CONCLUSIONS
CHAPTER-7

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The following conclusions are arrived at from the investigations carried out on the following aspects.

7.1 INVESTIGATIONS ON THE CONVENTIONAL AND LHR ENGINES WITH PURE DIESEL OPERATION.

1. BSFC increased by 8% in the LHR engine at manufacturer’s recommended injection timing of 27°bTDC at the peak load with pure diesel operation, when compared to the conventional engine.

2. The optimum injection timing obtained with the LHR engine was 31°bTDC, while it was 33°bTDC with the conventional engine at an injection pressure of 190 bars. When the injection timing was advanced to 31°bTDC, BSFC improved by nearly 3.50% in the LHR engine at 190 bars. BSFC further improved to 4.00% in the LHR engine at increased pressure of 270 bars.

3. BSFC decreased by 5.7% in the conventional engine at an injection pressure of 190 bars, when the injection timing was advanced to 33°bTDC when compared to the conventional engine at 27°bTDC.

4. Marginal variation in the optimum injection timing observed with increased injection pressure with pure diesel operation on conventional engine while there was no change in optimum injection timing in the LHR engine with the increased injection pressure.

5. Exhaust gas temperatures decreased from 475°C at 27°bTDC to 450°C when the injection timing was advanced to 31°bTDC in the LHR engine, while EGT in the conventional engine at 27°bTDC was 425°C.

6. EGT decreased from 425°C at 27°bTDC to 375°C when the injection timing was advanced to 33°bTDC in the conventional engine.

7. Coolant load increased by 12.5% in the LHR engine at 27°bTDC, when the injection timing was advanced to 31°bTDC coolant load decreased by 15% in the LHR engine, when compared to the conventional engine.

8. Coolant load increased by 10% in the conventional engine at 33°bTDC at an injection pressure of 190 bars when compared to 27°bTDC.
9. Volumetric efficiency increased from 78% at 27°bTDC to 82% when the injection timing was advanced to 31°bTDC in the LHR engine, while volumetric efficiency in the conventional engine at 27°bTDC was 85%.

10. Volumetric efficiency increased marginally in the conventional engine by 4% at 33°bTDC at an injection pressure of 190 bars when compared to 27°bTDC.

11. Smoke levels increased by 20% in the LHR engine at 27°bTDC; when the injection timing was advanced to 31°bTDC smoke levels reduced by 10% at an injection pressure of 190 bars when compared to the conventional engine. Smoke levels further reduced by 17% at increased pressure of 270 bars at 31°bTDC.

12. Smoke levels decreased by 37% in the conventional engine at 33°bTDC at an injection pressure of 190 bars when compared to 27°bTDC.

13. NOx levels increased by 52% in the LHR engine at 27°bTDC; when the injection timing was advanced to 31°bTDC, NOx levels increased by 35% at an injection pressure of 190 bars and recorded 30% higher at increased pressure of 270 bars, when compared to the conventional engine at 27°bTDC.

14. NOx levels increased by 40% in the conventional engine at 33°bTDC at 190 bars when compared to 27°bTDC.

15. The magnitude of PP increased in the LHR engine from 48.1 bars at 27°bTDC to 56.5 bars when the injection timing was advanced to 31°bTDC. PP increased to 58.3 bars at increased pressure of 270 bars.

16. PP increased from 50.4 bars in the conventional engine at 27°bTDC to 62.2 bars when the injection timing was advanced to 33°bTDC at an injection pressure of 190 bars.

17. TOPP shifted nearer to TDC in the conventional and LHR engines at the advanced injection timings and with the increase of injection pressure.

18. MRPR increased marginally when the injection timings were advanced to their respective optimum values in the conventional and LHR engines.

19. No change was observed in TOMRPR in the conventional and LHR engines with the increase of injection pressure and advancing of the injection timings.
7.1.1 FINITE ELEMENT ANALYSIS FOR PREDICTING THE ISOOTHERMS AND HEAT FLOW IN THE PISTON AND LINER FOR CONVENTIONAL AND LIHR ENGINES.

i. ANSYS programme in which finite element mesh generated employing eight noded quadrilateral isoparametric elements predicted isotherms well for insulated piston, insulated liner, conventional piston and conventional liner for the conventional and LHR engines.

ii. The peak surface temperature of superni crown of the insulated piston of LHR engine was predicted increased to 753°C from 249°C of the piston of the conventional engine amounting to an increase of 202%.

iii. The peak surface temperature of top edge of the insulated liner of the LHR engine was predicted increased to 217°C from 150°C of the liner of the conventional engine, amounting to an increase of 45%.

iv. The temperature of the air in the air gap of insulated piston of the LHR engine predicted by FE analysis matched well with the experimental investigations of Rama Mohan [26]. Temperature predicted with FE analysis is 8% more when compared to the experimental measurement of temperature.

v. The temperature of the air in the air gap of insulated liner of LHR engine predicted by FE analysis matched well with the experimental investigations. Temperature predicted with FE analysis is 8% more when compared to the experimental measurement of temperature.

vi. Heat flow analysis showed average reduction of 31% of heat flow through the insulated piston of the LHR engine in comparison with piston of the conventional engine.

vii. Heat flow analysis showed average reduction of 16% of heat flow through the insulated liner of the LHR engine in comparison with the liner of conventional engine.

