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Research Article

Prediction of recital characteristics of a CI diesel engine operated by bio-fuel extracts from cotton seed oil, linseed oil and mahua seed oil using ANN method

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ABSTRACT

In the wide survey, it is explored that the potential of artificial neural network is used to foretell the recital (performance) characteristics of a four stroke single cylinder diesel engine using the biofuel obtained from cottonseed, linseed and Mahua seed. The test engine was powered with diesel and biofuel with its blends from cotton seed, linseed and Mahua seed separately. Experimental results of the cotton seed oil, linseed oil and mahua oil as a substitute for diesel revealed that linseed oil provides the better engine performance nearly equal to diesel. The ANN is used to compute the performance characteristics such as Indicated power, Brake power, Friction power, Thermal efficiency, brake mean effective pressure, brake thermal efficiency, Brake specific fuel consumption, Indicated thermal efficiency, indicated mean effective pressure, Mechanical efficiency, Indicated specific fuel consumption, volumetric efficiency and combustion characteristics as compression ratio at different conditions of torque, speed, water flow , air rate and fuel rate. An ANN sculpt was developed with 80% of training data and 20% of testing data from experimental values. In this model, back propagation feed forward neural network with five inputs and eleven outputs has been used. The ANN model result accuracy was found to agree nearly with the experimental results with the regression coefficient value approximately equal to one and low mean square error value. Thus, the proposed ANN model was legitimate tool for predicting the combustion and performance of diesel engine.

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INTRODUCTION

Energy resources have a vital part in enhancing economic growth and the demand of fossil fuels also increases day by day. Fossil fuels are the major source for transport and power generation [1].In order to find an alternate for the commercial fuel to overcome its depletion leads to the development of biofuels [2]. The benefits of using biofuel includes the reduction of carbon dioxide emissions, no sulphur content and aromatic compounds, renewable and easy to handle safely [3]. Biodiesel also has the properties includes higher lubricity, flash point and cetane number [4]. The researchers found that biodiesel having low exhaust emission, less oil consumption and reduced wear and tear of engine characteristics [5]. The observations on the viability of biofuel as a substitute shows that it requires long period for mass production and commercialize [6]. The renewable biofuels are obtained from edible feedstocks (vegetable oil, sunflower oil, palm oil and peanut oil), non-edible feedstocks (jatropha oil, mahua oil and Pongamia oil), animal fats, cooking greases and waste plastics [7]. Test of vegetable oil as biofuel proves that it performance satisfies short term quality and due to heavy deposition and higher wear, it dissatisfies long term quality [8]. Vegetable oil as a fuel it allows carbon deposits, poor gas atomization and also has high viscosity and cost [9]. Poor properties of vegetable oil are eliminated by either alkaline transesterification or acid catalyst transesterification process [10]. Ultrasonic cavitation technique can also be used for the extraction of biodiesel. In this technique, transesterification process occurs at ultrasonic reactor which decreases the reaction temperature and time [11]. The reviews illustrate to reduce the negatives of biodiesel and to enrich its quality by adding different type of additives [12]. The Production cost of biofuel was mostly determined by the feedstock material from the agricultural industry which are available inexpensively. Biofuel production cost is very economical with the petroleum manufacturing cost.

Authors experimented cotton seed oil and its blends for diesel engine results that suitability of 40% blends for short term performance and emission [13]. The use of compressed natural gas with cotton seed oil and its blends provides better thermal efficiency and reduced emissions [14]. Results exposed that cotton seed oil with ZnO improves catalytic properties and also increases surface to volume ratio [15].Cotton seed oil with low cost calcium oxide from egg shell as catalyst provides lower emissions of CO and unburnt hydrocarbon [16]. The observation from the experimentation shows that B50 and B75 blends of cotton seed oil increases the brake thermal efficiency [17].

Linseed comprises of high amount of fatty acids which can also be converted to biofuel and also renewable energy source with lower oxidative stability [18].Studies found that addition of low level of linseed oil increases in-cylinder pressure and high heat release rate with decreased indicated thermal efficiency [19]. The combination of linseed and rubber seed oil blends provides the better mechanical performance of the diesel engine [20]. Pre-heated linseed oil decreases viscosity used with titanium dioxide nano particle which has high oxygen content to enhance the engine performance and reduces the emissions of smoke, carbon monoxide and hydrocarbon [21]. Pre-heated linseed oil in coated engines increases the combustion efficiency and emission of oxides of nitrogen [22]. The mixture of soybean, linseed and crambe biodiesel provides lower SO_2 emissions and suggested as a partial alternate of commercial fuel [23].

