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Development of intelligent model to predict the characteristics of biodiesel operated CI engine with hydrogen injection

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Abstract. Multiple Inputs and Multiple Outputs (MIMO) Fuzzy logic model is developed to predict the engine performance and emission characteristics of pongamia pinnata biodiesel with hydrogen injection. Engine performance and emission characteristics such as brake thermal efficiency (BTE), brake specific energy consumption (BSEC), hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2) and nitrous oxides (NO_X) were considered. Experimental investigations were carried out by using four stroke single cylinder constant speed compression ignition engine with the rated power of 5.2 kW at variable load conditions. The performance and emission characteristics are measured using an Exhaust gas analyzer, smoke meter, piezoelectric pressure transducer and crank angle encoder for different fuel blends (Diesel, B10, B20 and B30) and engine load conditions. Fuzzy logic model uses triangular and trapezoidal membership function because of its higher predictive accuracy to predict the engine performance and emission characteristics. Computational results clearly demonstrate that, the proposed fuzzy model has produced fewer deviations and has exhibited higher predictive accuracy with acceptable determination correlation coefficients of 0.99136 to 1 with experimental values. The developed fuzzy logic model has produced good correlation between the fuzzy predicted and experimental values. So it is found to be useful for predicting the engine performance and emission characteristics with limited number of available data.

Keywords: biodiesel; fuzzy logic; hydrogen; injection; emission

1. Introduction

Biodiesel act as an effective alternate fuel to replace the conventional fuels. The vanishing of conventional fuels is due to the development in automotive sector. Also the usage of conventional fuels contributes a lot to the global warming. The world resources of fuel will be totally exhausted within 60 years which create the gap between energy requirement and availability. Contribution of biofuels is not only to fulfil the requirement but also to reduce the global warming to safeguard the world from pollution. To overcome this all problem, there is need of development in biodiesel. Already the investigations are carried throughout the world to predict the characteristics of biodiesel. The biodiesel is considered to be the primary fuel for internal combustion engine. It is

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prepared from edible and non-edible vegetable oils which considerably reduce the CO_2 emission when compared to diesel and also it acts as promising fuels in the upcoming decades. This segment describes the literature review in the area of computational intelligence and it also defines the various methods and problems related to these aspects.

Saravanan *et al.* experimented by inducting the hydrogen into the intake manifold and injecting the biodiesel into the combustion chamber with different LPM rate. The flow of hydrogen should be found out by using hydrogen flow meter. Hydrogen enriched air in diesel engine enables the realization of increase in brake thermal efficiency, resulting in lower specific energy consumption. However the NO_X tends to be increased due to the presence of hydrogen. At full load, NO_X emission comparatively increased compared to diesel operation. However, there may be a probability of manifold leakage and back pressure in hydrogen induction. (Saravanan *et al.*. 2008).

Saravanan and Nagarajan observed that the performance and emission characteristics of the optimized injection timing, duration and optimized flow rates of hydrogen are calculated. Hydrogen is injected into the intake manifold and diesel is injected directly inside the combustion chamber with a constant hydrogen flow rate. The optimized timing for the injection of hydrogen is 5 degree BGTDC with injection duration of 30 degree CA. Therefore, the optimized timing for the hydrogen injection is found to be from 0 to 90 degree. (Saravanan and Nagarajan 2009).

Oliveira *et al.* developed the electronic hydrogen injection system for diesel operation engine fueled with hydrogen. The tests were carried out with hydrogen injected in the intake manifold and diesel oil directly injected in the combustion chamber. And also they analyzed and concluded that the duration of injector opening with different injection pressure for variable loads is achieved. The results shows that injection valve opening periods is necessary to obtain hydrogen mass flow rates equivalent to 5%, 10%, 15% and 20% of the diesel oil mass replaced. The measured hydrogen mass flow rate injected is presented as a function of load power demand and hydrogen concentration in the fuel. (Oliveira *et al.* 2013).

Sakthivel *et al.* proposed the fuzzy logic model to predict the engine performance and emission characteristics of fish oil biodiesel with diethyl ether. The fish oil ethyl ester was transparent light yellow colour contained no suspended matter. The fish oil biodiesel and diethyl ether blends were examined in the laboratory using ASTM test standards. By the use of four stoke single cylinder compression ignition engine the performance and emission characteristics are analyzed and developed using the fuzzy logic model. FIS Editor graphical user interface in the fuzzy logic toolbox within the framework of lab view. Predicted results clearly demonstrated that, the proposed fuzzy models produced less deviations and exhibited higher predictive accuracy. (Sakthivel *et al.* 2013).

Rai *et al.* designed the fuzzy logic model to predict the output parameters of a LPG-Diesel dual fuel engine. In this work, fuzzy logic has been used to model performance and emission parameters in Liquid Petroleum Gas (LPG)-diesel dual fuel engine. The input parameters used for modeling includes % load, % LPG and injection timing and the output parameters includes performance and emission parameters. By the use of input and output parameters the membership functions were setup and the rules are framed. ANFIS was found to outperform conventional fuzzy logic based model for prediction and emission with high R2 value, and high prediction accuracy on test data thereby establishing its effectiveness. (Rai *et al.* 2012).

