CHAPTER 7

CONCLUSIONS

In this chapter the contribution and merits of this research work are highlighted and future research scopes are explained.

The objective of the research is to simulate the complete diesel cycle to compute the cylinder pressure the brake thermal efficiency and brake specific fuel consumption. Also, to determine NO\(_x\) formation during combustion process at different engine speeds, compression ratios, and water percentage in the diesel-water emulsion.

In the simulation, the cylinder pressure during combustion increases with the water amount in the emulsion. The average increase in cylinder pressure during combustion is found to be 0.85% for DW10 and 1.9% for DW20 fuels.

In the simulation, the net heat release rate increases with water amount in the emulsion. The effective mixing of fuel and air due to micro-explosion in the diesel water emulsion increases the net heat release rate during the combustion process.

In the simulation, the net work done during the cycle is increasing with the water amount in the emulsion due to increased expansion work and decreased compression work. The increase in net work done is 1.93% for DW10 and 4.25% for DW20 fuels. The increase in net work done is realized
in the increase in the brake thermal efficiency with water amount in the emulsion.

In the simulation of NO\textsubscript{x} formation, it is found that

(i) NO\textsubscript{x} formation decreases with engine speed. At lower engine speed, the reactive gas provides a longer time for the nitric oxide to form and this causes higher nitric oxide concentration in the combustion chamber.

(ii) NO\textsubscript{x} formation increases with compression ratio due to increase in pressure and temperature at the end of compression process.

(iii) NO\textsubscript{x} formation decreases with water amount in the emulsion due to reduction in the temperature of gases due to the cooling effect caused by water evaporation in the emulsion.

In the experiments conducted at injection pressure 150 bar, 200 bar and 250 bar with diesel as fuel, it is found that

(i) The quantity of fuel injected increases with injection pressure, so, the BSFC increases and BTE decrease over the range of test conducted. At 5 kW load the fuel consumption is increased by 3% to 4% for higher injection pressures.

(ii) At 5 kW load, CO\textsubscript{2} emission decreases in the order of 200-150-250 bar injection pressure.

(iii) At 5 kW load NO\textsubscript{x} emission decreases in the order of 200-150-250 bar injection pressure.

(iv) At 5 kW load, HC emission decreases in the order of 250-150-200 bar injection pressure.
(v) Smoke opacity is found to be same up to 60% load but, at 5 kW load the smoke opacity increases in the order of 150-200-250 bar injection pressure.

The injection of water along with diesel, in general, increases the brake thermal efficiency and decreases brake specific (diesel) fuel consumption and decreases the NO\textsubscript{x}, and HC emissions at all loads and smoke opacity increases only at full load operation.

From the tests performed with diesel and diesel-water emulsion as fuel, it is found that beyond the maximum load of 5 kW the brake specific fuel consumption increases and CO\textsubscript{2}, HC and smoke emissions increase drastically and NO\textsubscript{x} slightly decreases. So, the best operating load for the engine is 5 kW.

At 5 kW load, it is found that

(i) The average decrease in brake specific fuel consumption is 10% and 20% for DW10 and DW20 respectively.

(ii) Brake thermal efficiency increases by 4.1% for DW10 and 9.3% for DW20 at 150 bar, 4% for DW10 and 8.9% for DW20 at 200 bar and 3.8% for DW10 and 8.6% for DW20 at 250 bar injection pressure respectively.

(iii) NO\textsubscript{x} emission decreases by 4.2% for DW10 and 16.4% for DW20 at 150 bar, 10% for DW10 and 24% for DW20 at 200 bar and 11.4% for DW10 and 19.3% for DW20 at 250 bar injection pressure respectively.

(iv) HC emission decreases by 23% for DW10 and 37% for DW20 at 150 bar, 26% for DW10 and 42% for DW20 at 200 bar and
17% for DW10 and 20% for DW20 at 250 bar injection pressure respectively.

(v) The average increase in smoke opacity is 10% for DW10 and 19% for DW20 fuels respectively.

In the experiments with diesel-water emulsion and fuel additive, the effect of the NanoXXL fuel additive on brake specific fuel consumption and brake thermal efficiency is insignificant. However, the NanoXXL fuel additive effectively minimizes the NO\textsubscript{x}, HC and smoke emissions in the diesel engine at all injection pressures. The average reduction of NO\textsubscript{x} emission is 15%, HC emission is 20% and smoke opacity is 33% when the NanoXXL fuel additive is mixed with the diesel-water emulsion for all loads.

The simulated pressure during the cycle is compared with the measured cylinder pressure from IVC to EVO. During combustion, the average increase in simulated pressure is 0.85% for DW10 and 1.9% for DW20 fuels at 5 kW load. In the experiments, for different water amount in the emulsion, it is observed that the pressure rise during combustion is insignificant. However, the peak pressure is increasing with water amount in the emulsion. The difference between simulated and measured peak pressure is in the range of 4% - 6% at 5 kW load.

The simulated and experimental values of BSFC are compared at 5 kW load. The average difference between simulated and experimental values of BSFC is 15% for DSL, 7.4% for DW10 and 11.6% for DW20 fuels respectively.

The experimental NO\textsubscript{x} emission with amount of water in the emulsion is compared with the simulated values at 5 kW. The simulated values are less than the experimental values. The model is able to predict the NO\textsubscript{x} emission with an error of 1% for DSL, 2.2% for DW10 and 3.2% for
DW20 respectively. The error in the simulation is due to the assumptions in the single zone model.

The kinematic viscosity of lubricating oil was determined at 100 °C for 200 hours of operation at full load. It was found that the kinematic viscosity of lubricating oil is higher when the engine is operated with DW10 and it decreases for both DSL and DW10 with number of hours of operation. So, the life of lubricating oil will be more when the diesel-water emulsion is used in diesel engine.

Experimentally it is found that the diesel-water emulsion has the potential to reduce the NO\textsubscript{x} and HC emission effectively at all loads. Moreover, injecting water in the form of emulsion in diesel engine using the same fuel injector does not require any engine modification or retrofitting. Using the diesel-water emulsion as alternative fuel in diesel engine the existing diesel reserve can be extended for few more years as there is improvement in brake specific fuel consumption. However, the optimum quantity of water to a particular type of engine is to be determined.

**Future research scopes**

1. Computational Fluid Dynamics model may be used to predict the cylinder pressure and NO\textsubscript{x} formation more accurately closer to the experimental values.

2. The simulation study may be extended to multi cylinder heavy duty engines.

3. In the present research the in-cylinder NO\textsubscript{x} formation control is successfully studied using water injection method. Exhaust Gas Recirculation may also be tried both in light duty and heavy duty engines.
4. The diesel-water emulsion injection may be tried in multi
cylinder heavy duty engines to understand its potential to
improve the brake specific fuel consumption and pollutant
emissions.

5. Newer methods like spray of water with emulsifier in the high
pressure fuel line may be developed to produce diesel-water
emulsion for the requirement of heavy duty engines.

6. Other fuel additives may be tried to control the NO\textsubscript{x} emission.