International Journal of Heat and Technology
Vol. 42, No. 6, December, 2024, pp. 1994-2000
Journal homepage: http://iieta.org/journals/ijht

Exploring Experimentally Al_2O_3 Nanoparticles Impact on a Four-Stroke Diesel Engine's Performance and Emissions

Safaa A. Ghadhban[1*], Hussein Al-Gburi[2], Isbeyeh W. Maid[3]

[1] Electrical Engineering Technical College, Middle Technical University, Baghdad 10022, Iraq
[2] Al-Mussaib Technical College, Al-Furat Al-Awsat Technical University, Babylon 51006, Iraq
[3] Technology Engineering College, Al-Turath University, Baghdad 10022, Iraq

Corresponding Author Email: safaaabid@mtu.edu.iq

https://doi.org/10.18280/ijht.420616

Received: 28 September 2024
Revised: 18 November 2024
Accepted: 26 November 2024
Available online: 31 December 2024

Keywords:
Nano-Al_2O_3, four-stroke, diesel engine

ABSTRACT

This work demonstrates the enhancement of the performance of engine and emission features by introducing nanoparticles into gasoline. Aluminum oxide (Al_2O_3) has been utilized as an additive to the fuel in a 4-stroke diesel engine with a single cylinder and compression ignition. Three different weight percentages of Al_2O_3 were evaluated (0.25% Al_2O_3-Di, 0.5% Al_2O_3-Di, and 0.75% Al_2O_3-Di.) compared with pure diesel fuel. The findings suggest that using nano-diesel and higher nanoparticles amount in diesel fuel contributed to enhancing engine performance. The engine brake thermal efficiency demonstrated a notable improvement, while the brake-specific fuel consumption (Bsfc) demonstrated a reduction of 3.4% compared with pure diesel fuel. Furthermore, the increase in (Al_2O_3) amount in diesel fuel causing a decrease in CO, HC, and NOx releases by 13%, 16.9%, and 28.8%, respectively, compared with pure diesel fuel. Yet carbon dioxide emissions rose by 21.4% compared with those using pure diesel fuel. Furthermore, the findings revealed that nonfuel with 0.75% nanoparticles performs better than pure diesel fuel.

1. INTRODUCTION

A compression ignition engine is one of the most influential power systems for both fixed and mobile uses. Through strategies including fuel optimization, engine design changes, and exhaust gas treatment, several researchers have attempted to enhance the engines' performance while lowering releases. The best course of action is to modify engine combustion since this usually only calls for small changes to already-existing engine systems, as opposed to introducing new designs or extra parts [1, 2].

The increasing petroleum price, rising related air contamination, and the impacts of global warming have indeed renewed global efforts to explore alternative fuels for engines. Nano-diesels have been a significant focus of this search, and various types have been tested over the years for their potential as viable substitutes for petroleum-based fuels. Nano-fuel additives are one of the many options that have been thought to help resolve energy and environmental challenges. Nano-oxide additives such as Al_2O_3, TiO_2, CeO_2, Co_3O_4, and Fe_2O_3 were used to decrease exhaust releases and fuel consumption [3-5].

Including nanoparticles enhances the engine's performance because they increase thermal efficiency and decrease the amount of specific fuel used. The enhanced surface-to-volume proportion from the nanoparticles decreases pollutant amount and increases the reaction rate. This faster reaction is likely due to a shorter delay than pure diesel. Nano-diesel reduces NOx releases through various methods, such as emulsification, gas recirculation, nano-particle addition, and oxygen enrichment [6, 7].

Additives containing nanoparticles lower the cloud point temp, enhance engine cold-start efficiency in cold climates, and raise the surface-area-to-volume proportion. Causing micro-explosions that speed up mass transfer promotes faster and more effective combustion. Heating flow, thermal loading, and the temp of the components in the combustion chamber are all reduced when diesel is mixed with a nano-additive. The nano-additive alters the fuel's chemical makeup, which enhances emission features. Furthermore, even at low mass fractions (10 ppm), the enhanced broadness of the nano-additive enhances the combustion process [8-10].

Without negatively impacting fuel efficiency or power output, Nano-Al_2O_3 may lengthen the fuel penetration length, enhance flame and combustion efficiency, and lower pollutants from internal combustion engines. These nanoparticles' chemical and thermal features both help accelerate the combustion cycle. Furthermore, solubilized nanoparticles distribute fuel droplets uniformly during the combustion chamber [11-14].

Naturally, combustion parameters may impact noise and vibration levels, which are important factors in engine performance. By strengthening the fuel's features or encouraging enhanced atomization, adding nanoparticles to fuel mixes may increase combustion efficiency. This may thus result in less noise and vibration from the engine and better engine functioning [15, 16].

