CHAPTER 7

SUMMARY, CONCLUSIONS AND SCOPE OF FUTURE WORK

In the previous chapters, the results of vibration, combustion, performance and emission characteristics of VCR diesel engine are discussed for engine fuelled with diesel and NME. The engine vibration is tested at various compression ratios like 14, 15, 16 and 17 along vertical, lateral, and longitudinal directions. The effect of NME on engine vibration, combustion, performance and emission characteristics is discussed at all the compression ratios and the most significant direction of combustion induced vibration is determined. Then the vibration is tested in that direction for fuels B10, B20, B30, B40, NME, diesel-biodiesel-methanol blended fuels B1 and B2 at maximum compression ratio 17.5. Performance, combustion and emission characteristics are also investigated at the same compression ratio for the above said fuels and the results are compared with diesel. The main conclusions from the present research work are listed down in this chapter. The scope for future research works is also discussed.

7.1 CONCLUSIONS

7.1.1 Engine Vibration at Fixed Compression Ratio (CR) 14 for Diesel and NME

- It is observed that highest peak is obtained at the frequency of 25 Hz within the range of 0-100 Hz, for engine running with both diesel and biodiesel. Moreover, at low frequency zone, higher vibrations are noticed along lateral and longitudinal directions compared to vertical direction. It may be due to higher mechanical induced vibration along lateral and longitudinal directions at low frequencies, which is because of the motion of reciprocating and rotary components of engine leading to unbalanced forces.
- In vertical direction, a maximum reduction of 58.2% is obtained in engine’s high frequency vibration for NME over diesel at three fourth load.
- In lateral direction, the highest peak acceleration amplitudes are observed in between 2000 Hz to 3000 Hz for both diesel and NME and moreover they are lower for engine fuelled with NME.
In lateral direction, a maximum reduction of 34.46% and 38.25% is obtained in engine’s high frequency vibration for NME over diesel at three fourth and full load conditions.

In longitudinal direction, at high frequency zone, the highest peak amplitude of vibration is observed in between 2000 Hz and 3000 Hz for both diesel and NME and it is higher for diesel compared to NME.

In longitudinal direction, the change in peak acceleration amplitude is 91.97 % and 77.2 % in case of diesel and NME when load is changed from 0 kW to maximum of 3.5 kW. It is noticed that, in longitudinal direction, engine vibration, at low frequency zone, is significantly affected with respect to load for both diesel and NME. It may be due to increase of unbalanced forces as a result of variation of gas pressure inside the cylinder. However, the effect of fuel is not significant at low frequencies but considerable changes are observed in engine vibration at high frequencies.

The change in vibration at full load and at fundamental frequency of 25 Hz is 2.8%, 0.35% and 4.2% along vertical, lateral and longitudinal directions when fuel is changed from diesel to NME. However, at high frequency zone, the increase in vibration at full load is 49.1 %, 61.93% and 11.5% along vertical, lateral and longitudinal directions when fuel is changed from NME to diesel.

It is realized that combustion induced vibration is reduced when engine is operated with NME in place of diesel.

7.1.2 Effect of CR on Engine Vibration for Diesel and NME

In vertical direction, at full load condition, high frequency vibration is increased by 41.3% and 49.1% for diesel and NME as the compression ratio is increased from 14 to 17.

In vertical direction, at high frequency (or) combustion frequency zone, at all the loads, and at all compression ratios, engine’s combustion induced vibration is reduced for NME over diesel.
• In vertical direction, at no load condition, when fuel is changed from diesel to NME, the decrease in combustion induced vibration is 29.3% at CR 14, 36.9% at CR 15, 25% at CR 16, and 23.62% at CR 17.

• In vertical direction, at full load condition, when fuel is changed from diesel to NME, the reduction in combustion induced vibration is 32.92% at CR 14, 42.2% at CR 15, 39.4% at CR 16, and 29.23% at CR 17.

• In lateral direction, at full load condition, for NME, high frequency vibration is increased by 38.64% when compression ratio is increased from 14 to 17.

• In lateral direction, at high frequency (or) combustion frequency zone, at no load condition, when fuel is changed from diesel to NME, the change in vibration is 3.3% at CR 14, 4.05% at CR 15, 11.76% at CR 16, and 12.95% at CR 17.

• In lateral direction, at high frequency (or) combustion frequency zone, at full load, when fuel is changed from diesel to NME, the change in vibration is 38.25% at CR 14, 27.1% at CR 15, 46.35% at CR 16, and 1.64% at CR 17.

• In longitudinal direction, at high frequency (or) combustion frequency zone, at no load condition, when fuel is changed from diesel to NME, the change in vibration is 22.6% at CR 14, 19.45% at CR 15, 16.61% at CR 16, and 2.8% at CR 17.

• In longitudinal direction, at high frequency (or) combustion frequency zone, at full load, when fuel is changed from diesel to NME, the reduction in vibration is 10.3% at CR 14, 13.1% at CR 15, 14.52% at CR 16, and 5.56% at CR 17.

