

RESEARCH ARTICLE

OPEN ACCESS

EXPERIMENTAL EVALUATION OF DIESEL ENGINE PERFORMANCE, COMBUSTION AND EMISSIONS OPERATED ON ABD BLENDED WITH Al_2O_3

Jayaprakash Parala¹, D. Anjan Kumar Reddy², Mangalapally Srikanth³, G Harinath Gowd⁴,
U. Sreekanth⁵, and Harinadh Vemanaboina^{*6}

¹Sree Venkateswara College Of Engineering, Nellore, India.

²Sri Venkateswara College of Engineering, Tirupathi, India.

³Sreyas Institute of Engineering and Technology, Hyderabad, India.

^{4,5,6} VEMU Institute of Technology, Chittoor, India.

¹<https://orcid.org/0000-0003-2996-4228>, ²<https://orcid.org/0000-0002-1226-4674>, ³<https://orcid.org/0009-0002-5916-8302>,

⁴<https://orcid.org/0000-0002-7531-8625>, ⁵<https://orcid.org/0009-0004-5941-9575>, ⁶<https://orcid.org/0000-0001-9745-5463>

Email: sietkjayaprakash@gmail.com, anjankumarreddy.d1@svcolleges.edu.in, m.srikanth9977@gmail.com, gowdmits@gmail.com, sreekanthphd51@gmail.com, *harinadh.vh@gmail.com

ARTICLE INFO

Article History

Received: September 5, 2025

Reviewed: January 5, 2026

Accepted: April 5, 2026

Published: May 29, 2026

Keywords:

Acacia biodiesel,
 Al_2O_3 nanoparticles,
Compression-ignition engine,
Combustion characteristics,
Exhaust emissions (NO_x, CO,
HC, smoke).

ABSTRACT

This study evaluates a single-cylinder CI engine fuelled with Acacia biodiesel (ABD) and ABD doped with Al_2O_3 nanoparticles (100 and 200 ppm), benchmarked against petro-diesel. ABD satisfied ASTM D6751 with viscosity 4.14 cSt, density 0.88 g/mL, flash point 80 °C, gross calorific value 35,707 kcal/kg, and cetane index 44.59 (diesel 48.48). Tests used a TV1 four-stroke engine (bore 87 mm, stroke 110 mm, compression ratio 17.5:1) at 1500 rpm. Relative to neat ABD, nano-additives significantly improved combustion stability and decreased CO, HC and smoke at all loads; notably, NO_x also declined with optimized injection timing. The 200-ppm dose delivered consistent gains. Overall, low-ppm Al_2O_3 leveraged ABD's higher flash point and density to promote faster oxidation, lower tailpipe emissions, and diesel-comparable ignition quality, indicating ABD+ Al_2O_3 as a practical drop-in for cleaner CI operation.



Copyright ©2026 by authors and Galileo Institute of Technology and Education of the Amazon (ITEGAM). This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

I. INTRODUCTION

Due to the rapid population growth and the swift depletion of fossil fuels, the demand for clean energy is steadily rising. Bio-mass-based fuels are highly preferred as alternative fuels due to their sustainability, affordable production, and low carbon emissions. Commonly used vegetable oils like palm oil, soybean oil, and Jatropha oil have been employed in the production of biodiesel. Diesel engines are extensively utilised in the vehicle, manufacturing, and power production segments owing to their superior energy efficiency and durability [1], [2]. The drawbacks of diesel engines lie in their detrimental impact on the natural environment through the emission of toxic pollutants such as nitrogen oxides [3], unburned hydrocarbons [4], carbon monoxide [5], and smoke [6]. Numerous research articles have documented an increase in NO_x emissions when using biodiesel blends with diesel [7].

