Global NEST Journal, Vol 25, No X, pp 1-5

Analysis of hybrid nano-emulsified Jatropha methyl ester-diesel blend (B20) in a direct injection engine: an experimental study

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Received: 02/08/2023, Accepted: 22/08/2023, Available online: 07/09/2023
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https://doi.org/10.30955/gnj.005277

Graphical abstract

Abstract

The purpose of this research was to comprehensively evaluate the performance and emission characteristics of a diesel engine using a novel fuel blend comprising a hybrid nano emulsified JME-Diesel blend (B20). The fuel blend consisted of a mixture of 50 ppm of ferric oxide (Fe_2O_3) and Silicon Dioxide (SiO_2) nanoparticles . The engine's performance and emissions were investigated under different load conditions ranging from 0 to 100%. This study involved conducting a series of experiments on an engine to evaluate the engine's efficiency (BTE) and fuel consumption (BSFC). Additionally, emissions in exhaust including NOx, CO, HC and excess O_2 were measured to assess the environmental impact of the hybrid nano emulsified JME-Diesel blend (B20). The results obtained from the experimental investigations revealed that the adding of nano Fe_2O_3 and SiO_2 to the JME-Diesel blend improved the engine's performance and reduced emissions. An increase in the proportion of nanoparticles 50 ppm led to a significant improvement in BTE, while simultaneously reducing BSFC. Regarding emissions, the hybrid nano emulsified JME-Diesel blend (B20) demonstrated a considerable reduction in CO_2, CO and HC emissions than neat diesel. Notably, the emission reductions were more pronounced as the nanoparticle proportion increased. This indicates the potential of the hybrid nano emulsified fuel blend to contribute towards environmental sustainability and mitigate the adverse effects of diesel engine emissions. In insinuation, the results demonstrate the promising characteristics of an engine fueled with a hybrid nano emulsified JME-Diesel blend (B20). The findings suggest that the inclusion of nano Fe_2O_3 and SiO_2 in the fuel blend can enhance engine efficiency while reducing harmful exhaust emissions.

Key words: Nano emulsions, biodiesel, hybrid nano, IC engine, emissions and performance

1. Introduction

Biodiesel has become a promising alternative fuel for internal combustion (IC) engines as it likely to reduce gas emissions. However, the of pure biodiesel or biodiesel-diesel blends can present challenges related to engine characteristics. To tackle such challenges, investigators have been exploring number of approaches to enhance the performance and emissions of biodiesel-diesel blends. One such approach is the incorporation of combined (hybrid) nano elements, which involve the combination of two or more nano additives, into the fuel matrix. The influence of hybrid nano additives on IC engine performance and emissions has emerged as an important area of research in recent years.

The impact of biodiesel on has been extensively studied (Amar Deep *et al*., 2019; Chiranjeeva Rao Seela and B. Ravi Sankar, 2022). While biodiesel exhibits favorable properties such as higher CN and lower sulfur compared to conventional diesel fuel, it also possesses certain limitations. Biodiesel's higher viscosity, lower heating value, and different combustion characteristics can affect engine performance, combustion efficiency, and emissions profiles (M.S. Gad *et al*., 2023: Seela C.R. and B., R.S., 2020). Consequently, there is a need to improve physiognomies of fuel blends to ensure their optimal utilization in IC engines. In modern times, researchers have turned their attention to hybrid nano additives as a potential solution for attractive properties of biodiesel-diesel blends. Hybrid or combination of two or more nano additives, each with unique physicochemical properties, to create synergistic effects and address multiple combustion-related challenges simultaneously. These nano additives include nanoparticles of metals, metal oxides, and other carbon-based materials (Manzoore Elahi M *et al*., 2018). The incorporation of hybrid nano additives into biodiesel-diesel blends holds the potential to overcome the limitations of biodiesel and optimize engine performance and emissions characteristics. Numerous studies have investigated the effects of hybrid nano additives in biodiesel-diesel blends on IC engine performance and emissions. Chinmoy Jit Sarma al. (2021) conducted a comprehensive investigation on the engine with fuel containing TiO_2 Nano fluids. The study demonstrated improved combustion efficiency and reduced emissions due to the enhanced fuel atomization and combustion stability imparted by the hybrid nano additive. Wang *et al*. (2020) explored the synergistic effect of CeO_2 and TiO_2nanoparticles in biodiesel-diesel fuel. The researchers observed enhanced combustion performance and emission characteristics, attributed to improved fuel oxidation and combustion kinetics facilitated by the hybrid nano additive. Moreover N. Senniangiri *et al*. (2022) investigated the influence of SnO2 and Ag nanoparticles in biodiesel-diesel blends. The study revealed improved combustion and emission characteristics, including reduced ignition delay and lower emissions of nitrogen oxides (NOx), as a result of the synergistic effects of the hybrid nano additive. These studies demonstrate the potential of hybrid nano additives in enhancing IC engine performance and reducing emissions. But, it is important to note that the field of research on hybrid nano additives in biodiesel-diesel is still evolving, and there is a need for further investigation. The current review aims to provide a comprehensive understanding of the influence of hybrid nano particles in biodiesel-diesel blends on IC engine operational expectations. By examining the recent literature, including studies by Junshuai Lv al. (2022), and Chiranjeeva Rao Seela & B. Ravisankar (2018) we will analyze the key findings, methodologies used, and research gaps in this field. This review will contribute to the knowledge base and guide future research efforts to optimize the characteristics of engine using hybrid nano emulsified fuels.

