

Experimental Investigation of Emissions in the Role of SiO₂ Nano Additives on Methyl Ester – Diesel Fuel Blends in Compression Ignition Engine

Charanraj.V^{1*}, Raghunath.E², Prakash.R³, Murugesan.A⁴, Kumaravel.A⁵

^{1,2,3,4,5}Department of Mechanical Engineering, K.S. Rangasamy College of Technology,
Tiruchengode-637215, Tamilnadu, India.

***Email:** raghunath10091@gmail.com¹

Abstract

The increase of emissions from fuel causes environmental pollution and several health issues. In this experimental exploration Mahua methyl ester with SiO₂ nano additive diesel blends characteristics of compression ignition (CI) engine were examined to reduce pollution which aligns with sustainable development goals like SDG 3: Good Health and Well-being, SDG 7: Affordable and Clean Energy, and SDG 13: Climate Action. Based upon the previous literature, up to 20% mahua methyl ester fuel blends without nano additives are suitable for CI engines without disturbing the engine features. In this paper SiO₂ nano additive dopped into the B40 (40% mahua biodiesel- diesel) blended at the rate of 50 ppm for developing the test fuels. The SiO₂ nano additive blends improve the properties like viscosity, calorific value, and decrease the flash point and fire point. The observation of results, 40 MEOM + 50 ppm dopped fuels, improved the brake thermal efficiency (1%), the emissions like CO, HC, CO₂ and smoke are slightly decreased and slightly increased NO_x emissions. The combustion characteristics like maximum pressure rise, heat release rate is increased (1%) compared to other fuel combinations. The results are considered, a blend of 40 MEOM+ SiO₂ 50 ppm is the best blend ratio.

Keywords

CI engine, Emissions, Nano fuel additives

Introduction

In recent days, research on Internal Combustion (IC) engines for alternative fuels has been growing due to rise in the environmental worries and conventional fuels price. (Sabarish et al., 2018; Vijayakumar et al., 2015). Diesel locomotives are functioning under transient settings with biodiesel fuel combinations the thermal efficiency of diesel locomotives is not considerably affected when replacing diesel by biodiesel fuel both pure and blended. It is decreasing in PM, HC and CO, and a growth in NO_x emissions. The cause of NO_x emission is the inoculation process is marginally progressive with biodiesel (Lapuerta et al. 2008). Various research on the decrease in pollution has been in progress on fuel additives to decrease harmful emissions. Fuel properties are produced by spending some additives to improve combustion efficiency and to reduction of pollutant emissions (Lissianski et al., 2011; Kasper et al., 1999).

Submission: 20 July 2026; **Acceptance:** 20 October 2026; **Available online:** October 2026



Copyright: © 2026. All the authors listed in this paper. The distribution, reproduction, and any other usage of the content of this paper is permitted, with credit given to all the author(s) and copyright owner(s) in accordance to common academic practice. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license, as stated in the website: <https://creativecommons.org/licenses/by/4.0/>

Nevertheless, in common, these metallic based additives have been practiced and analyzed to determination of decreasing particulate emissions in the diesel engine. The additives reduction the formation of particulates in cylinders and exhaust arrangements. In summation, the additives boost the oxidation of particulate in diesel particulate filters. The particulate emissions and oxidation temperature were reduced the diesel engine fueled with additive in diesel fuel (Gürü et al., 2002; Yang et al.,1998). Biodiesel –diesel blends used in a diesel engine, the purpose for reducing three emissions (PM, smoke and CO) and increasing NOx emission with biodiesel combinations was mainly due to the existence of oxygen in their molecular structure (Arul Mozhi Selvan et al., 2009; Nabi et al., 2009; Karabektas et al., 2009). Biodiesel with metal-based additives, fuel used in diesel engines exposed less emission features compared to diesel fuel without additives (Park et al., 2006). Nanoparticles have an improving effect on the emissions of biodiesel and its blends in CI engines, as they can promote secondary atomization and increase reaction area. By using nanoparticles as fuel additives, there is a potential to improve the properties of biodiesel and address its shortcomings (Zheng et al., 2024; Mikky et al., 2024).

