EXPERIMENTAL AND ANALYTICAL INVESTIGATION ON THE EMISSION AND COMBUSTION CHARACTERISTICS OF CI ENGINE FUELED WITH TAMANU OIL METHYL ESTERS

by

Navaneetha Krishnan PERUMAL [a*] ***and Vasudevan DURAIRAJ*** [b]

[a] Department of Mechanical Engineering, Bharathidasan Institute of Technology, Anna University, Tiruchirappalli, Tamil Nadu, India
[b] Department of Mechanical Engineering, PSNA College of Engineering and Technology, Dindigul, Tamil Nadu, India

Original scientific paper
DOI: 10.2298/TSCI16S4099P

The emission and combustion characteristics of a four stroke multi fuel single cylinder variable compression ratio engine fueled with tamanu oil methyl ester and its blends 10%, 20%, 40%, and 60% with diesel (on volume basis) are examined and compared with standard diesel. Biodiesel produced from tamanu oil by trans-esterification process has been used in this study. The experiment has been conducted at a constant engine speed of 1500 rpm with 50% load and at compression ratios of 16:1, 17:1, 18:1, 19:1, and 20:1. With different blend and for selected compression ratio the exhaust gas emissions such as CO, HC, NO_x, CO_2, and the combustion characteristics are measured. The variation of the emission parameters for different compression ratios and for different blends is given, and optimum compression ratio which gives best performance has been identified. The results indicate higher rate of pressure rise and minimum heat release rate at higher compression ratio for tamanu oil methyl ester when compared with standard diesel. The blend B40 for tamanu oil methyl ester is found to give minimum emission at 50% load. The blend when used as fuel results in reduction of polluting gases like HC, CO, and increase in NO_x emissions. The previously mentioned emission parameters have been validated with the aid of artificial neural network. A separate model is developed for emission characteristics in which compression ratio, blend percentage and load percentage were used as the input parameter whereas CO, CO_2, HC, and NO_x were used as the output parameter. This study shows that there is a good correlation between the artificial neural network predicted values and the experimental data for different emission parameters.

Key words: *biodiesel, tamanu oil methyl ester, emission, combustion, variable compression ratio engine*

Introduction

The development of biofuels can be found from early 19th century. Indeed, the historical development of Diesel engines and biofuels has continuous technological advancements and economic struggle. Biofuels provide greater employment opportunities and livelihood generation, leading to regional as well as national independence [1]. These types of research works are

* Corresponding author; e-mail: navaneethak@gmail.com

expose that different kinds of vegetable oils has been used as an alternative fuel. The engine showed an better performance with reduction in smoke, HC, and CO emissions and increase in NO_x emission in all these cases. In this way, a articulate image has been formed by seeing the relative performance and emission characteristics of these fuels [2, 3].

Arul Mozhi Selvan *et al*. [4] using diesel and biodiesel ethanol blends as fuel related the combustion characteristics of single-cylinder four stroke direct injection variable compression ratio (VCR) engine under the compression ratios 15:1, l7:1, and 19:1. It has been detected that the cylinder gas pressure and heat release rate increase with higher ethanol concentration due to longer ignition delay. The exhaust gas temperature T_{exh}, was found to be less. The study also tested the fuel burning characteristics of the diesel biodiesel ethanol blends under various compression ratios and loading conditions. The performance and emission tests were carried out by using the fuel blends on a computerized VCR engine and compared with standard Diesel engine [5]. Gumus and Kasifoglu [6], using apricot seed kernel oil methyl ester and its blends with diesel, studied the performance and emission characteristics of a compression ignition Diesel engine without any modification, the lower concentration of apricot seed kernel oil methyl ester blends gives a larger improvement in the engine performance and exhaust emissions.

Panwar *et al*. [7] examined the engine performance of *castor* methyl ester and *potassium* hydroxide catalyst in four stroke single cylinder VCR type Diesel engine at various loads and determined the low blends of bio diesel increases the break thermal efficiency and reduces the fuel consumption. The exhaust gas temperature T_{exh}, has been increased with increasing bio diesel concentration. Raheman and Ghadge [8], at VCR, injection timing and engine loading, studied the performance of the engine using biodiesel obtained from mahua oil and its blend with diesel. The T_{exh} and specific fuel consumption increased, whereas brake thermal efficiency decreased with increase in the percentage of bio diesel in the blends for compression ratios 18:1, 19:1, and 20:1. The researcher concluded that, at any of the compression ratio and injection timing if the bio diesel could be blended with high speed diesel up to 20% for receiving fairly accurate performance as that of diesel.

