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Effects of Nano Additives on Performance and Emission Characteristics of CI Engine with Mahua Biodiesel and Diesel Blends as Fuel

Sharanappa Godiganur[1], Srikanth H.V.[2,*], Veerbhadrappa T.[3]

Abstract

Due to growing environmental concerns and the imminent depletion of fossil fuels, the development of eco-friendly alternative fuels, such as biodiesel, is imperative. To improve the performance and emission properties of diesel engines utilizing biodiesel blends, the effective introduction of metallic and non-metallic nano-additives has been established. This research aimed to investigate the blending ratios of biodiesel (B0, B10, B20, and B40) in a compression ignition engine. Furthermore, the impact of graphene nanoparticles on the engine's performance and emissions was evaluated and compared to pure diesel fuel. The addition of graphene as a nano-additive to B20, with a concentration of 150 ppm, demonstrated a significant enhancement in both performance and emission characteristics. B20G150 exhibited a notable 6% decrease in brake-specific fuel consumption (BSFC), a 25% reduction in carbon monoxide (CO) emissions, and a 6.5% increase in brake thermal efficiency (BTE). This study revealed that the addition of graphene nanoparticles improves the performance characteristics of the compression ignition engine

Keywords: Biodiesel, Nano additive, Graphene, CI engine, Performance, Emission

INTRODUCTION

The demand for fossil fuel continues to rise due to its extensive use in sectors such as agriculture, automotive, and various power generation fields. Among the available energy sources, the diesel engine stands out as the most compact, reliable, and durable option, offering high brake thermal efficiency and a favorable torque-to-weight ratio [1]. However, the escalating price of diesel fuel, caused by its insufficient supply, is adversely impacting the Indian economy [2]. Annually, India spends approximately 80,000 crore on crude oil imports from Middle Eastern countries, creating a significant economic burden [3]. Furthermore, the use of diesel engines contributes to air pollution and global warming, posing environmental challenges. Consequently, emission regulations necessitate innovations in diesel engines and diesel fuel technologies. Incorporating biodiesel blends into diesel fuel holds promise for mitigating global warming, as plants absorb nearly all carbon emissions from biofuels through photosynthesis [4, 5]. Additionally, the adoption of at least 5% biofuel usage could alleviate an annual economic burden of 400 crores in India [2]. Several researchers have proposed the use of biodiesel in diesel engines, resulting in a notable reduction of harmful emissions like unburnt HC and CO, with the exception of increased NOx emissions [6, 7]. Nevertheless, the performance of CI engines may be compromised when using biodiesel due to reduced power generation and increased BSFC,

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attributed to the lower calorific value of biodiesel compared to mineral diesel [5]. Therefore, enhancing the performance characteristics of diesel engines operating with biodiesel is crucial. Using nanoadditives to adulterate biodiesel is a widely employed method for achieving favorable fuel properties and enhancing the performance of diesel engines. The fundamental requirements for any fuel additives are as follows: (1) They should decrease exhaust emissions and enhance oxidation intensity within the combustion chamber. (2) They should maintain the necessary operational properties of the engine without failure. (3) They should influence the stability of the fuel they are blended with. (4) They should not disrupt the functioning of particulate filters or contribute to increased harmful emissions [8]. Nanoparticles exhibit a high surface-to-volume ratio, which positively impacts their catalytic, reactive, and magnetic properties [9]. The addition of metal and metal oxide additives in biodiesel allows for improved diesel engine performance, alongside favorable emission characteristics [10]. However, certain additives like cerium oxide, which fall under the category of metal and metal-oxide additives, can raise the viscosity of biodiesel, leading to combustion issues [11, 12]. Exploring novel nanoadditives for biodiesel that can address the shortcomings of existing ones is crucial. Considering the limited available literature on employing graphene as a nanoadditive in biodiesel, this study focuses on blending graphene with mahua oil biodiesel to evaluate its impact on test engine performance parameters.

