Abstract—Biodiesel is getting increasing attention each passing day because of its compatibility with diesel fuel and mainly its capacity to reduce the emission to certain extent. According to the research, Biodiesel blending besides improves the performance of diesel engines, it also over looks to control exhaust emissions as per government regulations. Therefore, this study is focused the prediction of the exhaust emissions, carried out for neural networks to define how the inputs affect the outputs using the biodiesel blends. Generally, 80% of the obtained experimental data is employed for training process. In addition, 10% of the data (randomly selected) is used for network validation and the remaining data is employed for testing the accuracy of the network. The mean square error function is employed for evaluating the performance of the network. The results show that the artificial neural network can efficiently be used to predict emissions from the tested engine with about 10% error. This study shows that, as an alternative to classical modeling techniques, the Artificial Neural Network (ANN) approach can be utilized to accurately predict the emissions of internal combustion engines.

Keywords— Artificial Neural Network, Carbon Monoxide, Nitrogen Oxide, Biodiesel, Diesel Engine

I. INTRODUCTION

Diesel-exhaust emissions influence air pollution significantly. Especially, NOx, smoke level and SO2 emissions have damaging effects upon the environment and people. Therefore, in the case of the internal-combustion engine, decreasing the level of exhaust gas emissions is always regarded as an important target to be achieved. As the petroleum bi-products are extinguishing year by year, has resulted on growing interest in alternative fuels like Bio-fuels, alcohols, biogas and solar energy. Among these Biodiesel has become highly pronounced in the present context. Bio fuel blending with diesel is an interesting factor, since diesel engines are applied in almost all areas. NOx is a main component in the formation of photochemical smog, while PM emissions causes increased cardiovascular mortality rates, impaired lung development in children, and a host of other health impacts. The result of this, emission control regulatory bodies have legislated substantial reductions in PM and NOx emissions from diesel engines, which made great difficulties for the diesel engine manufacturers to offer a quite efficient engine to satisfy the consumers. Particulate matter (PM), NOx production and engine noise are purely depends on the combustion process. CO and CO2 gasses results in greenhouse effect, depletion of ozone layer and acid rain [10].

A. Artificial Neural Network

Artificial neural networks (ANNs) are a family of models inspired by biological neural networks (the central nervous systems of animals, in particular the brain) and are used to estimate or approximate functions that can depend on a large number of inputs and are generally unknown. Artificial neural networks are mostly presented as systems of interconnected "neurons" which exchange messages between each other. The connections have numeric weights that can be tuned based on experience, making neural nets adaptive to inputs and capable of discovering and capable of learning.

Neural-networks have been developed to perform complex functions in various fields of application, including pattern recognition, identification, classification, speech, vision, and control systems. At present, neural-networks can be educated to solve problems that are difficult for conventional computers or human beings to solve. There are different learning algorithms used in training the ANNs. A popular algorithm is the back-propagation algorithm, which has different variants. Algorithms such as conjugate gradient, quasi-Newton, and Levenberg–Marquardt (LM) use standard numerical optimization techniques. Errors during the learning process can be estimated using statistical error evaluation techniques: root-mean-squared (RMS), R², and mean % error values are widely used techniques and are employed in our application. In applications, the input and output layer values are normalized within the range of (-1, 1) or (0, 1). A neural network system has three layers, namely the input layer, the hidden layer and the output layer as shown in figure 1. The input layer consists of all the input factors, information from the
input layer is then treated in the course of one hidden layer, and following output vector is computed in the output layer.

Figure 1

B. Procedure for adopting Ann

The estimation problem using neural network models has three consecutive steps: model building or neural network architecture; the learning or training procedure; and the testing procedure. An important stage when accommodating a neural network is the training step, in which an input is introduced to the network together with the desired outputs, the weights and bias values are initially chosen randomly and the weights are adjusted so that the network attempts to produce the desired output. The weights after training contain meaningful information, whereas before training, they are random and have no significance. When a satisfactory point of performance is reached, the training stops, and the network use these weights to make decisions. ANN has been applied successfully in various fields of mathematics, engineering, medicine, economics, meteorology, psychology and neurology.