The adding of Nano-Al_2O_3 to diesel fuel improves several performance metrics. Specifically, it enhances exhaust gas temperatures, increases thermal efficiency, and reduces specific fuel consumption. Furthermore, it decreases HC and CO releases, although it does result in a slight increase in NOx releases. Testing various dosages of Nano-Al_2O_3 in diesel-biodiesel blends reveals that an amount of 100 ppm significantly enhances performance comparison with diesel and biodiesel blends alone [17-29]. Bunyan and Hassan [20], along with Daud et al. [21], conducted studies aimed at improving engine emissions and performance using various types of additives in solid, liquid, and gaseous forms. Additives such as hydrogen, alcohol, and metal oxides have been shown to effectively enhance performance and reduce emissions. These studies also examined the effects of adding Nano-Al_2O_3 to diesel fuel on engine emissions and performance. Three concentrations of aluminum oxide (25 ppm, 50 ppm, and 100 ppm) were prepared. Adding Al_2O_3 to diesel fuel (Al_2O_3 + DF) improves the fuel's physical properties.

The inclusion of Al_2O_3 reduces CO emissions by 20.5%, decreases NOx emissions by 12.2%, increases CO_2 emissions by approximately 2.27%, and lowers UHC emissions by about 13.5%. Ghanbari [22] investigated the impact of Nano- Al_2O_3 in diesel fuel on the performance and emission characteristics of a six-cylinder, four-stroke diesel engine. The study demonstrated that using nanoparticles and increasing their concentration in diesel fuel reduced CO and HC emissions by 13.1% and 23.4%, respectively, while increasing NOx and CO_2 emissions by 33.3% and 29.5%, respectively, compared to pure diesel fuel.

E et al. [23] explored the impact of using 75 ppm Nano-Al_2O_3 in a B20 diesel-biodiesel mixture on engine performance and exhaust emissions. The study revealed improvements, including a 9.3% increase in brake thermal efficiency and a 13.6% increase in the heat release rate. Additionally, BSFC (Brake Specific Fuel Consumption) was reduced by 16.6%.

Ozgur et al. [24] studied the optimal concentration of Nano-Al_2O_3 in a Jojoba biodiesel-diesel (JB20D) fuel blend. The use of Al_2O_3 improved engine performance, with optimal emission characteristics observed at a concentration of 20 mg/L. At this level, significant reductions in emissions were achieved: CO was reduced by 80%, NOx by 70%, smoke opacity by 35%, and UHC by 60%.

El-Seesy et al. [25] empirically investigated the effects of adding Nano-Al_2O_3 on the ignition characteristics of diesel fuel. The findings demonstrated significant improvements in the radiative and heat transfer properties of diesel fuel. Additionally, the likelihood of ignition on a hot plate increased markedly.

Tyagi et al. [26] examined the emission characteristics and performance of a diesel engine operating with diesel fuel supplemented with iron and aluminum nanoparticles. The results showed a 4% increase in peak cylinder pressure and a 9% increase in brake thermal efficiency, while BSFC was reduced by 7%. Furthermore, CO and unburned hydrocarbon (UHC) emissions decreased by 8% and 40%, respectively.

Given the diverse applications of Nano-Al_2O_3 in diesel engines, this study aims to assess the impact of Nano-Al_2O_3 additives on diesel engine combustion performance and emission behaviors under constant load and variable speed conditions. Additionally, the study seeks to determine the extent to which different additive concentrations (0.25% Al_2O_3-Di, 0.5% Al_2O_3-Di, and 0.75% Al_2O_3-Di) can enhance efficiency and reduce the environmental impact of diesel engines.

2. METHODOLOGY

The tests in this investigation were conducted in several phases, as outlined below:

1. Operating the engine exclusively with pure diesel.
2. Operating the engine with various mix proportions of diesel fuel and Aluminum Oxide Nano-Al_2O_3, as described previously. Table 1 shows the thermal and physical characteristics of the nano-diesel blends: 0% Aluminum Oxide + 100% Diesel Fuel (Pure), 0.25% Aluminum Oxide + Diesel Fuel, 0.50% Aluminum Oxide + Diesel Fuel, and 0.75% Aluminum Oxide + Diesel Fuel.

All analyses were performed on a single-cylinder engine at speeds ranging from 1500 to 3500 RPM under a constant load.

2.1 Experimental setup

The experiments assessed the fuel's types impact on the performance and release of 4-stroke diesel engines at variable speeds and constant loads. All tests were conducted at the I.C.E. Laboratory of the Power Mechanics Engineering Faculty at Technical College Al-Mussaib (TCM), Al-Furat Al-Awsat Technical University (ATU), Kufa, Iraq. The experimental setup involved a single-cylinder, air-cooled diesel engine (model TD111), as demonstrated in Figure 1. This direct-injection diesel engine features a piston combustion chamber bowl. Table 2 demonstrates the key features of the engine utilized in this research. The tests have been conducted with four different fuels at a constant engine load.

2.2 Testing procedure

1. Begin by draining and flushing the fuel system before filling it with the desired fuel blend. Ensure any air bubbles in the system are removed.
2. Confirm that no residual fuel remains in the engine tank, as leftover fuel may influence the accuracy of the readings.

