CHAPTER 8

CONCLUSION

8.1 INTRODUCTION

The combustion of the fossil fuel produced from diesel engines has polluted the environment through the exhaust emissions of hydrocarbons (HCs), oxides of nitrogen (NO\textsubscript{x}), carbon monoxide (CO), and oxides of sulfur (SO\textsubscript{x}). Moreover, NO\textsubscript{x} and CO\textsubscript{2} are the greenhouse gases, and SO\textsubscript{x} causes acid rain. On the other hand, vegetable oils present a very promising alternative to diesel oil since they are renewable and have similar properties. Many researchers have studied the use of vegetable oils in diesel engines. Vegetable oils offer almost the same power output, with slightly lower thermal efficiency when used in diesel engines. Reduction of engine emissions is a major research aspect in engine development with the increasing concern on environmental protection and the stringent exhaust gas recirculation. The tremendous growth of vehicular population of the world has led to a steep rise in the demand for petroleum products. Biodiesel such as jatropha, karanja, sunflower and rapeseed are some of the popular biodiesel currently considered as substitutes for diesel. These are clean burning, renewable, non-toxic, biodegradable, and environmentally friendly transportation fuels that can be used in neat form or in blends with petroleum derived from diesel engines. Methyl and ethyl esters of karanja oil can be used as fuel in compression ignition engine.
8.2 MATHEMATICAL EQUATION BETWEEN HIGHER HEATING VALUE AND THERMAL PROPERTIES

A mathematical equation has been determined between higher heating value and viscosity, density and flash point using multiple regression, first order and second order polynomial equation. From the above model developed, the equation that predicts the HHV with less % of error is chosen. The mathematical model to predict the HHV of vegetable oil and biodiesel is given in equation (8.1) and (8.2)

\[
\text{HHV} = 0.4527 \nu - 0.0008 \rho - 0.0003 \text{FP} + 40.3667 \quad \text{(8.1)}
\]

The mathematical model to predict the HHV of biodiesel is given in equation (8.2)

\[
\text{HHV} = -0.769 \nu - 0.009 \rho - 11.059 \text{FP} + 56.80 \quad \text{(8.2)}
\]

The experimental determination of higher heating value requires special instrumentation, whereas (viscosity, density and flash point) data can be obtained relatively easily by using common laboratory equipment.

The ultimate and proximate analysis of the oils are not required for the estimation of their HHV, the laboratory equipments are therefore reduced. The heating values of the vegetable oils and their methyl esters can be calculated by using their viscosity, density, flash point obtained from simple physical measurements.

It is found from the model equation of vegetable oils, the viscosity has more influence than other properties in predicting the higher heating value.
The method is applied to various vegetable oils methyl ester and biodiesel. Therefore it can be used for all kinds of oils independently of their origin. There is an excellent agreement between the measured and predicted values of the higher calorific value. A new method of HHV estimation of vegetable oils and biodiesel is presented. Using the equation we can predict the HHV of vegetable oil and biodiesel up to 99.8% accuracy.

The mathematical model developed predicts the higher heating value of karanja biodiesel with 0.1% error compared to measured value. The new model developed is used to predict any type of oil.

The newly developed higher heating value models, correlated with biodiesel fraction, density, and kinematic viscosity, have significant application in the investigation of combustion characteristics, engine performance and emissions during engine simulation and development.
8.3 **TO DEVELOP MATHEMATICAL EQUATION BETWEEN CETANE NUMBER AND THERMAL PROPERTIES**

The main objective was to study the properties of biodiesel and to develop a mathematical correlation between Cetane number and thermal properties of karanja oil.

Based on the results of this study, the Conclusions can be drawn as follows:

The study is aimed to develop the mathematical relationship between kinematic viscosity, density, calorific value, flash point and cetane number (CN). An equation was developed relating the cetane number and thermal properties. The predicted cetane number values are compared with the measured cetane number values. This work establishes the general dependence of cetane number on the thermal properties of biodiesel.

Equations (8.3) have been developed to calculate cetane number of various vegetable oils and their biodiesel from their kinematic viscosity, density, flash point and higher Calorific value.

\[
CN = C_1 \rho + C_2 FP + C_3 HV + C_4 \nu + C_5
\]  

(8.3)

The developed equation can effectively predict the CN of the biodiesel based on its physical properties.

It was able to predict with 99.56% accuracy. The developed equation can effectively predict the CN of the biodiesel based on its physical properties, without measuring the cetane number of biodiesel.
8.4 STUDY ON PERFORMANCE AND EMISSIONS OF DIESEL ENGINE BY VARYING DIFFERENT PARAMETERS

To increase the efficiency and to reduce the fuel consumption, emissions, modification is done in engine. In the current study, experiments were done to evaluate the effects of engine parameter values (compression ratio, injection pressure, injection timing and power) while working with karanja methyl ester as fuel.

