ARTIFICIAL NEURAL NETWORK PREDICTION OF PERFORMANCE CHARACTERISTICS OF BIOFUEL PRODUCED FROM SWEET POTATO (*IPOMOEA BATATA)*

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ABSTRACT: Fossil fuel depletion and the harm it causes to the environment has led to the development of alternative fuels. In this research, biofuel (ethanol) was produced and characterized from sweat potatoes. Blends of premium motor spirit with 0% (E0), 2% (E2), 4% (E4), and 10% (E10) of the produced biofuel at various percentages were separately used to power a four-stroke, single-cylinder SI engine on an engine test bed, and data of the engine performance - brake power, brake torque, brake mean effective pressure (BMEP), and the exhaust gas temperature reported in each test. The results of the physicochemical analysis revealed that the physical state of the biofuel is colorless, the viscosity at 30^0C, density, calorific value, and pH level are 0.9834 mPa.s, 0.85 g/cm^3,19 kJ/kg, and 1.82, respectively. It was observed that an increase in ethanol in the blend increases the performance of the engine, although the BMEP at E0 gave the highest value of 0.3 bar compared to other blends. An *artificial neural network* (ANN) model for predicting engine performance characteristics was developed, trained, validated, and tested using the reported data. The result of the ANN model revealed that the *Levenberg-Marquardt training algorithm* (LMTA) with 10 hidden layer neurons offers the best fit for the features for both training, validation, testing, and overall. With the *R* for training equal 1, validation equal to 0.99468, testing equal to 0.90103, and overall *R* equal to 0.93842 as compared to the rest in terms of the number of neurons and training algorithms.

KEYWORDS: *Biofuel, Characterization, Engine Performance, Artificial Neural Network, Algorithm*

1.0 INTRODUCTION

Energy is an important commodity that contributes to the standard of living and economic growth of humanity. Between 2010 and 2030, global basic energy demand is expected to rise by 1.6% per year [1]. A larger percentage of the primary energy consumed is gotten from fossil resources, essentially coal (29%), crude oil (35%), and natural gas (24%), while nuclear and renewable resources constitute about 7% and 5% of world energy consumption, respectively [1]. Fossil fuels are thus the largest source of energy, accounting for 88% of the total global energy consumption. Meanwhile, fossil fuels are being consumed rapidly. In 2013, it was projected that a peak in the world's crude oil production would occur between 2015 and 2030 based on the then production rates [2].

Furthermore, internal combustion (IC) engines are the primary source of poisonous gas emissions that have negative effects on the environment and human health, such as acid rain, greenhouse effect, global warming, unprecedented flooding, and other negative effects. The search for alternative fuels is on the rise for possible emission reduction, reducing fuel prices, providing clean energy, improving fuel availability, and reducing reliance on fossil fuels [3,4].

A great deal of biomass has been considered for producing sustainable alternative fuels. However, the most combative issue with the production of this biomass is the use of agricultural land for biomass production [2]. This means that lands that were intended to produce foods to meet consumption requirements are now being used for biomass production. Meanwhile, sweet potatoes (*Ipomoea Batata*) are grown in Nigeria, especially in Kogi, Benue, Plateau (Bui), Taraba (Mambilla Plateau), and Borno in commercial quantities [5]. Nigeria is among the largest producers of sweet potatoes in sub-Saharan Africa, with yearly production estimated at 4.03 million tons per year [6]. Also, sweet potatoes can do well both in tropical and temperate regions, whereas Irish potatoes grow well only in temperate regions [5].

Consequently, undertaking experiments with vehicle engines and determining fuels' multiple parameters requires substantial amounts of fuel, which can be a challenge from new sources [2]. Moreso, fuel evaluation requires sophisticated equipment and expert personnel, which can be costly. For this reason, ANN that can predict from small data sets was employed.

2.0 MATERIALS

The following materials were employed for this study:

i. The biomass used for this research work is sweet potato, which was sourced from a local market (E.g. a general market), in Idah area of Kogi State.
ii. A weighing balance was used for weighing the starch extracted from the biomass in the laboratory and the reagents used.
iii. A grader was used to grade the biomass (sweet potato) into smaller sizes.
iv. A conical flask/beaker was used to prepare the solution and collect the biofuel during the distillation process.
v. A thermometer was used for taking temperature readings during the production of biofuel.
vi. Reagents: Reagent such as tetraososulphate (VI) acid (H_2SO_4) was used to hydrolyse the compound (the starch), alpha-amylase (dehydrogenase enzyme) was used for breaking down starches in grains into fermentation sugars, glucoamylase (amylo-glucosidax) was used for breaking down starches into glucose, and saccharomyces levadura yeast was used to convert the sugar after liquefaction and saccharification process into biofuel.