The main aim of this paper is to develop the Fuzzy model for the investigation and prediction of performance and emission characteristics of diesel engine using pongamia pinnata biodiesel with hydrogen injection.

2. The proposed fuzzy model

2.1 Fuzzy model

The proposed model was developed using the FIS Editor graphical user interface in the fuzzy logic toolbox within the framework of MATLAB V 7.6. The developed MIMO fuzzy logic model is shown in the Fig. 2.1, which is used to predict the engine performance and emission characteristics for various blends of pongamia pinnata biodiesel operated CI engine with hydrogen injection.

2.2 Fuzzification of input and out variables

Fuzzy logic model is developed to predict the performance and emission characteristics of various blends of pongamia pinnata biodiesel operated CI engine with hydrogen injection. Experiments were carried out using four-stroke, single cylinder and stationary compression ignition engine at a constant speed of 1500 rpm with the rated power of 5.2 KW. The performance parameters such as Brake thermal efficiency (BTE), Brake specific energy consumption (BSEC) were measured by the use of DAQ (Data acquisition system) and to measure the various emission parameters such as Nitrous oxides (NO_x), Hydrocarbon (HC), Carbon monoxide (CO), Carbon dioxide (CO_2), the setup was equipped with AVL gas analyzer. The above said parameters were measured continuously with varying Load and Blends. Therefore the parameters such as BTE, BSEC, NO_x, HC, CO and CO_2 are considered as output and the parameters such as Load and Blends are considered as an input in the developed fuzzy logic model. The source of data sets were taken experimentally using four-stroke, single cylinder and stationary compression ignition engine at a constant speed of 1500 rpm with the rated power of 5.2 KW. The data sets were considered as different input and output parameters for developing fuzzy logic model. The observed experimental data are normalized for improving the performance of the model.

