VENKATA RAMESH MAMILLA
S. BHAGAVAN SREEDHAR
and
PADILAM RAMA KRISHNA

An artificial intelligent prediction model for evaluating the engine performance and emission characteristics using waste cooking oil biodiesel blends

Bio-fuels or bio-diesels are biodegradable fuels and are not toxic in nature. In this study, bio-fuels are produced by transesterification process from waste oils of cooking, animal fat and vegetable oils. During the process, these oils are reacted with an alcohol generally ethanol or methanol in the presence of sodium hydroxide as catalyst resulting in ester called as bio-diesel with a byproduct of glycerin. The manufactured pure bio-diesel is generally less flammable when compared to diesel and having burning point of 50 degrees celsius. Bio-diesel blends are formed by combination of bio-diesel and petroleum diesel in different proportions and the flash and gel points lie between those of pure fuels depending on the mixture.

Artificial neural networks (ANNs) are soft computational models that mimic the behaviour of human neurons. ANNs are formed by the interconnections between the building blocks called neurons which are simple processing units that process the data and the performance of network depends on parameters involved and the architecture used. These are used for obtaining the correlation between the dependent and independent process parameters that are nonlinear in nature. ANNs find application in classification and prediction problems, provides results that are fast and are very close approximation to actual output.

This study indicates bio-diesel is produced from waste cooking oil methyl ester and various blends are made with different proportions of bio-diesel and petroleum diesel. The experiments are conducted on diesel engine with bio-diesel blends and the performance parameters are brake power (BP), specific fuel consumption (SFC), brake thermal efficiency and the engine exhaust emissions. The ANNs are trained with the partial blend data used for experimentation as input to the model and the performance parameters as output using different activation functions. The model is tested with the remaining data to assess the percentage error between the actual and predicted values. The results reveal that blends of bio-diesel provide good performance and emission characteristics. It is concluded from the study that the ANN model can predict the exhaust emissions and engine performance well.

Keywords: ANN, performance; diesel engine; exhaust emission; waste cooking oil methyl ester.

Dr. Venkata Ramesh Mamilla, Professor and Messrs. S. Bhagavan Sreedhar and Padilam Rama Krishna, UG Student, Department of Mechanical Engineering, Sri Vasavi Engineering College, Tadepalligudem, West Godavari District, Andhra Pradesh, India. E-mail: maa_ram@yahoo.co.in

1.0 Introduction

Dr. G. Lakshmi Narayana Rao et. al (2006) studied the effect of blend of bio-diesel on engine performance and exhaust emissions of CI engine. Also an attempt is made to find the optimal proportions of bio-diesel in blends using ANN. ANNs are used to assess SFC, emissions of NO_x and HC for all the blends of bio-diesel and petroleum based diesel. The conclusions are the work proposed an effective method for estimation of the optimal bio-diesel blends with good predictability of ANN model close to the experimental values.

B. Ghobadian et al (2009) had studied about the ANN model for diesel engine using waste oil of cooking for the prediction of BP, torque, SFC and engine exhaust emissions. The engine is operated under different engine speeds which were fuelled with the biodiesel blend. The ANN model based on standard back propagation algorithm for the engine was developed. It was observed that the ANN model can predict the performance and exhaust emissions of engine quite well with correlation coefficient for engine torque, SFC, CO and HC emissions respectively.

From the paper they had concluded that the results are in good agreement on the actual values and the BP and torque developed are 18.2 kW and 64.2 Nm at seeds of 3200 rpm and 2400 rpm respectively. With the bio-diesel by adding 20% of waste vegetable oil methyl ester, an increase of 2.7% is observed in maximum power and 2.9% in torque and also the decrease in concentration of CO and HC emissions.

