



Effect of Camphor, Zinc Oxide and Aluminum Oxide Nano Particles as Additives to Cotton Oil Biodiesel on Engine Performance and Gas Emission

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ABSTRACT

Nanoparticles have been shown to be a potential additive to improve the performance and reduce harmful gas emissions of biodiesel fuels. The aim of this study is to investigate the effects of nanoparticles on cotton oil-derived biodiesel fuels, focusing on engine performance and gas emissions. The experiment involved producing biodiesel fuel from cotton oil using a transesterification process and then incorporating varying concentrations of nanoparticles into the fuel. A single-cylinder four-stroke diesel engine was used to evaluate the engine performance of the biodiesel fuel-nanoparticle blends as test samples. The engine was operated under various load conditions and relevant parameters such as brake-specific fuel consumption, thermal efficiency and exhaust gas temperature were measured and analyzed. Additionally, gas emissions, including nitrogen oxide (NO_x), carbon monoxide (CO) and particulate matter, were monitored using an exhaust gas analyzer. The concentration of these emissions was compared across different nanoparticle concentrations to assess their impact on emission levels. The results showed that the incorporation of nanoparticles into biodiesel fuel improved engine performance parameters such as brake-specific fuel consumption and thermal efficiency, especially at higher nanoparticle concentrations. Also, gas emission analysis showed a visible reduction in NO_x and CO emissions through the addition of nanoparticles. These results suggest that nanoparticles have a positive impact on the engine performance and gas emissions of cotton oil-derived biodiesel.

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INTRODUCTION

The demand for sustainable energy solutions has led to biodiesel emerging as a promising alternative to traditional diesel fuel (Abdulrahman and Nayebzadeh 2021). However, engine performance and emissions remain a challenge. Nanotechnology has gained considerable attention in recent years as a potential solution to improve the properties of biodiesel fuels (Jin et al. 2023). Previous studies have shown that nanoparticles can alter various properties of biodiesel such as combustion behavior and emissions (Nagappan and Babu

2023). For example, zinc oxide nanoparticles have shown promising results in improving fuel combustion efficiency by enabling better fuel-air mixing and catalytic activity. Alumina nanoparticles are also known for their catalytic properties, which can improve the combustion process and reduce emissions in other applications (Mofijur et al. 2023). Equally intriguing are camphor nanoparticles, whose antimicrobial and antioxidant properties offer a potential opportunity to improve the stability and performance of biodiesel fuels while reducing the risk of fuel degradation and increasing the

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efficiency of the combustion process (Sarma et al. 2023).

As the world looks to transition to more sustainable energy sources, biodiesel is receiving increasing attention as a viable alternative to traditional diesel fuel (Bitire et al., 2023). However, there is a need to improve the properties of biodiesel to increase engine performance and reduce emissions. A promising solution is the use of nanotechnology, in which nanoparticles are specifically added to the biodiesel fuel as additives (Shelare et al. 2023). In this study, we aim to evaluate the effects of camphor, zinc oxide and aluminum oxide nanoparticles on engine performance and gas emissions when added to cotton oil biodiesel.

MATERIAL AND METHODS

In this experiment, suitable methods were employed to synthesize camphor, zinc oxide, and aluminum oxide nanoparticles. Sodium hydroxide (NaOH) was utilized as the catalyst for the transesterification reaction. The necessary equipment consisted of a mechanical stirrer, weigh balance, measuring cylinder, beaker, bottles, eddy current dynamometer, standard burette, stopwatch, IMR 1400 gas analyzer, and Chromel/Alumel (K-Type) thermocouple.

Biodiesel fuel preparation

Transesterification process was used to produce biodiesel from cottonseed oil (Encinar et al., 2016). Biodiesel is an environmentally friendly alternative to traditional diesel fuel obtained from renewable sources (Murugesan et al., 2009). The process involves three main components: feedstock, alcohol and a catalyst. First, the raw material (cotton seed oil) was pretreated to remove impurities such as water, free fatty acids and solid particles. This step was crucial to ensure optimal transesterification performance. The purified feedstock was then mixed with methanol (our reactant) to break down fats into free fatty acid alkyl esters, the main component of biodiesel. Finally, the catalyst (sodium hydroxide) was added to accelerate the reaction and convert the triglycerides present in the feedstock into biodiesel. The transesterification reaction took

place in a temperature range of 60–70 °C and atmospheric pressure. This process took several hours to achieve a significant conversion of triglycerides into biodiesel.

After the reaction was complete, the mixture was allowed to settle, resulting in the separation of the biodiesel layer from the glycerol layer. The biodiesel was then washed several times with water to remove residual impurities and catalysts and then dried to obtain our final product (Hariram et al., 2017). The final product was used directly in diesel engines. Predetermined ratios of camphor, zinc oxide and aluminum oxide were incorporated into the biodiesel fuel in different concentrations.