The metallic-based additives were actual in reducing CO emissions. CO emissions with Mn and Mg based additives are reduced by 16.35% and by 13.43%, respectively. CO₂ and Smoke is considerably compact with the additives. Thus, the emission of NOx was reduced by using this metallic based additive compared with base diesel (Kannan et al.,2011; Ali Keskin et al., 2011). The carbon monoxide, NOx and HC emissions are reduction with the role of nano blends compared with diesel (Sadhik Basha et al.2009). The alumina nanoparticles mingled water-diesel fuels used in diesel engines and analyzed under static conditions. It makes better combustion characteristic of nanoparticles and significant decrease in the harmful NOx & smoke as an outcome of improved fuel properties by incorporating the nanoparticles in the water-diesel emulsion fuels (Metin Guru et al. 2010). The biodiesel blends reduced NOx emissions more than Bio-Si nanoparticle blends (Jayabal, et al.2023). Magnesium oxide nano additives are also employed in a sort of industrial bids (Ramadhas et al., 2005; Shaafi et al., 2015). In this experimental study using SiO₂nano additive dopped with bio diesel-diesel blended fuel in diesel engine for analysis the performance, emission characteristics.

Methodology

Mahua is known as Illupai maram in Tamil and Hippa in Kannada in India. It's grown up from the dry lands. The seeds from the tree are known as an Indian butter tree. The Mahua oil is purchased from local shops nearby Hosur, Tamil Nadu, and it is utilized as a fuel for diesel engine with some chemical modifications by transesterification process. In this present investigation is using SiO₂ nano additives doped with 40MEOM fuel blends for testing the DI-CI engine. The nano powder is selected based on the dissolving capability of the nano additives with the Mahua methyl ester- diesel blends and the characters of nano powder like purity, atmospheric changes and toxic to human beings (Sadhik Basha et al. 2009). From those good characters we have selected the SiO₂nano particles for the experimental investigations. Nano additives were procured from M/s sigma-Aldrich, USA with the purity of 99.9% and the size of <50nm. Nano SiO₂powder mixed with Mahua methyl ester blend (40MEOM) done with Magnetic stirring process.

Characteristics of Test samples

The test sample characteristics of diesel, 20MEOM. 40 MEOM and 40 MEOM with SiO₂ dopped nano additive fuel blends are compared with ASTM standards presented the Table1. It

was observed that nano additive Mahua methyl ester is close to properties of without additive Mahua methyl ester. Fuel properties of 40 MEOM+50 ppm are almost nearer than diesel.

Table 1. Properties comparison of Diesel, 20 MEOM and SiO₂ additives fuel

Properties	Diesel	20 MEOM	40 MEOM	40 MEOM + SiO ₂ 50ppm	ASTM Standards for biodiesel
Kinematic viscosity at 40°C (cSt)	4.2	4.6	4.9	4.7	1.9 - 6.0
Calorific value (MJ/kg)	43.4	42.5	41.1	42.0	40 min
Density (kg/m ³)	830	849	865	855	875 - 900
Flash point (°C)	56	62	71	64	130°
Fire point (°C)	68	70	79	73	65°

Experimental setup and Procedure

The engine experiments were carried out on a one-cylinder, 4 s, naturally aspirated, constant speed, CI engine. The photographic view of the engine setup is shown the Figure 1. The engine had a bore diameter of 80 mm, stroke length of 110 mm and a maximum power of 3.7 kW. The tests were carried out at a constant speed of 1500 rpm. Each test was repeated three times to ensure the reproducibility of data.



Figure 2. Experimental setup for the CI engine.

The engine was first operated on diesel fuel with no loads for few minutes at rated speed of 1500 rpm up to the cooling water and the lubrication oil temperature reaches 65°C. The identical temperature was sustained through the testing with all the fuel modes. The basic line parameters were obtained at 0%, 25%, 50%, 75%, and 100% of load on the engine with the diesel fuel. The diesel fuel was changed with the different Mahua methyl ester- diesel blends with nano additives and the test is steered by varying the loads in the same method. The nano doped fuel does not necessitate any modification to the diesel engines. Hence, directly doped nano additive is used for the test. The mass of the fuel consumption was dignified by using a fuel tank fitted with the burette and a stopwatch.

Results and Discussion

Brake Thermal Efficiency

Figure 2 shows the effect of brake thermal efficiency with different engine loads. It indicates the ability to evaluate how efficient the energy in the fuel can be transformed into mechanical output. Among the fuel blends with nano additives, 40 MEOM + 50 ppm has a determined brake thermal efficiency of 30.8%. The brake thermal efficiency increased by 1% with the addition of 50 ppm SiO₂ nano additives compared with 40 MEOM (30.7%) fuel blends. This is due to the high surface area and subsequently great chemical reactivity of the nano particles lead to increase the combustion efficiency of the nano particle doped fuel blends.