Table 1. Thermal physical characteristics of nano-diesel

Sample	Density (kg/m^3)	Dynamic Viscosity $*10^{-3}$ (kg/m.s)	Flashpoint & Firepoint OC	Calorific Magnitude kCal/kg	Cetane Number
Diesel pure	844.3	2.788	65-70	10941.08	51.8
D+0.25% Al_2O_3	846.8	2.878	72-76	10945.23	53.1
D+0.50% Al_2O_3	847.8	2.906	75-78	10948.33	54.1
D+0.75% Al_2O_3	850.3	2.966	77-79	10951.41	54.7

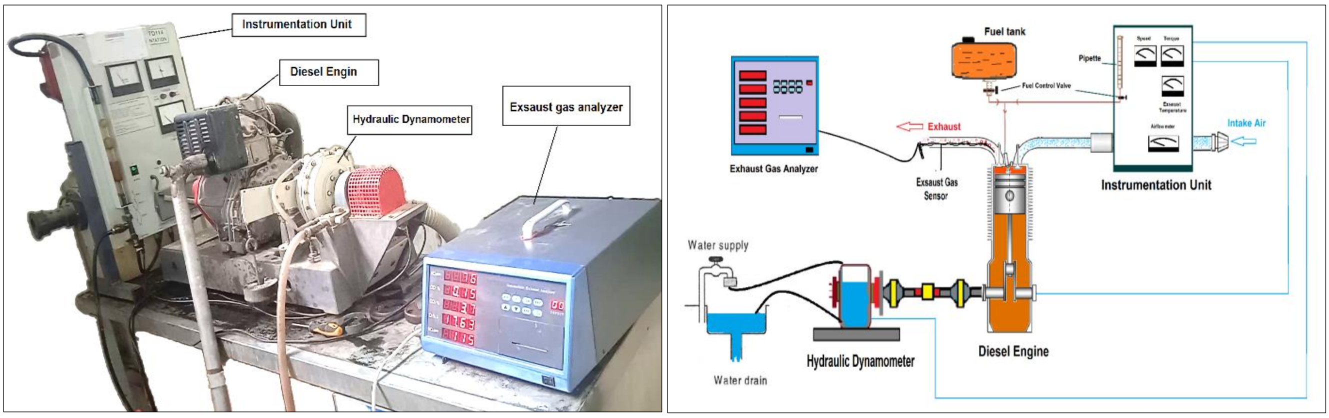

Figure 1. Diagram illustrating the experimental setup

Table 2. Engine specifications

Engine Parameters	Specification
Model	TD111
Manufacturer	TQ Education and Training Limited
General	Air-cooled, Variable speed, Compression ignition, four-stroke, and Single-cylinder
Fuel	Diesel
Bore	70 mm
Stroke	65 mm
Swept volume	250 cm^3
Maximum speed	4000 rpm
Weight	45 kg

3. Start the engine using pure diesel fuel and run it at five engine speeds (1500, 2000, 2500, 3000, and 3500 RPM) with a fixed engine torque of 5 N·m. At each speed, allow the engine to run for 3-5 minutes to achieve a stable operating condition.
4. Once a steady operating condition is reached, measure the fuel consumption rate by recording the time it takes the engine to consume 8 ml of fuel. Simultaneously, record exhaust emission data (HC, CO, CO_2, and NOx) using an exhaust gas analyzer, ensuring that stable values are maintained.
5. Repeat steps 1-4 under the same operating conditions for each of the following fuel blends:
•0.25% Al_2O_3-Diesel Fuel
•0.50% Al_2O_3-Diesel Fuel
•0.75% Al_2O_3-Diesel Fuel

2.3 Exhaust gas analyzer

This device is an essential tool for understanding and the emissions of an engine. The exhaust gas analyzer model HPC501 used to measure the concentration of various gases present in vehicle exhaust, including hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NOx). This achieved by placing an exhaust gas sensor in the exhaust pipe, which allows for accurate and real-time measurements, by analyzing these gas concentrations.

2.4 Environmental factors

Environmental factors such as temperature and humidity affect combustion efficiency and emissions, while engine wear over time, which causes worn engine parts such as valves and piston rings, reduces performance and increases CO_2 emissions. The experimental errors, poor calibration of inaccurate sensors can also, increase CO_2 and other emissions. The increase CO_2 emissions contribute to global warming, and the need for better maintenance, cleaner fuels, and advanced technologies to reduce the impact.

2.5 Preparation of neat diesel with nanoparticle Al_2O_3

In this study, the addition of Nano-Al_2O_3 with variations of 0.25%, 0.50%, and 0.75% with diesel fuel. As illustrated in Figure 2, the fuel and nanoparticles were blended with a magnetic stirrer for 30 minutes at a temperature ranging from 80°C-90°C. The fuel samples are used directly in the engine once the temperature has returned to room temperature. The specifications for the Nano-Al_2O_3 are detailed in Table 3.

