AN ENERGY, AND EMISSION ASSESSMENT OF DIESEL ENGINES POWERED WITH SHOREA ROBUSTA BIODIESEL AND BLENDS

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SUMMARY

The present investigation examines the exergy, energy, and pollutants of a diesel-powered engine fuelled with a blend of Shorea Robusta Biodiesel (SRB) and normal diesel. The impact of engine power, speed, and fuel mix on emissions and operating characteristics are investigated. The use of blended fuels including SRB reduces a number of performance metrics, including BTE, exergy efficiency, and the sustainability index. Furthermore, CO (carbon monoxide), smoke, and HC (hydrocarbon) emissions are reduced when compared to utilising pure diesel fuel. SRB20 has the lowest HC emissions among the mixes SRB. At an engine speed of 1500 rpm and a power output of 5.5kW, SRB10, SRB20, and SRB30 blends lower HC emissions by 8.92%, 10.71%, and 7.14%, respectively. Similarly, when compared to conventional diesel fuel, SRB10, SRB20, and SRB30 blends reduce CO emissions by 1.25%, 5%, and 6.25%, respectively.

KEYWORDS

SRB, Transesterification technique, BSFC, HC, CO & NO

NOMENCLATURE

BP	shaft power
BTE	brake thermal efficiency
BSFC	brake specific fuel consumption
$C_{p,a}$	isobaric specific heat
ES	exergy based sustainability
Ew	exergy rate of coolant
$\dot{E}_x$	rate of exergy
CV	caloricfic value (MJ/kg)
$\dot{m}$	flow rate of mass (kg/s)
N	shaft speed(rpm)
$\dot{n}$	moles number
SRB10	10% shorearobusta biodiesel blend
SRB20	20% shorearobusta biodiesel blend
SRB30	30% shorearobusta biodiesel blend
P	pressure (bar)
R	gas constant
rpm	revolution per minute
$\dot{S}_{gen}$	rate of entropy generation
T	temperature (°C)
Y	mole fraction
ϕ	chemical exergy factor

SUBSCRIPT

a	air
c	coolant
des	destruction
f	fuel
l	loss
g	exhaust gas
gen	generation
ref	dead state
w	shaft power
Ph	physical
Ch	chemical

1. INTRODUCTION

The rising global energy demand and the detrimental effects of traditional energy sources on the environment present substantial challenges. In order to establish a cleaner and sustainable energy future, it is crucial to expedite the shift towards renewable energy sources, enhance energy efficiency, and adopt innovative technologies that mitigate environmental impact. Biofuels, derived from renewable biological sources such as plants, algae, and organic waste materials, have garnered significant interest as a feasible substitute for traditional non-renewable energy sources. Continued technological advancements and an increasing emphasis on sustainability are expected to propel the growth and utilization of biofuels in the global quest for a low-carbon future (Pandey et al., 2021).

Several research articles [Koçak et al., 2007, Utlu et al., 2007, Dhar et al., 2012, Utlu et al., 2008, and Can, 2014, Zhou et al., 2024] were readily available that focused on analyzing energy, emissions, and combustion characteristics in engines utilizing various biodiesel-diesel blends. An engine's performance and pollutant characteristics were assessed by Man et al., 2016 using blended fuels made up of diesel and biodiesel at concentrations of 10%, 20%, 30%, and 100%. The experiment's findings showed that adding more biodiesel to a mix decreased HC, PM, and CO emissions, while raising levels of NOx, formaldehyde, acetaldehyde, and benzene. The operational and pollutant characteristics of a diesel powered engine powered by blends of cymbopogonflexuosus biodiesel at concentrations of 10%, 20%, 30%, 40%, and 100% were studied by Dhinesh et al., 2016. The experimental results indicate that the fuel blend comprising 20% cymbopogonflexuosus biodiesel exhibited a performance profile that was comparable to that of conventional diesel fuel. When using the 20% mix gasoline, the engine's BTE increased whiles its pollutant level of CO, smoke, and HC lowered. These results indicate the biodiesel mix with 20% cymbopogonflexuosus has the potential to be a fuel substitute.