Engine performance and emission testing

For the experiment, a standard single-cylinder, four-stroke diesel engine was utilized. The engine underwent testing under different load conditions, with measurements taken for parameters such as brake power, brake torque, BSFC, and BTE. Exhaust gas composition analysis was conducted to evaluate NO_x, CO, and PM emissions. To compare results, both pure cotton oil biodiesel and conventional diesel fuel were utilized during the experiment.

Engine Test Procedure

A compression ignition engine was used to conduct an engine test in which various parameters including braking power, mean effective brake pressure, specific fuel consumption and brake thermal efficiency were measured. The motor was connected to an eddy current test stand. Before testing, the engine was test run and allowed to warm up for approximately 15 minutes. The engine initially ran on diesel fuel only, followed by various mixtures. For each mixture, full load conditions were applied at different speeds of 500 rpm, 1000 rpm, 1500 rpm and 2000 rpm. Finally, the time required for a given fuel to be consumed at each speed was recorded (Fahd et al., 2013).

A dynamometer was used to measure engine torque. The engine was attached to a test stand and its output shaft was connected to the dynamometer rotor. The rotor was braked by

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electromagnetic, hydraulic or mechanical friction to convert the energy provided by the engine into heat that cooled the dynamometer. The torque exerted on the stator was measured using a balance weight, springs, pneumatic or electronic methods, and other engine parameters such as the mean effective brake pressure, the specific fuel consumption and the thermal efficiency of the brake were calculated using equations (Kaisan et al., 2017).

Exhaust Gas Analyses

The fire gas analyzer IMR 1400, model 2014, was used to analyze combustion gases. The IMR 1400 model was manufactured by Environmental Equipment Incorporation, located on Central Avenue, St. Petersburg, Florida, USA 33711. This high-quality combustion gas analyzer features modern sensor technology that makes it user-friendly while determining all the necessary parameters to adjust and optimize the combustion process, as described by Kaisan et al. (2017). This device is both portable and compact, housed in a sturdy aluminum casing. It is capable of simultaneously measuring oxygen (O₂), carbon monoxide (CO), flue gas temperature (FGT), excess air, combustion efficiency, losses, carbon dioxide (CO₂), sulfur dioxide (SO₂), nitrogen oxide, etc. Nitrogen oxide, as described by Gaji et al. (2022).

RESULTS AND DISCUSSION

The incorporation of camphor, zinc oxide and aluminum oxide nano particles in cotton oil biodiesel resulted in noticeable improvements in the engine performance and emission characteristics when compared to pure biodiesel and conventional diesel fuel. The combustion efficiency was enhanced due to the nano-additives catalyst effect resulting in the reduced BSFC and improved BTE. The emission testing revealed reduced levels of NO_x, CO and PM attributed to increased oxygen availability and enhanced fuel air mixing (Mehregan and Moghiman. 2020).

Performance Evaluation in CI Engine

Brake Thermal Efficiency

Brake thermal efficiency is the power output of an engine per rate of heat input into the engine. This shows how an engine converts the heat energy supply by fuel into useful work, therefore different fuels with different calorific values (i.e., their capacity to supply heat), when tested on the same engine will produce different brake thermal efficiency. Hence, Table 1 shows the brake thermal efficiencies of the blends used in this experiment. From the data presented in Table 1, mixture D has the highest brake thermal efficiency at 1500 rpm and a load of 4.5.

Table 1: Variation of brake thermal efficiency of diesel and blends at constant load

Samples	Additive	BTE %
A	2% Camphor	4.05
B	4% Camphor	4.04
C	2% ZnO	3.79
D	4% ZnO	4.15
E	2% Al ₂ O ₃	3.92
F	4% Al ₂ O ₃	3.72
G	Control (no additive)	3.99

This is due to the relatively low density, high cetane number and high calorific value, as well as the presence of a 4% ZnO additive. It is also noteworthy that the thermal braking efficiency of diesel (no additive) is worse than that of A (2% camphor), B (4% camphor), and D (4% ZnO). This

may be due to the lower density of blends B and D, the lower blend viscosity of B, the higher cetane number of A and B, and the higher calorific value of D. In contrast, the BTE of diesel is higher than that of C (2% ZnO), E (2% Al₂O₃) and F (4%

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Al₂O₃), which is due to the higher viscosities of the mixture and the lower cetane number.

