CHAPTER 6

EXPERIMENTAL RESULTS AND DISCUSSIONS-VIBRATION, COMBUSTION, PERFORMANCE AND EMISSION ANALYSIS FOR BLENDS B10, B20, B30, B40, B1 and B2

In chapter 4, it is observed that most significant reduction in engine’s combustion induced vibration is along vertical direction compared to lateral and longitudinal directions. Therefore, further investigations on engine vibration are done in vertical direction. In this chapter, engine vibration is measured in vertical direction at maximum CR 17.5, for NME blends B10, B20, B30 and B40, diesel-NME-methanol blends B1 and B2. Combustion, performance and emission analysis is also presented for the above said fuels.

6.1 Effect of Biodiesel Blends B10, B20, B30 and B40 on Engine Vibration

6.1.1 Time waves for Diesel and Biodiesel Blends B10, B20, B30 and B40 at No Load and Full Load Conditions

Fig. 6.1 shows super imposed time waves of engine vibration at no load condition when it is run with diesel, B10, B20, B30 and B40. Time waves indicate instantaneous vibration of engine which is due to mechanical and combustion induced forces. It is noticed that, instantaneous vibration is changing in the range of -2856 m/s² to 3034 m/s² for diesel, in the range of -3271 m/s² to 2905 m/s² for B10, in the range of -2681 m/s² to 3486 m/s² for B20, in the range of -4432 m/s² to 3843 m/s² for B30, and in the range of -2742 m/s² to 2911 m/s² for B40. It is noticed that absolute value of peak amplitudes of vibration is lower for B20 with an amplitude of 2681 m/s² and it is higher for B30 with an amplitude of 4432 m/s².

Fig. 6.2 shows super imposed time waves of engine vibration at full load condition when it is run with diesel, B10, B20, B30 and B40. It is noticed that, instantaneous vibration is changing in the range of -3240 m/s² to 3942 m/s² for diesel, in
the range of $-3279 \text{ m/s}^2$ to $3572 \text{ m/s}^2$ for B10, in the range of $-2945 \text{ m/s}^2$ to $3230 \text{ m/s}^2$ for B20, in the range of $-4147 \text{ m/s}^2$ to $3817 \text{ m/s}^2$ for B30, and in the range of $-3104 \text{ m/s}^2$ to $4058 \text{ m/s}^2$ for B40. It is noticed that absolute values of peak amplitudes of vibration are lower for B20 with an amplitude of $3230 \text{ m/s}^2$, and it is higher for B30 with an amplitude of $4147 \text{ m/s}^2$. However, time waves may not be a valid parameter to distinguish combustion induced vibration from mechanical induced vibration.

![Fig. 6.1 Superimposed time waves for diesel, B10, B20, B30 and B40 at no load](image-url)
6.1.2 Overall Vibration Velocity for Diesel, B10, B20, B30 and B40

Overall vibration velocity with % load, in vertical direction, when engine is fuelled with diesel, B10, B20, B30 and B40, is shown in Fig. 6.3. Overall vibration is calculated from time wave. It is root mean square value of the engine vibration. It is noticed that engine run with biodiesel blends produced lesser vibration velocity at various loads. At full load condition, vibration velocities are observed as 17.32 mm/s, 14.86 mm/s, 15.24 mm/s, 14.91 mm/s and 14.54 mm/s for engine fuelled with diesel, B10, B20, B30 and B40. The highest overall vibration velocity is observed for diesel whereas lowest value is observed for B40.
6.1.3 Peak Acceleration Amplitudes within 100 Hz for Diesel, B10, B20, B30 and B40 at No Load and Full Load

Fig. 6.4 shows peak acceleration amplitudes within 100 Hz in vertical direction, for engine running with diesel, B10, B20, B30 and B40 at no load. It is noticed that highest peak amplitudes are obtained at the frequency of 25 Hz for all the fuels and engine running with diesel produced highest peak amplitude of 1.63 m/s² and the lowest value of 1.2 m/s² is obtained for B40. Harmonics are obtained at the multiples of 25 Hz.
Fig. 6.4 Peak acceleration amplitudes within 100 Hz at no load for diesel, B10, B20, B30 and B40

