in **Figure 1** improves engine performance under varied scenarios. The ECU controls fuel flow and injectors by regulating air and coolant temperatures and mass air pressure. The AVL Digas 444 exhaust analyser analyses NO_X, CO, CO_2, and HC emissions, while instrumentation measures combustion pressure, airflow, fuel flow, and temperature. A panel box with an air box, dual fuel tanks, pressure gauges, and cooling water flow rotameters are included. Summary of emission data in **Table 3**.

Table 1. Diesel-biodiesel and biodiesel blended Nps properties.

Properties	**Standard Method**	**Diesel (D100)**	**(Jatropha Biodiesel 20% +Diesel 80%) (BD20)**	**BD20 + Al_2O_3 NP (50 ppm)**
Density @ 25° C (Kg/ m^3)	D287	816	838	840
Calorific Value (Cal/gm)	D4809	10235	9723	9801
Flash Point °C	D9358T	53	61	58
Fire Point °C	D9358T	56	68	62
Kinematic Viscosity @40°C	D445	2.09	2.38	2.77
Specific heat capacity (J/kg K)	ASTM E1269–11	2050	2090	1774

In order to evaluate the operational efficiency of an engine utilizing diesel-biodiesel and biodiesel blends, a series of engine tests were conducted. The engine employed in these tests adhered to the parameters indicated in **Table 2**. The actions undertaken adhered to established protocols for conducting performance testing on experimental data.

Table 2. VCR CI engine specification.

Product	Computerized Engine Test- VCR
Engine	Kirloskar, Single Cylinder, 4 Stroke, Water Cooled
Bore	87.5 mm
Stroke	110 mm
Power	3.5 kilowatts
RPM	1500
CR Range	12-18
Dynamometer	Eddy current, water cooled with loading unit
Fuel Tank	Capacity 15 liter

Table 3. Exhaust gas analyser's technical specification.

Model	**AVS DI GAS 444N.**
Display	LCD
Interface	USB
Operating Range	100-300vV AC,50-60 Hz
Weight	4.5 kg
Power Consumption	Max. 10W

2.1. Uncertainty analysis

Table 4. Instrument uncertainty.

Instrument	**Measurement**	**Range**	**Accuracy**	**Uncertainty**
AVL DI Gas 444 N Five gas analyzer	CO	0-10 % Vol.	± 0.03%	±0.2
	CO_2	0-10 % Vol.	± 0.1	±0.15
	HC	0-20,000 ppm	± 10 ppm	±0.2
	O_2	0-22 % vol.	± 0.1 %	±0.5
	NO_X	0-5000 ppm	± 50 ppm	±1
AVL 437 C smoke meter	Opacity (%)	0-100 %	0.1	± 1%
Crank angle encoder		720°	± 1%	± 0.2%
Pressure Sensor		0-250 bar	± 1%	± 0.2%

The present engine testing encompassed various flaws attributed to calibration, equipment precision, environmental conditions, and observer inaccuracies, among other factors. Uncertainty analysis is conducted to obtain accurate results. The uncertainty propagation method, commonly referred to as the root mean square approach, was employed to assess the uncertainties inside the engine system [41]. The formula was employed to ascertain the uncertainty of the engine performance characteristics.

$$\omega_R = \left[\left(\frac{\partial R}{\partial x_1}\omega_1\right) + \left(\frac{\partial R}{\partial x_2}\omega_2\right) + \ldots + \left(\frac{\partial R}{\partial x_n}\omega_n\right)^2\right]^{1/2}$$

R is a function determined by independent variables such as x_1, x_2, x_3,,. x_n. Additionally, ω_R is characterized as the total percentage error, while ω_1, ω_2, ..., ω_n represent the errors in the independent variables [37]. **Table 4** summarizes the error percentages for different quantities. An error analysis was conducted utilizing Taylor's theorem to validate the precision of the test results. The total level of uncertainty is denoted by,

$$\boldsymbol{Overalluncertainity} = \sqrt{[(BTE)^2 + (BSFC)^2 + (HC)^2 + (CO)^2 + (NOx)^2 + (Smoke)^2]}$$

$$= \sqrt{[(1.0)^2 + (1.0)^2 + (0.2)^2 + (0.1)^2 + (0.2)^2 + (1.0)^2]} \quad = \pm \mathbf{1.77}\%$$

