CHAPTER 5

CONCLUSION

Based on the analysis and results obtained from the three stages of testing of CNSL blends in compression ignition engines of different types, the following conclusions are drawn.

5.1 GREAVES ENGINE TESTING

Initial performance testing of straight CNSL - Diesel blends upto 20% CNSL by volume, was done in DI diesel engine Greaves Lombardini make, GL400 engine.

5.1.1 Performance

Power developed by the engine using CNSL blends was comparable to power developed by diesel fuel. However it was found that 15% CNSL blend performed well yielding better BTE and can be said to have optimum performance since this engine is a high speed diesel engine.

5.1.2 Emission

Smoke level observed was well within limits as per the Bharat stage IV norms. It varies within five percentage of the corresponding value
for diesel. Hence it is possible to use CNSL successfully in the above engine without any problem.

5.1.3   Endurance

Endurance test, as per IS: 10000 – 1980, was performed using 15% CNSL blend and diesel. Deposits on piston were weighed and compared with neat diesel operation. It was found that carbon deposit was slightly more for CNSL run piston(0.376g) compared to diesel run piston(0.37g). However, the resolution of the precision balance itself is 0.01g. Hence it can be concluded that both carbon deposits are comparable. CNSL blend operated piston deposits were found to have similar pattern of deposits as on the diesel operated piston. Corrosion and pitting were remarkably absent.

5.2   KIRLOSKAR IDI ENGINE TESTING

In the testing of Kirloskar IDI engine, the combustion chamber plug was modified for the adaptor of Kistler pressure sensor. A proximity sensor NPN type with TDC pulse was also fitted to the engine. This enabled plotting the P-θ diagram using LabVIEW software. Based on the test results, the following conclusions can be drawn.

5.2.1   Performance

Upto 30% CNSL blends performed well in Kirloskar Mahabali single cylinder, water-cooled IDI Diesel engine. The engine developed full power using CNSL blends as in the case of diesel run. However, it was found that there was a slight reduction in BTE and increase in SFC. The performance is better than Greaves engine due to pre-combustion chamber.
Pressure – Crank Angle analysis was done for CNSL blends upto 30% and compared with diesel. The pattern of the curves followed the same trend as that of diesel.

### 5.2.2 Emission

Smoke level as measured by Netel smokemeter, was well within limits as per Bharat stage IV norms. It varies within few percentage of the corresponding values of diesel run.

Hence it is possible to use upto 30% CNSL blends, successfully in the above engine without any problem while satisfying the pollution control norms as well.

### 5.3 KIRLOSKAR DI ENGINE TESTING

The final stage testing was done using upto 40% CNSL blends in Kirloskar TAF1 single cylinder DI diesel engine which involved detailed investigations of influence of various parameters on combustion, emission and performance of the engine. The effects of using straight CNSL - diesel blends of 10%, 20%, 30% and 40% by volume, were evaluated for brake power, thermal efficiency, combustion characteristics, emissions and the following conclusions are drawn:

#### 5.3.1 Combustion

Experiments show that the combustion phases are almost similar for CNSL blends and neat diesel. Blends show lower combustion delay, however slower heat release rate compared to diesel. Combustion duration for
CNSL blends are higher than diesel and it increases as engine load increases. The peak cylinder pressure, heat release rate for CNSL-diesel blends are slightly lower than those of neat diesel operation. It is deduced from the pressure - crank angle curve that power output is steady upto 35% CNSL operation.

Diesel knocking was observed for 40% CNSL; engine could not reach full load. This was mitigated by using DEE as ignition improver. Using 5% DEE addition with the 40% CNSL blend gave stable operation in the Kirloskar engine without signs of knocking due to better combustion.

5.3.2 Performance

The engine developed full output using CNSL blends as to that of diesel fuel and it was found that there was a slight reduction in BTE and increase in SFC. Slight reduction in BTE is compensated by increased fuel consumption of CNSL blend.

Brake thermal efficiency decreases with increasing CNSL proportion (for 30% CNSL blend BTE is less by 2.6% to diesel) and specific energy consumption behaviour is vice-versa.

