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Effect of adding nanomaterial using Ruta oil methyl esters on engine performance and combustion emissions

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Abstract .

The focus on alternative fuels has increased greatly because of the diminishing availability of petroleum resources and the rising worries about the environment. Biodiesel, a sustainable fuel source, has the capacity to serve as a feasible alternative to traditional fossil fuels. The latest progress in nanotechnology has enabled the development of fuel additives made of nanoparticles that can be used in internal combustion engines. Studies conducted in the past have demonstrated that these additives have the ability to improve the performance of the engine. In this innovative research, we explored the impact of adding aluminum oxide nanoparticles (Al2O3) to a fuel mixture consisting of 20% Ruta biodiesel and 80% diesel, aiming to evaluate enhancements in performance and decreased emissions. In our experiments, we utilized a diesel engine with a single cylinder and four strokes, running steadily at 1500 revolutions per minute. The RB20 mixture underwent exposure to a 35 ppm concentration of Al2O3 nanoparticles through the utilization of an Ultrasonicator. The findings show that the brake-specific fuel consumption (BSFC) was enhanced when using the DF80+RB20 mixture. In comparison to regular diesel fuel, the brake thermal efficiency (BTE) saw an increase when using a blend of 80% diesel fuel and 20% rapeseed biodiesel. The emissions, a key element affected by the type of fuel used, were reduced for all mixed fuels in comparison to pure diesel fuel (DF). The presence of nanoparticles also played a role in lowering the rate at which combustion pressure increased, leading to a decrease in combustion. These findings suggest that the DF8 0+R B2 0 blend is suitable for diesel engines without the need for alterations.

Keywords: Ruta, Castor methyl ester, biodiesel, Al_2O_3 Nano fuel, Engine Performance

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1.Introduction

The diesel engine is essential in several areas, including industry, agriculture, and transportation. In reaction to the urgent global warming issues, governments enforcing stringent environmental emission restrictions are implementing measures to enhance combustion efficiency, reduce hazardous emissions from various fossil fuels, and maintain a clean environment [1][2][3][4][5][6]. The necessity to confront the imminent exhaustion of fossil fuel-based goods, now the predominant energy source, underscores the significance of shifting to renewable and eco-friendly alternatives. As a result, many academics in this domain are diligently addressing these difficulties and investigating sustainable solutions [7][8][9][10][11].

Modifying biodiesel, a viable and economically advantageous energy source for diesel engines, has become increasingly imperative because to escalating fuel prices, environmental concerns, and the swiftly diminishing quantity of crude oil [12][13]. Biodiesel is often seen as an economical, environmentally sustainable, and accessible resource. Recent studies have thoroughly examined the influence of different raw materials for biodiesel synthesis from various renewable sources on engine performance measures [14][15][10][16]. Previous studies indicated that biodiesel was produced in multiple forms and utilised in engines [17][18]. Kadera et al. [19][20] Investigated the thermal transesterification of tamarind seed oil using a fire tube. Tamarind oil demonstrates enhanced fuel quality compared to alternative solutions. A 20% biodiesel blend exhibited remarkable performance, demonstrating equal brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and emission characteristics compared to the base fuel in engines with high NOx emissions [21][22]. Mahua seed biofuel reduces pollutants and enhances brake thermal efficiency compared to conventional diesel [23][24]. The utilisation of biodiesel, due to its elevated cetane number, increased oxygen content, and superior lubricating properties, enhances the thermal efficiency of engine systems. Likewise, without necessitating modifications to the engine system, cottonseed oil was utilised in engines as a biodiesel blend with diesel fuel [25][26]. Lemon peel biodiesel has enhanced performance owing to its reduced density and lower boiling point [13]. Incorporating 10% dimethyl carbonate into tamarind seed biodiesel with diesel enhanced brake thermal efficiency (BTE). Integrating certain additives into biodiesel can address many engine issues, including emissions and performance, improving overall engine efficiency. A nanoparticle-based combustion catalyst is one of the foremost innovations that is now accessible. This catalyst offers several advantages, such as increased energy density, optimised combustion, and decreased emissions. Additionally, using nanoparticles with biodiesel has demonstrated an improved surface-to-volume ratio, thereby enhancing oxidation and evaporation [27][28]. Various nanoparticles of distinct sizes, including as carbon nanotubes, titanium oxide, cerium oxide, and aluminium oxides, enhanced the characteristics of fuel [29][30]. Rashedul et al. evaluated the impact of diverse additives on multiple fuel characteristics, emissions, combustion, and performance metrics of CI engines. Utilising 100% biodiesel with oxygenated additions decreases viscosity and density while increasing oxygen levels. Anbarasu et al. [29][31] employed biodiesel and AL_2O_3 nanoparticles to examine engine characteristics. The engine's brake thermal efficiency improved, accompanied by a decrease in carbon monoxide, unburned hydrocarbons, and smoke opacity, with an increase in nitrogen oxides due to the nanoparticles. Prasad et al. [32][33][34] indicate that CI engines operating on 20% tamarind biodiesel have specific features. Utilising 30% pilot fuel injection in lieu of 100% main fuel injection resulted in a 4.79% enhancement in brake thermal efficiency at maximum load. Hosseini et al. [3] examined an engine utilising biodiesel derived from cooking oil, employing a carbon nanotube catalyst at concentrations of 30, 60, and 90 parts per million. Performance enhanced, and at 90 ppm, nanoparticle emissions decreased. The study by Raju et al. [35][36] Researchers examined how MgO nanoparticles and methyl ester biodiesel made from cooking oil could be used together in a compression ignition engine. They concluded that integrating nanoparticles decreased engine emissions and improved efficiency by around 12%. The literature above demonstrates that biodiesel sourced from various renewable materials was utilised as feedstock for biodiesel production and subsequently employed as fuel in a diesel engine to evaluate changes in engine performance. Tamarind seeds are widely available in various sites across India. Tamarind seeds include around 20–35% oil. Furthermore, the nanoadditives enhance engine performance and diminish emissions. Material about tamarind seed is scarce as a feedstock for biodiesel synthesis, and no prior attempts have been made to include it with various nanoparticles to improve the efficiency of CI engines while reducing emissions. This research utilised tamarind seed oil as the principal component for biodiesel synthesis. As a result, transesterification performed at a lower temperature range produced biodiesel from tamarind seeds. Additionally, diesel was mixed to create B20-grade biodiesel to evaluate the engine characteristics. Multiple research investigations have shown nanoparticle concentrations between 20 ppm and 100 ppm for the production of nanofuels. This study optimised the concentration by experimental trials at 50 ppm [10–14]. Three unique nanofuels were synthesised utilising ultrasonic wave techniques by mixing magnesium oxide (MgO), silicon dioxide (SiO2), and aluminium oxide (Al2O3) nanoparticles. These nanofuels are utilised to operate the CI engine to analyse its emissions, combustion, and performance. This study looks at how nanoparticles in tamarind seed biodiesel change how a CI engine works without making any changes. The goal is to find the best alternative fuel—tamarind seed oil-based nanoparticle-enhanced biodiesel—for better engine performance and lower emissions. This study aims to analyse the performance and emissions of a single-cylinder, four-stroke, constant compression ignition engine fuelled by biodiesel, a diesel fuel combined with nanoparticles. Nanoparticles are utilised in certain diesel engines to enhance emissions and fuel physical characteristics. These gasoline additives diminish emissions, including fine particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), unburnt hydrocarbons (UHC), and smoke opacity [37][38][39][40]. Rao,s,c et.al [41] investigated experimentally the effect of addition of ZnO and CeO_2 Nanoparticles to diesel fuel on the performance of compression ignition engine. They used a four stroke one- cylinder engine. Power of the engine was measured by a rope brake dynamometer. Their results illustrated that nanoparticles addition to diesel fuel led to improve the combustion characteristics by increasing