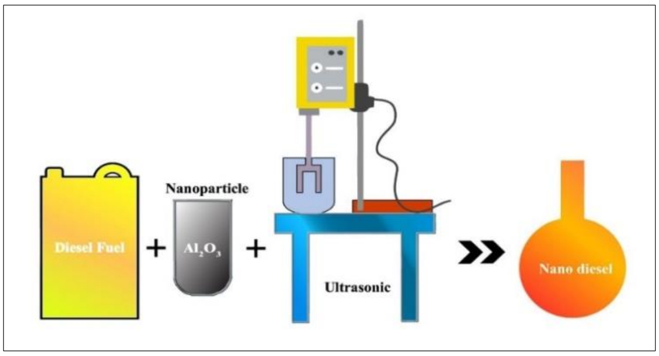

Figure 2. Diagram representing the experimental setup

Table 3. Properties of nanoparticles

Item	Specifications
Chemical name	Nano Aluminum Oxide, (Al_2O_3-Gamma) 99.9%, USA
Density	3.9 g/cm^3
Average particle size	20nm
Appearance	White Powder
Melting point	2045°C
Boling point	2980°C
BET surface area (SSA)	>150 m^2/g

During the experiments, glass cylinders were utilized with pure diesel and nano-diesel in varying proportions, as demonstrated in Figure 3: a- pure diesel, b- contains the diesel-nano- diesel mixture at the proportion of (0.25% Al_2O_3+ Di), c- contains (0.50% Al_2O_3+ Di), and d- (0.75% Al_2O_3+ Di).

Figure 3. a) Pure diesel; b) 0.25% Al_2O_3+Di; c) 0.50% Al_2O_3+Di; d) 0.75% Al_2O_3+Di

2.6 The performance characteristics

Mixing ratio (ϕ) specified as the proportion of the size of nanoparticles to the total size of nanoparticles with the volume of fuel (*vf*) [27].

$$\phi = \frac{V_{np}}{V_{np} + V_f} \tag{1}$$

The power at the output shaft is referred to as the brake power, where τ=torque and N=speed engine rpm [27, 28].

$$Bp = \frac{2\pi N\tau}{60} \tag{2}$$

Braking-specific consumption of fuel (Bsfc) is the quotient obtained by dividing the mass flow rate ($\dot{m}_f$) of fuel by the brake pressurization (BP) [29].

$$Bsfc = \frac{\dot{mf}}{Bp} \tag{3}$$

Brake thermal efficiency (ηbth) is the proportion of the energy contained in braking power divided by the energy of the propelling fuel [29, 30].

$$\eta bth = \frac{BP}{\dot{mf} \times Q_{HV}} \tag{4}$$

3. RESULTS AND DISCUSSION

The objective of this work is to explore the influence of engine speed and fuel type as independent factors on emission and performance characteristics.

Figure 4 demonstrates the influence of diesel fuel nanoparticles on ηBth at different speeds with constant load. It can be detected that ηBth increased with the higher the nano amount in the diesel fuel. The highest thermal efficiency was recorded at an engine speed of 3500 rpm for (0.75% Al_2O_3 + Di) relative to pure diesel fuel.

Figure 5 illustrates the difference in (Bsfc) with engine speed and nano-diesel fuels under constant load conditions. With an increase in the nano amount of diesel fuel, the Bsfc of the engine reduces at all engine speeds. Incorporating Al_2O_3 into the diesel fuel results in a decrease in the Bsfc compared with pure diesel. The detected enhancement may be ascribed to the enhanced physical characteristics, namely the increased surface area-to-volume proportion of Nano-Al_2O_3 concerning diesel fuel [30, 31]. Significantly, the combination of (0.75% Al_2O_3+ Di) yields the lowest Bsfc (Broad-Specific Fuel Compression) among all fuel kinds. The maximal reduction in Bsfc is reported as 3.4% for (Al_2O_3 0.75%+Di) comparison with Pure diesel fuel.

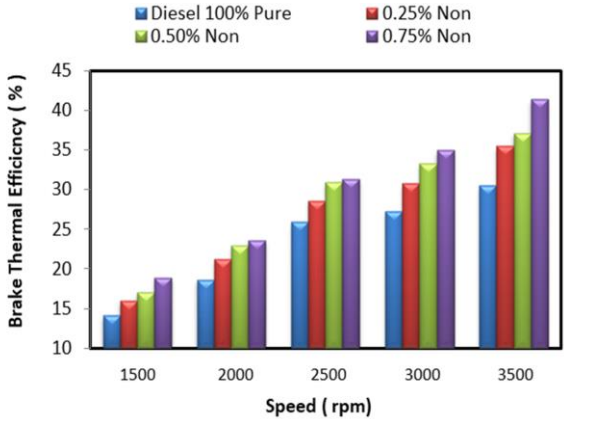

Figure 4. Relationship between ηBth at various engine speeds and nano-diesel fuel mixes