Figure 2

Many alternative training processes, such as back-propagation, Levenberg–Marquardt are available. The goal of any training algorithm is to downplay the global error level, such as the mean error, root-mean-squared (RMS), and absolute fraction of variance (R²). An important characteristic of this function is differentiable throughout its domain. The errors for the hidden layers are found out by propagating back the error determined for the output layer.

II. LITERATURE REVIEW

Hari Prasad et al [1], have conducted experiment using 4 stroke, single cylinder, Kirloskar make, water cooled diesel engine for their study on, “Performance and Exhaust Emissions Analysis of a Diesel Engine Using Methyl Esters of Fish Oil with Artificial Neural Network Aid”. In their study, the applicability of an ANN for determining the performance and exhaust emissions of a diesel engine fueled with biodiesel blends was investigated. Then, after showing the applicability of ANNs, the performance and exhaust emissions from a diesel engine using biodiesel blends with diesel fuel up to 100% – namely 0% 20%, 40%, 60%, 80%, and 100% – have been predicted. All the experiments are at constant engine speed of 1500-rpm. In their work, feed forward neural network is employed with two hidden layers are used. Biodiesel blended with diesel and conducted at different loads. Using some of the experimental data for training, an ANN model based on a feed forward neural network for the engine was broken. Emission characteristics were called from the developmental network. They observed that the ANN model can predict the engine exhaust emissions quite well with correlation coefficients, with very low root mean square errors. This study shows that, as an alternative to classical modeling techniques, the ANN approach can be used to accurately predict the performance and emissions of internal combustion engines.

Erol Arcaklioglu et al [2] In their experimentation on “A diesel engine’s performance and exhaust emissions”, they used artificial neural-networks (ANNs) to find the performance and exhaust emissions from a diesel engine with respect to injection pressure, engine speed and throttle position. Experiments have been performed for four pressures, namely 100, 150, 200 and 250 bars with throttle positions of 50, 75 and 100%. Exhaust emissions such as SO₂, CO₂, NOx and smoke level (%N) have been investigated. The back propagation learning algorithm with three different variants, single and two hidden layers, and a logistic sigmoid transfer-function have been used in the network. In order to train the network, the results of these measurements have been used. Injection pressure, engine speed, and throttle position have been used as the input layer; performance values and exhaust emission characteristics have also been employed as the output layer. Their aim was to show the possibility of using the neural networks for predictions of engine performance and exhaust emissions of a diesel engine. Results show that, in
most of the cases, the network produces results parallel to the experimental ones; therefore they can be used as an alternative way in these systems.

D. Karonis et al [3], have conducted experiment on “A Neural Network Approach for the Correlation of Exhaust Emissions from a Diesel Engine with Diesel Fuel Properties”. The measurements were performed on a Petter AV1-LAB single-cylinder diesel engine, of nominal power 3.7 kW at 1500 rpm. The base fuels used for their study were four gas oils with different properties. Radial Basis Function (RBF) network was chosen due to the remarkable advantages as far the simplicity of the structure and the speed of the training algorithms were concerned. The predictions were based on specific levels of the distillation curve, the cetane number, density, and kinematic viscosity of the fuels. In the case of particulate matter emissions, sulfur content was also used. The predictions obtained were found very beneficial for all the emissions considered.

Gholamhassan NAJAFI [4], have conducted an experiment on “Combustion Analysis of a CI Engine Performance Using Waste Cooking Biodiesel Fuel with an Artificial Neural Network Aid”. A comprehensive combustion and emission analysis has been conducted to evaluate the performance of a commercial DI engine, water cooled two cylinders, in-line, naturally aspirated, RD270 Ruggerini diesel engine using waste vegetable cooking oil as an alternative fuel. A Horiba gas analyser model MEXA-324GB was used for measuring CO and HC emissions. A popular algorithm is the backpropagation algorithm, which have different variants. The two input variables are engine speed in rpm and the percentage of biodiesel blending with the conventional diesel fuel. The four outputs for evaluating engine performance are engine torque in Nm, Brake Specific Fuel Consumption (bsfc) in lit/KW hr, and emissions including HC and CO in ppm. An artificial neural network (ANN) was developed based on the collected data of this work. The input layer consisted of 2 neurons which corresponded to engine speed and levels of biofuel blends and the output layer had 4 neurons.