3.0 METHOD

3.1 Biofuel production from sweet potatoes

The experimental procedure for the production of biofuel from sweet potatoes is shown in Figure 1. The biofuel production procedure was adopted from Salelign and Duraisamy in the year 2021 [7]. In this work, 400 g of sweet potato starch was mixed with 1600 ml of distilled water (1:4). The mixture was stirred properly and heated at a temperature of 80^0C for the gelatinization process. During the liquefaction process, tetraososulphate (VI) acid (H_2SO_4) was added to achieve the pH level. The sample was allowed to cool down to a temperature of 65^0C, then 100 g of the alpha-amylase was mixed into 250 ml of distilled water and poured into the sample to liquefy the heated sample slowly. Consequently, the sample was allowed to cool down to a temperature of 30^0C through natural convection. After that, 10 g of the glucoamylase was mixed with 20 ml of distilled water and poured into the sample. The sample was further cooled, and 40 g of saccharomyces cerevisiae yeast was mixed with 100 ml of distilled water and poured into the sample. The sample was kept for 72 hours at room temperature in a closed vessel for the fermentation process. The fermentation process lasted 72 hours. The biofuel crude was transferred to the distillation apparatus for the distillation process where the biofuel was collected.

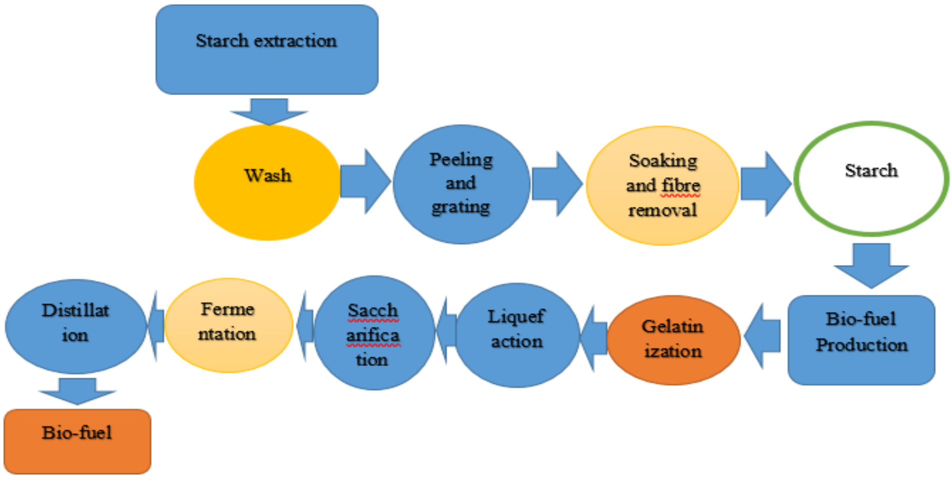

Figure 1: Experimental procedure for biofuel production from sweet potatoes

3.2 Physicochemical characterization of the biofuel produced

Physicochemical characterization of the biofuel produced was achieved through the American Society for Testing and Material (ASTM) standard test procedure. ASTM D3588, D1298-99, D445, and D6423 were used to determine the heating value, density, viscosity, and pH value of the fuel produced.

3.3 Engine performance evaluation of blends of the biofuel produced

The engine performance was carried out using a TQ200 small engine testbed with specifications shown in Table 1. The experimental setup consists of four strokes, and a single-cylinder carburetor SI engine coupled with a dynamometer for load control. The instrumentation unit is connected to a computer system using the versatile data acquisition system (VDAS) software for taking readings. Torque, engine speed, brake power, brake mean effective pressure (BMEP), and exhaust gas temperature of the blends were measured. The experimental setup for the evaluation of engine performance is shown in Figure 2.

