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Comparative Investigation of the Effect of Diethyl Ether and Nanoparticles as Fuel Additives in Diesel-biodiesel Blends on Performance Characteristics of Diesel Engine

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Abstract

Biodiesel, one of the most efficient alternative fuel sources for diesel, can meet today's energy needs. Biodiesel exhibits almost the same physicochemical qualities as diesel fuel. However, the dense nature of biodiesel creates an injector-clogging problem. Therefore, the primary aim of the paper is to enhance the fuel properties and performance of the diesel engine by utilizing fuel additives, namely diethyl ether (DEE) and aluminum oxide (Al_2O_3) nanoparticles, in the diesel-biodiesel blend. Biodiesel was prepared in-house from waste cooking oil using transesterification process. First, dual fuel blend of diesel and biodiesel oil is made by mixing 20% of waste cooking oil biodiesel (B20) volume/volume fraction with mineral diesel. After that, the above fuel additives are added to create ternary blends. The B20 fuel was mixed with 2.5% (B20E1) and 5% (B20E2) DEE by volume, and 1 g (B20N1) and 2 g (B20N2) concentration of Al_2O_3 nanoparticles. For a comparative investigation of dual fuel with ternary fuel, a 1-cylinder, 4-stroke diesel engine is operated at a constant speed of 1800 rpm with the variation of load conditions. The results of ternary fuel blends are analyzed compared to pure diesel and dual fuel blends. The results show that B20N2 (20% biodiesel and 2 g Al_2O_3) demonstrated the best performance parameters among all dual fuel blends and diesel fuel. B20N2 ternary blend exhibits an overall increase in brake thermal efficiency of 2.3% and 6.9%, an increase in indicated thermal efficiency of 17.1% and 3.7%, and a decrease in brake-specific fuel consumption of 9.3% and 13.3%, respectively.

Keywords

Biodiesel, Additives, Diethyl ether; Nanoparticles, Diesel engine

Introduction

Diesel engine performance is primarily influenced by operating conditions, engine design, and fuel types. The global exhaustion of diesel fuel has prompted the search for alternative sources [1]. Researchers have recently focused on biodiesel as an alternative to diesel, but its pure form is considerably viscous and can cause a clogging problem. The viscosity effect of biodiesel is suppressed by mixing a small fraction of biodiesel in diesel fuel. The blend B20 (20% biodiesel + 80% diesel) exhibits acceptable properties with the diesel fuel. It can be used in engines without needing to be modified. The fuel and engine performance characteristics can be further enhanced using ternary blends. It involves mixing the binary blend with additives such as ether, alcohol, or nanoparticles. Biodiesel fuel is obtained from sources like edible oil, non-edible oil, waste cooking oil, animal fat, and algae. Singh et al. [2] reviewed production of biodiesel using waste cooking oil (WCO) and its application as a fuel in CI engines. The physicochemical parameters of WCO biodiesel were comparable to those of diesel fuel. WCO biodiesel significantly decreased hydrocarbon (HC), particulates

(PM), carbon monoxide (CO), and smoke emissions when used in CI engines. The consequence of the oxygenated nature of biodiesel is higher NOx and CO_2 emissions compared to diesel fuel. To reduce emissions, antioxidants are added to biodiesel. Naik et al. [3] examined that mixing B20 with DEE at 5%, 10%, and 15% v/v can be beneficial in replacing the diesel fuel in the blend to raise the biofuel part in the blend without compromising engine characteristics. He showed that only 15% ether addition had better performance characteristics than other blends. The emission characteristics of all ether blends were better than diesel and biodiesel. Rajasekar et al. [4] looked into the application of aluminium oxide (Al_2O_3) in combination with B20 with watermelon seed oil to accomplish particular fuel qualities, enhance diesel engine performance characteristics, and produce improved engine emissions control without major modifications. Kumar et al. [5] analyzed the emission and performance parameters of diesel blends with biodiesel obtained from cedar wood oil with fuel additives like ZrO_2 and TiO_2 nanoparticles. It was found that all fuel blends showed improved performance parameters and reduced emission parameters of a diesel engine. Very few works of literature illustrate the comprehensive investigation of the diesel engine performance characteristics under the effect of triplicate blends of diesel-WCO biodiesel-DEE and diesel-WCO biodiesel-Al_2O_3 nanoparticles. Therefore, this study primarily aims to analyze the comparative effects of the triplicate blends on the diesel engine performance parameters such as brake power (BP), indicated power (IP), brake thermal efficiency (BTE), indicated thermal efficiency (ITE), brake-specific fuel consumption (BSFC), and mechanical efficiency vis-à-vis dual fuel blends (diesel + 20% WCO) and mineral diesel.