Using a dual biodiesel blend fuel made of Jatropha and Turpentine biodiesel, Dubey and Gupta, 2017 conducted an examination of combustion and pollutant levels. Their study's findings supported the merits of using biodiesel mix fuels in the context of compression ignition (CI) engine applications as well as their prospective advantages. Yilmaz et al., 2018 experimental examination of the operation and emissions of engines running on quaternary mixes of pentanol and propanol combined with diesel, vegetable oils, and biodiesel. The test findings indicated a significant decrement in NOx levels but increment in CO and HC levels, due to the higher alcohols' poor auto-ignition capabilities. When employing mixtures of animal-origin biofuels and diesel, Duda et al., 2018 examined the operational and polluting properties of diesel powered engines. The study shown that, it is possible to manufacture high-quality gasoline from waste fatty materials. The study also found that although there could be a modest loss in engine operational characteristics, mixtures with up to 75% bio-component are compatible with contemporary CI engines. Using fuel made from a mixture of waste cooking biodiesel (WCOB) and diesel, Yesilyurt, 2019 performed a research to look at the effects of various injection pressures, ranging from 170 bar to 220 bar, on the operational and polluting properties of diesel-powered engines. The study's findings showed that 210 bars was the ideal fuel injection pressure for WCOB and diesel mixes in order to get the best performance.

To enhance the operational efficiency of a diesel-powered engine using a combination of diesel and Shorearobusta methyl ester (SRME) biodiesel, Rai et al., 2020 used Taguchi and Grey optimization techniques. Through experimental inquiry and analysis, it was discovered that a fuel mix with 30% SRME, a load of 10 kg, and a compression ratio (CR) of 17 produced the optimum engine performance and heat losses. In their research, Rai et al., 2021 investigated the emissions, exergy, energy characteristics, and sustainability of an engine. The study examined various conditions, including CR, engine load, and the proportion of Shorearobusta methyl ester (SRME) biodiesel in the fuel. The results of the study suggest that enhancements in BTE, second law efficiency, engine durability, and exergy destruction rate can be achieved by elevating the engine load, CR, and the concentration of SRME in diesel fuel.

Saraswat et al., 2022 carried out an experimental investigation on a VCR engine using different compression ratios and mixtures of algae biodiesel and diesel. The experimental findings showed that while NO emissions increased, HC and CO emissions decreased when biodiesel was blended in. Kothare et al., 2023 carried out the experimental examination of SI engine using a combination of binary and ternary n-pentanol, ethanol and gasoline to enhance the performance and reduce emissions. The engine with 10% ethanol,1.5% n-pentanol, and gasoline blend provides minimal CO and HC emissions with highest BTE and lowest BSFC. The operational stability of a dual fuel engine using a combination of diesel and methanol under varied injection strategies was investigated by Kakati et al., 2024. It is demonstrated that the partially premixed mode under the split injection strategy shows considerable promise in lowering the operating harshness, backed up by a lower peak pressure grow, and raising the combustion cycle recurrence as indicated by significantly lower ratings of the parameters taken into consideration for visualizing stability.

In summary, the investigation of alternative sources for biofuel production has led researchers to consider the potential of SRB as a viable option. The aim of this investigation is to evaluate the possible usefulness of SRB as a source of fuel for diesel engines and assess its performance attributes, including energy and emission attributes such as HC, CO, and NO emissions in an engine operating at different power and speed.

2. FUEL PREPARATION, MEASUREMENT OF PROPERTIES, AND EXPERIMENTAL INVESTIGATION FOR SHOREA ROBUSTA BIODIESEL FUEL

2.1 INGREDIENTS AND FUEL PREPARATION TECHNIQUES

Biodiesel derived from Shorea robusta was procured from a vendor located in Varanasi, India. Sodium hydroxide (NaOH), methanol and potassium hydroxide (KOH) were procured from a chemical supplier located in Varanasi, India. The production of SRB involves a one-step