Fig. 6.5 Peak acceleration amplitudes within 100 Hz at full load for diesel, B10, B20, B30 and B40
Fig. 6.5 shows peak acceleration amplitudes within 100 Hz in vertical direction, for engine running with diesel, B10, B20, B30 and B40 at maximum load condition. It is noticed that highest peak amplitudes are obtained at the frequency of 25 Hz for all the fuels and engine running with diesel produced highest peak amplitude of 1.67 m/s$^2$ and the lowest value of 1.19 m/s$^2$ is obtained for B40. Harmonics are obtained at the multiples of 25 Hz.

6.1.4 Superimposed Frequency Spectrums for Diesel vs Biodiesel blends B10, B20, B30 and B40 at No Load.

Fig. 6.6 shows superimposed frequency spectrums at no load condition for engine fuelled with diesel and B10. The highest peak amplitudes are observed at the frequencies of 706 Hz and 2206 Hz with amplitudes of 1.35 m/s$^2$ and 1.44 m/s$^2$ in case of an engine operated with diesel whereas the highest peak amplitudes are observed, at the frequencies of 719 Hz and 2608 Hz with amplitudes of 1.58 m/s$^2$ and 1.33 m/s$^2$ for B10.

Fig. 6.6 Superimposed frequency spectrums at no load condition for diesel and B10
Superimposed frequency spectrums, at no load condition for engine fuelled with diesel and B20, are shown in Fig. 6.7. The highest peak amplitudes are observed, at the frequencies of 732 Hz and 2570 Hz with amplitudes of 1.19 m/s² and 0.92 m/s² for B20. Vibration is reduced by 11.85% and 36.11% for B20 when compared to diesel at first and second highest peak amplitude frequencies.

Fig. 6.8 shows superimposed frequency spectrums at no load condition for engine fuelled with diesel and B30. The highest peak amplitudes are observed, at the frequencies of 700 Hz and 2543 Hz with amplitudes of 1.29 m/s² and 1.27 m/s² for B30. Vibration is reduced by 4.44% and 11.81% for B30 when compared to diesel at first and second highest peak amplitude frequencies.

![Superimposed frequency spectrums at no load condition for diesel and B20](image)

Fig. 6.7 Superimposed frequency spectrums at no load condition for diesel and B20
Fig. 6.8 Superimposed frequency spectrums at no load condition for diesel and B30

Fig. 6.9 Superimposed frequency spectrums at no load condition for diesel and B40
Fig. 6.9 shows superimposed frequency spectrums at no load condition for engine fuelled with diesel and B40. The highest peak amplitudes are observed, at the frequencies of 661 Hz and 2573 Hz with amplitudes of 1.31 m/s$^2$ and 1.42 m/s$^2$ for B40. Vibration is reduced by 2.96 % and 1.4% for B40 when compared to diesel at first and second highest peak amplitude frequencies. At no load condition lowest vibration is observed for B20 fuel compared to other fuels.

6.1.5 Superimposed Frequency Spectrums for Diesel vs Biodiesel Blends B10, B20, B30 and B40 at Full Load

Fig. 6.10 shows superimposed frequency spectrums at full load for engine fuelled with diesel and B10. The highest peak amplitudes are observed at the frequencies of 685 Hz and 2516 Hz with amplitudes of 4.05 m/s$^2$ and 1.58 m/s$^2$ in case of an engine operated with diesel. The highest peak amplitudes are observed, at the frequencies of 689 Hz and 2640 Hz with amplitudes of 2.49 m/s$^2$ and 1.02 m/s$^2$ for B10. Vibration is reduced by 38.52 % and 35.44 % for B10 when compared to diesel at first and second highest peak amplitude frequencies.

