

Emission and vibration characteristics of Niger seed oil biodiesel fueled diesel engine

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ABSTRACT

The present investigation dwells the experimental investigation for the assessment of emission, vibration, and noise parameters of single-cylinder, DI diesel engine functioning through the blends of conventional diesel and Niger seed oil methyl ester (NSOME) at different engine operating loads namely 25%, 50%, 75%, and 100% at a constant speed. The carbon monoxide (CO), unburnt hydrocarbons (UHC), and smoke opacity emissions have come down significantly for all the blends of NSOME namely B10, B20, and B40 while the NO_x increased marginally. Besides, the vibration and noise extremity of the engine was lowered while operating with biodiesel blends as compared to conventional diesel. B20 has specified a significant reduction in emission, vibration, and noise too at all the loads range from minimum to maximum. At maximum load condition the CO, UHC, smoke opacity, root mean square (RMS) velocity, and RMS noise of B20 have reduced by 93.9%, 37.87%, 5.54%, 45.78%, and 26.15% respectively even as the NO_x was increased by 12.76% compared to standard.

Keywords: Noise; Niger seed oil methyl ester; emissions; root mean square.

INTRODUCTION

In the present existence, the researchers have attempted repeatedly to find numerous new renewable resources associated with pollution concern, limited relieve in use, the growing shortage of fuel, and quick diminution of fossil fuels. Biodiesel is the most selected option for the standard diesel owing to less carbon content and its environmental benefits [1]. Biodiesel is an alternative fuel extracted from different vegetable oils and capable of use in compression ignition engines by blending appropriately with standard diesel. On account of durability and high combustion efficiency, the CI (compression ignition) engines are broadly used in the farming field in addition to the industry for mobile and immobile applications. Although, the consumers are strongly influenced by the exhaust emissions, noise, and vibrations developing from the burning of fuel powered-engines [2-4].

Biodiesel and their blends with conventional diesel cloud strongly reduce the exhaust emissions like CO, unburned hydrocarbon (UHC) and smoke opacity on account of superior combustion and amount of oxygen presence [5]. The sound and vibrations produced from the

IC engine are the major drawbacks and have harmful effects on the human body. The primary source of engine vibration is due to the rotational and reciprocating components of the engine. An additional lead source of vibration and hence noise in the CI engine is owing to the efficient burning of fuel which extensively depends on the type of fuel and fuel injectors used [6, 7]. The noise levels could be estimated by converting the vibration signals employing Fast Fourier Transformation (FFT), Wavelet transforms (WT), and Short-time Fourier Transform (SFFT) analysis. Since the noise measurement in the combustion chamber is a tough task [8]. The vibration amplitude is estimated and compared to in terms of root mean square (RMS) since it confers the time history which is proportional to the vibration signature [9]. The vibration and noise could decrease while the engine is operating with biodiesel and their blends on account of better combustion efficiency [10, 11].