Various researchers have made numerous attempts to minimise NO_x emissions, such as employing homogenous blend preparation by port fuel injection and after-treatment methods [8]. However, researchers have demonstrated that they can reduce NO_x emissions without altering the engine architecture by introducing nanoparticles as an additive and modifying the fuel [7], [9]. The nanoparticle facilitates increased surface area contact between the air-fuel combination, hence enhancing heat transfer and leading to a reduction in ignition delay and an increase in latent heat of evaporation [10]. The incorporation of magnesium (Al-Mg) nanoparticles into jatropha biodiesel has been demonstrated to significantly reduce exhaust emissions while simultaneously improving engine performance metrics [6].

By [11] did a study that showed the enhancement of engine performance and reduction of pollutants by accumulating silver oxide nanoparticles in Neem biodiesel. This is due to the rapid evaporation of air-fuel combinations, which suggests a shorter delay period. In turn, [12] find that the addition of ethanol and cerium oxide nanoparticles, biodiesel, and diesel mixtures hints at a decline in the amount at which heat is released and a little reduction in the time it takes for ignition to happen. According to [13] examined the impact of including Al_2O_3 Nano additives in jojoba methyl ester on emission properties. In their 2017 study [14] demonstrated that the use of Nano additives in biodiesel can enrich engine performance and decrease emissions. The increased surface contact space among air-fuel mixes is the reason for this. Research findings indicate that the addition of nanoparticles to methyl ester accelerates combustion. The experimental effort's originality lies in the use of Al_2O_3 nanoparticles, combined with ABD in varying amounts, to effectively decrease NO_x and smoke emissions [15], [16]. This study presents a groundbreaking approach to enhancing diesel engine performance by introducing a novel fuel blend that integrates aluminium oxide (Al_2O_3) nanoparticles into acacia-derived biodiesel.

By incorporating these nanoparticles, the research aims to improve the combustion efficiency, emission characteristics, and overall fuel properties of biodiesel, thereby offering a more sustainable and efficient alternative to conventional diesel fuel. This innovative method not only explores the synergistic benefits of nanotechnology and biofuels but also contributes to the development of cleaner and more advanced energy solutions for modern diesel engines. The integration of aluminium oxide nanoparticles into acacia biodiesel creates a unique fuel blend that significantly enhances the overall performance of diesel engines. This innovative combination leads to more efficient combustion by promoting better atomization and faster oxidation of the fuel, resulting in a more complete burn. As a result, harmful emissions such as carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter are substantially reduced. Additionally, the improved combustion process contributes to enhanced engine power output and smoother operation. This advancement represents a major step forward in the pursuit of cleaner, more efficient, and sustainable transportation technologies, offering a promising alternative to conventional fossil fuels.

II. EXPERIMENTATION

II.1 PRODUCTION PROCESS

Acacia biodiesel (ABD) is produced by the method of transesterification. The following displays the FAME properties of derived biodiesel. The ultrasonic device was used to combine Al_2O_3 nanoparticles with fuel and acacia methyl ester. The addition of 0.050 g of the Nano additive to one litre of methyl ester, diesel, is equivalent to a concentration of 50 parts per million (ppm), or 0.050 g/l. Next, the combination is vigorously agitated and then kept inside an ultrasonic vibrator operating at a frequency of 20 kilohertz for a duration of 30 minutes. This process guarantees an even distribution of dispersion [6]. Similarly, we created blends with concentrations of 200 ppm and 100 ppm [9]. Table 2 displays the characteristics of experimental energies.

Table 1: Oil Contents in the FFA.

Fatty Acids	ABD (% by weight)
C18:3 (Linolenic)	15.50
C18:2 (Linoleic)	41.60
C18:1 (Oleic)	20.98
C18:0 (Stearic)	07.29
C16:0 (Palmitic)	12.79

Source: Authors, (2026).

Table: 2. Comparison of properties with ASTM Standards.

Properties	DIESEL	ABD	ASTM (D6751 – 08)
Cetane Index	48.48	44.59	47
Flashpoint (°C)	60	80	50-90
Gross Calorific Value (Kcals/Kg)	45188	35707	35564-36401
Kinematic Viscosity @ 40°C (cst)	2.59	4.14	1.90 - 6.10
Density@30°C (gm/ml)	0.85	0.88	0.860 - 0.890

Source: Authors, (2026).