Superimposed frequency spectrums at full load for engine fuelled with diesel and B20, are shown in Fig. 6.11. The highest peak amplitudes are observed, at the frequencies of 685 Hz and 2515 Hz with amplitudes of 3.2 m/s$^2$ and 1.28 m/s$^2$ for B20. Vibration is reduced by 20.99 % and 18.99% for B20 when compared to diesel at first and second highest peak amplitude frequencies.
Fig. 6.10 Superimposed frequency spectrums at full load for diesel and B10

Fig. 6.11 Superimposed frequency spectrums at full load for diesel and B20
Fig. 6.12 shows superimposed frequency spectrums at full load for engine fuelled with diesel and B30. The highest peak amplitudes are observed, at the frequencies of 684 Hz and 2513 Hz with amplitudes of 4.13 m/s$^2$ and 1.19 m/s$^2$ for B30. Vibration is increased by 1.97\% and decreased by 24.68\% for B30 when compared to diesel at first and second highest peak amplitude frequencies.

Fig. 6.13 shows superimposed frequency spectrums at full load for engine fuelled with diesel and B40. The highest peak amplitudes are observed, at the frequencies of 683 Hz and 2522 Hz with amplitudes of 3.78 m/s$^2$ and 1.34 m/s$^2$ for B40. Vibration is decreased by 6.67\% and 15.2\% for B40 when compared to diesel at first and second highest peak amplitude frequencies. At full load, major reduction of vibration is noticed for B10 over other fuels.
6.2 Combustion Analysis for Diesel and NME Blends B10, B20, B30 and B40

6.2.1 Combustion Pressure for Diesel and NME Blends B10, B20, B30 and B40

Fig. 6.14 shows variation of maximum combustion pressure of cylinder with load for diesel and NME blends B10, B20, B30, and B40. It is shown that cylinder pressure is increasing for all fuel blends with respect to load. It may be due to more amount of fuel consumption at higher loads. It is also observed that engine running with standard diesel fuel produced higher cylinder pressure up to 75% load compared to NME blends which may be due to slightly higher delay period of diesel compared to biodiesel blends. However, at full load B30 has produced slightly higher cylinder pressure compared to diesel. From no load to full load, cylinder peak pressures are changing from 48 bar to 63.6 bar, 45.88 bar to 62.58 bar, 46.12 bar to 62.69 bar, 47.39 bar 63.7 bar and 47.94 bar to 62.87 bar for engine running with standard diesel, B10, B20, B30 and B40.

Variation of cylinder pressure with crank angle is shown in Fig. 6.15, for diesel and NME blends B10, B20, B30 and B40 at full load. Higher cylinder pressures are
obtained for diesel and B30 whereas lower values are obtained for B10 and B20. Lowest cylinder pressure of 62.58 bar is obtained for engine run with B10.

Fig. 6.14 Maximum combustion pressure of cylinder with load for diesel, B10, B20, B30, and B40
Fig. 6.15 Combustion pressure with crank angle for diesel, B10, B20, B30, and B40

6.2.2 NHRR for Diesel and NME Blends B10, B20, B30 and B40

Fig. 6.16 shows maximum NHRR for standard diesel and NME blends B10, B20, B30 and B40 with % load. It is noticed that maximum NHRR is increasing with load for all the fuels and the lowest NHRR is observed for B40 compared to the other fuels at all loads. Fig. 6.17 shows variation of NHRR with crank angle for standard diesel and NME blends B10, B20, B30 and B40, at full load. It is observed that at the beginning, negative HRR is observed. It may be due to vaporization of the fuel which is accumulated during ignition delay. It is also observed that start of combustion is advanced for NME blends compared to diesel and moreover it is higher for B40. It is due to advanced injection timing for biodiesel blends as they have higher density and bulk modulus over diesel [47, 56]. Biodiesel blend B40 has shown lowest maximum HRR compared to diesel and other
fuel blends as it may be due to poor evaporation, atomization and smaller ignition delay of biodiesel blends owing to higher cetane number. Maximum HRR is observed for B10 and minimum is obtained for B40. At full load, maximum heat release rates of engine are obtained as 45.7 J/°CA, 46.83 J/°CA, 46.5 J/°CA, 43.8 J/°CA, 41.1 J/°CA for standard diesel and fuel blends B10, B20, B30 and B40.