3. Result and discussion

To compare the differences between diesel fuel, biodiesel, and biodiesel with aluminum dioxide nanoparticles, an experiment was conducted. The experiments were carried out inside a controlled environment, where a consistent rotating speed of 1500 revolutions per minute (rpm) and a compression ratio of 18 were maintained. The experiments were carried out under different load situations, encompassing both the absence of load and weights ranging from 0 kg (No Load) to 12 kg. The Experimental Gas Analyzer (EGA) collected a range of data points, encompassing measurements of velocity, fuel consumption rate, and emissions of nitrogen oxides (NO_X), carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC) under the designated load conditions. In light of the aforementioned information, a comprehensive inquiry was conducted to assess and juxtapose the operational efficacy and emission attributes of compression ignition (CI) engines across different load scenarios. This examination involved the utilization of diesel, biodiesel, and biodiesel augmented with Al_2O_3 nanoparticles.

3.1. Brake specific fuel consumption (BSFC)

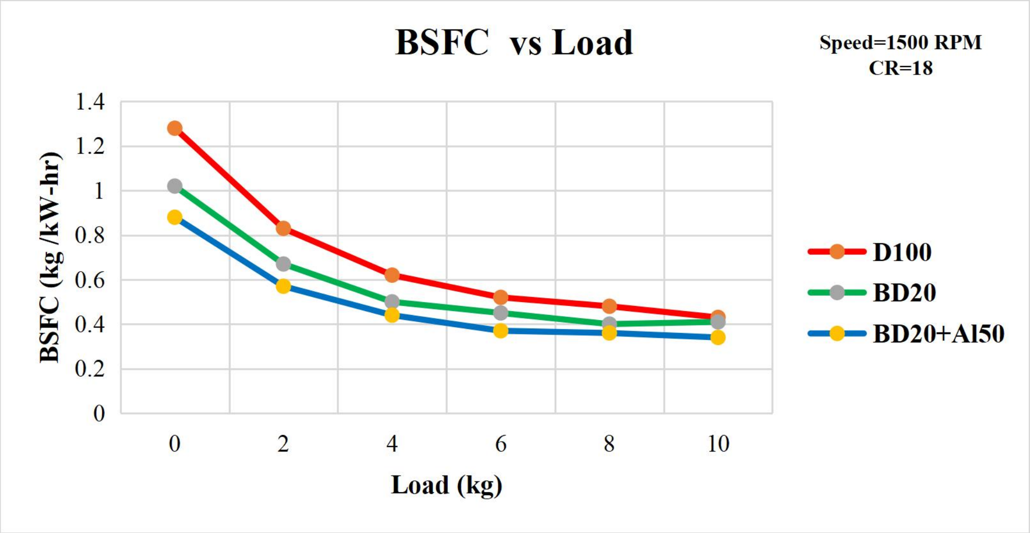

Figure 3. Brake specific fuel consumption variations versus load at constant compression ratio for regular diesel biodiesel and biodiesel with nanoparticles.

Figure 3 illustrates the brake specific energy consumption (BSFC) across diesel, biodiesel, and biodiesel with Al_2O_3 nanoparticles. It has been established that the brake specific fuel consumption (BSFC) exhibits a decrease when metal additives are added. The utilization of Al_2O_3nanoparticles as an energy accumulator, the outcome is a decrease in brake specific fuel consumption (BSFC) at various loads. The utilization of Al_2O_3 nanoparticles as an energy accumulator leads to a decrease in the brake specific fuel consumption (BSFC) value when the full load is applied. This phenomenon may be attributed to enhanced air-energy intermingling, resulting in improved combustion efficiency. Consequently, the incorporation of Al_2O_3 nanoparticles in biodiesel energy leads to a reduction in energy consumption almost 22.87%, while maintaining comparable performance levels to that of pure biodiesel energy.

3.2. Brake thermal efficiency (BTE)

Brake Thermal Efficiency (BTE) varies as a function of load (as shown in **Figure 4**) for both diesel-biodiesel and biodiesel that have adopted Al_2O_3 Nanoparticle. When the load is increased, the thermal efficiency of the brakes increases proportionally. The thermal efficiency of biodiesel increases dramatically with a load of 12 kg. Improved combustion methods and fine-tuning the air-fuel ratio could be behind the recent rise in Brake Thermal Efficiency. Al_2O_3 nanoparticles added to biodiesel improve brake thermal efficiency (BTE) at full throttle. The inclusion of Al_2O_3 nanoparticles may explain the observed behavior by causing a more uniform mixture of fuel and air within the cylinder.