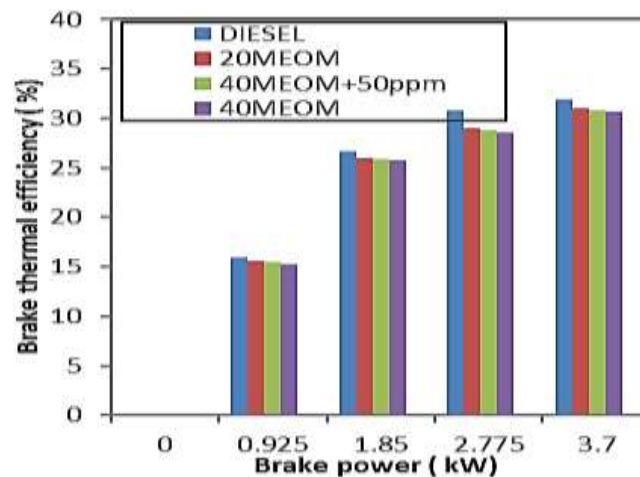


Figure 2. Effect of brake thermal efficiency with different engine loads

Nitrogen Oxide Emission

The effect of NO_x emission with different engine loads is shown in figure 3. NO_x emissions are mainly dependent upon combustion temperature and the amount of oxygen. The NO_x emission dramatically increases by adding nano additives in the methyl ester fuel blends. The NO_x emissions of nano doped test fuels at maximum load are 912 ppm. It is closer to 20 MEOM (910 ppm). It is owing to complete combustion fuel and greater combustion temperature. It leads to higher NO_x emission.

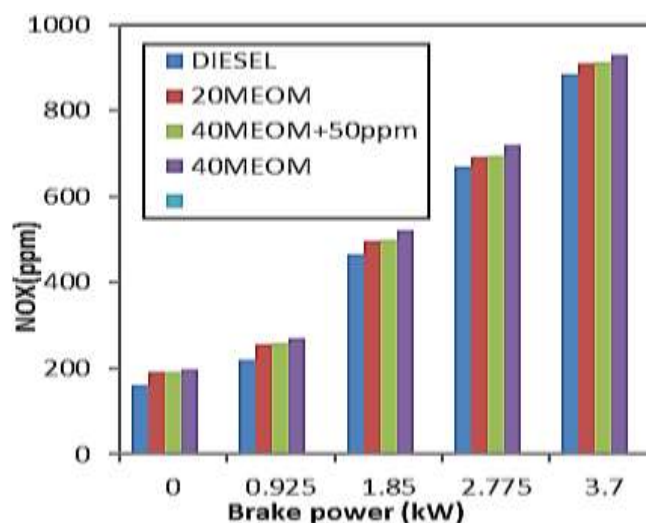


Figure 3. Effect of NO_x emissions with different engine loads

Smoke Emission

Figure 4 shows the effect of smoke emissions with different engine loads. The smoke emissions of nano doped test fuels at maximum load are 84.5 HSU. Reduced smoke opacity is observed in the case of 40 MEOM + 50 ppm fuel blends. It's closer to 20 MEOM (85 HSU) fuel blends. This could be attributed due to shorter ignition delay and better combustion characteristics of nano additive fuel blends.