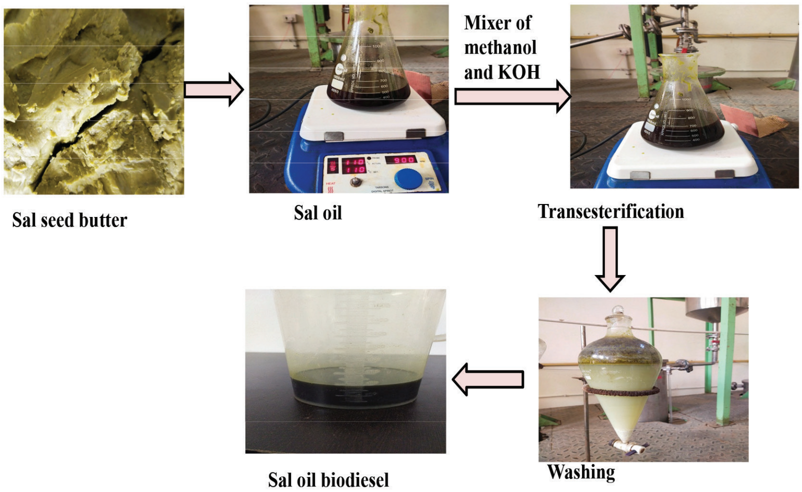

Figure 1. Preparation of for shorearobusta biodiesel

Table 1. Thermophysical characteristics of SRB blend fuels

Characteristics	**ASTM**	**Diesel**	**SRB10**	**SRB20**	**SRB30**
Density (kg/m^3)	ASTMD1298	863	870	872.4	875.6
Viscosity (cP)	ASTMD445	3.28	3.49	3.56	3.70
CV (MJ/kg)	ASTMD240	42.76	38.66	37.92	37.44
Flash Point (^{o}C)	ASTMD93	68.4	77.4	79.8	82.6
Fire Point (^{o}C)	ASTMD93	78.3	87.2	90.2	93.5

transesterification procedure wherein methanol is utilised as a reactant in the presence of a KOH catalyst to initiate a chemical reaction with triglycerides.

$$\text{Methanol} + \text{Triglycerides} \xrightarrow{\text{KOH catalyst}} \text{glycerol} + \text{Mixture of fatty ester}$$

During the transesterification process, a mixed fuel was subjected to the addition of a 0.5% (w/w) KOH catalyst at a temperature of 65°C. The process was sustained for duration of 90 minutes, with a consistent agitation rate of 450 revolutions per minute. Figure 1 illustrates the methodologies employed in the production of biodiesel from orange peel.

FUEL PROPERTIES MEASUREMENT

The study conducts experimental measurements of various properties, including calorific value, density, flash point, kinematic viscosity, and fire point for diesel fuel and SRB blended fuels. The measurements are carried out using a variety of equipment. The fuel properties of different fuel blends utilised in the experimental analysis are diesel, SRB10, SRB20, and SRB30. The blends utilised in this experiment were formulated with a specific objective in mind, and the fuel characteristics were determined in accordance with the ASTM standard presented in Table 1. The study evaluated various fuel blends, namely.

2.2 EXPERIMENTAL ANALYSIS

Experimental investigations were conducted on a variable speed, water-cooled CI engine with four cylinders and four strokes. A strain gauge load cell coupled to a hydraulic dynamometer was used to assess engine load. Table 2 provides detailed specifications of the CI engine, and Fig. 2 depicts the actual experimental setup. The examinations were carried out at different combinations of

Table 2. Engine specification

Engine attributes	**Description**
Engine type	TATA INDIGO
Cylinders	Four
Stroke	4-stroke
Cooling agent	Water
Combustion type	Compression ignition
Compression ratio	21:1
Aspiration type	Turbo charged
Fuel inject system	Common rail direct injection (CRDi)
Injection timing	23^{o}bTDC
Bore (mm)	75
Stroke length (mm)	79
Volume (CC)	1396