• Most significant reduction in engine vibration is noticed in vertical direction for NME over diesel at all loads and compression ratios.

7.1.3 Combustion Characteristics with Respect to CR for 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.
- It is noticed that % change in maximum combustion pressures from no load to full load are decreasing as compression ratio is increasing for both diesel and NME.

- Percentage changes in maximum combustion pressures from no load to full load are higher at CR 14, and they are 71.5% and 72.25% for diesel and NME. The lowest % changes are noticed at CR 17 and they are 49.76% and 44.62% for diesel and NME.

- 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 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.

- At all CRs, the RPR first decreased 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 to NME.

- At full load, highest maximum RPR values of 4.46 J/deg and 3.6 J/deg are obtained for diesel and NME at CR 17, 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.

- At CR 14, it is observed that 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. 90% mass fraction burned is occurred at an angle of 33.88° after TDC and 31.89° after TDC for diesel and 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 and 29.50° after TDC for diesel and NME.
7.1.4 Performance Characteristics with Respect to CR for Diesel and NME

- It is noticed that BTE is increasing with load for both the fuels at all compression ratios.
- Highest brake thermal efficiencies of 30.57% and 31.17% are obtained at CR 16 for both diesel and NME.
- 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.

7.1.5 Emission Characteristics with Respect to CR for Diesel and NME

- At all compression ratios, CO emissions are decreasing with load for both diesel and NME due to complete combustion at higher loads.
- At higher loads, NME has shown lesser CO 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.
- At all compression ratios, CO₂ 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.
- 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.
- NOₓ emissions are observed to be lesser for NME over diesel at low compression ratios.
At all compression ratios, smoke density is higher for NME over diesel and it is maximum at higher loads. Smoke density of NME is higher compared with diesel at all compression ratios.

7.1.6 Performance, Combustion, Emission and Vibration Characteristics for Blends of NME Like B10, B20, B30 & B40

- At no load condition, maximum reduction of vibration is observed for B20 fuel compared to other fuels. Vibration is reduced by 11.85% and 36.11% for B20 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 and it is reduced by 38.52% and 35.44% for B10 when compared to diesel at first and second highest peak amplitude frequencies.
- 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.
- 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. It is also observed that start of combustion is advanced for biodiesel blends compared to diesel and moreover it is higher for B40.
- At lower loads biodiesel blends have almost same maximum rate of pressure rise with that of standard diesel. However, 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.
- 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 is 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.
- At 75% and 100% load condition, engine operated with B40 has got 3.8% and 1.2% higher BTE compared to diesel.
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. Lower BSFC is obtained for B10 at all the loads.

Blends B10 and B20 have produced low NO\textsubscript{X} emission compared to other fuels.

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.

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.

Low CO\textsubscript{2} emissions are produced when engine is operated with B30 and B10. However, blend B40 has shown higher CO\textsubscript{2} emission compared to other biodiesel blends.

At 75% and 100% load conditions B10 has shown lower HC emission over other fuels.

7.1.7 Performance, Combustion, Emission and Vibration Characteristics for Engine Running with Diesel, NME, B1, and B2

At full load condition, BTE is higher by 24.74% for diesel-biodiesel-methanol blended fuel B2 over diesel. At all loads, BSFC is lower for B1 when compared to diesel, NME and blend B2.

Maximum pressure, maximum NHRR and maximum RPR are observed to be higher for NME compared to blends B1 and B2, and lower when compared to diesel.

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-biodiesel-methanol blended fuel B2 has slightly higher rate of pressure rise over B1 which may be due to its higher ignition delay period.
It is noticed that 50% mass fraction burned is observed at an angle of 3.09° and 2.37° after TDC for B1 and B2 which is 19.5% and 38.3% earlier than diesel fuel.

At full load condition, fuels B1 and B2 have resulted in 60.7% and 36.4% higher NO\textsubscript{X} emissions compared to diesel and NME. It is noticed that higher smoke levels are observed for NME and B2 up to 75% load condition.

At no load condition, 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. It is also noticed that peak amplitude at the third highest frequency is higher for B2 when compared with B1 by 55.8%.

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. It is also 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.

Finally, it is concluded that neem methyl ester (NME) has produced lower engine vibration and considerable reduction in emissions over other fuels. Among different biodiesel blends tested, B10 and B1 has produced lowest vibration and comparably good performance over other blends. As stringent emission norms are being implemented all over the world, it is suggested that NME, blends B10 and B1 can be used as prominent fuels in diesel engines in view of lesser emissions and vibrations.

### 7.2 Scope for Future Work

- Engine vibration may be measured for various biodiesels and biodiesel blends.
- The present work can be extended by changing the methanol content from 0-30% by volume in the step of 5%. The engine vibration may also be tested by taking different alcohols like ethanol, propanol, butanol etc.
- Vibration analysis of engine may be done by using time frequency spectrums and water fall plots.
- Engine knocking may be measured using vibration analysis.