CHAPTER 5

EXPERIMENTAL RESULTS AND DISCUSSION-COMBUSTION, PERFORMANCE AND EMISSION ANALYSIS FOR DIESEL AND NME

5.1 Combustion Analysis with Respect to CR for Diesel and NME

In this chapter combustion, performance and emission analysis is presented for engine running with diesel and NME at compression ratios 14, 15, 16, and 17.

5.1.1 Combustion Pressure with Respect to CR for Diesel and NME

Fig. 5.1 shows the variation of combustion pressure with the crank angle at full load condition at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. It is noticed that cylinder combustion pressures are increasing for diesel and NME when CR is increasing and the maximum combustion pressures are obtained at CR 17. At CR 14, maximum combustion pressure of 45.55 bar is obtained for diesel and it is higher by 1.9%, when compared with NME. At CR 15, maximum combustion pressure of 48.30 bar is obtained for diesel and it is higher by 1.2%, when compared with NME. At CR 16, maximum combustion pressure of 50.02 bar is obtained for diesel and it is higher by 2.1%, when compared with NME. At CR 17, maximum combustion pressure of 53.67 bar is obtained for NME which is slightly higher for NME over diesel by 1.3%.

Fig. 5.2 shows maximum combustion pressures in cylinder with load, at different compression ratios, when engine is operated with diesel and NME. It is shown that maximum combustion pressures are increasing with load for both the fuels and at CR 14, 15, and 16, it is higher for diesel over NME which may be due to higher delay period of diesel over NME. However, at CR 17, maximum combustion pressures are slightly higher for NME over diesel. Change in maximum combustion pressures from no load to full load, for diesel and NME, are 71.5% and 72.25% at CR14, 57.7% and 61.8% at CR15, 52.5% and 53.12% at CR 16, 49.76% and 44.62% at CR 17. It is noticed that
percentage change in maximum combustion pressures from no load to full load are decreasing as compression ratio is increasing for both diesel and NME.

Fig. 5.1 Combustion pressure with the crank angle at full load condition for diesel and NME at (a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
Fig. 5.2 Maximum combustion pressure with the load for diesel and NME at
(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
5.1.2 Net Heat Release Rate (NHRR) with Respect to CR for Diesel and NME

Fig. 5.3 shows the variation of NHRR with the crank angle at full load condition at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. At all compression ratios, 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 over diesel which may be due to higher bulk modulus and density of NME over diesel. At CR 14, the maximum NHRR values are observed as 49.2 J/deg and 40.2 J/deg for diesel and NME and maximum NHRR of NME is lesser by 18.29% when compared with diesel. At CR 15, the maximum NHRR values are observed as 47.51 J/deg and 40.4 J/deg for diesel and NME and maximum NHRR of NME is lesser by 14.96% when compared with diesel. At CR 16, the maximum NHRR values are observed as 43.1 J/deg and 38.2 J/deg for diesel and NME and maximum NHRR of NME is lesser by 11.4% when compared with diesel. At CR 17, the maximum NHRR values are observed as 44.38 J/deg and 35.2 J/deg for diesel and NME and maximum NHRR of NME is lesser by 20.68% when compared with diesel. It is noticed that maximum NHRR is lesser at higher compression ratios compared to lower compression ratios for both diesel and NME. It may be due to the air entrainment and lower air/fuel ratio [70]

Fig. 5.4 shows variation of maximum NHRR with load, at different compression ratios, when engine is operated with diesel and NME. It is shown that maximum NHRR is increasing with load for both the fuels at all compression ratios. At any load and at any CR, maximum NHRR is higher for diesel over NME. It may be due to lesser viscosity and better spray formation of diesel over biodiesel [71]. Change in maximum NHRR from no load to full load, for diesel and NME, are 278.5% and 231 % at CR14, 236.9% and 213.2 % at CR15, 201.4% and 185% at CR 16, 197.8% and 158.8% at CR 17. It is noticed that % change in maximum NHRR from no load to full load is decreasing as compression ratio is increasing for both diesel and NME.
Fig. 5.3 NHRR with the crank angle at full load condition for diesel and NME at (a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
Fig. 5.4 Maximum net heat release rate with the load for diesel and NME at
(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
5.1.3 Rate of Pressure Rise (RPR) with Respect to CR for Diesel and NME