Numerous authors have performed different researches on emission characteristics and very few investigations were gone through in the field of engine vibrations and noise. Jaikumar et al. [12] experimented with variable compression ratio (VCR) diesel engine using Niger seed oil biodiesel blends. From their results, the combustion parameters were improved and the emissions of CO, UHC, and smoke opacity were decreased while the NO_x was noticed higher than conventional diesel. Vijay et al. [13] experimentally investigated on blends of mango seed oil methyl ester and diesel. The results have revealed that the notable reduction in emissions was noticed apart from NO_x. Senthur et al. [14] explored the emission parameters of used cooking oil biodiesel on CI engine and reported that a momentous diminution in CO and UHC were observed with a minor rise in NO_x. Some researchers have attempted experimental studies on vibration and noise analysis. How et al. [15] conducted tests on coconut methyl ester and diesel blends. RMS acceleration (vibration) was observed to be decreased by 13.7% with B50. Zhi et al. [16] investigated vibration analysis and performance of biodiesel derived from *Calophyllum*. It was concluded that the B20 blend exhibited lower vibrations than standard diesel. The effect of different engine speeds operating with biodiesel blends was investigated by Heidaryet et al. [17]. They accomplished that the B10 and B15 blends produced higher vibrations and it was found that most of the vibrations are in engine piston direction. Uludamar et al. [18] studied the influence of different biodiesel blends on vibration and noise characteristics of the CI engine. The results concluded that the engine vibration and noise levels were minimized with raise in blend ratio. Zhen et al. [19] have investigated the noise signature of four-cylinder turbocharged CI engine for biodiesel blends B50 and B100 which revealed that the noise levels of biodiesel and their blends were marginally greater. Further, the noise levels have increased with increase in blend ratio from B50 and B100. Sanjid et al. [20] compared the diesel engine noise running with palm and jatropha biodiesel. The results concluded that the noise levels have reduced significantly than the standard diesel. Jaikumar et al. [21] examined the vibration and noise constraints of Niger seed oil biodiesel and hydrogen in dual fuel operation by varying different compression ratios. Their results revealed that the vibrations and noise were decreased with biodiesel blends and hydrogen-enriched blend as well.

Based on the existing literature, more than a few investigations have been carried on the exhaust emission parameters. Besides, fewer research studies have been carried out on vibration and noise and thus still there is some gap in detailed investigations in terms of varying engine loads. In the present investigation, the emission, vibration, and noise parameters were assessed by varying dissimilar load conditions. Hence, the load variation

from lower load to higher load condition of assessing these operating parameters with Niger seed oil methyl ester (NSOME) blends has been centered as a novel attempt.

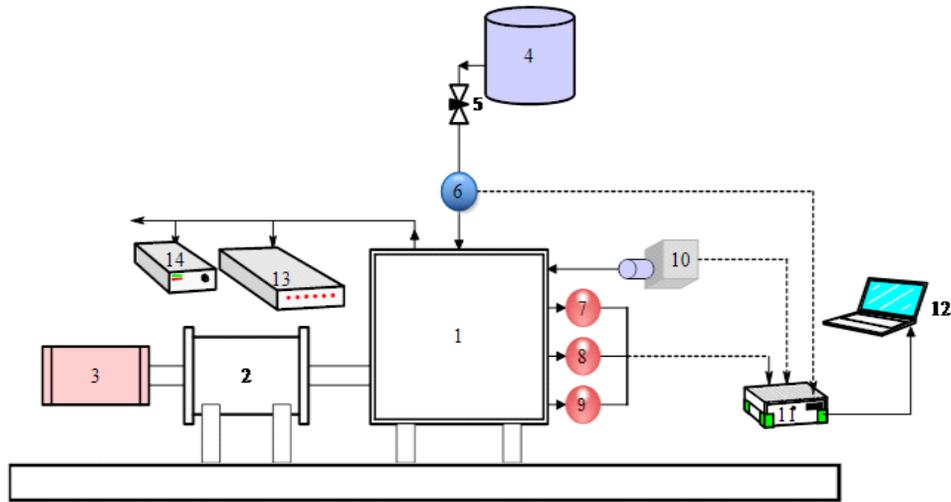
MATERIALS AND METHODS

NSOME has been prepared by transesterification technique [12] and three different blends were prepared by mixing with diesel. The test fuels are designated as diesel, B10, B20, and B40 by blending NSOME (B100) with diesel at different proportions namely 0%, 10%, 20%, and 40 % respectively by volume [12]. The physic-chemical properties of NSOME and their blends were tested and presented in the Table1.

Table 4. A Thermo-physical property of diesel and diesel – NSOME blends.