J. Mohammadhassani et al [5], have conducted an experiment on “Prediction of NOx Emissions from a Direct Injection Diesel Engine Using Artificial Neural Network”. The test engine used to conduct the experiments is a heavy duty (HD) six-cylinder, direct-injection, four-stroke diesel engine. Engine properties such as exhaust emissions (NOx, soot, HC, CO, CO2), air-fuel ratio (AFR), and intake air temperature are measured by various connected instruments. To get the best prediction by the network, many parameters should be adjusted such as biases, weights, number of hidden layers, number of hidden layer neurons, and type of transfer function. The biases and weights must be modified in every epoch by using training algorithms such as LM algorithm. Artificial neural network is used to model the relationship between NOx emissions and operating parameters of a direct injection diesel engine. 80% of a total of 144 obtained experimental data is employed for training process. In addition, 10% of the data (randomly selected) is used for network validation and the remaining data is employed for testing the accuracy of the network. They concluded that, the artificial neural network can efficiently be used to predict NOx emissions from the tested engine with about 10% error.

Mustafa Canakci et al [6], have conducted the experiment on “Prediction of performance and exhaust emissions of a diesel engine fueled with biodiesel produced from waste frying palm oil”. The tests were performed at different engine speeds for full load conditions. The engine speeds of 1000, 2000 and 3000 rpm were selected, and controlled within 25 rpm through the test duration. The inputs are fuel properties, engine speed, both flow rates, injection pressure, while all the emissions (CO, CO2, UHC, NOx, and smoke level SL), engine load BT, maximum cylinder gas pressure CP, thermal efficiency TE are the outputs. In this study, for all the networks, the learning algorithm called back-propagation was applied for the single hidden layer. ANN was trained and tested by means of the MATLAB software on a usual PC. In order to identify the output precisely for training stage, increased number of neurons (5–8) in the hidden layer was tried. Errors that happened at the learning and testing stages are described the RMS and R2, mean error percentage values were reduced.

Shiva Kumar et al [7], have conducted an experiment on Radial-Basis-Function-Network-based prediction of performance and emission characteristics in a bio diesel engine run on waste cooking oil ester. The performance and emission tests were conducted on a computerized 5.2KW single cylinder, four stroke, naturally aspirated, direct injection, variable compression ratio, and water cooled diesel engine test rig. An AVL Digas 444 exhaust gas analyzer was used to measure the CO, HC, and NOx emissions in the engine exhaust. An AVL 437C smoke meter was used to measure the smoke intensity in the engine exhaust. For training the networks, load percentage, compression ratio, blend percentage, injection timing, and injection pressure were taken as the input parameters and brake thermal efficiency, brake specific energy consumption, exhaust gas temperature and engine emissions NOx, smoke, and CO and UBHC were used as the output parameters. Mean square error (MSE) has been used for evaluating the network performance. Error limit of 5% was considered for performance parameters and 10% for emission parameters.

R. Senthil Kumar et al [8], in their study on “Performance and Emission Analysis Using Pongamia Oil Biodiesel Fuel with an Artificial Neural Network”, used a Single cylinder, four-stroke
diesel engine fuelled with pongamia pinnata biodiesel and diesel fuel blends and operated at different engine speeds and load, artificial neural network (ANN) modeling was adopted to predict the brake power, torque, specific fuel consumption and exhaust emissions of the engine. The data obtained were implemented for training and testing the proposed artificial neural network. The results proved that, the training algorithm of Back-Propagation was sufficient enough in predicting engine torque, specific fuel consumption and exhaust gas components for different engine speeds and different fuel blends ratios.

