Chapter 5
CONCLUSIONS AND
SCOPE FOR FUTURE WORK

5.1 Conclusions
The present study aims to discuss a possible solution of the twin crisis of fossil fuel depletion and environmental degradation. It deals with use of karanja oil biodiesel (KOME) and aviation turbine fuel (ATF) in military diesel engines. Based on the exhaustive engine tests, it can be concluded that KOME biodiesel and ATF can be adopted as an alternative fuel in military diesel engine without any major modification in the engine hardware.

5.2 KOME Biodiesel
KOME Biodiesel fuel development aspects
The KOME biodiesel is developed from karanja oil through the process of transesterification. On the basis of experimental investigations, following conclusion can be drawn.

- Esterification is an effective method to alter the molecular structure of vegetable oils. Care must be taken to maintain low levels of agitation during washing and catalyst removal from biodiesel.
- Infrared (IR) spectroscopy and Nuclear magnetic resonance (NMR) spectroscopy confirms the presence of ester group in biodiesel and hence confirmed the successful transesterification of karanja oil.
- Viscosity of karanja oil biodiesel (KOME) reduces drastically (43.1 cSt to 5.57 cSt @ 40°C) after transesterification. Density, flash point, cloud and pour point of karanja biodiesel are found to be higher than the mineral diesel. Calorific value of biodiesel (39.8 MJ/Kg) is found to be slightly lower than mineral diesel (43.08 MJ/Kg).
- Cetane number of karanja oil biodiesel (KOME) increased after transesterification. Cetane number of KOME biodiesel (51) is found to be
substantially higher than mineral diesel (48).

- Elemental analysis shows that karanja oil biodiesel (KOME) is free from sulfur. C/H ratio is lower for biodiesel and it contains 10% oxygen in its molecules. All tests for characterization of biodiesel show that properties of karanja oil biodiesel (KOME) are found to be in a very close range to mineral diesel and thus make it a potential replacement for mineral diesel in unmodified CI engines.

**Performance, Emission and combustion characteristics of biodiesel (KOME)**

- The brake power (<3.6%) and torque (<6.3%) of engine slightly decrease when diesel engine was fueled with biodiesel (KOME) fuel.
- The bsfc increases with karanja biodiesel by 3.53% as compared to diesel fuel.
- Smoke opacity decreases by 57% with biodiesel (KOME) fuel at full load condition in comparison with diesel fuel.
- CO emission decreases by 80% when diesel engine fuel is replaced with biodiesel (KOME) fuel at full load condition.
- The UBHC decreases by 42% at full load condition with karanja biodiesel.
- NOx emission increase by 10% with biodiesel (KOME) in comparison with diesel fuel at full load condition.
- Engine sound decreases by 8% with biodiesel (KOME) in comparison with diesel fuel at full load condition.
- All standard engine operating conditions, lower emissions of CO, HC and smoke opacity are observed in case of KOME biodiesel but NOx emission (>10%) are found to be slightly higher.
- Heat release analysis indicate that KOME biodiesel fuel exhibits similar combustion stages as mineral diesel.
- Combustion starts earlier (<2°) in case of KOME biodiesel compared to mineral diesel.
- Biodiesel has lower heat release rate compared to diesel during premixed combustion phase. Under all engine operating conditions, heat release always
takes place earlier for KOME biodiesel compared to mineral diesel. Cumulative heat release is found to be lower for KOME biodiesel.

- Combustion duration is observed to be higher for KOME biodiesel, however maximum rate of pressure rise for KOME biodiesel was found to be lower (<6.66%) compared to mineral diesel. Thus the performance of the KOME biodiesel fuelled engine is found to be marginally better than the mineral diesel fuelled engine.

**Endurance tests and engine wear of biodiesel (KOME)**

- Lower carbon deposits on in-cylinder parts were found in case of KOME biodiesel fuelled engine.
- Physical measurements show lower wear (30%) for various vital engine components except bearings in case of KOME biodiesel fuelled engine.
- For piston rings, maximum wear was found for second piston ring in both the cases but for KOME biodiesel fuelled engine piston ring wear reduces by 25-30%.
- Scanning electron microscopy also shows similar trend for engine cylinder liner wear in case of KOME biodiesel fuelled engine.