Fuel property	Method ASTM	ASTM Range	B100	B40	B20	B10	Diesel
Relative Density at 15°C (kg/m³)	D-1298	860-900	887.9	883	877	872	831
Heating value (kJ/kg)	D-4809	42,000	41,300	41,420	41,630	41,900	43,800
Fuel quality (Cetane Number)	D-976	47 (min.)	59	58	57	54	50
Copper Corrosion	D-130	1 (max)	1a	1 a	1a	1 a	1a
Kinematic Viscosity at 40°C (Cts)	D-445	2.5-6	4.2	4.07	3.94	3.86	2.6
Cloud point (°C)	D-97	6 (max.)	3	3	3	3	-2
Flashpoint (°C)	D-92	130 (min.)	157	155	148	131	51

Figure 1 depicts the representation of a four-stroke single cylinder VCR diesel engine and the engine specifications were tabulated in Table 2. In the present investigation, the engine is coupled through the dynamometer in conjunction with the load controller. On one side of the engine, the fuel tank is connected with a fuel flow sensor. Further on the other side, the exhaust emissions measurement device (MARS smoke meter and MARS gas analyzer) is connected. The engine is also linked to a Laser Doppler Vibrometer (LDV) to measure the vibration magnitude at a fixed point by detecting the signals through a laser beam. These signals were captured from USB based vibrosoft-20 software and FFT analyzer. The detailed specifications of LDV are presented in Table 4. The sensors and LDV are coupled to a computer via an analogue to digital converter which displayed the results. The vibrations and noise levels are recorded at engine head which accounts for the bulk of vibrations generated. Accuracy of the instruments used in this study is shown in Table 3.



- | | | |
|------------------|------------------------|-----------------------|
| 1. Engine | 6. Fuel flow sensor | 11. ADC |
| 2. Dynamometer | 7. Pressure sensor | 12. Computer |
| 3. Load control | 8. Speed sensor | 13. MARS gas analyzer |
| 4. Fuel tank | 9. Crank angle encoder | 14. MARS smoke meter |
| 5. Control valve | 10. LDV | |

Figure 1. Schematic of the engine test rig.

Table 2. Experimental test rig specification.

Parameter	Description
Type	TAF-1
Cylinders	1
Cylinder bore	87.5 mm
Compression ratio	17.5
Length of stroke	110 mm
Fuel Injection pressure	200 bar
Maximum power	3.5 kW
Rotational speed	1500 rpm
5-gas analyzer make	MARS
Smoke meter make	MARS

The experimentation was carried at four different load conditions of 25%, 50%, 75%, and 100% at a constant speed of 1500 rpm. At every load, the emissions parameters were measured with the help of 5-gas analyzer and smoke meter respectively. Furthermore, the vibration signals were captured and noise data has been mapped using FFT. For vibration and noise analysis, FFT was used. The programs were furnished in vibrosoft-20 software for

vibration analysis and origin software was used for noise analysis. In origin software the signals were converted into noise in decibels (dB (A)) and also RMS analysis was used to compare the arbitrary wave vibration amplitude values. The experiments were repeated thrice and the mean values were presented in the graphs. RMS is characterized for comparing vibrations at different conditions. The mean values of total velocity in RMS were compared. The following Equation. (1) is used to calculate RMS velocity.

Table 3. Accuracy of measurements.

Parameter	Accuracy
Load	± 0.2 kg
Speed	± 30 rpm
Temperature	± 1%
Piezo sensor	± 0.1%
Crank angle	± 0.2%
CO	± 0.001%
UHC	± 1 ppm
NOx	± 1 ppm
Smoke	±0.1%

Table 4. Practical specifications of LDV.

Parameter	Description
Vibrometer type	PDV-100 Portable Digital Vibrometer
Software	Vibrosoft-20
Operational distance (meters)	0.2- 30
Range of Noncontact velocity (kHz)	0-20
Connection	USB based, dual-channel

$$V_{rms} = \left[\frac{1}{n} \sum_{k=1}^n V^2(t) \right]^{1/2} \tag{1}$$

where V_{rms} =RMS velocity, n = Number of readings during a time period, $V(t)$ = Velocity concerning time.

