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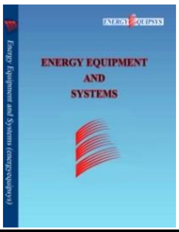

Performance and emission properties of CI engine using blends of diesel and 1-butanol

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ABSTRACT

Marine diesel engines, which heavily rely on fossil fuels, release harmful emissions into the atmosphere. To reduce this, we need to find alternative fuels, either by developing new options that reduce emissions or by exploring biofuel alternatives for marine engines. The present study investigates the performance characteristics and emission profiles of a marine compression ignition (CI) engine. Experiments were conducted utilizing three distinct blends of pure diesel, BDB5 (95% diesel + 5% 1-butanol), and BDB10 (90% diesel + 10% 1-butanol), with their properties confirmed to be within the acceptable limits of American Society for Testing and Materials (ASTM) standards. Testing was performed on a dedicated compression ignition engine test apparatus under 100% loading conditions, spanning an engine speed range from 1000 to 3200 rpm. The experimental result shows that the average decrease in the torque, brake power (BP), and exhaust gas temperature (EGT) is observed 1.2%, 1.35%, and 1.33% for BDB5, and 6.4%, 6.87%, and 2.19% for BDB10, respectively. The decrement in exhaust gases like oxides of Nitrogen (NO_x), carbon monoxide (CO), and Carbon dioxide (CO_2) is decreased by 6.9%, 4.79%, and 3.65% for BDB5 and 11.07%, 6.53%, and 7.93% for BDB10, respectively. A significant decrease of 18.29% & 32.88% in smoke is noted for BDB5 and BDB10 fuel blends, respectively, when compared with pure diesel. An increment of 2.14% (BDB5) and 8.55% (BDB10) is observed in brake-specific fuel consumption (BSFC). Despite the minor compromises, the substantial emission reductions offered by 1-butanol/diesel blends indicate their strong potential as a cleaner alternative fuel for marine propulsion systems.

Keywords: Diesel; Emissions; Performance; 1-Butanol; Blends.

1. Introduction and Literature Review

Marine diesel engines are one of the world's most representative fossil fuel users. Alcohol based fuels are thought to be ideal as carbon-neutral, eco-friendly alternatives to fuels for marine CI engines. The working of land-based automotive and marine diesel engines is practically the same. The shipping industry still relies heavily on fossil fuels. These fuels, which include petroleum diesel, are a finite resource and are being depleted at a rapid rate [1, 2]. Hydrocarbon-based fuel emissions pose a threat to both human health and the environment [3, 4]. Globally, enormous amounts of research are being done to find a fuel substitute for petroleum [5, 6]. Countries have different oil

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feedstocks that are used to make biodiesel and alcohol based fuel, which has been suggested to be the best substitute for petroleum diesel [7–9]. Researchers have examined the emission and performance of CI engines running on 1-butanol, although the mixing of diesel and biodiesel has been extensively researched. Magin et al. [10] studied ethanol and n-butanol blends to test the steady-volume engine auto-ignition feature. The results showed that ethanol improves auto-ignition quality more than n-butanol does. Analogous research on the effects of ethanol and n-butanol was conducted by Dimitrios et al. [11], who determined that the proportion of n-butanol and ethanol reduces NO_x emission. Peter et al. [12] suggested that the cost of n-butanol influences the manufacturing of biodiesel. Sukjit et al. [13] revealed that the performance characteristics (such as BP, torque, BTE, BSFC, etc) and emission parameters (such as HC, CO, CO_2, NO_x, etc.) are significantly influenced by short-chain alcohol-based additives. Chotwichien et al. [14] found that at lower temperatures, n-butanol reduces instability. Qing et al. [15] found that the cold filter plugging point (CFPP) decreases from 5.8 to 0.2 as the cetane number rises. Karabektas et al. [16] examined diesel and isobutanol blends and determined that performance characteristics are slightly increased and emission parameters decrease. Yilmaz et al. [17] examined the characteristics and emission parameters, which are slightly deviated. Researchers have found that when CI engines run on a diesel-butanol blend, they exhibit improved performance and reduced emissions. Specifically, the BSFC and BTE increase, while EGT, CO, HC, and NO_x emissions decrease [18,19]. Atmanli et al. [20] investigated the use of n-butanol and vegetable oil blends with diesel on CI engines and found variations in parameters. Lujaji et al. [21] worked on croton oil and butanol with diesel and found that performance characteristics increase and emission parameters decrease. Chen et al. [22] investigated the mixture of diesel with n-butanol and evaluated the various performance characteristics and emission gases of CI engines. Zhang et al. [23] and Yoshimoto et al. [24] studied the mixture of diesel, butanol, and biodiesel, and the result shows that the performance characteristics improved and characteristics for the emission are reduced. Z. Zhang et al. [25] investigated the emission and characteristics of CI engines using blends of diesel and biodiesel. They found that these characteristics improved when using an Fe_2O_3-based diesel oxidation catalyst (DOC) and selective catalytic reduction (SCR) catalysts. It has been observed that by reducing the in-cylinder pressure, nozzle diameter, temperature, the nitrous oxide (NO) emissions increase but soot emissions and hydrocarbon (HC) decrease [26]. The characteristics & emission for the combustion of the marine engine are improved by water and hydrogen [27]. I. Baratian et al. [28] examined the blends of bioethanol and gasoline using technique for order preference by similarity to ideal solution (TOPSIS) methodology in Spark Ignition (SI) engine & found that CO_2 and NO_X emissions rise, but unburned hydrocarbons (UBHC) and CO emissions fall.