D. Vinay Kumar etal (2013) prepared bio-diesel from various vegetable oils and animal fats with blend ratios using transesterification process which is simple. The application of thermal barrier coatings on the engine components is a seriously perused area of interest with low frade fuels like bio-diesel fuels. It has been observed that from the experimental observations that there is an improvement in BSFC of the order of 4.16% with Lanthanum Zirconate coated engine operation compared to standard diesel engine operation. A neural network with back propagation algorithm was used with 3-6-5 configuration to predict the SFC, brake thermal efficiency, diesel engine emissions of CO, HC, NO_x. The results show that the error between experimental and predicted values less than 6.8% are acceptable.

P. Pai Srinivas et al (2010) stressed the need for the development of bio-diesels to handle the hike in fuel prices as well as ill-effects of environmental pollution. In the present work bio-diesel was prepared from Honge oil and used as a fuel in CI engine. Experiments were conducted for different percentage of blends of Honge oil with diesel at various compression ratios. Artificial neural networks were used to predict the engine performance and emission characteristics of the engine. The compression ratio, blend percentage, percentage load were used as the input variables whereas engine performance parameters together with engine exhaust emissions were used as the output variables. They concluded that 20% blend with diesel (B20) gave maximum efficiency at all compression ratios and the efficiencies of all other blends are very close to diesel. Under all the compression ratios the emissions like CO, HC were reduced for WCO biodiesel blends in comparison with diesel values.

M. M. Deshmukh et al (2014) developed ANN model for prediction and optimization of BTE, BSFC and Texh of engine. For training of back propagation of neural network, 60% of experimental data are used and remaining data are for testing. The prediction results for BTE, BSFC and Texh are 0.96198, 0.96237 and 0.94702 for correlation coefficients and mean square error are within 1.885% which is allowed.

The whole ANN modelling and analysis were done in the neuro solution environment. This work has resulted in the study of ANN modelling completely for predicting engine performance at various engine speeds. This reduces the experimental efforts and hence can serve as an effective tool for predicting the performance of the engine and emissions under various operating conditions with different biodiesel blends.

Dr. M. Rajendran et al (2012) had studied about the artificial neural network modelling of a diesel engine using nakthamala oil biodiesel. The properties of biodiesel produced from nakthamala oil was measured based on ASTM standards. The experimental results revealed that blends of nakthamala oil methyl ester with diesel fuel provide improved emission characteristics. Using some of the data for training, an ANN model was developed based on standard back propagation algorithm for the engine. The results showed that the training algorithm of back propagation was sufficient enough in predicting engine emissions for different fuel blends ratios. Analysis of the experimental data by the ANN revealed that there is a good correlation between the predicted data resulted from the ANN and measured ones. Therefore the ANN proved to be a desirable prediction method in the evaluation of the tested diesel engine parameters.

R. Manjunatha et al (2010) studied about the effectiveness of various biodiesel fuel properties on engine operating conditions on diesel engine combustion towards the formation of exhaust emissions. The performance characteristics such as brake power, brake thermal efficiency, brake specific fuel consumption, volumetric efficiency, exhaust gas temperature were measured along with regulated and unregulated exhaust emissions of CO, HC and NO_x. An artificial neural network was developed based on the available experimental data. The different activation functions and several rules were used to train and validate the normalized data pattern and an acceptable percentage error was achieved by Levenberg-Marquardt design optimization algorithm. The results showed that training through back propagation was sufficient enough in predicting the engine emissions. This shows that was able to predict CO, HC and NO_x emissions for the new bio-diesel and it blends with improved accuracy. Thus the work shows that for analyzing complex problems of emission analysis of bio-diesels and their blends, artificial neural network is suitable, adaptable and flexible computing tool that can be used for diagnostic purposes.

Yakup Sekmen et.al. (2006) had studied that the fuel injection pressure is one of the significant operating parameters affect atomization of fuel and mixture formation, therefore, it determines the performance and emissions of a diesel engine. Increasing the fuel injection pressure decrease the particle diameter and caused the diesel fuel spray to vaporize quickly. In this study the artificial neural networks are used to determine the effects of injection pressure on smoke emissions and engine performance in a diesel engine. Injection pressure and engine speed have been used as the input layer, smoke emission, engine torque and specific fuel consumption have been used as the output layer. The two different algorithms were studied. The best results were obtained by Levenberg Marquardt algorithm with 11 neutrons has produced the best results and for the torque the mean absolute percentage errors are limited to about 7-9% in both algorithms. With these results it is believed that the ANN can be used for prediction of torque and specific consumption as an appropriate method in diesel engine.

