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Experimental Analysis on Performance and Emission Characteristics of Diesel Engine Using Lemongrass Biodiesel and TiO_2 Nano Additives Blends

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Abstract

The performance and emissions of a 4-S, single-cylinder, water-cooled diesel engine employing diesel and its various blending combinations with LGO and TiO_2 nano additive are evaluated experimentally. LGO is extracted by Soxhlet equipment from lemongrass (renewable, sustainable, and eco-friendly) and biodiesel is prepared through transesterification. The several BMs of diesel and LGB with TiO_2 additives are termed LGB20, LGB20$TiO_2$25ppm, LGB20$TiO_2$50ppm, LGB20$TiO_2$75ppm, and LGB20$TiO_2$100ppm and their qualities are tested according to ASTM standards. By varying the load ranges from 0 - 5 kg the primary engine performance metrics such BSFC, BTE, and EGT as well as emissions such as NOx, HC, CO, and CO_2 are analyzed. The obtained results demonstrate that LGB20$TiO_2$100ppm is the best performer, with a BTE approaching that of diesel fuel. The recovered LGO appears to be a diesel substitute for energy generation in the future.

Keywords

Lemongrass biodiesel, TiO_2 nano additive, Performance, Emission

Abbreviations

ASTM: American society for testing and materials; BSFC: Brake specific fuel consumption; BTE: Brake thermal efficiency; CO: Carbon monoxide; CO_2: Carbon dioxide; EGT: Exhaust gas temperature; HC: Hydrocarbon; NOx: Nitrogen oxides; BD: Biodiesel; CI: Compression Ignition; LGO: Lemongrass Oil; LGB: Lemongrass biodiesel; MCV: Microalgae *Chlorella*; FCR: Fuel consumption rate; BM: Blending mixture; TiO_2: Titanium dioxide; LGB20: LGB 20% Diesel 80%; LGB20$TiO_2$25ppm: LGB 20% Diesel 80% TiO_2 25ppm; LGB20$TiO_2$50ppm: LGB 20% Diesel 80% TiO_2 50ppm; LGB20$TiO_2$75ppm: LGB 20% Diesel 80% TiO_2 75 ppm; LGB20$TiO_2$100ppm: LGB 20% Diesel 80% TiO_2 100 ppm.