II.2 INVESTIGATIONAL ARRANGEMENT

The present research is being carried out on a CI engine with a single cylinder and a four-stroke cycle. The AVL DI gas444 and AVL 437 devices were utilised to quantify the levels of smoke opacity, CO, HC, and NO_x . The fuel qualities were obtained using the ASTM testing process. The trial was conducted by preliminary testing the engine with diesel fuel to establish uniform or proper readings (warm-up state) and then testing with diesel, ABDAl_2O_3 100, and ABDAl_2O_3 200. We experiment with a constant speed. Table 4 provides the engine specifications and accuracy level of the exhaust gas analyzer.

Table 3: Investigation Device Specifications

Constraint	Specifications for the Engine
Engine	TV1 Make, Four-stroke diesel engine, single cylinder, maximum power 5.2kW at maximum speed 1500 rpm, cooled by water, L is 110 mm, r is 17.5, d is 87 mm.
Temperature Sensor	Thermocouple
Rotameter	Calorimeter Range: 25-250 litres per hour, Engine Cooling: 40-400 litres per hour
Dynamometer	Water Cooled, and Eddy's current
Piezoelectric Sensor	Range:5000 PSI
Data acquisition gadget	16-bit, NI USB - 6210, 250 kilobytes per second
Crack angle Sensor	Speed 5500 rpm, Resolution 1 Deg.

Source: Source: Authors, (2026).

Table 4: Accuracy of the Gas Analyser.

Pollutant	Measuring Range	Resolution	Accurateness
NO _x	0-5000 ppm vol	1 ppm vol	+/- 5 ppm 1% rel
CO	0-14 % Vol	0.011% Vol	0-11%+/-0.19% abs +/-3% rel 10.01 %-15% +/-5% rel
Smoke Meter	0 - 100%	0.1%	+/- 1% of full scale
HC	0 - 30000 ppm vol	≤ 2000:1 ppm vol > 2000:10 ppm vol	0-4000 ppm +/-8 ppm 3% rel 4001-10000 ppm 5% rel 10001-30000 ppm 10% rel

Source: Authors, (2026).

III. RESULTS AND DISCUSSIONS

III.1 HC EMISSION

During the combustion and compression procedure in an engine, a sudden rise in pressure takes place, causing the air-fuel mixes in the combustion chamber to be pushed into the corner portions [17]. These gases are not part of the initial combustion process. Throughout the expansion and exhaust procedure, these gases escape from the fissures, which is consequential in the presence of unburned hydrocarbons. Inadequate atomization of fuel droplets can result in decreased cylinder wall temperature, which in turn is a clue to incomplete combustion and the presence of unburned hydrocarbons. Figure 1 depicts the fluctuation in HC emissions for ABD, ABDAl₂O₃100, and ABDAl₂O₃200. ABD exhibits lower hydrocarbon (HC) emissions in comparison to diesel because of its greater oxygen content, which facilitates more efficient combustion. ABDAl₂O₃100, and ABDAl₂O₃200 exhibit lesser HC emissions compared to ABD due to their increased surface area, which promotes chemical reactivity with air-fuel combinations [18], [19].