7.1.2 PREDICTION OF PERFORMANCE OF CONVENTIONAL AND LHR ENGINES WITH PURE DIESEL OPERATION BY MULTI-ZONE COMBUSTION MODEL.

(a) Multi-zone combustion model predicted the performance of the conventional and LHR engines very successfully.
(b) The peak pressures of the LHR engine were predicted lower in comparison with the conventional engine at the recommended injection timing and pressure.

(c) The model predicted higher by 7% of peak pressures in comparison with the experimental results for both conventional and LHR engines.

(d) Computer predictions showed the reduction of peak gas temperatures in the LHR engine from 1750 K to 1700 K, while the conventional engine showed increase of peak gas temperatures from 1552 K to 1662 K when the injection timings were advanced to the respective optimum injection timings.

(e) Multi-zone combustion model evaluated the gas temperatures with reasonable accuracy as was confirmed indirectly from the magnitudes of the temperatures predicted at the instant of exhaust valve opening tallying with the measured temperatures of the exhaust gases.

7.2 INVESTIGATIONS ON DIESEL-ALCOHOL MIXTURES WITH CONVENTIONAL AND LHR DIESEL ENGINES.

1. Maximum induction of alcohol was 35% on mass basis with best possible efficiency at all loads in the conventional engine while it was 50% in the LHR engine.

2. LHR engine with 50% alcohol induction showed improved performance when compared to the conventional engine with 35% alcohol induction.

3. Peak brake thermal efficiency increased by 7% with methanol operation on conventional engine, while it increased by 17.8% with 50% methanol induction when compared to pure diesel operation on conventional engine.

4. With 35% alcohol induction, conventional engine showed improved performance when compared to the LHR engine.

5. Ethanol operation on conventional engine showed improved performance over methanol operation on the same configuration of the engine. Methanol operation on LHR engine showed improved performance in comparison with ethanol operation on the same version of the engine.

6. Increase of injection pressure from 190 bars to 270 bars increased the amount of alcohol induction in the conventional engine from 35% to 40% while alcohol induction remained same in the LHR engine.

7. The maximum induction of alcohol was 35% in the conventional engine at 33°bTDC, while it was 45% in the LHR engine at 31°bTDC.
8. Brake thermal efficiency increased in both versions of the engine with maximum induction of alcohol when the injection timings were advanced and with the increase of injection pressure.

9. Exhaust temperatures lowered with the alcohol induction in both versions of the engine. With 35% alcohol induction, conventional engine showed lower magnitude of EGT when compared to the LHR engine.

10. Coolant load decreased with the alcohol induction in both versions of the engine. LHR engine with 50% alcohol induction showed lower coolant load when compared to 35% alcohol induction on conventional engine. Ethanol operation on both versions of the engine showed higher coolant load when compared to methanol operation.

11. Percentage replacement of energy increased with the amount of alcohol induction. Ethanol operation showed marginally higher energy replacement compared to methanol operation.

12. Volumetric efficiency decreased with the induction of alcohol in both versions of the engine, when compared to the pure diesel operation on the conventional engine. LHR engine showed lower volumetric efficiency when compared to the conventional engine with alcohol operation. Volumetric efficiencies increased marginally in both versions of the engine, when the injection timings were advanced and injection pressures increased.

13. Smoke levels decreased with alcohol induction when compared to pure diesel operation on conventional engine. 35% induction of methanol in the conventional engine showed the reduction of 27% smoke levels while the LHR engine with 50% methanol induction recorded 50% reduction of smoke levels when compared to the pure diesel operation on conventional engine.

14. Ethanol operation on conventional engine and methanol operation on LHR engine reduced smoke levels. 35% induction of ethanol in the conventional engine showed the reduction of 37% smoke levels while the LHR engine with 50% ethanol induction recorded 41% reduction of smoke levels when compared to the pure diesel operation on conventional engine.

15. Smoke levels decreased in the conventional and LHR engines with maximum induction of alcohol when the injection timings were advanced to 33° bTDC with the conventional engine and 31° bTDC with the LHR engine at increased injection pressure.
NOx levels reduced with alcohol induction in both versions of the engine. Conventional engine with 35% methanol induction showed 50% reduction of NOx levels, while LHR engine with 50% methanol induction recorded 33% reduction of NOx levels when compared to the pure diesel operation on conventional engine.