of thermal efficiency. Increasing of nanoparticles dosing reduces the flash and fire point which makes the ignition delay shorten. Also, addition of nanoparticles reduced temperature of the exhaust and smoke emission is decreased in comparison with neat diesel fuel. Zinc oxide displayed higher efficiency at small amount of concentration. Ozgour et al. [42] The impact of Nano-particle addition to diesel fuel on NO_x emissions. This study used a (4-cylinder 4-stroke) and cooling water. Nine nanoparticles, including, Al_2O_3,

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MgO, Tio_2 , ZnO, SiO, Fe_2O_4, Fe_2O_3 and Fe_2O_2, were utilized. The incorporation of all nanoparticles save $A1_20_3$ resulted in a reduce in NOx emissions. The greatest less decrease occurred at a dosage of 100 ppm of MgO. Ranaware et al. [41] presented a correlation between engine performance and emission characteristics of a compression ignition engine using water-based ferrofluid and cerium oxide nanoparticles as an additive to diesel fuel. The experimental rig was a single cylinder with four strokes with a variable compression ratio. They suggested that cerium oxide nanoparticles work as an oxygenated catalyst, which provides oxygen to oxidize carbon monoxide or absorb oxygen for the reduction of NOx, which promotes complete combustion. Sajith et al. [42] studied The impact of IDE nanoparticles on biodiesel Engine emissions caused by the addition of cerium oxide. The test was conducted on a single-cylinder, 4stroke, constant speed 1500 rpm, 5.5kW, water-cooled direct injection diesel engine. The nanoparticle size was (10-20nm with 80 ppm and 20 ppm dosages. The NO_x decreased by 30% with 80 ppm. UHC was reduced by the addition of CeO2, which happened to transfer from the standard CeO_2 (+4) valence state to the CeO2 (+3) state, a cross-relative low energy relation. Aalam et al.[43]studied performed an experiment to determine the effects of Al_2O_3 as an additive to biodiesel. The examination was conducted on a one-cylinder, cooling water system engine. They used a fuel blend of 25% zizipus jujube methyl ester (ZJME25). Aluminium oxide nanoparticles were included as additives in bulk fractions of 25 and 50 ppm along ZJME25. Balaji et.al [44] Conducted an experimental investigation on the impact of alumina oxide (AL_2O_3) Nano additive on the performance and emissions of a direct injection diesel engine fuelled by neem oil methyl ester. The alumina oxide nanoparticles were combined at varying concentrations of 100 ppm, 200 ppm, and 300 ppm with biodiesel. The dimensions of nanoparticles ranged from 1 to 110 nanometers. The performance and emissions are evaluated in a single-cylinder, four-stroke, stationary diesel engine operating at a constant speed of 1500 rpm with a rated output of 3.5 kW and water cooling. Karthikeyan et al. [45] studied the impact of incorporating zinc oxide (ZnO) nanoparticles with biodiesel fuel (Pomolion stearin wax) on combustion parameters and emissions. This research was conducted on a stationary, single-cylinder, air-cooled direct injection engine operating at a constant speed of 1500 rpm. Mass fractions of 50 ppm and 100 ppm were utilised, with nanoparticle dimensions under 100 nm. The blended fuel consisted of (D80 B20 ZnO50) including 80% diesel, 20% palm seed waste methyl ester, and 50 ppm zinc oxide, as well as (D80 B20 ZnO100). Karthikeyan et al. [46] studied The impact of combining biodiesel fuel (canola oil methyl ester) with (ZnO) zine oxide on combustion, performance, and emission characteristics was experimentally investigated by An air-cooled, direct-injection diesel engine with one cylinder and four strokes was subjected to this test at a speed of (1500 rpm). We used three different concentrations of ZnO (50, 80, and 100 ppm). Twenty percent biodiesel was added to the diesel fuel.