During the performance evaluation test, the biofuel was blended with premium motor spirit (PMS) obtained from a reliable filling station in Idah area of Kogi State, Nigeria. The blends were code named E2, E4, E6, E8, and E10, respectively. Where E2 represents 2% of the biofuel produced, mixed with 98% of the PMS, and so on. The performance evaluation was carried out for each blend at a constant speed of 3,000 rpm, and the results are presented in the result and discussion sections

Table 1: TD200 small petrol engine testbed (TQ brand) specifications

Engine type	4-stroke, single cylinder
Continuous rated power	2.6 kW at 3000 rpm 2.9 kW at 3600 rpm
Bore/stroke/crank radius	67mm/49mm/24.5mm
Displacement vol.	172cc
Compression ratio	8.5:1
Engine cool/fuel	Water cool/gasoline (petrol)
Ignition system	electric
Maximum dynamometer rating	7.5 KW at 7000 rpm

Figure 2: Experimental set up for engine performance test

3.4 Engine performance characteristics prediction of the biofuel using artificial neural network (ANN)

Due to the sophisticated nature of the equipment used for fuel testing, and the scarcity of expert personnel needed in fuel evaluation, and also, high cost of undertaking experiments that relate to fuel produced from new sources, an ANN model was developed to help in the rapid evaluation of new fuel that might be produced from sources similar to the source used in this study.

An artificial neural network is a collection of interconnected neurons grouped into a network [8]. The network consists of the input layer, hidden layer, and an output layer. The input layer accepts data (features) and communicates the data with the hidden layer. The hidden layer is where the computation and activation of neurons occurs. The output layer gives the predicted results.

Activation of the neurons depends on the type of activation function (such as Sigmoid, Relu, Threshold, Hyperbolic tangent, etc.) used. However, irrespective of the activation function, weight parameterization is what is taking place in the hidden layer, which is then summed up and caused to activate the neurons. For example, assuming there are $x_1, x_2, x_3, \dots, x_n$ number of inputs, and $w_1, w, w_3, \dots, w_n$ number of weight, respectively, the sum of the products of the inputs and weight ($i = 1$ to $i = n$) as shown in equation 1, produced the activation, *a*, of the neuron [8].

$$a = \sum_{i=1}^{n} x_i w_i \tag{1}$$

For this work, the ANN model as in Figure 3 accepts the engine speed and fuel-blend ratio as the inputs to the network. The torque, brake mean effective pressure (BMEP), brake power (BP), and exhaust gas temperature (EGT) of the blends gotten from the testbed were entered into the network as the target outputs All photographs and figures should have good resolution, and contrast quality. At least 300 dpi is applied for the resolution.

The *Levenberg-Marquardt training algorithm* (LMTA) and the *Bayesian Regularization algorithm* (BRA) were used for training the network. The training was done for three sets of hidden layer neurons - the first, second, and third sets consist of 10, 15, and 7 neurons, respectively. The data was divided into three random sets: training, testing, and validation data set which are 70%, 15%, and 15%, respectively.

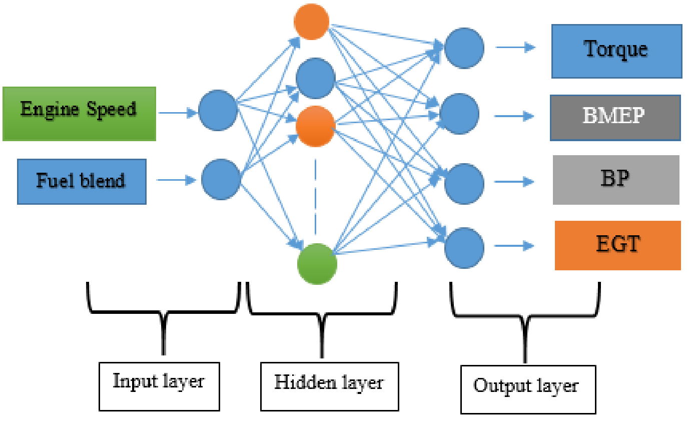

Figure 3: Artificial neural network for predicting engine performance characteristics of biofuel

4.0 RESULTS AND DISCUSSION

4.1 Physicochemical properties of the biofuel produced

The physicochemical properties of the characterized biofuel are summarized in Table 2. The biofuel is colorless and has an affinity for water and is readily miscible with PMS. Table 2 shows that the biofuel has a density of 0.85 g/cm^3 and the viscosity of the biofuel produced was 0.9834 mPa.s at a temperature of 30^{0}C. Biofuel and PMS have very close specific gravity, making them miscible to form a homogeneous substance [4]. The result also shows that the pH (1.82) level of the produced biofuel is very low, which is responsible for a very high acidic content compared to the pH level of PMS and a standard biofuel.