Ethanol operation on both versions of the engine showed increase in NOx levels when compared to methanol operation. Conventional engine with 35% ethanol induction showed 45% reduction of NOx levels, while LHR engine with 50% ethanol induction recorded 12% reduction of NOx levels when compared to the pure diesel operation on conventional engine.

With maximum methanol induction at 190 bars, NOx levels increased by 40% in the conventional engine while they decreased by 14% in the LHR engine when the injection timings were advanced to 33° bTDC with the conventional engine and 31° bTDC with the LHR engine, when compared to same configurations of the engine at 27° bTDC.

With maximum ethanol induction at 190 bars, NOx levels increased by 51% in the conventional engine while they decreased by 8% in the LHR engine when the injection timings were advanced to 33° bTDC with the conventional engine and 31° bTDC with the LHR engine, when compared to same configurations of the engine at 27° bTDC.

At an injection timing of 27°bTDC, NOx levels increased by 13% in the conventional engine with 35% methanol induction, while they decreased by 18% in the LHR engine with 50% methanol induction when the injection pressure was increased from 190 bars to 270 bars.

At an injection timing of 27°bTDC, NOx levels increased by 20% in the conventional engine with 35% ethanol induction, while they decreased by 18% in the LHR engine with 50% ethanol induction when the injection pressure was increased from 190 bars to 270 bars.

Aldehyde emissions increased with the induction of alcohol in both versions of the engine. Conventional engine increased formaldehyde concentrations by 520% and acetaldehyde concentrations by 606%, while LHR engine increased formaldehyde concentrations by 343% and acetaldehyde emissions by 413% with 50% ethanol induction when compared to the pure diesel operation on conventional engine.
23. LHR engine decreased formaldehyde emissions by 28% and acetaldehyde concentrations by 28% when compared to the conventional engine with 50% alcohol induction.

24. Conventional engine with 35% methanol induction increased formaldehyde concentrations by 40% and increased acetaldehyde emissions by 30% with 35% ethanol induction when the injection was advanced from 27° bTDC to 33° bTDC. However, LHR engine with 50% methanol induction decreased formaldehyde concentrations by 43% and acetaldehyde concentrations by 34% with 50% ethanol induction at the advanced injection timing of 31° bTDC when compared to 27° bTDC.

25. All combustion characteristics were within the limits for alcohol induction in both versions of the engine.

26. Increase of peak pressures, decrease of TOPP and marginal increase of MRPR were observed with the alcohol induction in both versions of the engine. All combustion characteristics were improved with the increase of injection pressure and at the advanced injection timings in both versions of the engine.

7.2.1. PREDICTION OF PERFORMANCE OF CONVENTIONAL AND LHR DIESEL ENGINES WITH ALCOHOL-DIESEL OPERATION BY ZERO DIMENSIONAL MULTI-ZONE COMBUSTION MODEL

(a) Combustion model predicted higher peak pressures than experimental results by around 7.5%.

(b) Reduction of peak gas temperatures were predicted in both versions of the engine with maximum percentage of methanol when compared to pure diesel operation on conventional engine.

(c) Computer predictions showed the peak gas temperatures in the LHR engine were at 1470K with 50% methanol induction while they were at 1386K in the conventional engine with 35% methanol induction.

(d) Increase of gas temperatures was predicted from 1386K at 27° bTDC to 1466K at 33° bTDC in the conventional engine with 35% methanol induction, while gas temperatures were predicted to be decreased in the LHR engine from 1470 K at 27° bTDC with 50% methanol induction to 1438 K at 31° bTDC with 45% methanol induction.

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Multi-zone combustion model evaluated the gas temperatures with reasonable accuracy as was confirmed indirectly from the magnitudes of the temperatures predicted at the instant of exhaust valve opening tallying with the measured temperatures of the exhaust gases.

7.3 INVESTIGATIONS ON CONVENTIONAL AND LHR DIESEL ENGINES WITH THE VEGETABLE OILS

1. Vegetable oil operation (Jatropha and Pongamia oils) at 27°bTDC on conventional engine showed the deterioration in the performance, while LHR engine showed improved performance, when compared to pure diesel operation on conventional engine.

2. Preheating of the vegetable oils improved performance when compared to normal vegetable oils in both versions of the engine.

3. Esterified vegetable oils showed improved performance over the crude vegetable oils in both versions of the engine.

4. Peak thermal efficiency was higher with pongamia oil operation, while BSEC at peak load was lower with jatropha oil in both versions of the engine.

5. Improvement in the performance was observed with the advancing of the injection timing and with the increase of injection pressure with the vegetable oil operation on both versions of the engine.