Materials and Method

Fuel preparation

The transesterification procedure, which comprises reacting WCO with methanol under the presence of NaOH catalyst, is used to transform WCO into biodiesel chemically [6]. Diesel-biodiesel-DEE and diesel-biodiesel-Al_2O_3 are the ternary blends utilized in this study. Due to similar physiochemical properties to diesel and biodiesel, DEE can be blended easily as an additive with these fuels [7]. An ultrasonicator (mLabs, 3.2 Ltr., 40,000 Hz frequency, 0 - 80 ˚C temperature) that uses ultrasonic frequency pulses is utilized for mixing Al_2O_3 nanoparticles in a predetermined proportion to avoid the pile-up in diesel-biodiesel blends. A homogenizer is then used to blend it with a sizable sample. Table 1 lists the different fuel blends that are tested in this study. Table 2 displays the various physicochemical characteristics of the examined fuels. The calorific value of the samples is measured by using a bomb calorimeter (Make: Parr 6200), fire point and flash point by Pensky Martin apparatus (Make: Macro Scientific Works Pvt. Ltd.), kinematic viscosity by Redwood viscometer (Make: Aditya, Model: No. 1), and density by the gravimetric method that is, dividing the mass of samples to the volume.

Table 1: Nomenclature for evaluated blends.

Sample No.	Fuel	Diesel	Biodiesel	DEE	Al_2O_3 nanoparticle
		(% vol)	(% vol)	(% vol)	(gram)
1	Diesel	100	0	0	0
2	B20	80	20	0	0
3	B20E1	77.5	20	2.5	0
4	B20E2	75	20	5	0
5	B20N1	80	20	0	1
6	B20N2	80	20	0	2

Experimental setup

The present study was conducted on a 1-cylinder, 4-stroke Mahindra Jeeto diesel engine. The engine is coupled to an eddy current dynamometer, as illustrated in figure 1. The engine is loaded using an eddy current dynamometer at various speeds and load conditions. Table 3 shows the detailed specifications of the engine and dynamometer. A steady state was achieved at a rated speed of 1800 rpm when the engine run for 15 to 20 minutes. The results are plotted at the rated speed of 1800 rpm with variation in load from 5 to 25 N-m in step size of 5 N-m. A gravimetric meter mounted on the dynamometer panel measured fuel consumption.

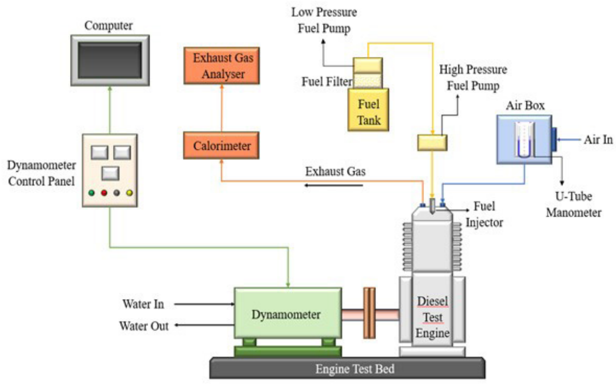

Figure 1: Diagrammatic illustration of the experimental setup.