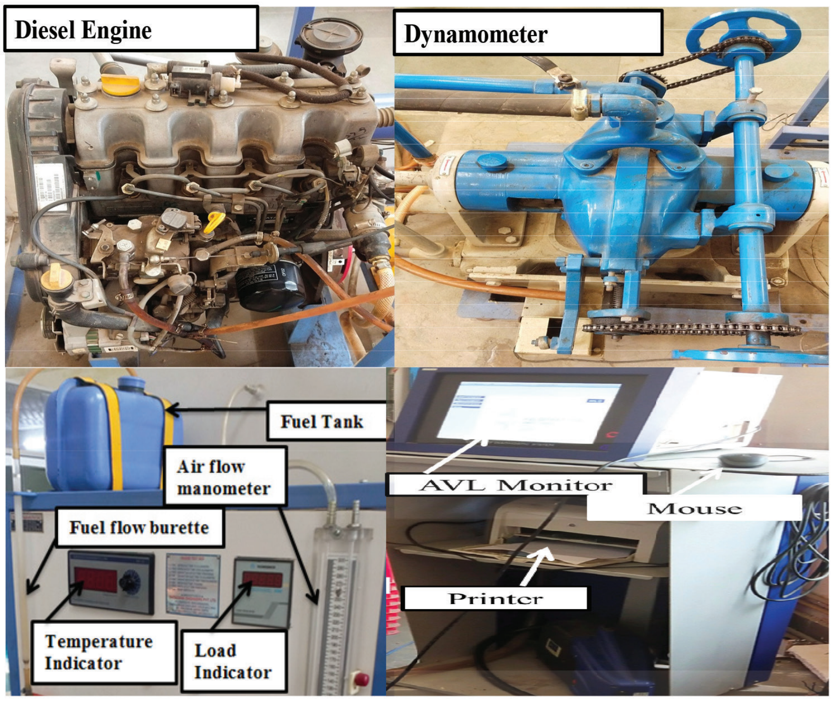

Figure 2. Image of the experimental setup

engine speed, engine load, and biodiesel blending ratios. Various parameters such as engine torque, fuel utilization rate, air flow rate, temperature of coolant, exhaust gas, and calorimeter water were recorded for each set of control parameters. The Non Dispersive Infrared (NDIR) approach was used to analyse emissions, including CO and HC levels, using an AVL DIGAS 1000 gas analyzer. The NOx emissions were measured using a pre-calibrated electrochemical sensor. The measurements for NOx and HC were reported in parts per million (ppm), while CO was reported as a percentage.

2.3 DATA EXTRACTION FOR PERFORMANCE EVALUATION

Several assumptions were made for these calculations, including the assumption of steady engine operation, the ideal gas behaviour of the exhaust gas, homogeneity of the combustion product within the control volume, and negligible influence of kinetic and potential exergy rates.

The engine's power is denoted as,

$$BP = \frac{2\pi NT}{60} \quad (1)$$

The engine BTE is estimated as,

$$BTE = \frac{BP}{\dot{m}_f . CV} \quad (2)$$

The engine's BSEC and BSFC are stated as,

$$BSFC = \frac{\dot{m}_f}{BP} \quad (3)$$

3. RESULT AND DISCUSSION

The operating parameters and emissions characteristics for various fuel samples are analysed in the section that follows, taking varying engine speed and engine power into account. BTE, BSFC, and exhaust gas temperature, are some of the performance factors taken into account. On the other side, the emissions properties looked at include HC, CO, and NO. The link between these metrics and qualities for the various fuel samples stated previously is the main topic of the discussion.

3.1 EFFECTS OF ENGINE POWER, ENGINE SPEED, AND SRB BLENDING ON BSFC AND BTE

The link between engine BSFC and various fuel samples in terms of engine speed and power is shown in Figure 3. For each fuel type, the BSFC drops as engine power and speed rise. Brake power and fuel utilisation rate are combined to determine an engine's BSFC. The reported fuel conversion efficiency increases initially and then decreases as engine power increases at a fixed speed because mechanical efficiency increases. The overall impact leads to a reduction in BSFC. However, an increase in BSFC results from a fall in stated fuel conversion efficiency. Because the mechanical efficiency factor has a bigger influence than the reported fuel conversion efficiency factor, the BSFC falls as engine power increases at a fixed speed. The drop in BSFC with increasing engine speed while maintaining a constant output is negligible. Lower BSFC is the result of reduced heat loss time at higher speeds. However, when engine friction losses raise, BP decreases and BSFC increases. Additionally, greater air intake and fuel consumption rates brought on by higher engine speeds improve fuel combustion in the engine cylinder. The BSFC experiences a decline while maintaining constant engine power due to the improved combustion efficiency and reduced heat losses. The engine BSFC is seen to rise when biofuel and diesel are blended. The reason for this phenomenon is that blended fuel exhibits a reduced calorific value and an elevated kinematic viscosity in comparison to diesel fuel in its pure form. As a result, in order to produce the same amount of power as diesel fuel, It is necessary to inject additional fuel.