Table 2: Physicochemical properties of the biofuel from sweet potatoes

S/N	PARAMETER	UNIT	RESULT
1	Physical state	-	Colorless
2	Density	g/cm^3	0.85
3	Viscosity at 30^{0}C	mPa.s	0.9834
5	Calorific value	kJ/kg	19
6	pH	-	1.82

4.2 Engine performance evaluation

4.2.1 Torque

The result of the engine performance test conducted shows that as the percentage of the biofuel increases in the blend, the torque equally increases as shown in Figure 4, with the highest value recorded by E10. This corresponding increase in torque may be due to the low heating value, high density, and higher latent heat of evaporation of the biofuel compared to that of base gasoline [9]. The produced biofuel, therefore, exhibits the potential to increase the ability of an engine to perform work, which agrees with the work of [4].

4.2.1 Exhaust Gas Temperature (EGT)

The behaviour of EGT with a change in biofuel blends is shown in Figure 5. During the performance test, it was observed that as the biofuel percentage increased in the blend, there was an increase in the exhaust gas temperature at a constant speed of 3000 rpm. Meanwhile, the increase in the EGT between E0 and E2 is twice as high as that of E2 to E10. This behaviour shows that the biofuel produced moderates EGT as the blend increases. Figure 5 reveals that E10 has a maximum value of EGT, which is 481^{0}C. The scope of this work does not cover the emission analysis of the produced biofuel. However, according to [10] an increase in EGT at a high speed of around 6000 rpm causes about three times increase in nitrogen oxide (NOx) emission. And basically, EGT is an indication of the air-to-fuel mixture of an engine.

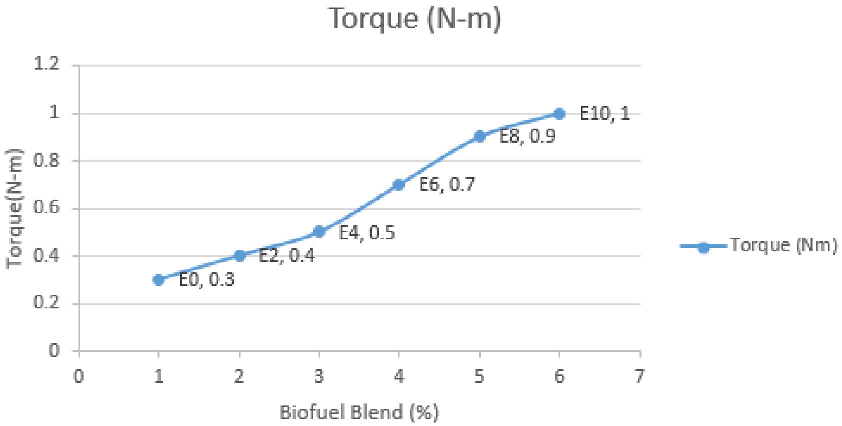

Figure 4: The engine torque (N/m) with ethanol blend (%)

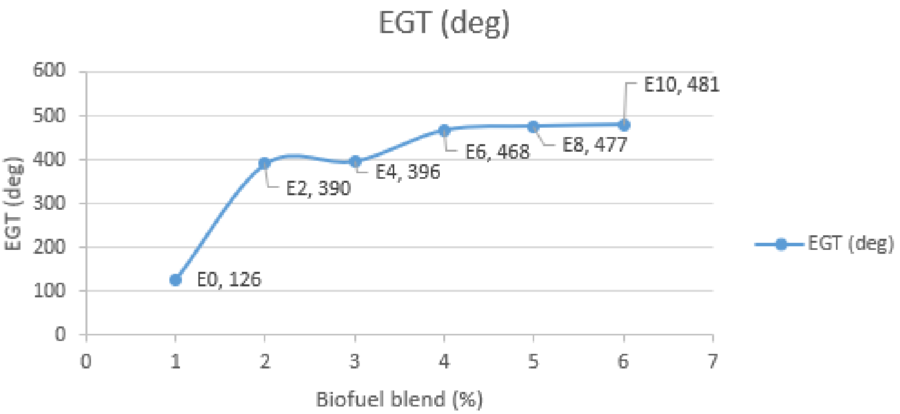

Figure 5: EGT (^{0}C) of the biofuel blend (%)

4.2.3 Brake Power (BP)

The brake power is the power available at the crankshaft. In the case of the IC engine, it is the output power. From the engine performance test, the result shows that the biofuel blends increase the brake power, respectively, at a constant speed of 3000 rpm, as shown in Figure 6. Therefore, using a fuel blend with biofuel is useful to improve the engine power output.