Vinay Kumar. D et al [9], in their study on “Prediction of Performance and Emissions of a Biodiesel Fueled Lanthanum Zirconate Coated Direct Injection Diesel engine using Artificial Neural Networks”, conducted experiments a single cylinder diesel engine whose combustion elements are coated with an experimental thermal barrier coating material made from Lanthanum Zirconate. Biodiesel was prepared from Pongamia Pinnata oil through transesterification process. A series of experiments are conducted on the engine with and without thermal barrier coating using diesel and biodiesel fuels. Performance and emissions data from the experiments were used to train the network with the load, fuel type and coating being the input layer and the brake specific fuel consumption, brake thermal efficiency, CO, HC and NOx emissions being the output layer.

III. RESULTS AND DISCUSSION

Incomplete combustion results in the liberation of toxic gasses to the atmosphere. Combustion process has to be optimized in order to reduce toxic emission. Literatures results have taken below for discussion.

T. Hari Prasad et al [1], from their experimental results they concluded that, there is a significant reduction in the CO, CO2 and HC emission levels due to better combustion characteristics exhibited by the test fuels. NOx level a considerable amount of increase due to excess oxygen present in the biodiesel. Results show that, in most of the cases, the network produces results parallel to the experimental ones as shown in figure 3, therefore they can be used as an alternative way in these systems. The RMS error values are smaller than 0.02 and R2 values are about 0.999, which may easily be considered within the acceptable range.

Erol Arcaklıoğlu et al [2], in their study, initially, used five hidden neurons in a single hidden-layer for all the algorithms. Then, they increased the number of neurons. Similarly varying pairs of two hidden-layers have been applied on the network. Their results revealed that, the optimum number of hidden neurons was different for different algorithms. They concluded that NOx emission decreases as the injection pressure increases and the ANN trend will follow experimental results as shown in figure 4, with R2 error 0.999 and R error 0.002.

D. Karonis et al [3], in their study, mathematical expressions that predict exhaust emissions from a single-cylinder diesel using the neural network approach was adopted. The results were obtained by considering a total of 59 fuels from which 29 were used for training the models and the remaining 30 were used for validating the models. The predictions obtained were very good for all types of emissions (carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter). Figure 5 shows the graph of measured and predicted values of NOx which had minimum error.
According to the results, the fuel parameters affecting most significantly the emissions from diesel engines were cetane number, density, and the backend volatility. Fuels with low density have the lower NO\textsubscript{x} emissions. CO emission decreases as cetane number increases. They concluded that, the accuracy of the neural network models can be illustrated by calculating the correlation coefficient $R^2$ on the validation data. These results are presented in Table 1 and compared with $R^2$ values obtained using simple linear regression.

Table I $R^2$ values for ANN V/s linear model

<table>
<thead>
<tr>
<th>emissions</th>
<th>$R^2$ (neural networks)</th>
<th>$R^2$ (linear models)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.898</td>
<td>0.925</td>
</tr>
<tr>
<td>HC</td>
<td>0.870</td>
<td>0.839</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>0.837</td>
<td>0.833</td>
</tr>
<tr>
<td>particulate matter</td>
<td>0.99</td>
<td>0.987</td>
</tr>
</tbody>
</table>

From the Table 1 shows significant improvement, that justifies the utilization of the more sophisticated nonlinear neural network modeling technique for prediction.

Gholamhassan Najafi [4], from his study, have realised that, biodiesel contains oxygen in its structure. When biodiesel is added to diesel fuel, the oxygen content of fuel blend is increased and thus smaller oxygen is needed for combustion. However oxygen content of fuel is main reason for better combustion and CO and HC emission reduction. The ANN provided the best accuracy in modelling the emission indices (HC and CO). He concluded that, emission of unburnt HC decreases as blend percentage increases as shown in figure 6. Multi-layer perceptron network (MLP) was used for nonlinear mapping between the input and the output parameters. Different activation functions and several rules were used to assess the percentage error between the desired and the predicted values. The results showed that the training algorithm of Back Propagation was sufficient enough in predicting the engine torque, specific fuel consumption and exhaust gas components for different engine speeds and different fuel blends ratios. It was found that the $R^2$ ($R$: the coefficient of determination) values are 0.99994, 1, 1 and 0.99998 for the engine torque, specific fuel consumption, CO and HC emissions, respectively.