Introduction

Due to the rising pollution and energy consumption in the industrialized world issues brought on by the extensive use of fossil fuels, there is a growing need to find renewable energy sources with minimal negative environmental effects [1]. Fossils are used because of their adaptability, increased burning productivity, dependability, and facility maintenance. Fossil reserves are limited; hence their increasing depletion attracts researchers from all over the world to develop endless fuels that are locally accessible, ecologically acceptable, and globally feasible [2]. Biofuel, in contrast to conventional oil-based fuel, can be derived from a variety of sources such as oil from plants, creature fats, waste oil, algae oil, etc. It also offers several appealing features, such as being non-poisonous, biodegradable, and sulfur free. Furthermore, significant attention has been dedicated globally to the development of alternative energy sources [3]. Bio-oil is made by combining triglyceride and alcohol (such as methanol or ethanol) in a trans-esterification process. Trans-esterification is a synthetic reaction that occurs when greasy oil reacts with alcohol such as ethanol, methanol, etc. in the presence of an impetus, resulting in as a result of the synthesis of methyl ester and glycerol side-effects [4]. Various researchers used a different variety of biofuels such as edible oil; non-edible oil blended with diesel mixed with and without additives for the diesel engine performance and emissions. Suresh et al. [5] evaluated the manufacture of BD from different non eatable oils, like used cooking oil, warmed palm oil, Jatropha oil, Karanja oil, etc. It also acts as a measurement for assessing the combustion output performance and emission characteristics of diesel engines with variable compression ratios which mix biodiesel with diesel. Gaur et al. [6] This literature article focuses on how additives like nanoparticles and antioxidants affect engine efficiency and exhaust gas concentrations, and emission properties. The main result of this study was that waste polymers and nanoparticles have an impact on engine performance by lowering NOx, CO, and HC emissions while raising BTE and BSFC. Yaashikaa et al. [7] the main topic of this review uses bio-based materials as catalysts for the generation of biodiesel. Along with process variables like reaction time, temperature, feedstock, and catalyst concentration, the bioreactor in which the process takes place is also covered. It is important to use a few cutting-edge techniques that lead to successful BD production for commercial and effective BD manufacturing. Tayari et al. [8] investigated experimentally the effect of three feedstock such as *Eruca sativa*, Waste cooking oil, and MCV on the performance and emissions of a diesel engine. The result shows that among the various feedstocks MCV was best as it reduces CO and HC emissions by a larger amount. Purushothaman et al. [9] in this study Peppermint oil in the proportion of P10, P20, P30, and P40 was used to test the diesel engine performance, combustion, and emissions properties. At maximum load, the P20 blend had a brake thermal efficiency of 31.89% which was better than fossil fuel. Furthermore, the value of smoke emitted by various combinations of peppermint oil with fossil fuel was reduced. From the above literature, it is found that without the use of any additive performance of diesel engine is not increasing more and also emissions such as HC, CO, CO_2, and NOx is not decreasing as much so due to this several researchers are using different types of additives for the analysis of diesel engine. Prabu et al. [10] focused on the effect of Jatropha BD on the CI engine by using two different nano additives Such as alumina (Al_2O_3) and cerium oxide (CeO_2) in the concentration of 10, 30, and 60 ppm. The result shows that, by blending nano additives in Jatropha BD and diesel, reduces emissions such as HC, CO, and NO by 33%, 60%, and 13%, respectively. It was also noted that BTE was improved but lower than diesel fuel. Gumus et al. [11] experimented on diesel engines using Al_2O_3 and CuO nanoparticles stirred with fuel diesel. From the outcomes, the result found that there was an increment in BTE and there was a reduction in engine emissions such as CO, HC, and NO_X. They also observed that BSFC was highly reduced. Kumar et al. [12] studied the effect of waste orange peel oil BD blended with TiO_2 nanofluid in the range of 50 and 100 ppm on a diesel engine. From the observation, it was found that on adding TiO_2 nanofluid BTE was increased, and there was a reduction in emissions. Annamalai et al. [13] have been investigated experimentally the effect of LGB blended with ceria nanoparticles on a diesel engine. From the observation, they found that by adding ceria nanoparticles in LGB there was a drop in smoke, NOx, CO, and HC as compared to pure LGB. Rajendran [14] studied the effect of antioxidant additives such as p-phenylenediamine, A-tocopherol acetate, and L-ascorbic acid blended with Annona BD and diesel. The results show that among the antioxidant additives p-phenylenediamine was best and reduces NOx up to 25.4% in comparison to diesel. Nanthagopal et al. [15] has investigated experimentally the role of ZnO and TiO_2 nano additives blended with *Calophyllum inophyllum* BD on a double cylinder diesel engine. Nano additives were prepared in the concentration of 50 and 100 ppm. From the observation, they concluded that BTE was improved as compared to other blends. Further, emissions such as CO and HC gases were decreased as difference to pure diesel and other blends but in the case of NOx it was reduced when nano additive was added but when it was compared with pure diesel it was slightly higher. Fangsuwannarak and Triratanasirichai [16] have done a comparison between characteristics of BD and performance in engine using palm oil BD in the proportion of BD2, BD10, BD20, BD30, BD40, BD50, and BD100 blended with TiO_2 in the concentration of 0.1 and 0.2%. The result shows that the addition of 0.1% TiO_2 in BD improves the properties and reduces the emissions and enhances engine performance. By viewing the above literature, it was found that several researchers have only focused on the diesel engine performance and emission analysis with the use of different additives, very few researchers reported using additives like TiO_2 blended with diesel for the performance and emission analysis. Present work deals with the use of TiO_2 as an additive blended with diesel for the performance and emissions analysis of diesel engines.