The main aims of this experimental work are:

1.Prepare two types of fuel, first prepare biodiesel in different proportions with pure diesel, and second prepare the best proportion of biodiesel and mix it with nanomaterial (AL_2O_3).

2. Running a diesel engine on biodiesel according to the proportions, as well as on biodiesel mixed with nanomaterial to study its performance and emission characteristics compared to diesel fuel operation

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2. Material and methods

2.1. Engine experimental setup

The tests were conducted on a diesel engine using diesel and biodiesel blends with and without nanoparticles. Different engine loads and fuel mixtures were tested, with the engine shaft connected to an eddy current meter. The engine speed was maintained at a constant 1500 rpm. The measurements were recorded for each power output level. Information about the diesel engine test can be found in Table (2-1) (2-2). To conduct the tests. The fuel consumption was measured using a graduated fuel tank with a loading capacity ranging from (0 to 1000) ml. To find out the fuel consumption in the graduated cylinder, the difference between the first reading and the second reading over a specified time (t) was used. After engine testing, the fuel was characterized according to ASTM standards as shown in Table (2-3). The experimental engine setup is shown in figure (2-1)

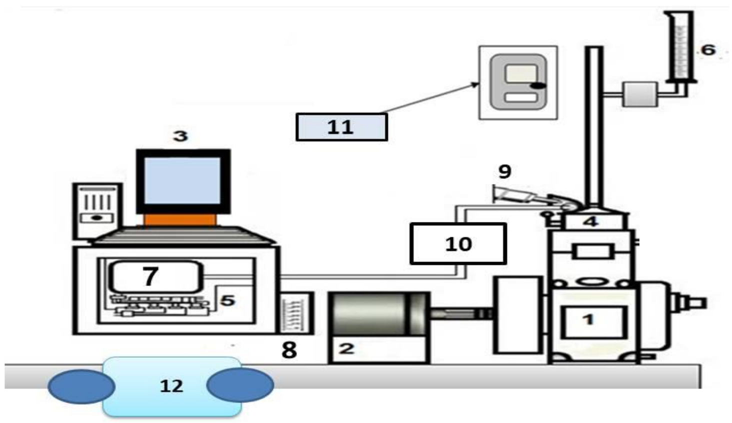

figure (2-1)Schematic of experimental setup.

Table (2-1) Schematic of experimental setup.

1	Engine block	5	Data Logge	9	Fuel injector
2	Eddy current dynamometer.	6	Fuel tank	10	Intake air
3	PC	7	Air surge tank	11	Voltage regulator
4	Cylinder head	8	Water manometer	12	Gas analyzer

Table (2-2) Diesel Engine Specifications [47]

MODEL	1NDIA
Overview	One Cylinder, 4- Stroke, cooling water

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Cylinder Bore	80 mm
Stroke length	110 mm
S	1500 rpm
V_S	553 cm^3
V_C	0.03687 m^3
CR	12.5-17.5
Power	3.7 KW
Injection Timing	-30 BTDC
Injection Pressure	160 Bar
Start Of Injection	150 $°CA$
End Of Injection	190 $°C$A
Nozzle Diameter	0.02 mm

Table (2-3) Fuel characterization.

Property	**Diesel**	**10% RME**	**20% RME**	**30% RME**	**100% RME**	**Oil Ruta**
Density at 15 °C (kg/m^3)	824.9	829.3	834.7	835	867.3	904.6
Viscosity at 40 °C (pa.s)	0.00228	0.00256	0.00297	0.00333	0.00914	0.0038
Calorific value (MJ/kg)	45.85	45.78	45.7	45.71	45.21	45.89
Cetane number	53.4	53.1	54.1	55.2	---	---

2.2 Procedures for combining diesel fuel with different blends of RME

Biodiesel RME was pre-prepared in the laboratory by mixing it with diesel fuel in various volumetric ratios: B0% RME, B10% RME, B20% RME, and B30% RME. The experimental testing was carried out at a constant engine speed of 1500 rpm and a compression ratio of 16.5 with five different loads indicated by load levels of 0, 25, 50, 75, and 100. The aim of the research was to create a basic database under constant conditions. Note that the diesel engine of each type was operated for half an hour, after which data or readings were collected from the engine and other devices for the purpose of comparing the results. Ultimately, the experimental findings revealed that the 20% RME blend exhibited

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the most favorable performance, showing slight variations while significantly reducing carbon emissions compared to diesel fuel.

2.3 Procedures for preparing Nano blended fuel

In this study, Al_2O_3 nanoparticles were chosen, sourced from an authorized chemical supplier. The crystalline structure and properties of the nanoparticles were verified using (X-ray diffraction) technology [48]. The experimental work for this phase was conducted in the University of Babylon's Faculty of Materials Engineering laboratories, as described in Appendix C. The nanoparticle doses were selected based on existing literature, with three concentrations used: 25 ppm and 35 ppm. The mass of nanoparticles (m_p) required for each concentration is specified in [49]. The requisite quantity of powder for each dosage is precisely measured with a precision balance, as illustrated in the figure. (2-2).