Trials with four values of compression ratio, injection pressures, injection timing and blend as against the standard values set by manufacturer for diesel as fuel (210 bar, 23° Btdc and 17.5 CR)

Out of the five design and operating parameters compression ratio, injection pressure and injection timing are having a very high influence on the response.

Compression ratio is having the strongest influence on BTE.

All the other parameters are having very little influence over BSFC.

Increase in compression ratio associated with increase in injection pressure improves the performance of the engine used in study with regard to the engine performance measured in terms of BSFC and BTE.

In this research work the best combinations of parameters and their levels to maximize the engine efficiency and to minimize the fuel consumption and emissions are identified.

By implementing the modifications in the design and control parameters based on this research work the BTE can be increased and fuel
economy and emissions can be reduced. The usage of biodiesel has the significance in the economical growth of world.

8.5 OPTIMIZATION OF ENGINE PARAMETERS USING TAGUCHI DESIGN OF EXPERIMENTS

In order to simultaneously improve the fuel economy and reduce emissions optimization techniques are used effectively. Accordingly in this research Taguchi method of design of experiments is used. The results of the experiments conducted on the naturally aspirated water cooled direct injection 5.2 kW, 1500 rpm diesel engine under steady state conditions were analyzed. Five parameters were chosen for investigation. The influence of each parameter on BTE, BSFC and emissions were studied. The optimal selection of these parameters is done based on sixteen test runs using S/N ratio, next using multi object optimization the optimal combination was found out to minimize the BSFC, emissions and to maximize the BTE.Finally comparisons are made between optimized results obtained by Taguchi method and actual confirmation results.

The observation from the test run are tabulated as response table for statistical analysis, The Analysis of variance was done using ANOVA. The contribution of the individual design and control parameter on the response variables BTE, BSFC, HC, CO and NOₓ were identified. After exhaustive experimental analysis, a final confirmatory experiment using the optimum conditions was performed, and the results were compared.

Based on the results of this study, the Conclusions can be drawn as follows:

BSFC and BTE are considerably improved with the increase in CR compared to the original CRs. Increasing CR enhances density of air charge
in cylinder. The more density the higher angles of spray cone results in increase of amount of air entrainment in the spray. Enough air in the fuel spray contributes to the completion of combustion. For all CRs, the emissions of HC with biodiesel blends are lower than that of diesel fuel.

With the increase in CR, the temperature reached was also high and HC emissions are exhausted in engine. But, this effect increased NO\textsubscript{x} emissions.

By retarding the injection timing of biodiesel, the emissions can be reduced without much compromise on the thermal efficiency. The original IT gave the best results of BSFC and BTE compared to the other ITs. The increased IT causes more time for carbon oxidation and leads to higher temperatures during the expansion stroke and so HC reduced. NO\textsubscript{x} emissions reduced with decreased IT owing to lower combustion temperature in the cylinder. The influence of injection timing on the performance characteristics of diesel and biodiesel is less significant as compared to emission characteristics. The best injection timing for diesel based on efficiency and emission levels is 27° bTDC, and for neat karanja biodiesel the injection timing is 23° bTDC for the present engine.

Increasing the injection pressure contributed for better BTE with lesser BSFC at all injection timings with lower HC emissions and higher NO\textsubscript{x}. However when too high was the injection pressure, the results were negated.

The increased IP gave the better results for BSFC and BTE compared to the original and decreased IP. Finer breakup of fuel droplets obtained with increased IP provide more surface area and better mixing with air and this effect improved combustion. HC emissions decreased and NO\textsubscript{x} emissions increased with the increase in IP for the all fuel blends.
To obtain an optimal combination of engine parameters considering performance and emissions multiple objective optimizations is used. The S/N ratios is calculated using the following equation (8.4)

\[
S / N = W_1SN_1 + W_2SN_2 + W_3SN_3 + W_4SN_4 + W_5SN_5
\]  

(8.4)

The optimum combinations recommended are valid within the selected range of input parameters, the optimum setting are CR-17.9, IP-200 bar, IT-23° bTDC, B20. P -3.64kW is the optimal combination which achieves multiple-performance characteristics of the engine and the values of the BTE, BSFC, HC, CO and NO\textsubscript{x} were found to be 34.75%, 0.2393 kg/kWh, 22 PPM 0.015% and 598 PPM respectively.

The confirmation test was conducted with optimized parameters and the results are close to predicted value. Thus, optimization through Taguchi method is validated.