Celikten *et al*. [9] compared the performance and emissions of diesel fuel from *soybean* oil and rapeseed methyl esters injected at different pressures (250, 300, and 350 bars). It has been found that the torque and power of diesel fuel engine reduced with increasing injection pressure. Smoke level (%) and CO emission also reduced while NO_x emission increased as the injection pressure is increased. Jindal *et al*. [10] studied the engine design parameters such as fuel injection pressure, compression ratio, and the performance parameters such as brake thermal efficiency, fuel consumption, emissions of CO_2, CO, NO_x, HC, and smoke opacity with *jatropha* methyl ester as fuel. A comparison of performance and emission for various compression ratios along with injection pressure and the feasible blends for operating engine with *jatropha* methyl ester has been found. It is found that the increase in injection pressure and compression ratio increases the brake thermal efficiency and reduces the brake specific fuel consumption while reducing the emissions.

Anand *et al*. [11] considered the combustion performance and exhaust emission characteristics of *turpentine* oil fuel blended with conventional diesel fuel in a diesel engine. Saravanan *et al*. [12] examined the combustion characteristics of crude rice *bran* oil methyl ester blend in a direct injection compression ignition engine and found that the cylinder pressure was comparable whereas the delay period were lower than that of diesel. Muralidharan and Vasudevan *et al*. [13] studied the performance, emission, and combustion characteristics of a single cylinder multi fuel four stroke VCR engine when fuelled with waste cooking oil methyl ester and it blends with diesel and compared with SD. It is evident that the blend B40 is found to give maximum thermal efficiency, reduction in HC, CO, and increase in NO_x.

Pachbhai *et al*. [14] to acquire data for training and testing the proposed artifical neural network (ANN), a single cylinder, four-stroke compression ignition (CI) engine was fuelled with diesel and exhaust gas temperature operated at different loads. Using 60% experimental data for training, an (ANN) model based on back propagation neural network for the engine was developed. The performance of the ANN predictions were observed that the ANN model can predict the engine brake thermal efficiency, brake specific fuel consumption, and exhaust gas temperature quite well with correlation coefficients of about 0.96198, 0.96237, and 0.94702 and the mean square error (MSE) values were within 1.885%. This study shows that, as an alternative to classical modeling techniques, the ANN approach can be used to accurately predict the performance parameters of internal combustion engines. Kumar *et al*. [15] experimental investigations on the performance parameters from the engine were done. The ANN were used to predict the engine performance. To train the network compression ratio, blend percentage, percentage load were used as the input variables where as engine performance parameters were used as the output variables. The ANN results showed good correlation between the ANN predicted values and the desired values for various engine performance values. The coefficient of multiple determination R^2, values were very close to 1 and the mean relative error values were less than 9%.

Numbers of experiments are conducted in various types of engines with bio diesel prepared from different oils. The effect of parameters on the performance of the engine with emission characteristics and combustion characteristics of the biodiesel has been emphasized in many studies [12, 16-18]. Very few experimental analyses have been done by varying the compression ratio of bio diesel in VCR engine [4, 10, 12]. The effects of emission and combustion characteristics have not been studied extensively. Hence this study has been dedicated to find suitable compression ratio which gives optimum performance.

In this study, tamanu oil (methyl esters of tamanu oil) and its blends with diesel is chosen as a fuel for VCR multi fuel engine. The various blends of tamanu oil and SD fuel are prepared and the following testes are carried out.

The emission and combustion characteristics of VCR engine using various blends at compression ratios 16:1, 17:1, 18:1, 19:1, and 20:1 for 50% load and its comparison with the results of SD fuel.

The combustion characteristics such as variation of cylinder pressure, mass fraction burnt and heat release rate are discussed with reference to the crank angle (CA) for various compression ratios.

Experimental set-up

The experimental set-up for this study is shown in fig. 1. The set-up consists of a VCR multi fuel engine coupled with eddy current dynamometer. For measuring the load applied to the engine, a strain gauge type load cell is fixed at the output shaft of the eddy current dynamometer. To measure the combustion pressure and the corresponding CA, the Kistler piezoelectric pressure transducer and a CA encoder

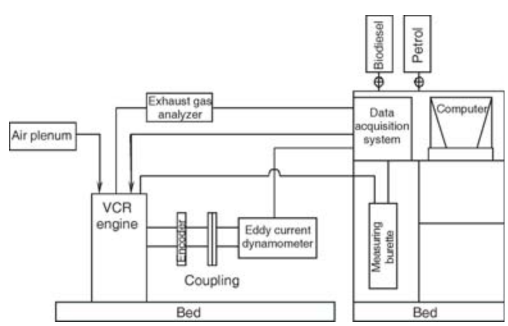

Figure 1. Experimental set-up

are mounted on the engine head. The pressure transmitter type 6613CA contains an integrated charge amplifier and a piezoelectric sensor. The fuel flow quantity is measured by 20 cm^3 burette and stopwatch with lever sensors. The airflow rate is measured by the mass air flow sensor. To measure engine exhaust gas temperature, water inlet and outlet of calorimeter, ambient temperature, engine cooling water outlet, and calorimeter exhaust by type K-chromel thermocouples are used. A small shell and tube gas to liquid heat exchanger is used as a calorimeter for conducting the heat balance. With the help of various sensors a computerized data acquisition system, the data are collected and analyzed the data during the experiment.

