Abstract  Biodiesel is an alternative fuel to replace fossil-based diesel fuel. It has fuel properties similar to diesel which are generally determined experimentally. The experimental determination of various properties of biodiesel is costly, time consuming and a tedious process. To solve these problems, artificial neural network (ANN) has been considered as a vital tool for estimating the fuel properties of biodiesel, especially from its fatty acid (FA) composition. In this study, four ANNs have been designed and trained to predict the cetane number (CN), flash point (FP), kinematic viscosity (KV) and density of biodiesel using ANN with logsig and purelin transfer functions in the hidden layer of all the networks. The five most prevalent FAs from 55 feedstocks found in the literature utilized as the input parameters for the model are palmitic, stearic, oleic, linoleic and linolenic acids except for density network with a sixth parameter (temperature). Other FAs that are present in the biodiesels have been considered based on the number of carbon atom chains and the level of saturation. From this study, the prediction accuracy and the average absolute deviation of the networks are CN (96.69%; 1.637%), KV (95.80%; 1.638%), FP (99.07%; 0.997%) and density (99.40%; 0.101%). These values are reasonably better compared to previous studies on empirical correlations and ANN predictions of these fuel properties found in literature. Hence, the present study demonstrates the ability of ANN model to predict fuel properties of biodiesel with high accuracy.

Keywords  biodiesel, fuel properties, artificial neural network, fatty acid, prediction

1  Introduction

Biodiesel has been considered as one of the alternative fuels to be used as a good replacement for diesel fuel in compression ignition engines for several reasons, among which is its production from a renewable source such as vegetable oils (VOs) and animal fats [1,2] Biodiesel is produced from the various feedstocks which are readily available in our environment. Biodiesel is produced from different sources; majorly from VOs, animal oils and fats, waste cooking oils, algae, grease [3,4], insect oils [5,6] and other oil-based wastes [7–9].

The physical and chemical fuel properties of biodiesel fundamentally depend on the fatty acids (FAs) distribution of the triglyceride obtained from the raw material used for biodiesel production [10,11]. The amounts and types of FA compositions contained in VOs determine the overall fuel properties of biodiesels such as viscosity, flash point (FP), high heating values, etc. [5,12]. The properties of the various fatty esters are determined by the structural features of the FA and the alcohol moieties that comprise a fatty ester. Structural features that influence the physical and fuel properties of a fatty ester molecule are chain length, degree of unsaturation, and branching of the chain [10,11].

Experimental methods are often used in the determination of fuel properties which provide good and high degree of accuracy results. This experimental determination of biodiesel fuel properties has to be conducted in accordance with standard test methods which have been provided for in different standards world over. The cost of running these tests is high, and is technically challenging, energy and time consuming. In a case in which these three issues are considered to be a minor issue, the availability of a well-equipped laboratory to perform these tests is scarce. Subject to the above, mathematical models, statistical models and artificial neural network (ANN) have been used in predicting the properties of biodiesel either from the FA composition or the level of saturation of VOs [11].

Mathematical models have been developed which can
be used, to a great extent, with a high level of accuracy in predicting the properties of biodiesels from their FA compositions [13–17]. Some studies have reported the development of statistical models for predicting the fuel properties of biodiesels by the correlation of their different FA compositions [12,18,19]. Of note is the fact that transeserification does not alter the FA composition of the feedstock employed in biodiesel production [11].

Artificial intelligence systems are widely used as a technology offering an alternative way to tackle complex and ill-defined problems. ANNs are types of artificial intelligence systems that endeavor to mimic the way the human brain works. They are nonlinear information processing devices, which are built from interconnected elementary processing devices called neurons. They can learn from examples or garnered data and are fault tolerant in that they are able to handle noisy and incomplete data. They are also able to deal with nonlinear problems or data, and once trained can perform prediction and generalization at high speeds [20].

The ANN method involves the use of certain properties of biodiesel which have been previously known or obtained via experimental results to predict future biodiesel properties. Few studies have employed ANN to predict the properties of biodiesels from their FA compositions. Cheenkachorn [12] combined statistical models (using best subset method) and ANNs to predict viscosity, higher heating and cetane number (CN) of biodiesels. The data primarily collected from literature has been used to predict the properties of biodiesels using the FA compositions of various VOs. It has been concluded that the statistical model can fairly predict viscosity and CN of biodiesel while the ANN model can accurately predict these properties, and that the predicted values are close to the experimental results. Ramadhas et al. [21] have developed and trained a multi-layer feed forward ANN to reliably predict the CN of biodiesel using the FA compositions of biodiesels and the experimental values of CN. ANN predicted CNs has been found to be in good agreement with the experimental CNs. Furthermore, ANN has been designed to predict the density of various VO-based methyl esters. The experimental densities obtained have been used to train the networks by applying a three-layer back propagation neural network. The results from the networks are in good agreement with the measured data [22].

The facts that previous studies employing ANN for the prediction of biodiesel properties from their FA compositions are scarce and that few numbers of feedstocks have been used for such work have necessitated the present study. To effectively train and predict biodiesel fuel properties from the FA compositions of feedstocks using ANN, FA compositions of 55 different feedstocks obtained from literature have been used during the course of this study. The primary objective of this study is to train and predict some key fuel properties of biodiesel from the FA composition using ANN model.

2 Materials and method

2.1 Artificial neural network (ANN)

ANN is trained to learn the complex relationship between two or more variables or data sets. Usually, ANN are trained and adjusted so that a particular input leads to a specific target output. To achieve a good network, many data sets, that is, input/target pairs are needed to train the network. How the ANN transforms its input vector into output vector depends on the neuron model and architecture. The computation of the output includes the product of the output and weight of the neuron summed with the bias of the neuron, which is passed through a transfer function in order to get the output of the neuron. Neurons may be simulated with or without bias [22].

2.2 ANN modeling

ANN modeling consists of the input layer, the hidden layer and the output layer which are connected to each other. The input layer receives the input data outside the network and sends it to the hidden layer. The hidden layer contains interconnected neurons for adjusting the weights on the connections. They contain several functions and variables including weights, transfer functions, and methods to add up all inputs and bias values. The sum of all products of all the inputs multiplying the weights and the bias values pass through a nonlinear transfer function as the output of each neuron [12]. Neurons that receive the same input and use the same transfer function may be grouped in layers. In back propagation (BP), networks often have one or more layers of sigmoid neurons followed by an output layer of linear neurons. The results from the hidden layer are sent to the output layer as the outputs. A 5:2:4 ANN architecture with neurons in each layer has been used in this study as shown in Fig. 1.

![Fig. 1 Architecture of ANN (5:2:4)](image-url)