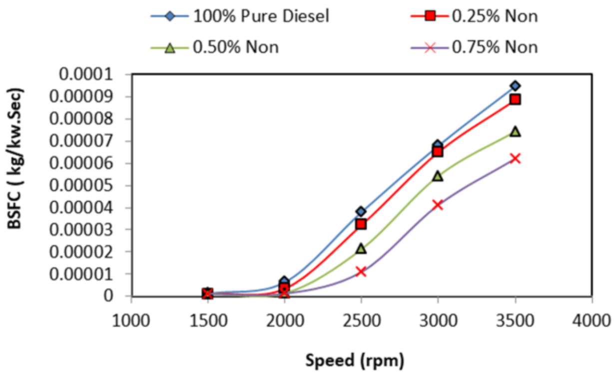

Figure 5. Relationship between Bsfc and different speeds

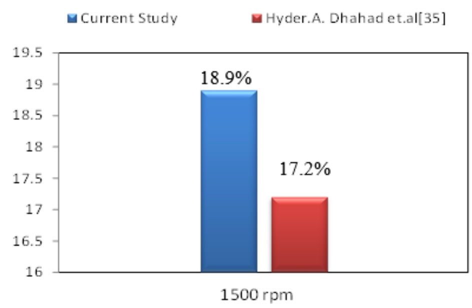

Figure 6. The comparison of brake thermal efficiency with the addition of Al_2O_3

Figure 6 presents a comparison of brake thermal efficiency observed in the current study with values reported in other literature [32], considering the addition of Al_2O_3 at an engine speed of 1500 rpm. The results indicate that the brake thermal efficiency obtained in this study is 8.99% higher compared to the previous research, as shown in Figure 6.

Figure 7 illustrates the correlation between the release of carbon monoxide (CO) at various amounts of Nano-Al_2O_3 in diesel fuel and the change in engine speed. Evidence indicates that the use of Nano-Al_2O_3 in diesel fuel leads to a reduction in CO releases. Compared with pure diesel fuel, the lowest reduction in CO releases is documented at 13% for (0.75% Al_2O_3+Di). This phenomenon is ascribed to the decrease in ignition delay and the improvement of combustion performance as the amount of (Al_2O_3) in the diesel fuel increases [33, 34].

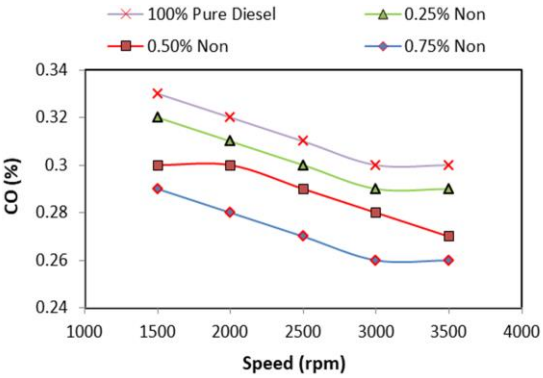

Figure 7. Relationship between Carbon monoxide (CO) and different speeds

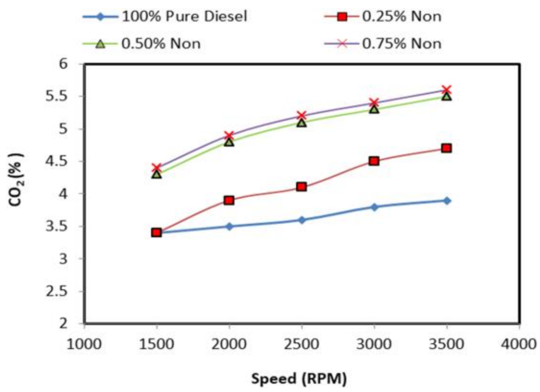

Figure 8. CO_2 at various engine speeds and nano-diesel fuel mixes

Figure 8 illustrates that CO_2 releases vary with engine speed and nano-diesel blends. CO_2 amount increases as the nanoparticle amount increases. It reveals that the addition of (0.75% Al_2O_3) demonstrates the highest increase of 30% in CO_2 values at ultimate speed comparison with pure diesel; the rise in CO_2 amount is attributed to the increased fuel oxygen resulting from higher Al_2O_3 amounts, which improves of combustion [35].

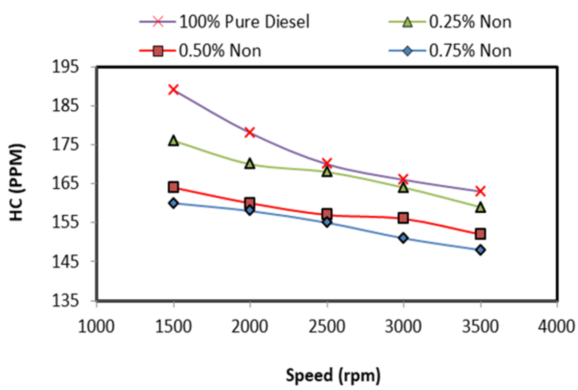

Figure 9. HC at various engine speeds and nano-diesel fuel mixes

Figure 9 demonstrates the relation between HC releases at various amounts of Nano-Al_2O_3 in diesel fuel with engine speed variation. The unburnt (HC) measurement reflects incomplete fuel combustion during the combustion stages. An inverse relationship exists between nanoparticle amount and HC amount. This phenomenon may be ascribed to the decrease in the carbon temperature of activation, which augments combustion as the amount of nanoparticles increases [36].