FFT converts a signal commencing the time domain to the frequency domain and vice versa. For a given data set of $y(k)$ with n number of data samples, the FFT can be calculated using Equation. (2).

$$y(k) = \left[\sum_{j=1}^n y(j) \omega_n^{(j-1)(k-1)} \right] \tag{2}$$

where $\omega_n = e^{(-2\pi i)/n}$ = Angular velocity.

RESULTS AND DISCUSSIONS

Emission characteristics

The emission characteristics namely carbon monoxide (CO), unburnt hydrocarbons (UHC), smoke opacity, and nitrogen oxides (NO_x) were presented at different engine loads and different blends of NSOME.

Carbon monoxide (CO)

Figure 2 depicts the change in CO emissions of different experimental test fuel blends at diverse load conditions.

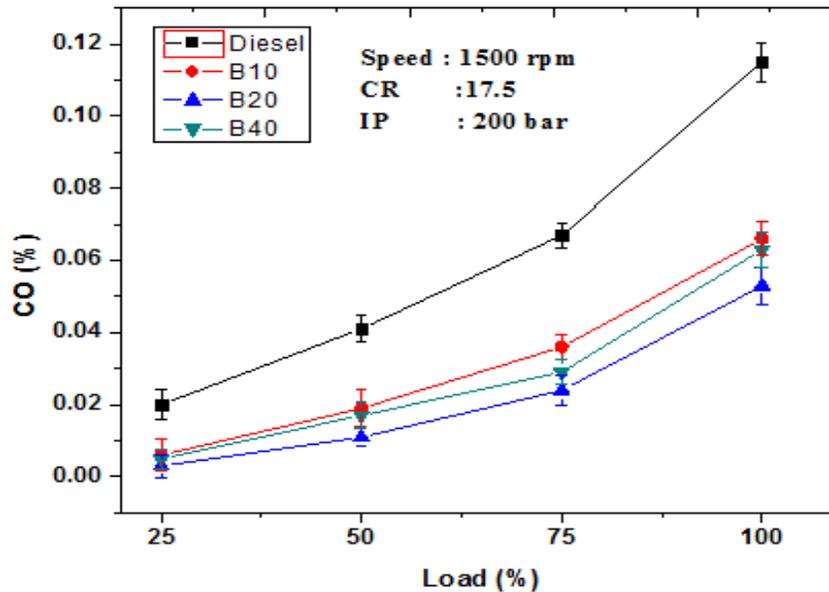


Figure 2. Carbon monoxide emissions.

CO emissions were observed elevated from lower load to higher loads regardless of experimental test fuel blends. The reason intended for this was owing to the richer air-fuel ratio and the reduction in oxidation at upper load condition [13]. Further, a notable fall in CO levels was noticed with NSOME blends. This lessening was in consequence of more amount of oxygen there in the biodiesel than conventional diesel which leads to superior combustion [12, 22]. The CO emissions were 115%, 0.066%, 0.053%, and 0.063 % respectively for diesel, B10, B20, and B40 at full load. Among the leftover test fuels used, the B20 has specified lower CO emissions.

Unburnt hydrocarbons (UHC)

The disparity of UHC emissions with load was manifested in Figure 3. The rising trend of UHC emissions was observed from lower loads to maximum load condition. The foremost cause for attaining lofty UHC emissions at maximum load was on account of more amount of fuel supply to maintain a constant output power for a given quantity of air. As a result, this makes the wealthier air-fuel mixture and results in higher UHC emissions [5]. The identical trend was continued for all the experimental test fuels. It was noticed that the NSOME blends

have far lower UHC emissions compared to diesel on account of superior combustion efficiency which was owing to greater cetane number and more oxygen existence in the biodiesel [12, 23]. Further, the B20 has given least UHC emissions at all the load conditions as compared to other fuels in scrutiny. The emissions of UHC at maximum load were about 140 ppm, 130 ppm, 90 ppm, and 115 ppm, respectively in favor of standard diesel, B10, B20, and B40.