One of the primary reasons for investigating hybrid nano in biodiesel-diesel blends is the potential for synergistic effects to enhance fuel combustion. Synergistic effects refer to the combined effect hybrid additives is greater than the individual effects. These effects can significantly influence fuel atomization, combustion efficiency, and emissions reduction in internal combustion engines (IC engines). Recent studies have highlighted the importance of synergistic effects in fuel combustion. For example, Rajendran Selvabharathi *et al*. (2022) investigated the effects of a hybrid ceria and zirconia nanoparticles nano additives in biodiesel-diesel blends. They found that the synergistic interaction between the two additives led to improved fuel atomization, enhanced combustion stability, and reduced emissions. The authors attributed these effects to the complementary characteristics of ceria and zirconia nanoparticles, such as their high thermal conductivity and catalytic properties. Furthermore S. Manigandan *et al*. (2020) explored the influence of hybrid nano additives composed of cerium oxide (CeO_2) and titanium dioxide (TiO_2) in biodiesel-diesel blends. The researchers observed a synergistic effect between the two additives, resulting in improved fuel oxidation and combustion characteristics. The combination of CeO_2 and TiO_2 nanoparticles led to enhanced oxygen release, increased reactive oxygen species, and improved fuel-air mixing, ultimately leading to improved combustion efficiency and reduced emissions.

These studies demonstrate that the combination of two or more nano additives can result in synergistic effects that enhance fuel combustion. By exploring hybrid nano additives in biodiesel-diesel blends, researchers can harness these synergistic effects to optimize engine performance and reduce emissions.

2. Materials, methods and experimentation

The Jatropha oil was obtained from the Seetampeta in Andhra Pradesh, India, and converted into biodiesel by transesterfication. The required diesel-biodiesel (B20) blends were prepared and the selected SiO_2 and Fe_2O_3 nanoparticles of 50 ppm are dispersed into B20 by ultrasonicator at 20 kHz for 30 minutes. The dispersion of nano particles is ensured at this frequency (Chiranjeeva Rao Seela & B. Ravisankar (2018)

A good number of experiments were undertaken to assess the operational output traits of a single-cylinder four-stroke direct injection (DI) diesel engine, utilizing both modified and base fuels. The engine was subjected to testing with the aid of a rope brake dynamometer. The engine's specifications can be found in Table 1. Emission characteristics were measured during steady-state operation using INDUS 5 gas analyzer. The uncertainties in parameters are tabulated in Table 2.

Table 1. specifications

Engine	**HS CI**	**Brake power**	**5HP (3.72kw)**
Make	AV-1-Kirloskar	RPM	1500 rpm(constant)
cylinders	Single	Bore (mm)	80
Loading type	Mechanical	Stroke (mm)	110
Injection pressure	200 bar	Brake drum Dia (m)	0.315

Table 2. Uncertainties in parameters

S.no	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Criterion	Speed (RPM)	Consumption time of fuel (s)	Torque (N-m)	BTE (%)	CO (vol)	NOx (ppm)	HC (ppm)
Uncertainty (%)	1	1.1	0.7	1.5	0.008	50	12

3. Results and Discussions: present the obtained outcomes from the operation as follows:

Figure 1 showcases the variations in BTE at different loads. The inclusion of SiO_2 and Fe_2O_3 in B20 fuel results in an improvement in BTE. Specifically, a remarkable (2.2 increment) 8% enhancement in BTE is observed at maximum load. This could be because of the enhanced burning with the nano additive. The particles in nano size alter the combustion characteristics and performance of the fuel when introduced in controlled amounts. These nanoparticles might affect factors like combustion efficiency and energy release