Materials and Methods

Materials

LGO was acquired from at market in Lucknow, Uttar Pradesh, India, for the transesterification process. Chemicals like methanol, TiO_2, and sodium hydroxide of analytical grade are acquired from Sigma Aldrich and SDFCL, India. Diesel was bought from a local fuel pump (Hindustan Petroleum Corporation), Gorakhpur, Uttar Pradesh, to mix with BD. Table 1 shows the properties of BD, blending mix, and diesel.

Method for BD production

In this paper, the methodology for the preparation of LGB, the mechanism of the reaction, and the experimental setup were presented in figure 1 and figure 2. The detailed procedure for the preparation of LGB through the transesterification process is discussed as: 100 ml of LGO, 25 ml of methanol (dehydrated), and 1.4 g of NaOH (catalyst) are used for the transesterification process. The measured NaOH and methanol are stirred until they dissolved properly. LGO is

Table 1: Properties of BD, BM, and diesel.

Properties	Measuring apparatus	Diesel	LBD20	LBD20 + TiO_2 25 ppm	LBD20 + TiO_2 50 ppm	LBD20 + TiO_2 75 ppm	LBD20 + TiO_2 100 ppm
Density (kg/m^3)	Hydrometer	829	843	841	838	835	832.5
Calorific value (kJ/kg)	Bomb calorimeter	43625	42190	42210	42240	42245	42256
Flash point (°C)	Pensky Martens	67	51	56	61	66	69
Fire point (°C)	Pensky Martens	58	69	68	65	63	60

stirred with a mechanical stirrer and heated at the same time to get rid of any moisture from it. When the temperature of LGO reaches 60 °C then stop stirring because when the temperature exceeds 60 °C then methanol gets evaporated. The solution is also stirred at a speed ranging from 450 to 720 rpm. After an hour, the sample was put in a separating funnel for up to 24 hours, where the BD settled at the top and glycerin settled at the bottom portion. The BD gets washed with water repeatedly until no glycerin appears in it. Figure 1 shows the reaction mechanism of LGB and figure 2 shows procedure and experimental setup.

Preparation of BM of test fuel

After the preparation of BD blending of diesel with LGB20 and TiO_2 nanoparticle was done. Firstly, TiO_2 nanoparticle was mixed with LGB20 in the concentration of 25, 50, 75, and 100 ppm with the help ultrasonication process. In the ultrasonication process, the sample was blended at a frequency of 50 Hz, 120 W for 1/2 hour for each sample because the size of the TiO_2 nanoparticle was very small than the size of the fuel injector nozzle diameter. The prepared samples are LGB20, LGB20$TiO_2$25ppm, LGB20$TiO_2$50ppm, LGB20$TiO_2$75ppm, and LGB20$TiO_2$100ppm.

Engine specification and mathematical calculation

After the preparation of blending of BD with diesel, performance, and emission analysis of four stroke single cylinder diesel engine coupled with rope brake dynamo meter was done. Figure 3 shows the experimental setup of the diesel engine. The engine performance parameters like BSFC, FCR, and BTE are calculated for diesel and BM, and emissions such as CO, NOx, CO_2, and HC for diesel as well as BM were noted with the help of gas analyzer. Engine specifications were shown in table 2. The mathematics for the related calculations is presented as follows: [17].

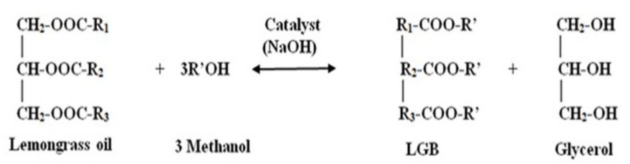

Figure 1: Reaction mechanism of LGB production.