Fig. 5.5 shows the variation of RPR with the crank angle at full load condition at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. Analysis of RPR is essential in study of engines as it determines how well the combustion process progresses in the cylinder. The maximum RPR must be lower for reduction of noise and improvement in the lifespan of the engine. At all CRs, it is observed that the RPR decreased initially during the delay period for both 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. At CR 14, maximum RPR of 3.7 bar/deg and 2.97 bar /deg is observed for diesel and NME and it is higher by 26.94% for diesel when compared to NME. At CR 15, Maximum RPR of 3.9 bar /deg and 3.3 bar /deg are observed for diesel and NME and it is higher by 18.2% for diesel when compared to NME. At CR 16, maximum RPR of 3.95 bar /deg and 3.6 bar /deg is observed for diesel and NME and it is higher by 9.7% for diesel over NME. At CR 17, maximum RPR of 4.46 bar /deg and 3.6 bar /deg is observed for diesel and NME and it is higher by 23.8% for diesel over NME. At full load, % Change in maximum RPR is 20.54% and 21.2% for diesel and NME when CR is changing from 14 to 17.

Fig. 5.6 shows variation of maximum RPR with load, at various compression ratios, when engine is operated with diesel and NME. It is shown that maximum RPR is increasing with load for both the fuels at all compression ratios. Change in maximum RPR from no load to full load, for diesel and NME, are 516.7% and 234 % at CR14, 457% and 371.4 % at CR15, 393.7% and 350% at CR 16, 395.6% and 227.3% at CR 17.

5.1.4 Mass Fraction Burned (MFB) with Respect to CR for Diesel and NME

Fig. 5.7 shows the variation of MFB with the crank angle at full load condition at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. Mass fraction burned (MFB) represents the percentage of fuel burned in the combustion process for certain duration of crank angle [72]. At lower compression
Fig. 5.5 RPR with crank angle for diesel and NME at
(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
Fig. 5.6 Maximum RPR with the load for diesel and NME at (a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
ratios, MFB is observed to be slightly higher for NME over diesel which may be due to the oxygen content of NME. Due to higher oxygen of NME, combustion is also continued in the diffusive combustion period [73]. However, at higher compression ratio 17, MFB is lower for NME over diesel. At CR 14, it is observed that NME has taken a
lesser duration of crank angle rotation for 5%, 10%, and 90% MFB over diesel as it has more oxygen. 90% MFB is occurred at an angle of 33.88° after TDC and 31.89° after TDC for diesel and NME. At CR 15, it is observed that NME has taken a lesser duration of crank angle rotation for 5%, 10%, 50% and 90% mass fraction burned over diesel. 90% mass fraction burned is occurred at an angle of 30.54° after TDC for diesel and 28.83° after TDC for NME. At CR 16, NME has taken a lesser duration of crank angle rotation for 5%, 10% and 90% mass fraction burned over diesel as it has more oxygen. However, 50% MFB is observed little earlier for diesel compared with NME. At CR 17, 5% and 10% MFB is done earlier for NME over diesel whereas 50% and 90% MFB is done earlier for diesel over NME. 90% mass fraction burned is occurred at an angle of 26.17° after TDC for diesel and 29.50° after TDC for NME.

5.2 Performance Characteristics with Respect to CR for Diesel and NME

5.2.1 Brake Thermal Efficiency (BTE) with respect to CR for Diesel and NME

Fig. 5.8 shows the variation of BTE with the load at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. BTE depends on calorific value and fuel consumption [59]. It is noticed that BTE is increasing with load for both the fuels at all compression ratios. It is due to reduction of heat loss and increase in power output with increase in load [74]. At CR 14, BTE is higher for diesel over NME at all loads and it is 1.7% higher for diesel over NME at full load condition. At CR 15, BTE is slightly higher for diesel over NME at all the loads and BTE is 1.7% higher for diesel over NME at full load condition. At CR 16, BTE is slightly higher for NME over diesel at all the loads and BTE is 1.96 % higher for NME over diesel at full load condition. At CR 17, BTE is increasing with load for both the fuels and it is almost same up to three fourth load and slightly higher for diesel over NME by 1.7% at full load condition. Highest brake thermal efficiencies of 30.57% and 31.17% are obtained at CR 16 for both diesel and NME.
Fig. 5.8 BTE with the load for diesel and NME at
(a) CR-14  (b) CR-15  (c) CR-16  (d) CR-17
5.2.2 BSFC with Respect to CR for Diesel and NME