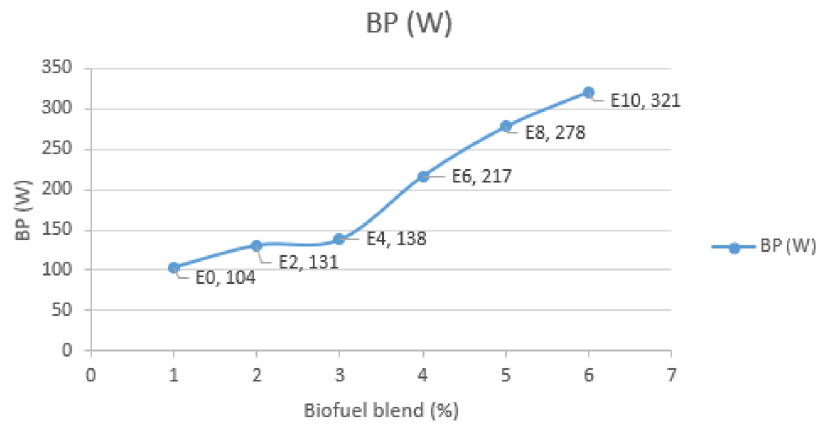

Figure 6: Engine performance on brake power (W) with biofuel blend (%)

4.2.4 Brake Mean Effective Pressure (BMEP)

The brake mean effective pressure is a calculation of the engine cylinder pressure that would give the measured brake power. It is an indication of engine efficiency regardless of capacity or engine speed. From the engine performance test, it was also observed that the brake mean effective pressure (BMEP) of the pure PMS has the highest value (0.3 bar) in comparison to the ethanol blend of E2, E4, E6, E8, and E10, respectively, at a constant speed of 3000 rpm as shown in Figure 7. Therefore, the PMS gave the higher engine efficiency, meanwhile, E4 indicates a competitive engine efficiency having a BMEP value of 0.28%.

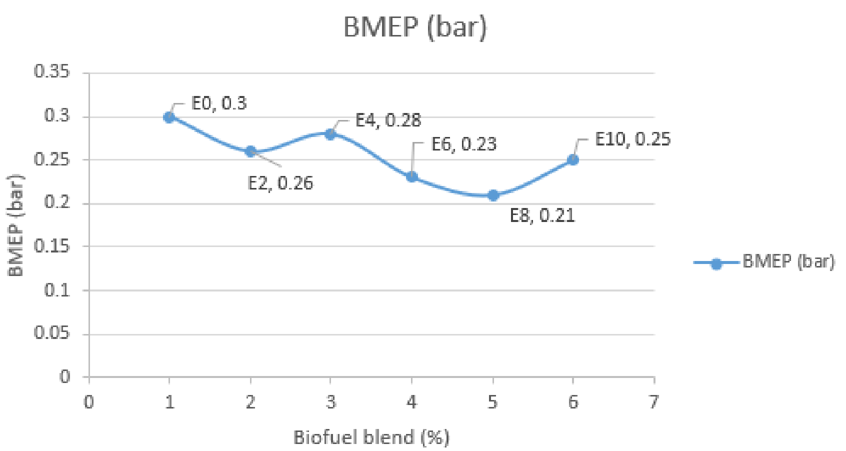

Figure 7: The BMEP (bar) of an engine with different ethanol blend (%)

4.3 Artificial Neural Network Model of the engine performance characteristics

The neural network model revealed that the LMTA training algorithm with 10 hidden layer neurons as in Figure 8 offers the best fit for the features for both training, validation, and testing as compared to fifteen- and seven-layer neurons as is Figure 9 and Figure 10, respectively. With the, *R*, value for training equal to 1, validation equal to 0.99468, testing equal to 0.90103, and overall, *R*, equal to 0.93842 as compared to the rest in terms of the number of neurons and training algorithms. Figure 9 to Figure 10 are the regression plots for the 15 neurons and 7 neurons optimized with LMTA.