Bio-diesels refer to a family of CI engine fuels that are produced from natural sources such as oils of sunflower palm, poongami and jatropha. It is believed that bio-diesels which may be the oils themselves or their esters are the most likely successors to petroleum derived diesel. It is also more practical that these alternate fuels are introduced gradually as blends with diesel so that the production facilities are able to grow and markets are able to switch from petroleum derived diesel to bio-diesels. Studies have shown that often best results are achieved in blending a bio-diesel with diesel in suitable proportions and the results obtained are better than those of diesel or the pure bio-diesel. Hence it becomes extremely necessary to evaluate these blends of Biodiesels with diesel for their performance and emission characteristics. So far most of the research has been concentrated on the testing of the bio-diesel or some particular ratio of blend. Some studies reveal that the characteristics of these blends do not vary in a linear fashion and there may be certain combinations that might be more advantageous than others from the performance and emissions point of view. Artificial neural networks have been employed as they can produce accurate correlations for nonlinear data.

Artificial neural networks (ANNs) are recently developed techniques which are invariably used in obtaining accurate correlations which involves nonlinear data. An ANN can be considered to be consisting of interconnected group of relatively simple processing elements or nodes, called neurons, where the global behaviour is determined by the connections between the processing nodes and the network parameters. Neural networks, when trained properly are good at providing very fast, extremely close approximations of the correct output for nonlinear data. Their applications can be categorized into classification, pattern recognition and identification, assessment, monitoring and control, and forecasting and prediction. Modern neural networks can be trained to solve problems that seem impossible for conventional computers or human beings. The objective of this study is to establish correlations in the form of networks between the percentage of bio-diesel in the blend along with the bio-diesel's properties and the performance and emission characteristics of a CI engine and to obtain the optimal blend of bio-diesels with diesel which would result in reduced values of SFC, NO_x and HC. Due to the nonlinear nature of the problem and the number of variables associated mathematical modelling and/or statistical analysis becomes complicated. However the required objective might be achieved by implementing ANNs, which have already proved to play an important role in the modelling and prediction of the performance and control of combustion processes and in the prediction of exhaust emissions as a function of fuel properties.

2.0 Performance analysis

2.1 Brake Thermal Efficiency

The BTE variations with load for various blends of methyl esters are shown in Fig.1.

From the Fig.1, it is observed that the BTE is slightly lower than the diesel for palm oil methyl ester and its blends. The BTE is less for palm methyl ester because of less calorific value.

The brake thermal efficiency is based on BP of the engine.

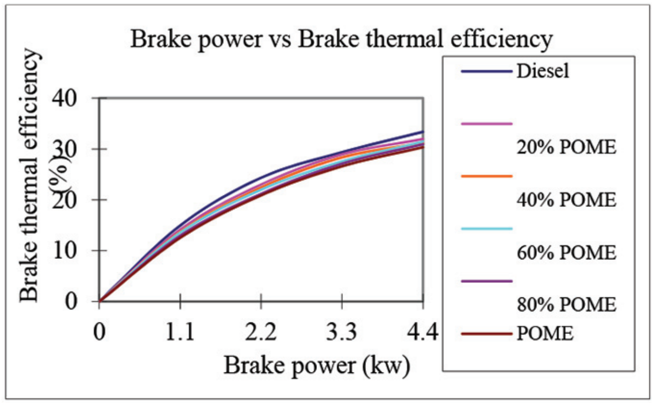

Fig.1: Variation of brake thermal efficiency with brake power

This efficiency gives an idea of the output generated by the engine with respect to heat supplied in the form of fuel. For CI engine brake thermal efficiency gradually increases with increase in BP.