Figure 10 demonstrates the relation between NOx releases at various amounts of Al_2O_3 in diesel fuel and engine speed variation at constant load. It reveals that the addition of (0.25% Al_2O_3) demonstrates the highest reduction of 12.6% in NOx value at lower speed comparison with pure diesel, due to ignition delay reductions causing decreases in adiabatic flare temps, early combustion, and consequently NOx releases [37].

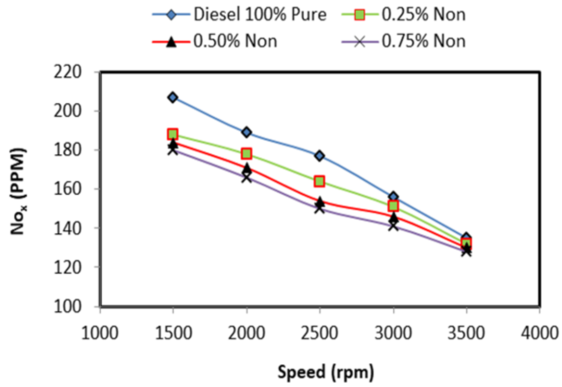

Figure 10. Relationship between Nitrogen oxide (NOx) and different speeds

4. CONCLUSIONS

The impacts of Al_2O_3 nanoparticles added to diesel fuel on engine releases and performance. The investigation detected better stability with the nano-diesel blend. The conclusions are as follows.

1. The brake thermal efficiency (ηBth) increases with higher proportions of Al_2O_3 -diesel fuel blends. The maximum efficiency was observed at a 0.75% Al_2O_3-diesel blend at an engine speed of 3500 rpm.

2. Adding Al_2O_3 illustrates the highest reduction of 3.4% in (Bsfc) detected at an engine speed of 3500 rpm and (0.75% Al_2O_3+Di) mix comparison with neat diesel.

3. Increasing the concentration of Al_2O_3 nano-particles (0.25% to 0.75% by weight) under a constant load and speeds varying effectively reduces HC, NOx, and CO emissions.

4. The CO_2 release rises with the increase in the proportion of nano-diesel blend fuel.

REFERENCES

[1] Abdel-Rehim, A.A., Akl, S.Y. (2016). An experimental investigation of the effect of aluminum oxide (Al_2O_3) nanoparticles as fuel additive on the performance and emissions of a diesel engine (No. 2016-01-0828). SAE Technical Paper. https://doi.org/10.4271/2016-01-0828

[2] Nouri, M., Isfahani, A.H.M., Shirneshan, A. (2021). Effects of Fe_2O_3 and Al_2O_3 nanoparticle-diesel fuel blends on the combustion, performance and emission characteristics of a diesel engine. Clean Technologies and Environmental Policy, 23(8): 2265-2284. https://doi.org/10.1007/s10098-021-02134-8

[3] Yousif, S.S., Al-Obaidi, M.A., Al-Muhsen, N.F. (2024). Towards more efficient refrigeration: A study on the use of TiO_2 and Al_2O_3 nanoparticles. International Journal of Heat and Technology, 42(4): 1251-1256. https://doi.org/10.18280/ijht.420415

[4] Chaitanya, N.S.C., Satyanarayana Murthy, Y.V.V., Satyanarayana, M.R.S. (2021). Experimental investigations on ci engine for performance, and emissions fuelled with stabilised binary diesel/jme blends doped with nano metallic oxide additive particles using dee, and non- ionic surfactants. International Journal of Engineering Trends and Technology, 69(8): 161-173. https://doi.org/10.14445/22315381/IJETT-V69I8P220

[5] Gad, M.S., Abdel Razek, S.M., Manu, P.V., Jayaraj, S. (2021). Experimental investigations on diesel engine using alumina nanoparticle fuel additive. Advances in Mechanical Engineering, 13(2): 1687814020988402. https://doi.org/10.1177/1687814020988402

[6] Ghadhban, S.A., Aun, S.H.A., Jehhef, K.A. (2020, July). Numerical modelling of fluid flow and heat transfer of (TiO_2-Water) nanofluids in wavy duct. IOP Conference Series: Materials Science and Engineering, 881(1): 012162. https://doi.org/10.1088/1757-899X/881/1/012162

[7] Kaushik, Y., Verma, V., Saxena, K.K., Prakash, C., Gupta, L.R., Dixit, S. (2022). Effect of Al_2O_3 nanoparticles on performance and emission characteristics of diesel engine fuelled with diesel–neem biodiesel blends. Sustainability, 14(13): 7913. https://doi.org/10.3390/su14137913