Research shows a significant amount of work has been done on ternary fuel blends. However, there is limited investigation into binary fuel blends of diesel and 1-butanol, especially concerning their performance under varying speeds and constant loads. The current study employs a 4-stroke, single-cylinder CI engine test rig with a blend of diesel & 1-butanol in different ratios. Evaluations are conducted using an 18:1 compression ratio, a speed range from 1000 to 3200 rpm, and continuous full load conditions. The performance and emission characteristics are plotted against speed for various blends under consideration. The graphs are plots for EGT, BP, torque, BTE, BSFC, HC, CO, CO_2, and NO_x.

The novelties of this study are following:

- Focus on binary blends with 1-butanol under varying speeds and constant load.
- Detailed performance and emission mapping across a wide speed range.
- Investigation of Engine Noise with 1-butanol blends.

Abbreviations

ASTM	American society for testing and materials
BSFC	Brake-specific fuel consumption
BTE	Brake thermal efficiency
BP	Brake power

kW	Kilo-watt
EGT	Exhaust gas temperature
CO_2	Carbon dioxide
CO	Carbon monoxide
NO_x	Oxides of nitrogen
HC	Hydrocarbon
%	Percentage
°C	Degree celsius
BDB5	Diesel 95% + 1-butanol 5%
BDB10	Diesel 90% + 1-butanol 10%

2. Experimental Parameters

Two stages of testing were carried out: the first stage focused on the creation and characterization of the blends, while the second stage involved experimental inquiry to assess the emission and performance characteristics.

2.1. Characterizations and Preparation of Blends

When making the blends, 1-Butanol is an essential ingredient because its key characteristics include removing impurities from biodiesel, speeding up the reaction process, enhancing cold-flow characteristics, and reducing viscosity. The volume percentage-based blends that consider diesel and 1-butanol. The blends maintained the same 1-butanol % contribution to diesel. Table 1 gives the nomenclature and blend-specific contributions of diesel and 1-butanol. Several physical and chemical characteristics are assessed during characterization using the ASTM standard test procedure.

2.2. Investigations of the Experiment

For the study, experiments were conducted on a 4-stroke compression ignition engine test rig. The details of the CI engine are provided in Table 2.

The studies were conducted with varying speeds (1000 rpm to 3200 rpm) and full load conditions. The different performance characteristics, for example BP, BSFC, BTE, and EGT, are observed while the characteristics of emissions, such as HC, CO, CO_2 and NO_x are also observed with the help of MGA-2 gas analyzer made by Netel. All other performance criteria are computerized, as the engine test rig, such as speed of the engine, temperature, water levels in the rotameter, and torque, are noted and all the data were recorded in a computer and provided in Table 3. The digital image of the test rig of CI engine is provided in Fig. 1.