Blend F has the lowest BTE, which may be due to its relatively high density and viscosity, lowest cetane number value, and the presence of Al₂O₃ additive at 4%. It is worth noting that fuel atomization is one of the factors affecting heat release. Higher fuel density and viscosity lead to poor atomization and lower combustion efficiency, resulting in lower BTE (Bragadeshwaran et al., 2018). Based on the results of the experiment conducted, it was observed that the camphor additive had a significant impact on the BTE, followed by the ZnO additive which had a minimal impact on the BTE. The Al₂O₃ addition, on the other hand, had a reducing effect on the BTE. Furthermore, BTE was found to be more affected by an additive concentration of 4%, whether increasing or decreasing, compared to an additive concentration of 2%.

Analysis of Variance for Brake Thermal Efficiency

Table 2: Analysis of variance for brake thermal efficiency

Source of Variation	SS	Df	MS	F	p-value	F crit
Rows	0.0038	1	0.0038	0.0923	0.7898	18.5128
Columns	0.0525	2	0.0263	0.6473	0.6070	19
Error	0.0811	2	0.0406			
Total	0.1374	5				

Brake Specific Fuel Consumption (BSFC)

Assessing engine efficiency is critical, and brake specific fuel consumption (BSFC) is a key metric for this. It measures the amount of fuel an engine uses per unit of usable power. In simple terms, BSFC indicates how efficiently an engine uses fuel to produce work. A lower BSFC value indicates better fuel efficiency, meaning the

The data presented in Table 2 refers to the BTE of the CI engine operating at a speed of 1500 rpm under 4.5 N. The fuel source used in this experiment was cotton oil biofuel mixed with three different nanoparticles (camphor, ZnO, Al₂O₃) at two different concentrations (2 and 4%). After a two-way analysis of variance, all effects were found to be statistically insignificant at the 0.05 significance level. The *F* ratio for the series was *F* (1,5) = 0.0925, *p* > 0.05, indicating that there was no significant difference in the mean BTE for the different nanoparticle additives. Therefore, any of the three nanoparticles can be used as an additive without significantly affecting the BTE. The *F* ratio for the columns was *F* (2,5) = 0.6473, *p* > 0.05, indicating that there was no significant difference in the mean BTE for the different nanoparticle concentrations. This means that adding 2 or 4% nanoparticles as an additive has no significant impact on BTE. Overall, these results suggest that the mean BTE for various nanoparticle 280 additives and concentrations used in this study was not statistically significant.

engine requires less fuel to produce the same power. Conversely, a higher BSFC means poor efficiency, meaning the engine uses more fuel for a given amount of power. To determine which fuel mixture is most efficient for the engine, we can refer to Table 3. This table highlights the differences in BSFC for different fuel blends so we can compare their efficiency.

Table 3: Variation of brake specific fuel consumption of diesel and blends at constant load.

Samples	Additive	BSFC %
A	2% Camphor	2.08
B	4% Camphor	2.06
C	2% ZnO	2.18
D	4% ZnO	1.98

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Samples	Additive	BSFC %
E	2% Al ₂ O ₃	2.08
F	4% Al ₂ O ₃	2.17
G	Control (no additive)	2.09

To save fuel costs, every engine must have a lower BSFC. Interestingly, fuels with high calorific value tend to have lower BSFC values (Bragadeshwaran et al., 2018). In Fig. 4.13 we see that the mixture C (2% ZnO) and F (4% Al₂O₃) has a higher BSFC than diesel (no additive). This is probably due to the high viscosity and density values of Mixture F. However, blends A (2% camphor), B (4% camphor), D (4% ZnO) and E (2% Al₂O₃) all have a lower BSFC compared to diesel. This could be attributed to the higher calorific value of D and E, the higher cetane number of A and B and the low density of B, D and E. Mixture D (4% ZnO) had the lowest BSFC due to its low BSFC density, relatively high calorific value, the ZnO addition and its concentration.

According to Bragadeshwaran et al. (2018), fuels with high viscosity and density tend to have higher BSFC values because more fuel is injected into the combustion chamber. They also found that fuels with inherent oxygen content have higher BSFC values because the oxygen content reduces the heat content of the fuel. Based on the experiment, it is clear that the ZnO additive has a significant impact on the BSFC, followed by the Al₂O₃ additive, which has a similar effect. The addition of camphor had a small reducing effect on BSFC. Furthermore, it appears that an additive concentration of 4% has a greater impact on

reducing BSFC than a concentration of 2%, with the exception of camphor.