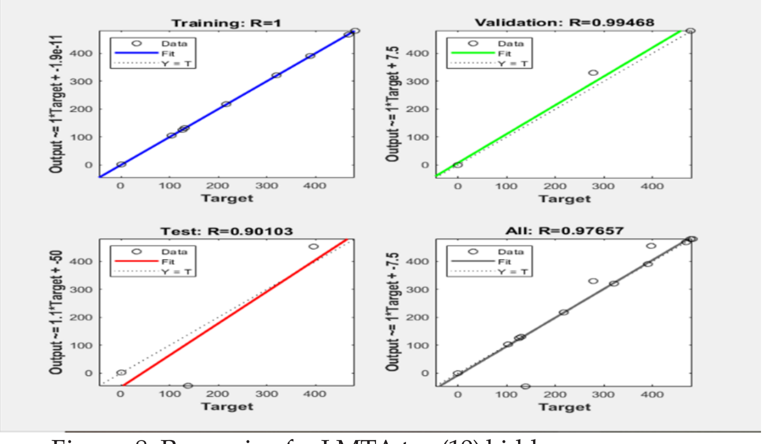

Figure 8: Regression for LMTA ten (10) hidden neurons

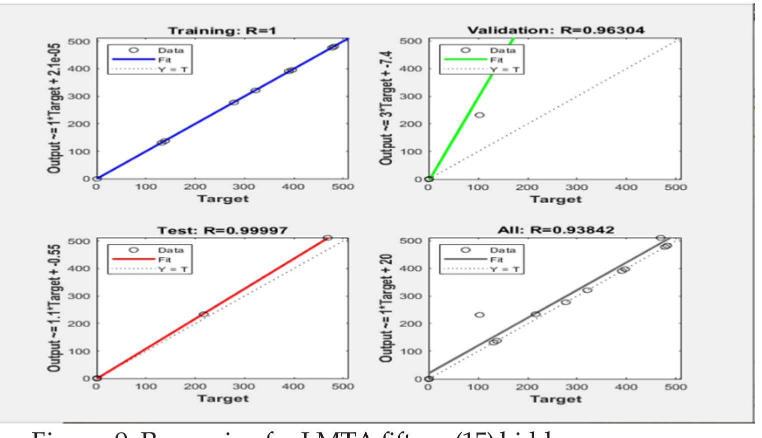

Figure 9: Regression for LMTA fifteen (15) hidden neurons

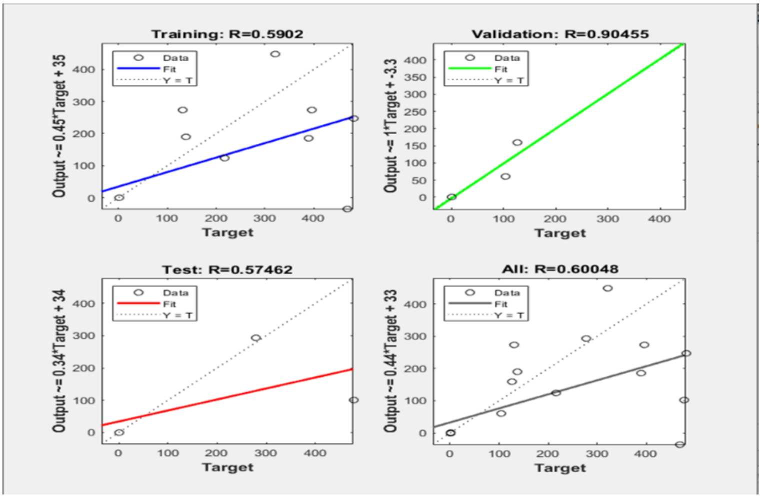

Figure 10: Regression for LMTA seven (7) hidden neurons

5.0 CONCLUSION

Biofuel has been produced from sweet potato and characterized. The results showed that it has a density of 0.85 g/cm^3, viscosity of 0.9834 mPa.s, calorific value of 19 kJ/kg, and a pH level of 1.82. The torque, brake mean effective pressure (BMEP), brake power (BP), and exhaust gas temperature (EGT).

Engine performance evaluation on separate mixtures of commercial gasoline fuel and the produced biofuel revealed that there is about 20% increase in brake power (BP) as the ethanol content increases in the blend. The petrol E0 happens to have the highest brake mean effective pressure (BMEP) compared to the blends. The torque of the engine increases as the blend increases as a result of high density and low heating value. The exhaust gas temperature (EGT) increases as the blend of ethanol increases as a result of improved combustion, and the speed was constant throughout the experimental process at 3000 rpm.

Consequently, for the ANN model, the LMTA training algorithm with 10 hidden layer neurons offers the best fit for the features, having a *R* value for training equal to 1, validation equal to 0.99468, testing equal to 0.90103, and overall *R* equal to 0.93842.

6.0 RECOMMENDATION

The biofuel produced from sweet potato (*Ipomoea Batata*) as an alternative fuel for internal combustion engines has shown positive engine performance characteristics when blended with PMS. However, there is a need for emission analysis to be carried out to check the impact of its use on the environment.

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