Table 1. Blends nomenclature and contributions of diesel and 1-butanol to blends

Nomenclature of Blend	Diesel	1-Butanol
Diesel	100	0
BDB5	95	5
BDB10	90	10

Table 2. Technical details for the test rig of a 4-stroke compression ignition engine

S. No	Name	Details
1	Make & Model	TV- 1 & Kirloakar
2	Engine Type	Vertical CI engine
3	Cooling	Water Cooled
4	Number of Stroke	4
5	Number of cylinders	1
6	Bore X stroke (mm)	87.5 X 110
7	Compression ratio	17.5:1
8	Dimensions LXWXH (mm)	617 X 504 X 877
9	Fuel tank capacity (liters)	6.5
10	Engine weight (kg)	160
11	Flywheel rotation	Clock wise
12	Type of Fuel Injection	Direct Injection
13	Rated power (kW)	5.2
14	Dynamometer	Eddy current

Table 3. Experimental device with measuring range

Name	Range
Pressure intake sensor	0 to 5 bars
Pressure exhaust sensor	1 to 10 bars
Temperature intake sensor	-40 to +85^{0}C
Temperature exhaust sensor	0 to 1000^{0}C
Meter for fuel consumption	0 to 50 kg/hr
Meter for air flow	0 to 500 slpm
Dynamometer	0 to 100 kW
	CO: 0-10%vol
Exhaust gas analyzer	CO_2: 0-16%vol
	NO_x: 0-5000ppm

Fig. 1. Compression ignition engine test bench

3. Results and Discussion

3.1. Characterizations

When characterizing attributes, both chemical and physical, compared to petroleum diesel, 1-butanol has been found to have higher density and kinematic viscosities. Similarly, when comparing 1-butanol to petroleum diesel, it is noted that the lower value of cetane number and lower heating values. The measured density falls between 834 and 842 kg/m^3. Similarly, the observed values of cetane number, kinematic viscosity, and lower heating are 51-53, 2.40-2.82 mm^2/s, and 41.1-42.7 MJ/kg, respectively. Table 4 shows how the attributes of the blends under discussion vary.

Table 4. Variation in the qualities of the blends that are being studied

Blend Nomenclature	**Kinematic Viscosity (mm^2/s)**	**LHV (MJ/kg)**	**Cetane number**	**Density (kg/m^3)**
Measuring Instruments	Visco-meter bathtub	Bomb calorimeter	Ignition quality tester	Hydro-meter
Unit	mm^2/s	MJ/kg	Number	Kg/m^3
ASTM Std	ASTM D445	ASTM D240	ASTM D613	ASTM D941
Diesel	2.42	42.31	51.03	840.52
BDB5	2.62	41.62	51.49	839.03
BDB10	2.81	41.16	52.41	835.74

3.2. Performance Characteristics

Figure 2-6 demonstrates the diesel and 1-butanol blends' performance characteristics. Figure 2 shows the torque with respect to speed. The value of torque was found to be maximum at 1400 rpm for all blends. The maximum value of torque was found 34.68, 34.10, and 32.63 Nm for diesel, BDB5, and BDB10, respectively. The value of torque decreases with increasing the proportion of 1-butanol in the blend. Figure 3 provides information on brake power with the variation of speed. The maximum value of brake power occurs at 2600 rpm. Brake power reduces as the quantity of butanol increases in the blend. Figure 4 illustrates the BSFC with respect to speed. The BSFC drops as the speed increases, reaching its lowest point of 254.12 gm/kWh at 2400 rpm. Beyond this speed, the BSFC rises to 400 gm/kWh at 3000 rpm. Additionally, the minimum BSFC value increases as more 1-butanol is added to the fuel blend. Figure 5 shows the information about BTE with respect to speed. The maximum value of BTE was 31.92% at 2400 rpm for BDB5. The reduced values of BTE were observed with the increased butanol quantity in the fuel blend. Figure 6 provides information about EGT in the variation of speed. It was observed that the maximum gas temperature occurs at 2600 rpm for all blends. The value of EGT decreases with the quantity of 1-butanol increases in the blends and is observed 651°C for BDB10.

