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Performance and Emission prediction Artificial Neural Network model of Diesel engine using blends of biodiesel diesel and ethanol blend.

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***Abstract* - This study deals with experimental analysis non-edible oil karanja biodiesel, diesel and ethanol blend fuel on the Compression Ignition engine. The experiments were conducted with various combinations of input operating parameters of Injection angle, compression ratio, Blend % and load to obtained performance and emission responses of CI engine. It aims to develop and ANN model based on multilayer perceptron to predict the performance and emission of engine using experimental data. The ANN model was developed to predict the output at four different input parameters. The feed forward back propagation training algorithm, trainlm (Levenberg-Marqardt) has been used in Matlab R2013b , which has good prediction accuracy. The predicted parameters of performance were BTE,BSFC,EGT and of emission were CO2, CO, HC, NOx. The regression correlation coefficient (R) obtained are 0.9982, 0.9918, 0.9984, 0.9711,0.9904, 0.9539,0.9423 for BTE,BSFC,EGT,CO2,NOx,CO, HC respectively. The percentage deviation of predicted values from experimental values is in the range below 10%. ANN has huge ability to develop a prediction model where it very complex to develop mathematical model.**

Keywords: Karanja biodiesel, Diesel, Ethanol, ANN model, Artificial Neural Network, Matlab.

I. INTRODUCTION

The increasing demand of petroleum fuel due to large scale development of industries in the world. The dependence on fossils fuel is too much in the world, which is a big threat due to its limited availability. As the population is growing at faster rate the rate of consumption of fuel is also increasing, which again leads the threat of pollution and green house effect. Hence researchers are focusing on renewable source of energy to eradicate or reduce the fear of green house effect and air pollution. Alternative fuels such as natural gas, biofuels, blends of biofuel with diesel , hydrogen, fuel cell, compressed air, solar energy etc. are getting importance to reduce environmental impact. The non edible oils like Karanja, Jatropha, Neem , cottonseed oil etc. are examined and showed good results. The use of ethanol upto 10% is already popular to use in SI engines and now it is permitted for CI engine too. This paper focus on the use of non edible oil seed Karanja biodiesel and ethanol blends with diesel to study the performance and exhaust emissions of DI, four stroke, water cooled, having variable injection timing and compression ratio arrangement diesel engine. The ANN is a similar kind of biological neural system to model various problems related to science and it application (medical and engineering). The ANN is well tested approach for conventional and non conventional modeling. It is a power full tool to simplify the complicated problems, which are highly difficult to solve by mathematical modeling. The ANN model has ability to predict the value, hence its usage to find engine performance and emissions by performing limited number of experimental tests instead. Which can save time and money. But still there is scope for researchers to find simple methodology to obtained multi objective optimization models for engine [1]. An Artificial neural networks system normally consists of three layers a) input layer b) the hidden layer c) output layer. The ANN model usually built with three steps neural network architecture, the training and activation function and testing [2]. The ANN model using back propagation algorithm was proposed to develop well trained model, having MLP network. The mapping between input and out is done to predict the engine performance and emission correlation coefficient [3]. The neural network architecture are framed initially for training network with input data and target output data by choosing randomly weight and bias values. Sometimes it is observed that overtraining of network is