From the Fig.1, it is observed that brake thermal efficiency is low at low values of BP and is increasing with increase of BP for all blends of fuel. For a blend of 20% the brake thermal efficiency is high at low BP values when compared to other blends of fuel and is very close to diesel at high values of BP. Hence at the blend of 20% of methyl ester the performance of the engine is good.

2.2 Specific Fuel Consumption

The comparison of variation of specific fuel consumption with brake power for diesel, with different blends of palm oil methyl esters are shown in Fig.2.

From the Fig.2, it is observed that the methyl esters shows higher SFC compared to diesel as calorific value is less. It was observed that 20% blend is having comparable closer values with diesel. However SFC is higher for all the other blends. The SFC decreases with the increasing loads. It is inversly proportional to the thermal efficiency of the engine.

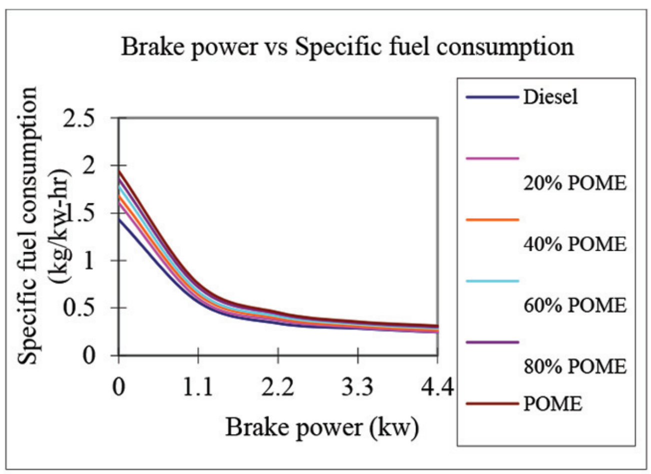

Fig.2: Variation of specific fuel consumption with brake power

3.0 Emission analysis

The bio-diesel showed better emission characteristics compared to conventional diesel, whereas oxides of nitrogen are slightly higher than diesel. The bio-diesel runs in normal diesel engine without modifications and its performance is same as diesel engine except odour. The viscosity of less for Transesterified vegetable oils, results in better automization of fuel in the combustion chamber and improved injection process. For the reduced emissions the bio-diesel can be blended in various proportions and an increase in lubrication properties allow better running of vehicle.

The emission properties like carbon monoxide, nitrogen oxides, hydrocarbons and smoke density for different load conditions for various blends of palm oil methyl esters are analyzed and graphs are shown.

3.1 CO Emission

The comparison of variation of carbon monoxide (CO) emissions with brake power for diesel, with different blends of palm oil methyl esters are shown in Fig.3.

From Fig.3, it is observed that with increase in load CO decreases for various blends of palm oil methyl esters. The CO reduces with increase in percentage of blends of palm oil methyl esters. With the increase in % of bio-diesel in fuel, the concentrations of CO decrease. This results in the presence of O_2 in bio-diesel provide necessary oxygen for complete combustion from carbon monoxide to carbon dioxide. It can be observed that a slight reduction in CO emissions with bio-diesel of 20% blend with diesel when compared to that of diesel.

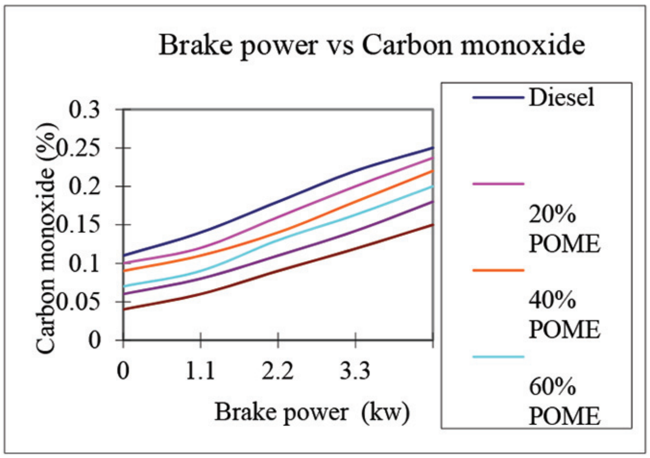

Fig.3: Variation of CO emission with brake power

3.2 CO_2 Emission

The comparison of CO_2 emissions for diesel, neat methyl ester and blends are shown in Fig.4.