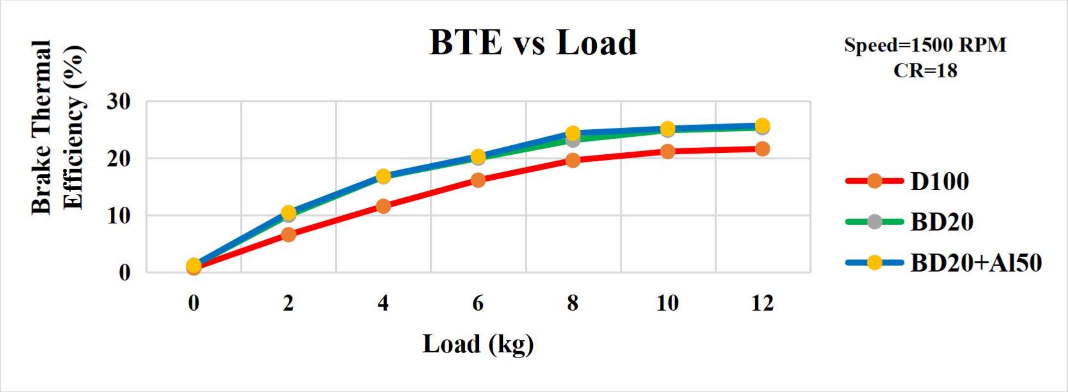

Figure 4. Brake thermal efficiency variation versus load at constant compression ratio for regular diesel biodiesel and biodiesel with nanoparticle.

3.2. Fuel consumption (kg/hr)

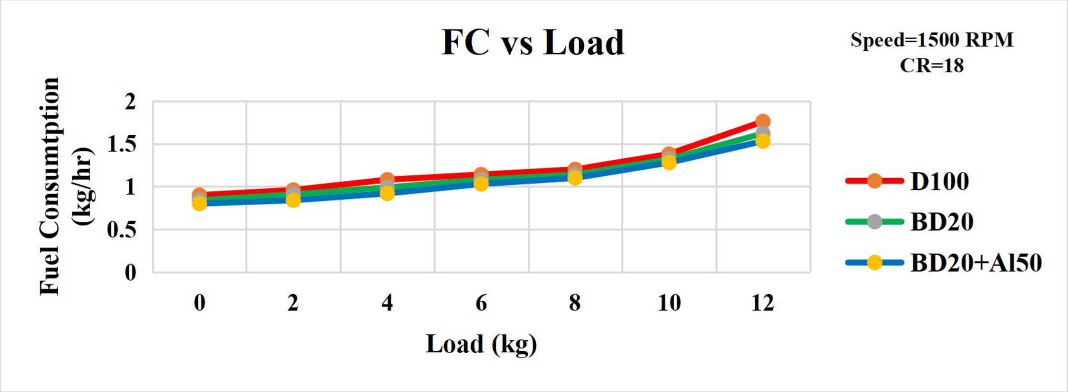

Figure 5. Fuel consumption variation versus load at constant compression ratio for regular diesel biodiesel and biodiesel with nanoparticle.

Fuel energy consumption versus load can be seen graphically in **Figure 5** for diesel-biodiesel, and biodiesel with nonadditive Al_2O_3 at varied quantities (0 kg, 2 kg, 4 kg, 6 kg, 8 kg, 10 kg, and 12 kg). When subjected to full load, the fuel consumption of different tested percentages exhibits a range between 1.53 kg/hr and 1.76 kg/hr. Blends have lower kinematic viscosities than diesel, as well as advantageous characteristics components, such as fuel atomization, vaporization, and dispersion, that contribute to a more complete combustion. Because blends have a lower calorific value (41,164 kJ/kg) than diesel (42,987 kJ/kg), blends use more fuel overall than diesel, which results in higher specific energy consumption (SEC) and worse brake thermal efficiency. Based on the literature review, it was observed that the fuel consumption of the different fuel mixtures evaluated demonstrates a positive correlation with the increase in load.