actually not effects the correlation coefficient, it degrades the test set. Usually the training data and cross validation is different, the training stops when cross validation deteriorates [4].The ANN model can accommodate various inputs and can predict multiple outputs for which the model is trained. The specific application of ANN model is the prediction property based on experimental results. It also has the ability to validate and test the results. The ANN model is much faster means takes less iteration to predict the results from any conventional simulation model [5].The study of Genetic Algorithm , multi-objective optimization, pareto optimal solution required attention where the regression models for individual performance and emission parameters may be developed using Minitab 2017. These model equations were used as fitness function for optimization. The ANN model was so developed to predict the output at different input parameters using four transfer functions and created different ANN models. It is observed that the feed forward back propagation training algorithm, trainlm (Levenberg-Marqardt) has lowest MAPE (mean absolute percentage error) and good prediction accuracy [6].The various network models were tested by varying hidden layers and neurons using trial and error method to predicts significance of injection timing and injection pressure on performance, emission and combustion of diesel engine. but the better correlation coefficient for two hidden layers and 11 neurons are obtained . This Artificial neural network model was validated with the experimental data and it was well correlated [7]. It is further investigated the performance and emissions of a single cylinder, DI CI air cooled engine using and diesel-DEE blends were estimated by ANN model. ANN model predicts exhaust emissions and engine performance with a regression coefficient (R2) at 0.964–0.9878 interval. At the same time, mean relative error (MRE) values ranged from 0.51% to 4.8%, which were under the acceptable range [8].The ANN modeling based on experimental investigation for performance and emission parameters. The standard back propagation algorithm was used in training model and multi level perceptron network was used for mapping between input and parameters. It is found that ANN can predict the engine performance and emission with a correlation coefficient upto 0.999 [9]. An AAN model is developed to predict NOx emissions at input operating parameters. The results obtained by ANN model can predict NOx emissions with an error within 10% [10].It successfully predicted the engine performance and emissions of a SI engine fueled with blend n-butanol-gasoline at various equivalence ratio by ANN model. The input to ANN model are equivalence ratio, blend percentage ,compression ratio and engine load while brake thermal efficiency, brake-specific fuel consumption, carbon monoxide, unburned hydrocarbons, and nitrogen oxides were the performance and emission output parameters respectively. The accurate R2 value ranging from 0.9929 to 0.9996 and a MRE ranging from 0.1943% to 9.9528% were obtained [11]. An ANN modeling for marine diesel engine were developed to predicted the output parameters viz brake power, brake specific fuel consumption, output torque, volumetric efficiency and brake thermal efficiency . The prediction model was based on back propagation Levenberg Marquardt method and the results obtained shows the experimental data has high accuracy with predicted data [12].The CI engine performance and emission parameters using biodiesel (waste cooking oil percent max 20%) were evaluated predicted by ANN model, where the inputs parameters load (0, 25, 50, 75 and 100%) and speed (1700, 2100, 2500 and 2900 rpm). There is good agreement between predicted and experimental results were observed [13]. The ANN back propagation model to predict emissions and performance for spark ignition engine was presented . It is also investigated that ANN model is most effective than any other mathematical model [14] .The use of ANN method to explore the effect of engine speed , injection advance, and load on brake specific fuel consumption of engine. They stated that the created model was a robust way to predict of brake specific fuel used [15]. In addition, some other researchers have also used the BP ANN algorithm to evaluate engine parameters. They observed that ANN models can be used in internal combustion studies and its development. [16,17]. ANN model was used for the prediction of the engine performance and exhaust emissions characteristics and the mean relative error was studied, it is observed that mean relative error was slightly more and the accuracy slightly reduced for predicted values for the combined model [18]. So it is observed that individual model is better and easy than combined model, The ANN model establish the relationship among the input and the output parameters and develop non linear regression. It depends on architecture of network ie. Neurons, hidden layer and activation function [19, 20,21].

This paper deals with ANN model of an diesel engine using blends of biodiesel, diesel and ethanol to predict the performance BTE,BSFC,EGT and emissions CO,CO2,Nox , HC of the engine. The Matlab R13b ANN tool is used for the study in which four inputs and single node output model is used, the number of hidden layers and neurons are selected by trial and error Method till satisfactory regression value is achieved.