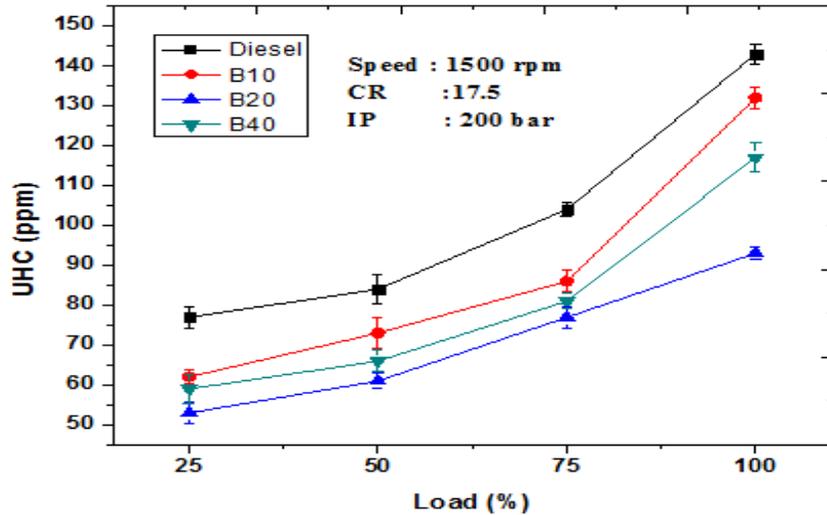


Figure 3. Unburnt hydrocarbons under different loads.

Smoke opacity

Figure 4 portrays the variation of smoke opacity against different loads. The smoke opacity primarily controlled by the type of fuel used and the air-fuel ratio. It was perceived that the smoke opacity for the blends of NSOME was lowered than conventional diesel. This was attributable to oxygen dominance and better fuel quality in NSOME blends.

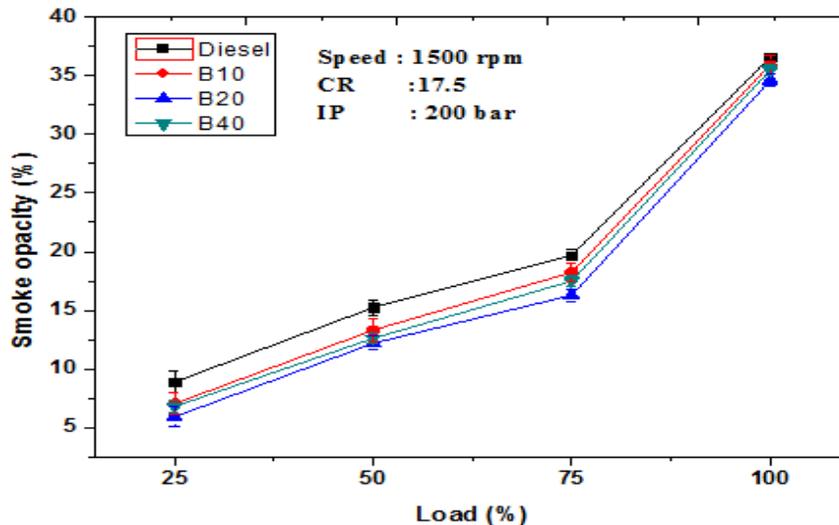


Figure 4. Smoke opacity under different loads.

Further, the smoke opacity was enhanced from lesser load to the utmost load despite all the fuel blends [24]. This was due to lesser oxidation at maximum load condition owing to the greater amount of fuel injected at a particular supply of air. Therefore, the smoke opacity increased at higher loads. The smoke opacity at maximum load was noticed as 36.34%, 35.92%, 34.58%, and 35.49% respectively meant for conventional diesel, B10, B20, and B40. Of all test fuels under scrutiny, B20 has noticed lower smoke opacity with all the load conditions.

