CHAPTER 5

CONCLUSIONS

In the present work different methods to improve the performance of a vegetable oil fuelled compression ignition (CI) engine were investigated and compared. Experiments were conducted with rubber seed oil and its methyl ester. The effects of blending, preheating, dual fuelling with hydrogen and DEE injection have been extensively studied through performance, emissions and combustion parameters. All the experiments were conducted at a constant speed of 1500 rpm. The following are the main conclusions drawn based on this experimental work. The conclusions have been categorized.

5.1 EXPERIMENTS WITH NEAT RUBBER SEED OIL AND ITS METHYL ESTER

- Brake thermal efficiencies are far superior with the esters as compared to neat oils. RSOME results in a higher thermal efficiency of 27.9 % where as RSO results in 26.6 %. The maximum efficiency with diesel is about 29.9 %.

- RSOME results in lower exhaust gas temperatures in comparison to neat RSO on account of faster combustion. However, it is still higher than diesel values.

- NOx emissions for the RSO operation are 6.9 g/kWh and 9.6 g/kWh with RSOME at full load. NOx emissions are
higher with RSOME than RSO because of higher combustion temperature.

- High viscosity and poor volatility of RSO lead to higher HC and CO levels than diesel. At the maximum output, the HC values are 0.7 g/kWh, 0.6 g/kWh and 0.6 g/kWh respectively for RSO, RSOME and diesel.

- Smoke level of RSOME is lower as compared to neat RSO. The smoke level for neat RSO is 6.1 BSU and 5.5 BSU for its ester at full load. In the case of diesel it is 3.4 BSU.

- Increased cylinder peak pressure and maximum rate of pressure rise were noticed with RSOME and diesel compared to RSO, due to the low viscosity of fuels. The cylinder peak pressure at full load is 74.3 bar with RSOME and 72 bar with RSO.

- Due to the poor mixture formation tendency of RSO, the premixed heat release rate is not high even though the ignition delay is the highest. Combustion duration with vegetable oils is high, mainly because of the slow diffusion phase. The premixed heat release with neat RSO is low. This is because, it not only depends on the amount of fuel accumulated during the ignition delay period but also on how much of it is prepared to burn.

5.2 BLENDS OF RUBBER SEED OIL AND DIESEL

- Engine operation with the blend of rubber seed oil and diesel results in better performance than neat RSO. At full load, the brake thermal efficiency with neat RSO is 26.6 % and for the
optimum blend of R70-D30 it is 27.7 % and with diesel it is 29.9 %.

- Exhaust gas temperature is higher with RSO as compared to diesel due to slow combustion. The exhaust temperature decreases with increase in quantity of diesel in the RSO-diesel blend.

- NOx emissions for the RSO operation are 6.9 g/kWh and 10.7 g/kWh with diesel at full load. With an increase in percentage of diesel in the RSO-diesel blend (R70-D30) NOx increases to 9.3 g/kWh.

- Both HC and CO emission are found to be high for RSO. The RSO-diesel blend results in lower CO and HC emissions at high load. This may be because of its reduced viscosity at high operating temperatures. The HC and CO emission for the optimum blend quantity of R70-D30 is 0.6 g/kWh and 3.6 g/kWh respectively.

- There is a reduction in smoke level with RSO-diesel blend in comparison to neat RSO due to better mixture formation with the blend resulting in improved combustion. The smoke level with R70-D30 blend is 4.7 BSU and for neat RSO it is 6.1 BSU. Smoke level for diesel is 3.4 BSU.

- Peak pressure and the maximum rate of pressure rise are higher with RSO-diesel blends due to improved premixed combustion.

- Heat release with neat RSO indicates higher diffusion burning and lower premixed burning rates as compared to diesel. Blending of diesel with RSO increases the premixed
combustion phase which leads to increase in the brake thermal efficiency.