[8] Abduljleel, M.A., Yasin, N.J., Ghadhban, S.A., Soomro, S.A. (2024). Performance improving for the flat plate solar collectors by using nanofluids: Review study. Journal of Techniques, 6(1): 52-68. https://doi.org/10.51173/jt.v6i1.1891

[9] Angappamudaliar Palanisamy, S.K., Rajangam, S., Saminathan, J. (2024). Experimental investigation to identify the effect of nanoparticles based diesel fuel in VCR engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 46(1): 9709-9723. https://doi.org/10.1080/15567036.2020.1778142

[10] Firew, D., Nallamothu, R.B., Alemayehu, G., Gopal, R. (2022). Experimental investigation on the effect of three elemental nanoparticles on the performance characteristics of ethanol-diesel emulsion. Journal of Engineering, 2022(1): 5778990. https://doi.org/10.1155/2022/5778990

[11] Devarajan, Y., Munuswamy, D.B., Mahalingam, A. (2019). Investigation on behavior of diesel engine performance, emission, and combustion characteristics using nano-additive in neat biodiesel. Heat and Mass Transfer, 55: 1641-1650. https://doi.org/10.1007/s00231-018-02537-2

[12] He, S., Liu, H., Wang, Y. (2022). The effect of carbon emission trend on urban thermal environment from the perspective of transportation energy consumption. International Journal of Heat & Technology, 40(4): 1061-1068. https://doi.org/10.18280/ijht.400424

[13] Hameed, A.Z., Muralidharan, K. (2023). Performance, emission, and catalytic activity analysis of Al_2O_3 and CEO2 nano-additives on diesel engines using mahua biofuel for a sustainable environment. ACS Omega, 8(6): 5692-5701. https://doi.org/10.1021/acsomega.2c07193

[14] Yaşar, A., Keskin, A., Tosun, E., Yıldızhan, Ş. (2020). Catalytic effect of metal based nanoparticles on emission and vibration analysis of diesel engine. International Journal of Automotive Engineering and Technologies, 9(3): 113-121. https://doi.org/10.18245/ijaet.730092

[15] Abbas, A.S., Mohammed, A.A. (2023). Enhancement of plate-fin heat exchanger performance with aid of (RWP) vortex generator. International Journal of Heat & Technology, 41(3): 780-788. https://doi.org/10.18280/ijht.410336

[16] Abdillah, M., Amaliyah, N., Putra, A.E.E. (2023). Biodiesel performance improvement with the addition of Al_2O_3 nanoparticles on diesel engine. International Journal of Heat and Technology, 41(2): 423-430. https://doi.org/10.18280/ijht.410217

[17] Al-Kheraif, A.A., Syed, A., Elgorban, A.M., Divakar, D.D., Shanmuganathan, R., Brindhadevi, K. (2021). Experimental assessment of performance, combustion and emission characteristics of diesel engine fuelled by combined non-edible blends with nanoparticles. Fuel, 295: 12590. https://doi.org/10.1016/j.fuel.2021.120590

[18] Dhahad, H.A., Hamadi, A.S., Ali, S.A. (2017). Effect of aluminum oxide nanoparticles fuel additives on the performance and emissions of diesel engine. Engineering and Technology Journal, 35(9A): 956-960. https://doi.org/10.30684/etj.2017.139931

[19] Wei, J., Yin, Z., Wang, C., Lv, G., Zhuang, Y., Li, X., Wu, H. (2021). Impact of aluminium oxide nanoparticles as an additive in diesel-methanol blends on a modern DI diesel engine. Applied Thermal Engineering, 185: 116372. https://doi.org/10.1016/j.applthermaleng.2020.116372

[20] Bunyan, S.T., Hassan, A.A.K.M. (2020). Experimental investigation of the influence of adding alumina to diesel fuel on the engine performance and emission characteristics. Engineering and Technology Journal, 38(4A): 523-529. https://doi.org/10.30684/etj.v38i4A.498

[21] Daud, S., Hamidi, M.A., Mamat, R. (2022). A review of fuel additives' effects and predictions on internal combustion engine performance and emissions. AIMS Energy, 10(1): 1-22. https://doi.org/10.3934/energy.2022001

[22] Ghanbari, M. (2021). Experimental study on the effect of Al_2O_3 nanoparticles in diesel fuel on the performance and emission characteristics of a diesel engine. The Journal of Engine Research, 61: 35-45.