Analysis of Variance for Brake Specific Fuel Consumption (BSFC)

Table 4 shows the BSFC of a CI engine operating at 1500 rpm and 4.5 N using cotton oil biofuel mixed with three different nanoparticles (camphor, ZnO, Al₂O₃) at two concentration levels (2 and 4%). is operated. Two-way analysis of variance was used to evaluate the results, with nanoparticles grouped into columns and concentrations grouped into rows. All effects were considered statistically insignificant at a significance level of 0.05. The rows yielded an F ratio of F (1,5) = 0.2628, p > 0.05, indicating that the mean BSFC difference was unimportant for the different nanoparticle additives. This means that any of the three nanoparticles can be used as an additive and will not significantly affect the BSFC. The columns gave an F ratio of F (2,5) = 0.1608, p > 0.05, indicating that the mean BSFC difference was unimportant for the different nanoparticle concentrations. Therefore, the use of 2 or 4% nanoparticles as an additive has no significant effect on BSFC. These results suggest that the mean BSFC was statistically insignificant for different nanoparticle additives and different nanoparticle concentrations used in the current study.

Table 4: Analysis of variance for brake specific fuel consumption

Source of Variation	SS	Df	MS	F	p-value	F crit
Rows	0.0028	1	0.0028	0.2628	0.6591	18.5128
Columns	0.0034	2	0.0017	0.1602	0.8619	19
Error	0.0214	2	0.0107			
Total	0.0277	5				

Brake Mean Effective Pressure (BMEP)

The pressure, which remains constant and does the same amount of work per cycle, is

crucial in determining the braking torque produced by the engine (Sheng et al., 2022). The relationship between this pressure and the BMEP

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for various mixtures is shown in Table 5. From the table it can be seen that Diesel (no additive) has a higher BMEP compared to most mixtures B (4% camphor), C (2% ZnO), D (4% ZnO), E (2% Al₂O₃) and F (4% Al₂O₃), except mixture A (2% camphor). This is due to diesel's higher cetane number and its lower viscosity and density compared to the blends. Blend A (2% camphor) produced the highest BMEP, while Blend C (2% ZnO) produced the lowest BMEP, which can be explained by the differences in the density and calorific values of the fuel, as reported by (Sheng et al., 2022). The

experiment found that camphor additive had a significant effect on increasing and decreasing BMEP compared to diesel, followed by Al₂O₃ additive which had a decreasing effect on BMEP. The ZnO addition had a reducing effect on the BSFC. Furthermore, it was observed that only the 2% camphor additive had a more significant impact on BMEP, while the 4% concentration appeared to have a positive effect on the other additives.

Table 5: Variation of brake mean effective pressure of diesel and blends at constant load

Samples	Additive	BMEP %
A	2% Camphor	4.99
B	4% Camphor	4.88
C	2% ZnO	4.73
D	4% ZnO	4.86
E	2% Al ₂ O ₃	4.83
F	4% Al ₂ O ₃	4.85
G	Control (no additive)	4.94

Analysis of Variance for Brake Mean Effective Pressure (BMEP)

Table 6 shows the BMEP of the CI engine running at 1500 rpm and a load of 4.5 N. The fuels used were cotton oil biofuel in combination with three different nanoparticles (camphor, ZnO, Al₂O₃) in two concentration levels (2 and 4%). Results were analyzed using two-way analysis of variance, with nanoparticles arranged in columns and concentrations in rows. All effects were not statistically significant at a significance level of 0.05. The series yielded an F ratio of F (1,5) = 0.0369, p > 0.05, indicating that the mean BMEP difference was insignificant for the different

nanoparticle additives. This means that any of the three nanoparticles can be used as an additive and the effect on BMEP is not significant. The columns gave an F ratio of F (2,5) = 1.4157, p > 0.05, indicating that the mean BMEP difference was insignificant for the different nanoparticle concentrations. Therefore, the addition of 2 or 4% nanoparticles as an additive has no significant effect on the BMEP. This finding suggests that the mean BMEP for various nanoparticle additives and concentrations used in the current study was not statistically significant.

Table 6: Analysis of variance for brake mean effective pressure

Source of Variation	SS	Df	MS	F	p-value	F crit
Rows	0.0003	1	0.0003	0.0370	0.8653	18.5128
Columns	0.0204	2	0.0102	1.4157	0.4140	19
Error	0.0144	2	0.0072			
Total	0.0351	5				

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Variation of exhaust gas temperature (EGT) with load

The temperature of the exhaust gas is an indicator of the quality of combustion in the chamber, and higher exhaust gas temperatures can lead to energy losses (Misra, 2016). Figure 4 shows the variation of EGT for different blends and Table 7 shows that diesel (without additive) has the highest compared to blends A (2% camphor), B (4% camphor), C (2% ZnO) and D EGT (4% ZnO), E (2% Al₂O₃) and F (4% Al₂O₃). This could be because the blended fuels contain oxygen, which reduces the heat of combustion in the cylinder, and their relatively higher viscosity reduces fuel atomization. Additionally, diesel's higher cetane number and calorific value may be responsible for combustion temperatures being so high, as more heat is released in the process.