3.3. Nitrogen oxide emission (NO_X)

Nitrogen dioxide encompasses both NO and NO_2, as specified by the NO_X equations. The mitigation of the most hazardous gaseous emissions originating from engines is consistently pursued by specialists and manufacturers in the field of engine technology. The production of nitrogen oxides (NO_X) is predominantly influenced by factors such as in-cylinder temperatures, oxygen concentration, reaction duration, and air excess ratio. The rise in NOx emission with a constant speed and compression ratio is shown in **Figure 5** for the case of maximal load. The elevated temperatures associated with combustion, reaching approximately 1800K, induce the disruption of the robust triple bond present in nitrogen molecules. As a result, the molecules experience separation, leading to a transition into their state of atoms. Subsequently, they engage in processes that include the consumption of oxygen. As a consequence of these reactions, thermal NO_X is generated. This phenomenon can be attributed to the heightened temperature resulting from the augmented magnitude of the load. The development of NO_X is mostly attributed to the reaction between nitrogen and oxygen, which occurs at elevated temperatures. Consequently, the two key factors contributing to NO_X production are high temperatures and the presence of oxygen. **Figure 6** demonstrates the impact of including Al_2O_3 Nanoparticles into biodiesel fuel, revealing a notable rise in the concentration of NO_X. This observation implies an improvement in combustion efficiency. The percentage increase in nitrogen oxide (NO_X) emissions during maximum load conditions.

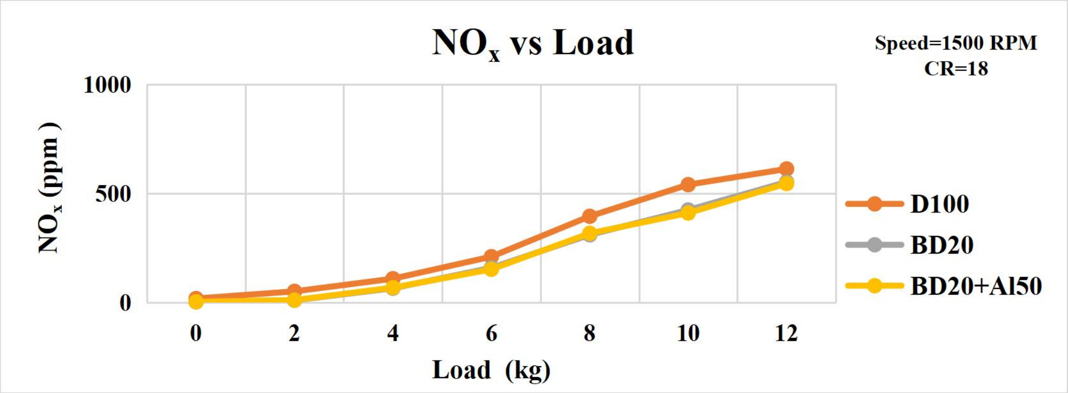

Figure 6. Nitrogen oxide variation versus load with regular diesel bio diesel and biodiesel with nanoparticle.

3.4. Carbon monoxide emission (CO)

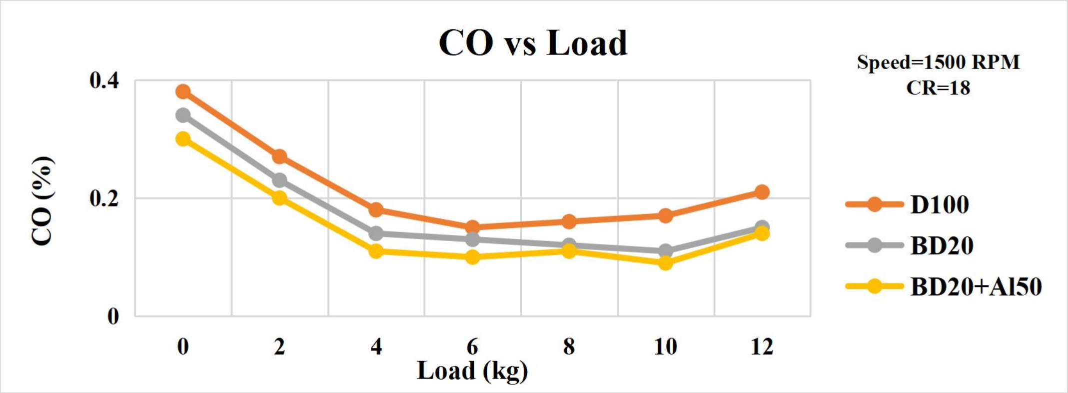

Figure 7. Carbon monoxide variation versus load with regular diesel, bio diesel and biodiesel with nanoparticle.