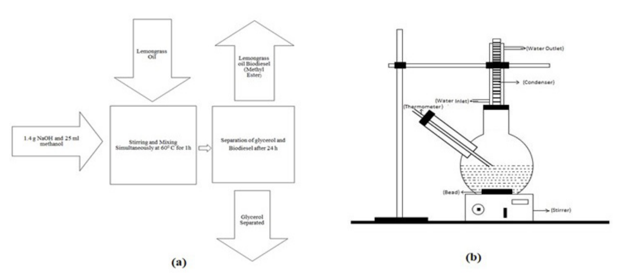

Figure 2: (a) Procedure and **(b)** Experimental setup.

The FCR in kg/hour. is calculated as:

$$FCR = \frac{v}{t} \text{ x } \frac{3600}{1000} \text{ x } \rho \quad (1)$$

Where, v is the volume of blend in milliliters, t is the time required to consume the fuel in seconds and ρ is the density g/ml of the blend.

The BSFC in kg/kW hour is given as:

$$BSFC = \frac{FCR}{BHP} \quad (2)$$

Break horsepower is in kW and can be estimated as:

$$BHP = \frac{2\pi NT}{1000 \text{ x } 60} \quad (3)$$

The important parameter BTE is calculated as follows:

$$BTE(\%) = \frac{BHP * 3600}{FCR * CV} * 100 \quad (4)$$

Where, CV is the calorific value in kJ/kg.

Results and Discussion

In this paper, examine the diesel engine performance and released gases characteristic of a single type of cylinder diesel engine by using LGB blended with TiO_2 nano additive by varying a concentration of 25 ppm, 50 ppm, 75 ppm, and 100 ppm by varying loading condition (0 - 5 kg). The result from comprehensive engine performance analysis and characteristics of emission test of diesel engine were as follow:

Performance characteristics

Brake-specific fuel consumption

Figure 4 indicates fluctuation of BSFC with different

Table 2: Engine specification.

Particular/Parameter (unit)	Description/Value
Engine type	Single cylinder, vertical, 4-S CI engine
Number of cylinders	1
Bore (mm)	102
Stroke (mm)	110
Cubic capacity (cm^3)	898
Injection pressure (bar)	220
Spray hole diameter (µm)	290
Revolution of Flywheel	Clockwise
Maximum H.P.	10 HP

Figure 3: Experimental setup.

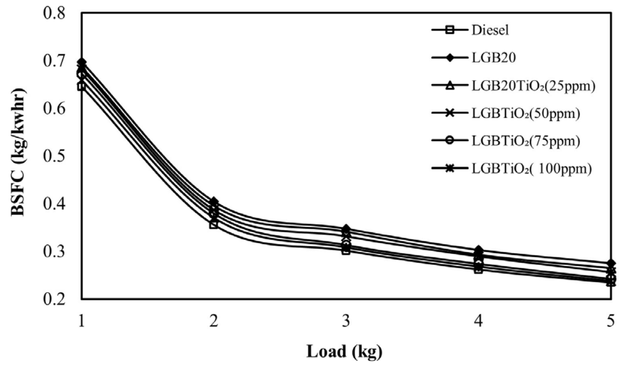

Figure 4: Fluctuation of BSFC vs load

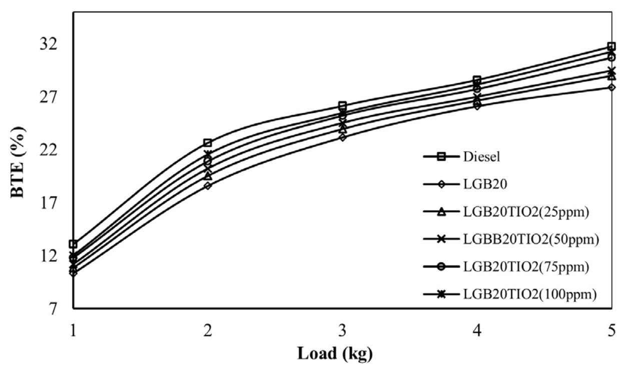

Figure 5: Fluctuation of BTE vs load.