8.6 OPTIMIZATION OF OPERATIONAL PARAMETERS ON PERFORMANCE AND EMISSIONS OF A DIESEL ENGINE USING BIODIESEL

The objective is to carry out multi-objective optimization on thermal performance and engine exhaust emissions using RSM to find the optimum operating conditions. Response surface methodology was employed in the present study for modeling and analysis of response parameters in order to obtain the characteristics of the engine.

Based on the results of this study, the conclusions can be drawn as follows:

The maximum brake thermal efficiency is 35% for the compression ratio 17.9 and fuel blend between B10-B20, whereas low brake thermal
efficiency lies in the region around 17.7 CR and fuel blend between B30-B40. The effects of the variation in CR on the BTE indicate that at higher CRs improve the engine efficiency.

During advancement of injection timing BTE increased. This could be due to the following fact: in-cylinder charge temperature and pressure decreased with an advancement of the injection timing resulting in extended ignition delay of the injected fuel. Simultaneously, the penetration of fuel Spray enhanced reaction between fuel and air improved and ultimately resulted in premixed or rapid combustion phase of the Combustion process.

Increasing the injection pressure from 190 bar to 230 bar increased BTE. Increasing the injection pressure beyond 220 bar, the inverse trend was noticed at all injection timings. The above result could be due to the following fact: With increase in injection pressure, better atomization of the fuel resulted in the smaller droplet size; faster evaporation of fuel sprays; and improved reaction between fuel and air. These resulted in comparatively better combustion and contributed for higher BTE at all injection timings. Beyond 220 bar of injection pressure, faster velocity of the fuel jets caused most fuel particles to hit the wall of combustion chamber where the fuel particles got cooled and not participated in the combustion process effectively which would result in incomplete combustion. The above discussions revealed that an compression ratio 17.9, injection pressure of 220 bar combined with advanced injection timing 27° BTDC produced highest BTE.

The BSFC generally increased with the increase in biodiesel percentage in the fuel blend. It can be considered that the decrease in the lower heating value of the blends by adding biodiesel requires more fuel to be injected into the cylinder to get the same power output, leading to the increase in the BSFC. When there is an increase in CR, the maximum cylinder pressure increases due to the fuel injected in hotter combustion chamber and
this leads to higher effective power. Therefore, fuel consumption per output will decrease. As the BSFC is calculated on weight basis, obviously higher densities resulted in higher values for BSFC. As density of karanja biodiesel was higher than that of biodiesel for the same fuel consumption, on volume basis, pure biodiesel yields higher BSFC. The higher densities of biodiesel blends caused higher mass injection, for the same volume, at the same injection pressure. The calorific value of the biodiesel is less than diesel. Due to these reasons, the BSFC for the other blends was higher than that for diesel.

There is a significant decrease in the HC emission level with karanja oil as compared to pure diesel. The HC emission is minimum 33 PPM which occurs at CR (18.1) and blend B30, so the value of HC reduces as compression ratio and fuel blend increases. HC concentration decreases with biodiesel addition and this suggests that adding oxygenate fuels can decrease HC from the locally over rich mixture. Furthermore, oxygen enrichment is also favorable to the oxidation of HC in the expansion and exhaust process. As confirmed increased CR reduced the HC emissions by 4% and reduced CR increases the HC emissions. At lower CR, insufficient heat of compression delays ignition and so HC emissions increase. These reductions indicate that more complete combustion of the fuels and thus, HC level decreases significantly. The reduction in HC emission was linear with the addition of biodiesel for the blends.

The amount of NO\textsubscript{x} produced for B10-B50 is in the range of 720-1300 ppm as compared to diesel which varies from 300-900 ppm. It can been seen that the increasing proportion of biodiesel in the blends increases No\textsubscript{x} as compared with diesel. This could be attributed to the increased exhaust temperatures and the fact that biodiesel had some oxygen content in it which facilitated NO\textsubscript{x} formation. Since the size of injected particles of vegetable oils is bigger than that of diesel fuel, combustion efficiency and maximum
combustion temperatures with vegetable oils were lower. Therefore, NO\textsubscript{x} emissions were lower. Increased CR increased the NO\textsubscript{x} emissions by 10% and reduced CR decreased NO\textsubscript{x} emissions by 12% compared to the results of original CR for B50. Reduced CR is to reduce the in-cylinder temperatures and thus flame temperatures during the combustion to suppress NO\textsubscript{x} emissions.

NO\textsubscript{x} emissions were also higher at part loads for biodiesel. This is probably due to higher bulk modulus of bio-diesel resulting in a dynamic injection advance apart from static injection advance provided for optimum efficiency. Excess oxygen (10%) present in bio-diesel would have aggravated the situation.

