Journal of Advanced Research in Mechanical Engineering and Technology
Volume 6, Issue 1&2 - 2019, Pg. No. 32-37
Peer Reviewed Journal

Review Article

A Review on Application of ANN Model for the Prediction of Fuel Properties of Biodiesel

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DOI: https://doi.org/10.24321/2454.8650.201906

I N F O

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How to cite this article:
Nithyananda BS, Anand A, Prakash GVN. A Review on Application of ANN Model for the Prediction of Fuel Properties of Biodiesel. *J Adv Res Mech Engi Tech* 2019; 6(1&2): 32-37.

Date of Submission: 2019-05-27
Date of Acceptance: 2019-08-02

A B S T R A C T

The methyl esters of vegetable oils, known as biodiesel are becoming increasingly popular because of their low environmental impact and potential as a green alternative fuel for diesel engine. Non-edible oils are second generation biodiesel feedstock which contributes meagre of total global biodiesel production. Still there is a wide scope to explore potential non-edible oil feedstocks for biodiesel. Chemical structures are different from one feedstock to other in terms of chain length, degree of unsaturation, double bond configuration and number of double bonds. These contribute for fuel properties of biodiesel. The experimental characterization of biodiesel and its blends requires significant amount of sample, standardized equipment's and time. Therefore, it is very much required to consider the prediction model to estimate fuel properties of biodiesel. ANN Prediction modelling can be a useful tool in accurately predicting biodiesel fuel properties instead of choosing costly and time-consuming experimental tests. The main aim of this paper is to review the literatures to discuss the application of ANN approach to characterize the biodiesel and its blends. This review has concluded that the ANN approach has high potential to accelerate the biodiesel research in India.

Keywords: Second Generation Feedstock, Artificial Neural Network (ANN), Biodiesel

Introduction

Biodiesel produced from seed oils and fats has combustion properties similar to regular petro diesel fuel. Biodiesel is advantageous as it is biodegradable, nontoxic, and has significantly less emissions than petro diesel when burned. Biodiesel as bio lubricants is preferred in so many applications.

At present, the biodiesel cost is too high compared to petro diesel due to conversion cost and feedstock cost. Biodiesel produced from oil feedstocks represents the potential source for production but it cannot be used on commercial scale for production because the cost of raw vegetable oil itself is too costly. Even biodiesel can also be produced from waste vegetable oil which is obtained for free or low price, but the impurities should be removed before converting oil into biodiesel.

The edible oil feedstocks were used to produce biodiesel on a commercial scale and biodiesel produced from these edible oil feedstocks are first generation biodiesel. The fuel-food conflicts have made first generation biodiesels unsustainable in the longer run.[1] This has forced the researchers across the globe to explore non-edible oil feedstocks to overcome the problems of using first generation feedstock.

Artificial Neural Network (ANN)

Neural Networks models are most popular predictive tool for complex problems involving nonlinear multivariable relationships. Artificial neural networks are inspired by biological neurons to simulate in a way human brain processes information. In brain, coded information is passed to axon from synapses. The information is communicated in between axon of each neurons. Artificial Neural Network models avoids expensive and time-consuming experiments and possible to predict from smaller data samples. Artificial Neural Networks model solve any complex problems through learning from the data by identifying the patterns and relationships through experience. ANN model is used in many disciplines because it works like black box model, when there are only sets of input and output data without complete information about the problem.[2] Neural cells are the smallest unit which form the ANN model, receive data from other sources and performs operation on the data and gives the output as shown in figure 1.

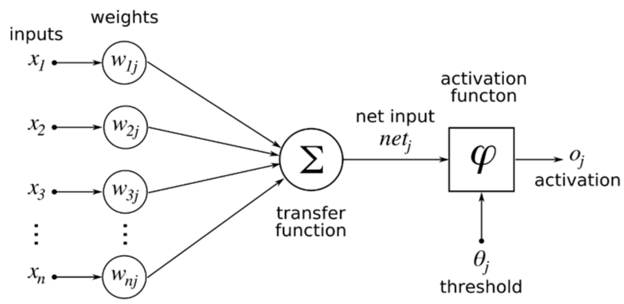

Figure 1.Structure of ANN

ANN model is composed of 3 main layers namely input, hidden and output.[3] The input layer in network comprises of input variables and these variables are important since it affects the outputs of the ANN model. In hidden layer, the input data are processed within the weights and biases with predefined nonlinear activation functions. The output layer consists of output parameters. ANN model works in steps creating and configuring the network, where the number of neurons at the hidden, input parameter, number of hidden layers, activation function and network architecture is defined. Then network is trained by initializing the weights and biases with error minimisation. The trained network is used for prediction of parameters.