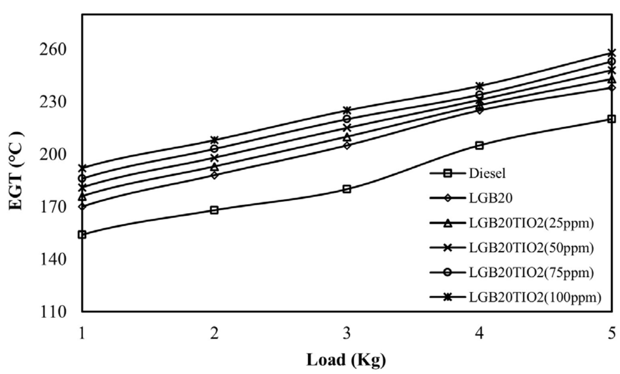

Figure 6: Fluctuation of EGT vs load.

loads. In result of the BSFC at full load was found 0.234, 0.274, 0.265, 0.256, 0.241, and 0.237 for diesel, LGB20, LGB20$TiO_2$25ppm, LGB20$TiO_2$50ppm, LGB20$TiO_2$75ppm, and LGB20$TiO_2$100ppm, respectively. The result shows that BSFC decreases for the LGB20 blends with the increases in TiO_2 percentage. These decreases in BSFC for biodiesel blends may be due to TiO_2 nanoparticle, which act as an oxygen booster that accelerates full combustion.

Brake thermal efficiency

Figure 5 indicates the fluctuation of BTE with different loading, the result of the BTE at full load was found as 31.73, 27.89, 28.99, 29.45, 30.68, and 31.23 diesels, LGB20, LGB20$TiO_2$25ppm, LGB20$TiO_2$50ppm, LGB20$TiO_2$75ppm, and LGB20$TiO_2$100ppm, respectively. The result shows that if the quantity of TiO_2 nanoparticles in the given blend of BD increases then the BTE also increases at maximum load conditions. The efficiency was increased also because of the internal oxygen present in the TiO_2 nanoparticles which enhances the combustion and increases the rate of heat release.

Exhaust gas temperature

Figure 6 indicates the fluctuation of EGT with different loads. The outlet gas temperature for the various loads at maximum loading condition was found to be 220, 238, 243, 248, 253, and 258, for the diesel, LGB20, LGB20$TiO_2$25ppm, LGB20$TiO_2$50ppm, LGB20$TiO_2$75ppm, and LGB20$TiO_2$100ppm, respectively. When the proportion of BD increases in diesel then the viscosity of fuel also increases. High viscosity content fuel mixes with oxygen/air in fewer amounts due to this temperature of exhaust gas rises with a rise in the proportion of BD in the mixture.

Emission characteristics

In this part, practical analysis of the impact of TiO_2 additives on emission properties of four stroke diesel engines is noted with help of exhaust gas analyzer ATS-206A. The emission parameters like CO, HC, NOx, and CO_2 were noted.

Hydrocarbon's emission

Figure 7 indicates the fluctuation of HC with different loads. The result shows that at maximum load the HC was found to be 167, 155, 145, 133, 125, and 110 ppm for diesel, LGB20, LGB20$TiO_2$25ppm, LGB20$TiO_2$50ppm,

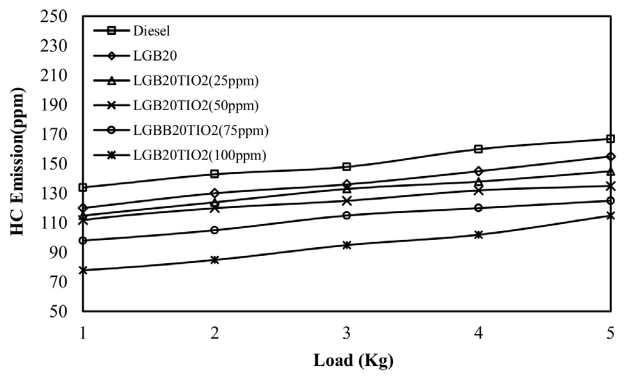

Figure 7: Fluctuation of HC vs load.