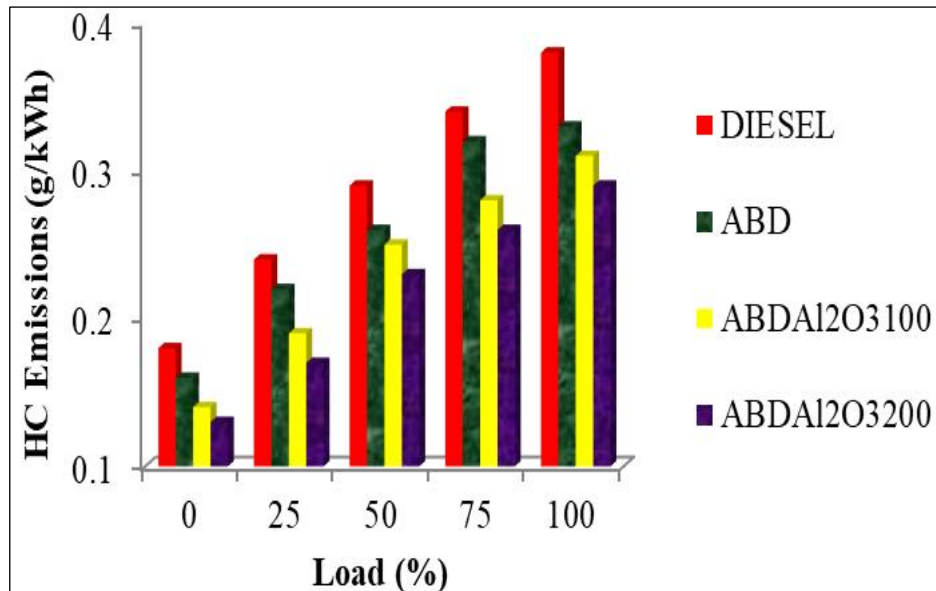


Figure 1: Load vs. Hydrocarbon Emissions.

Source: Authors, (2026).

III.2 CO EMISSION

Insufficient oxygen leads to the formation of carbon monoxide emissions when there are rich air-fuel combinations. Carbon monoxide emissions can arise due to insufficient mingling, insufficient oxygen for burning air-fuel combinations, and limited combustion [20]. Figure 2 shows the carbon monoxide discharge fluctuations for ABD, ABDAl₂O₃100, and ABDAl₂O₃200. ABD exhibits lower CO emissions in comparison to diesel, mostly owing to its greater oxygen content. ABDAl₂O₃100, and ABDAl₂O₃200 exhibit lower CO emissions compared to ABD across all loads. The presence of nano additives in biodiesel boosts its catalytic activity, leading to further effective combustion and reduced emissions of CO [1], [18].

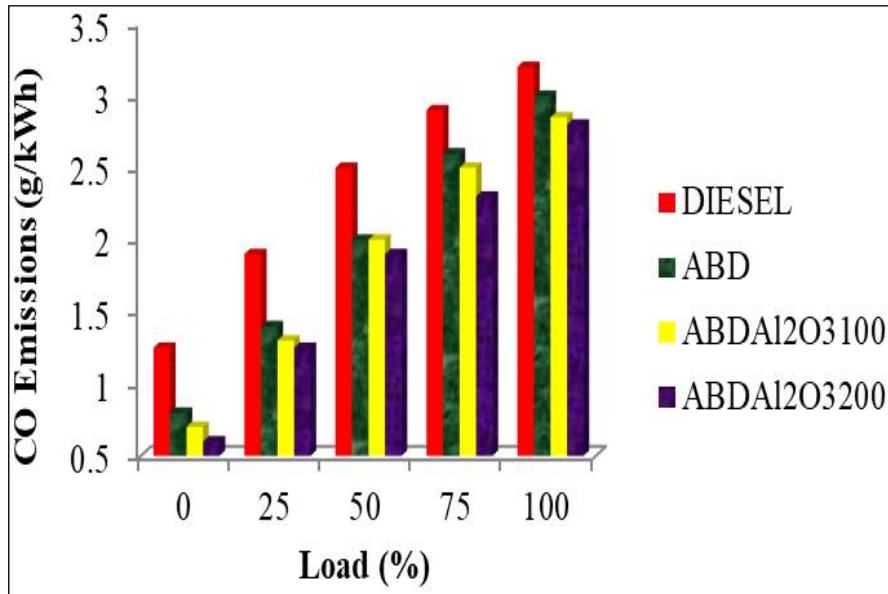


Figure 2: Load vs. Carbon Monoxide Emissions.
Source: Authors, (2026).