Experimentation results of the mixture of equal amount of rapeseed and mahua seed oil as a biofuel exposes that dual biodiesel blend BL20 delivers reduced CO,HC and smoke emissions at full load conditions and higher NOx emission [24]. Research investigation on blending ratios of Kusum methyl ester, Karanja methyl ester and Mahua methyl ester biodiesel shows better brake thermal efficiency, thermal efficiency and brake power [25]. The sway of Mahua biodiesel blends used in the diesel engine observed that 25% of mahua oil with diesel improves engine performance with slightly increased nitrogen oxide emission compared with diesel [26]. The limitations of Mahua oil has overwhelmed by the transesterification reaction with oxygenated and metal based additives [27]. The physicochemical characteristics of mahua and jatropha biofuel evaluation reported that it met the requirements of Europe, USA and Indian standards. The mathematical model and the formulation of regression equations achieve the higher regression coefficient [28].

Generally, the emission characteristics of biofuels have an advantage compared with petro fuels. Burning of biofuel emits less $CO_{2,}$ SO_2 and carbon monoxide emissions. The rate of fuel consumption is based on the emissions where the higher concentrations of CO2 emission indicate the completion of combustion. As the biofuel concentration increases in the fuel mixture, CO_2 emission decreases due the dilution of exhaust measurements caused by excess air. Increased peak fuel pressure with decreased premixed combustion and higher diffusion combustion phase was observed for cotton seed oil [29].Studies reveals that cotton seed methyl ester blends with compressed natural gas provides lower emissions and greater thermal efficiency [30] Mahua oil blends in the exhaustive engine have better performance with less emissions of smoke, hydrocarbon and carbon monoxide. Nitrous oxide emission was controlled by adding suitable catalytic converters and for good combustion of biofuels the injection timing and duration to be analyzed [31].The performance of biofuels with the addition of hydrogen increases BTE and decreases the emission of smoke, CO and unburned hydrocarbons [32] and very small addition of algae biofuel blends shortens the ignition delay [33].The review shows that emission and combustion characteristics of biofuels are comparable to the commercial fuel.

T. Agarwal et al. experimented the engine performance fueled with biodiesel –alcohol blends and optimized the performance parameters using taguchi method, multiple regression and artificial neural network. From the observations, it was stated that neural network techniques can be opted for prediction process and the taguchi method for finding the optimal working conditions [34]. The optimization of multiple parameters of diesel engine was performed with the grey taguchi method. Finally the optimized parameters were used in ANN model to validate the experimental results [35]. Artificial neural network (ANN) solves various issues in science and engineering and it has applications in various fields. An ANN model are capable to re-learn without any prior knowledge and advances the performance by predictive technique from the trained data [36].ANN technique used for modeling the physical parameters without any mathematical representations [37].An ANN model predicts multiple outputs with high accuracy compared to the conventional methods and mathematical models. It is simpler and has the ability to add or remove any inputs and outputs depend on the user application [38]. Some of the application areas of ANN include data compression, pattern recognition, weather forecasting, medical diagnosis and so on. Studies recognized that ANN approach improves in detecting the engine system reliability [39]. The review on the optimization and prediction technique reveals that ANN was the best choice for the confirmation test results.

In this work, experiments were done with the fuels collected from cottonseed, linseed and mahua seed and with all its blends separately. In addition, to estimate the performance characteristics of the diesel using these biofuels, artificial neural network model was constructed using the values obtained from the experimentation.

EXPERIMENTAL EXPLORATION

Preparation of Bio Fuels

Bio-fuel is extracted from both edible feedstocks and non-edible feed stocks which are renewable and biodegradable resources and it also free from sulphur and aromatic hydrocarbon compounds. Various methods are available for the biodiesel production includes microwave radiation, direct use and blending, pyrolysis, micro-emulsification, heterogeneous catalyst and transesterification. In these methods, transesterification is

$$\text{Glycerol ester (Triglycerides)} + \text{alcohol} \xleftrightarrow{\text{Catalyst}} \text{Mono-alkyl ester} + \text{Glycerol}$$

The mostly used technique for the biodiesel production. Transesterification is the production of mono alkyl ester from the glycerol ester of long-chain fatty acid. The chemical rejoinder of triglyceride oil with alcohol results in the formation of glycerol. Ester is formed as by-product in the occurrence of acid or base catalyst which speed up the reaction and complete it by separating the glycerol and ester (either methyl or ethyl ester depends on the reactant i.e., methanol or ethanol).