- Ignition delay and combustion duration are lower than neat RSO with blends of RSO and diesel. At full load, the ignition delay and combustion duration is 7°CA and 45°CA respectively with the optimum blend of R70-D30 compared to neat RSO which is 8°CA and 47°CA.

5.3 OPERATION WITH PREHEATED RUBBER SEED OIL USING EXHAUST GAS

- Preheating using exhaust gas significantly lowers the viscosity of RSO and improves mixture formation and combustion. When RSO is preheated to 155°C (temperature at which viscosity of RSO is equal to diesel viscosity) brake thermal efficiency increases from 26.6 % to 27.8 %. Higher combustion rates lead to a reduced exhaust gas temperature.

- The exhaust gas temperature is higher for RSO (427°C) compared to RSO at 155°C (387°C). Higher combustion rates lead to a reduced exhaust gas temperature with preheated RSO.

- Marginal increase in NOx emissions with preheated rubber seed oil is observed compared to RSO because of increased fuel temperature that leads to high combustion temperature. NOx emission for RSO at 155°C is 8.5 g/kWh at full load, where as for diesel and neat RSO it is 10.7 g/kWh and 6.9 g/kWh respectively.

- HC emissions reduce to 0.64 g/kWh with preheating the RSO at 155°C. The increase in fuel temperature reduces the CO emission level marginally. The CO emission of RSO without
heating is 4.8 g/kWh and with preheating to the temperature of 155°C it reduces to 3.4 g/kWh.

- Significant reduction in smoke level is observed with preheated RSO compared to raw RSO. The smoke level with RSO is 6.1 BSU and for RSO at 155°C the smoke level is 4.6 BSU. This is due to better mixture formation of preheated RSO.

- Preheating leads to a more prominent premixed heat release phase as more of the fuel accumulated in the ignition delay period gets prepared for combustion.

- Combustion duration and ignition delay is longer with RSO as compared with diesel. There is a reduction in combustion duration and ignition delay with preheated RSO.

5.4 DUAL FUELLING WITH HYDROGEN

- Duel fuelling with hydrogen increases the brake thermal efficiency with all fuels due to an increase in the premixed combustion rate. At full load, with hydrogen induction, the brake thermal efficiency of RSO and RSOME increases from 26.6 to 28.1 % and 27.9 to 29.3 % at the hydrogen share of 8.4 % and 8.7 % on energy basis. The increase in brake thermal efficiency at lower loads is minimum.

- High hydrogen energy rates lead to too rapid combustion and knock at outputs beyond 50 % and deteriorate the thermal efficiency.

- NOx emission increases from 6.9 g/kWh to 10.8 g/kWh for RSO with 0 % to 8.4 % of hydrogen energy share and for RSOME it increases to the maximum of 11.8 g/kWh at hydrogen energy share of 8.7 %. This is mainly due to the
enhanced combustion temperature on account of the high premixed combustion.

- There is a reduction in the HC and CO levels at all loads with the induction of hydrogen for all injected fuels. The values with RSO are higher than the other fuels on account of inferior combustion due to poor mixture formation and higher amount of the main fuel used. At full load, HC and CO emissions reduce from 0.72 to 0.55 g/kWh and 4.8 to 3.2 g/kWh respectively at maximum efficiency point in RSO-Hydrogen dual fuel mode.

- At full load, the smoke level is reduced from 6.1 BSU to 3.8 BSU at the higher brake thermal efficiency point of energy share from hydrogen with RSO. Similar trends were found with RSOME and diesel. This is mainly due to the reduction in the amount of main fuel injected and improved combustion rate with hydrogen induction.

- The peak pressure and maximum rate of pressure rise increases mainly at higher power outputs. At 25 % and 50 % load, the peak pressure and maximum rate of pressure rise reduces with hydrogen induction due to the weak ignition source.

- The ignition delay increases for all the fuels with hydrogen induction. This will also contribute to higher heat release rate in the initial stages of combustion.