Experimental methodology

The Kirloskar single cylinder VCR multi-fuel engine (VCR 5 to 20) of constant speed 1500 rpm water cooled loaded with eddy current dynamometer is started by using the standard diesel and it is allowed to reach the operating temperature. The compression ratio is achieved by raising the bore and head of the engine . The warm up period for engine is awaited till cooling water temperature reaches 60 °C. Then the 50% load is applied. The tests are conducted at the rated speed of 1500 rpm. In each test, the exhaust gas emissions such as CO, CO_2, NO_x, and HC are measured with respect to compression ratio 16:1, 17:1, 18:1, 19:1, and 20:1 for different blends of tamanu oil methyl esters are calculated and tabulated. The characteristics of combustion and exhaust emission levels are also calculated and stored in personal computer for every operating condition for further processing of results. The viscosity, fire point, flash point, actual density, and gross calorific value were measured in the laboratory. Table 1 shows the properties of the diesel fuel and biodiesel blends.

Table 1. Fuel properties of diesel and biodiesel blends

Properties	Diesel	B10	B20	B40	B60	Biodiesel	Standards ASTM D 6751-02
Calculated cetane index	45-50	55	52	49	45	31	41 minimum
Gross calorific value [$kJkg^{-1}$]	45.240	44.070	42.793	42.295	40.608	40.055	–
Density [kgm^{-3}]	0.835	0.8413	0.8527	0.8676	0.8906	0.9322	0.86
Viscosity at 40 °C [mm^2s^{-1}]	1.382	1.407	2.970	3.670	4.560	5.720	1.9-6.0
Flash point	42 °C	52 °C	62 °C	96 °C	114 °C	204 °C	> 130 °C
Fire point	68 °C	70 °C	85 °C	114 °C	162 °C	212 °C	–
Water content, [%]	0.02	0.02	0.025	0.03	0.03	0.04	<0.03

Emission analysis

Procedure

For measuring the exhaust gas emissions, an AVL DIGAS 2200 five gas analyzer was used. The probe of the analyzer was inserted into the exhaust pipe of the engine before taking the measurements. Once the engine has been steadied at working condition, the exhaust emissions were measured. With the help of this analyzer, O_2, CO, CO_2, HC, and NO_x were measured for different blends of tamanu oil methyl ester with SD and examined for different compression ratios. The various Indian standards used for emission analysis are given in tab. 2 [19]. The results of tamanu oil methyl ester and blends of bio diesel are within the acceptable limits.

Table 2. Indian standards used for emission analysis

Elements	Standards
Carbon dioxide	IS 13270:1992 (reaffirmed 1999)
Carbon monoxide	IS 13270:1992
Nitrogen oxides	IS 11255 – (PART 7) – 2005
Hydrocarbon	–

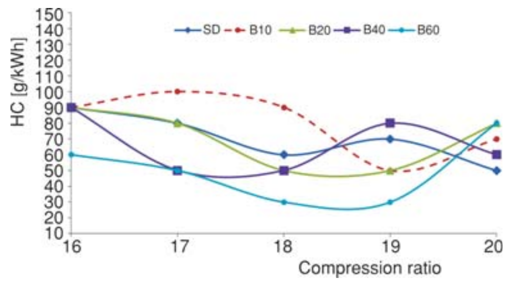

Figure 2. Variation of HC emission for different blends of tamanu oil methyl ester and SD at various compression ratios

Results and discussion

Hydrocarbon emission

The variation of HC emission for different blends and diesel at different compression ratios for different blends is given in fig. 2. It states that the HC emission of various blends is higher at higher compression ratios. The effects of viscosity on the fuel spray quality are expected to produce some HC increase with vegetable oil fuels [20]. From this study, it shows that the increase in compression ratio increases the HC emission especially for B40 at compression ratio 19:1. The other blends B10, B20, and B60 emit lesser HC at higher compression ratio than the SD. The accumulation of fuel in the combustion chamber may increase HC emission due to longer ignition delay. The amount of HC emitted for diesel and B40 at compression ratio 19:1 are 70 g/kW, and 80 g/kW, respectively.

Nitrogen oxide emission

Figure 3 shows the variations of NO_x emission of the different blends and diesel for compression ratio. From the figure it is evident that with increase in compression ratio the NO_x emission for diesel and other blends increase. Also, it is noticeable that NO_x emission for the tamanu oil blend B40 is higher than that of diesel at compression ratio 19:1. The cause for the higher NO_x emission for blends is due to higher peak temperature but the reduction in NO_x is the prime aim of the engine researchers. The NO_x emission for blend B40 for compression ratio 19:1 is 180 ppm and for diesel is 220 ppm, respectively.