Finally, they concluded that, the artificial neural network offers the advantage of being fast, accurate and reliable in the prediction or approximation affairs, especially when numerical and mathematical methods fail. There is also a significant simplicity in using ANN due to its power to deal with multivariate and complicated problems.

J.Mohammadhasanii et al [5], in their study, they used artificial neural network to predict the NO\textsubscript{x} emissions from a direct injection diesel engine using LM training algorithm. The results show that the ANN with LM training algorithm is an appropriate technique, which can accurately predict NO\textsubscript{x} emissions for different engine operating parameters including engine speed, intake air temperature, and mass fuel rate. A comparison between the predicted and the measured values of NO\textsubscript{x} emissions are depicted in figure 7.

The proposed ANN model for prediction of the NO\textsubscript{x} emissions gives the correlation factors of 0.92, 0.98, and 0.89 for training, validating, and testing the network, respectively. They concluded that, ANN model is potentially feasible tool for prediction of NO\textsubscript{x} emissions from a diesel engine with respect to the engine operating parameters, especially in medium engine speeds.
indicates the lost chemical energy that is not fully utilized in the engine. In general, they concluded that, NOx emission is affected by equivalence ratio, fuel type, atomization ratio, injection timing, engine load and speed. Figure 8 shows the changes in the NOx emissions for different fuel blends.

![Figure 8](image-url)

Shiva Kumar et al [7], have made an attempt to build RBF neural network. Fixing the widths of RBF units rather than using variable widths calculated using $P$-nearest neighbor heuristic gave better results. RBF network results matched closely with the experimental results for the test data with the prediction accuracy of more than 90% for performance parameters and around 70% for emission parameters as shown in Figure 9. Hence, they concluded that, RBFNN can be effectively used for modeling a biodiesel engine.

![Figure 9](image-url)

ANN prediction on the performance and emission parameters of a CI engine helps in reducing the experimental efforts and cost, and improves the accuracy of prediction

R. Senthil Kumar et al [8], from their experimental results revealed that, better engine performance and enhanced emission characteristics were obtained from blends of Pongamia pinnata methyl ester with diesel fuel. For training ANN model they used some of the experimental data and also developed standard Back-Propagation algorithm for the engine. Multi-layer perception network (MLP) was used for non-linear mapping between the input and output parameters. Different activation functions and several rules were used to assess the percentage error between the desired and predicted values. They have observed that the ANN model can predict the engine performance and exhaust emissions quite well with correlation coefficient (R) 0.9487, 0.999, 0.929 and 0.999 for the engine torque, SFC, CO and HC emissions, respectively. The prediction MSE (Mean Square Error) error was between the desired outputs as measured values and the simulated values were obtained as 0.0004 by the model.

Vinay Kumar. D et al [9], from the experimental observations they found that, the Lanthanum zirconate coated engine has shown an improvement in BSFC in the order of 4.16% lower with LZ diesel operation compared to the standard diesel operation. 2.9% lower BSFC was concluded. Hence the coating of engine components with lanthanum zirconate TBC resulted in improved engine efficiency with reduced emissions.

ANN model was tested for its accuracy to predict the performance and emissions of the engine with the R values of 0.99 for both the training and test data with a mean square error of 0.002. The results were in agreement less than 6.8% average relative error with those obtained experimentally.

### IV. CONCLUSIONS

Based on the literature review, the following conclusions can be drawn:

- ANN model is thus being used as a flexible computing tool for diagnostic purposes. It will avoid time consuming and costly experiments.
- By increasing the number of training samples, the accuracy, in terms of regression coefficient can be increased.
- ANNs are feasible for the prediction of engine parameters because of its ability to learn and generalize a wide range of experimental conditions.
- ANN proved to be a desirable prediction method in the evaluation of the tested diesel engine parameters.
- There is also a priority in using artificial neural networks, since other mathematical and numerical algorithms might fail due to the complexity and multivariate nature of the problem.
- Finally, ANN providing accuracy and simplicity in the analysis of the diesel engine performance and emission test.

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