MATERIALS AND METHODS

Graphene

Table 1 presents the properties of graphene, which is an incredibly thin material consisting of carbon atoms arranged in a honeycomb-like structure. Its bond length between carbon-carbon atoms measures 0.142 nm, while the inter-planar distance is approximately 0.335. At room temperature, graphene exhibits exceptional thermal conductivity, measuring 5000 W/mK, and possesses a significant specific surface area of 2630 m^2/g. Notably, it can undergo complete combustion within a combustion chamber, even at temperatures as low as 3500°C, without releasing any particulate matter emissions [13].

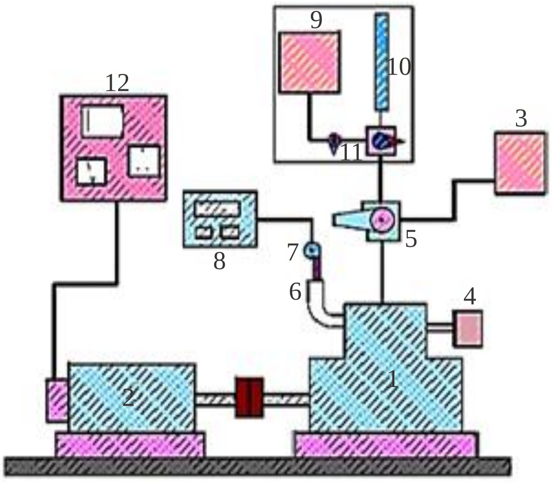
Biodiesel

The trans-esterification process was used to extract biodiesel from crude mahua oil in the current study. Mahua oil, when reacted with an alcohol in the presence of a catalyst, forms biodiesel and glycerol. The resulting mixture of biodiesel was thoroughly stirred and left to settle for 24 hours. After settling, the mixture separated into two layers, with methyl ester floating atop glycerol. The glycerol was separated, and the methyl ester underwent water washing to complete the trans-esterification process. Triglycerides, consisting of glycerol and three fatty acids, are present in almost all vegetable oils. Table 1 presents the properties of diesel, crude oil, and methyl ester, respectively. An ultrasonicator was used to uniformly mix nanoparticles with B20 and B40 blends. The grapheme nanoparticles (99.5% pure), with average particle size of 22.5–26 mm,surface area of 492 m^2/gm and thermal conductivity of 3000 W/m-K were dosed in three different quantities ranging from 50 ppm to 150 ppm

EXPERIMENTATION

The study was conducted to investigate the performance and emission characteristics of the Kirslokar TV1 engine. The experimental work involved using a single-cylinder engine operating on the diesel cycle, cooled with water, and featuring an 80 mm bore, 110 mm stroke length, and a compression ratio of 16.5:1. Figure 1 illustrates the layout of the experimental test rig and its instrumentation.

Initially, the engine was started using diesel fuel and allowed to reach a steady state. The experimental fuels included diesel, as well as blends of 20% and 40% mahua biodiesel with diesel fuel by volume. Furthermore, experiments were carried out to examine the impact of graphene nanoadditives on the engine's performance and emission characteristics by adding three different quantities to the B20 and B40 blends. The engine was operated at a constant speed of 1500 rpm and loaded with an eddy current dynamometer under various operating conditions. The emission characteristics are determined using an AVL exhaust gas analyser.



1. Engine 2. Eddy current dynamometer 3. Diesel tank
4. Air ?lter 5. Three-way valve 6. Exhaust pipe
7. Probe 8. Exhaust gas Analyzer 9. Biodiesel tank
10. Burette 11. Three-way valve 12. Control panel

Figure 1. The experimental test rig.

Table 1. Properties of diesel, raw mahua oil, and mahua methyl ester [14].

Properties	Diesel	Raw Mahua oil	Mahua Biodiesel
Specific gravity	0.85	0.924	0.916
Fire point (°c)	63	246	141
Flash point (°c)	56	230	129
Kinematic viscosity at 40°C	3.05	39.45	5.8
Calorific value (kJ/kg)	42,800	37,614	39,400
Density (kg/m^3)	850	924	916

RESULTS AND DISCUSSION

The initial experiments aimed to optimize the optimal blend of three variations of diesel and Mahua bio-diesel. After determining the optimized blend, nanoparticles with varying dosages are added to it for further analysis. Consequently, the impact of nanoadditives on performance and emission characteristics is investigate.