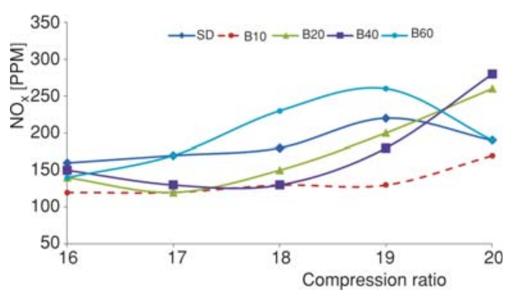

Figure 3. Variations of NO_x emission for different blends of tamanu oil methyl ester and SD at various compression ratios

Carbon monoxide emission

The variation of CO emission for different blends of tamanu oil methyl ester and SD at various compression ratios are shown in fig. 4. At compression ratio19:1 the CO emission for the blend B40 is found to be higher than that the other blends B10, B20, B60, and SD. The percentage of CO emission for B40 and SD are 0.5% and 0.3%, respectively. Due to rising temperature in the combustion chamber, physical and chemical properties of the fuel, air-fuel ratio, shortage of oxygen at high speed, and lesser amount of time available for complete combustion the percentage of CO increases [21]. The viscosity of vegetable oil fuels on quality of fuel spray might increase some CO [22].

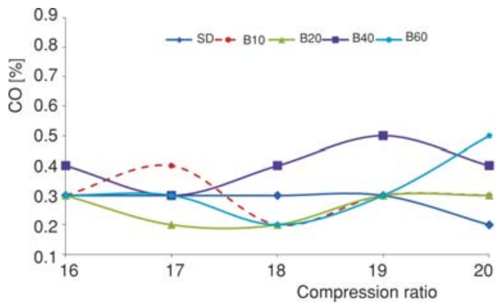

Figure 4. Variation of CO emission for different blends of tamanu oil methyl ester and SD at various compression ratios

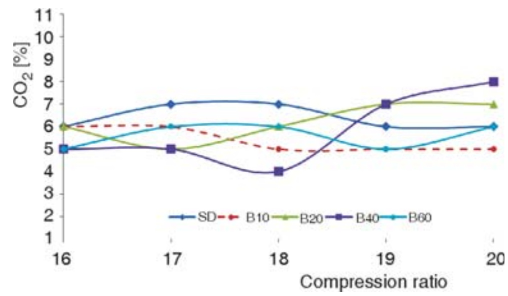

Figure 5. Variation of CO_2 emission for different blends of tamanu oil methyl ester and SD at various compression ratios

Carbon dioxide emission

Figure 5 shows the variation of CO_2 emission for different blends of tamanu oil methyl ester and diesel at different compression ratios. It is clear that, at low compression ratios the blends produce low percentage of CO_2 than diesel and *vice versa*. When the amount of CO_2 emission increases, it indicates the complete combustion of fuel in the combustion chamber. It also relates to the exhaust gas temperature. The CO_2 emission for the blend B40 at compression ratio 19:1 is found to be higher due to better combustion and enough supply of oxygen to the combustion chamber. The increase of CO_2 in the atmosphere leads to many environmental pollution and creates environmental problems like ozone depletion and global warming by greenhouse effect. The CO_2 emission from the combustion of bio fuels can be absorbed by the plants and its level can be maintained constant in the atmosphere.

Artificial neural network approach

In ANN approaches, the back propagation learning algorithm is used in this study. This system has one input layer, one hidden layer, and one output layer. To train and test the neural networks, input data and corresponding targets are required. From the available data 80% of the data to be used for training of the network and the remaining data is used to verify the capability of the network. To minimize the error between the network output and actual value the weights are adjusted in the input and output pairs are given to the network. Once training is completed, a new set of data will be available using the already trained network. The inputs are load in percentage, compression ratio, and blends and the output is CO, CO_2, HC, and NO_x. The neural networks toolbox of MATLAB R2013a is used to form the ANN. Input layer of network has three neurons and the output layer has four neurons. Twelve neurons are used in hidden layer [23].

The Levenberg-Marquardt algorithm is very well suited to neural network training, where the performance index is the MSE. In order to understand whether an ANN is making good predictions, test data that has never been presented to the network are used and the results are checked at this stage. The statistical methods of root MSE, the coefficient of multiple determination, R^2 values have been used for making comparisons [24, 25].

Figures 6 and 7 shows that each predicted CO, CO_2, HC, and NO_x values of the ANN are very close to the experimental results.