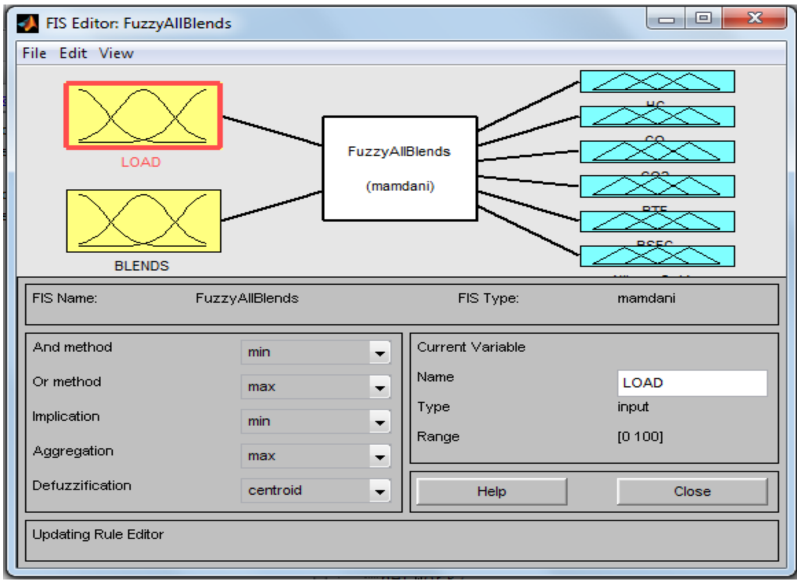

Fig. 2.1 Developed fuzzy model

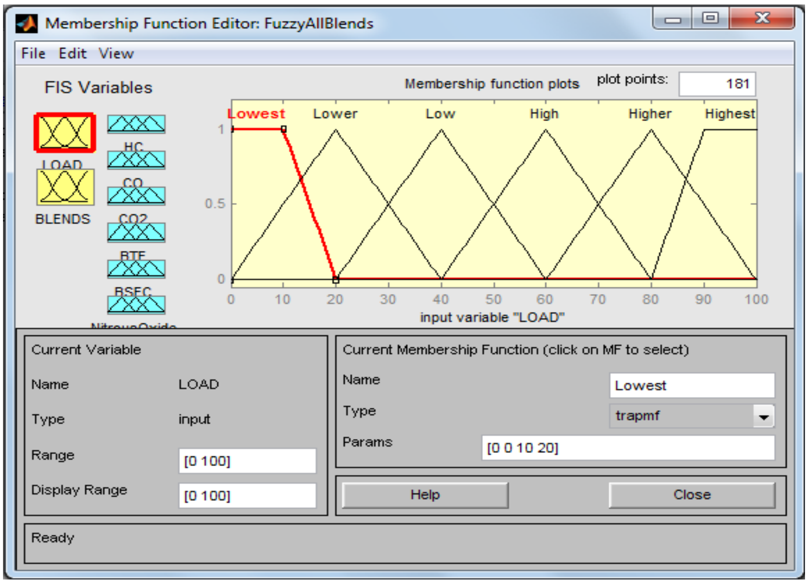

Fig. 2.2 Membership function for input variable load

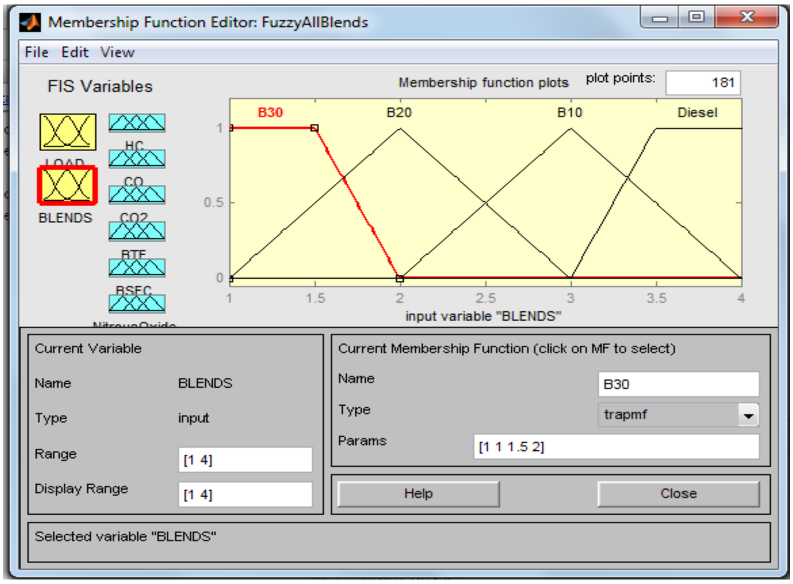

Fig. 2.3 Membership function for input variable blends

Normalization of data sets was done with the help of experimental values. For example the first input parameter load which contains data sets such as 0, 20, 40, 60, 80 and 100%. To draw the membership function for trapezoidal we require four points, therefore to draw the first membership function for the first input parameter load 0, 0, 10, and 20 is chosen. To draw the membership function for triangular we require three points, therefore to draw the second membership function for the first input parameter load 0, 10 and 20 is chosen. Likewise the normalization was carried out for every parameter. The input and output variables are quantified by using linguistic terms.

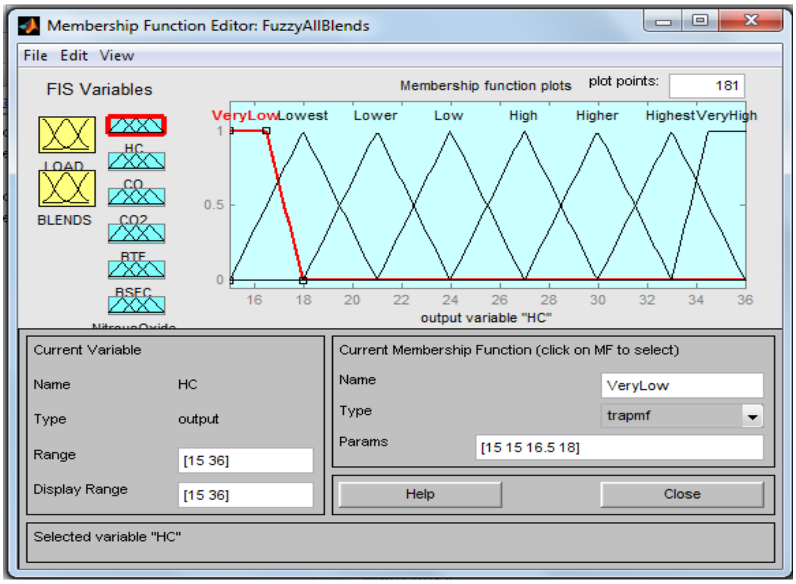

Fig. 2.4 Membership function for output variable HC

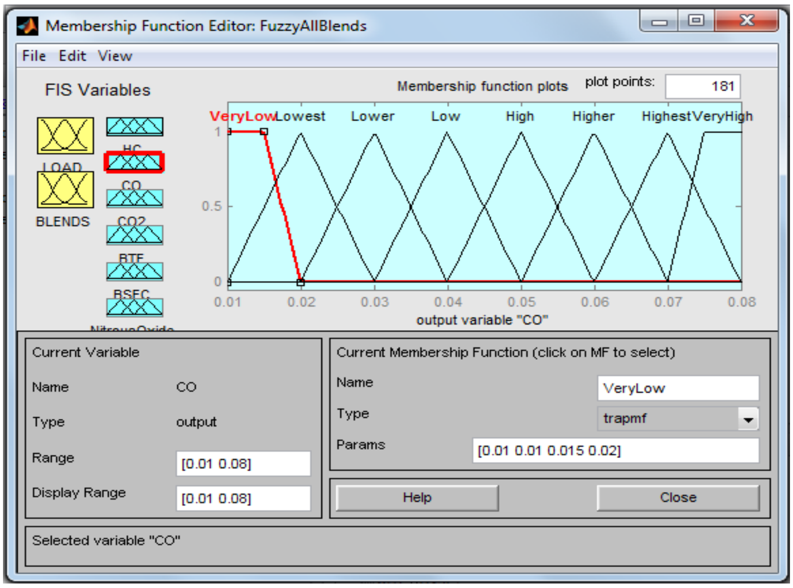

Fig. 2.5 Membership function for output variable HC

For this multi-input and multi-output model, input variables includes loads and various blends of the engine are expressed into fuzzy sets namely lowest, lower, low, high, higher, highest and B30, B20, B10 and Diesel.