**Lubricating oil tribology of biodiesel (KOME)**

- Comparative studies on various lubricating oil samples indicate ash content, density, moisture content, viscosity increases with the usage of lubricating oil.
- The density of lubricating oil increases with usage due to various possible contaminants such as wear debris, soot, resins and lubricating oil oxidation. Lower increase in density of lubricating oil of KOME biodiesel fuelled engine shows lower wear and better performance of biodiesel fuelled engine. Ash content, which mainly represents wear debris, is also found to be lower in case of biodiesel fuelled engine.
- Viscosity of lubricating oil is found to have decreased with usage. Lower decrease is observed with biodiesel fuelled engine. Similar trend for moisture content is also observed.
- Pentane and benzene insoluble are found to be lower in case of biodiesel fuelled engine reflecting lower wear and lower degradation of lubricating oil.

- TBN of lubricating oil is found to have decreased with usage but lower decrease in TBN of biodiesel fuelled engine suggests lower depletion of corrosion inhibitors (additives) and hence better lubricating oil condition in case of biodiesel fuelled engine.

- The results of AAS tests conducted on the lubricating oil indicate lower amount of metallic wear debris (Fe, Cu, Zn, Mg, Cr and Ni) hence it indicates lower wear in case of biodiesel fuelled engine. Pb and Al concentration are initially lower in case of B100 fuelled engine but found to have increased after 80 hours of engine operation. This indicates the effect on biodiesel on the paint of different engine components and also the higher wear of bearings.

- Ferrography result shows lower number density and lesser wear debris for biodiesel fuelled engine.

Based on these studies, it is concluded that transesterification is an effective technique for the vegetable oil formulation as a fuel. It resolves problems associated with long-term utilization of vegetable oils such as fuel filter plugging, ring sticking, formation of carbon deposits in combustion chamber, injector coking and contamination of lubricating oils. Biodiesel fuels are superior in comparison to mineral diesel and can be successfully used in diesel engine without any major hardware modification.
5.3 Aviation Turbine Fuel (ATF)

Performance, Emission and combustion characteristics of ATF

- Directly replacing diesel fuel with ATF fuel leads to a performance reduction, due to lower density and consequently less mass of fuel injected.
- It is possible to match the performance of the engine with diesel fuel by increasing the volume of ATF fuel to match the mass of fuel per stroke, due to their reduced energy content.
- The 4.5% higher BSFC at 100% load may need to go beyond direct compensation for lower density of ATF fuel, due to increased mechanical losses in the fuel system with lower viscosity.
- Emissions (CO, Hydrocarbons, NOx, and Smoke opacity) decreased with ATF fuel.
- BSFC increased with ATF fuel by 4.5% on a supercharged engine.
- Smoke opacity decreased by 28% at 100% load condition with ATF fuel.
- CO emission decreases up to 23% at 100% load condition with ATF fuel.
- UHC decreased by 16% with ATF fuel.
- NOx emission reduced by 40% at 100% load condition with ATF fuel.
- Combustion noise decreases up to 5% at 100% load condition with ATF fuel.
- Scanning electron microscopy and piston rings weight measurement were found similar / slightly lower (< 5-6%) wear as compared with diesel fuel.

Investigation has been carried out to evaluate the effect of using ATF fuel on combustion, performance, emissions, and engine wear of a heavy-duty military diesel engine. The study has subsequently utilized the obtained insight to propose engine calibration, minimum modification capable of minimizing fuel penalty and reducing exhaust emission.
5.4 Scope for Future Work

In the present study, an attempt has been made to utilize karanja oil and ATF as an alternative diesel engine fuel.

- Most previous researchers have reported that NOx emission is slightly increased by using biodiesel fuel. Exhaust gas re-circulation (EGR) are very effective in reducing NOx emissions in compression ignition engines. The detail investigated to be carried out in future for understanding long term effects of biodiesel on environment and human health.

- Detailed studies can be conducted to quantify the effect of bulk modulus of biodiesel on fuel injection. The effect of this on NOx formation can also be investigated. Effect of injection time on engine performance and optimization of fuel injection timings with the use of modern electronic fuel injection control will also help to improve engine performance and reduce NOx emission.

- Studies related to purity and utilization of glycerol (by-product of transesterification) is required to reduce the cost of biodiesel production.

- Fundamental studies of combustion initiation and completion in a well instrumented rapid compression machine along with computational chemical kinetic studies and spray characteristic investigation can be carried out in future for in depth understanding of combustion and emission of biodiesel and ATF fuel.

- Detailed studies can be conducted on fuel dilution rate for biodiesel and diesel after the endurance test, since fuel dilution of engine oil is an important factor for testing engine wear. Biodiesel fuel degrades diesel engine oil performance to a great extent. Oil which is fuel-diluted with biodiesel, and is known to contain unsaturated hydrocarbon bonds, would be expected to be more prone to oxidation. Thus engine oil diluted with biodiesel fuel can lead to increased engine wear.