Figure 4 BTE variation versus engine power and speed with SRB blended fuel during the process of combustion. The blend with 30% SRB had the greatest BSFC across all engine power and speed conditions of all the blends evaluated.

For instance, the BSFC of the engine with SRB10, SRB20, and SRB30 fuel mixes is 1.58%, 2.09%, and 3.13% larger than that of the engine with pure diesel fuel, respectively, at an engine speed of 1500 rpm and power of 5.5kW. Compared to engine power, engine speed fluctuation has a less substantial effect on BSFC.

The link between engine BTE and various fuel samples regarding engine speed and power is depicts in Figure 4. The BP and thermal energy intake work together to calculate an engine's BTE. The mechanical efficiency of the engine rises with increased engine power at constant speed, which boosts the engine's stated fuel conversion efficiency. This improvement is the consequence of a reduction in the magnitude of thermal energy required to create one unit of BP, which increased BTE. Additionally, a rise in the fuel-air ratio due to a rise in engine power at a given speed enhances the combustion process inside the cylinder, further enhancing engine BTE. Conversely, raising engine speed while maintaining a constant load results in an increase in frictional power, which lowers engine BTE.

However, by reducing heat losses to the environment, the utilization of fuel energy improves, leading to an increase in engine BTE. Overall, the increase in engine

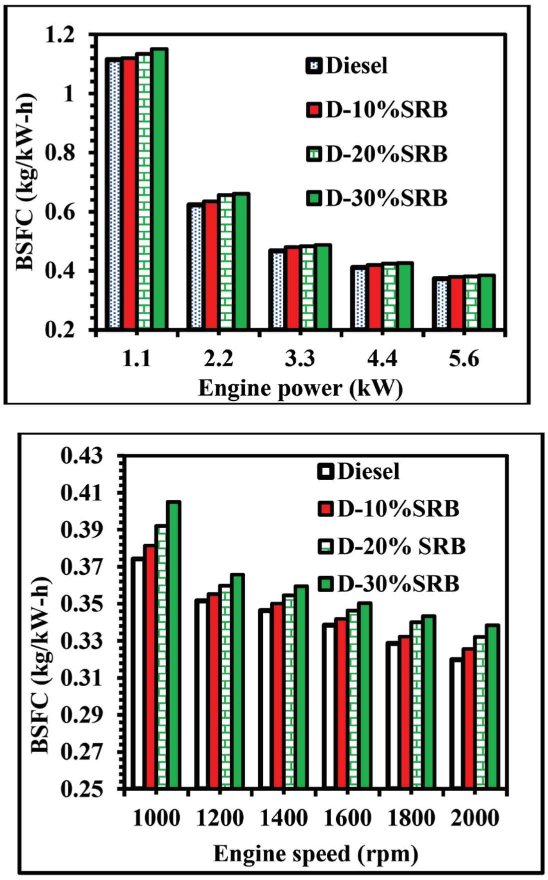

Figure 3. BSFC variations versus engine power and speed with SRB blended to diesel

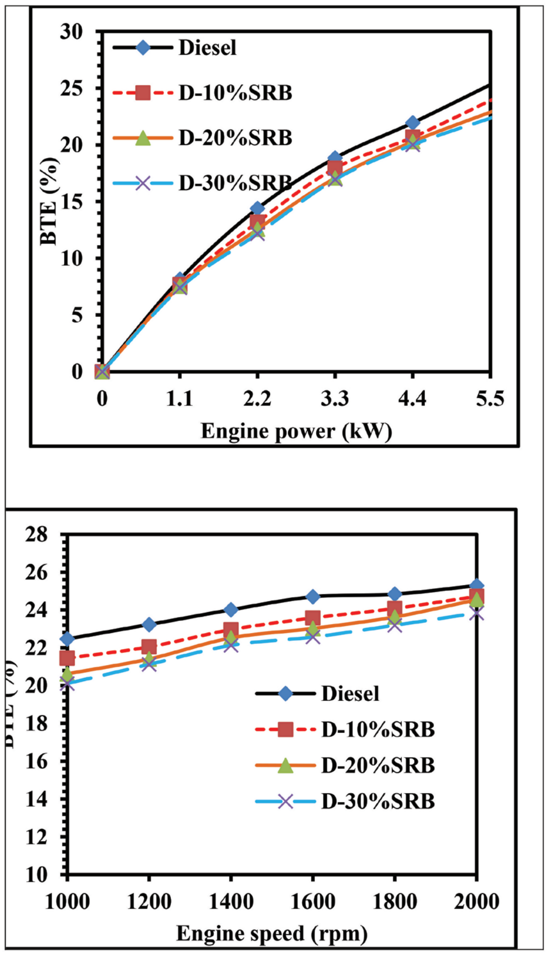

Figure 4. BTE variations versus engine power and speed with SRB blended to diesel