Fig. 6.16 Maximum NHRR with load for diesel, B10, B20, B30, and B40
6.2.3 RPR for Diesel and NME Blends B10, B20, B30 and B40

Fig. 6.18 shows variation of maximum RPR with % load for standard diesel and NME blends B10, B20, B30 and B40. It is noticed that RPR is increasing with load for all the fuels and the trend of the graph is similar to NHRR. At higher loads, B40 blend has shown lowest maximum RPR compared to other fuels. At full load, maximum RPR of 5.1 bar/deg is obtained for blends B10 and B20 and minimum of 4.6 bar/deg is obtained for B40. It may be due to lower atomization and vaporization of blended fuel with higher % biodiesel. At lower loads, biodiesel blends have almost same maximum RPR with that of standard diesel. Fig. 6.19 shows RPR with respect to crank angle for diesel and
biodiesel blends at full load. It is observed that the RPR is decreased initially during the delay period for all the fuels and then it increased before the start of combustion with a sharp rate of rising after the start of combustion. At full load, maximum RPR values are obtained as 5 bar/°CA, 5.1 bar/°CA, 5.1 bar/°CA, 4.9 bar/°CA and 4.6 bar/°CA for diesel and biodiesel blends B10, B20, B30 and B40.

Fig. 6.18 Maximum RPR with load for diesel, B10, B20, B30, and B40
6. 2.4 MFB for Diesel and NME Blends B10, B20, B30 and B40

Fig. 6.20 shows variation of MFB with respect to crank angle at full load for standard diesel and NME blends B10, B20, B30 & B40. 5% and 10% MFB is greatly advanced for B40 compared to other fuels which may be due to higher density and bulk modulus and this occurred at angles of 5.5° BTDC and 4.25° BTDC for B40. 90% MFB is done lately for B30 over other fuels and it is observed at an angle of 24.72 ° after TDC.
Fig. 6.20 Mass fraction burned with crank angle for diesel, B10, B20, B30, and B40

6.3 Performance Characteristics for Diesel and NME Blends B10, B20, B30 and B40

Fig. 6.21 shows the variation of BTE with the load for diesel, NME blends B10, B20, B30, and B40. It is noticed that BTE is increasing for all the fuels and it is noticed that at every load, one of the NME blends is having slightly higher BTE over diesel. At 75% and 100% load conditions, engine operated with B40 has got 3.8% and 1.2% higher BTE compared to diesel. Fig. 6.22 shows the variation of BSFC of the engine for diesel, NME blends B10, B20, B30, and B40 at various loads. The higher BSFC is observed for NME blends other than B10 which may be due to their low calorific value and high viscosity over B10. Among the different biodiesel blends, B10 has got lower BSFC at all the loads.
6.4 Emission Characteristics for Diesel and NME Blends B10, B20, B30 and B40

Fig. 6.23 shows the NO\textsubscript{X} emission with the load for diesel, NME blends B10, B20, B30 and B40. Blends B10 and B20 have produced low NO\textsubscript{X} emission compared to other fuels. At 75% and 100% load conditions, blend B30 has produced 10.14% and 123% higher NO\textsubscript{X} emission over diesel due to the availability of higher oxygen content in B30. The smoke density of the engine with the load for diesel, NME blends B10, B20, B30 and B40 is shown in Fig. 6.24. It is noticed that at all the loads, smoke levels are reduced for all biodiesel blends compared to diesel. The lowest smoke density is observed for blend B10 and it is lesser by 74.29%, 44.51%, 64.62%, 37.78% and 34.89% over diesel at 0%, 25%, 50%, 75%, and 100% loads.

The variation of CO emission for diesel, NME blends B10, B20, B30 and B40 is shown in Fig. 6.25. In general, for all fuels, CO emissions are decreasing as load is increasing due to complete combustion at higher loads. At 25% load condition, B10 fuel has resulted in 66.67% lesser CO emission as compared to diesel fuel. Variation of CO\textsubscript{2} emission for diesel, NME blends B10, B20, B30 and B40 is shown in Fig. 6.26. CO\textsubscript{2} emissions are observed to be decreasing with the load for all fuels. Low CO\textsubscript{2} emissions
are produced when engine is operated with B30 and B10. However, blend B40 has shown higher CO$_2$ emission compared to other biodiesel blends. The HC emission for diesel, NME blends B10, B20, B30 and B40 is shown in Fig. 6.27. HC emissions are decreasing with the load for all fuels due to complete combustion at higher loads. At no load condition, HC emission is higher for all NME blends and it is maximum for blend B40 over diesel by 100%. At 75% and 100% load conditions, B10 has shown lower HC emission over other fuels.