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II. EXPERIMENTAL INVESTIGATION

The experimental data used in this paper are collected in the laboratory over the research engine in which blends of biofuel with diesel can be used. The major specifications of the engine are tabulated in Table 1.The schematic engine test rig layout is shown in "Fig.1". The experimentation was conducted at constant speed 1500 rpm, varying injection angle (19deg,21deg,23 deg from bTDC) compression ratio (16,17,18) various blend ratio and load (0Kg, 3Kg, 6Kg, 9Kg, 12kg) to find the performance and emission of a single cylinder four stroke DI diesel engine. The blend configurations are B20 (biodiesel 15%, ethanol 5%, diesel 80%), B25(biodiesel 15%, ethanol 10%,diesel 75%, B30 (biodiesel 20%, ethanol 10%,diesel 80%). The physio chemical properties are tabulated in Table 2 .The emission readings are recorded manually.

Table 1 Engine specifications

Parameter	Specification
Engine manufacturer	Kirloskar
Engine Type	Single cylinder, 4 stroke, Multifuel, VCR, 661cc, Stroke: 110mm, Bore: 87.5, Fuel injection 23ºbTDC (Std.), IOP 210 bar (Std.), Constant Speed 1500rpm
Diesel mode	3.5 KW, 1500 rpm, CR range 12-18 (Std.17.5). Injection angle variation: 0- 25^0 bTDC
Dynamometer	Type eddy current, water cooled
Calorimeter	Type Pipe in pipe
ECU	PE3 Series ECU, Model PE3-8400P, full build, potted enclosure. Includes pe Monitor& pe Viewer software.
Peizo sensor	Combustion: Range 350Bar, Diesel line: Range 350 Bar, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Data acquisition device (DAQ)	NI USB-6210, 16-bit, 250kS/s.
Software	"Enginesoft" Engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
GAS Analyser	Five gas analyzer AirRex , Model HG540

III. ARTIFICIALNEURALNETWORK DESIGN

Haykin actually defines and used the neural network like a parallel processor, which has an ability to develop the mapping of input and output parameters, this knowledge of network can be used when it is required. The neural network resembles the human brain as it get trained during learning process, the concept of inter connection of neurons and weight stores the knowledge. In human body the biological neurons acts as receptors for input combines them and performs nonlinear / linear operation to get final output. The neural network consists of input layer, hidden layers, and output layer.

A back-propagation training algorithm with gradient descent is popular algorithm to be used by researchers but it is slow for practical problems. In addition the faster algorithms are preferable are Levenberg–Marquardt (LM), quasi-Newton, conjugate gradient which uses standard optimization techniques which eliminates the disadvantages. ANN with feed forward back-propagation algorithm learns by changing the weights, these changes are stored as knowledge. The inputs and target output in the ANN model scaled between 0 to1. The activation function usually selected in hidden layer is tan sigmoid function or logsig. However the structure of network weights , biases, activation functions, training algorithm, maximum number of epochs, target, error etc are well defined. The Transig transfer function and synaptic weights variation are used by software in MATLAB. The Matlab ANN tool is simple to use which uses ,the back propagation algorithm (trainlm) in training models. This algorithm is called as supervised training technique, which minimizes the error by gradient descent rule. The whole data is randomly divided into 70%,15% and 15% for training, validation and testing set of data respectively. The Matlab ANN tool has capacity to validate and test the model and develop the regression correlation coefficient between experimental and predicted data.

Training: It is presented to the network during training, and the network is adjusted according to its error.

Validation: These are used to measure network generalization, and to halt training when generalization stops improving.

Mean square error (MSE): Mean Squared Error is the average squared difference between outputs and targets. Lower values are better., Zero means no error. This was used to check performance of the network function.

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Testing: These have no effect on training and so provide an independent measure of network performance during and after training.