Results and Discussion

The comparative effects of the triplicate blends (B20E1, B20E2, B20N1, and B20N2) on various performance characteristics of 1-cylinder diesel engine vis-à-vis dual fuel

Table 2: Thermophysical properties of different blends.

Properties	Diesel	B20	B20E1	B20E2	B20N1	B20N2
CV (kJ/kg)	44800	44623.28	44574.53	44384.52	44913.26	44949.37
Density (g/ml)	0.83	0.85	0.82	0.80	0.83	0.84
Flash point (˚C)	55	80	75	70	110	100
Fire point (˚C)	65	95	85	77	130	120

Table 3: Detailed specifications of engine and dynamometer.

Engine Specifications	
Make	Mahindra Jeeto
Engine type	1-cylinder, 4-stroke
Bore	93 mm
Stroke	92 mm
Swept Volume	625 cc
Rated power	8.2 kW at 3000 rpm
Compression ratio	18:1
Cooling system	Water-cooled
Dynamometer Specifications	
Model	E-51'LC'
Type	Eddy current
Max H.P.	70
RPM	4100/10000

blend (diesel + 20% WCO) and mineral diesel are discussed below.

Indicated power (IP)

Figure 2 shows the IP variance versus engine load. For all test fuels, IP increases with increasing load. It is evident from the graph that biodiesel and its blends have a higher IP in contrast to diesel. This is a consequence of biodiesel's higher oxygen concentration and cetane number than diesel, resulting in a shorter ignition delay (ID) and better combustion. In this study, the IP of B20 was 9.5% higher than that of diesel. Devkota et al. [8] and Malvade et al. [9] found a similar trend, where the IP of the B20 blend was 11.6% and 9.6% higher than that of diesel, respectively. DEE blends have higher IP than diesel because, although DEE has a lower CV, its lower density and viscosity improve fuel atomization quality and increase combustion efficiency [10]. B20N1 and B20N2 have higher IP than diesel by 0.44% and 1.17%, respectively, due to the nanoparticles enhancing the combustion process due to their high surface area to volume ratio and catalytic effect [11]. A similar trend is observed by Bello et al. [11], where the IP of the nanoparticle blend was 8% higher than diesel. Further, it was observed that biodiesel blended with nanoparticles had a lower IP compared to B20. A corresponding trend was observed by Das et al. [12], where the IP of the nanoparticle blend was 0.7% lower than that of biodiesel blend B20.

Brake power (BP)

The variance of BP versus engine load is depicted in figure 3. It is seen that biodiesel and DEE blends have somewhat

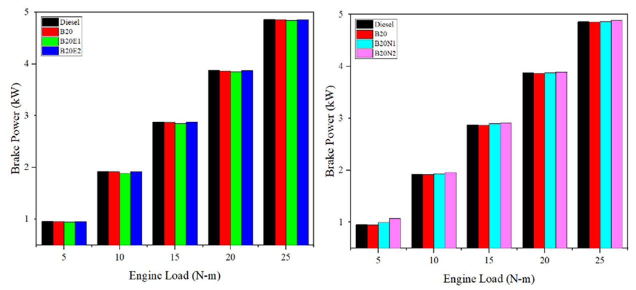

Figure 3: Variance of BP versus engine load.

lower BP than diesel, whereas the addition of nanoparticles has slightly increased BP. In this study, B20, B20E1, and B20E2 blends have BP lower by 0.18%, 0.43%, and 0.06%, respectively. Ali et al. [10] noticed a similar trend, where the BP of DEE blended fuel was 0.66% lower than that of B30. A fractional increase in BP was witnessed upon adding nanoparticles. This is because the Al_2O_3 nanoparticles raise the heat of fuel evaporation, which increases the fuel-air charge's density and, thus, the BP. This increase is attributed to Al_2O_3 high surface area and energy levels, which enable better oxidation [13]. Gumus et al. [14] noticed a similar trend, where a fractional increase in BP was noticed with the addition of nanoparticles.