Extraction of Bio Diesel from Mahua Oil

Mahua seed oil is renewed into biodiesel by the process of transesterification. Methanol (6:1 molar ratio) as a reactant and sodium hydroxide as a catalyst are used in making of biodiesel from Mahua oil. The reaction was carried out at 60^{0}C for 60 min. Then, the by-product was allowed to settle down. The upper layer was Mahua biodiesel and the bottom layer was the glycerol. The obtained Mahua methyl ester (Mahua biodiesel) was combined with diesel to make the blends as D100 (100% pure diesel), B5 (5% of mahua oil+ 95% of diesel), B10 (10% of mahua oil + 90% of diesel), B20 (20% of mahua oil+ 80% of diesel), B30 (30% of mahua oil+ 70% of diesel). The process of extraction of Mahua oil is shown in the Figure 1.

Extraction of Bio Diesel from Linseed Oil.

Methanol (99% pure) and sodium hydroxide was taken in a Pyrex glass beaker. 20% of methanol and 0.5 % of sodium hydroxide was taken for preparation. To obtain sodium methoxide, the mixture was shacked well for 15 minutes for thorough mixing of the chemicals to make it hot fumed. The linseed oil was thinned by heating the glass

Figure 1. Mahua oil extraction process.

Figure 2. Linseed oil extraction process.

Figure 3. Cotton oil extraction process.

beaker in a gas stove at temperature 40°C to 50°C. Then, Sodium methoxide is added to the hot oil and stirred well for one hour, to mix thoroughly. It is further kept in the gas stove for 24 hours at temperature 55°C.Clear reddish liquid is formed on the top with heavy glycerin settling at the bottom. Then the linseed biodiesel (reddish liquid) at the top was separated manually. For the experimentation, the linseed oil blends (B5, B10, B20, B30 and D100) were used. The process of extraction is shown in the Figure2.

Extraction of Bio Diesel from Cotton Seed Oil

Cotton seed biofuel was also prepared by the trans-esterification process. It was performed by using 200 ml of methanol with 3.5 g of potassium hydroxide per one litre of cotton seed oil. The mixture was enthused for 60 min at 70°C in the reactor. The mixture is kept 24 hours, to patch up the glycerol at the bottom and then Cotton seed methyl ester is removed through the funnel. Cotton seed biofuel can also be mixed with dimethyl carbonate (DMC). The blend of cotton seed oil includes blends with DMC (D100, DMC5, DMC10 and DMC15) and also without DMC (B5, B10, B20, B30, B40 and D100). Dimethyl carbonate was used as a blending compound because it has high oxygen content and low calorific value which diminishes the density of the fuel mixtures. The process of extraction is shown in Figure 3.

Determination of Flash and Fire Point

In general, the indicators of flammability for a liquid fuel specimen are the flash and fire points. Flash point is defined as the temperature of the fuel specimen, when referred to a barometric pressure of 101.3 kPa should be low, at which the purpose of an ignition source causes the vapor of the fuel specimen to catch fire shortly. Fire point is defined as the temperature of the fuel specimen, which should be the lowest, at which vapor combustion and flaming commence. The flash and fire points are determined by using Pensky-Marten's apparatus as shown in Figure 4(a).

Determination of Calorific Value

The energy liberated per kg of fuel when it is burnt is defined as the calorific value of fuel specimen. Bomb Calorimeter is used to quantify the calorific value of fuel. The calorimeter as shown in Figure 4 (b), contains a cylindrical vessel and it comprises of a lid that support two electrodes. The electrodes are in contact with the fuse and fuel sample. The weight of the fuse and fuel sample are predetermined. The lid has an inlet valve from which oxygen gas is delivered in a pressure 25 to 30 atm. The intact lid containing fuel sample is kept within a copper calorimeter. The calorimeter contains water and its weight is measured. A perfunctory stirrer is attached to stir the water to enhance