- The combustion duration decreases with hydrogen induction at all loads. This is due to the enhanced flame velocity as a result of the gaseous form of hydrogen.
• There is a significant difference in heat release rates between the neat RSO mode and the RSO–hydrogen dual fuel mode. A sharp rise in the initial heat release, which is due to the combustion of the accumulated injected fuel and the entrained hydrogen, is seen at full load. Similar trends are also seen when the engine is operated with RSOME and diesel.

5.5 DEE INJECTION WITH RUBBER SEED OIL

• The brake thermal efficiency of neat RSO is 26.6 % at the rated output which is lower than diesel efficiency of about 29.9 %. Injection of DEE with RSO increases the brake thermal efficiency. The maximum brake thermal efficiency is 28.5 % with 200 g/h of diethyl ether.

• The exhaust gas temperature is higher for RSO (410°C) compared to diesel (364°C). This is due to the late burning of RSO. It is further reduced with DEE.

• NOx levels are higher with DEE compared with neat RSO due to the higher premixed heat release rate. NOx emission is 9.3 g/kWh with RSO-DEE at the optimum DEE quantity of 200 g/h, where as for diesel and RSO it is 10.7 g/kWh and 6.9 g/kWh respectively.

• DEE injection reduces hydrocarbon and the carbon monoxide emissions from 0.7 g/kWh to 0.6 g/kWh and 6.7 g/kWh to 5 g/kWh respectively at optimum flow rate of 200 g/h at peak power output. The decrease in HC and CO level with DEE operation is due to combustion enhancement by the DEE.

• There is a large reduction in smoke emission of engine with RSO-DEE operation from 6.1 BSU with neat RSO to 4 BSU
with DEE at the optimum quantity of 200 g/h at rated power. The reduction in smoke emission is due to the better combustion of injected fuel in the hotter combustion chamber by the early combustion of DEE. The smoke emission of base diesel engine is 3.4 BSU at rated output.

- The cylinder peak pressure increases from 72 bar to 75.2 bar with DEE at the optimum quantity of 200 g/h at rated power.

- The premixed combustion phase with DEE is higher than RSO due to the early burning of DEE.

- RSO results in higher combustion duration than diesel. The addition of DEE with RSO reduces the combustion duration. The combustion duration reduces from 47°CA to 44°CA with DEE injection. This is mainly due to faster diffusion combustion rate as compared to neat RSO.

5.6 SUMMARY

On the whole, it is concluded that rubber seed oil and its methyl esters can be directly used in diesel engines without any modification for a short term use. Methyl esters are better than neat vegetable oils in terms of performance and emissions. Blends of RSO with diesel can improve performance. Exhaust heating of vegetable oils is a very effective way to lower their viscosity and improve the performance.

Hydrogen can be used in the dual fuel mode with vegetable oils or their esters as main fuels. This method is very effective in improving the brake thermal efficiency and reducing smoke levels at peak power output. Hydrogen induction can also produce good results if measures are taken to control the combustion rate at high loads and flow rates. Severe knocking and NO formation are the major hurdles in using hydrogen at high outputs.
Adding small quantities of diethyl ether to RSO can also improve the performance at all loads. A significant reduction in emission of smoke and carbon monoxide can be achieved with DEE injection. The optimum quantity of DEE flow rate is 200 g/h.

Finally it is concluded that DEE injection with RSO is the best method for improving the performance and reducing the smoke and other emissions.

5.7 SUGGESTIONS FOR FUTURE WORK

- The effect of using semi adiabatic combustion chambers can be evaluated with vegetable oils.
- Effect of swirl on engine performance and emissions can be studied with vegetable oils. Enhanced injection pressure and pulsed injection with common rail systems can be used with vegetable oils to improve combustion.
- Effect of introduction of CO$_2$, N$_2$ and water, to lower the NOx levels in dual fuel mode with hydrogen, can be investigated.