III 3 NOX EMISSIONS

The fuel supply and the timing of the blending process influence the exhaust emissions in a CI engine [21]. The injection of gasoline immediately before the combustion procedure causes uneven fuel circulation, resulting in a heterogeneous blend. This leads to a swift escalation of the temperature of the combusted gas within the cylinder, resulting in the discharge of NO_x [10]. Figure 3 depicts the fluctuations in NO_x emissions for ABD, ABDAl₂O₃100, and ABDAl₂O₃200. The greater NO_x emission in ABD compared to diesel is caused by the higher oxygen concentration and resting temperature during combustion [20]. The combination of nanoparticles like ABDAl₂O₃100, and ABDAl₂O₃200 with biodiesel results in lower NO_x emissions when compared with ABD under all load conditions. The inclusion of Al₂O₃ reduces the period it takes for ignition to happen and enhances the efficiency of the catalytic reaction between the air-fuel mixes, leading to a significant decrease in NO_x emissions [22].

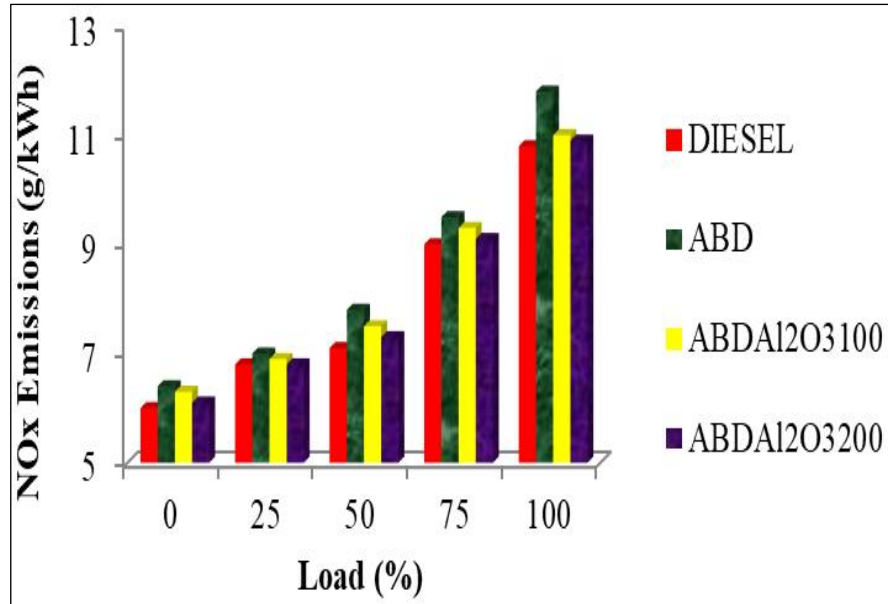


Figure 3: Load Vs Oxides of Nitrogen Emissions.
Source: Authors, (2026).

III.4 SMOKE

The below figure depicts the changes in smoke when operated with ABD, ABDAl₂O₃100, and ABDAl₂O₃200. The creation of smoke emissions is caused by fuel pyrolysis, which leads to the tendency for a rich fuel mix to accumulate in high-temperature regions [23]. ABDAl₂O₃100, and ABDAl₂O₃200 exhibit lower levels of smoke emissions in comparison to ABD and diesel. The presence of nanoparticles in the energy mixture enhances turbulence, leading to increased mixing of the air-fuel combination during combustion. This results in reduced emissions at all loads, as documented in reference [21], [24].