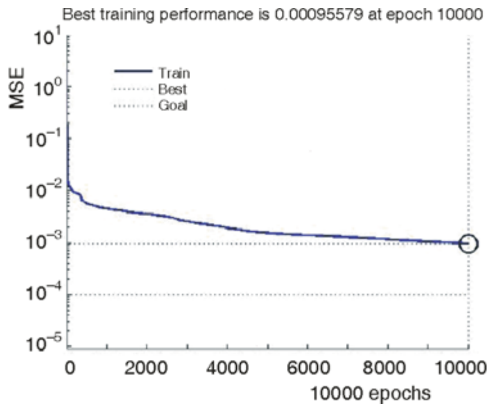

Figure 6. Variation of MSE

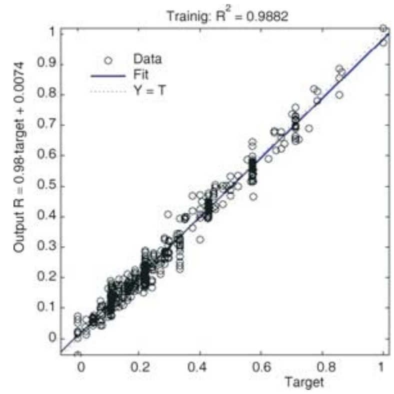

Figure 7. Variation of target with output ratio for ANN

Combustion analysis

Combustion pressure

Figures 8-12 show the variation of combustion pressure with respect to CA for different blends and for different compression ratios. It has been observed from the variation of cylinder pressure for various compression ratios 16:1, 17:1, 18:1, 19:1, and 20:1 that the tamanu oil blends give high combustion pressure but little less than that of SD due to the lower cetane number of the blend and may be due to longer ignition delay of tamanu oil. The fuel absorbs more amount of heat from the cylinder immediately after injection resulting in longer ignition delay [22]. It is observed that 56.79088 bar, 56.13575 bar, 56.48208 bar, 56.11176 bar, and 55.56685 bar for SD and tamanu oil blends B60, B40, B20, and B10. The combustion pressure for blends are higher for higher compression ratios and the combustion pressure for diesel is higher for lower compression ratios. The increase in combustion pressure is at maximum rate with increase in the compression ratio. The reason behind the increased pressure rise is the oxygen enrichment in the blend due to the addition of bio diesel [4]. This is due to the complete and faster combustion of fuel inside the combustion chamber. At lower compression ratios, the maximum combustion pressure for diesel is higher than that of diesel biodiesel blends. The