Each neuron cells in the neural network is linked to other neuron cells through a communication channel and is connected with a weight which has information about input. This information is considered to be vital for the neuron cells to analyze complex problem because weight generally excites or obstructs the communication signal. Each neuron cells have an internal state activation pulse. The combination of input signal and rule of activation gives the output and then it is sent to other neurons in the network.

ANN makes use of different training algorithm but the back-propagation algorithm was most popular among them. However, back propagation training algorithm is considered to be too slow for complex problem since they need smaller learning rates. Conjugate gradient, quasi-Newton and Levenberg-Marquardt (LM) were considered to be quicker algorithms and use standard numerical optimization techniques.[4] Errors during learning process of the network are determined by using error evaluation methods namely Root Mean Square (RMS), R^2 and mean percentage error techniques. Figure 2, shows the working principle of Artificial Neural Network.

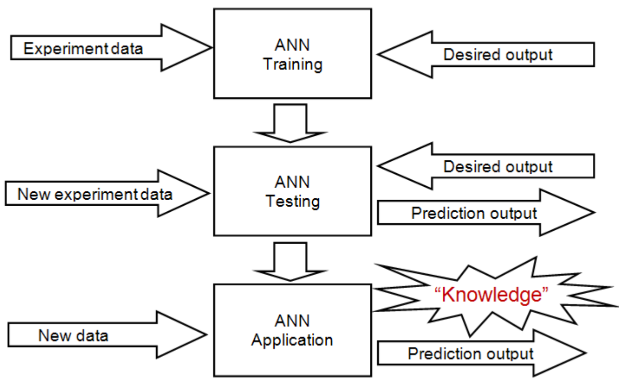

Figure 2.Working Principle of ANN

Fuel Properties of Biodiesel

Biodiesel produced from vegetable oils and fats are the mono alkyl esters of long chain fatty acids.[5] Vegetable oils and animal fats consists of 90%-98% of triglycerides, small percentages of mono and diglycerides and free fatty acids. The biodiesel fatty acid composition is dependent on feedstock and is affected by many factors. The most commonly found fatty acids in biodiesel is listed in the Table 1.

The fuel properties of biodiesel vary between feedstock and chemical composition of vegetable oils plays a pivotal role in deciding biodiesel fuel properties. The fuel properties of biodiesel like kinematic viscosity, flash and fire point, density, cetane number, calorific value, iodine value, cloud point, pour point etc. are dependant on its fatty acid composition. The fuel characterization of biodiesel and its blends are most important as they affect the storage of biodiesel fuel, transportation, handling, atomization and combustion.[6] The fuel properties need to be determined and compared with ASTM standard before running an engine with biodiesel as it poses practical problems.[7] The characterization of biodiesel involves more cost and time which hinders the development and exploration of biodiesel

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201906

research. Determination of these fuel properties requires considerable number of samples, standardized equipment's and significant cost. Therefore, it is required to find an alternate method of determining fuel properties rather than going for conventional experimentation. Artificial Neural Network fits into this gap and is most widely used prediction technique than regression models.[8]

Table 1.Fatty Acid Composition in biodiesel[5]

Fatty acid	Chemical structure
Caprilic (8:0)	$CH_3(CH_2)_6COOH$
Capric (10:0)	$CH_3(CH_2)_8COOH$
Lauric (12:0)	$CH_3(CH_2)_{10}COOH$
Myristic (14:0)	$CH_3(CH_2)_{12}COOH$
Myristoleic (14:1)	$CH_3(CH_2)_5$ CH=CH $(CH_2)_5$ COOH
Pentadecenoic (15:0)	$CH_3(CH_2)_{13}COOH$
Palmitic (16:0)	$CH_3(CH_2)_{14}COOH$
Palmitoilic (16:1)	$CH_3(CH_2)_6$ CH=CH $(CH_2)_6$ COOH
Meptadecenoic (17:0)	$CH_3(CH_2)_{15}COOH$
Stearic (18:0)	$CH_3(CH_2)_{16}COOH$
Oleic (18:1)	$CH_3(CH_2)_7$ CH=CH $(CH_2)_7$ COOH
Linoleic (18:2)	$CH_3(CH_2)_4$ CH=CHCH$_2$CH=CH $(CH_2)_7$ COOH
Linolenic (18:3)	$CH_3(CH_2)_2$CH=CHCH$_2$CH=CHCH$_2$CH=CH$(CH_2)_7$ COOH
Arachidic (20:0)	$CH_3(CH_2)_{18}COOH$
Behenic (22:0)	$CH_3(CH_2)_{20}COOH$
Erucic (22:1)	$CH_3(CH_2)_9$ CH=CH $(CH_2)_9$ COOH
Lignoceric (24:0)	$CH_3(CH_2)_{22}COOH$