Fig (2-2) a precision balance

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After weighing the nanomaterial in the sensitive balance and according to the selected proportions (25ppm ,35ppm), it is then mixed with the best selected proportion of biodiesel, which is (20%RME), using the (GLOVE) protection device, which must be completely emptied of air before starting the mixing process, as shown in Figure (2-3).

Fig (2-3) Box of glove

The nanoparticles and the 20% RME fuel are thoroughly mixed using a magnetic stirrer for one hour to ensure even Diffusion of nanoparticles inside biodiesel, as show Figure no (2-4).

Fig (2-4) Magnet stirrer

After the mixing process is completed, the sample is placed using a magnetic stirrer device. In order to disperse the nanomaterial inside the biodiesel (20%RME), an ultrasonic device is used for forty minutes for each sample, as shown in Figure (2-5).

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Fig (2-5) (MTI) The Ultrasonicator

The selected samples were determined according to the mentioned percentages (20% + 25 ppm, 20% + 35%ppm) and the samples were sent for examination in the laboratory of the College of Materials Engineering at the University of Babylon to determine the physical properties as shown in Figure (2-6) and below the physical specifications in Table No. (2) and the examination details in Appendix C

Fig (2-6) Example Products

Table (2-4) Qualities of Example Products

Property	B20% RME	B20RME25ppm	B20RME35pm
Density at 15	811	807	818

^{o}C (kg/m^3)			
Viscosity at 40 ^{o}C (pa.s)	0.003897	0.003926	0.003953
Flash point(^{o}C)	85	84	82
Fire point (^{o}C)	94	93	91
Cetane number	516	51.8	52.7

2.4Experimental procedure

The experimental procedures focus on investigating the impact of biodiesel on engine performance and emission characteristics, as well as incorporating nanomaterials into biodiesel. Initially, biodiesel is prepared by mixing it with pure diesel in specific proportions: B10% (10% RME, 90% diesel), B20% (20% RME, 80% diesel), and B30% (30% RME, 70% diesel). This mixture is thoroughly blended to achieve homogeneity, after which samples are analyzed in the laboratory to assess their physical properties.

A diesel engine—a single-cylinder, four-stroke model with a constant speed of 1500 RPM, a water-cooled system, and a fixed compression ratio of (16.5 bar) is operated on pure diesel for 30 minutes. This establishes a baseline by stabilizing the exhaust gas temperature. Engine performance parameters, including temperature, load, and fuel consumption, are recorded at various loads (0%, 25%, 50%, 75%, and 100%). Subsequently, the engine is tested with B10% biodiesel at the same load levels, followed by B20% and then B30% biodiesel, with readings taken at each stage. After gathering data on engine performance metrics and exhaust emissions—such as carbon monoxide, carbon dioxide, oxygen, and nitrogen oxides—these results are compared against those from pure diesel.

Based on the findings between pure diesel and biodiesel, the optimal biodiesel blend is identified for further experiments involving the addition of nanomaterials, evaluated at the same load levels. The results of engine performance and emissions are discussed in section 3

3. Results and discussions

3.1 The effect of adding nanoparticles on engine performance

Adding nanoparticles, particularly Al_2O_3, into a 20% biodiesel blend markedly enhances engine performance by increasing several operating parameters. Nanoparticles function as combustion enhancers owing to their catalytic capabilities, leading to improved fuel atomization and air-fuel mixing. This leads to enhanced combustion efficiency.

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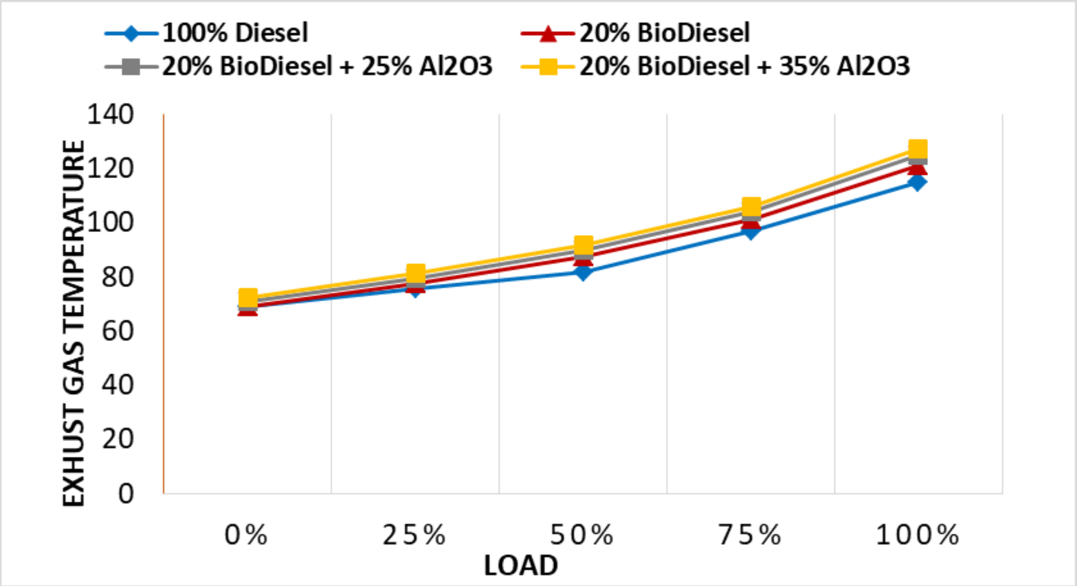
3.1.1 EGT vs. load with (20%biodiesl) and nanoparticles

Exhaust gas temperature (EGT) indicates fuel combustion efficiency within the engine. In Figure (3-1), the addition of nanoparticles to 20% biodiesel results in an increase in exhaust gas temperature. The temperature rise is attributable to enhanced combustion efficiency resulting from the presence of nanoparticles, particularly at elevated concentrations of Al_2O_3. Nanoparticles enhance the atomisation and amalgamation of fuel with air, leading to more thorough combustion. Consequently, higher exhaust temperatures were recorded with 35% Al_2O_3 in comparison to 25%. This also signifies a reduction in unburned hydrocarbons, illustrating improved fuel efficiency, which is essential under elevated loads.