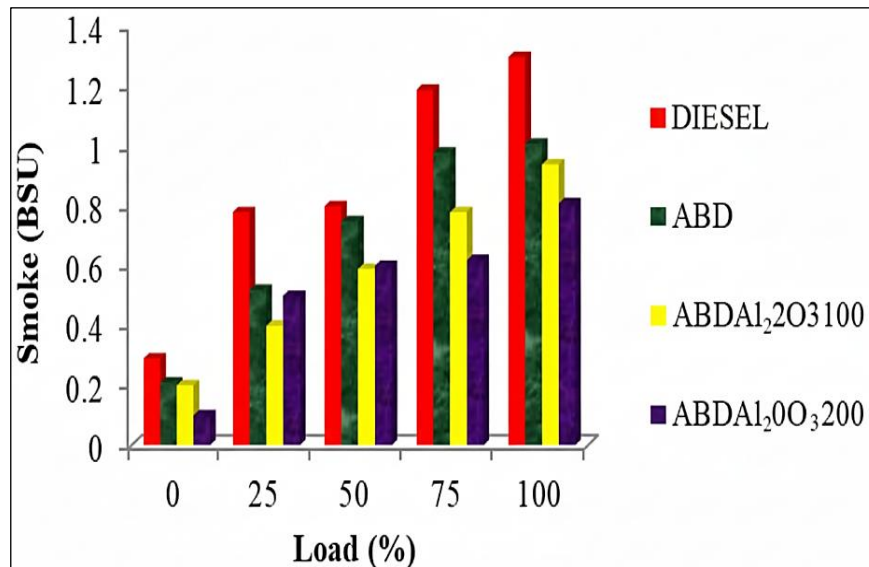


Figure 4: Load vs. Smoke.
Source: Authors, (2026).

IV. CONCLUSIONS

This study focuses on a CI engine that runs on diesel, ABD, ABDAl₂O₃100, and ABDAl₂O₃200 fuel. This examination uses a four-stroke, single-cylinder engine design. An investigation was conducted to examine the emission properties of Al₂O₃ nanoparticles when combined with base fuels (diesel and ABD). This study investigated the environmental impacts of petroleum diesel and non-petroleum fuels by examining their respective footprints.

- The presence of nanoparticles (ABDAl₂O₃100 and ABDAl₂O₃200) in biodiesel results in decreased emissions of smoke, CO, and HC at all levels of engine load in comparison to regular diesel fuel.
- The NO_x was higher for ABD, ABDAl₂O₃100, and ABDAl₂O₃200 compared to diesel.
- The presence of Al₂O₃ in ABD results in a decline in smoke, HC, and CO emissions under all operating circumstances. This is owed to the catalytic impact and increased surface space contact with the gas mixes.
- The presence of ABDAl₂O₃100, and ABDAl₂O₃200 in nanofluids leads to a decline in NO_x emissions equated to ABD. This is owed to the smaller ignition delay and the ability of aquatic molecules to absorb heat.
- No measures were implemented to extract the nanoparticle from the exhaust system following combustion. However, future research will investigate the removal of nanoparticles from the tailpipe after combustion.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Jayaprakash Parala, G.Harinath Gowd.

Methodology: Anjan Kumar Reddy.

Investigation: Jayaprakash Parala and Mangalapally Srikanth.

Discussion of results: Jayaprakash Parala, and U. Sreekanth.

Writing – Original Draft: Harinadh Vemanaboina.

Writing – Review and Editing: U. Sreekanth and Harinadh Vemanaboina.

Resources: Jayaprakash Parala and Mangalapally Srikanth.

Supervision: G.Harinath Gowd and Harinadh Vemanaboina.

Approval of the final text: Jayaprakash Parala, G.Harinath Gowd and Harinadh Vemanaboina.