With the help of the experimental data for every parameter, the MFs were generated. For example in our model the first input parameter was load which can be varied from 0% to 20%, 20% to 40%, 40% to 60%, 60% to 80% and 80% to 100%. Likewise for every parameter the MF values are generated with the set of experimental input and output readings. We have chosen

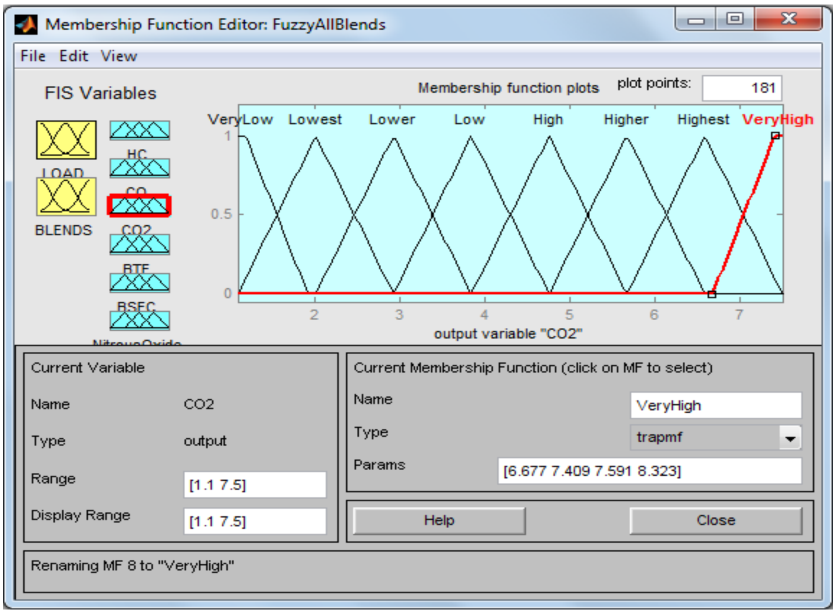

Fig. 2.6 Membership function for output variable CO2

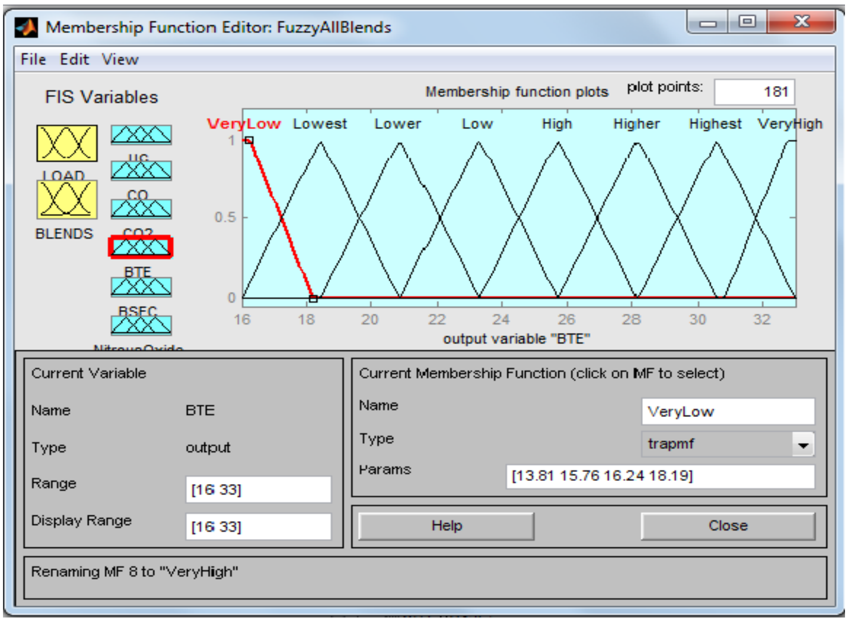

Fig. 2.7 Membership function for output variable BTE

trapezoidal membership function for the first and last values in every parameter and for remaining values, triangular membership function is chosen. The reason for choosing the above membership functions is due to its simplicity in normalizing the data sets.

The generated fuzzy membership function for the input load is shown in the Fig. 2.2.

The membership function generated for input variable blends is shown in the below Fig. 2.3.