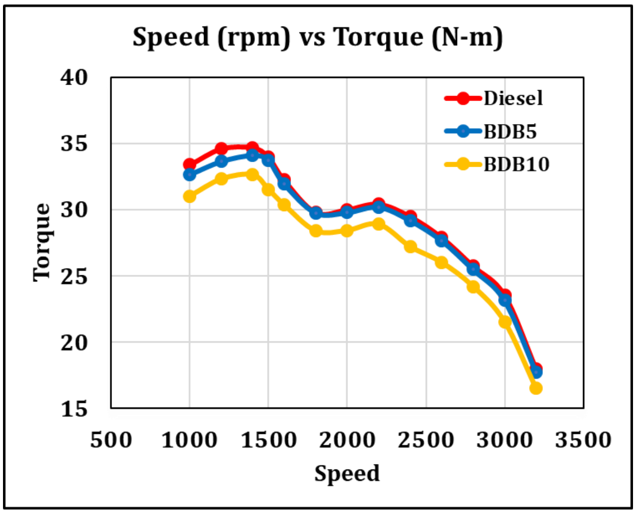

Fig. 2. Torque vs engine speed

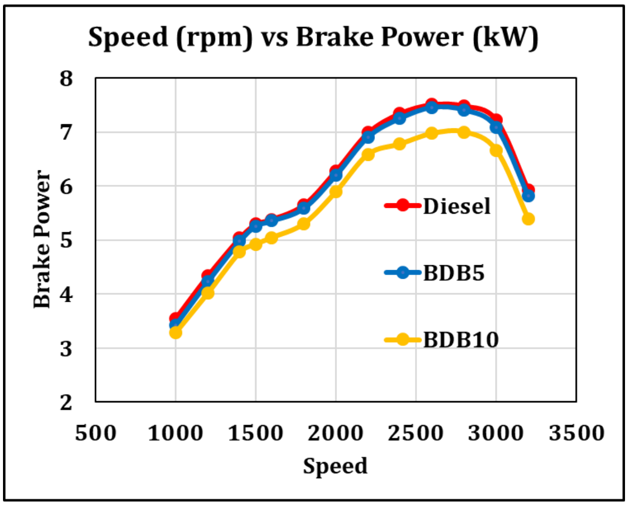

Fig. 3. Brake power vs engine speed

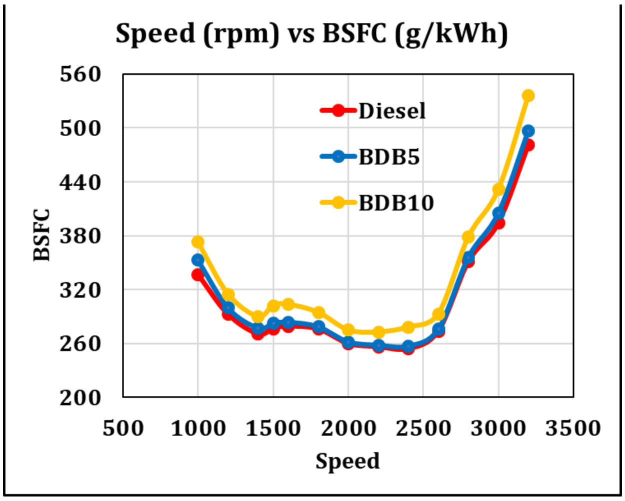

Fig. 4. BSFC vs engine speed

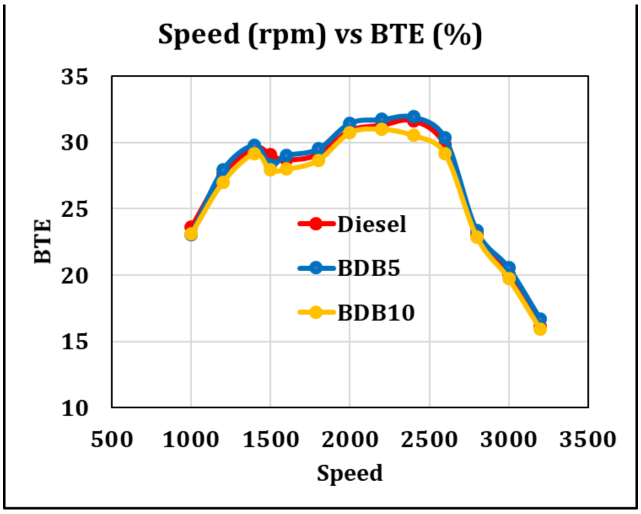

Fig. 5. BTE vs engine speed

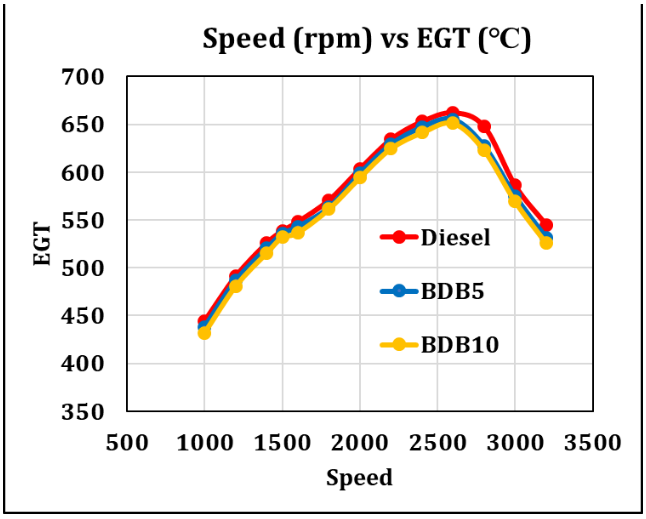

Fig. 6. EGT vs engine speed

3.3. Emission Characteristics

The particles released by marine diesel engines are complex in composition, consisting of inorganic micron-sized particles mostly composed of sulfates and ashes. The carbonaceous particles range in size from a few nanometers to less than one micron. The emission properties of diesel and 1-butanol blends is illustrated in Figs. 7-11.