BTE brought on by anrise in engine speed pales in comparison to the impact of engine power.

The engine BTE is seen to be lower when using SRB10, SRB20, and SRB30 diesel mix fuels compared to pure diesel fuel. The aforementioned phenomenon can be ascribed to the higher fuel viscosity, larger fuel droplet size, and slower fuel atomization rate of biodiesel blended fuels in comparison to diesel fuel. At an engine speed of 1500 rpm and a power of 5.5kW, the engine using SRB10, SRB20, and SRB30 diesel blends has a BTE that is lower than pure diesel fuel by 5.50%, 9.75%, and 11.90%, respectively. Compared to the fluctuation in engine power, the effect of engine speed variation on BTE is less substantial.

3.2 EFFECT OF ENGINE SPEED, POWER, AND OPB BLENDING ON HC AND NO EMISSIONS

The graphical representation depicted in Figure 5 showcases the correlation between engine speed and power with respect to the emissions of HC. The emissions of HC exhibit an upward trend in correspondence with the increase

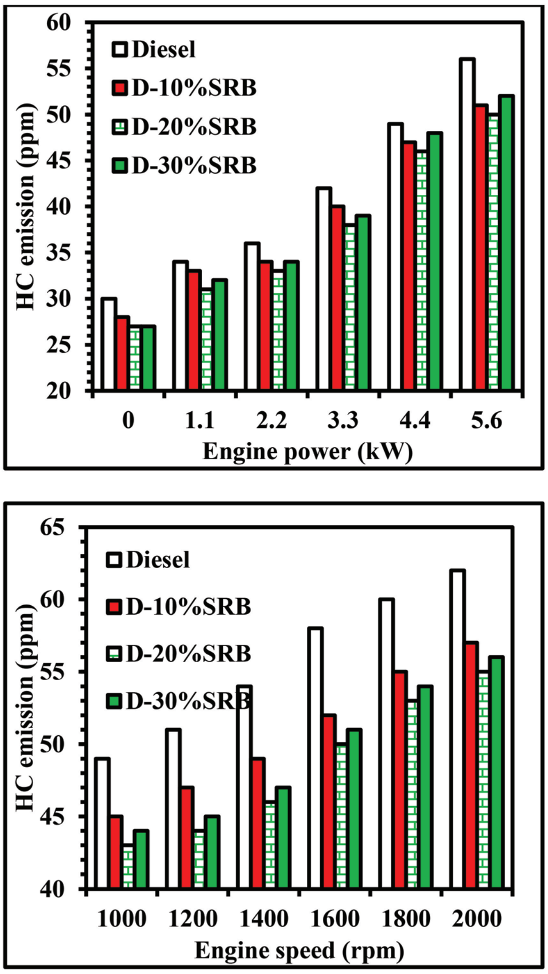

Figure 5. HC emissions variation versus engine power and speed with SRB blended fuel

in both engine power and speed for every fuel specimen. When the engine power is enhanced while maintaining a constant speed, the rate of fuel supply increases while the rate of air supply remains constant. The outcome of this phenomenon is a heterogeneous blend within the cylinder and inadequate fuel combustion, leading to a rise in HC emissions.

The incorporation of biofuel into diesel fuel has been found to decrease HC emissions due to the elevated oxygen content present in biofuels. Biofuel blends with higher cetane numbers have been found to enhance fuel combustion by reducing the ignition delay, thereby resulting in reduced HC emissions. The blending of SRB in diesel fuel has been observed to result in a reduction of HC emissions by as much as 20%, as indicated by experimental findings. Nevertheless, exceeding this particular mixture proportion leads to a rise in HC levels. The phenomenon under consideration can be ascribed to the notable augmentation in the fuel supply rate consequent to elevated SRB blending ratios. The aforementioned phenomenon results in the creation of a highly diverse amalgamation within the combustion chamber, which in turn causes an elevation in HC emissions. The study evaluated various blends and found that the engine's HC emissions were reduced with the SRB10, SRB20, and SRB30 diesel blends compared to the standard fuel. Specifically, at 5.5kW power and 1500 rpm, the HC emissions were lowered by 8.92%, 10.71%, and 7.14%, respectively.