VI. REFERENCES

- [1] A. Arul Gnana Dhas, Y. Devarajan, and B. Nagappan, "Analysis of emission reduction in ethyne–biodiesel-aspirated diesel engine," *International Journal of Green Energy*, vol. 15, no. 7, pp. 436–440, May 2018, doi: 10.1080/15435075.2018.1473774.
- [2] K. N. Balan, U. Yashvanth, P. B. Devi, T. Arvind, H. Nelson, and Y. Devarajan, "Investigation on emission characteristics of alcohol biodiesel blended diesel engine," *Energy Sources Part a Recovery Utilization and Environmental Effects*, vol. 41, no. 15, pp. 1879–1889, Nov. 2018, doi: 10.1080/15567036.2018.1549166.
- [3] N. Joy, Y. Devarajan, B. Nagappan, and A. Anderson, "Exhaust emission study on neat biodiesel and alcohol blends fueled diesel engine," *Energy Sources Part a Recovery Utilization and Environmental Effects*, vol. 40, no. 1, pp. 115–119, Nov. 2017, doi: 10.1080/15567036.2017.1405119.
- [4] N. Joy, D. Yuvarajan, and N. Beemkumar, "Performance evaluation and emission characteristics of biodiesel-ignition enhancer blends propelled in a research diesel engine," *International Journal of Green Energy*, vol. 16, no. 4, pp. 277–283, Jan. 2019, doi: 10.1080/15435075.2018.1561455.
- [5] A. K. Pandian, D. B. Munuswamy, S. Radhakrishana, R. B. B. Ramakrishnan, B. Nagappan, and Y. Devarajan, "Influence of an oxygenated additive on emission of an engine fueled with neat biodiesel," *Petroleum Science*, vol. 14, no. 4, pp. 791–797, Sep. 2017, doi: 10.1007/s12182-017-0186-x.
- [6] A. Mahalingam, D. B. Munuswamy, Y. Devarajan, and S. Radhakrishnan, "Emission and performance analysis on the effect of exhaust gas recirculation in alcohol-biodiesel aspirated research diesel engine," *Environmental Science and Pollution Research*, vol. 25, no.13, pp. 12641–12647, Feb. 2018, doi: 10.1007/s11356-018-1522-4.