This study uses the four parameters (IA, CR, B% and Load) of input data and seven parameters (BTE, BSFC, EGT,CO2, CO, Nox , HC) of target data obtained by experimentation. The NN tool was used in which four input parameter and single output parameters as target was evaluated. The neural network with four nodes of input parameters and one node of output as target is indicated in "Fig.2" and Flow chart for ANN model training is shown in "Fig.3". The seven such network are prepared for seven targets as output. The results of single output than multi output network is better and easy to handle using Matlab NN tool. The input layer in this study consists of four neurons and output layer has one neuron. The neurons of hidden layers was adjusted unless good value of regression correlation coefficient (R) is obtained after training of network ,the regression graphs are shown in "Fig 4". The regression value obtained between 0.94 and 0.999. The number of neurons in hidden layer and over all value of R is tabulate in Table 3 . The 'R' value for the training, validation and testing of the ANN model found to be very close to one, which shows that the model is most suitable for the prediction of the output parameters of the engine. The mathematical relation between output and target is illustrated in table 4 and the flow chart for ANN model prediction is shown in "Fig.5".

Table 2 Physiochemical Properties

Type of Blend /units	B 20	B 25	B 30	Etha-nol (99.5)	Kar-anja Biod-iesel	Diesel ASTM D975 (2016)
Density at 40°C, kg/m3	844	845	842	786.85	860	850.786
Viscosity at 40°C,mm^2 /s	2.53	2.64	2.48	1.068	4.78	1.3 - 4.1
Flash Point (°C)	16	17	16	13	144	60 - 80
Cetane Number	46	45.7	43.8	8	42.7	47-51
Calorific value (KJ/Kg)	41.4	41.22	40.5	26.8	37	42 - 46

Table 3 Number of neurons in hidden layer and Over all value of R.

Parameters	No. of Neurons	Over All value of R
BTE	20	0.9982
BSFC	20	0.9918
EGT	20	0.9984
CO2	30	0.9711
NOx	30	0.9904
CO	20	0.9539
HC	35	0.9423

Table. 4 Mathematical Model to get Predicted output.

Parameters	Mathematical Model (Predicted output)
BTE	Output =0.99*Target+0.067
BSFC	Output =1*Target -0.00022
EGT	Output =1*Target +1.2
CO2	Output = 0.95*Target +0.15
NOx	Output =1*Target -23
CO	Output = 0.9*Target +0.008
HC	Output = 0.93*Target +0.67

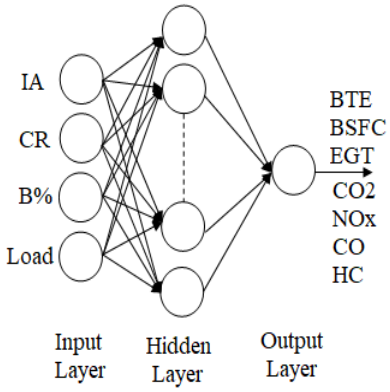

Fig.2 Neural Network Design

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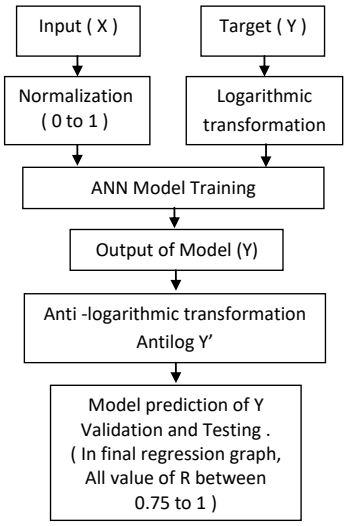

Fig 3. Flow chart for ANN model training

IV. VALIDATION OF ANN MODEL

The research model was developed using Taguchi optimization method and the seven optimal combination of parameters were obtained, further to

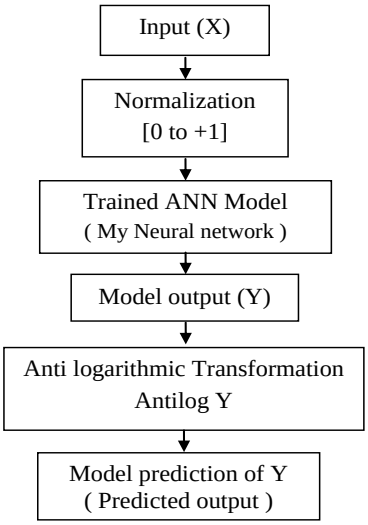

Fig.5 Flow chart for ANN model prediction

obtain single optimal solution, multi objective optimization Gray relational analysis was used. To predict the values at any other combination of parameters it is reviewed that ANN model is best for prediction accuracy. Hence the Artificial neural network model is validated by using optimal combinations obtained by Taguchi optimization method and Gray relational analysis. The validation of predicted and experimental results is compared in Table 5 and the validation of ANN model show "Fig 6" by presenting error analysis.