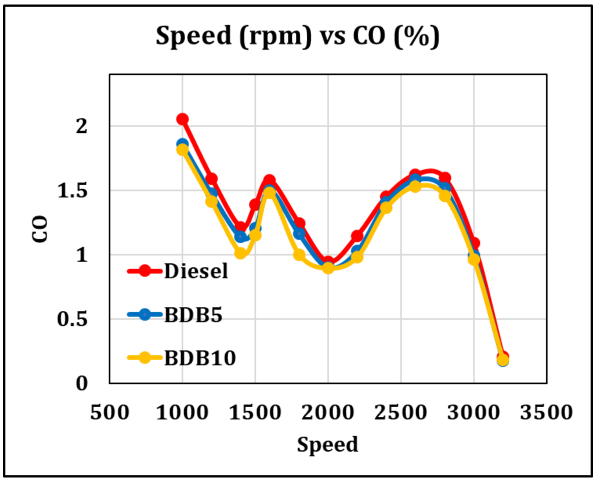

Fig. 7. CO vs engine speed

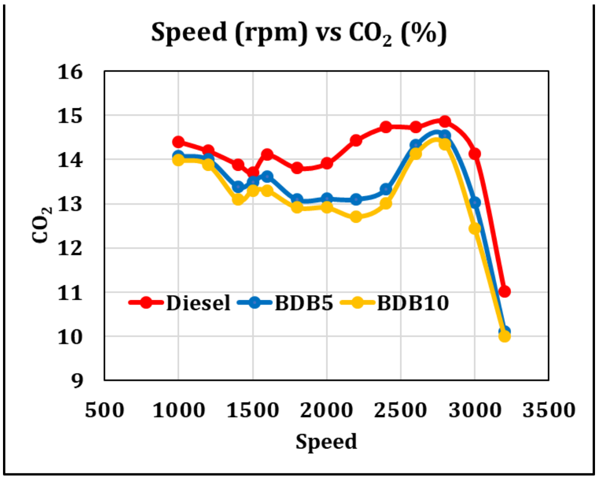

Fig. 8. CO_2 vs engine speed

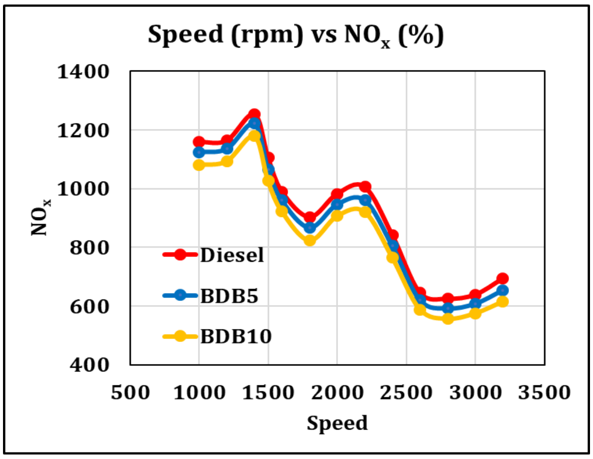

Fig. 9. NO_x vs engine speed

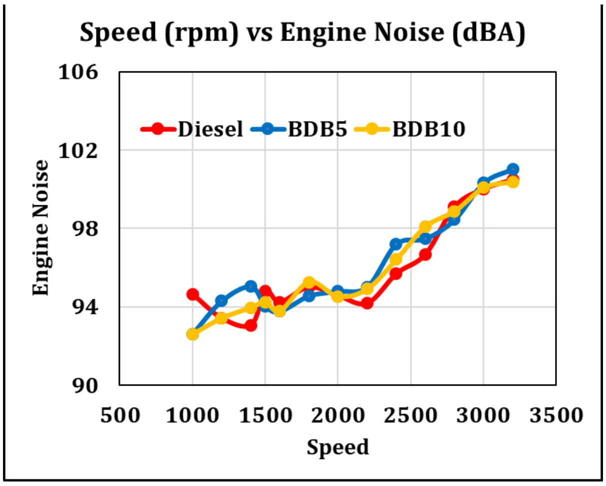

Fig. 10. Engine noise vs engine speed

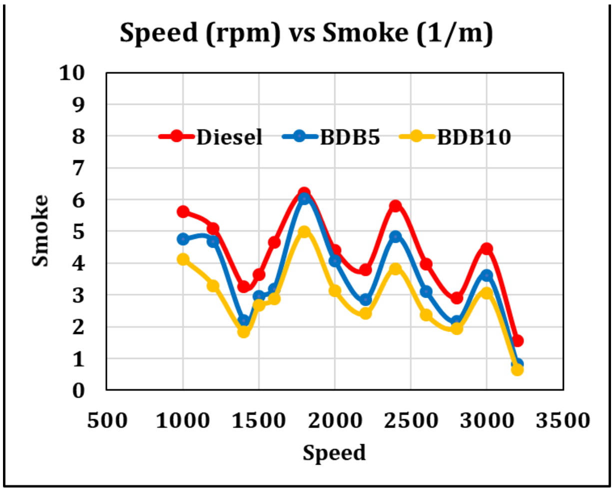

Fig. 11. Smoke vs engine speed

Figure 7 shows that as speed increases, the emission gas carbon monoxide (CO) reduced. 1-butanol has a higher oxygen content compared to diesel, which contributes to a reduction in soot emissions. CO emission decreases by 7, and 11% for BDB5 and BDB10, respectively. Fig. 8 shows CO_2 emissions with respect to speed. The maximum value of CO_2 emission was found to be 14.86, 14.54 and 14.34 % for Diesel, BDB5, and BDB10, respectively. It was found that as the 1-butanol content rises in the blend, CO_2 emission reduces. According to Fig. 9, nitrogen oxide (NO_x) emissions increase with speed. NO_x is composed of both nitrogen monoxide (NO) and nitrogen dioxide (NO_2), with a higher proportion of NO. The peak NO_x emission was observed at 1400 rpm. The specific NO_x emissions for diesel, BDB5, and BDB10 were measured at 1253 ppm, 1221 ppm, and 1179 ppm, respectively. Fig. 10 shows engine noise with respect to speed. The highest engine noise was observed at 3200 rpm and the lowest engine noise was observed at 1200 rpm. The noise of the engine was reduced by increasing in the amount of alcohol in the blends. Fig. 11 illustrates the information about smoke with speed. The maximum value of smoke was measured at 1800 rpm for pure diesel. The amount of smoke decreases with an increase in the quantity of alcohol in the blend.

4. Conclusions

Based on experiments with a Kirloskar compression-ignition (CI) engine test rig using a blend of 1-butanol and diesel in different ratios. The various key findings were observed.