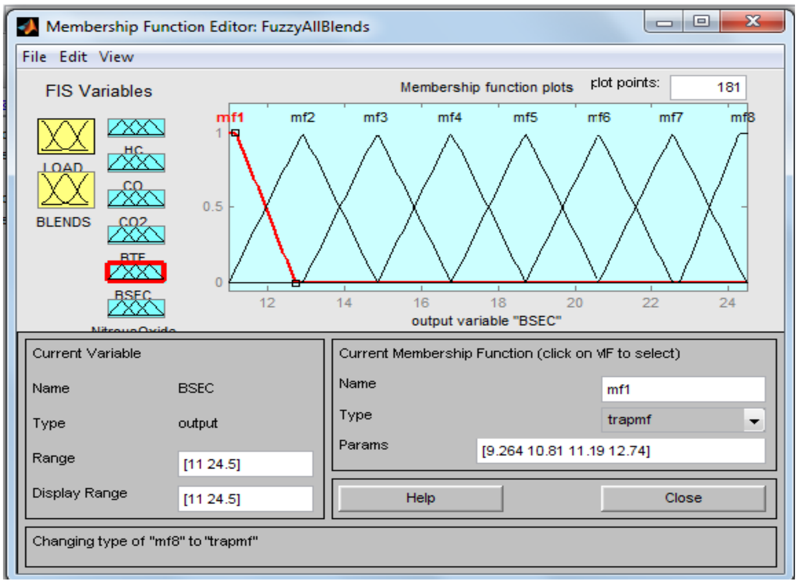

Fig. 2.8 Membership function for output variable BSEC

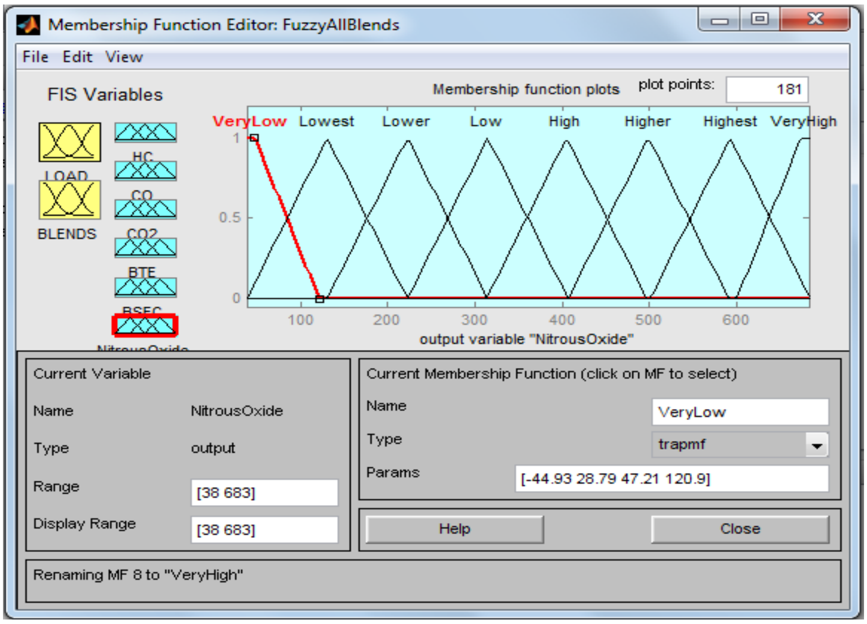

Fig. 2.9 Membership function for output variable NOX

In this fuzzification process of modeling the input and output variables triangular and trapezoidal membership functions is used. The membership function generated for output variable hydrocarbon (HC) is shown in the Fig. 2.4.

The membership function generated for output variable carbon dioxide (CO) is shown in the Fig. 2.5 and the membership function generated for output variable carbon dioxide (CO_2) is shown in the Fig. 2.6.