Indicated thermal efficiency (ITE)

Figure 4 depicts the variance of ITE with engine load. The ITE for all the fuels decreases with increasing load due to increased mechanical friction [15]. Biodiesel and its blends have a higher ITE than diesel since biodiesel has more oxygen content than diesel, which aids in combustion [15]. A similar trend was observed by Liu et al. [15] and Singh et al. [16], where the ITE of the biodiesel blend was 5.2% and 4.6% higher than diesel, respectively. In this study, the ITE of B20E1 and B20E2 is 1.62% and 9.45% higher than diesel, respectively. Similarly, Chaudhary [10] and Ilangkumaran et al.[11] noted that the thermal efficiency of DEE blends was 8.5% and 3.2% higher than diesel, respectively. It is observed that the B20E2 blend has a higher ITE than the B20E1 blend by 7.7%. This was primarily caused by the DEE's higher volatility and decreased viscosity, which resulted in more efficient combustion [17, 18]. Lamani et al. [19] noticed a similar trend, where higher additive concentration increased the ITE by 5.2%. The ITE of the B20 blend with Al_2O_3 nanoparticles is higher in contrast to diesel on account of the increased combustion rate. This is attributable to the high surface-to-volume ratio of Al_2O_3 nanoparticles that enhances fuel oxidation by improving the rate at which the air-fuel ratio is mixed, leading to rapid heat

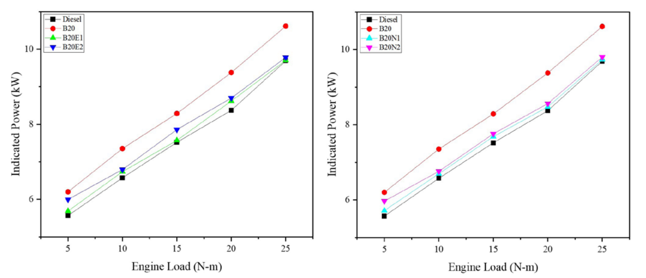

Figure 2: Variance of IP versus engine load.

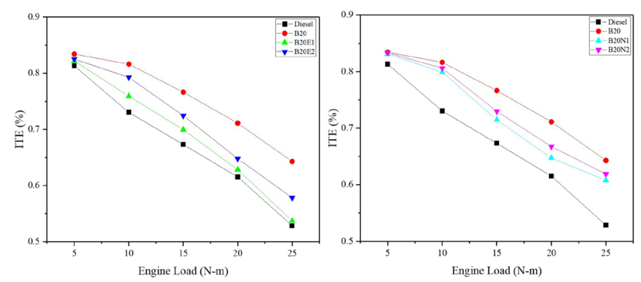

Figure 4: Variance of ITE versus engine load.

release, and increasing the BTE [20]. The ITE of B20N1 and B20N2 is 15.1% and 17.14% higher in contrast to diesel, respectively. Nagaraja et al. [20] found a corresponding trend, where the ITE of biodiesel blended with nanoparticles is higher by 13.1% compared to diesel.

Brake thermal efficiency (BTE)