Figure(3-1) EGT vs. load with (20%biodiesl) and nanoparticles

3.1.2 Input Power vs. Load with (20%biodiesl) and nanoparticles

Input power denotes the energy necessary for engine operation. As the load escalates, the input power increases, indicating the necessity for enhanced energy to sustain performance under stress. Utilising nanoparticles enhances fuel properties, as shown in Figure(3-2), resulting in a 25% and 35% increase in input power for Al_2O_3. The 35% Al_2O_3 mixture exhibits a more pronounced increase in input power owing to enhanced combustion quality and energy output. This pattern underscores the capacity of nanoparticles to diminish energy losses by improving the engine's thermal efficiency, particularly under high loads.

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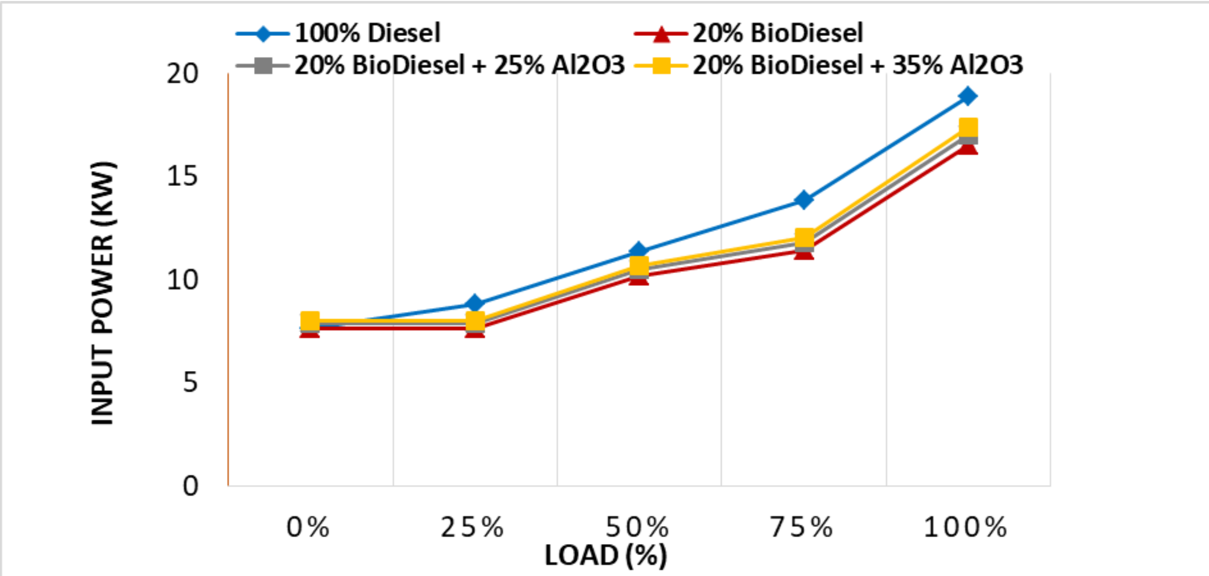

Figure (3-2) Input power vs. load with (20%biodiesl) and nanoparticles

3.1.3 Brake Mean Effective Pressure (BMEP) with (20%biodiesl) and nanoparticles

BMEP is an important indicator of engine efficiency since it quantifies the pressure within the engine cylinders. The findings indicate that the Brake Mean Effective Pressure (BMEP) dramatically escalates when the load grows, particularly with biodiesel augmented by nanoparticles. The use of Al_2O_3 enhances combustion, resulting in elevated pressures. The 35% Al_2O_3 mix attains a greater Brake Mean Effective Pressure (BMEP) than the 25% blend and pure biodiesel, signifying enhanced energy extraction from the fuel as shown in figure(3-3). This indicates that biodiesel boosted with nanoparticles can provide greater mechanical power, improving total engine efficiency.