Desirability approach of the response surface methodology was found to be the simplest and efficient optimization technique. A high desirability of 0.995 was obtained at the optimum engine parameters of compression ratio of 17.9, injection pressure 200 bar, injection timing of 23\degree bt dc fuel blend B20 and 3.64 kW power, where the values of the BTE, BSFC, HC and NO\textsubscript{x} and found to be 33.86%, 0.268 kg/kWh, 31 ppm, 0.098 %, and 884 ppm, respectively.

The optimum combinations recommended are valid within the selected range of input parameters.

8.7 MATHEMATICAL EQUATION USING MULTIPLE REGRESSIONS

The objective is to validate the developed model equation using experimental results. A relationship between the chosen design and control parameters and the responses variables BTE, BSFC, NO\textsubscript{x}, HC and CO are established through multiple regression modeling. These regression equations are very much useful to predict the response variable without experimental
testing and optimization techniques. A good agreement was observed between the measured output variables and the predicted values.

\[ \eta_{\text{ITTH}} = -1.353CR - 0.032IP - 0.301IT - 0.1278B - 1.586P + 79.60 \] \hfill (8.3)

\[ \text{BSFC} = 0.0344CR + 0.00032IP + 0.0033IT + 0.0014B + 0.0202P - 0.59 \] \hfill (8.4)

\[ \text{NO}_X = -121.50 CR + 22.07 IP + 1.74 IT - 4.77 B + 99.95 P - 1764 \] \hfill (8.5)

\[ \text{HC} = 40.5CR - 3.12IP - 1.64IT - 0.170B + 43.9P - 115 \] \hfill (8.6)

\[ \text{CO} = -0.27 CR - 0.055 IP + 0.58 IT - 0.002 B + 1.963 \] \hfill (8.7)

From the five empirical model developed a C++ PROGRAM is written. Using these program 1024 combinations of input parameters can be given and the responses can be obtained.

Mathematical equations for performance and emission parameters of the diesel engine were developed. It may not always be convenient to make experimentation every time while switching over from one blend to another. Mathematical equations are thus helpful and it allows active optimization of engine performance without experimentation.

The results from Response surface methodology, Taguchi method and Regression equation for optimum settings, the confirmation run are well within the predicted range. Hence, it can be concluded that all the method is showing good reproducibility and the experiment is valid.
8.8 CONCLUSION

Based on the results of this study, it can be concluded that

The mathematical model developed to predict the higher heating value and cetane number of vegetable oil methyl ester, non edible oil (karanja) and biodiesel, predicts the higher heating value and cetane number with less than 0.2 % error. Thus the model developed can be used to predict the higher calorific value and cetane number of vegetable oils, biofuel and biodiesel without measuring the values in the laboratory.

Compression ratio is having the maximum influence in all the response, hence it is recommended to increase the compression ratio from 17.5 to 17.9.

By varying the different input parameters, the brake thermal efficiency of the 5.2 kW diesel engine using karanja biodiesel was 33.5 %. Thus it have been increased to 6.3 % compared to the manufacturer design.

The emissions HC, CO and NOx have been reduced within the boundaries of EURO IV norms.

For the given parameters the maximum and minimum HC produced is 0.02g/kWh and 0.004 g/kWh that is very less compared to EURO – IV Norms (max 0.55 g/kW-hr).

The maximum and minimum NOx produced is 1.61g/kW-h and 0.99g/kW-h, that is much less than, mentioned in EURO – IV Norms (max 3.5g/kW-h).
The maximum and minimum CO produced is 0.01 g/kWh and 0.00165 g/kWh, which is much less than, mentioned in EURO - IV Norms (max 1.5 g/kWh).

In this research work the best combinations of parameters and their levels to maximize the engine efficiency and to minimize the fuel consumption and emissions are identified. Using Response surface method and Taguchi Method the engine is optimized for maximum efficiency and minimum fuel consumption. By implementing the modifications in the design and control parameters based on this research work the BTE can be increased and fuel economy and emissions can be reduced.

The recommended design of 5.2 kW diesel engine were an compression ratio of 17.9, injection pressure 200 bar, injection timing of 23° bTDC.

The usage of biodiesel has the significance in the economical growth of world.

8.9 SUGGESTIONS FOR FUTURE STUDIES

Other optimization techniques like simulated annealing, genetic algorithm, particle swarm method, can be used to optimize and the results can be compared.

Multicylinder diesel engine can be used to study the performance, emissions and combustion.

Test should must be conducted on actual road vehicles, to see how the impact of driving a car in varying climates, which affects the emissions, efficiency and performance of the oil.

Combustion analysis can be done for diesel engine using biodiesel. More input parameters can be varied and optimization can been done.