Fig. 5.9 BSFC with the load for diesel and NME at

(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17

Fig. 5.9 shows the variation of BSFC with the load at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. Fuel properties like
viscosity, density, and calorific value will influence BSFC [75]. In general, for both the fuels, BSFC is decreasing with load and it is higher for NME when compared to diesel at all compression ratios. It may be due to its low calorific value and high viscosity of NME over diesel. BSFC for NME is higher by 32.31% and 10.34% at CR 14; 19.67% and 10.3% at CR 15; 7.8% and 7.1% at CR 16, and 11.5% and 10.3% at CR 17, over diesel at 25% and 100% load conditions.

5.3 Emission Characteristics for Diesel and NME with Respect to CR

5.3.1 CO Emission

Fig. 5.10 shows the variation of CO emission with the load at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. CO emission occurs due to incomplete combustion of fuel which is because of inadequate supply of air and inappropriate pre-mixing of fuel with air [76]. At all compression ratios CO emissions are decreasing with load for both diesel and NME due to complete combustion at higher loads. At part load condition, NME has shown higher CO emission compared to diesel at all compression ratios, but at higher loads NME has shown lesser emissions compared to diesel. CO emissions are decreasing as compression ratio is increasing for both diesel and NME which may be due to complete combustion at higher compression ratio.

5.3.2 CO$_2$ Emission

Fig. 5.11 shows the variation of CO$_2$ emission with the load at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. Higher amount of CO$_2$ is an indication of complete combustion of fuel. At all compression ratios CO$_2$ emission is initially increasing, and after reaching to maximum value it starts decreasing and the lowest emissions are obtained at full load condition for diesel and NME.
Fig. 5.10 CO emission with the load for diesel and NME at
(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
Fig. 5.11 CO$_2$ emission with the load for diesel and NME at
(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
5.3.3 HC Emission

Fig. 5.12 shows the variation of HC emission with the load at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. HC emissions are observed to be decreasing with the load for both diesel and NME at all compression ratios due to complete combustion at higher loads. At full load condition, HC emissions for NME are lesser by 60% at CR14, 100% at CR 15, 87.5% at CR 16, 100% at CR 17, when compared with diesel. HC emissions are decreasing as compression ratio is increasing for both diesel and NME.

5.3.4 NO\textsubscript{x} Emission

Fig. 5.13 shows the variation of NO\textsubscript{x} emission with the load at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. NO\textsubscript{x} emissions are due to high temperature of combustion and high oxygen content in the cylinder [77]. At all compression ratios, NO\textsubscript{x} emissions are increasing initially as load is increasing, after reaching to maximum value, it starts decreasing. NO\textsubscript{x} emissions are observed to be lesser for NME over diesel at low compression ratios. At full load condition, NO\textsubscript{x} emissions for NME are reduced by 65% at CR14, 56.25% at CR15, 57.43% at CR16, 13.89% at CR 17, when compared to diesel. It may be due to lower combustion temperatures of NME over diesel. The similar result is obtained for another researcher [76].

5.3.5 Smoke Emission

Fig. 5.14 shows the variation of smoke emission with the load at different compression ratios ranging from 14 to 17, when engine is fuelled with diesel and NME. At all compression ratios, smoke density is higher for NME over diesel and it is maximum at higher loads. At full load, smoke density of NME is higher compared with diesel, by 5.6% at CR 14, 14.3% at CR 15, 11.63% at CR 16, and 9.2% at CR 17.
Fig. 5.12 HC emission with the load for diesel and NME at
(a) CR-14  (b) CR-15  (c) CR-16  (d) CR-17
Fig. 5.13 NO\textsubscript{X} emission with the load for diesel and NME at
(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17
Fig. 5.14 Smoke emission with the load for diesel and NME at
(a) CR-14 (b) CR-15 (c) CR-16 (d) CR-17