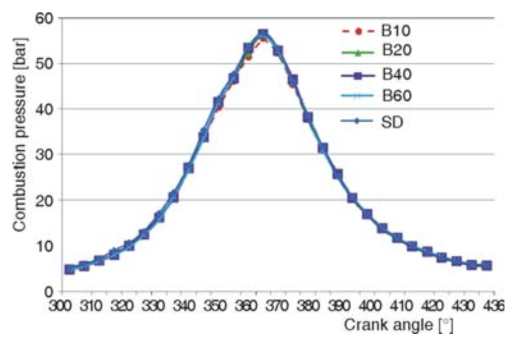

Figure 8. The variation of combustion pressure at compression ratio 16:1

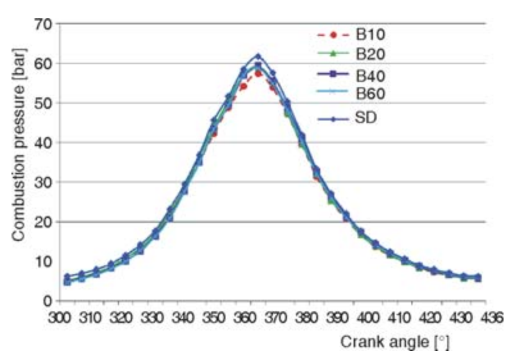

Figure 9. The variation of combustion pressure at compression ratio 17 :1

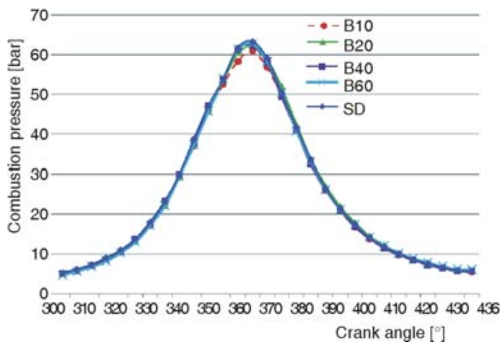

Figure 10. The variation of combustion pressure at compression ratio 18:1

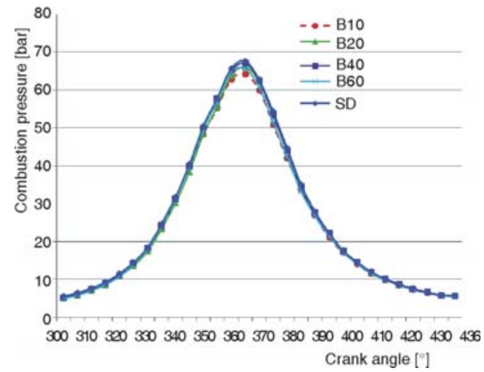

Figure 11. The variation of combustion pressure at compression ratio 19:1

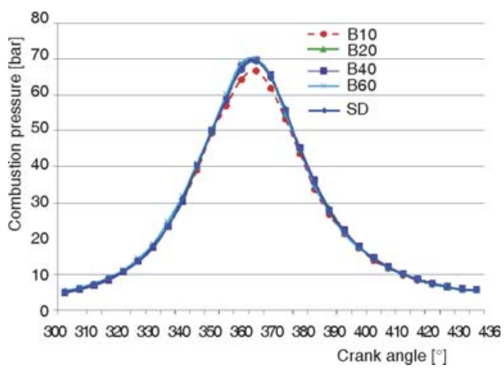

Figure 12. The variation of combustion pressure at compression ratio 20:1

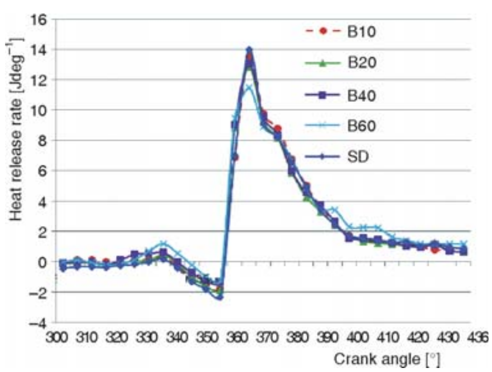

Figure 13. The variation of heat release rate at compression ratio 16;1

maximum rate of increase in pressure is increasing with increase in compression ratio for different blends.

Heat release rate

Figures 13-17 shows the variation of heat release rate with respect to CA for different blends and for different compression ratios, respectively. Based on the changes in CA variation of the cylinder, the heat release is examined. It has been detected that the heat release rate increases at the lower compression ratios and slightly decreases at higher compression ratios. This may be due to the lower air-fuel mixing rate and viscosity of the blends. Due to its reduced viscosity and better spray formation the heat release rate of oil blend is lower than SD [20]. For increase in compression ratios, the heat release rate of tamanu oil blends decreases compared to diesel. This may be due to the reduction in viscosity and good spray formation with increase in compression ratio in the engine cylinder. The mass fraction burnt of blends is slightly higher at lower compression ratio and closely follows the SD at higher compression ratio. Combustion is sustained in the diffusive combustion phase due to the oxygen content of the blend. At higher compression ratios, the engine reaches stoichiometric region. More fuel is accumulated in the combustion stage and it causes immediate heat release [4]. At lower compression ratio, the tamanu oil blends causes longer duration for combustion and at higher compression ratio it causes lesser duration for combustion.