Figure 6 depicts the alterations in engine NO emissions across diverse fuel samples under varying engine speed and power conditions. As the engine's velocity and output escalate, the NO emissions rise for all types of fuels owing to augmented fuel-air ratios and heightened post-combustion temperatures and pressures within the cylinder. The utilisation of SRB diesel blend fuels in the engine results in higher NO emissions compared to diesel fuels across various engine loads and speeds. The observed phenomenon can be attributed to the elevated oxygen content of biodiesel fuel, which facilitates expedited combustion and consequent augmentation of pressure and temperature. Moreover, the presence of double bonds in biodiesels results in the generation of a greater number of radicals, thereby exacerbating the release of NO emissions.

The findings indicate that the SRB30 fuel displays the most elevated levels of NO emissions in comparison to all other fuels across various engine loads and speeds within the SRB blend fuel category. The reason for this phenomenon can be attributed to the reduced ignition delay and heightened oxygen concentration of biodiesel fuel. Under the operating conditions of 5.5kW power and 1500 rpm, it was observed that the combustion of SRB10, SRB20, and SRB30 diesel blend fuels resulted in NO emissions that were 8.58%, 7.78%, and 9.18% higher, respectively, compared to the combustion of diesel fuel in the engine.

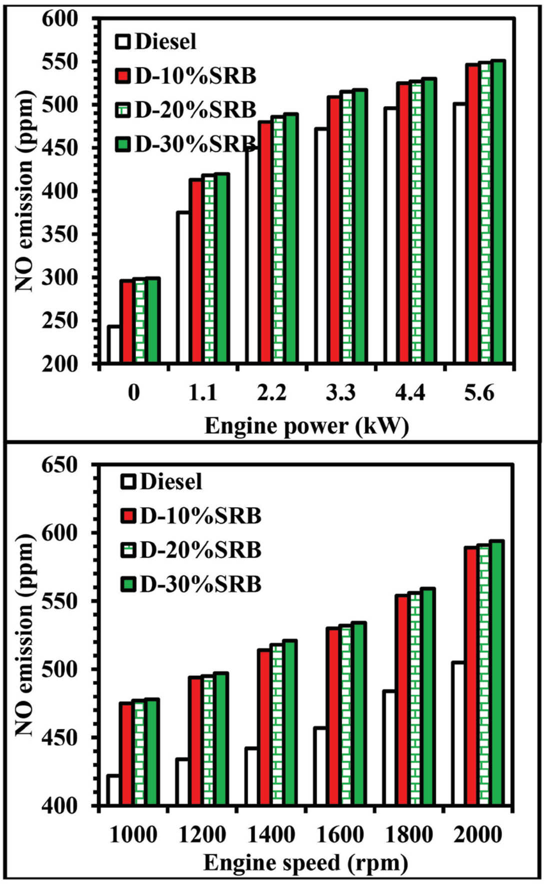

Figure 6. NO emissions variation versus engine power and speed with SRB blended fuel