Uncompleted combustion of diesel fuel leads to the production of carbon monoxide (CO). While the theoretical amount of air needed for combustion may be sufficient, its practical sufficiency may be questionable. Consequently, the process of incomplete combustion yields a mixture of byproducts consisting of residual oxygen and carbon monoxide. The production of carbon monoxide (CO) in exhaust gases is indicative of the presence of unutilized chemical energy within the engine. **Figure 7** presents the variations observed in carbon monoxide (CO) emissions in the exhaust gases emitted by engines, namely diesel engines, biodiesel engines, and biodiesel engines including Al_2O_3 nanoparticles, in proportion to the engine load. The observed trend is that the concentration of CO decreases as the load increases. The amount of heat generated within the cylinder increases proportionally to the load, hence leading to enhanced combustion. Furthermore, the introduction of aluminum dioxide nanoparticles into biodiesel results in reduced the carbon monoxide

(CO) emissions resulting from the utilization of regular diesel and biodiesel fuels under various operational loads. The emission of carbon monoxide is diminished when the system is functioning at maximum operational capability. The potential cause of this phenomenon could be attributed to the utilization of Al_2O_3 nanoparticles as air buffers, which leads to enhanced combustion.

3.5. Hydrocarbon emission (HC)

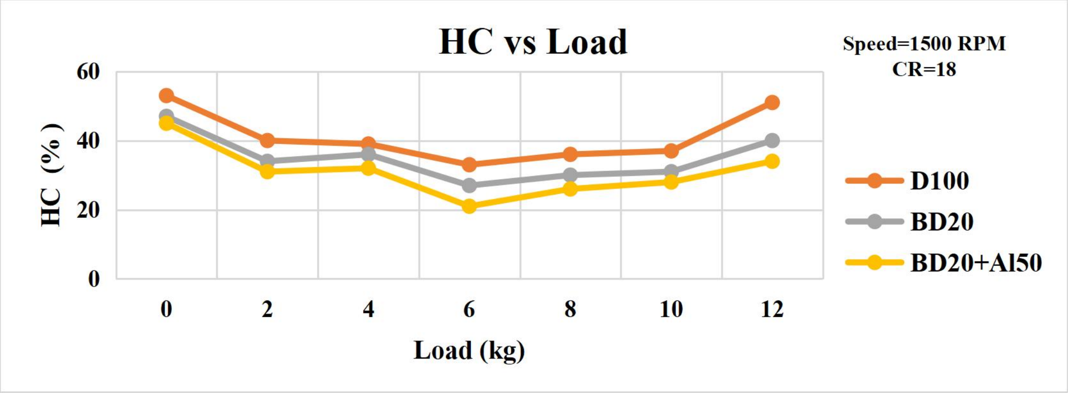

Figure 8. Hydrocarbon variation versus load with regular diesel, biodiesel and biodiesel with nanoparticle.

The hydrocarbons present in the fuel are expelled from the cylinder along with the exhaust gases. **Figure 8** illustrates the hydrocarbon (HC) emissions observed in the exhaust of a diesel engine when utilizing biodiesel containing Al_2O_3 nanoparticles. As the magnitude of the load is augmented, there is a corresponding decrease in the concentration of hydrocarbons (HC). Moreover, recent studies have revealed that the integration of Al_2O_3 nanoparticles into biodiesel leads to a decrease in hydrocarbon (HC) emissions as compared to the utilization of traditional diesel fuel. **Figure 8** illustrates a significant decrease in hydrocarbon (HC) emissions, amounting to around 18.63%, while utilizing Al_2O_3 nanoparticles in biodiesel fuel during the most demanding load scenario. The reduction in hydrocarbon (HC) emissions may be related to the inclusion of Al_2O_3 nanoparticles. These nanoparticles act as oxygen buffers, leading to enhanced combustion.