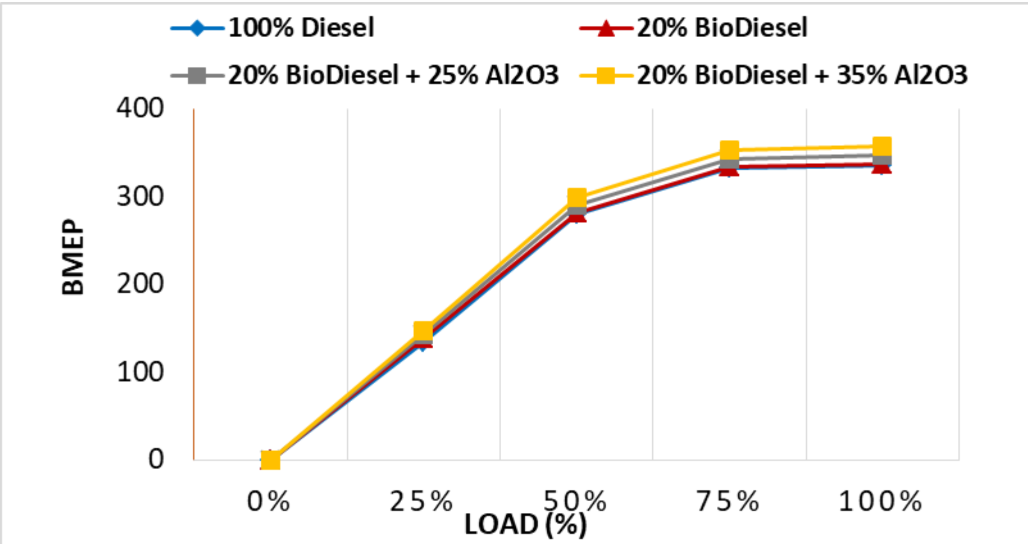

Figure (3-3) BMEP vs. load with (20%biodiesl) and nanoparticles

3.1.4 Brake power efficiency with (20%biodiesl) and nanoparticles

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Brake power efficiency quantifies the ratio of useful power output to energy input. Figure (3-4)illustrates the enhancement of brake power efficiency as load increases, especially with the incorporation of nanoparticles in biodiesel. The efficiency gains are notably enhanced with the 35% Al_2O_3 blend, indicating improvements in combustion and reduced frictional losses. This indicates that nanoparticles improve the combustion properties of the fuel, facilitating more efficient energy conversion across different loads, particularly under high-load conditions where the engine experiences increased mechanical losses.

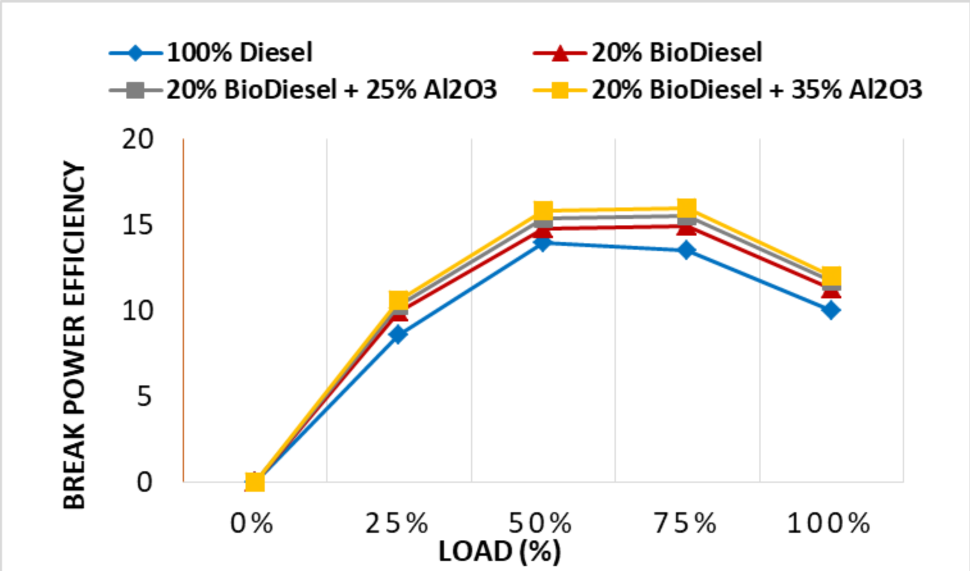

Figure (3-4) Break Power efficiency vs. load with (20%biodiesl) and nanoparticles

3.2 Emissions Analysis with (20%biodiesl) and nanoparticles

3.2.1 CO2 Emissions with (20%biodiesl) and nanoparticles

The use of nanoparticles in biodiesel markedly decreases CO_2 emissions under various loads. Enhanced combustion efficiency reduces fuel consumption for equivalent power generation, diminishing total carbon emissions. Figure (3-5) illustrates that the 35% Al_2O_3 blend exhibits the lowest CO_2 emissions, indicating the beneficial environmental effects of nanoparticle-enhanced biodiesel. Moreover, increased loads often correlate with elevated CO_2 emissions, yet the reductions attributable to nanoparticles are apparent even under substantial loads.

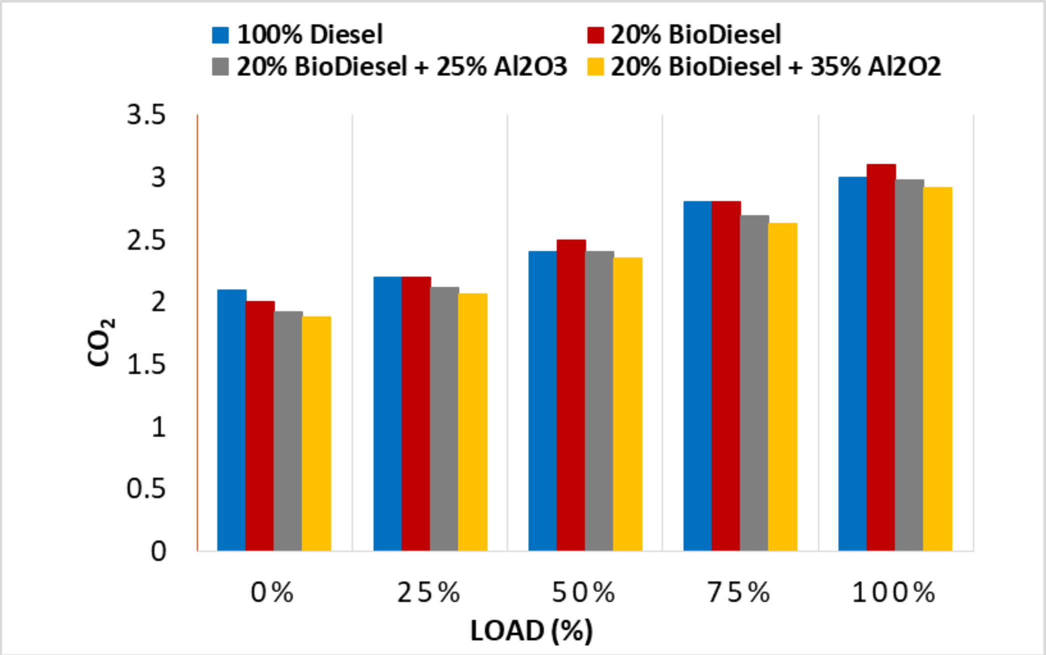

Figure (3-5) CO_2 emission variation depending on engine loads with (20% biodiesl) and nanoparticles