[23] E., J., Zhang, Z., Chen, J., Pham, M., et al. (2018). Performance and emission evaluation of a marine diesel engine fueled by water biodiesel-diesel emulsion blends with a fuel additive of a cerium oxide nanoparticle. Energy Conversion and Management, 169: 194-205. https://doi.org/10.1016/j.enconman.2018.05.073

[24] Ozgur, T., Tuccar, G., Uludamar, E., Yilmaz, A.C., et al. (2015). Effect of nanoparticle additives on NOx emissions of diesel fuelled compression ignition engine. International Journal of Global Warming, 7(4): 487-498. https://doi.org/10.1504/IJGW.2015.070051

[25] El-Seesy, A.I., Attia, A.M., El-Batsh, H.M. (2018). The effect of Aluminum oxide nanoparticles addition with Jojoba methyl ester-diesel fuel blend on a diesel engine performance, combustion and emission characteristics. Fuel, 224: 147-166. https://doi.org/10.1016/j.fuel.2018.03.076

[26] Tyagi, H., Phelan, P.E., Prasher, R., Peck, R., Lee, T., Pacheco, J.R., Arentzen, P. (2008). Increased hot-plate ignition probability for nanoparticle-laden diesel fuel. Nano Letters, 8(5): 1410-1416. https://doi.org/10.1021/nl080277d
[27] Muhammad, S.K., Eqqab Maree, I., Ibraheem, R.R. (2022). Influence of intake air temperature on the performance of gasoline engines using a different type of fuel. Al-Qadisiyah Journal for Engineering Sciences, 15(4): 229-237. https://doi.org/10.30772/qjes.v15i4.806
[28] Hanafi, H., Hasan, M.M., Rahman, M.M., Noor, M.M., Kadirgama, K., Ramasamy, D. (2016). Numerical modeling on homogeneous charge compression ignition combustion engine fueled by diesel-ethanol blends. MATEC Web of Conferences, 74: 00037. https://doi.org/10.1051/matecconf/20167400037
[29] Al-Gburi, H., Kareem, D.F., Hawas, M.N. (2022). Investigate the impact of biodiesel fuel blends on the characteristics of engine and releases of single-cylinder, four strokes. Frontiers in Heat and Mass Transfer (FHMT), 18(1): 1-6. https://doi.org/10.5098/hmt.18.28
[30] Aun, S.H.A., Abdullah, M.L., Al-Zuhairy, R.C. (2020). The influence of ambient conditions on compression ignition engine performance: Experimental study. Journal of Mechanical Engineering Research and Developments, 43(7): 317-325.
[31] Krupakaran, R.L., Hariprasasd, T., Gopalakrishna, A., Babu, P. (2016). The performance and exhaust emissions investigation of a diesel engine using γ-Al_2O_3 nanoparticle additives to biodiesel. Carbon Management, 7(3-4): 233-241. https://doi.org/10.1080/17583004.2016.1218713
[32] Dhahad, H.A., Ali, S.A., Chaichan, M.T. (2020). Combustion analysis and performance characteristics of compression ignition engines with diesel fuel supplemented with Nano-TiO_2 and Nano-Al_2O_3. Case Studies in Thermal Engineering, 20: 100651. https://doi.org/10.1016/j.csite.2020.100651
[33] Selvan, V.A.M., Anand, R.B., Udayakumar, M. (2009). Effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ethanol blends on the performance and emission characteristics of a CI engine. ARPN Journal of Engineering and Applied Sciences, 4(7): 1-6.
[34] Raj, N.M., Gajendiran, M., Pitchandi, K., Nallusamy, N. (2016). Investigation on aluminum oxide nano particles blended diesel fuel combustion, performance and emission characteristics of a diesel engine. Journal of Chemical and Pharmaceutical Research, 8(3): 246-257.
[35] Sajith, V., Sobhan, C.B., Peterson, G.P. (2010). Experimental investigations on the effects of cerium oxide nanoparticle fuel additives on biodiesel. Advances in Mechanical Engineering, 2: 581407. https://doi.org/10.1155/2010/581407
[36] Heydari-Maleney, K., Taghizadeh-Alisaraei, A., Ghobadian, B., Abbaszadeh-Mayvan, A. (2017). Analyzing and evaluation of carbon nanotubes additives to diesohol-B2 fuels on performance and emission of diesel engines. Fuel, 196: 110-123. https://doi.org/10.1016/j.fuel.2017.01.091
[37] Nematizade, P., Ghobadian, B., Najafi, G. (2012). Investigation of fossil fuels and liquid biofuels blend properties using artificial neural network. International Journal of Automotive and Mechanical Engineering, 5: 639-647. https://doi.org/10.15282/ijame.5.2012.10.0051

NOMENCLATURE

ηBth	Brake thermal efficiency, %
BP	Brake power, Kw
QHv	Higher heat value, kj/kg
$\dot{m}f$	Mass fuel rate, Kg/sec
Bsfc	Brake specific fuel consumption, kg/kw.sec
CO	Carbon monoxide, %
CO_2	Carbon dioxide, %
HC	Hydrocarbon, ppm
NOx	Nitrogen oxides, ppm
Di	Diesel fuel
Al_2O_3	Aluminum oxide
CO_3O_4	Cobalt oxide
FeO_3	Iron oxide
TiO_2	Titanium dioxide
CeO_3	Cerium oxide