3.6. Carbon dioxide (CO_2)

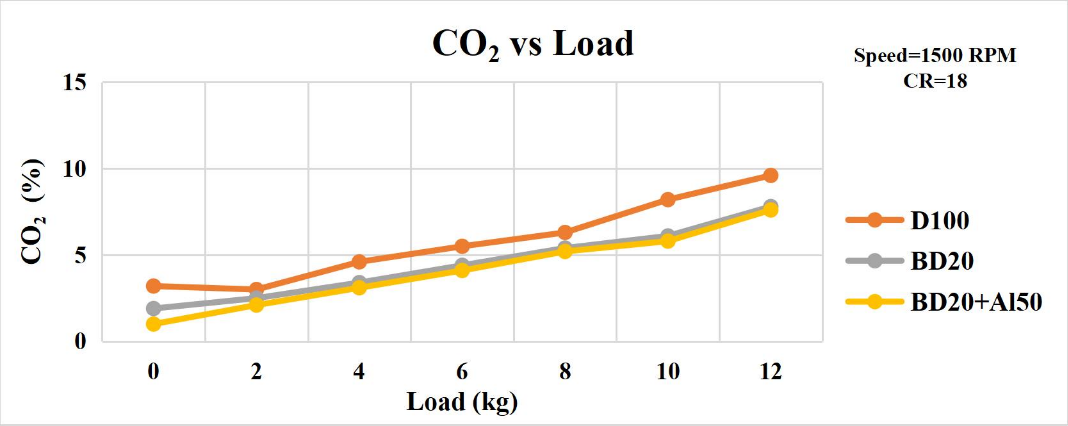

Figure 9. Carbon dioxide variation versus load with regular diesel, biodiesel and biodiesel with nanoparticle.

Figure 9 demonstrates the variations in carbon dioxide (CO_2) emissions in exhaust gases from engines in correlation to load for both biodiesel and biodiesel infused with Al_2O_3 nanoparticle. There is a positive correlation observed between the increase in load and the growth in CO_2 levels. This phenomenon occurs due to the direct correlation between increased load and higher temperatures within the cylinder, hence leading to enhanced combustion. Moreover, the introduction of Al_2O_3 nanoparticles into biodiesel results in elevated levels of CO_2 emissions, particularly under heavier load conditions, in comparison to the usage of pure diesel fuel. The utilization of Al_2O_3 nanoparticles as a addition leads to an increase in carbon dioxide emissions, particularly under maximum load conditions.

4. Conclusions

Ultrasonic was employed to achieve a constant distribution of nanoparticles of Al_2O_3 in biodiesel. Experimental measurements were conducted to determine the physico-chemical parameters of a fuel sample. The presence of Al_2O_3 nanoparticles enhances the concentration, mass, and thickness of the fuel specimen. In contrast with diesel-biodiesel blends, it has been observed that the inclusion of Al_2O_3 nanoparticles in fuel samples leads to a modest increase in their calorific value, specifically by 0.53%. Furthermore, previous studies have demonstrated that including Al_2O_3 nanoparticles into biodiesel fuel as an additive lead to a little improvement of 0.3% in brake thermal efficiency (BTE) when operating at maximum load conditions. The utilization of Al_2O_3 nanoparticles leads to a significant reduction of 20.23% in brake-specific fuel consumption under maximum load conditions. The utilization of Al_2O_3 nanoparticles leads to a significant increase of 27% in NO_X emissions during maximum load conditions. However, the incorporation of Al_2O_3 nanoparticles into biodiesel fuel leads to a significant reduction of 18.62 % in hydrocarbon emissions, 25% in carbon monoxide emissions, and 29% in carbon dioxide emissions during maximum load conditions.

Nomenclature:

Nomenclature	
D100	Regular Diesel
BD20	Regular Diesel 80 % +Biodiesel 20%
BD20+NP **OR** BD20+Al50 **OR** BD+Al50	Regular Diesel 80% + Biodiesel 20% + Al_2O_3Nano Particle 50 (parts per millions)
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
NO_X	Nitrogen Oxide
HC	Hydrocarbons
ASTM	American Society For Testing Material

Conflict of interest

The authors declare no conflict of interest.

References

1. BP, & Dudley, B. (2011). BP Energy Outlook 2030. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2011.pdf
2. Gopal, G., Rao, P. S., Gopalakrishnan, K. V., & Murthy, B. S. (1982). Use of hydrogen in dual-fuel engines. International Journal of Hydrogen Energy, 7(3), 267-272.
3. Varde, K. S., & Frame, G. A. (1983). Hydrogen aspiration in a direct injection type diesel engine-its effects on smoke and other engine performance parameters. International Journal of Hydrogen Energy, 8(7), 549-555.
4. Nina, K. S., Suntoro, D., Al Irsyad, M. I., Srikandi, G. P., Khaldun, T., & Anggarani, R. (2021, May). Performance and emission effects of biodiesel 30%(B30) usage in oil-fired power plants and gas engine power plants. In IOP Conference Series: Earth and Environmental Science (Vol. 749, No. 1, p. 012056). IOP Publishing.
5. A. Nazari, S. Riahi, S. Riahi, S. Fatemeh Shamekhi, and A. Khademno, “Influence of Al2O3 Nanoparticle on the compressive strength and workability of blended concrete Enhancing the adhesion of diamond-like carbon films to steel substrates using silicon-containing interlayers View project Influence of Al 2 O 3 Nanoparticle on the

compressive strength and workability of blended concrete," 2010. [Online]. Available: http://www.americanscience.orgeditor@americanscience.org