Nitrogen Oxides (NO_x)

The emission of NO_x at dissimilar loads was depicted in Figure 5. It was scrutinized that the NO_x was augmented for B10, B20, and B40 than conventional diesel. The corresponding NO_x emission values were about 698 ppm, 855 ppm, 856 ppm, and 826 ppm correspondingly at maximum load. The possible reason intended for this surge in NO_x was on account more oxygen availability and greater temperature of exhaust gas [12, 22].

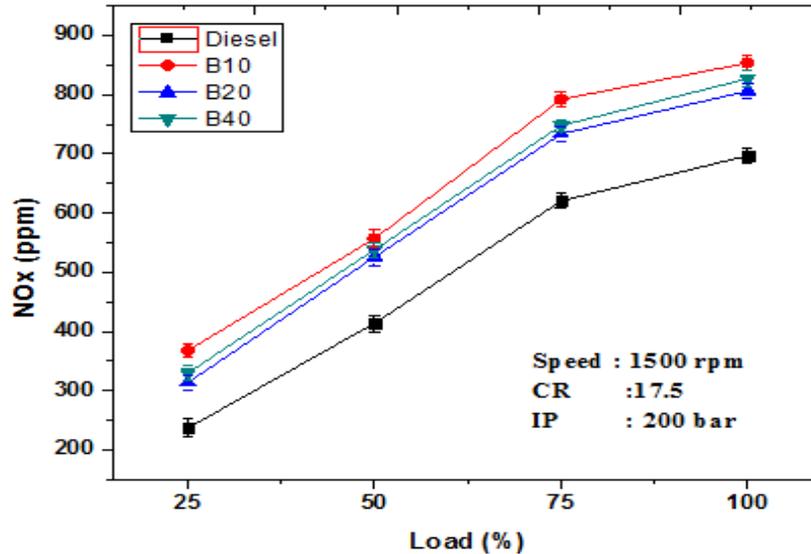


Figure 5. NO_x emissions under different loads.

Further, the NO_x has observed a rising trend towards increasing load irrespective of all the test fuels. The standard diesel has perceived lower NO_x emissions than NSOME blends.

Vibration and noise characteristics

The vibration and noise assessment of NSOME and their blends are studied at different loads. The vibration magnitude discussed in terms of velocity (m/s) and the noise levels were presented in terms of sound pressure levels dB (A). The variation in RMS velocity with time was shown at maximum load and the RMS velocity at all the loads was also presented.

RMS velocity

The time variation in vibration of different test fuels blends was depicted in Figure 6 and the RMS velocity variation relating to load was presented in Figure 7. It was noticed that the vibration levels of B10, B20, and B40 were lower whereas for diesel it was noticed higher

range. Since the NSOME blends have improved cetane number and superior oxygen quantity [12, 25]. Therefore, the combustion superiority attained for NSOME blends and consequently the tendency of knocking reduced. Since the major source of vibration developing from the engine was on account of knocking which was produced in consequence of inappropriate combustion [12, 21].

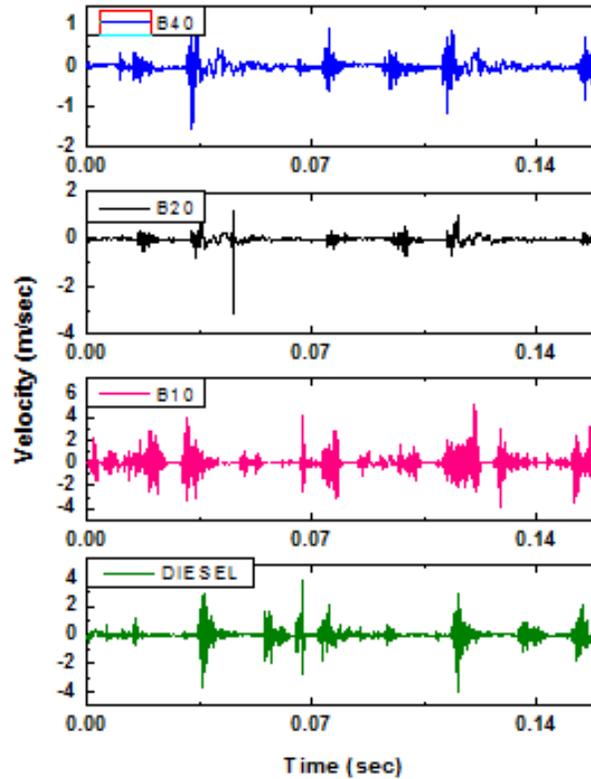


Figure 6. Variation in velocity with time at maximum load.