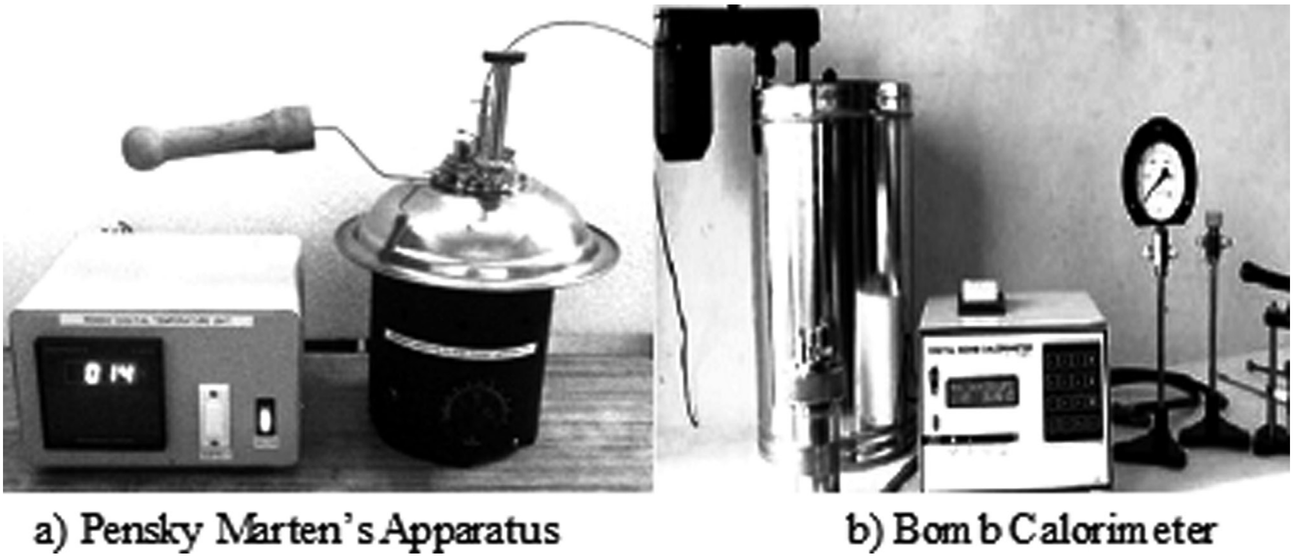

Figure 4. Testing of properties of liquid fuel specimen.

Table 1. Fuel properties

Properties	Diesel	Cotton seed oil (CSME)	Linseed oil (LSME)	Mahua oil (MOME)
Calorific value (MJ/kg)	43.35	40.5	39.37	42.24
Flash Point (°C)	58	156	185	180
Fire point (°C)	62	166	192	186

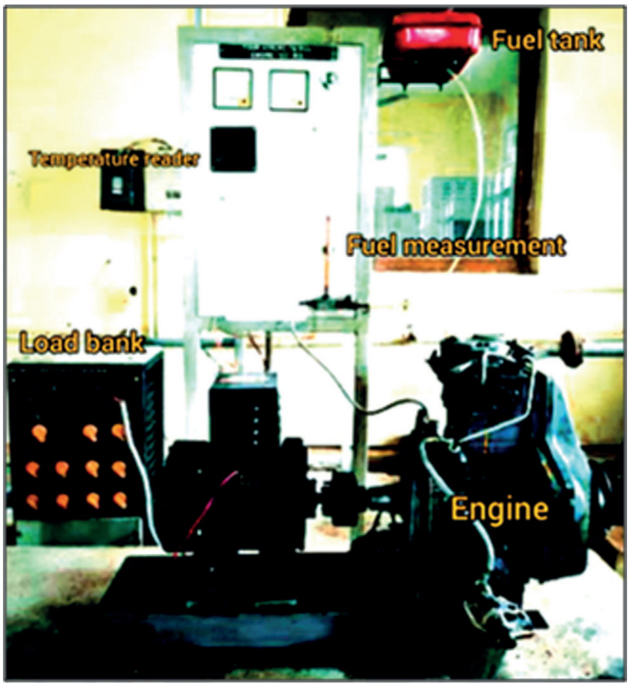

Figure 5. Engine setup.

uniform heating of the water. A thermometer is attached to estimate the temperature difference of water due to the combustion of fuel in lid. The flash point, fire point and calorific value is listed in the Table 1.

Procedure for Performance Test

The performance test was conducted in the engine setup as shown in Figure 5. The engine specifications are listed in the Table 2. The engine is united to a loading system which is a DC GENERATOR. The load set up has a bank of resistive lamps, which takes load with the support of DC switches. It also serves motoring test facility to find out frictional power of the engine. The engine shaft is directly attached to the DC Generator which can be encumbered by lamp bank. The load can be assorted by switching ON the load bank. The fuel is delivered to the engine from the main fuel tank through a graduated Burette. The fuel consumption of the engine is measured by filling the burette by opening the cock. The time in use to devour 10 cc of fuel by the engine is measured by using a stop watch. The test are carried out with the cotton seed oil blends with and without DMC, linseed oil blends and Mahua oil blends separately. The performance analysis includes BP, IP, FP, BSFC, ISFC, BMEP, IMEP, VE, BTE, ITE and ME. Extensive Experimentation has been made and the observations have been analyzed and plotted in graphs. For the experimentation, torque, speed, fuel rate, air rate and water flow are kept as the controlling inputs and then the engine performance were made. BSFC measures the volume of input energy needed to develop one-kilowatt power. B20 blends of cotton seed oil, DMC15 blends of cotton seed oil with DMC, B20 and B30 blends of linseed oil and B5 blends of Mahua oil has lower BSFC values compared to the diesel