![Fig. 6.23 NO$_X$ with % load](image1)

![Fig. 6.24 Smoke density with % load](image2)
Fig. 6.25 CO emission with % load

Fig. 6.26 CO$_2$ emission with % load

Fig. 6.27 HC emission with % load
6. 5 Effect of Diesel-NME-Methanol Blended Fuels B1 and B2 on Engine Vibration

6.5.1 Overall Vibration Velocity

Fig. 6.28 Overall vibration with % load

Fig. 6.28 shows overall vibration velocity of engine head with respect to load for various fuels like NME, diesel-biodiesel-methanol blended fuels B1 and B2 as compared to diesel. Overall vibration velocity is RMS value of engine vibration which is calculated from time wave. It can be observed that the overall vibrations are lower in the case of NME compared to diesel and fuels B1 and B2. At full load condition, the overall engine vibrations are higher in the case of diesel compared to other fuels. Maximum overall vibration is obtained at three-fourth load for diesel, NME, and B1. Fuels B1 and B2 have produced the higher overall vibration when compared to NME.
6.5.2 Time waves and Frequency Spectrums for Engine Running with Diesel, NME, B1, and B2 at No Load

Fig. 6.29 show superimposed time waves and frequency spectrums of an engine vibration, in the vertical direction, when it is fuelled with diesel and NME, at no load condition. From Fig. 6.29 (a), it is realized that instantaneous vibration is varying in the range of -220 m/s² and 310 m/s² for diesel and in the range of -175 m/s² and 160 m/s² for NME. The highest peak amplitudes are observed at the frequencies of 723 Hz, 1840 Hz and 2134 Hz with amplitudes of 1.5 m/s², 2.29 m/s² and 1.55 m/s² in case of engine operated with diesel, whereas the highest peak amplitudes are observed at the frequencies of 715 Hz, 1845 Hz and 2180 Hz with amplitudes of 0.87 m/s², 1.97 m/s² and 1.08 m/s² when engine is operated with NME as shown in Fig. 6.29 b. It is also realized that peak amplitudes of vibrations are dominating for engine fuelled with diesel compared to NME and the first highest peak amplitude is higher by 72.4% for diesel compared to NME which may be due to lower cetane number of diesel over NME.

Fig. 6.30 shows superimposed time waves and frequency spectrums of an engine vibration, in the vertical direction, when it is fuelled with B1 and B2, at no load condition. From Fig. 6.30 (a), it is noticed that instantaneous vibration is varying in the range of -200 m/s² and 235 m/s² for B1 fuel and in the range of -201 m/s² and 186 m/s² for B2 fuel. From Fig. 6.30 (b), it is noticed that peak amplitude at the third highest frequency is higher for B2 when compared with B1 by 55.8% and it may be due to the difference in RPR of the blends.

6.5.3 Time waves and Frequency Spectrums for Engine Running with Diesel, NME, B1, and B2 at Full Load

Fig. 6.31 shows superimposed time waves and frequency spectrums of an engine vibration, in the vertical direction, when it is fuelled with diesel and NME, at full load condition. From Fig. 6.31 (a), it is realized that instantaneous vibration is varying in the range of -207 m/s² and 225 m/s² for diesel and in the range of -174 m/s² and 188 m/s² for NME. The vibration is observed to be lower for NME. From Fig. 6.31 b, it is noticed
Fig. 6.29 (a) Time waves for engine running with diesel and NME at no load
(b) Frequency spectrums for engine running with diesel and NME at no load

Fig. 6.30 (a) Time waves for engine running with B1 and B2 at no load
(b) Frequency spectrums for engine running with B1 and B2 at no load
Fig. 6.31 (a) Time waves for engine running with diesel and NME at full load.
(b) Frequency spectrums for engine running with diesel and NME at full load.