- [7] Y. Devarajan, "Experimental evaluation of combustion, emission and performance of research diesel engine fuelled di-methyl- carbonate and biodiesel blends," Atmospheric Pollution Research, vol. 10, no. 3, pp. 795–801, Dec. 2018, doi: 10.1016/j.apr.2018.12.007.
- [8] S. Vellaiyan, A. Subbiah, and P. Chockalingam, "Multi-response optimization to obtain better performance and emission level in a diesel engine fueled with water-biodiesel emulsion fuel and nanoadditive," Environmental Science and Pollution Research, vol. 26, no. 5, pp. 4833–4841, Dec. 2018, doi: 10.1007/s11356-018-3979-6.
- [9] Y. Devarajan, D. B. Munuswamy, and A. Mahalingam, "Influence of nano-additive on performance and emission characteristics of a diesel engine running on neat neem oil biodiesel," Environmental Science and Pollution Research, vol. 25, no. 26, pp. 26167–26172, Jul. 2018, doi: 10.1007/s11356-018-2618-6.
- [10] I. V. Kanna, A. Devaraj, and K. Subramani, "Bio diesel production by using Jatropha: the fuel for future," International Journal of Ambient Energy, vol. 41, no. 3, pp. 289–295, Apr. 2018, doi: 10.1080/01430750.2018.1456962.
- [11] D. Yuvarajan, M. D. Babu, N. BeemKumar, and P. A. Kishore, "Experimental investigation on the influence of titanium dioxide nanofluid on emission pattern of biodiesel in a diesel engine," Atmospheric Pollution Research, vol. 9, no. 1, pp. 47–52, Jun. 2017, doi: 10.1016/j.apr.2017.06.003.
- [12] V. Arul, M. Selvan, R. B. Anand, and M. Udayakumar, "Effects Of Cerium Oxide Nanoparticle Addition in Diesel And Diesel-Biodiesel-Ethanol Blends On The Performance And Emission Characteristics of A Ci Engine," Journal of Engineering and Applied Sciences, Jan. 2009. Available: https://www.envirox.pl/envirox_pdf/referencje/NITT.pdf
- [13] G. S. S. Rathinam, J. Sajin, S. Ganesan, and D. Yuvarajan, "Performance and emission study on the effect of oxygenated additive in neat biodiesel fueled diesel engine," Energy Sources Part a Recovery Utilization and Environmental Effects, vol. 41, no. 16, pp. 2017–2027, Dec. 2018, doi: 10.1080/15567036.2018.1549148.
- [14] A. K. Pandian, R. B. B. Ramakrishnan, and Y. Devarajan, "Emission analysis on the effect of nanoparticles on neat biodiesel in unmodified diesel engine," Environmental Science and Pollution Research, vol. 24, no. 29, pp. 23273–23278, Aug. 2017, doi: 10.1007/s11356-017-9973-6.
- [15] A. Prabhu and M. V. Ramanan, "Detailed analysis on injection timing retardation and simultaneous technology in a biodiesel-powered compression ignition engine," International Journal of Ambient Energy, vol. 41, no. 12, pp. 1437–1440, Jul. 2018, doi: 10.1080/01430750.2018.1501749.
- [16] N. P. J. Prakash and N. J. M. Babu, "Ignition Investigation of Pure Biodiesel in A Research Engine with Dual Fuels," Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 108, no. 1, pp. 1–12, Sep. 2023, doi: 10.37934/arfmts.108.1.112.
- [17] Y. Devarajan, R. K. Jayabal, D. Ragupathy, and H. Venu, "Emissions analysis on second generation biodiesel," Frontiers of Environmental Science & Engineering, vol. 11, no. 1, Dec. 2016, doi: 10.1007/s11783-017-0891-0.
- [18] S. Rathinam, S. J. A. Baby, Y. Devarajan, and A. T., "Influence of water on exhaust emissions on unmodified diesel engine propelled with biodiesel," Energy Sources Part a Recovery Utilization and Environmental Effects, vol. 40, no. 21, pp. 2511–2517, Aug. 2018, doi: 10.1080/15567036.2018.1503756.
- [19] J. Ravikumar and S. Saravanan, "Performance and emission analysis on blends of diesel, restaurant yellow grease and n-pentanol in direct-injection diesel engine," Environmental Science and Pollution Research, vol. 24, no. 6, pp. 5381–5390, Dec. 2016, doi: 10.1007/s11356-016-8298-1.
- [20] Y. Devarajan and V. R. Madhavan, "Emission Analysis on the Influence of Ferrofluid on Rice Bran Biodiesel," Journal of the Chilean Chemical Society, vol. 62, no. 4, pp. 3703–3707, Dec. 2017, doi: 10.4067/s0717-97072017000403703.
- [21] A. K. Pandian, D. B. Munuswamy, S. Radhakrishnan, Y. Devarajan, R. B. B. Ramakrishnan, and B. Nagappan, "Emission and performance analysis of a diesel engine burning cashew nut shell oil bio diesel mixed with hexanol," Petroleum Science, vol. 15, no. 1, pp. 176–184, Jan. 2018, doi: 10.1007/s12182-017-0208-8.
- [22] R. Siva, D. B. Munuswamy, and Y. Devarajan, "Emission and performance study emulsified orange peel oil biodiesel in an aspirated research engine," Petroleum Science, vol. 16, no. 1, pp. 180–186, Dec. 2018, doi: 10.1007/s12182-018-0288-0.
- [23] D. Yuvarajan, J. Ravikumar, and M. D. Babu, "Simultaneous optimization of smoke and NOx emissions in a stationary diesel engine fuelled with diesel–oxygenate blends using the grey relational analysis in the Taguchi method," Analytical Methods, vol. 8, no. 32, pp. 6222–6230, 2016, doi: 10.1039/c6ay01696k.
- [24] S. K. A. K. Muhammed, J. Joseph, B. Yelamasetti, H. Vemanaboina, and P. Paramasivam, "Investigating the performance and emission characteristics of sunflower biodiesel blends with n-butyl and isopropyl alcohol additives," AIP Advances, vol. 15, no. 1, Jan. 2025, doi: 10.1063/5.0223885.