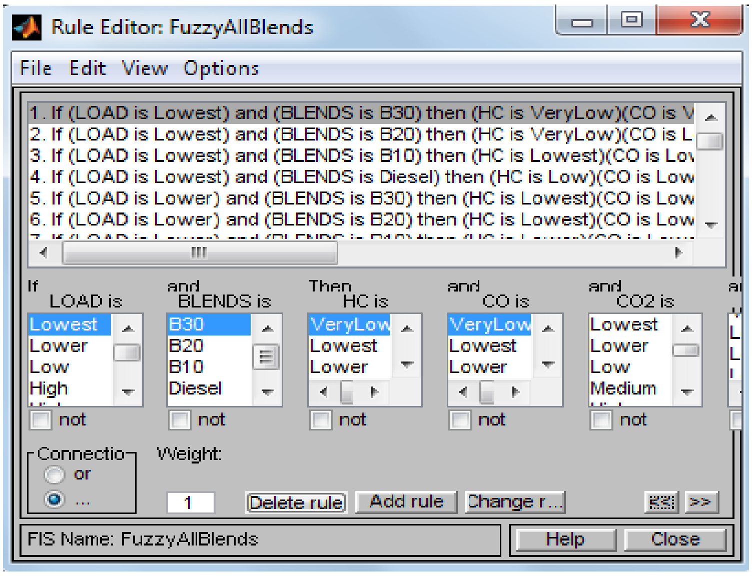

Fig. 2.10 Rule editor of the proposed model

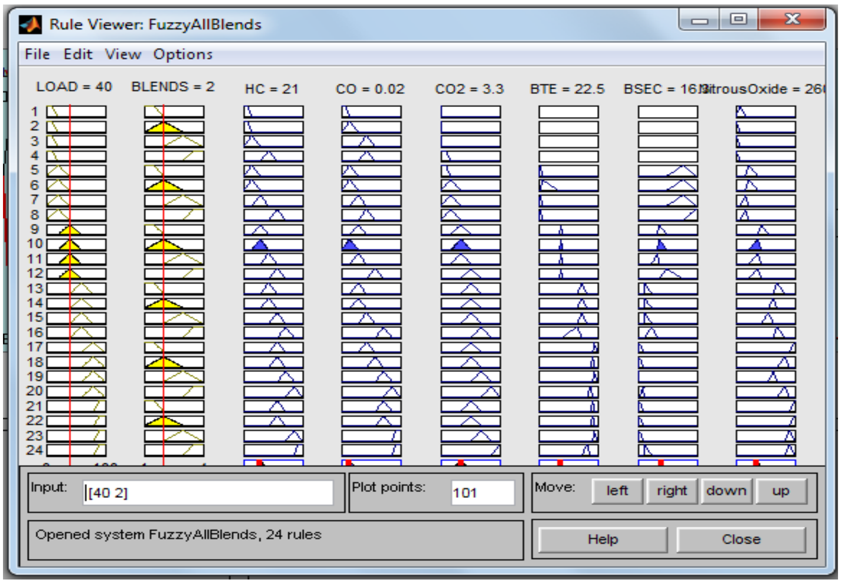

Fig. 2.11 Output viewer of the fuzzy model

The membership function generated for output variable brake thermal efficiency (BTE) is shown in the Fig. 2.7 and the membership function generated for output brake specific energy consumption (BSEC) is shown in the Fig. 2.8.

The observed data are standardized for refining the performance of the system and by varying the oxides of nitrogen with percentage of load depends on the peak flame temperature, ignition delay, and the content of nitrogen in the reacting mixture the proposed model using fuzzy. The membership function generated for output variable nitrous oxides (NO_X) is shown in the Fig. 2.9.

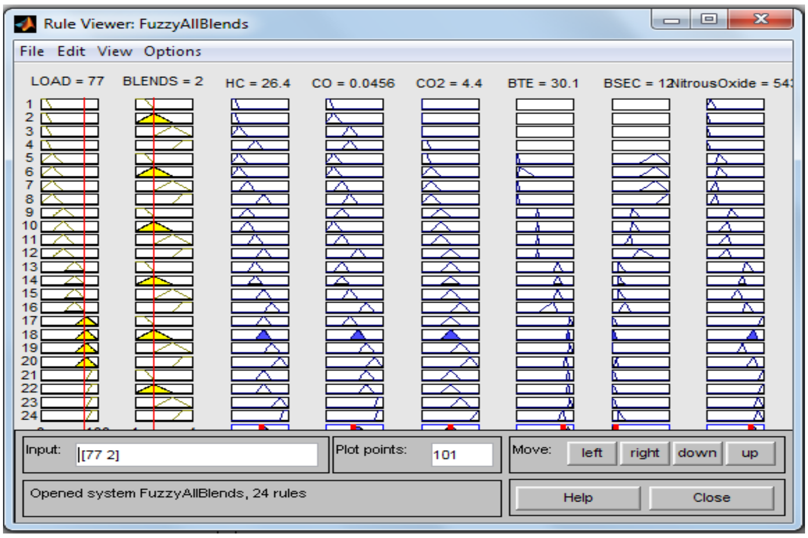

Fig. 2.12 Output viewer shows the output characteristics for change in input

2.3 Fuzzy Inferencing

The next stage of the fuzzy logic is to construct the IF-THEN rules to represent the relationship between input and output variables based on the linguistic terms. In this multi-input and multi-output fuzzy logic model, 6 rules are written by using rule editor for the best fit of the model. Fig. 2.10 shows the IF-THEN rule editor consisting of 24 rules of the model in MATLAB V 7.6 environment.

2.4 Defuzzification

The last stage of fuzzy model is Defuzzification process. In this model, Centre of area method is used for defuzzification. The developed fuzzy logic model provides a predicted performance and emission characteristics of various blends of pongamia pinnata biodiesel operated CI engine with hydrogen injection when proper loads and blends is fed into the model. The brake thermal efficiency (BTE), Brake specific energy consumption (BSEC), Nitrous oxides (NO_X), Hydrocarbon (HC), Carbon monoxide (CO) and Carbon dioxide (CO_2) characteristics of the engine are obtained from this fuzzy model when corresponding inputs are given. The defuzzification viewer of the fuzzy logic model is shown in Fig. 2.11. In which the output is obtained for the engine fueled with B20 biodiesel with hydrogen injection at 40% loading conditions.

The performance and emission characteristics of the engine fueled with B20 biodiesel with hydrogen injection at 77% loading conditions is predicted is shown in Fig. 2.12 by using this proposed fuzzy logic model.