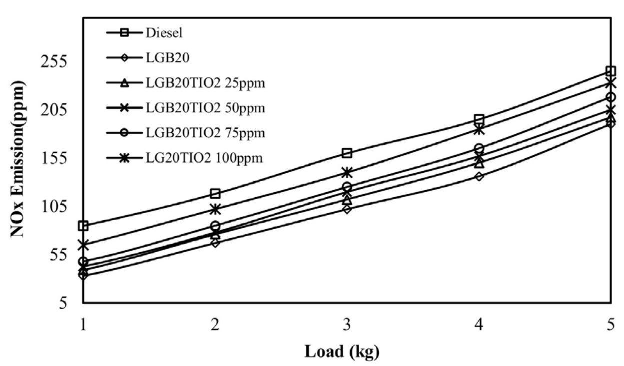

Figure 8: Fluctuation of NOx vs load.

LGB20TiO$_2$75ppm, and LGB20TiO$_2$100ppm, respectively. From the result, it can be found that HC decreases when the concentration of TiO_2 in BD increases, it was due to the internal oxygen present in the TiO_2 and BD which helps in the complete combustion and reduces HC [18].

Nitrogen oxides emission

Figure 8 indicates the fluctuation of NOx with different loads. It was found that NOx emission was more as compared to diesel it was due to the reason that BD and additive contain internal oxygen which helps in complete combustion. From the figure it was shown that a NO_X emission at maximum load was found as 245, 190, 197, 205, 218, and 233 ppm for diesel, LGB20, LGB20TiO$_2$25ppm, LGB20TiO$_2$50ppm, LGB20TiO$_2$75ppm, and LGB20TiO$_2$100ppm, respectively.

Carbon dioxide emission

Figure 9 indicates the fluctuation of CO_2 with different loads.CO_2 emission in term of % volume at maximum loading condition was found to be 1.22, 1.33, 0.82, 0.78, 0.73, and 0.63 for diesel, LGB20, LGB20TiO$_2$25ppm, LGB20TiO$_2$50ppm, LGB20TiO$_2$75ppm, and LGB20TiO$_2$100ppm, respectively. Higher CO_2 emission indicates the complete burning of the fuel. At higher combustion temperatures the amount of CO_2 emission increases that shows sufficient oxygen was present for the complete combustion. From the result, it was clear that with the rise in the concentration of TiO_2 nano additive the CO_2 emission was decreased.

Carbon monoxide emission

Figure 10 indicates the fluctuation of CO with different loads. When there is improper combustion, CO is generated. Partial combustion was the primary source of increased CO emissions. CO emissions for diesel, LGB20, LGB20TiO$_2$25ppm, LGB20TiO$_2$50ppm, LGB20TiO$_2$75ppm, and LGB20TiO$_2$100ppm blends were 0.079, 0.070, 0.064, 0.061, 0.055, and 0.046 at full load, respectively. From the figure it was clear that an increase in TiO_2 concentration in LGB20 resulted in larger CO emission reductions when compared to diesel fuel. TiO_2 acts as a catalyst help in the combustion of fuel. So, presence of TiO_2 results in complete oxidation of carbon molecules which results in higher formation of CO_2 and less formation of CO in fuel gas [19].

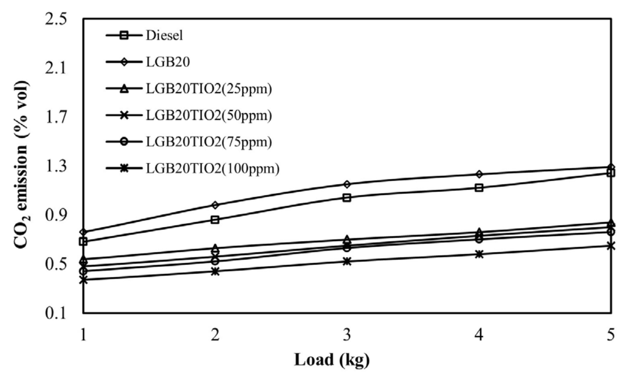

Figure 9: Fluctuation of CO_2 vs load.