6. Binu, K. G., Shenoy, B. S., Rao, D. S., & Pai, R. (2014). A variable viscosity approach for the evaluation of load carrying capacity of oil lubricated journal bearing with TiO2 nanoparticles as lubricant additives. Procedia materials science, 6, 1051-1067.
7. Köse, H., & Ciniviz, M. (2013). An experimental investigation of effect on diesel engine performance and exhaust emissions of addition at dual fuel mode of hydrogen. Fuel processing technology, 114, 26-34.
8. Bari, S., & Esmaeil, M. M. (2010). Effect of H2/O2 addition in increasing the thermal efficiency of a diesel engine. Fuel, 89(2), 378-383.
9. Gómez-Cuenca, F., Gómez-Marín, M., & Folgueras-Díaz, M. B. (2011). Effects of ethylene glycol ethers on diesel fuel properties and emissions in a diesel engine. Energy conversion and management, 52(8-9), 3027-3033.
10. Kannan, G. R., Karvembu, R., & Anand, R. J. A. E. (2011). Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel. Applied energy, 88(11), 3694-3703.
11. De Caro, P. S., Mouloungui, Z., Vaitilingom, G., & Berge, J. C. (2001). Interest of combining an additive with diesel–ethanol blends for use in diesel engines. Fuel, 80(4), 565-574.
12. Canakci, M., & Sanli, H. (2008). Biodiesel production from various feedstocks and their effects on the fuel properties. Journal of Industrial Microbiology and Biotechnology, 35(5), 431-441.
13. Kegl, B., & Hribernik, A. (2006). Experimental analysis of injection characteristics using biodiesel fuel. Energy & fuels, 20(5), 2239-2248.
14. Murugan, N., Venu, H., Jayaraman, J., & Appavu, P. (2022). Emission and performance characteristics study on nanographene oxide additives doped palm oil methyl ester blend in a diesel engine. International Journal of Ambient Energy, 43(1), 1304-1310.
15. Jayaraman, J., Alagu, K., Venu, H., Appavu, P., Joy, N., Jayaram, P., & Mariadhas, A. (2019). Enzymatic production of rice bran biodiesel and testing of its diesel blends in a four-stroke CI engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 45(2), 5340–5351. https://doi.org/10.1080/15567036.2019.1671554
16. Kavitha, K. R., Jayaprabakar, J., & Prabhu, A. (2022). Exergy and energy analyses on biodiesel–diesel-ethanol blends in a diesel engine. International Journal of Ambient Energy, 43(1), 778-782.
17. Avinash, A., Subramaniam, D., & Murugesan, A. (2014). Bio-diesel—A global scenario. Renewable and sustainable energy reviews, 29, 517-527.
18. Mehta, R. N., Chakraborty, M., & Parikh, P. A. (2014). Nanofuels: Combustion, engine performance and emissions. Fuel, 120, 91-97.
19. Basha, J. S., & Anand, R. B. (2014). Performance, emission and combustion characteristics of a diesel engine using Carbon Nanotubes blended Jatropha Methyl Ester Emulsions. Alexandria engineering journal, 53(2), 259-273.
20. Beloni, E., Hoffmann, V. K., & Dreizin, E. L. (2008). Combustion of decane-based slurries with metallic fuel additives. Journal of propulsion and power, 24(6), 1403-1411.
21. Bidita, B. S., Suraya, A. R., Shazed, M. A., Mohd Salleh, M. A., & Idris, A. (2014). Influence of fuel additive in the formulation and combustion characteristics of water-in-diesel nanoemulsion fuel. Energy & fuels, 28(6), 4149-4161.
22. Köse, S., Babagiray, M., & Kocakulak, T. (2021). Response surface method based optimization of the viscosity of waste cooking oil biodiesel. Eng Perspect, 1(1), 30-37.
23. Binboğa, F. (2022). VECTO Review: Reducing CO2 emissions from heavy duty vehicles. Engine Eng Perspect.
24. Towoju, O. A. (2022). Performance optimization of compression ignition engines: a review. Eng. Perspect., 2(2), 21-27.
25. Aydoğan, B. (2021). Combustion, performance and emissions of ethanol/n-heptane blends in HCCI engine. Engineering Perspective, 1(1), 5.
26. Kocakulak, T., & Arslan, T. A. (2023). Investigation of the Use of Fuel Cell Hybrid Systems for Different Purposes. Engineering Perspec-tive, 3, 1-8.
27. Ardebili, S. M. S., Nacak, Ç., Kocakulak, T., & Babagiray, M. (2021). Experimental investigation and optimization of HCCI engine fueled by isopropanol and heptane mixture. Engineering Perspective, 1(2), 63-78.
28. Kumaran, P., Natarajan, S., MP, S. K., Rashid, M., & Nithish, S. (2023). Optimization of Diesel Engine Performance and Emissions Characteristics with Tomato Seed Blends and EGR Using Response Surface Methodology. International Journal of Automotive Science and Technology, 7(3), 223-233.
29. Celik, M., Bayındırlı, C., & Kuş, R. (2023). Experimental Investigation of Effect of n-Hexane Addition in Diesel and Biodiesel Fuels on Performance and Emissions Characteristics. International Journal of Automotive Science and Technology, 7(2), 118-124.
30. Celik, M., Bayındırlı, C., & İlhak, M. İ. (2022). Investigation of the performance and emissions of an engine operated with CEO2 nano additive doped biodiesel. International Journal of Automotive Science and Technology, 6(2), 113-119.