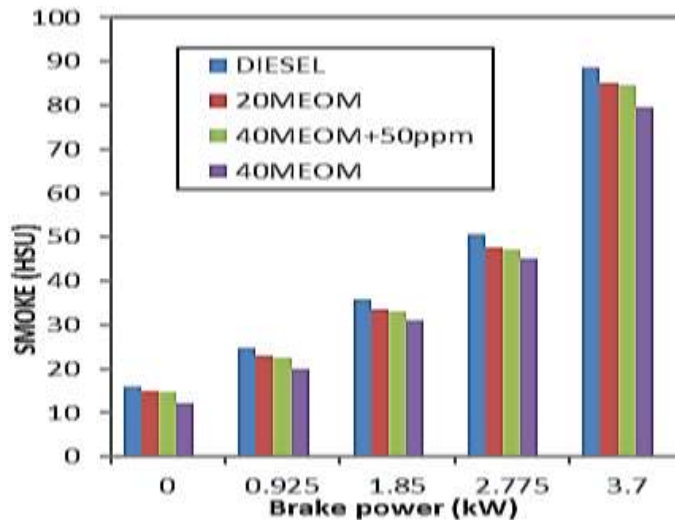


Figure 5. Effect of smoke emissions with different engine loads

Combustion Analysis

To investigate the combustion characteristics of fuel blends with SiO₂ nano additives, the combustion pressure sensor and Crank Angle Encoder were used to analyze the combustion characteristics. Figure 5 shows the effect of cylinder pressure with crank angle for fuel blends. The peak pressure of diesel, 20 MEOM and 40 MEOM is 72.322, 72.114 and 71.659 bar respectively. Whereas 40 MEOM + 50 ppm peak pressure is 71.859 bar. It clearly shows peak pressure of 40 MEOM +50 ppm is closer than diesel and higher than 40 MEOM without additive methyl ester combinations. This is owing to increased calorific value with doping of nano additives in the biodiesel blends compared to 40 MEOM without additive blends. Another reason is that nano particles have higher surface area to growths their chemical reactivity it decreases the ignition delay compared to without additive fuel blends.

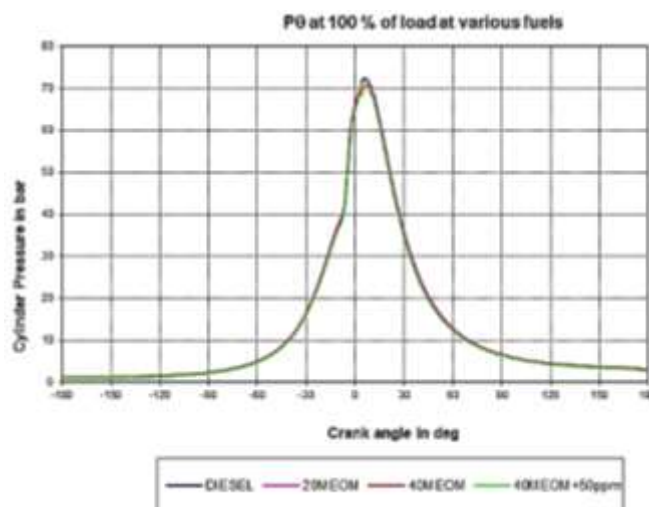


Figure 6. Effect of cylinder pressure with crank angle for fuel blends

Conclusions

Diesel is the most used fuel in the automobiles. If the emission of the diesel engine controlled means the world will protect from greenhouse effect. So only we used Nano technology for reduced emissions in internal combustion engines. The different engine characteristics of neat diesel, 20 MEOM, 40 MEOM with and without SiO₂ nano additive fuel blends are studied. This study found that the brake thermal efficiency of 40MEOM+50ppm fuel blend increased 1% compared with other tested fuel blends. NO_x emissions slightly increased by adding nano additives with Mahua methyl ester fuel blends. The combustion characteristic like maximum pressure rise is increased 1% compared to other fuel blends. From the experiment, 40 MEOM+ 50 ppm SiO₂ additive fuel blends is the best blend ratio for compression ignition engine compared to other fuel blends.

Acknowledgments

No grant or funding bodies to be acknowledged for preparing this paper.

References

- Ali Keskin, M., Gürü, M., & Altıparmak, D. (2011). Influence of metallic based fuel additives on performance and exhaust emissions of diesel engine. *Energy Conversion and Management*, 52, 60–65. <https://doi.org/10.1016/j.enconman.2010.06.039>
- Arul Mozhi Selvan, V., 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. *ARPJ Journal of Engineering and Applied Sciences*, 4(7). <https://envirox.pl/files/referencje/NITT.pdf>
- Gürü, M., Karakaya, U., Altıparmak, D., & Alicılar, A. (2002). Improvement of diesel fuel properties by using additives. *Energy Conversion and Management*, 43, 1021–1025. [https://doi.org/10.1016/S0196-8904\(01\)00094-2](https://doi.org/10.1016/S0196-8904(01)00094-2)
- Jayabal, R., Soundararajan, G., Ashok Kumar, R., Choubey, G., Devarajan, Y., Raja, T., & Kaliappan, N. (2023). Study of the effects of bio-silica nanoparticle additives on the performance, combustion, and emission characteristics of biodiesel produced from waste fat. *Scientific Reports*, 13, 46140. <https://doi.org/10.1038/s41598-023-46140-w>
- Jo-Yong Park, Y., Lee, Y.-J., Jun, K.-W., Baeg, J.-O., & Yim, D. J. (2006). Chemical synthesis and characterization of highly oil dispersed MgO nanoparticles. *Journal of Industrial and Engineering Chemistry*, 12(6), 882–887. https://www.researchgate.net/publication/281255682_Chemical_synthesis_and_characterization_of_highly_oil_dispersed_MgO_nanoparticles
- Kannan, G. R., Karvembu, R., & Anand, R. (2011). Effect of metal based additive on performance emission and combustion characteristics of diesel engine fueled with biodiesel. *Applied Energy*, 88, 3694–3703. <https://doi.org/10.1016/j.apenergy.2011.04.043>
- Kasper, M., Sattler, K., Siegmann, K., Matter, U., & Siegmann, H. C. (1999). The influence of fuel additives on the formation of carbon during combustion. *Journal of Aerosol Science*, 30(2), 217–225. [https://doi.org/10.1016/S0021-8502\(98\)00034-2](https://doi.org/10.1016/S0021-8502(98)00034-2)

