CHAPTER 6

CONCLUSIONS

6.1 GENERAL

Twelve biodiesel fuels including four blends were prepared and the properties were measured. Using these biodiesel fuels, experiments were conducted on a single cylinder, four stroke, air cooled, direct injection, 4.4 kW compression ignition engine at full load. The effects of unsaturated fatty acid ester composition on biodiesel properties, the effect of biodiesel properties in relation to unsaturated fatty acid ester composition on the combustion, performance, and emission parameters were investigated. Gradients were proposed between different parameters and percentage of unsaturation.

From the present work, the percentage of unsaturation in biodiesel was studied extensively with reference to the fuel properties, engine combustion, performance and emissions. The results revealed that unsaturation in biodiesel affect the fuel properties and engine combustion.

6.2 CONCLUSIONS

6.2.1 Fuel Properties

1. The density of biodiesel fuels increases with increase in percentage of unsaturation. An increase of 0.254 kg/m³ in
density could be expected for every one percentage increase in unsaturation. A biodiesel with 10% unsaturated composition shows a density of 0.872 kg/m³ and an increase of unsaturation from 10 to 88% exhibits an increase in density from 0.872 to 0.885 kg/m³. The density of biodiesel purely depends on the free space between the molecules, which in turn depends on the number of double bonds in the structure.

2. Kinematic viscosity of biodiesel fuels decreases with degree of unsaturation. But the present result shows an increase in viscosity with increase in unsaturation. It purely depends on the raw material and distribution of fatty acid ester composition. One percent increase in unsaturation may result in an increase of 0.029 mm²/s units in kinematic viscosity. A biodiesel with 10% unsaturated composition shows a viscosity of 2.62 mm²/s and it increases to 4.87 mm²/s when unsaturation increases to 88%.

3. The surface tension of biodiesel fuels increases with increase in percentage of unsaturation. An increase of 0.054 N/m in surface tension could be expected for every one percent increase in unsaturation. An increase in surface tension from 22.32 to 27.20 N/m is observed with a variation of unsaturation from 10 to 88%.

4. Heating value increases with chain length and decrease with degree of unsaturation. The present study reveals that the heating value decreases with increase in unsaturation of biodiesel. But the difference is not significant among the biodiesel fuels tested. An increase of 0.029 MJ/kg in heating
value could be expected for every one per cent increase in unsaturation.

5. Cetane number of biodiesel fuels increases with chain length and decreases with increase in degree of unsaturation. The trend between cetane number and unsaturation revealed that each percentage increase in unsaturation could reduce 0.295 units in cetane number.

6. Flash and Fire point of biodiesel has a positive trend with unsaturation. That is flash and fire point increases with increase in unsaturation of biodiesel.

7. Low temperature properties of biodiesel show a negative trend with unsaturation. This implies that as unsaturation increase, low temperature properties decrease.

8. Iodine value, which is a direct measure of unsaturation, increases with increase in percentage of unsaturation. One percent increase in unsaturation may increase 1.491 g iodine / 100 g oil in iodine value.

9. Saponification value decreases with increase in unsaturation and increases with increase in percentage of lower chain fatty acid esters.

10. The distillation temperature (T90) shows a positive trend with unsaturation. Short chain fatty acid ester has the lowest T90 compared to long chain fatty acid ester.

11. The molecular weight of biodiesel is governing the most important properties. As molecular weight increases, the saponification value decreases and heating value increases. But at same carbon number, as the molecular weight
decreases, that is, increase in double bond or degree of unsaturation, the heating value and cetane number decreases. Therefore to attain a good quality biodiesel, it is essential to control the short chain fatty acid ester content and the number of double bonds present.

### 6.2.2 Combustion Characteristics

1. Start of dynamic injection advances with increase in unsaturation and biodiesel density. An advance of 3 deg CA at full load is observed for the difference in unsaturation of 78%. This is attributed to the density variation of biodiesel due to the presence of double bonds. A positive gradient is proposed and a unit increase in percentage of unsaturation can advance the dynamic injection timing by 0.044 deg CA.

2. Ignition delay increases with increase in percentage of unsaturation and density. An increase of 0.016 deg CA in ignition delay may be predicted for an increase in each percentage of unsaturation. For the entire test, the variation of ignition delay is only 2 deg CA. This is mainly due to the higher density, viscosity, surface tension and cetane number of biodiesel fuel.

3. The maximum heat release rate decreases with increase in percentage of unsaturation. For the entire bandwidth of unsaturation, the variation of maximum heat release rate is only 16 J/deg. CA. The location (occurrence) of maximum heat release rate shifts towards TDC of the heat release diagram with increase in unsaturation. The cumulative heat release decreases with increase in unsaturation and the
variation is only 62 J in the entire test range. This is attributed to the lower heating value of the biodiesel fuel.

4. Peak pressure for biodiesel fuels decreases with increase in percentage of unsaturation. Every one percent increase in unsaturation may result in a decrease of 0.062 bar in peak pressure. The occurrence of peak pressure also shifted towards TDC of the heat release diagram with increase in unsaturation. The variation of peak pressure is only 7 bar for the entire unsaturation band with tested biodiesel fuels.