According to Hao et al. (2021), diesel had only a slightly higher EGT than all blends. Among the blends, blend D (4% ZnO) has the highest EGT, while blend B (4% camphor) has the lowest EGT, which may be due to the higher cetane number and lower density of blend B. The experiment showed that camphor nanoparticle additives significantly reduced EGT compared to diesel, followed by ZnO nanoparticle additives which also had a reducing effect on EGT. Finally, Al₂O₃ additives had a decreasing effect on EGT. Only a 4% concentration of camphor supplement had a significant effect on reducing EGT; Otherwise, both 2% and 4% additive concentrations appeared to have a positive impact on the blends in terms of reducing EGT.

Table 7: Variation of Exhaust gas temperature of diesel and blends at constant load

Samples	Additive	Temperature at the Exhaust °C
A	2% Camphor	277
B	4% Camphor	272
C	2% ZnO	277
D	4% ZnO	285
E	2% Al ₂ O ₃	284
F	4% Al ₂ O ₃	283
G	Control (no additive)	306

Analysis of Variance for exhaust gas temperature (EGT)

Table 8 shows the exhaust gas temperature (EGT) of a CI engine operating at 1500 rpm and 4.5 N. The fuels used were cotton oil biofuel mixed with three different nanoparticles (camphor, ZnO, Al₂O₃) in two concentration levels (2 and 4%). A two-way analysis of variance was performed on the results, placing nanoparticles in columns and concentration in rows. The results showed that all effects were statistically insignificant at a significance level of 0.05. The rows yielded an F ratio of $F(1,5) = 0.0300$, $p > 0.05$, indicating that the differences in mean EGT

for the different nanoparticle additives were insignificant. This means that each of the three nanoparticles can be used as an additive without significantly affecting the EGT. The columns gave an F ratio of $F(2,5) = 1.9473$, $p > 0.05$, indicating that the differences in mean EGT for the different nanoparticle concentrations were insignificant. Therefore, the use of 2 or 4% nanoparticles as an additive does not have a significant impact on EGT. These results suggest that the mean EGT for various nanoparticle additives and concentrations used in this study was not statistically significant.

Table 8: Analysis of variance for Exhaust gas temperature

Source of Variation	SS	df	MS	F	p-value	F crit
Rows	0.6667	1	0.6667	0.0301	0.8783	18.5128
Columns	86.3333	2	43.1667	1.9474	0.3393	19
Error	44.3333	2	22.1667			
Total	131.333	5				

Emissions Characteristics

Unburnt hydrocarbon (HC) emission in CI engine

Incompletely or partially burned fuel can produce hydrocarbon (HC) emissions. As Arumugam et al. (2014) explain that the amount of HC varies depending on the engine operating conditions and fuel characteristics. Figure 1 shows the range of unburned HC for different blends. Diesel has a higher proportion of unburned HC than most blends, with the exception of Blend F (4% Al₂O₃), which is due to the oxygen content of the blends. The excess oxygen allows for complete combustion and the low volatility of the mixture allows for more complete combustion, as Ragadeshwaran et al. have determined. (2018). The 4% camphor mixture (Mixture D) had the lowest unburned HC, while Mixture F had the

highest value. The high density and viscosity of Mixture F can limit its atomization performance and contribute to its high calorific value. In the experiment, the addition of camphor nanoparticles resulted in the most significant reduction in unburned HC compared to diesel. The ZnO nanoparticle addition also reduced unburned HC, while the Al₂O₃ addition had both a decreasing and increasing effect on unburned HC. Furthermore, it is noteworthy that the 2% camphor additive and the 4% ZnO additive had a more significant reduction in unburned HC. In general, both 2% and 4% additive concentrations appear to have a positive impact on the blends in reducing exhaust gas temperature (EGT), with the exception of the Al₂O₃ additive at 4% concentration.