6. Conventional engine with crude vegetable oil operation showed the optimum injection timing at 32°bTDC, while the LHR engine showed the optimum injection at 30° bTDC at an injection pressure of 190 bars. Esterified vegetable oil showed the same optimum injection timing as in the case of pure diesel operation in both versions of the engine. Marginal variation in the optimum injection timing observed with increased injection pressure with vegetable oil operation.

7. Exhaust gas temperatures increased with the vegetable oil operation on both versions of the engine when compared to the pure diesel operation on conventional engine. Exhaust gas temperatures decreased with esterified vegetable oils when compared to the crude vegetable oils. Exhaust gas temperatures reduced with the advancing of the injection timing and with increase of injection pressure in both versions of the engine with vegetable oil operation.
8. Volumetric efficiencies decreased with the crude and esterified vegetable oils operation on both versions of the engine when compared to the pure diesel operation on conventional engine. Volumetric efficiencies were lower in the LHR engine when compared to the conventional engine with the vegetable oil operation. Esterified vegetable oil operation improved volumetric efficiencies over the crude vegetable oils in both versions of the engine. Volumetric efficiency increased marginally with the advancing of the injection timing and with increase of injection pressure in both versions of the engine with vegetable oil operation.

9. At the recommended injection timing and pressure, crude vegetable oil operation on conventional engine increased smoke levels drastically and decreased NOx levels, while LHR engine increased smoke levels and NOx levels when compared to the pure diesel operation on conventional engine.

10. LHR engine reduced smoke levels marginally and increased NOx levels, when compared to the conventional engine with the vegetable oil operation.

11. Preheating of the crude vegetable oil decreased smoke levels marginally and increased NOx levels slightly in the conventional engine, while in the LHR engine preheating of the vegetable oils decreased smoke and NOx levels.

12. Esterified vegetable oils reduced smoke levels and increased NOx emissions in the conventional engine, when compared to the crude vegetable oil operation on conventional engine. In the LHR engine, esterified vegetable oils reduced smoke and NOx levels when compared to crude vegetable oil operation on LHR engine.

13. Conventional engine with vegetable oil operation decreased smoke levels and increased NOx levels, while LHR engine decreased smoke and NOx levels with the advancing of the injection timing and increase of injection pressure.

14. Lower peak pressures and more TOPP were observed with normal crude vegetable oils in the conventional engine.

15. LHR engine with vegetable oil operation increased PP and decreased TOPP when compared to the conventional engine.

16. Preheating increased PP and decreased TOPP when compared to normal vegetable oil operation on both versions of the engine.
7.3.1 PREDICTION OF PERFORMANCE OF CONVENTIONAL AND LHR DIESEL ENGINES WITH VEGETABLE OIL OPERATION BY ZERO DIMENSIONAL AND MULTI-ZONE COMBUSTION MODEL.

(a) Lower peak pressures and lower peak gas temperatures were predicted in the conventional engine, while higher peak pressures and higher gas temperatures were predicted in the LHR engine with crude vegetable oil operation at the recommended injection timing and pressure.

(b) Increase of peak gas temperatures in the conventional engine and decrease of the same were predicted in the LHR engine when the injection timing was advanced to the optimum value with the vegetable oil operation.

(c) Multi-zone combustion model evaluated the gas temperatures with reasonable accuracy as is confirmed indirectly from the magnitudes of the temperatures predicted at the instant of exhaust valve opening tallying with the measured temperatures of the exhaust gases with the crude vegetable oil operation.

(d) A deviation of 8% is observed between the experimental data and theoretical data predicted by the model with the vegetable oil operation on conventional and LHR engines.

7.4 SCOPE FOR FUTURE WORK

There is sufficient scope for carrying out further work on the following aspects

I. Other materials with low thermal conductivities and high strength can be tried out as crown materials.

II. Endurance tests on the LHR engine may have to be carried out.

III. Finite element analysis may have to be extended to study the thermal stresses and fatigue strength at different operating conditions.

IV. The effects of convective and radiative heat transfer modes across the air gap introduced into the finite element analysis.

V. The investigations on LHR engine can be carried out on indirect injection diesel engine, so the effect of varying swirl strength of induction air can be matched with injection system in the LHR engine to have more efficient utilization of the fuel.

VI. The effect of varying compression ratios on LHR engine can be studied in detail.
VII. The naturally aspirated engine can be changed to supercharged engine and its effect on the performance of LHR engine can be studied.

VIII. For controlling of NOx in LHR engine, catalytic converters can be designed.

IX. For reducing smoke levels in LHR engine with pure diesel operation suitable cyclone separators can be designed.

X. The degree of insulation of LHR engine can be increased further by coating cylinder head with ceramics and its effect in inducting alcohol in LHR engine can be studied.

XI. The study of SO₂ emissions with vegetable oil operation on conventional and LHR engines can be taken up.