In addition, the vibration intensity was increased at upper loads and attained maximum at full load as depicted in Figure 7. This was on account of enhanced rate of combustion that produced large thrust on the piston which results in higher vibrations at higher load condition [21]. The similar growing trend was observed in favor of all the test fuels regarding load and the minimum vibration intensity was observed with B20 than remaining fuel blends. RMS velocity on behalf of diesel, B10, B20, and B40 were in the order of 0.49117 m/s, 0.38483 m/s, 0.31499 m/s, and 0.35571 m/s respectively at maximum load.

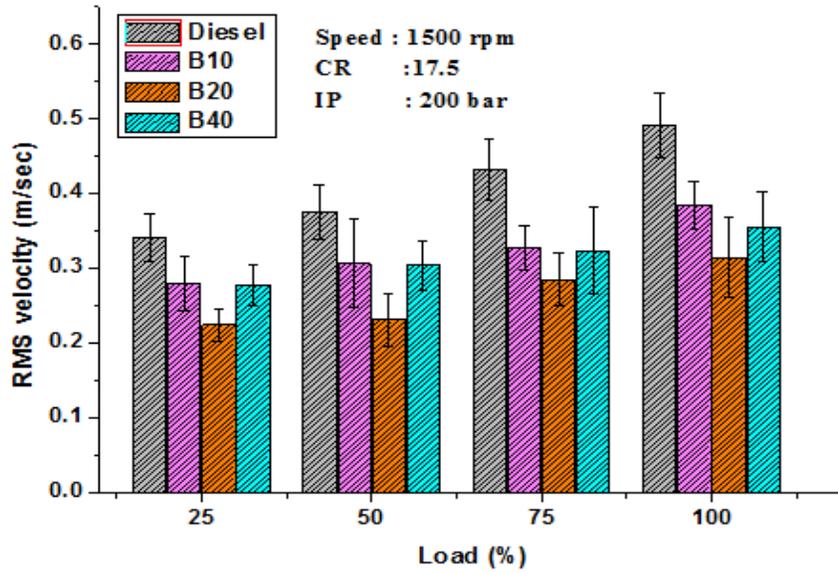


Figure 7. RMS velocity at different loads.

RMS noise

Figure 8 depicts the noise signature of different test fuel blends and the RMS noise at different loads was depicted in Figure 9.

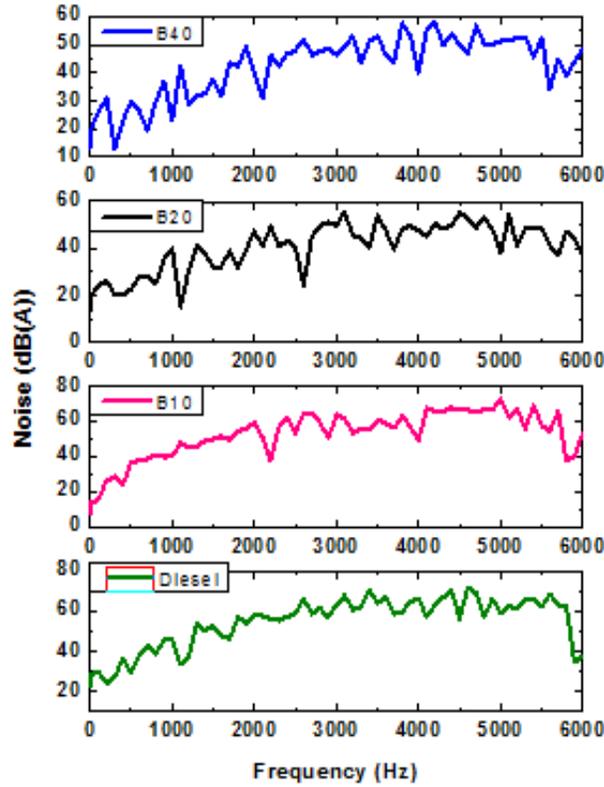


Figure 8. Variation of noise with frequency at maximum load.