ARTIFICIAL NEURAL NETWORK MODEL

ANN is a powerful tool to prognosticate the engine performance. ANN comprises of three parts as an input layer, some hidden layer and an output layer. Two stages of operation improves ANN model includes learning (training stage) and verification (testing) stage. In the feed forward neural network, interconnection of input layer with hidden layer and hidden layer with the output layer are connected by synaptic weights. Synaptic weights are modified on each iteration during the training phase in order to learn the patterns in the training data. In the verification stage, the hidden layer and output layer determine the output. To train the model, different training algorithms includes Levenberg Marquardt, Gradient descent, Bayesian and secant back propagation are used. The result of network model is subjected to the transfer function such as tangent sigmoid, logarithmic sigmoid and linear transfer functions are used. The ANN model performance is depends on the performance function termed as mean square error. The testing and training errors were evaluated by the index called the mean square error. The accuracy of ANN prediction between desired and measured values were estimated by regression.

The input parameters of the network model were torque, speed, fuel rate, air rate and water flow in engine. The performance parameters are BP, IP, FP, BSFC, ISFC, BMEP, IMEP, VE, BTE, ITE and ME. Levenberg Marquardt (TRAINLM) training algorithm and tangent sigmoid function was used in this model. Levenberg Marquardt (TRAINLM) training algorithm achieves highest regression and lowest mean square with less number of iteration. Eleven engine-out reactions and five inputs using ANN was illustrated in Figure 6. ANN design settings for the performance prediction, training data and testing data are taken in different ratio were listed in the Table 3.

EXPERIMENTAL INVESTIGATION

Figure 7, 8, 9, 10 depicts the variation of brake thermal efficiency with the brake power performance of the cotton seed oil blends without DMC, cotton seed oil with DMC, linseed oil and Mahua oil respectively. It was examined that the brake thermal efficiency for the cotton seed oil blend B10 and B30 were closer to diesel. Cotton seed oil with DMC blend DMC15 shows its performance nearer to diesel. The brake thermal efficiency of B20 linseed blend was nearly equal to the performance of diesel. Similarly mahua

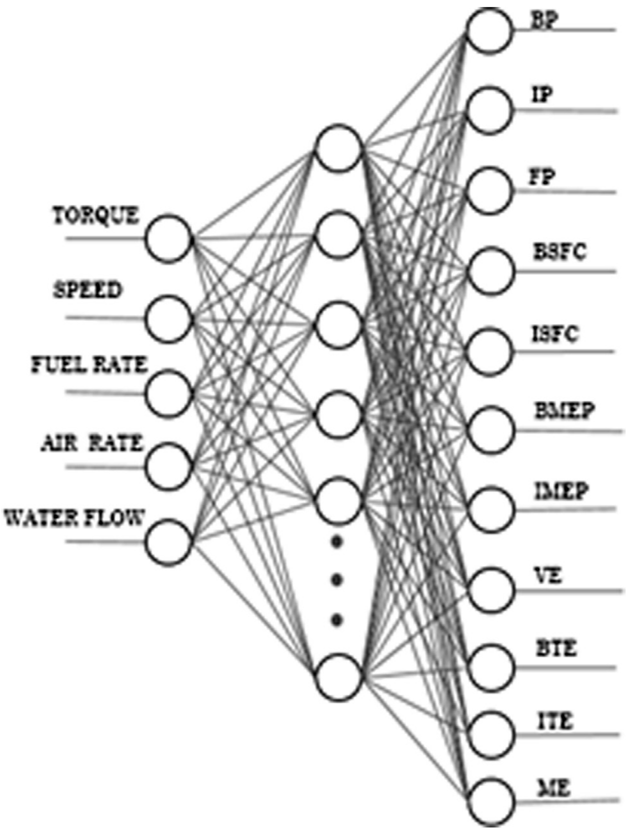

Figure 6. Proposed ANN architecture.

Table 3. ANN model settings on MATLAB tool

Network type	Feed Forward Back Propagation
Topology	5-20-11
Learning function	LEARNGDM
Training function	TRAINLM
Transfer function	Tansig
Performance function	MSE
Data	80% training, 10% Validation, 10% testing from experimental values

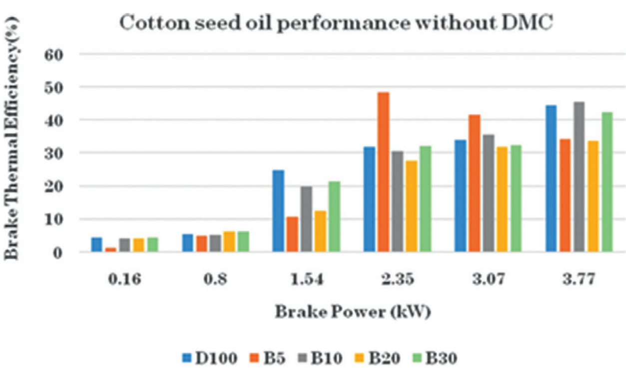

Figure 7. Variation of BTE with brake power at all cotton seed oil blends.