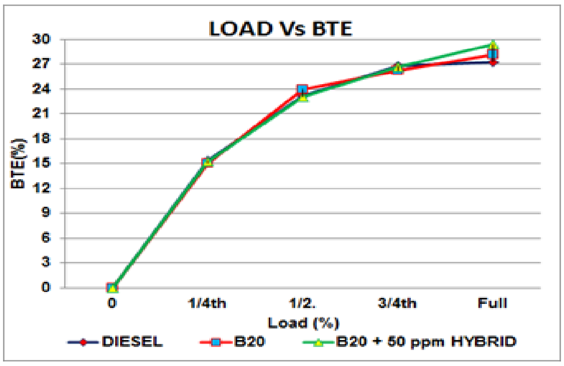

Figure 1. Brake Thermal Efficiency Vs Load

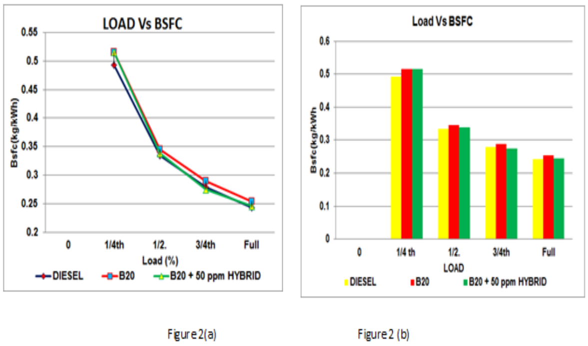

Figure 2(a&b). Variation of sfc with Load

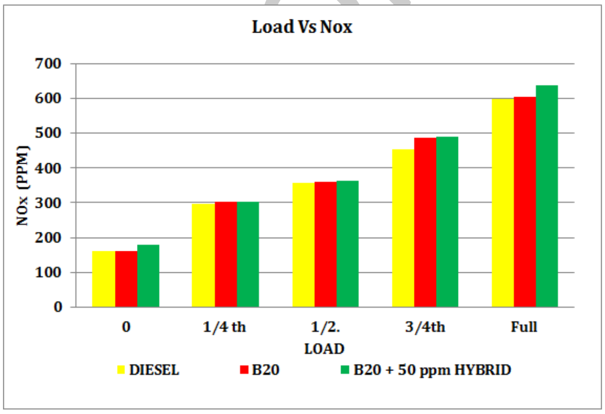

Figure 3. NOx Vs Load

The graph in Figure 2 (a) and (b) illustrates the changes in BSFC at different loads. The modified fuel is very close to diesel in terms of bsfc. Notably, the B20+50ppm hybrid nano demonstrates the most significant improvement about 2.1-5.2% lower SFC than the base fuels at loads as the hybrid nano attributed to uniform burning. The nanoparticles SiO_2 and Fe_2O_3 have higher LHV and lower ignition delay leads better combustion (Chen *et al.*, 2018).

Figure 3 presents the variations in nitrogen oxide (NOX) emissions for diesel, Jatropha-based biodiesel blend (B20), and hybrid nano added biodiesel blends. The NO_X emissions increase with the load due to elevated cylinder pressure and temperature across all fuel blends. Notably, the increase in NOx is very minimum (0 to 3 ppm) at intermediate loads compared to B20.

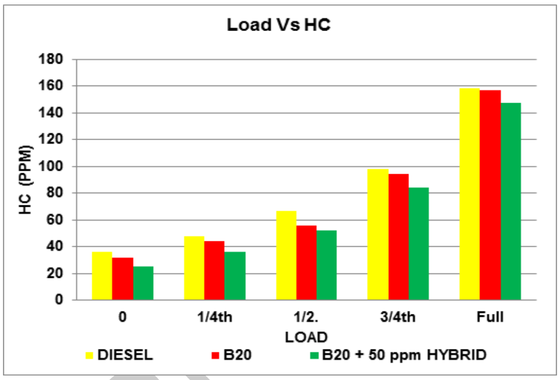

Figure 4. HC Vs Load

In Figure 4, the graph displays the variations in unburnt hydrocarbon (HC) emissions. Notably, the HC emissions for B20 operation are about 6-21% lower than those of diesel. Additionally, hybrid nano -added fuel blends exhibit 7 to 30% lower HC emissions compared to the 20 fuels at idle and full load conditions. .