Optimization of Biodiesel Blends

A characteristics comparison for performance and emission was conducted for a CI engine running at 1500 rpm, fueled with diesel and 3 blends of 10%, 20%, and 40% mahua oil. Figures. 2a and 2b show variations of BSFC and BTE with BP, respectively, at 0.8, 1.6, 2.4, and 3.2 kW load on the engine. Figure 2a shows that BSFC decreases sharply as BP increases since the increased fuel consumption is less in comparison with the increase in brake power. BSFC was lowest for diesel at all loading conditions when compared to blended fuel; BSFC was found to increase by 13.29% when compared between diesel and B40. For loads less than 2.3 kW, the BSFC for all blends was almost similar, but beyond 2.3 kW, the B20 blend had a better BSFC. B20 was found to have a minimal variety of BSFC in comparison with diesel. Figure 2b shows an increase in brake thermal efficiency with an increase in brake power since heat loss reduces as power increases. Out of all fuel samples, B20 has a good increment of BTE with an increase in BP, but beyond the 2.5 kW load, there was a rapid increase in BTE for diesel fuel. BTE was reduced by 9.4% in comparison with diesel and B40. B20 blend performance is a better match to that of diesel. The percentage of CO is decreased with BP for all the fuel blends, the blend B40 shows a significant decrease in CO% with respect to BP (Figure 3a). The unburnt hydrocarbons decrease with increase in BP the decreased HC emissions was found with B40 blend in comparison with other test fuels (Figure 3b). the Figure 3c indicates NOx emissions with BP, emissions of NOx increases with increase in the load for all the fuel blends, higher emissions was found with B40 due to increased oxygen content in biodiesel [7, 14].

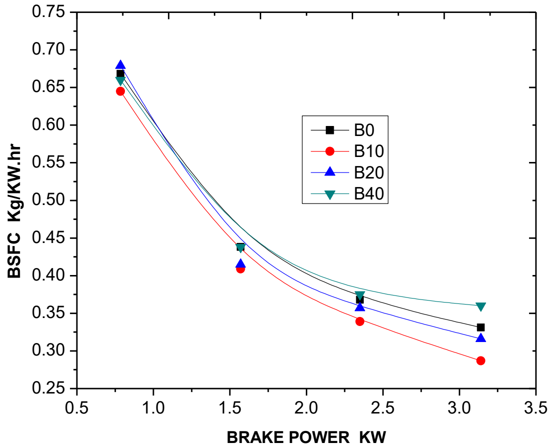


Figure 2. (a) Variation of BSFC with BP.

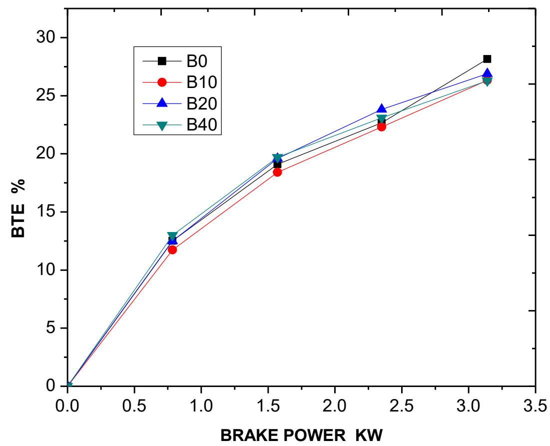


Figure 2. (b) Variation of BTE with BP.

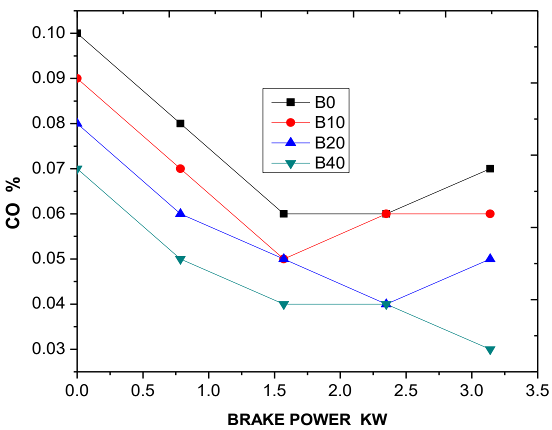


Figure 3. (a) Variation of CO% with BP.