From Fig.4, it is observed that CO_2 increases with increasing load for all the blends of palm oil methyl esters. If percentage of blends of palm oil methyl esters increases, CO_2 increases. The CO_2 emissions are directly proportional to the percentage of methyl ester in the fuel blend. Since methyl ester is an oxygenated fuel, it improves the combustion efficiency and hence increases the concentration of CO_2 in the exhaust.

3.3 HC Emission (in PPM)

The comparison of hydrocarbons (HC) emissions for diesel, neat methyl ester and blends of them are presented in Fig.5.

From Fig.5 it is observed that for all the blends of palm oil methyl esters, hydrocarbon increases with increasing load. The hydrocarbons reduce with increase in percentage of blends of palm oil methyl esters. The HC emissions are inversely proportional to the % of methyl ester in fuel blend. A significant inference on methyl ester and diesel based on HC emissions is that diesel operation showed the highest concentrations of hydrocarbons in the exhaust at all loads. Since methyl ester being oxygenated fuel, it reduces the HC concentration and improves the combustion efficiency. At rated load condition, 20% methyl ester blended with diesel significantly reduces hydrocarbon exhaust emissions.

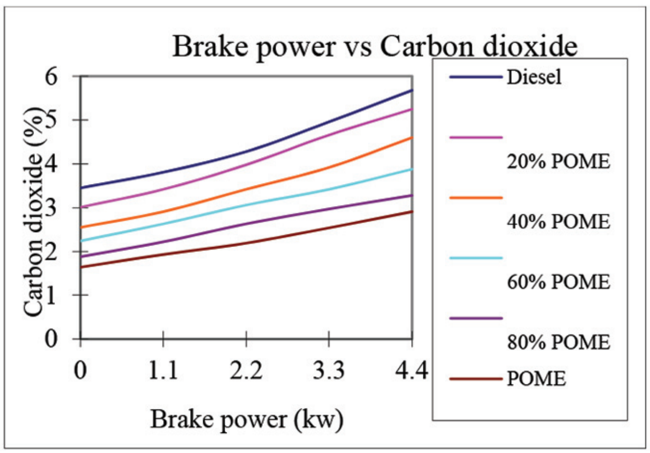

Fig.4: Variation of CO emission with brake power

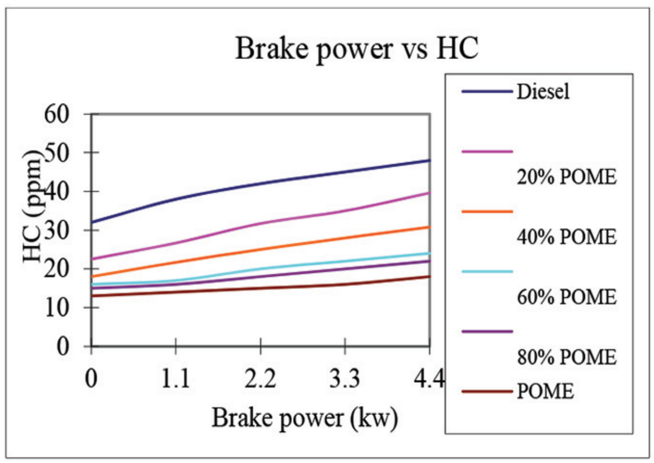

Fig.5: Variation of hydrocarbon carbon with brake power

3.4 NO_x Emission

The comparison of NO_x emissions for diesel, neat methyl ester and blends are shown in Fig.6.