- The maximum value of torque was found 34.68 N-m for diesel. The value of torque decreases with increasing the proportion of 1-butanol in the blend.
- The maximum value of BP 7.5 kW occurs at 2600 rpm for diesel. Furthermore, BP reduces as the quantity of 1-butanol increases in the blend due to the lower heating value of 1-butanol.
- The minimum value of BSFC is 254.12 gm/kWh at 2400 rpm for diesel. However, no significant increase was observed in the BSFC for the blends.
- The BTE increased with speed up to 2400 rpm and then decreased. The highest efficiency (31.92%) was recorded for the BDB5 blend at 2400 rpm.
- The EGT decreased with an increase in engine speed. However, using 1-butanol blends significantly lowered EGT (651°C for BDB10.) compared to pure petroleum diesel (662°C).
- The CO emission decreased by 7, and 11% for BDB5 and BDB10, respectively. The concentration of 1-butanol also led to a decrease in CO emissions as engine speed increased.
- As the 1-butanol content rises in the blend, CO_2 emission reduced. The minimum value of CO_2 emission was observed at 14.34 % for BDB10.
- The NO_x reduced as the concentration of 1-butanol increased in the blend. The minimum value of NO_x was found to be 1179 ppm for BDB10 at 1400 rpm.
- The maximum (101 dBA) and minimum (92.59 dBA) engine noise was observed at 3200 rpm and 1000 rpm, respectively, for BDB5 and BDB10.

It has been concluded from the results that the diesel has more torque and brake power due to better heating value, and the emission parameter can be reduced by using 1-butanol blends. However, to fully validate these findings and determine the optimal blend, a long-term test is necessary. Furthermore, an in-depth research is required to investigate long-term operational effects and broader economic viability.

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