5. Mass fraction burnt decreases with increase in unsaturation because of the change in combustion chemistry (polymersiation and oxidation) due to the presence of double bond. The crankangle at which, 90 % mass fraction burnt occurs earlier with lesser unsaturation compared to higher unsaturated biodiesel fuel.

6. The total combustion duration decreases with increase in percentage of unsaturation. A reduction of 0.268 deg CA in total combustion duration may be expected for every one percent increase in unsaturation.

6.2.3 Performance and Pollutant Emissions

1. Increase in unsaturation percentage results in an increase in BSFC and BSEC. Every one per cent increase in unsaturation may result in an increase of 0.0003 kg/kWh and 0.012 MJ/kWh in BSFC and BSEC respectively. This is attributed mainly due to the lower heating value and higher density of biodiesel fuel.
2. Brake thermal efficiency decreases with increase in percentage of unsaturation. Every one percent increase in unsaturation may result in an increase of 0.026 % in brake thermal efficiency. In the entire test range of unsaturation, the variation in brake thermal efficiency was only 2 %.

3. Exhaust gas temperature increases with increase in unsaturation percentage. An increase of 0.687 ºC may be predicted by increasing every one percentage of unsaturation. The variation in exhaust gas temperature is only 50 ºC in the entire test.

6.2.4 Emissions

1. Oxides of nitrogen increase with increase in percentage of unsaturation, density and iodine value. An increase of 0.049 g/kWh in brake specific NO\textsubscript{X} can be expected for each percentage increase in percentage on unsaturation. This is attributed to the injection timing advance because of higher density of biodiesel.

2. Carbon monoxide emissions increased with increase in percentage of unsaturation. Every one percent increase in unsaturation may cause an increase of 0.023 g/kWh in brake specific CO. This is attributed to the local air-fuel ratio of the mixture.

3. Unburnt hydrocarbon emissions increased with increase in percentage of unsaturation. Every one percent increase in unsaturation may cause an increase of 0.0013 g/kWh in brake specific UBHC.
4. Smoke decreases with increase in unsaturation. A decrease of 0.008 BSU in smoke may be expected for every one percent increase in unsaturation. This is attributed to the oxidation reaction and local oxygen availability.

5. Carbon dioxide emissions decreased with increase in percentage of unsaturation. A reduction of 0.021 g/kWh in CO₂ can be expected for every one percent increase in unsaturation.

The biodiesel fatty acid ester composition can have considerable influence on the biodiesel fuel properties with relation to the combustion, performance and emission parameters. From the present study, it can be observed that almost all the properties/parameters are adversely affected by unsaturated fatty acids. But still unsaturated fatty acids cannot be completely eliminated. Because some of the previous researches reveal that the unsaturated fatty acids can improve the cold flow properties of biodiesel. It therefore appears reasonable to enrich (a) certain fatty acid ester(s) with desirable properties in the fuel in order to improve the properties of the whole fuel. It may be possible in the future to improve the properties of biodiesel by means of genetic engineering of the parent oils, which could eventually lead to a fuel enriched with (a) certain fatty acid (s) that exhibits a combination of improved fuel properties.

6.3 SCOPE FOR FUTURE WORK

1. Effect of biodiesel saturated fatty acid ester composition can be investigated and optimized.

2. Effect of unsaturated fatty acid ester composition on fuel spray characteristics can be investigated.
3. Effect of individual fatty acid methyl esters like palmitic, stearic, oleic, linoleic, and linolenic on biodiesel combustion can be analysed. However, the economic viability must be studied.

4. Effect of oxidation on biodiesel quality and combustion can be investigated.
6.4 SOCIO ECONOMIC BENEFITS

1. A number of diesel exhaust emissions can be reduced substantially at relatively low cost without the need to replace millions of diesel engines with much more expensive technology.

2. Local and regional agriculture and urban agriculture could be supported as part of the fuel production process.

3. Jobs for local people (largely in agriculture but also in collection, processing and distribution) can be created.

4. Biodiesel is a candidate for inclusion in programs to develop more efficient vehicles such as diesel-electric hybrids. It is an enabling technology to further reduce emission since it is virtually sulfur free.

5. Biodiesel can be used to provide fuel for the technologies that will replace the diesel engine such as micro turbines and fuel cell in place of gasoline and methanol.

6. In addition to being a substitute for diesel engine fuel, biodiesel can be used to fuel heating, lighting and cooking appliances replacing kerosene. It could replace the use of wood for heating. Since the collection of firewood is increasingly problematic in many developing countries causing desertification and hardship for those involved in firewood collection, this is an important feature.

7. Oil-bearing crops are not necessarily derived only from edible oil seed crops and thus do not necessarily reduce the amount of food available feedstock can include oil from algae. Oils
from many different plants and trees and animal fats that are unfit for human consumption.

8. It is possible to visualize a farmstead village or region becoming more self-reliant, deriving most of its energy needs and a number of lubrication and cleaning products needs from local renewable sources.