3.2.2 Oxygen Emissions with (20%biodiesl) and nanoparticles

Oxygen emissions indicate the unreacted oxygen that traverses the engine without participating in combustion. An elevated concentration of O_2 in the exhaust may signify an inefficient combustion process. The research indicates that the incorporation of nanoparticles marginally elevates O_2 emissions. This is probably because of the nanoparticles' capacity to enhance the combustion process, leading to a more effective utilisation of the fuel-air combination, hence leaving residual oxygen in the exhaust. Figure (3-6), The 35% Al_2O_3 mix exhibits more O_2 emission than the 25% blend, consistent with the observation that enhanced combustion efficiency (resulting from full fuel combustion) retains more unreacted oxygen. As load increases, O_2 emissions generally diminish due to the engine's heightened use of oxygen to satisfy the augmented power requirement.

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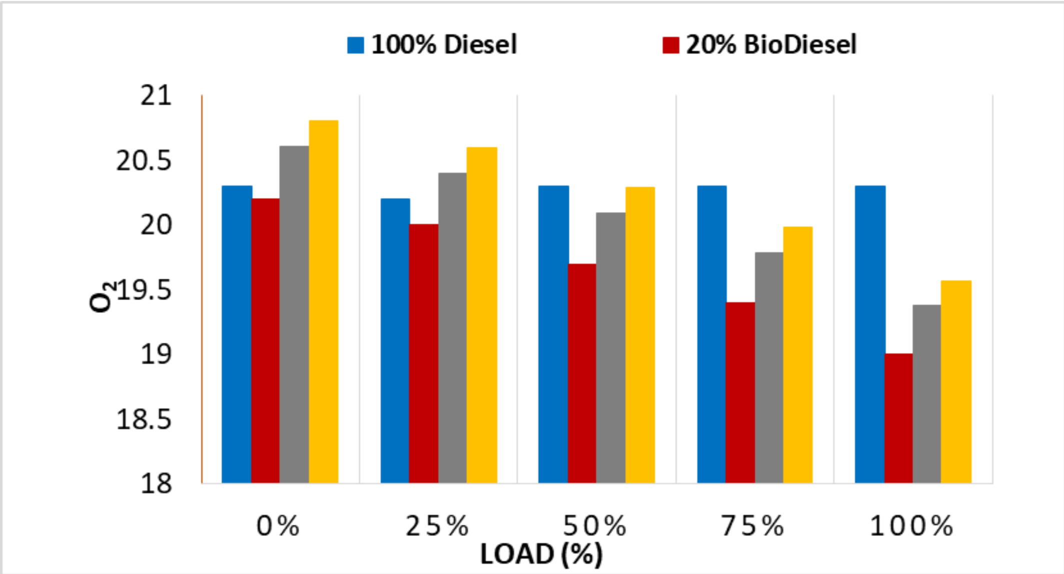

Figure (3-6) O_2 emission variation depending on engine loads with (20%biodiesl) and nanoparticles

3.2.3 NOx Emissions with (20%biodiesl) and nanoparticles

NO_x emissions often rise with increased combustion temperatures. Biodiesel typically generates elevated NO_x emissions owing to its increased oxygen content; however, using nanoparticles somewhat alleviates this issue by enhancing combustion stability, as seen in Figure (3-7). Nevertheless, NO_x emissions remain elevated for biodiesel compared to diesel, but the 35% Al_2O_3 mix demonstrates a significant decrease relative to the 25% blend.

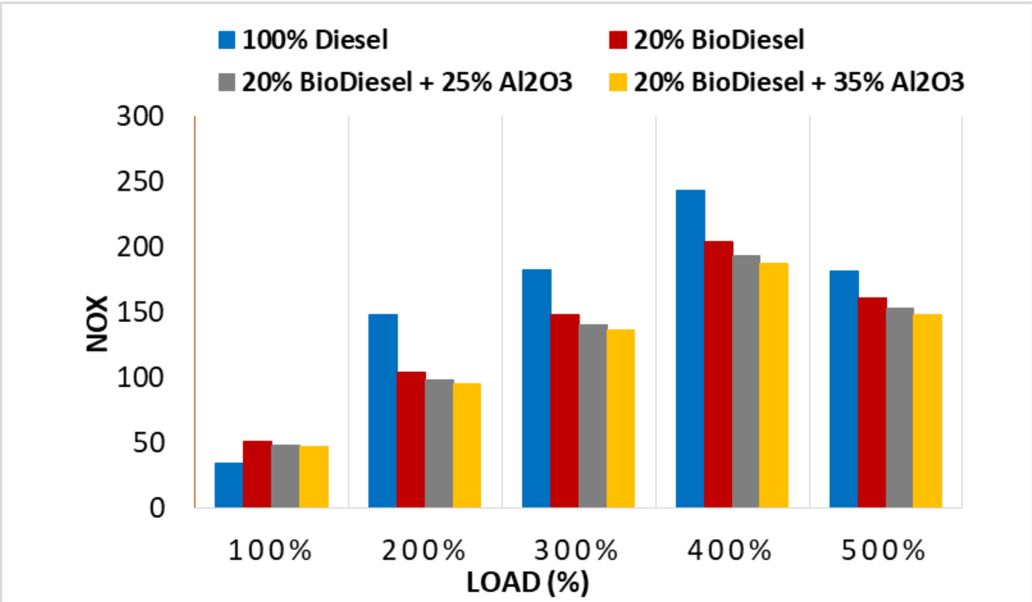

Figure (3-7) NOx emission variation depending on engine loads with (20%biodiesl) and nanoparticles

3.2.4 Hydrocarbon Emissions with (20%biodiesl) and nanoparticles

Hydrocarbon emissions signify the quantity of un-combusted fuel emitted during combustion. Figure (3-8) indicates a decrease in HC emissions by incorporating nanoparticles into biodiesel.