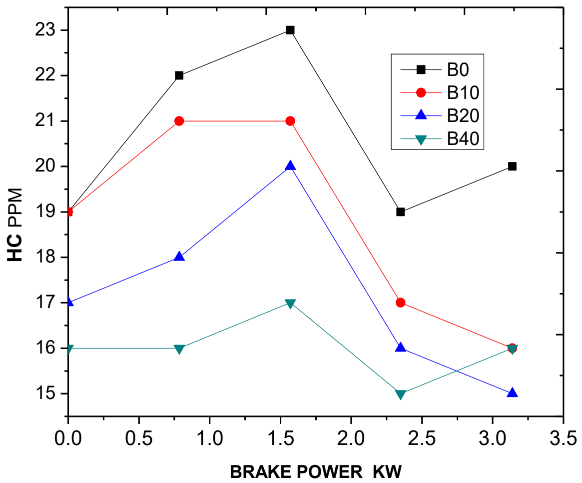


Figure 3. (b) Variation of HC with BP.

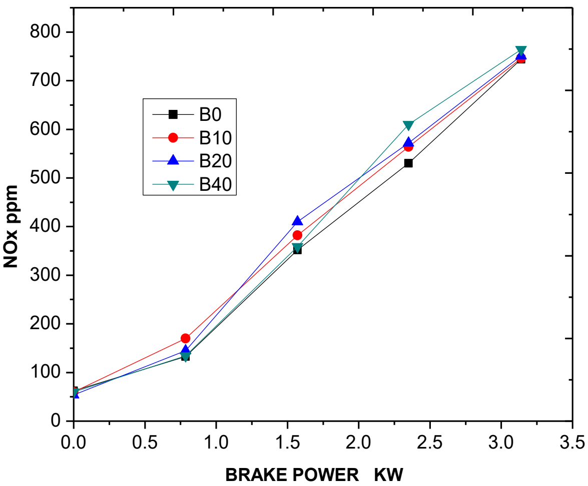


Figure 3. (c) Variation of NOx with BP.

EFFECT OF NANO ADDITIVES ON PERFORMANCE AND EMISSION.

Figure 4.a illustrates the relationship between load and BSFC consumption for B20 blend infused with varying amounts of graphene as a nanoadditive. It is evident from the figure that, regardless of the fuel tested, an increase in load corresponds to a decrease in BSFC. This reduction in BSFC is attributed to the enhanced surface area to volume ratio of the biodiesel combined with nanoparticles [15]. Moreover, at full load, B20 blends with nanoadditives (B20G50, B20G100, and B20G150) exhibit lower BSFC values compared to regular B20 blend. The magnitude of BSFC decrease corresponds to the quantity of graphene nanoadditive present in the blends. Specifically, the decrease in BSFC amounts to 1%, 3%, and 6% for B20G50, B20G100, and B20G150, respectively. Despite their lower calorific values, this performance can be attributed to effective atomization and combustion efficiency. Similar trends have been observed in previous studies [15, 16, 17]. Previous research concludes that the utilization of additives in combination with fuel in a CI engine is a promising approach to enhance its BTE [1]. The inclusion of additives facilitates complete combustion of fuel by reducing ignition delay and increasing flame temperatures [18, 19]. Figure 4 b illustrates the variation of BTE with load for B20 blended with different doses of graphene. In all cases, an increase in load results in an elevation of BTE, which can be attributed to decreased heat loss and increased power. This observation is evident in the comparison of BTE values for B20G50, B20G100, and B20G150, which surpass the B20 blend without graphene. The percentage increases in BTE for B20G50, B20G100, and B20G150 are 0.5%, 3.5%, and 6.5%, respectively, considering that

BTE is the inverse of BSFC. The magnitude of BTE improvement correlates with the additive content in the blends, which aligns with findings reported in the literature [18–20]. Figure 5a illustrates the relationship between load and measured volume percentage of CO for a CI engine fueled with a B20 blend of Mahua biodiesel, as well as a B20 blend with varying amounts of graphene nanoparticles. The introduction of non-metallic nano-additives to biodiesel blends is expected to enhance combustion by reducing ignition delay [21], leading to a decrease in CO emissions. In all tested B20 blend variations, CO levels decreased as the load increased. Analysis of Figure 5a reveals that B20G50, B20G100, and B20G150 exhibited lower CO emissions compared to the B20 blend at full load. The extent of CO reduction increased with higher concentrations of graphene nano-additives in the blends. Specifically, the CO reductions were 16.66% and 12% for B20G50 and B20G100, respectively.