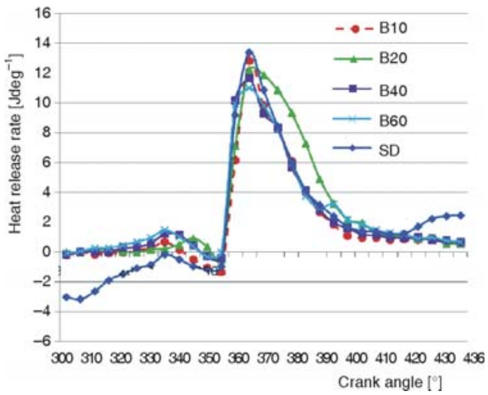

Figure 14. The variation of heat release rate at compression ratio 17:1

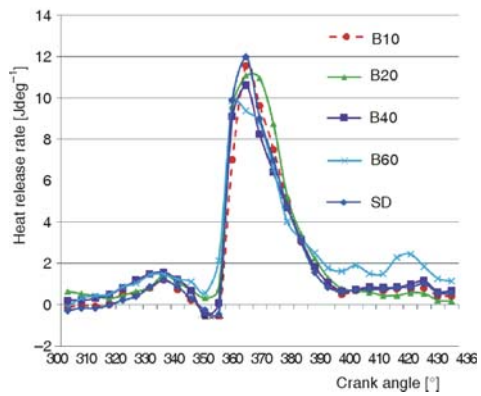

Figure 15. The variation of heat release rate at compression ratio 18:1

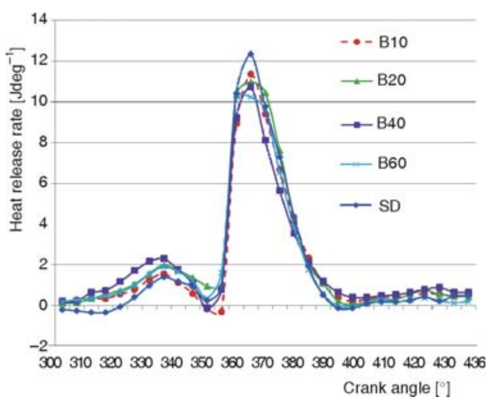

Figure 16. The variation of heat release rate at compression ratio 19:1

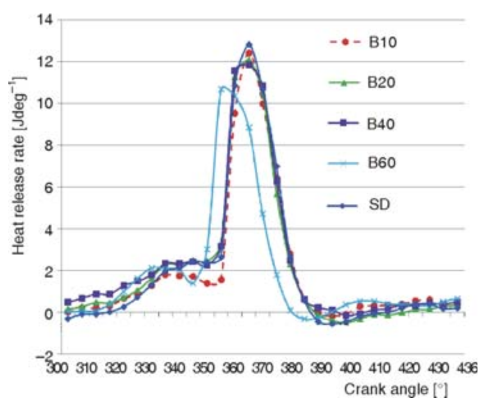

Figure 17. The variation of heat release rate at compression ratio 20:1

Conclusions

The emission and combustion characteristics of a four stroke multi fuel single cylinder VCR engine fueled with tamanu oil methyl ester and its blends 10%, 20%, 40%, and 60% with diesel (on a volume basis) are examined and compared with SD. It is clear from the experimental results that the HC, CO, CO_2, NO_x are a function of biodiesel blend, load and compression ratio. For the same operating conditions, increase in bio diesel percentage in the blend the exhaust emission gets reduced B40 blends. By varying the compression ratio, the engine exhaust emission varied and it becomes comparable with SD. The following conclusions are drawn from this experimental analysis:

- At higher compression ratio the HC emission of various blends is higher. In blend B40 the increase in compression ratio increases the HC emission. This is due to the effect of fuel viscosity on the fuel spray quality. The CO emission of the blend B40 is closer to the standard diesel and it is very higher at compression ratio 20:1. The CO_2 emission is also lesser at the same conditions due to incomplete combustion and inadequate supply of oxygen. The emission of NO_x from the tamanu oil blend B40 is higher than diesel. The NO_x

emissions are sensitive to oxygen content, adiabatic flame temperature and spray characteristics. Due to the higher peak temperature of blends the emission of NO_x is higher.
- At higher compression ratio tamanu oil blends gives higher combustion pressure. It is due to longer ignition delay, rate of pressure rise and lower heat release rate when compared to diesel.
- It is conclude that the ANN values are very close to the experimental results. The MSE is 0.00095 and the R_2 value is 0.9882%. It may be used as a good alternative for the analysis of the effects of emission parameters.

From the previous interpretations, it is clear that at compression ratio 19:1 the emission of the blend B40 is better than the SD. When compare with the SD the NO_x emission is slightly increased but still it is in the acceptable range. The experimental analysis result gives that the lower and medium percentages of tamanu oil methyl ester can be used for diesel fuel.

List of abbreviations

ANN – artificial neural network
ASTM – American society for testing and materials
B10 – 10% biodiesel+90% diesel
B20 – 20% biodiesel+90% diesel
B40 – 40% biodiesel+90% diesel
B60 – 60% biodiesel+90% diesel
MSE – mean square error
R^2 – coefficient of multiple determination
RMSE – root mean square erro
SD – standard diesel
TME – tamanu oil methyl ester
VCR – variable compression ratio