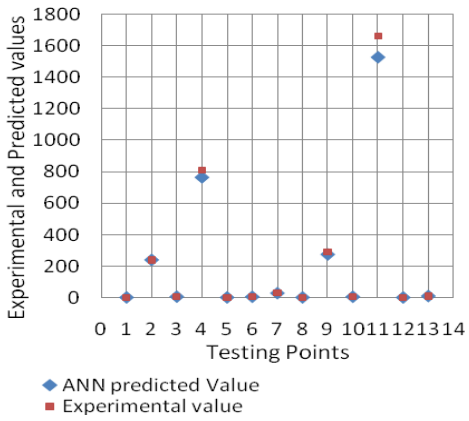

Fig 6 Validation of ANN Model

V. RESULTS AND DISCUSSION

- After the experimental analysis the data are divided into input parameters and taret parameters. Both input and target parameters are separately fed into ANN tool of Matlab R2013b.
- The simple Matlab code is to be developed to read the data file. In wchich data ia normalized between 0 to 01 for easy training process.
- The whole data get divided into three parts 75% for traing,15% for validation and 15% for testing.
- The number of neurons by default is 10 but it selected by researchers by trial and error method to get good results after training the ANN model in the MATLAB software. The regression graphs are checked and the overall regression correlation coefficient should lie between 0.95 and 1 as to prediction accurate results.
- The perfect number of neurons in hidden layer is determined by the process and it is between 20 to 30.
- The validation of ANN model is conducted at optimal testing points and it is observed that the error lies between 0 to 9.75%.
- The results obtained have good correlation between experimental and predicted . The numbers of neurons in hidden layer are for BTE,BSFC, EGT,CO2,NOx,CO and HC are 20,20,20,30,30,20,35 and the All regression values (R) obtained are 0.998, 0.991,

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0.998, 0.971, 0.991, 0.954 and 0.942 respectively. The regression values thus indicate that obtained ANN is well trained and able to predict the data. The ANN validation graph is mentioned above section.

VI. CONCLUSION

- Artificial neural network is power full tool to predict the results on respective input parameters, it is easier to use and robust than any other mathematical model. The NN tool in Matlab is used to get the ANN regression model and My neural network code file, which is used to predict the accurate output. It is observed that the number of neurons in hidden layer layers needs good attention to train the model, its selection is based on trail and error method till the good regression value is obtained. The number of neurons in hidden layer is obtained between range of 20 to 35 .The regression values thus indicates that obtained ANN is well trained and able to predict the data. The ANN validation graph is discussed in previous section. The percentage error among predicted and experimental values lies between 0 to 9.75% within range.