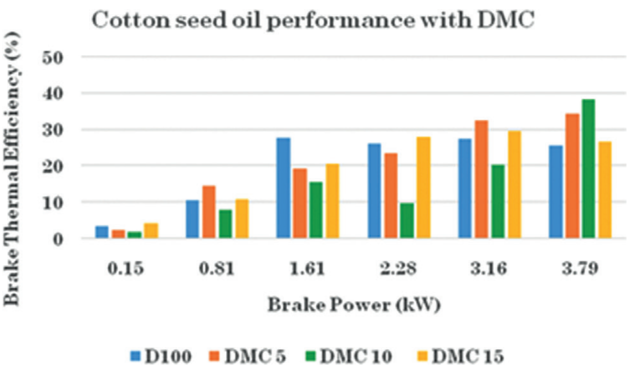

Figure 8. Variation of BTE with brake power at all cotton seed oil blends with DMC.

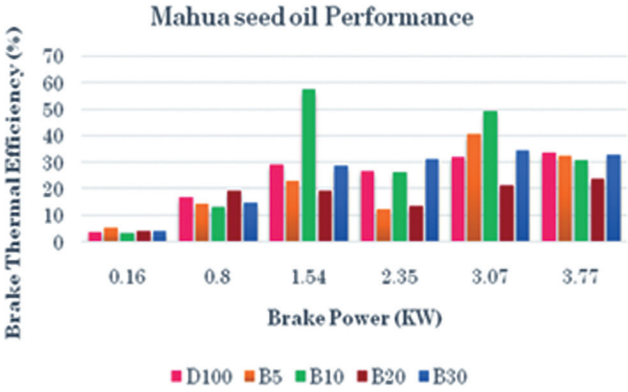

Figure 10. Variation of BTE with brake power at all mahua oil blends.

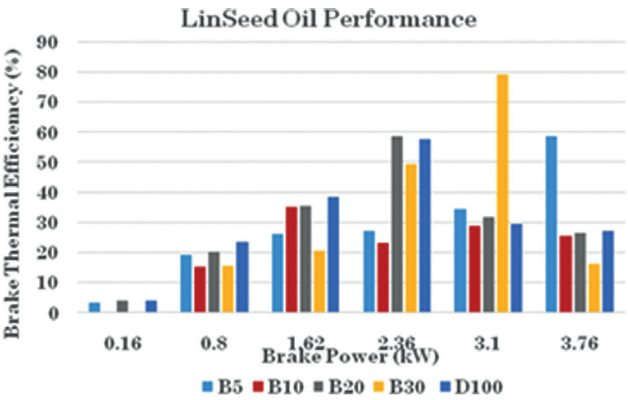

Figure 9. Variation of BTE with brake power at all linseed oil blends.

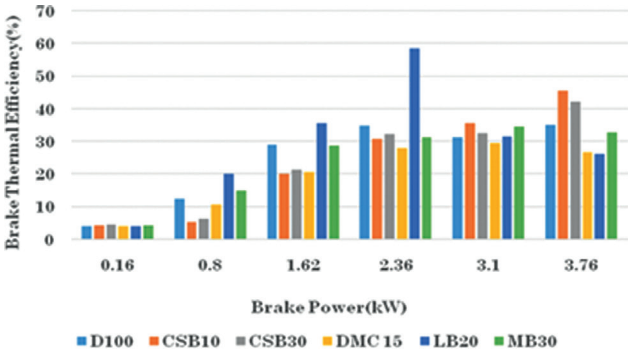

Figure 11. Comparison of BTE of blends of biofuels with diesel.

blend B30 shows higher similarity to diesel. Figure 11 determines the brake thermal efficiency of selected blends of cotton seed oil, linseed oil and Mahua oil. The selection of blends is based on the analyze of the graph between BTE and BP of various blends of biofuels as plotted in the Figure 7, 8, 9, 10. The values of linseed oil blend (LB20) are greater than or equal to the BTE of diesel.