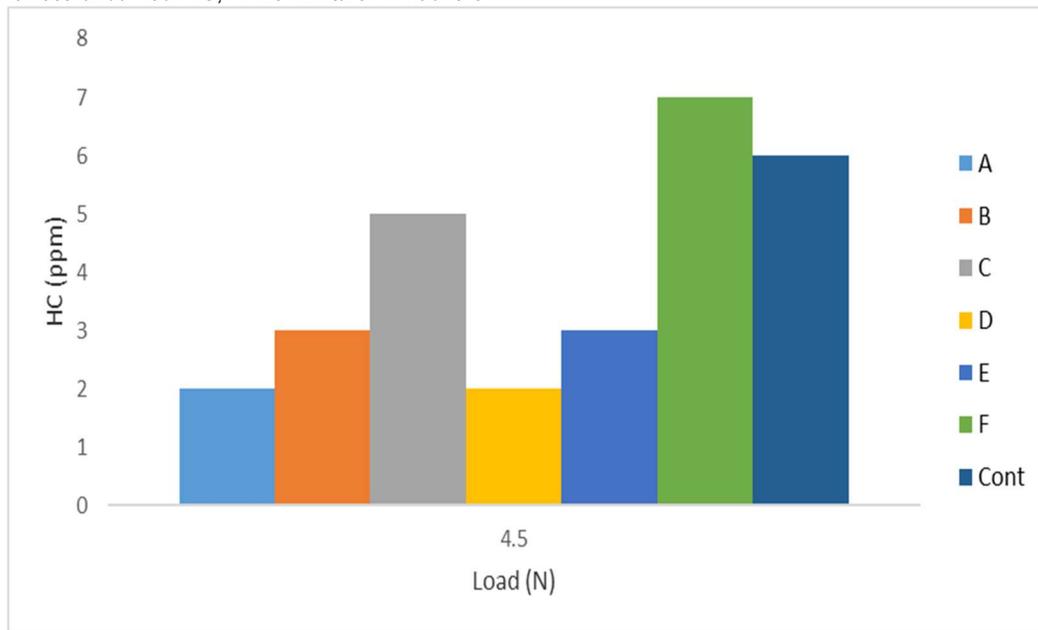


Figure 1: Variation of unburnt HC of diesel and blends at constant load

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Analysis Of Variance for Unburnt Hydrocarbon (HC)

Table 9 shows the unburned hydrocarbon (HC) emissions of a compression ignition (CI) engine running at 1500 rpm and a load of 4.5 N using cotton oil biofuel mixed with three different nanoparticles (camphor, ZnO, Al₂O₃) in two Concentration levels are operated (2% and 4%). Data were analyzed using a two-way statistical approach, with nanoparticles categorized into columns and concentrations categorized into rows. No significant differences were observed at the 0.05 significance level. The

rows yielded an F-ratio of $F(1,5) = 0.1081$ with a p -value greater than 0.05. This suggests that the addition of any of the three nanoparticles will not have a significant impact on unburned hydrocarbons. The columns gave an F-ratio of $F(2,5) = 0.5135$ with a p -value greater than 0.05. Therefore, the addition of 2% or 4% nanoparticles has no significant impact on unburned hydrocarbons. Overall, this study shows that there were no significant differences in unburned hydrocarbons across the different nanoparticle additives and concentrations tested.

Table 9: Analysis of variance for unburnt hydrocarbon

Source of Variation	SS	df	MS	F	p-value	F crit
Rows	0.6667	1	0.6667	0.1081	0.7735	18.5128
Columns	6.3333	2	3.1667	0.5135	0.6607	19
Error	12.3333	2	6.1667			
Total	19.33333	5				

Nitric oxide (NOx) emission CI engine

According to a recent report by Khan et al. (2021), NO_x formation is strongly influenced by factors such as combustion temperature, concentration and combustion duration. The diesel blend

marked "Cont" emits lower NO_x levels compared to blends A, B, C, D, E and F due to factors such as oxygen content, in-cylinder temperature and the presence of atmospheric nitrogen (Figure 2).