- Lissianski, V. V., Zamansky, V. M., & Maly, P. M. (2011). Effect of metal-containing additives on NO_x reduction in combustion and reburning. *Combustion and Flame*, 25, 1118–1127. [https://doi.org/10.1016/S0010-2180\(01\)00231-0](https://doi.org/10.1016/S0010-2180(01)00231-0)
- Lapuerta, M., Armas, O., & Rodríguez-Fernández, J. (2008). Effect of biodiesel fuels on diesel engine emissions. *Progress in Energy and Combustion Science*, 34, 198–223. <https://doi.org/10.1016/j.pecs.2007.07.001>
- Nabi, M. N., Rahman, M., & Akhter, M. S. (2009). Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. *Applied Thermal Engineering*, 29, 2265–2270. <https://doi.org/10.1016/j.applthermaleng.2008.11.009>
- Guru, M., Koca, A., Can, Ö., Çınar, C., & Şahin, F. (2010). Biodiesel production from waste chicken fat based sources and evaluation with Mg based additive in a diesel engine. *Renewable Energy*, 35, 637–643. <https://doi.org/10.1016/j.renene.2009.08.011>
- Mikky, Y. A., Bhuran, A. A., El-Araby, R. Y., Mohamed, A. M. A., Gadallah, A. G., & Shoaib, A. M. (2024). Optimization of biodiesel–nanoparticle blends for enhanced diesel engine performance and emission reduction. *Processes*, 12(11), 2471. <https://doi.org/10.3390/pr12112471>
- Karabektas, M. (2009). The effects of turbocharger on the performance and exhaust emissions of a diesel engine fueled with biodiesel. *Renewable Energy*, 34, 989–993. <https://doi.org/10.1016/j.renene.2008.08.010>
- Ramadhass, A. S., Muraleedharan, C., & Jayaraj, S. (2005). Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. *Renewable Energy*, 30, 1789–1800. <https://doi.org/10.1016/j.renene.2005.01.009>
- Sabarish, R., Mohankumar, D., PremJeyaKumar, M., & Manavalan, S. (2018). Experimental study of nano additive with biodiesel and its blends for diesel engine. *International Journal of Pure and Applied Mathematics*, 118(18), 967–979. <https://acadpubl.eu/jsi/2018-118-18/articles/18a/100.pdf>
- Sadhik Basha, J., & Anand, R. B. (2009). An experimental investigation in a diesel engine using alumina nanoparticles blended water-diesel emulsion fuel. *SAE Technical Paper*, 2014-01-1391, 1. <https://doi.org/10.4271/2014-01-1391>
- Shaafi, T., Sairam, K., Gopinath, A., Kumaresan, G., & Velraj, R. (2015). Effect of dispersion of various nano additives on the performance and emission characteristics of a CI engine fueled with diesel, bio diesel and blends—A review. *Renewable and Sustainable Energy Reviews*, 49, 563–573. <https://doi.org/10.1016/j.rser.2015.04.086>
- Vijayakumar, C., Murugesan, A., Aishwarya, B., Jeyaram, A., Gogul, G., & Nayak, P. A. (2013). Experimental investigation of Mahua methyl ester as an alternative fuel for diesel engine. *International Journal of PharmTech Research*, 8(2), 193–199. <https://www.cabidigitallibrary.org/doi/full/10.5555/20153241383>
- Yang, H. H., Lee, W. J., Mi, H. H., Wong, C. H., & Chen, C. B. (1998). PAH emissions influenced by Mn-based additive and turbocharging from a heavy-duty diesel engine. *Environment International*, 24(4), 309–403. [https://doi.org/10.1016/S0160-4120\(98\)00019-1](https://doi.org/10.1016/S0160-4120(98)00019-1)
- Zheng, F., & Cho, H. M. (2024). The comprehensive effects of nano additives on biodiesel engines—A review. *Energies*, 17(16), 4126. <https://doi.org/10.3390/en17164126>