The variance of BTE versus engine load for the respective fuels under investigation is depicted in figure 5. Biodiesel and DEE blends showed BTE lower than diesel, attributable to their higher density, viscosity, and lower calorific value, which decreased combustion efficiency [21]. BTE of B20, B20E1, and B20E2 were 4.3%, 9.42%, and 3.37% lower than diesel, respectively. Raju et al. [21] found a similar trend, where the BTE of B20 and B20 blended with DEE is 5.48% and 4.2% lower than diesel, respectively. The graph shows a considerable increase in BTE with the B20E2 blend, resulting from its lower density and viscosity, enhancing fuel atomization quality and increasing combustion efficiency [22]. The BTE of B20E2 is 6.67% higher than B20E1. A corresponding trend was observed by Sivalakshmi et al. [22], where BTE increased by 5.3% with the rise in DEE concentration. The Al_2O_3 nanoparticles assist in overcoming the low calorific value and high viscosity that lowers the BTE of B20 fuel blends. The increased oxygen content and greater availability of active contact surfaces of nanoparticles make it easier for air and fuel to mix appropriately, resulting in a higher HRR and complete combustion [23]. The BTE of B20N1 and B20N2 increased by 6.36% and 6.96% compared to B20. Krupakaran et al. [24] found a similar trend, where the BTE of biodiesel blended with nanoparticles increased by 4.2% compared to B20. In this study, the B20N2 blend demonstrated the highest BTE compared to the other tested fuels.

Mechanical efficiency (ME)

Figure 6 demonstrates the variance of ME versus engine load. The ME increases with increasing load due to a decrease in friction power with an increase in load. Biodiesel and DEE blends have lower calorific values, lowering their ME than diesel [25, 26]. In this study, the ME of diesel is 8.78% higher than B20. A similar observation was made by Sayyed et al. [18], where the ME of diesel was 9.5% higher than the biodiesel blend. Further, it is noted that the ME of blends increases as the additive content increases. This was primarily caused by the DEE's higher volatility and decreased viscosity, which resulted in better combustion [27]. Blending nanoparticles in B20 fuel blends improves the ME of the blends by allowing more fuel to react with air, enhancing the surface-to-volume ratio and encouraging complete combustion [28]. In this study, the ME of B20N1 and B20N2 is 6.7% and 5.61% less than diesel, respectively. Ninawe et al. [29] found a similar trend, where the ME of biodiesel blended with nanoparticles was 4.9% less than diesel.

Brake-specific fuel consumption (BSFC)

The variance of BSFC versus engine load is represented in figure 7. It is noticed from the graphs that the BSFC decreases as the load increases for all the sample fuels. The lower calorific value of B20, B20E1, and B20E2 blend fuels results in less efficient combustion and is primarily responsible for their higher BSFC [22]. In this study, the BSFC of B20, B20E1, and B20E2 is 4.6%, 11.92%, and 2.72% higher than diesel. A corresponding observation was made by Sivalakshmi et al. [22], where the BSFC of biodiesel and biodiesel blended with DEE was 11.72% and 4.8% higher than diesel. The graph shows a significant decrease in BSFC for the B20E2 blend attributed to its lower density and viscosity, improving fuel atomization quality, and increasing combustion efficiency [30]. In this study, the BSFC of B20E2 is 8.1% lower than B20E1. A similar observation was made by Raju et al. [21], where the BSFC decreased by 3.5% on increasing the concentration of additive DEE. The improved physical and thermal properties, for instance, higher calorific value and high ratio of surface-area-to-volume of fuel blends containing nanoparticles, stimulate shorter ID and better combustion efficiency, resulting in a lower BSFC than diesel and B20. In this study, the BSFC of B20N1 and B20N2 is 10.86% and 13.37% less than diesel, respectively. Nagaraja et al. [20] noted a similar trend, where the BSFC of biodiesel blended with nanoparticles was 11.1% less than diesel. The B20N2 blend demonstrated the lowest BSFC compared to the other tested fuels. Table 4 summarizes the percentage (%) deviation in performance characteristics

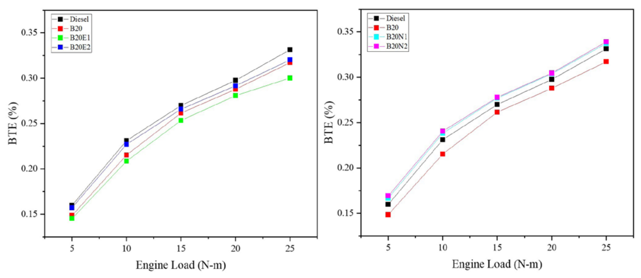

Figure 5: Variance of BTE versus engine load.