From Fig.6, it is observed that NO_x increases with increasing load for all the blends of palm oil methyl esters. If percentage of blends of palm oil methyl esters increases, NO_x increases. It can be seen that NO_x emissions increase with increase in percentage of methyl ester in the diesel-methyl ester fuel blend. The NO_x increase for methyl ester may be associated with the oxygen content of the methyl ester, since the fuel oxygen may augment in supplying additional oxygen for NO_x formation. Moreover, the higher value of peak cylinder temperature for methyl ester when compared to diesel may be another reason that might explain the increase in NO_x formation.

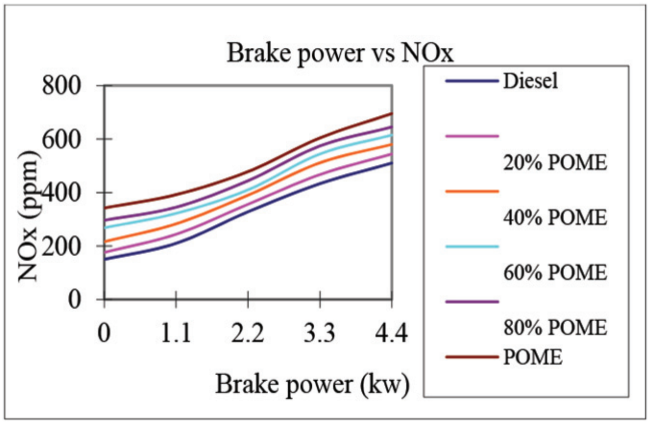

Fig.6: Variation of hydrocarbon carbon with brake power

4.0 Artificial neural network (ANN)

4.1 Modelling with the ANN

The ANN technique is a evolutionary soft computing model based on biological neurons. This technique is a powerful tool to handle real time industry related phenomenon that are nonlinear in nature. Also it is useful in situations that deal with parameters requiring time and sophisticated equipment. For the experimentation on diesel engine 10 blends with diesel and bio-diesel blended fuels were developed. The training of ANN model is done with randomly chosen 80% of the data was used and the remaining 20% of data was used for prediction and verification of the model.

4.2 Mean Square Error

Fig.7 shows the performance of the network during the training of model. The permissible error during network training was 10E-20, which is satisfactory response. The network satisfying this response was chosen from all the networks trained as final model. It is observed from the results that this trained model can predict the engine brake thermal efficiency and specific fuel consumption efficiently. Also it is observed that the developed ANN is proved as the

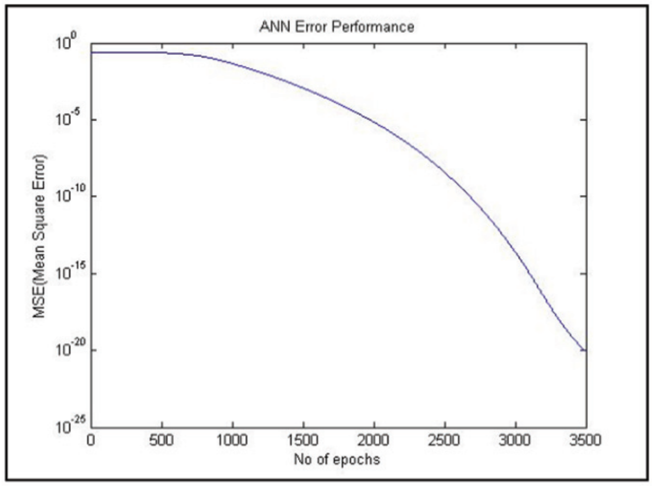

Fig.7 Mean square error

best model with good prediction accuracy in modelling the emission indices. The ANNs have the advantage of being accurate, fast, simple to use and reliable in predicting results over mathematical and numerical methods and is capable of dealing complicated and multivariate problems. The mean square error is 0.0009 using simulated values by the model.