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Nanoparticles, especially Al_2O_3, augment combustion by enhancing fuel atomisation and facilitating a more thorough burning of the fuel combination. The 35% Al_2O_3 mix exhibits a more significant reduction in HC emissions compared to the 25% blend, indicating enhanced combustion efficiency. Reducing HC emissions is especially significant when combustion often exhibits decreased efficiency at elevated loads. Consequently, the nanoparticles mitigate this inefficiency, decreasing the volume of unburned hydrocarbons sent into the environment.

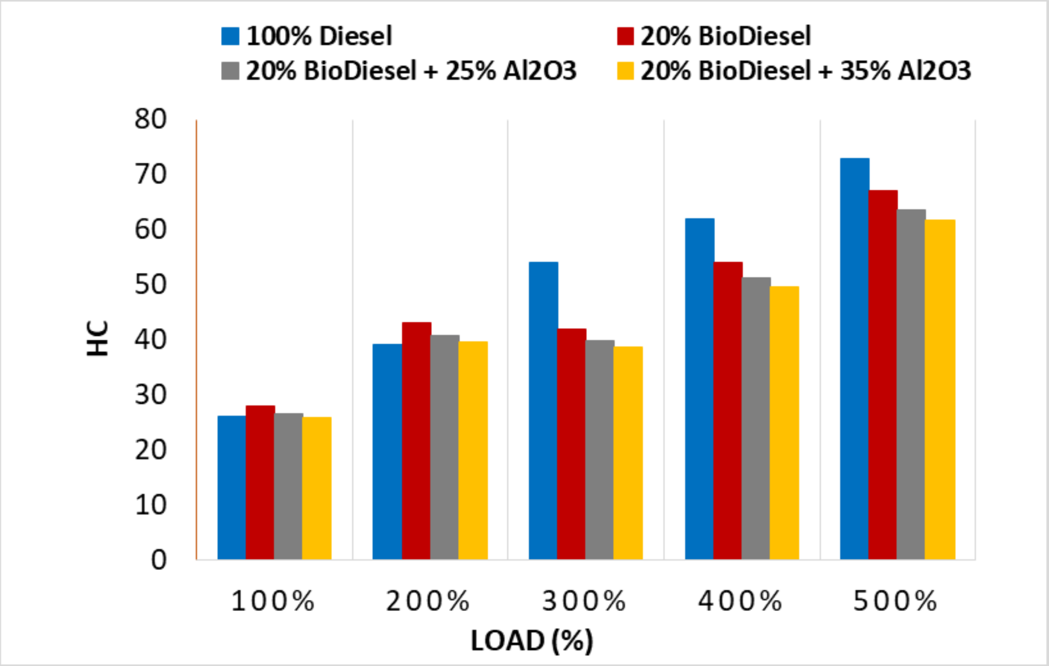

Figure (3-8) HC emission variation depending on engine loads with (20%biodiesl) and nanoparticles

4. Conclusions

This study thoroughly examines a diesel engine's performance and emission attributes utilizing biodiesel mixes containing nanoparticles. The principal conclusions derived from the research are as follows:

1. Enhancement of Engine Performance: Using biodiesel, namely the 20% blend (B20), improved the engine's mechanical efficacy. Critical parameters have significantly improved, including brake mean effective pressure (BMEP), brake power efficiency, and input power. Nanoparticles, especially Al_2O_0,

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greatly improved these performance parameters by making combustion more efficient by better-mixing air and fuel into tiny particles.

2. Decrease in Fuel Consumption: The B20 blend exhibited the most favourable fuel efficiency among all evaluated biodiesel blends. Fuel usage was markedly decreased, especially with the integration of nanoparticles. This drop happened because the catalytic properties of nanoparticles made combustion more efficient. This meant more energy could be extracted from the fuel, meaning less fuel was needed to keep the engine running.

3. Emission Control: Biodiesel blends decreased deleterious emissions, particularly when enhanced with nanoparticles. The 35% Al_2O_3 mix, specifically, attained minimal CO_2, CO, and hydrocarbon emissions compared to pure diesel and reduced biodiesel percentages. Although NO_x emissions rose somewhat with greater biodiesel percentages due to higher combustion temperatures, the overall environmental advantages were significant.

4. Improved Combustion Efficiency: The reduced fuel-to-air ratios associated with biodiesel blends, especially B20, demonstrated a more effective combustion process. Nanoparticles enhanced this efficiency, reducing fuel consumption and greater engine performance. The nanoparticles enhanced fuel combustion, minimizing unburned hydrocarbons and improving thermal efficiency.

5. Sustainability Advantages: The renewable characteristics of biodiesel and its diminished carbon impact establish biodiesel as a feasible substitute for traditional diesel. Nanoparticle-enhanced biodiesel blends boost engine efficiency while promoting environmental sustainability by decreasing greenhouse gas emissions and diminishing dependence on fossil fuels.

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