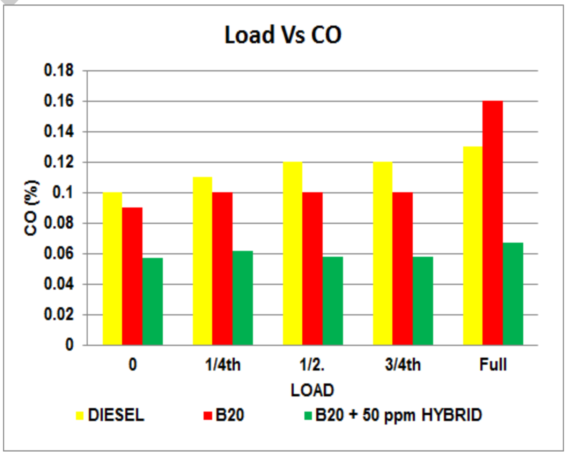

Figure 5. CO Emissions Vs Load

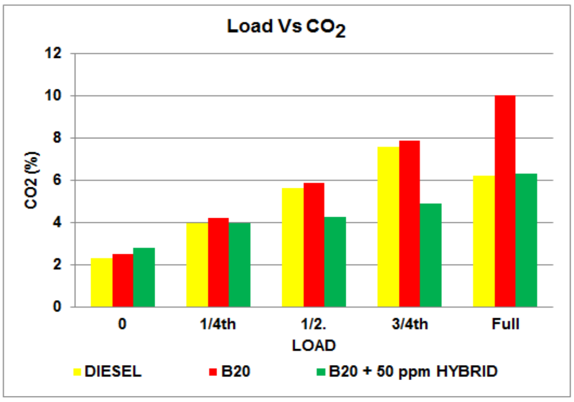

Figure 6. CO2 Emissions Vs Load

Figure 5 represents the carbon monoxide (CO) emissions. The inbuilt oxygen in biodiesel and uniform burning provoked by the hybrid nano additive led to lower CO emissions. For B20 it is 43 to 48 % lower compared to diesel and for the hybrid nano added B20 , it is 36 to 58 % in comparison to B20 blend operation

Figure 6 shows the trend of CO_2 at considered loads. The CO_2 increased with the load due to more fuel burn. Interestingly, blends B20 and with hybrid nano additive has exhibited lower CO_2 emissions compared to base fuels under all load conditions except at idle condition, indicating complete combustion. This reduction in terms of percentage is 5 to 37.

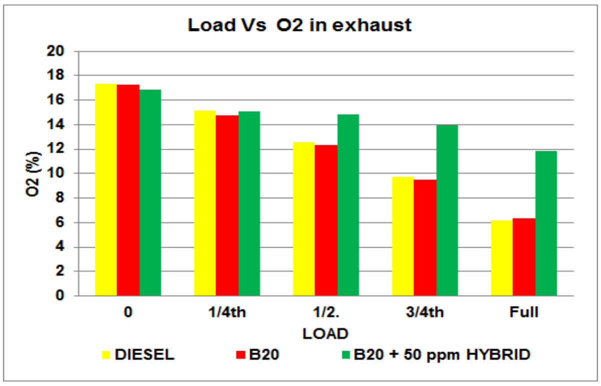

Figure 7. Variation of Excess Oxygen with Load

Figure 7 illustrates the decrease in exhaust oxygen (O_2) with increasing load. The oxygen content in fuel and selected nano additive led to improved O_2 in exhaust. The hybrid nano added B20 fuel leaves 2 to 85 % and 3 to 64 % more O_2 in comparison to neat diesel and B20 bled. .

4. Conclusions

1. The addition of TiO_2 and Fe_2O_3 in B20 fuel improves brake thermal efficiency (BTE) by 8% at maximum load also reduce specific fuel consumption (BSFC) significantly, from 2.1-5.2% than base fuels.
2. Hybrid nano-additives have a minimal impact on nitrogen oxide (NOX) emissions at intermediate loads compared to B20.
3. Unburnt hydrocarbon (HC) emissions are notably lower for B20 operation, around 6-21% compared to diesel, and further reduced (7-30%) in hybrid nano-added B20 at idle and full load conditions. Moreover, the hybrid nano-added B20 demonstrates lower carbon monoxide (CO) emissions by 36-58% compared to B20 blend operation. Additionally, blends with hybrid nano-additives show lower carbon dioxide (CO2) emissions, except at idle conditions, indicating complete combustion, with a reduction ranging from 5 to 37%. Hybrid nano-added B20 fuel also leaves a significantly higher amount of excess oxygen in the exhaust compared to neat diesel and B20 blend.

Nomenclature

JME	Jatropha methyl ester B20 diesel 80% and biodiesel 20%
BTE	brake thermal efficiency bsfc brake specific fuel consumption
SiO_2	silicon dioxide
Fe_2O_3	ferric oxide

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