It was identified that the noise levels of B10, B20, and B40 were originated inferior to conventional diesel. This was mainly due to the higher efficiency of combustion as a result of higher cetane number [12]. As the vibration and noise influenced by knocking and thus the engine knocking reduced with this improved combustion [21, 26]. Further, the noise was noticed higher at increasing load condition on behalf of all the fuels and the better reduction in noise level was exhibited by B20 at all the load conditions.

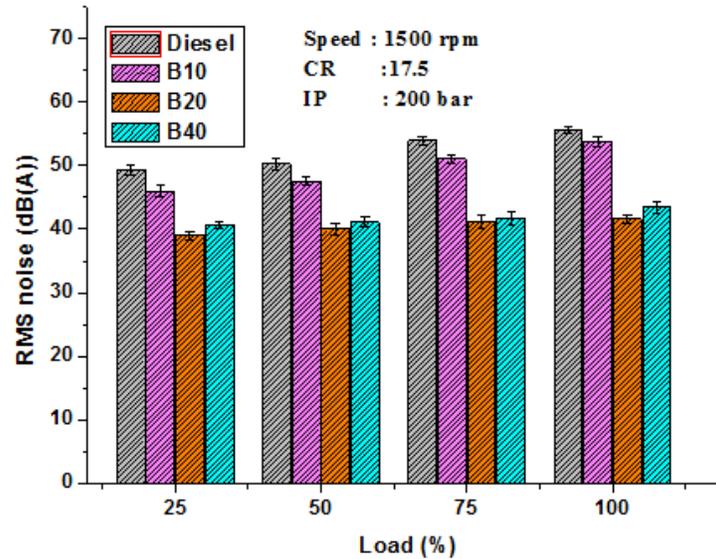


Figure 9. RMS noise at different loads.

The RMS value of noise for conventional diesel, B10, B20, and B40 was about 55.68525549 dB (A), 53.83839575 dB (A), 41.60468024 dB (A), and 43.45433219 dB (A) respectively at 100% load.

CONCLUSIONS

The following conclusions were made from this investigation:

- The properties of NSOME blends are within the ASTM range.
- The CO, UHC emissions, and smoke opacity were reduced for B10, B20, and B40 when compared against diesel. Nevertheless, there was a mild up surge in NO_x level with NSOME blends.
- Slightest emission values of CO, UHC, and smoke opacity were observed with B20 than remaining test fuel blends. But the NO_x was observed lowered for diesel fuel only. The similar observation was made at all the load conditions and the increasing trend was followed towards the rising load. At maximum load, the decrease in CO, UHC, and smoke opacity of B20 were 93.9%, 37.87%, and 5.54% respectively and NO_x increment was 12.76% in opposition to diesel.
- Further, the RMS velocity and RMS noise of B10, B20, and B40 were lowered than diesel at all the load conditions from lowest to highest load. However, the RMS velocity and RMS noise of the entire test fuels were improved towards the maximum load.

- The RMS velocity and RMS noise of B20 have depicted lower value than remaining blends of test fuels.
- For B20 blend, the vibration and noise levels were decreased by 45.78% and 26.15% respectively as compared to diesel.

Pertaining to above conclusions, B20 could be the possible replacement in the VCR diesel engine devoid of any adjustments. Further, the studies could be performed by altering the injection operating pressure to assess the emissions, vibrations, and noise parameters.

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