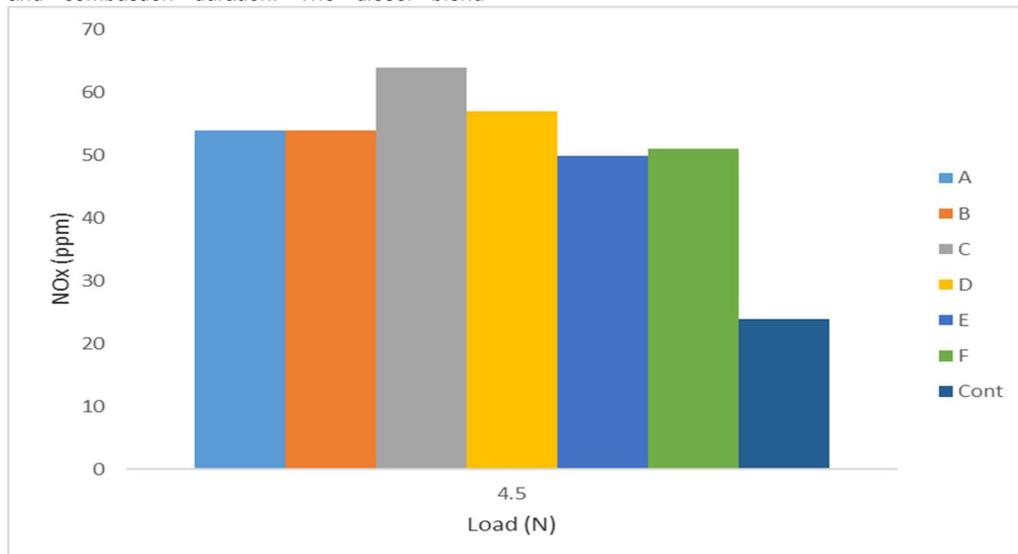


Figure 2: Variation of unburnt NOx of diesel and blends at constant load

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Nitrogen is initially inactive, but when exposed to high temperatures in the cylinder, it breaks down into unstable nitrogen atoms, which combine with oxygen to form NO_x. Apart from these factors, Bragadeshwaran et al. (2018) suggest that compression ratio, cylinder geometry, air inlet temperature and fuel properties also contribute to NO_x formation. Mixture C, which has a relatively high cetane number and a relatively high calorific value, had the highest NO_x values. This is because a higher cetane number shortens ignition delay, resulting in complete combustion and increased NO_x formation. During the experiment, the addition of ZnO nanoparticles significantly increased NO_x levels compared to diesel, while camphor nanoparticles resulted in increased HC emissions. The Al₂O₃ addition also contributed to higher NO_x values. Vinukumar et al. (2018) observed that both 2% and 4% additive concentrations had increasing influence on blends in increasing NO_x emissions.

Analysis of Variance for Nitric Oxides (Nox)

The results presented in Table 10 show the analysis of NO_x emissions from a CI engine

Table 10: Analysis of variance for Nitric oxide

Source of Variation	SS	df	MS	F	p-value	F crit
Rows	6	1	6	0.6318	0.5101	18.5128
Columns	103	2	51.5	5.4211	0.1557	19
Error	19	2	9.5			
Total	128	5				

Carbon monoxide (CO) emission CI engine

Incomplete combustion occurs when there is not enough oxygen in the combustion chamber, which is a common problem in engines. This problem leads to the formation of CO, a toxic gas that is harmful to both humans and the environment (Sheng et al., 2022). However, fuel type, engine speed, and air-fuel ratio are also important factors that can contribute to this problem, with most studies linking CO to incomplete in-cylinder combustion (Abdulrahman & Nayebzadeh, 2021). To determine the combustion properties, researchers conducted

running at 1500 rpm and 4.5 N. The study involved blending cotton oil biofuel with three types of nanoparticles at concentrations of 2% and 4%. Data analysis was performed using a statistical method called analysis of variance, with nanoparticles arranged in columns and concentrations in rows. The study found that none of the observed effects were statistically significant at the 0.05 significance level. The F ratio for the series was 0.6315 with a p value greater than 0.05, indicating that there were no significant differences in NO_x values with different nanoparticle additives. Likewise, the F ratio for the columns was 5.4210 with a p value greater than 0.05, indicating that there were no significant differences in NO_x values between different nanoparticle concentrations. Therefore, the study concludes that the addition of any of the three nanoparticles or their concentrations will not result in a significant change in NO_x emissions. Overall, the results show that the nanoparticle additives or concentrations examined in this study had no significant influence on the NO_x values.

experiments with different fuel mixtures and measured the level of CO emissions.

Surprisingly, they found that no CO emissions were detected in any of the fuel blends. This indicates that the engine is efficiently receiving more air, ensuring sufficient oxygen for complete combustion of the fuel mixtures. This also suggests that all fuel blends may have similar combustion characteristics as their cetane numbers are between 50 and 65 and their calorific values are between 42 and 45 kJ/kg, while pure diesel has a cetane number of 64.85 and a calorific value of 43.32. Although the fuel blends showed no CO emissions, studies by Chauhan et

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al. (2012) show that the CO emissions of biodiesel are lower than those of pure diesel fuel. This suggests that using biodiesel as a fuel source could potentially reduce CO emissions and improve the overall environmental impact of engines.

Carbon (IV) oxide (CO₂) emission CI engine

The formation of carbon dioxide (CO₂) is strongly influenced by the complete combustion that occurs when there is an excess of oxygen in the engine. According to Nagappan (2020), fuels are completely burned in the combustion chamber of the engine, resulting in the formation of CO₂. Figure 3 shows the frequency of CO₂ emissions for different blends and shows that blend C (2% ZnO) has the highest CO₂ emissions. All mixtures, including A (2% camphor), B (4% camphor), C

(2% ZnO), D (4% ZnO), E (2% Al₂O₃) and F (4% Al₂O₃), have CO₂ emissions greater than the control, which is due to the presence of oxygen in the mixtures. The excess oxygen in the mixtures facilitates complete combustion, while the low volatility of the mixtures provides sufficient scope for this, which is consistent with research by Bragadeshwaran et al. (2018) agrees.

The study by Chauhan et al. (2012) also found that the CO₂ emissions of pure diesel are lower compared to biodiesel blends, which is consistent with these results. The ZnO nanoparticle additive showed the greatest influence on CO₂ formation, followed by the camphor nanoparticle additive and finally the Al₂O₃ additive. Furthermore, both 2% and 4% additive concentrations result in a proportional increase in CO₂ emissions in the blends.