5.3.3 Emission

Emission levels of CNSL operation are comparable to neat diesel operation except NOx. This tendency is similar to any raw vegetable oil blend wherein nitrogen oxides’ emissions are always found to be higher than that of neat diesel. As CNSL contains more oxygen in it, nitrogen reacts with fuel oxygen at high temperature and forms NOx. Generally, higher the viscosity
of the oil, higher will be the NOx.

Smoke emission is slightly higher at lower loads, then it follows the trend of diesel which is due to lesser combustion temperature at low loads.

5.3.4 Effect of Modifications, DEE and EGR

Advancing and retarding of injection timings were studied and 3° crank angle advance in injection timing gave better emission results for higher CNSL blends. Increase in injection pressure resulted in better combustion and spray pattern. However, 240 bar injection pressure resulted in more NOx emission due to high overall combustion temperature inside the cylinder.

Addition of Diethyl Ether, as ignition improver, reduced NOx emissions and gave stable performance for 40% CNSL blend. DEE improved the quality of the fuel mist upon injection and lead to complete combustion of rich CNSL mixtures. DEE addition of 5% by volume, is enough to run 40% CNSL blend in the engine satisfactorily and NOx emissions also got reduced.

Exhaust gas recirculation for CNSL blends, resulted in reduction of NOx level below than that of neat diesel operation (without EGR). However, hydrocarbon and smoke emissions got slightly increased. This is a cheaper way of controlling NOx emission with CNSL blends. Changing inlet valve timing also resulted in similar but not significant reduction of NOx.

Heating of the fuel to two levels of temperature resulted better combustion, BTE and power but increased engine emissions to higher levels.
5.4 FUEL COST SAVINGS AND CASHEW VALUE CHAIN

The price of Cashew Nut Shell Oil is in the range of US $0.30 to 0.51 per litre (2011 prices) in India depending upon the location and grade. Thus the idea of blending CNSL up to 35% with diesel (US $0.9/litre) will result in direct fuel cost savings of 20 to 25%. Appendix 9 illustrates the price hike of petroleum fuel over 10 years. Figure A9.1 to 9.3 and Table A9.1 show steep rise in the last 3 years. Thus CNSL has got better edge over biodiesel which is 2 to 5 times costlier than diesel. The impact of this investigation is shown in Cashew Value Chain in Figure 5.1.

5.5 CONCLUDING REMARKS

Diesel Engines are the power horses of the modern world and diminishing petroleum reserves necessitates economically and readily available alternative, non-edible fuels such as CNSL.

A detailed and careful analysis of parameters such as incylinder peak pressure, rate of pressure rise, crank angle at which peak pressure occurs, mass burning rates etc. was carried out from the observed data for all the runs obtained from the experimental work with and without modification/additives.

The endurance testing had proven the merits of CNSL in view of deposits and operational durability.

It was observed that no undesirable combustion phenomenon was observed for blends up to 35% CNSL. Emission tests satisfy Bharat stage IV norms. Therefore there is no operational or pollution problem expected from
utilisation of the CNSL blends upto 35% in unmodified DI and IDI compression ignition engines.

Overall it can be affirmed that upto 35% CNSL-diesel blends can be safely used in CI engine without any additive or engine modification. Thus CNSL can power the CI engines for agriculture and transportation. Further it can also supplement the power requirements of cashew processing industries and surrounding places of cashew cultivation.

5.6 SUGGESTIONS FOR FUTURE WORK

The following are the suggestions for the future work using CNSL as an alternative fuel.

- New NOx reduction techniques can be studied by catalytic coated pistons and valves.
- Since CNSL is miscible with water, CNSL water micro-emulsion can be tested for their usage in IC engine.
- Mg and Mo based fuel additives can be used in diesel engine for performance and emission (Metin Guru 2008).
- CNSL behaviour can be studied using low heat release engines.
- Special purpose engine/engine modifications can be developed specifically for optimizing CNSL use in IC engines.
Figure 5.1 Cashew value chain