Fig. 6.32 (a) Time waves for engine running with B1 and B2 at full load.
(b) Frequency spectrums for engine running with B1 and B2 at full load.
that the highest peak amplitudes are observed at the frequencies of 683 Hz, 1847 Hz and 2165 Hz with amplitudes of 4.92 m/s², 4.22 m/s² and 1.93 m/s² in case of engine operated with diesel, whereas the highest peak amplitudes are observed at the frequencies of 678 Hz, 1851 Hz and 2155 Hz with amplitudes of 3.13 m/s², 2.08 m/s² and 1.15 m/s² when engine is operated with NME. At full load, vibration is reduced by 36.4%, 50.7% and 40.4% for NME compared with diesel at first, second and third highest peak amplitude frequencies.

Fig. 6.32 shows superimposed time waves and frequency spectrums of an engine vibration in the vertical direction, when it is fuelled with B1 and B2, at full load condition. From Fig. 6.32 (a), it is noticed that instantaneous vibration is varying in the range of -276 m/s² and 223 m/s² for fuel B1 and in the range of -218 m/s² and 205 m/s² for fuel B2. From Fig. 6.32 (b), it is noticed that the highest peak amplitudes are observed at the frequencies of 680 Hz, 1850 Hz and 2132 Hz with amplitudes of 3.21 m/s², 2.27 m/s² and 1.4 m/s² in case of engine operated with B1, whereas the highest peak amplitudes are observed at the frequencies of 685 Hz, 1855 Hz and 2138 Hz with amplitudes of 4.62 m/s², 2.62 m/s² and 2.05 m/s² when engine is operated with B2. It is noticed that vibration is increased by 44%, 15.4% and 46.4% for B2 compared with B1 at first, second and third highest peak amplitude frequencies.

6.6 Combustion Analysis for Diesel-NME-Methanol Blended Fuels

Fig. 6.33 shows the combustion pressure with the crank angle at full load for various fuels like diesel, NME, diesel-NME-methanol blended fuels B1 and B2. Highest peak pressure of 64.32 bar is obtained for diesel and it is higher by 4.5%, 8.8%, and 7.7% when compared with NME, B1, and B2. Diesel-NME-methanol blended fuel B2 has shown slightly higher combustion pressure when compared with B1 fuel. It may be due to the decrease in cetane number and an increase in latent heat of evaporation by the addition of methanol which further increases ignition delay of blended fuel [66].
Fig. 6.34 shows the variation of NHRR with the crank angle at full load condition for different fuels like diesel, NME, B1 and B2. For all the fuels, NHRR initially follows downwards at the end of compression stroke which abruptly changes its slope at the start of combustion. The abrupt change of slope is advanced for NME and B1 over other fuels which may be due to higher bulk modulus and density of NME and B1 over other fuels. The maximum net heat release rates are observed as 44.49 J/deg, 40.31 J/deg, 34.18 J/deg and 36.68 J/deg for diesel, NME, B1, and B2. The highest and lowest NHRR is observed for diesel and B1.

![Combustion pressure with crank angle](image1)

![Net heat release rate with crank angle](image2)

Fig. 6.33 Combustion pressure with crank angle  
Fig. 6.34 NHRR with crank angle

The RPR with respect to the crank angle, at full load condition for all the fuels, is shown in Fig. 6.35. Analysis of RPR is important in engine study because it determines how smoothly the combustion process progresses in the cylinder. The maximum rate of pressure rise must be lower for reduction of noise and improvement in the lifespan of the engine. It is observed that the RPR first decreased during the delay period for all the fuels and then it increased before the start of combustion with a sharp rate of rising after the start of combustion. The pressure rise rate is more for diesel when compared with NME and methanol blended fuels B1 and B2. Methanol blended fuel B2 has slightly higher rate
of pressure rise over B1 which may be due to its higher ignition delay period. Fig. 6.36 shows the percentage of MFB with the crank angle at full load for different fuels like diesel, NME, methanol blended fuels B1 and B2. It is observed that methanol blended fuel B2 has taken a lesser duration of crank angle rotation for 5%, 10%, 50% and 90% mass fraction burned over other fuels as it is higher oxygenated fuel. It is noticed that 50% mass fraction burned is observed at an angle of 3.84°, 3.44°, 3.09° and 2.37° after TDC for diesel, NME, B1, and B2.