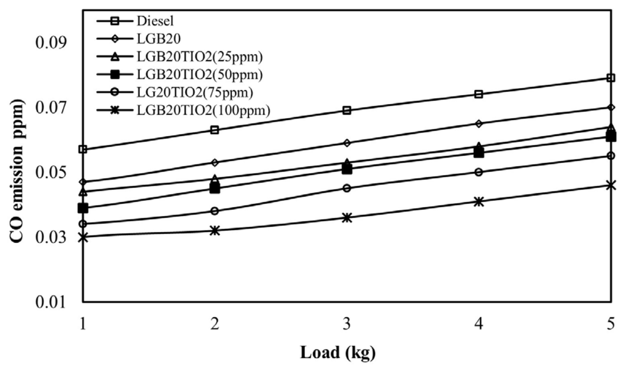

Figure 10: Fluctuation of CO vs load.

Conclusion

In this experimental analysis, the performance and emission evaluation of 4-S, single cylinder, water cooled diesel engine using diesel and its different BM of LGB with TiO_2 nano additive have been done and compared from diesel, based on experimental results some of the key conclusion found that:

- 83% yield of BD found from LGO after trans-esterification.
- BSFC decreases for the LGB20 blends with the increases in TiO_2 concentration because TiO_2 nanoparticle contains oxygen which enhances and boosts complete combustion.

- BTE was increased when the concentration of TiO_2 nano additive was increased at maximum load (5 kg) efficiency was closer to diesel.
- The emission result shows that CO and HC decrease with the utilization of TiO_2 nano additive and, but NOx emission was increased.

Overall, from this experimental work, it has been concluded that LGB20$TiO_2$100ppm is used as an alternate to pure diesel in the diesel engine.

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Conflict of Interest

The authors declare that there is no conflict of interest.

Credit Author Statement

Priyankesh Kumar and Gaurav Yadav: Conceptualization, Formal analysis, Data curation, Interpretation; Prashant Saini, Devesh Kumar and Jeeoot Singh: Experimentation, Writing - original draft preparation, Writing - review and editing. All the authors read and approved the manuscript.