31. Modi, M. A., & Patel, T. M. (2024). Modeling of specific fuel consumption for compression ignition engines fueled with polymer-based fuel: a response surface methodology approach. Engineering Research Express, 6(3), 035567.
32. Dubey, A., Prasad, R. S., & Singh, J. K. (2020). An analytical and economical assessment of the waste cooking oil based biodiesel using optimized conditions on the process variables. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-16.
33. Dubey, A., Prasad, R. S., Singh, J. K., & Nayyar, A. (2022). Optimization of diesel engine performance and emissions with biodiesel-diesel blends and EGR using response surface methodology (RSM). Cleaner Engineering and Technology, 8, 100509.
34. Dubey, A., Prasad, R. S., Singh, J. K., & Nayyar, A. (2023). Response surface methodology (RSM) based experimental and model analysis of diethyl ether-biodiesel-diesel blends with exhaust gas recirculation (EGR) on stationary diesel engine. Petroleum Science and Technology, 41(12), 1272-1291.
35. Dubey, A., Prasad, R. S., Singh, J. K., & Nayyar, A. (2022). Combined effects of biodiesel− ULSD blends and EGR on performance and emissions of diesel engine using Response surface methodology (RSM). Energy Nexus, 7, 100136.
36. Usman, M., Malik, M. A. I., Bashir, R., Riaz, F., Raza, M. J., Suleman, K., ... & Krzywanski, J. (2022). Enviro-economic assessment of HHO–CNG mixture utilization in spark ignition engine for performance and environmental sustainability. Energies, 15(21), 8253.
37. Usman, M., Khan, T., Riaz, F., Ijaz Malik, M. A., Amjad, M. T., Shah, M. H., ... & Nowak, W. (2023). Acetone–Gasoline blend as an alternative fuel in SI engines: a novel comparison of performance, emission, and lube oil degradation. ACS omega, 8(12), 11267-11280.
38. Medhat Elkelawy, E.A. El Shenawy, Salma khalaf Abd Almonem, M.H. Nasef, Hitesh Panchal, Hagar Alm-Eldin Bastawissi, Kishor Kumar Sadasivuni, Akhilesh Kumar Choudhary, Deepak Sharma, Mohammad Khalid,. Experimental study on combustion, performance, and emission behaviours of diesel /WCO biodiesel/Cyclohexane blends in DI-CI engine, Process Safety and Environmental Protection,Volume 149, 2021,Pages 684-697.
39. Vishal Kumbhar, Anand Pandey, Chandrakant R. Sonawane, A.S. El-Shafay, Hitesh Panchal, Ali J. Chamkha, Statistical analysis on prediction of biodiesel properties from its fatty acid composition, Case Studies in Thermal Engineering, Volume 30,2022, 101775
40. Medhat Elkelawy, Safaa El-din H. Etaiw, Hagar Alm-Eldin Bastawissi, Hassan Marie, Ahmed Elbanna, Hitesh Panchal, Kishorkumar Sadasivuni, Hitesh Bhargav. Study of diesel-biodiesel blends combustion and emission characteristics in a CI engine by adding nanoparticles of Mn (II) supramolecular complex, Atmospheric Pollution Research, Volume 11, Issue 1, 2020,Pages 117-128
41. Holman, J.P. Experimental Methods for Engineers, 8th ed.; Tata McGraw Hill Publications: New York, NY, USA, 2012.