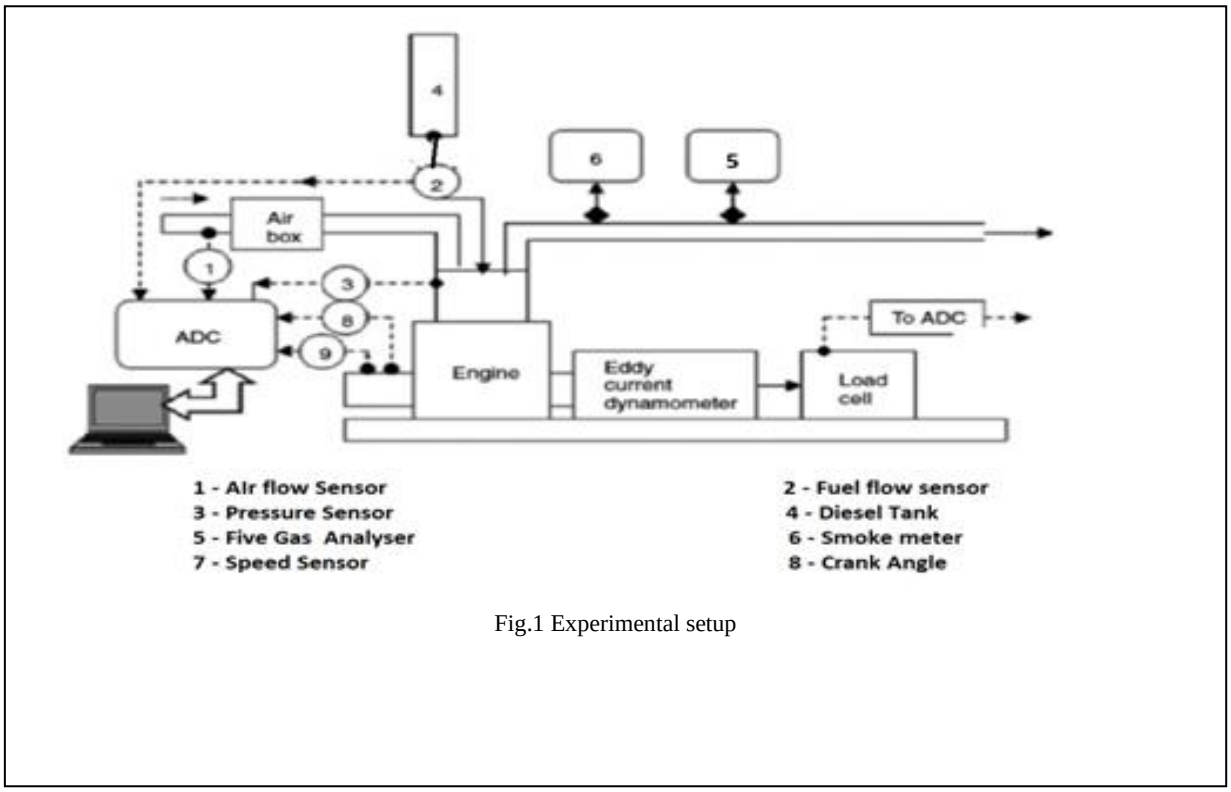

Fig.1 Experimental setup

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Table 5 Validation of Artificial neural network model by Taguchi optimal combination and multi objective optimization GRA optimal combination

Test Points	Optimal combination of parameters obtained by Taguchi method	Parameter	ANN predicted Value	Exper-imental value	% Error
1	IA21,CR18,B30, load12kg	BTE (%)	30.48	30.75	2.76
2	IA21,CR18,B30, load12kg	BSFC (kg/kwh)	0.2802	0.3010	6.91
3	IA19,CR18,B30, load 6kg	EGT (°C)	239.3485	238.99	1.5
4	IA19,CR18,B30, load 6kg	CO2 (%)	4.9859	5	0.014
5	IA23,CR16,B30, load 12kg	NOx (PPM)	765	810	5.55
6	IA21,CR18,B30, load12kg	CO (%)	0.1913	0.05	0.14
7	IA23,CR18,B20, load 6kg	HC (PPM)	4.39	4	9.75
Optimal combination of parameters obtained by GRA					
8	IA19,CR18,B30 and 9 Kg (75% load)	BTE (%)	27.09	27.64	0.1932
9		BSFC (kg/kwh)	0.31	0.31	0
10		EGT (°C)	274.12	288.69	5.04693
11		CO2 (%)	4.26	4.18	0.08
12		NOx (PPM)	1530	1663	7.99
13		CO (%)	0.055	0.051	0.004
14		HC (PPM)	9	9	0