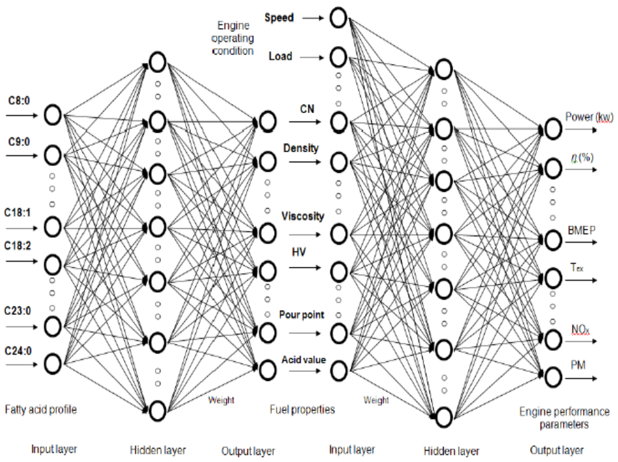

Figure 3.ANN Prediction Model[5]

ANN Model to Fuel Properties

Jahirul et al.[1] reviewed the literatures concerned with the application of ANN model for the estimation of biodiesel fuel properties and its effect on performance and emissions characteristics of CI engine (Figure 3). They found that there exists clear difference in chemical structure from one feedstock to another in terms of chain length, degree of unsaturation, number of double bonds and double bond configuration which decides the properties of biodiesel fuel. They suggested developing universal neural network model which can be used for prediction of performance parameters of different automobile engine and various fuels.

Bhattacharyulu et al.[2] developed ANN models inculcating the effect of operating conditions like temperature, time, oil to methanol ratio and amount of catalyst on viscosity of neem biodiesel. MATLAB was used to develop neural network model for the data got from the experiments. They concluded that neural network model has a huge potential in estimating the fuel properties of biodiesel fuel. The methodology used in their work can be explored further to cover more data samples from different design setups of experimental reactor. This will save the time and energy and increase the accuracy of the estimations. Figure 4, shows the architecture of proposed ANN model.

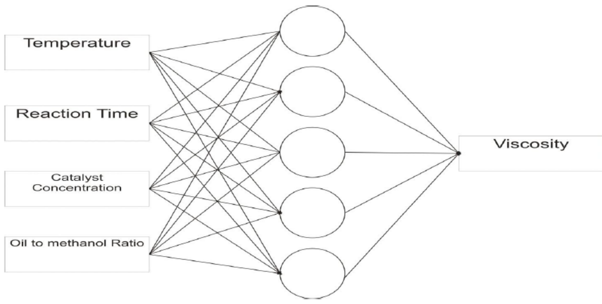

Figure 4.Architecture of ANN model

Jahirul et al.[5] have developed ANN model to estimate the viscosity of biodiesel using 27 parameters of composition of biodiesel as input and kinematic viscosity as output parameter. The MATLAB software was used to test and validate the neural model. The data required for training and simulating network is collected from research papers. They optimised architecture of neural network and algorithm used for learning, following trial and error method to predict viscosity more accurately. The neural network performance was assessed by estimating coefficient of determination, root mean squared and maximum average error percentage between predicted and experimental values. ANN model predicts the properties of biodiesel with high prediction accuracy and established the ability of neural model to understand the dependency of properties of biodiesel on its fatty acid composition.