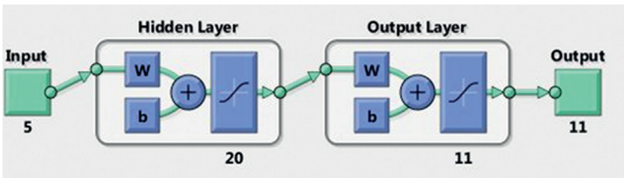

Figure 12. Proposed ANN model.

ANN MODEL SIMULATION RESULTS

The experimental data consists of the engine performance outcome of the biofuel obtained from the cotton seed and its blends (B5, B10, B20, B30, D100) with and without dimethyl carbonate, linseed and its blends (B5, B10, B20, B30, D100), mahua seed and its blends (B5, B10, B20, B30, D100). Based on the experimentation, an ANN sculpt was designed to foretell BP, IP, FP, BSFC, ISFC, BMEP, IMEP, VE, BTE, ITE and ME. Torque, Speed, Fuel rate, air rate and water flow are the input parameters for the neural network. The ANN model was trained with 80% of experimental value and tested with 20% includes validation. The proposed ANN model consists of five inputs and eleven outputs with 20 hidden layer neurons was shown in Figure 12. The ANN prediction was simulated in the MATLAB neural network toolbox.The ANN prediction was simulated in the MATLAB neural network toolbox. It provides in-built functions and apps for simulating the neural network. The tool automatically generate the code and perform the work automatically. Easier to develop a network using the apps to perform classification, clustering and regression.

Table 4. Regression coefficient and mean square error of biofuels

Fuel	Regression Coefficient				Mean Square Error
	Training	Validation	Testing	All	
Cotton Seed oil (without DMC)	0.99748	0.99363	0.99002	0.9956	0.1937
Cotton Seed oil (with DMC)	0.99782	0.97123	0.97898	0.98912	0.1239
Linseed oil	0.99848	0.99972	0.99952	0.99886	0.2472
Mahua seed oil	0.99581	0.99937	0.99955	0.99677	0.3378

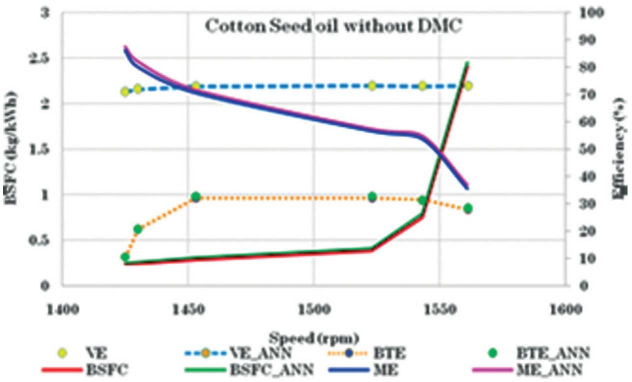

Figure 13. Experimented vs. ANN predicted values of engine performance tested with cotton seed oil without DMC.

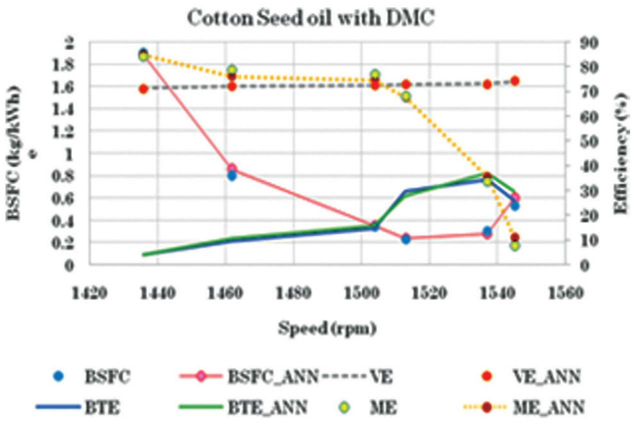

Figure 14. Experimented vs. ANN predicted values of engine performance tested with cotton seed oil with DMC.

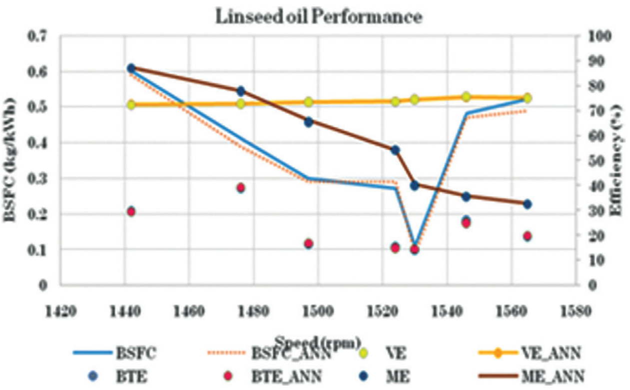

Figure 15. Experimented vs. ANN predicted values of engine performance tested with linseed oil.