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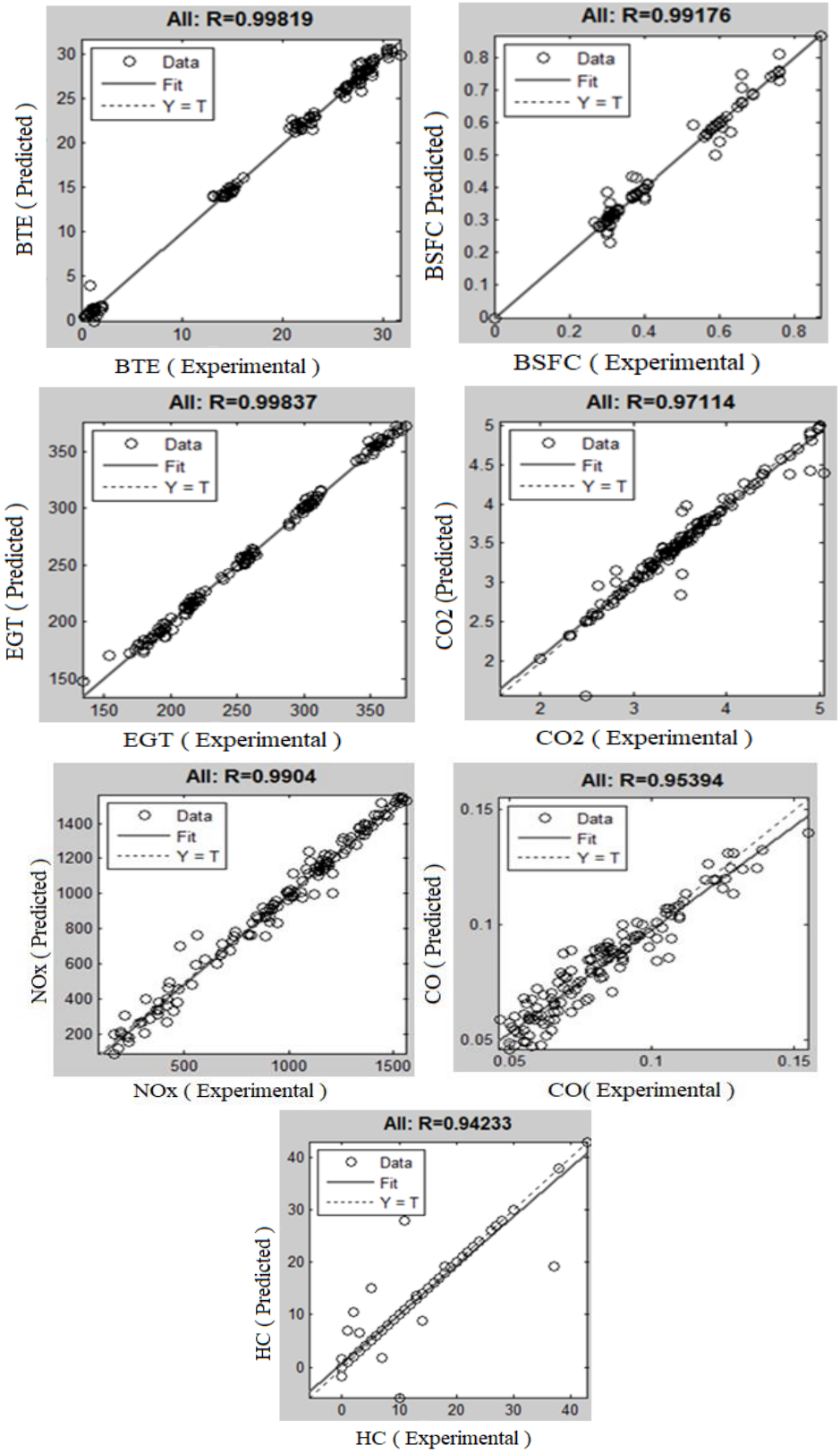

Fig. 4 Regression graph for BTE, BSFC,EGT, CO2, NOX, CO,HC

Vc

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