3. Results and discussions

The observations made after conducting the experiments,

For 100% load, the brake thermal efficiency was 31.07% and brake specific energy

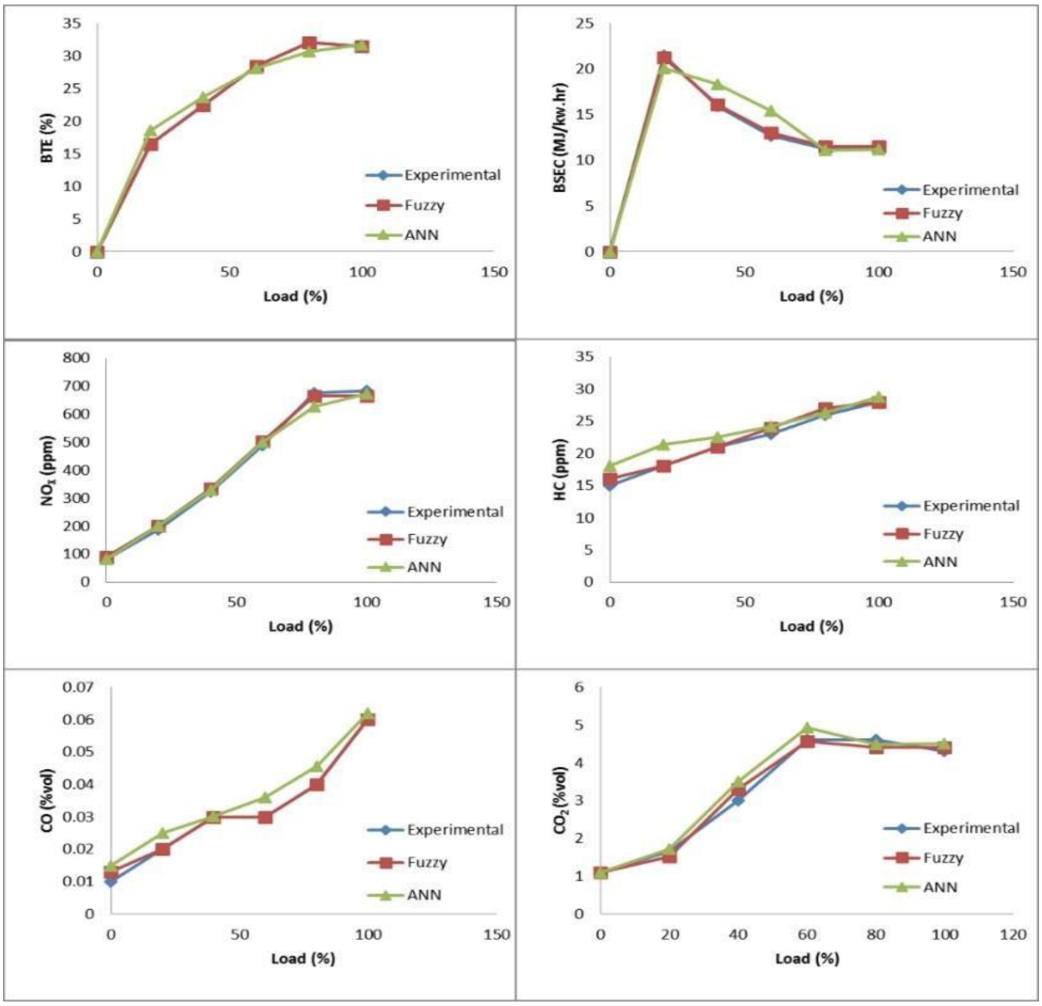

Fig. 3.1 Performance and emission results of fuzzy with hydrogen injection

consumption was 12132.11 kJ/kWh for the engine fueled with B30 biodiesel with hydrogen injection. Clearly, the injection of hydrogen inside the intake manifold influences the brake thermal efficiency and brake specific energy consumption. BTE increases with hydrogen injection whereas BSEC decreases due to the complete combustion occurring in dual fuel operation of hydrogen injection and biodiesel fuel. With B30 biodiesel with hydrogen injection increases the NO_X emission up to 675 ppm at 100% load. Also the carbon based emissions such as HC, CO and CO_2 decreases for the engine fueled with B30 biodiesel with hydrogen injection. This is due to the absence of carbon in hydrogen fuel.

The proposed fuzzy logic model is used to predict the performance and emission characteristics of the engine fueled with various blends of pongamia pinnata biodiesel with hydrogen injection.

Fig. 3.1 shows the performance and emission results of fuzzy over experimental data of the engine fueled with B30 biodiesel with hydrogen injection. The comparison between the predicted and the experimental values of brake thermal efficiency (BTE), Brake specific energy consumption (BSEC), Nitrous oxides (NO_X), Hydrocarbon (HC), Carbon monoxide (CO) and