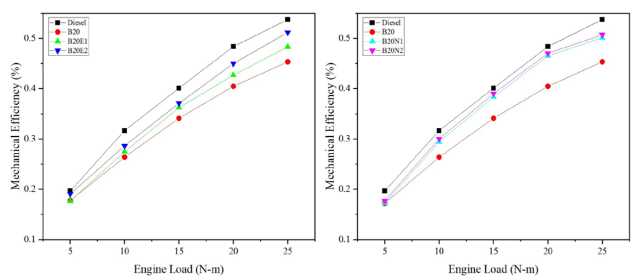

Figure 6: Variance of ME versus engine load.

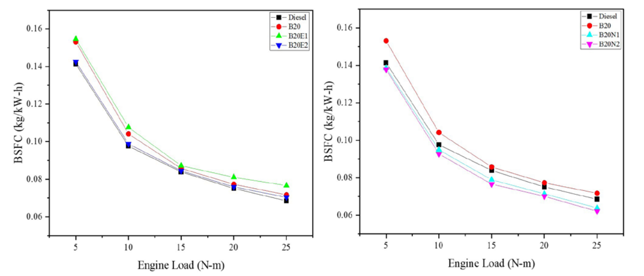

Figure 7: Variance of BSFC versus engine load.

Table 4: Percentage (%) deviation in performance characteristics on adding fuel additives with respect to pure diesel (B0) and blend B20.

Parameters	B20E1		B20E2		B20N1		B20N2	
	B0	B20	B0	B20	B0	B20	B0	B20
IP	↑0.15	↓8.57	↑0.96	↓7.84	↑0.44	↓8.31	↑1.17	↓7.64
BP	↓0.43	↓0.25	↓0.06	↑0.12	↑0.08	↑0.27	↑0.56	↑0.74
ITE	↑1.62	↓16.47	↑9.45	↓10.04	↑15.01	↓5.47	↑17.14	↓3.72
BTE	↓9.42	↓5.34	↓3.37	↑0.97	↑1.78	↑6.36	↑2.35	↑6.96
ME	↓10.08	↑6.56	↓4.74	↑12.89	↓6.70	↑10.56	↓5.61	↑11.86
BSFC	↑11.92	↑6.95	↑2.74	↓1.82	↓6.72	↓10.86	↓9.34	↓13.37

on adding fuel additives at a constant speed of 1800 rpm and engine load of 25 N-m.

Conclusion

The present study emphasizes analyzing the use of DEE and Al_2O_3 nanoparticles as additives in the diesel-biodiesel fuel blend to compare the improvement in diesel engine performance. The following conclusions can be drawn from the present comparative study:

- Ternary blends had higher IP and ITE values than diesel; B20N2 showed a maximum increment in IP and ITE, followed by B20N1, respectively, B20E2 and B20E1.
- Ternary fuel blends reduced the BSFC compared to diesel and B20. B20N2 exhibited a maximum reduction of 13.37%, followed by B20N1 with 10.86% compared to B20 fuel.
- Ternary fuel blends demonstrated an increase in BTE. B20N2 showed an increase of 6.96%, followed by B20N1 with 6.36% compared to B20 fuel.
- Ternary fuel blends evidenced a fractional increase in BP compared to diesel and B20 fuel.
- All ternary fuel blends presented a significant increase in ME. B20E2 exhibited an increase of 12.89%, followed by B20N2 with 11.86% compared to B20 fuel.

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None.

Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Himanshi Gupta: Investigation, Formal analysis, Writing - original draft preparation, Writing - review and editing; Jitendra N. Gangwar: Resources, Writing - original draft preparation, Writing - review and editing, Supervision; Ayushi Vishwakarma: Conceptualization, Methodology, Investigation, Formal analysis; Shantanu Srivastava: Conceptualization, Methodology. All the authors read and approved the manuscript.

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