Kumar and Bansal[6] used linear regression model and neural network model to evaluate the biodiesel fuel properties like flash point, fire point, density and kinematic viscosity. They used three different training algorithms namely batch gradient descent with momentum, Levenberg-Marquardt and Scaled Conjugate Gradient to train the neural network. They concluded that artificial neural model with Levenberg-Marquardt training algorithm is a better choice for prediction of fuel properties than regression model. They felt that artificial neural network may be improved further to get good results by modifyinf other parameters for training like goal, epoch, rate of learning, magnitude of the gradient etc. Table 2 shows the comparison of MSE of neural networks and statistical least square technique. The mean square error of ANN is comparatively much less than

ISSN: 2454-8650
DOI: https://doi.org/10.24321/2454.8650.201906

least square method. Figure 5 shows the experimental value and predicted value for kinematic viscosity of biodiesel.

Table 2.Comparison of Mean square error of ANN and Least square

Property	Mean Square Error	
	Least-squares	ANN
Flash point	5.74	0.16
Fire point	4.11	0.74
Viscosity	0.06	0.02
Density	5.3E-07	5.54E-06

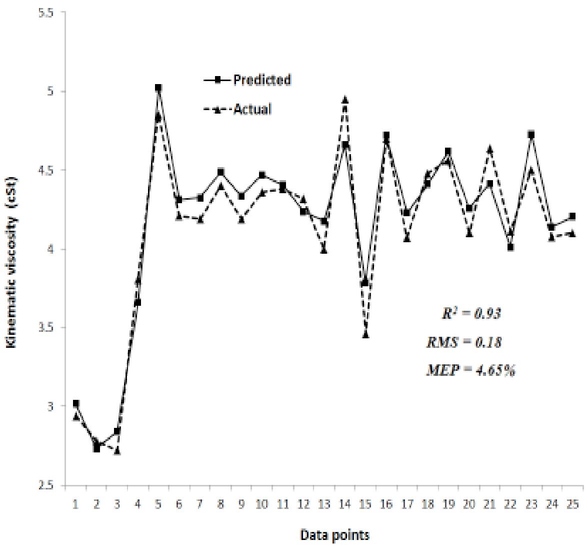

Figure 5.Experimental and Predicted Kinematic Viscosity

Giwa et al.[9] established ANN model to estimate the fuel properties of biodiesel from its fatty acid composition. They selected five prominent fatty acids present in biodiesel as input parameters. The developed ANN model involves five input parameters, a hidden layer and four output parameters. The ANN model predicted values nearer to experimental results having regression coefficients of 0.967, 0.958, 0.991 and 0.994 for cetane number, kinematic viscosity, flash point and density respectively.

Sousa et al.[10] have developed and tested several ANN models to estimate the iodine value of biodiesel. They used data obtained through experimentation for 98 samples with thirteen esters of fatty acids in the input layer and iodine value in the output layer. Levenberg Marquardt training algorithm was found to be a better network architecture with 0.99 correlation index for both testing and validation as seen in Table 3. Table 4, shows the network architecture design of trained network with activation function.

Table 4.Neural Network Architecture Design

Training parameters	Value
Backpropagation algorithms	Gradient descent Gradient descent with momentum BFGS quasi-newton Scaled conjugate gradien Resilient Propagation One-Step-Secant Leverberg-Marquardt
Activation function	tansig function logsig function purelin function
Number hidden layers	2
Performance function	MSE
Criteria generalization	Cross validation K-fold
Maximum validation error	and early stopping
iterations	20
Number of neurons by layer	2 – 25

Piloto et al.[11] have developed ANN model to predict cetane number from fatty acid composition of biodiesel which includes 48 and 15 samples for the modelling and validation respectively. They selected biodiesel samples for study based on different unsaturation characteristics and number of carbon atoms. They tested 24 different artificial neural networks in two phases. Phase one was back propagation algorithm and phase two was varied among back propagation, conjugate gradient descend, Levenberg-Marquardt, quasi newton and delta- bar- delta. Table 5 shows the trained neural network results with absolute error and correlation coefficient (%) for cetane number using linear and logistic output function. Figure 6 shows the comparison between two ANN models and experimental values of cetane number. The network

Table 3.Results of different Algorithms of ANN

Network	Algorithms	Activation Function	Training - R	Training - RMSE	Validation - R	Validation - RMSE	Test - R	Test - RMSE
9–4	Gradient descent	tansig	0.82	20.75	0.93	25.07	0.94	28.36
17–6	Gradient descent with momentum	tansig	0.94	10.3	0.99	7.337	0.92	22.61
9–9	BFGS quasi-newton	logsig	0.95	10.08	0.99	10.1	0.90	12.67
24–2	Scaled conjugate gradient	tansig	0.96	11,54	0.98	10,65	0.92	17,46
23–19	Resilient Propagation	tansig	0.98	8.008	0.99	4.445	0.95	12.5
25–15	One Step Secant	tansig	0.94	9.966	0.98	15.43	0.96	24.98
9–7	Leverberg Marquardt	logsig	0.99	4.3035	0.99	2.677	0.99	2,5832

with back propagation using conjugate gradient descent algorithm showing 96.3% of correlation for the validation data and 1.5 of mean absolute error was found to be better. The developed model was helpful in understanding the effect of individual fatty acids in the biodiesel on its cetane number.