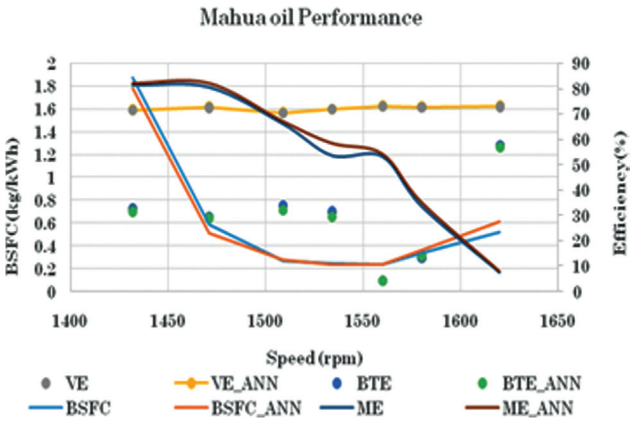

Figure 16. Experimented vs. ANN predicted values of engine performance tested with Mahua Seed oil.

The selection criteria for the optimum ANN forecast of output parameters for the test engine is the good correlation value and very low mean square error value. The regression coefficient embraces training, testing, validation and overall regression and the mean square error from ANN prediction for the tested biofuels are listed in Table 4.

The ANN estimates the performance of the diesel engine tested gave better performance result. Comparing the results of experimental and ANN prediction in the graph shows that tested with cotton seed oil blends can be precisely simulated by ANN. The comparison of experimented values and ANN predicted values for the engine performance such as BSFC, VE, ME and BTE using cotton seed oil as shown in the Figure 13and cotton seed oil with DMC is shown in the Figure 14.According to the obtained data, error between experimented and ANN predicted data was very less.

The test engine was performed with linseed oil and its blends to decide the engine performance in contrast with the commercial fuel (diesel). Variation of experimental and ANN predicted values of performance using linseed oil blends were shown in the Figure 15. The plotted results reveal that the experimented values are very much closer to the simulation results.

The test samples of mahua oil and its blends were tested in the diesel engine. The results of the ANN model and its graph shows a high degree of correlation between the experimental data and ANN predicted data. The plotted graph was shown in the Figure 16.

CONCLUSION

In this research, the extraction of biodiesel from the cotton seed, mahua seed and linseed were experimented by the transesterification process. The performance analysis of biodiesel (cotton seed oil, mahua oil and linseed oil) and its blends were tested in single cylindered four stroke diesel engine. The performance results were predicted by using ANN model. An ANN approach is used to envisage the performance parameters of diesel engine using back propagation algorithm in the multilayer feed forward neural network was simulated. The outcome of the trained ANN with the experimental value provides good association between the measured and the predicted data. The observations made from the experimentation and ANN prediction suggests the following conclusions,

- The performance plot showed that the brake thermal efficiency in relation with the brake power. The cotton seed blends oil without DMC (B10 & B30), with DMC (DMC15), linseed oil blend (B20) and mahua seed oil blend (MB20) revealed the brake thermal efficiency nearer to the engine performance using diesel.
- The brake Specific fuel consumption is lower when using linseed oil compared to the other biofuels such as cotton seed oil with and without DMC and mahua seed oil.
- The volumetric efficiency and the mechanical efficiency of all the biofuels were nearly same
- At the outset, based on the performance measure linseed has the properties nearly equal to diesel.
- ANN model predict the engine performance using the cotton seed oil and with DMC, linseed oil and Mahua oil with the correlation coefficient 0.9956, 0.98912, 0.99886, 0.99677 respectively.
- The mean square error between desired and measured output for cotton seed oil, linseed oil and Mahua oil were obtained as 0.1937, 0.1239, 0.2472 and 0.3378 respectively.
- ANN report showed a better relationship between the ANN predicted and experimental result. ANN is fairly powerful tool for predicting the engine performance.

NOMENCLATURE

ANN	Artificial Neural Network
BP	Brake Power
IP	Indicated Power
FP	Friction Power
BSFC	Brake Specific Fuel Consumption
ISFC	Indicated Specific Fuel Consumption
BMEP	Brake Mean Effective Pressure
IMEP	Indicated Mean Effective Pressure
BTE	Brake Thermal Efficiency
ITE	Indicated Thermal Efficiency
ME	Mechanical Efficiency
DMC	Di-Methyl Carbonate
CSME	Cotton seed Methyl ester
MOME	Mahua oil Methyl ester
LSME	Linseed Methyl Ester

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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