Numerous studies have demonstrated a reduction in HC emissions as a result of nano-additive inclusion [21, 22, 23]. Figure 5b displays the variations in HC emissions with load for B20 blends supplemented with different proportions of graphene. It is evident that increasing the amount of graphene in the fuel leads to a decrease in HC emissions. The greatest reduction in HC emissions, amounting to 25.8% compared to B20, was observed for the B20G150 blend. This performance is due to good atomization and combustion efficiency, despite the lower calorific values of the blends. Conversely, the combustion of diesel blended with 20% Mahua biodiesel causes an increase in temperature within the combustion chamber, resulting in elevated NOx emissions. However, the addition of graphene nanoparticles (as depicted in Figure 5c) resulted in a reduction in NOx emissions. The magnitude of NOx reduction increased as the concentration of nanoparticles in the fuel increased. The highest decrease in NOx emission, amounting to 7.6% compared to the B20 blend without graphene, was observed for the B20G50 blend.

CONCLUSION

Performance and emission tests were carried out on various blends of Mahua biodiesel with diesel, comparing them to pure diesel. Among the tested blends, B20 showed superior performance and emission characteristics. To evaluate the impact of incorporating graphene as a nano-additive, different concentrations of graphene were introduced to B20. The B20 blend with 150 ppm of graphene displayed a significant improvement in both performance and emission characteristics. Specifically, B20 with 150 ppm of graphene exhibited a 6% reduction in Brake Specific Fuel Consumption (BSFC), a 25% decrease in CO emissions, and a 6.5% increase in Brake Thermal Efficiency (BTE). These findings suggest that adding 150 ppm of graphene to B20 enhances the performance and emission characteristics of diesel engines without requiring any modifications to the engine hardware.

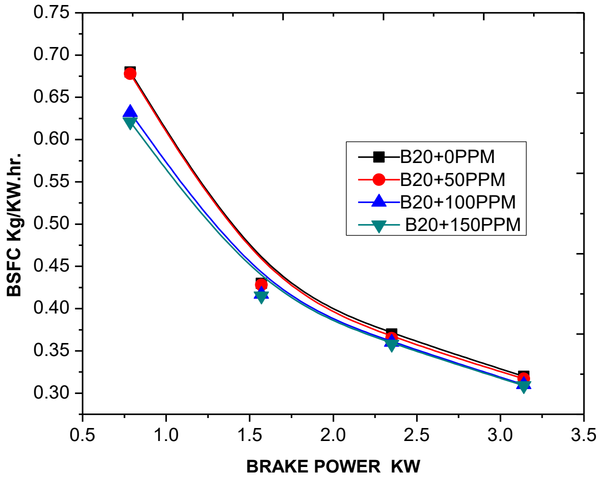


Figure 4. (a). Variation of BSFC with BP with graphene nano additives.

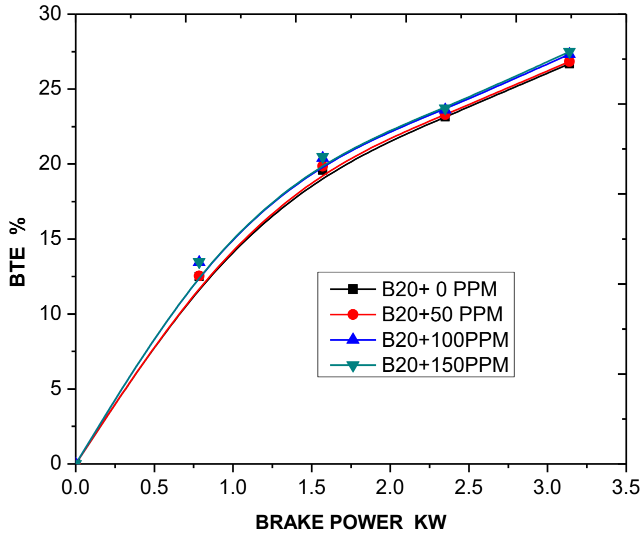


Figure 4. (b) Variation of BTE with BP with graphene nano additives.