![Fig. 6.35 RPR with crank angle](image1)
![Fig. 6.36 MFB with crank angle](image2)

6.7 Performance Characteristics for Diesel, NME, and Diesel-NME-Methanol Blended Fuels

6.7.1 BTE for Diesel, NME, B1 and B2

Fig. 6.37 shows the variation of BTE with the load for diesel, NME, diesel-NME-methanol blended fuels B1 and B2. It is noticed that B1 and B2 have shown higher BTE compared to diesel and NME at all loads. At full load condition, BTE is higher by 7.75 %, 21% and 24.74% for NME, B1, and B2 when compared to diesel. The engine operated
with methanol blended fuels B1 and B2 has got higher BTE which may be due to the higher oxygen content of the alcohol blends which increases the efficiency of combustion.

6.7.2 BSFC for Diesel, NME, B1 and B2

Fig. 6.38 shows the variation of BSFC of the engine for diesel, NME, B1 and B2 at various loads. BSFC of blends B1 and B2 are lower at all loads which may be due to their superior evaporation compared to diesel and NME. The higher BSFC is observed for NME which may be due to its low calorific value and high viscosity over other fuels.

6.8 Emission Characteristics for Diesel, NME, and Diesel-NME-Methanol Blended Fuels

Fig. 6.39 shows the NO\textsubscript{X} emission with the load for diesel, NME, diesel-NME-methanol blended fuels B1 and B2. NO\textsubscript{X} emissions are higher for all fuels at 75% and 100% load conditions due to higher combustion temperatures. Fuel B1 has produced higher NO\textsubscript{X} emissions at all loads which may be due to higher oxygen content. The
engine operated with B2 fuel has resulted in lower emission than B1 due to cooling effect with the further addition of methanol which reduces cylinder combustion temperatures. At full load condition, diesel-NME-methanol blended fuels B1 and B2 have resulted in 60.7% and 36.4% higher NO\textsubscript{X} emissions compared to diesel and NME. The smoke density of the engine with the load for diesel, NME, fuels B1 and B2 is shown in Fig. 6.40. It is noticed that higher smoke levels are observed for NME and B2 up to 75% load condition. At no load condition, smoke density is higher for B2 and lower for B1. The smoke density of B1 is lower compared to other fuel types up to 50% load. However, at full load condition smoke density for blend B1 is increased and it is higher by 8.98%, 0.6% and 8% when compared with diesel, NME, and B2.

The variation of CO emission for NME, B1 and B2 as compared to diesel is shown in Fig. 6.41. In general, for all fuels, CO emission is decreased with load due to complete combustion as the load is increased. At full load condition, methanol blended fuel B2 has resulted in 100% higher CO emission as compared to diesel fuel. It may be due to lower overall cetane number of B2 which increase their ignition delay and result in incomplete combustion. Variation of CO\textsubscript{2} emission for diesel, NME, B1 and B2 is shown in Fig. 6.42. CO\textsubscript{2} emissions are observed to be decreasing with the load for all fuels. Diesel-biodiesel-methanol blended fuel B1 and NME have produced higher emissions. At full load condition CO\textsubscript{2} emission is higher by 200% for NME, fuels B1 and B2 when compared with baseline fuel diesel. The HC emission for NME, B1 and B2 with reference to diesel is shown in Fig. 6.43. HC emissions are observed to be decreasing with the load for all fuels due to complete combustion at higher loads. Methanol blended fuel B1 has produced lower emissions at all loads. However, HC emissions are higher for B2 at no load and full load by 120% and 200% when compared to base fuel diesel. Higher HC emissions are produced for the engine operated with NME up to 50% load.
Fig. 6.39 NO\textsubscript{X} with % load

Fig. 6.40 Smoke density with % load

Fig. 6.41 CO with % load

Fig. 6.42 CO\textsubscript{2} with % load
Fig. 6.43 HC with % load