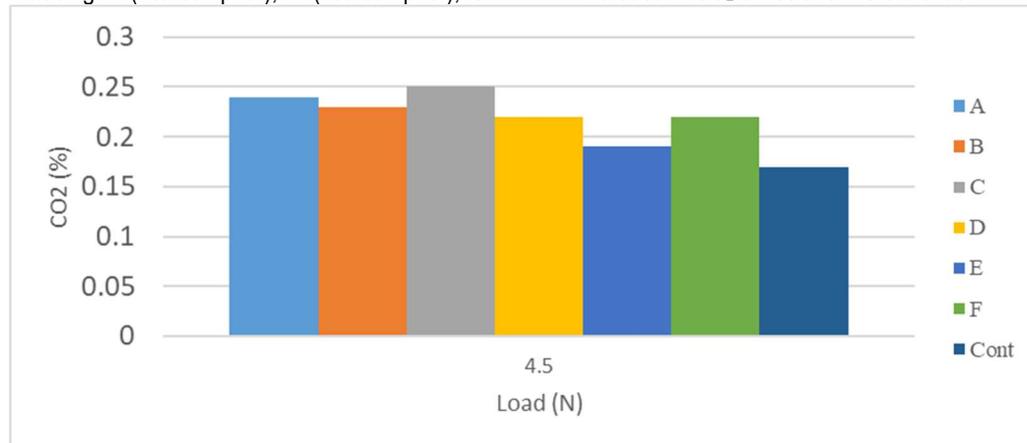


Figure 3: Variation of unburnt CO₂ of diesel and blends at constant load

Analysis of Variance for Carbon (IV) Oxide (CO₂)

Table 11 shows the CO₂ emissions of a CI engine running on diesel and various fuel blends, analyzed by one-way analysis of variance at a speed of 1500 rpm and 4.5 loads with seven fuel levels (A, B, C, D, E, F and cont.). Statistical analysis revealed no significant effects at the 0.05 significance level. The main analysis found that average NO_x emissions were not significantly different for both diesel and blended fuels. In addition, Table 15 shows the CO₂ emissions of a CI engine running at 1500 rpm and 4.5 N and fueled with cotton oil biofuel mixed with three

different nanoparticles (camphor, ZnO, Al₂O₃) and with two concentration levels (2% and 4%).

The results were subjected to a two-way analysis of variance, with nanoparticles grouped into columns and concentrations grouped into rows. All effects were not statistically significant at the 0.05 significance level. Row analysis yielded an F-ratio of $F(1,5) = 0.0357$ with a p-value greater than 0.05, indicating that the differences in mean CO₂ emission for the different nanoparticle additives were not significant. This means that any of the three nanoparticles can be used as an additive without having a significant impact on CO₂ emissions. Column analysis yielded an F ratio of

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$F(2,5) = 1.2857$ with a p -value greater than 0.05, indicating that the differences in mean CO_2 emission were not significant for the different nanoparticle concentrations. Therefore, this study

concludes that the mean CO_2 emission was not statistically significant for the different nanoparticle additives and concentrations.

Table 11: Analysis of variance for Carbon (IV) Oxide

Source of Variation	SS	df	MS	F	p-value	F crit
Rows	1.6700	1	1.6700	0.0357	0.8675	18.5128
Columns	0.0012	2	0.0006	1.2857	0.4375	19
Error	0.0009	2	0.0005			
Total	0.0022	5				

CONCLUSION

This research examined the potential of adding camphor, zinc oxide, and aluminum oxide nanoparticles to cottonseed oil biodiesel to improve efficiency and reduce gas emissions. The results showed that incorporating these nanoparticles into biodiesel fuel could provide promising results. The addition of nanoparticles led to significant improvements in efficiency and other engine performance parameters, especially at higher concentrations. The engine's fuel efficiency has increased, indicating improved fuel utilization. Thermal efficiency, a key indicator of how well the engine converts fuel energy into usable work, also increased.

The study additionally revealed a decrease in pollutant emissions, demonstrating positive environmental impacts. Nanoparticles significantly reduced harmful pollutants like nitrogen oxides (NO_x) and carbon monoxide (CO). This reduction in emissions contributes to cleaner, more environmentally friendly engine operation, leading to a lower environmental impact. In summary, this research highlights the effectiveness of camphor, zinc oxide, and aluminum oxide nanoparticles as beneficial additives for cottonseed oil biodiesel. The results suggest these nanoparticles can improve engine performance, reduce gas emissions, and promote the development of cleaner and more efficient biofuel options.

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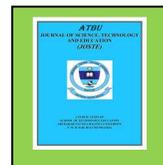
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