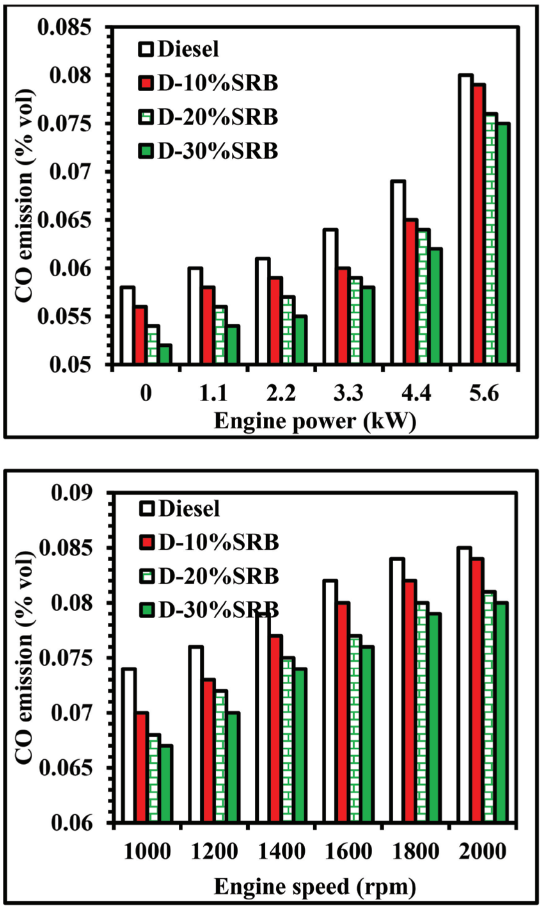

Figure 7. CO emissions variation versus engine power and speed with SRB blended fuel

3.3 EFFECT OF ENGINE POWER, ENGINE SPEED, AND SRB BLENDING ON CO

The graphical representation in Figure 7 depicts the correlation among engine power, velocity, and CO emissions. Insufficient oxygen leading to incomplete combustion is the principal factor that contributes to the formation of carbon monoxide. The escalation of engine power and speed is accompanied by a corresponding increase in fuel consumption, resulting in a decline in the availability of oxygen within the cylinder and an elevation in the fuel-air equivalence ratio. As aresult, carbon monoxide emissions increase. It is worth noting that engine power exceeding 4kW results in a considerable increase in CO emissions. This can be attributed to the elevated rates of fuel consumption, restricted oxygen availability, and the creation of fuel-rich zones.

In comparison to conventional diesel fuels, the utilisation of SRB diesel blend fuels results in a reduction of CO emissions across a range of engine power and speed levels. The reduction in performance can be attributed to the elevated levels of oxygen concentration in biodiesel fuels. Furthermore, the elevated cetane number exhibited by biofuel blends results in enhanced fuel combustion through the reduction of the ignition delay period, thereby facilitating the mitigation of CO emissions. Under the operating conditions of 5.5kW engine power and 1500 rpm, it was observed that the utilisation of SRB10, SRB20, and SRB30 diesel blend fuels resulted in a reduction of CO emissions by 1.25%, 5%, and 6.25%, respectively, in comparison to the utilisation of conventional diesel fuel.

4. CONCLUSION

Conclusively, the examination of the energy, exergy, and emission performance of a diesel engine employing SRB blended fuel has yielded significant findings. Through a comprehensive analysis of factors such as engine power, speed, and fuel composition, a thorough understanding has been gained regarding their impact on both performance and emissions. The aforementioned observation has been derived from the comprehensive analysis.

- According to the investigation, an increase in engine speed and power led to various enhancements in performance across all fuel samples. Significantly, the BSFC of the engine was decreased, implying a higher level of fuel efficiency. Furthermore, improvements were observed in parameters such as BTE, and exhaust gas temperature.

- Conversely, the utilisation of SRB blended fuels resulted in a reduction of the engine performance parameters such as BTE, as well as the emission parameters of CO, and HC.
- It is noteworthy that, within the category of SRB blended fuels, the fuel known as SRB20 demonstrated the least amount of hydrocarbon (HC) emissions. The results underscore the possible advantages of incorporating SRB blended fuels with regards to augmenting engine efficiency and mitigating emissions.
- The utilisation of diesel blends such as SRB10, SRB20, and SRB30 resulted in a reduction of HC emissions from the engine in comparison to the utilisation of pure diesel fuel. At the condition of 5.5kW power and 1500 rpm, the reductions observed were 8.92%, 10.71%, and 7.14%, respectively.
- The utilisation of diesel blend fuels such as SRB10, SRB20, and SRB30 resulted in a reduction of CO emissions from the engine. The reduction percentages were 1.25%, 5%, and 6.25%, respectively, in comparison to the emissions produced by regular diesel fuel under identical engine power and speed conditions.

The findings indicate that the utilisation of SRB blended fuels is efficacious in mitigating the emissions of CO, and HC. The results emphasise the viability of utilising SRB blends as a viable alternative to conventional diesel fuels, providing enhanced ecological efficiency by decreasing emissions.

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