References

1. Abbaszaadeh A, Ghobadian B, Omidkhah MR, Najafi G. 2012. Current biodiesel production technologies: a comparative review. *Energy Convers Manag* 63: 138-148. https://doi.org/10.1016/j.enconman.2012.02.027
2. Mofijur M, Atabani AE, Masjuki HA, Kalam MA, Masum BM. 2013. A study on the effects of promising edible and non-edible biodiesel feedstocks on engine performance and emissions production: a comparative evaluation. *Renew Sustain Energy Rev* 23: 391-404. https://doi.org/10.1016/j.rser.2013.03.009
3. Sathiyamoorthi R, Sankaranarayanan G. 2016. Effect of antioxidant additives on the performance and emission characteristics of a DICI engine using neat lemongrass oil–diesel blend. *Fuel* 174: 89-96. https://doi.org/10.1016/j.fuel.2016.01.076
4. Singh D, Sharma D, Soni SL, Sharma S, Sharma PK, et al. 2020. A review on feedstocks, production processes, and yield for different generations of biodiesel. *Fuel* 262: 116553. https://doi.org/10.1016/j.fuel.2019.116553
5. Suresh M, Jawahar CP, Richard A. 2018. A review on biodiesel production, combustion, performance, and emission characteristics of non-edible oils in variable compression ratio diesel engine using biodiesel and its blends. *Renew Sustain Energy Rev* 92: 38-49. https://doi.org/10.1016/j.rser.2018.04.048
6. Gaur A, Dwivedi G, Baredar P, Jain S. 2022. Influence of blending additives in biodiesel on physiochemical properties, engine performance, and emission characteristics. *Fuel* 321: 124072. https://doi.org/10.1016/j.fuel.2022.124072
7. Yaashikaa PR, Kumar PS, Karishma S. 2022. Bio-derived catalysts for production of biodiesel: a review on feedstock, oil extraction methodologies, reactors and lifecycle assessment of biodiesel. *Fuel* 316: 123379. https://doi.org/10.1016/j.fuel.2022.123379
8. Tayari S, Abedi R, Rahi A. 2020. Comparative assessment of engine performance and emissions fueled with three different biodiesel generations. *Renew Energy* 147: 1058-1069. https://doi.org/10.1016/j.renene.2019.09.068
9. Purushothaman P, Gnanamoorthi V, Gurusamy A. 2019. Performance combustion and emission characteristics of novel biofuel peppermint oil in diesel engine. *Int J Environ Sci Technol* 16: 8547-8556. https://doi.org/10.1007/s13762-019-02270-1
10. Prabu A, Anand RB. 2016. Emission control strategy by adding alumina and cerium oxide nano particle in biodiesel. *J Energy Inst* 89(3): 366-372. https://doi.org/10.1016/j.joei.2015.03.003
11. Gumus S, Ozcan H, Ozbey M, Topaloglu B. 2016. Aluminum oxide and copper oxide nanodiesel fuel properties and usage in a compression ignition engine. *Fuel* 163: 80-87. https://doi.org/10.1016/j.fuel.2015.09.048
12. Kumar AM, Kannan M, Nataraj G. 2020. A study on performance, emission and combustion characteristics of diesel engine powered by nano-emulsion of waste orange peel oil biodiesel. *Renew Energy* 146: 1781-1795. https://doi.org/10.1016/j.renene.2019.06.168
13. Annamalai M, Dhinesh B, Nanthagopal K, SivaramaKrishnan P, Lalvani JIJ, et al. 2016. An assessment on performance, combustion and emission behavior of a diesel engine powered by ceria nanoparticle blended emulsified biofuel. *Energy Convers Manag* 123: 372-380. https://doi.org/10.1016/j.enconman.2016.06.062
14. Rajendran S. 2020. Effect of antioxidant additives on oxides of nitrogen (NOx) emission reduction from *Annona* biodiesel operated diesel engine. *Renew Energy* 148: 1321-1326. https://doi.org/10.1016/j.renene.2019.10.104
15. Nanthagopal K, Ashok B, Tamilarasu A, Johny A, Mohan A. 2017. Influence on the effect of zinc oxide and titanium dioxide nanoparticles as an additive with *Calophyllum inophyllum* methyl ester in a CI engine. *Energy Convers Manag* 146: 8-19. https://doi.org/10.1016/j.enconman.2017.05.021
16. Fangsuwannarak K, Triratanasirichai K. 2013. Improvements of palm biodiesel properties by using nano-TiO2 additive, exhaust emission and engine performance. *Rom Rev Precis Mech Opt Mechatron* 43: 111-118.
17. Saini P, Gupta C, Shankar R. 2019. Characterization of corn oil biodiesel and its application in diesel engine. *Energy Sources A Recovery Util Environ* Eff 1-15. https://doi.org/10.1080/15567036.2019.1679913
18. Nanthagopal K, Ashok B, Saravanan B, Korah SM, Chandra S. 2018. Effect of next generation higher alcohols and *Calophyllum inophyllum* methyl ester blends in diesel engine. *J Clean Prod* 180: 50-63. https://doi.org/10.1016/j.jclepro.2018.01.167
19. Rangabashiam D, Munuswamy DB, Duraiswamy Balasubramanian S, Christopher D. 2020. Performance, emission, and combustion analysis on diesel engine fueled with blends of neem biodiesel/diesel/additives. *Energy Sources A Recovery Util Environ Eff* 1-11. https://doi.org/10.1080/15567036.2020.1764152