References

[1] Kishore, V. V. N., *Renewable Energy Engineering and Technology Principles and Practice*, TERI, TERI University, New Delhi, India, 2008
[2] Huzayyin, A. S., *et al*., Experimental Evaluation of Diesel Engine Performance and Emission Using Blends of Jojoba Oil and Diesel Fuel, *Energy Conversion and Management, 45* (2004), 13-14, pp. 2093-2112
[3] Pugazhvadivu, M., Jeyachandran, K., Investigations on the Performance and Exhaust Emissions of a Diesel Engine Using Preheated Waste Frying Oil as Fuel, *Renewable Energy, 30* (2005), 14, pp. 2189-2202
[4] Arul Mozhi Selvan, V., *et al*., Combustion Characteristics of Diesohol Using Bio Diesel as an Additive in a Direct Injection Ignition Engine Under Various Compression Ratios, *Energy & Fuels, 23* (2009), 11, pp. 5413-5422
[5] Arul Mozhi Selvan, V., *et al.*, Stability, Performance and Emission Characteristics of Diesel – Ethanol Blend with Castor Oil as Additive in Variable Compression Ratio Engine, *Proceedings*, International Conference of Fascinating Advances in Mechanical Engineering, Sivakasi, India, 2008, pp. 11-13
[6] Gumus, M., Kasifoglu, S., Performance and Emission Evaluation of a Compression Ignition Engine Using a Biodiesel (Apricot Seed Kernel Oil Methyl Ester) and its Blends with Diesel Fuel, *Biomass Bioenergy, 34* (2010), 1, pp.134-139
[7] Panwar, N. L., *et al*., Performance Evaluation of a Diesel Engine Fueled with Methyl Ester of Castor Seed Oil, *Applied Thermal Engineering, 30* (2010), 2-3, pp. 245-249
[8] Raheman, H., Ghadge, S. V., Performance of Diesel Engine with Biodiesel at Varying Compression Ratio and Ignition Timing, *Fuel, 87* (2008), 12, pp. 2659-2666
[9] Celikten, I., *et al*., Comparison of Performance and Emissions of Diesel Fuel, Rapeseed and Soybean Oil Methyl Esters Injected at Different Pressures, *Renewable Energy, 35* (2010), 4, pp. 814-820
[10] Jindal, S., *et al.*, Experimental Investigation of the Effect of Compression Ratio and Injection Pressure in a Direct Injection Diesel Engine Running on Jatropha Methyl Ester, *Applied Thermal Engineering, 30* (2010), 5, pp. 442-448
[11] Anand, P. B., *et al*., Performance and Exhaust Emission of Turpentine Oil Powered Direct Injection Diesel Engine, *Renewable Energy, 35* (2010), 6, pp. 1179-1184
[12] Saravanan, S., *et al*., Combustion Characteristics of a Stationary Diesel Engine Fuelled with a Blend of Crude Rice Bran Oil Methyl Ester and Diesel, *Energy, 35* (2010), 1, pp. 94-100

[13] Muralidharan, K, Vasudevan, D., Performance, Emission and Combustion Characteristics of a Variable Compression Ratio Engine Using Methyl Esters of Waste Cooking Oil and Diesel Blends, *Applied Energy, 88* (2011), 11, pp. 3959-3968
[14] Pachbhai, S., *et al*., Application of ANN to Optimize the Performance of CI Engine Fuelled with Cotton Seed Oil, *International Journal of Emerging Technology and Advanced Engineering, 4* (2014), 6, pp. 351-358
[15] Kumar, S., *et al*., Performance and Emission Characteristics of a 4 Stroke C.I. Engine Operated on Honge Methyl Ester Using Artificial Neural Network, *ARPN Journal of Engineering and Applied Sciences, 5* (2010), 6, pp. 83-94
[16] Xue, J., *et al*., Effect of Biodiesel on Engine Performances and Emissions, *Renewable Sustainable Energy Reviews, 15* (2011), 2, pp. 1098-1116
[17] Murugesan, A., *et al*., Bio-Diesel as an Alternative Fuel for Diesel Engines-A Review, *Renewable and Sustainable Energy Reviews, 13* (2009), 3, pp. 653-662
[18] Enweremadu, C. C., Rutto, H. L., Combustion, Emission and Engine Performance Characteristics of Used Cooking Oil Biodiesel-A Review, *Renewable & Sustainable Energy Reviews, 14* (2010), 9, pp. 2863-2873
[19] Arpa, O., *et al*., Experimental Investigation of the Effects of Diesel – Like Fuel Obtained from Waste Lubrication Oil on Engine Performance and Exhaust Emission, *Fuel Process Technology, 91* (2010), 10, pp. 1241-1249
[20] Devan, P. K., Mahalakshmi, N. V., A Study of Performance, Emission and Combustion Characteristics of a Compression Ignition Engine Using Methyl Ester of Paradise Oil – Eucalyptus Oil Blends, *Applied Energy, 86* (2009), 5, pp. 675-680
[21] Ramadhas, A. S., *et al*., Theoretical Modeling and Experimental Studies on Biodiesel-Fueled Engine, *Renew Energy, 31* (2006), 11, pp.1813-1826
[22] Devan, P. K., Mahalakshmi, N. V., Performance, Emission and Combustion Characteristics of Poon Oil and its Diesel Blends in a DI Diesel Engine, *Fuel, 88* (2009), 5, pp. 861-867
[23] Najafi, G., *et al*., Performance and Exhaust Emissions of a Gasoline Engine with Ethanol Blended Gasoline Fuels Using Artificial Neural Network, *Applied Energy, 86* (2009), 5, pp. 630-639
[24] Parlak, A., *et al*., Application of Artificial Neural Network to Predict Specific Fuel Consumption and Exhaust Temperature for a Diesel Engine, *Applied Thermal Engineering, 26* (2006), 8-9, pp. 824-828
[25] Sayin, C., *et al*., Performance and Exhaust Emissions of a Gasoline Engine Using Artificial Neural Network, *Applied Thermal Engineering, 27* (2007), 1, pp. 46-54

Paper submitted: September 15, 2015
Paper revised: January 12, 2016
paper accepted: February 4, 2016