5.0 Performance analysis by ANN

5.1 Brake thermal efficiency (Fig.8)

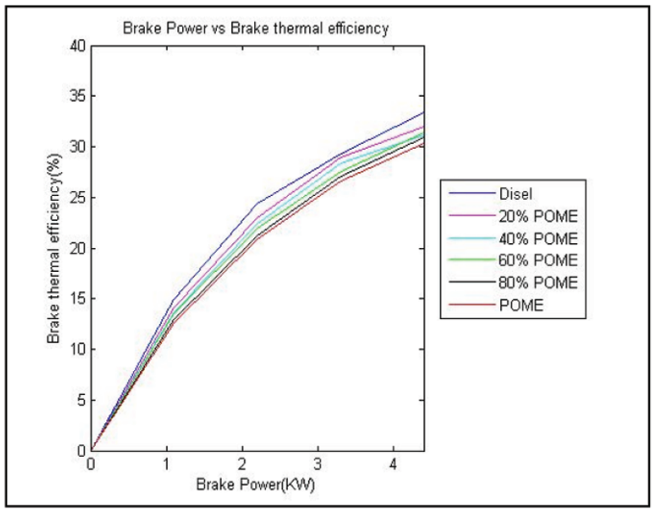

Fig.8: Variation of brake thermal efficiency with brake power by ANN

5.2 Specific fuel consumption (Fig.9)

6.0 Emission analysis by ANN

6.1 Carbon monoxide (Fig.10)

6.2 Carbon dioxide (Fig.11)

6.3 Hydro carbon (Fig.12)

6.4 NO_x Emission (Fig.13)

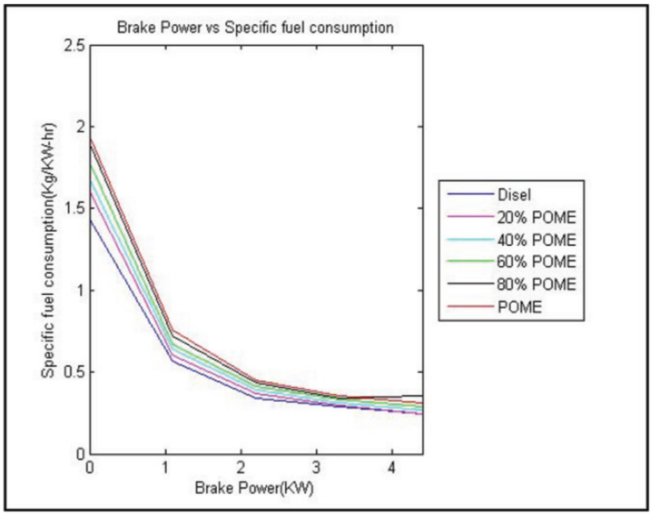

Fig.9: Variation of specific fuel consumption with brake power by ANN

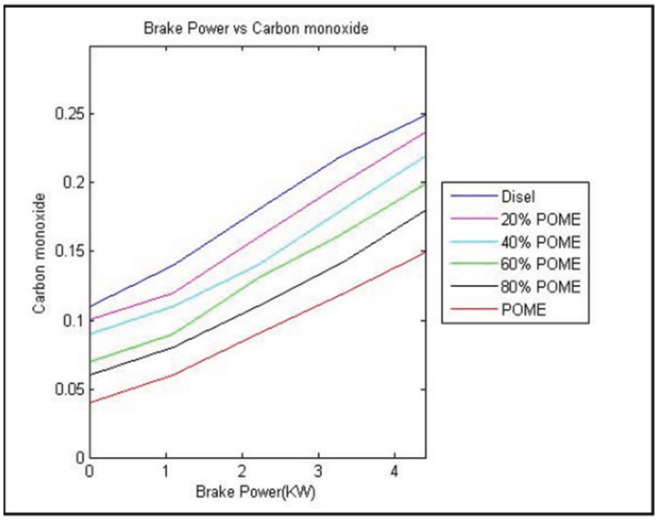

Fig.10: Variation of specific fuel consumption with brake power by ANN

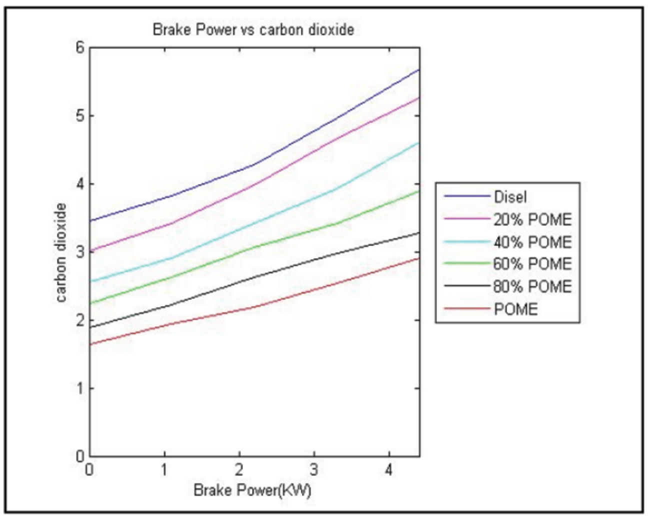

Fig.11 Variation of carbon dioxide with brake power by ANN

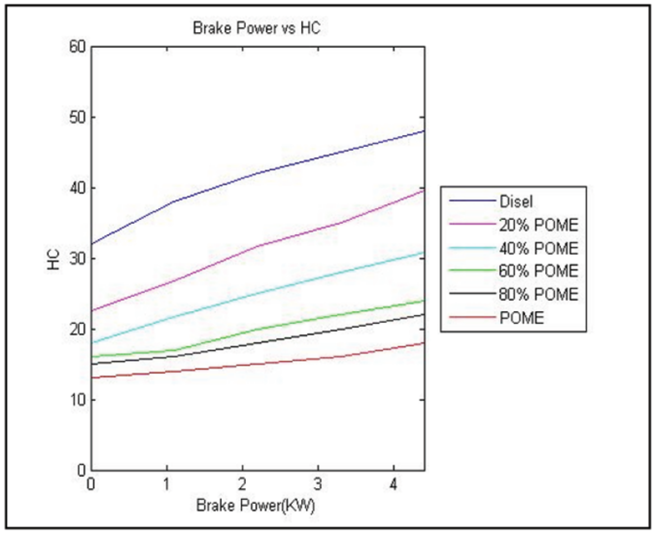

Fig.12: Variation of hydrocarbon with brake power by ANN

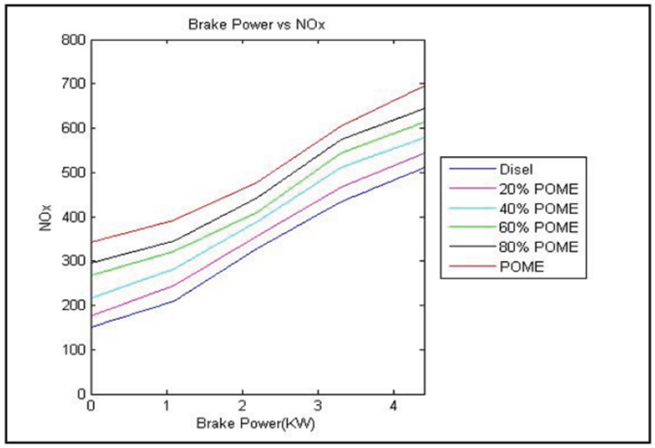

Fig.13: Variation of NO_x emission with brake power by ANN

7.0 Conclusions

The experiments are conducted on diesel engine with diesel fuel and blends of waste cooking oil methyl ester under same operating conditions. The results were found to be comparable. The brake thermal efficiency of 20% bio-diesel was 31.96 compared to 33.36% that of diesel. The bio-diesel results in reduced concentrations of HC and CO emissions.

The ANN trained with the data collected in this work is used for prediction model. The mean squared error between the predicted and actual values is found to be 0.0009. Hence the ANN model is proved to be reliable in predicting the engine performance parameters. The emission characteristics can be predicted efficiently using the developed model without experimentation facility. The ANN is found suitable in situations where the problem is complex and involves multivariate data such as performance evaluation of engine parameters and emission characteristics with accuracy in prediction and simplicity in implementation efficiently.

8.0 References

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