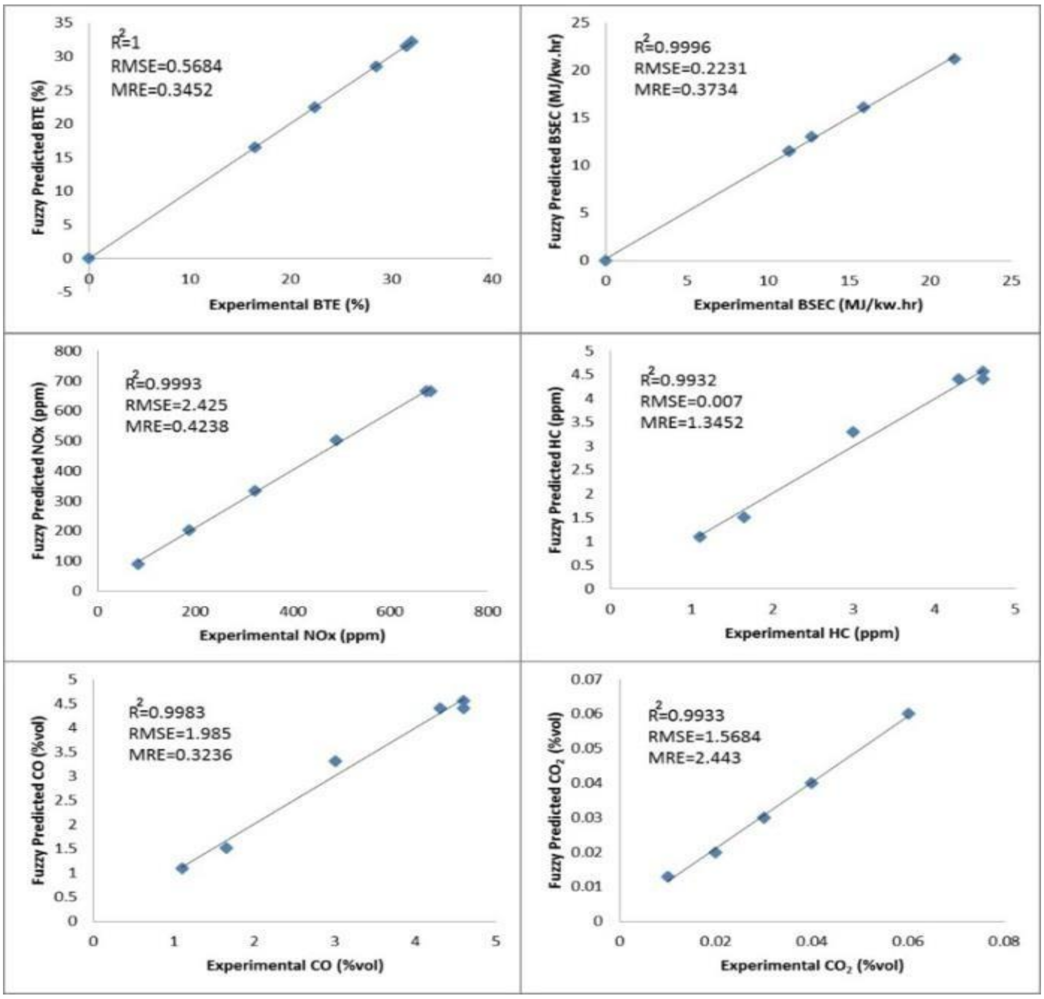

Fig. 3.2 Correlation, root mean square and mean relative error of fuzzy predicted over experimental values for B30 biodiesel with hydrogen injection.

Carbon dioxide (CO_2) are almost equal. It shows that the predicted values of fuzzy logic and artificial neural network model are nearer to experimental values. However, the predicted results of fuzzy shows minimal deviation over experimental results rather than artificial neural network.

The correlation coefficient, root mean square error (RMSE) and mean relative error are calculated for characterizing the network performance. Fig. 3.2 shows the correlation coefficient, root mean square error and mean relative error of the fuzzy predicted values over experimental values of the engine fueled with B30 biodiesel with hydrogen injection. The correlation coefficient of brake thermal efficiency and brake specific energy consumption are 1 and 0.9996, RMSE of 0.5684% and 0.2231% and MRE of 0.3452% and 0.3734% are obtained in the developed fuzzy logic model. NO_X, HC, CO, and CO_2 yields MRE of 0.4238%, 2.443%, 0.3236% and 2.443%, RMSE of 2.425%, 0.007%, 1.985% and 1.5684% and correlation coefficient of 0.9993, 0.9932, 0.9983 and 0.9933 respectively. Hence the predicted result of proposed model stretches to the accuracy of the engine. The predicted results of performance and emission are in good agreement with the experimental values. From the results it was observed that the proposed fuzzy logic model can predict the engine performance and exhaust emissions with a correlation coefficient of 0.9932 to 1. MRE for various parameters was found to be 0.3236% to 2.443% and the RMSE was found to be 0.007% to 2.425%.

4. Conclusion

This paper proposed a novel fuzzy logic model for predicting the engine performance and emission characteristics of various pongamia pinnata biodiesel combinations with hydrogen injection.

- It was shown that the developed fuzzy logic model is highly effective for predicting the engine parameters. The predicted values of fuzzy logic model and experimental values are highly correlated with correlation coefficient of 0.99136 to 1.
- The accuracy of fuzzy is greater depends upon more number of inputs. This reveals that the developed fuzzy logic model is useful to test the engine with the use of limited number of test data.

The fuzzy logic model can be useful for manufacturers and application engineers for predicting the engine parameters under different loads with different fuel blends.

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