Table 5.Absolute error and correlation coefficient (%) for cetane number using linear and logistic output function

nodes	BP	CGD	DBD	LM	QN	QP	nodes	BP	CGD	DBD	LM	QN	QP
3	2.7 (94.7)	2.4 (93.5)	2.4 (94.9)	1.9 (94.6)	1.9 (94.5)	2.1 (95.9)	3	2.2 (94.0)	2.1 (94.4)	2.6 (93.5)	2.2 (95.4)	2.4 (94.2)	2.3 (94.8)
4	2.9 (93.4)	1.6 (96.3)	2.3 (94.3)	2.4 (93.0)	1.5 (95.7)	2.4 (94.6)	4	2.8 (93.0)	2.6 (93.1)	2.4 (92.9)	2.3 (94.8)	2.5 (94.1)	2.4 (94.2)
5	2.3 (93.9)	2.6 (94.9)	2.0 (95.3)	2.3 (95.2)	2.1 (95.9)	2.1 (95.0)	5	2.2 (93.3)	2.5 (94.8)	2.0 (92.9)	2.4 (93.8)	2.2 (95.7)	2.1 (96.1)
6	2.3 (94.9)	2.5 (94.3)	2.0 (93.5)	1.9 (95.0)	2.4 (92.4)	1.9 (95.7)	6	2.1 (92.4)	2.3 (94.2)	2.0 (93.3)	2.7 (94.0)	2.0 (94.3)	2.4 (92.6)
7	2.7 (94.0)	2.3 (94.9)	2.6 (92.6)	2.0 (95.8)	1.8 (95.4)	2.1 (94.3)	7	1.9 (94.8)	2.3 (93.5)	2.2 (91.1)	2.5 (91.0)	2.5 (93.1)	2.3 (91.0)

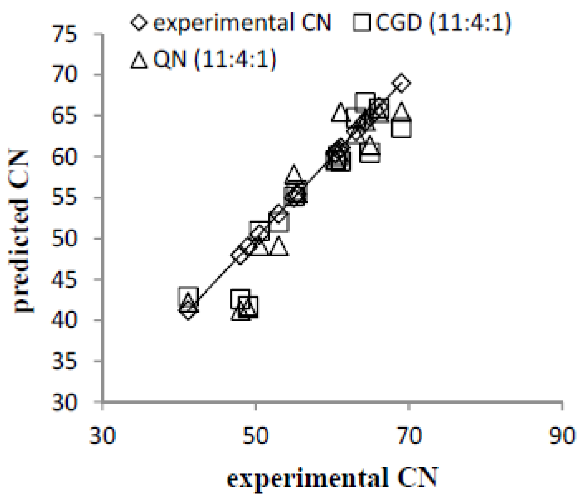

Figure 6.Comparison between two Neural Networks

Nazafi et al.[12] tested biodiesel for their heating values as per ASTM standards and these values were used as parameters in the output layer to train the neural model with fatty acids ethyl ester composition as input parameters. They designed a neural model with 4 neurons in the input and 1 neuron in the output layer. A 3-layer back propagation network with feed forward was developed in MATLAB software and different training functions and transfer functions were tested by adjusting epochs and error goal.

Conclusion

The Artificial Neural Network (ANN) technique developed for prediction of fuel properties of biodiesel are discussed. This helps in identifying the potential second generation feedstock for biodiesel production and also helpful for researchers for exploring potential feedstocks.

The following conclusions are drawn by reviewing the literatures.

- ANN model understands complex association between fatty acid composition of biodiesel and its fuel properties.
- ANN is powerful prediction method for characterization of biodiesel and its blends which will avoid time consuming and costly experiments.
- ANN model is the better choice for the prediction biodiesel fuel properties over statistical models.

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