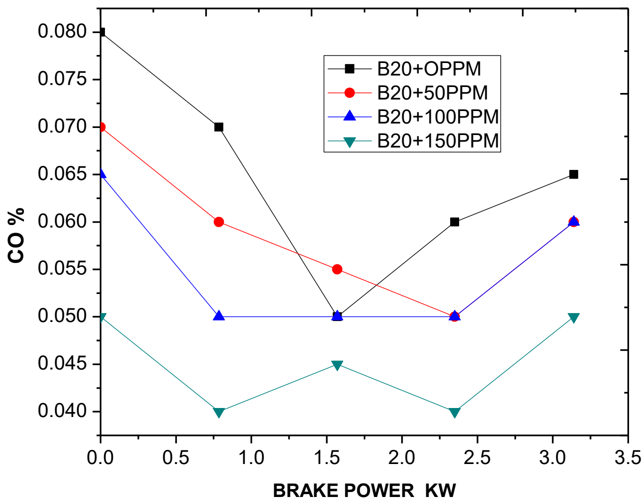


Figure 5. (a) Variation of CO with BP with graphene nano additives.

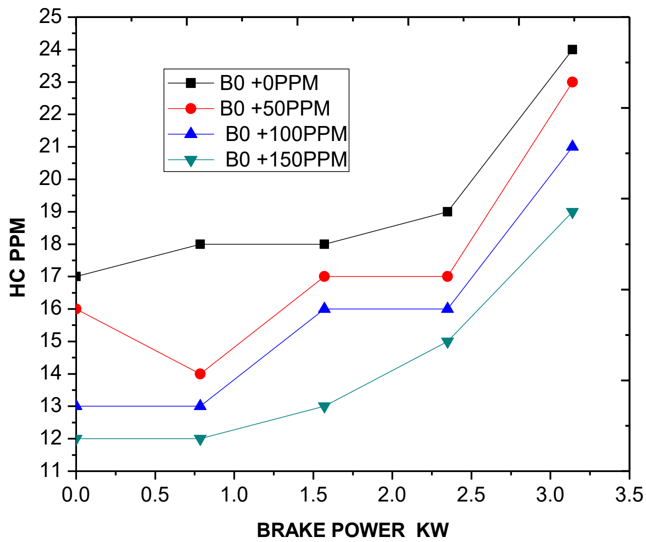


Figure 5. (b) Variation of HC with BP with graphene nano additives.

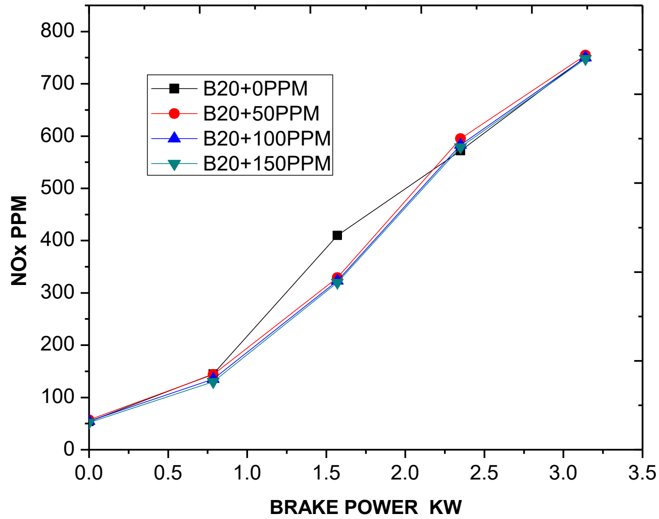


Figure 5. (c) Variation of NOx with BP with graphene nano additives.

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Conflict of Interest

Authors have no conflict of interest to declare

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