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Artificial Neural Network Prediction of Viscosity Index and Specific Heat Capacity of Grease Lubricant produced from Selected Oil Seeds and Blends

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ABSTRACT: *Artificial neural network modeling was employed to predict Viscosity index and specific heat capacity of grease lubricant produced from selected oil seeds. These oils were extracted from their seeds using solvent extraction method and characterized in Food Science Laboratory, University of Agriculture, Makurdi, Benue State of Nigeria. The neural model was developed to capture two groups of inputs data namely; materials formulation, and operating conditions. The effects of material formulation were represented by 5 parameters while the operation conditions were represented by 4 parameters. The neural network architecture BR 09 [5-4-3-2]$_4$**2** fitted the input/output relationship for the prediction of viscosity index and specific heat capacity; after series of training using different training algorithms. There were visual checking of predicted and experimental viscosity index and specific heat capacity which confirm that the artificial neural network model was successful in modeling the viscosity index and specific heat capacity.*

Keywords: *Artificial neural network, Grease lubricants, Oil seeds, Viscosity index, and specific heat capacity*

I. INTRODUCTION

Lubrication is the process, or technique employed to reduce wear of one or both surfaces in close proximity, and moving relative to each other, by interposing a substance called lubricant between the surfaces to carry or to help carry the load (pressure generated) between the opposing surfaces. In the most common case the applied load is carried by pressure generated within the fluid due to the frictional viscous resistance to motion of the lubrication fluid between the surfaces [1].

Adequate lubrication allows smooth continuous operation of equipment, with only mild wear, and without excessive stresses or seizures at bearings. When lubrication breaks down, metal or other components can rub destructively over each other, causing damage, heat and failure [2]

Typically, lubricants contain 90 % base oil (most often petroleum fractions, called mineral oils) and less than 10 % additives. Additives deliver reduced friction and wear, increased viscosity, improved viscosity index, resistance to corrosion and oxidation, aging, contamination, etc. [3].

Grease consists of oil and/or other fluid lubricant that is mixed with a thickener, a soap, to form a solid. Soap is a metallic salt of fatty acid, which forms an emulsion with oil.

Greases are used where a mechanism can only be lubricated infrequently and where a lubricating oil would not stay in position. They also act as valuable sealants to prevent ingress of water and dust [4].

The current trend in the production of grease is use of base oil from petroleum source. Petroleum base stock for grease production is often scarce or expensive, not renewable and highly volatile. There is increased cost of exploitation and processing of mineral based lubricating oils, stringent environment regulation and dwindling reserves of petroleum crude [5]. Petroleum (mineral) base grease is not biodegradable and causes upstream and downstream environmental pollution. It is toxic and can harm aquatic organisms [6]. Free fatty acids (FFA) that forms metallic soaps with metal surfaces during lubrication of metals under boundary lubrication condition often encountered in metal work and to a large extent, in gear transmission system is very low with petroleum oils. These actually have caused renewed and more intensive search for alternative, biodegradable and environmental friendly grease for engineering applications from short rotation plantation oil seeds that are regenerative and a veritable source of renewable oil seeds [7].

Seeds of interest included wide melon seeds, yellow oleander seeds and calabash seeds. Shea butter oil and oils extracted from the seeds of interest above are the base oils for the grease production.

The use of artificial neural network modeling in the fields of engineering is at increasing rate. Researchers like [8] studied neural network prediction of brake friction material wear. Artificial neural network usage in predicting erosive wear was also investigated by [9]. [10] Studied wear volume prediction with artificial neural network. [11] Investigated prediction of wear and friction coefficient of brake pads developed from palm kernel fibres using artificial Neural etc.

This work uses artificial neural network to predict the Viscosity index and specific heat capacity of greases produced from selected oil seeds and their blends..

II. MATERIALS AND METHODS

2.1Materials

The following oil seeds were used for this work; Calabash, Yellow Oleander and Wild Melon. Calabash and Wild Melon oil seeds were procured from open markets in Nasarawa and Benue state of Nigeria respectively while Yellow Oleander oil seeds were obtained in the wild in Benue state. The oils were extracted using solvent method. This method according to [12] has a high oil yields. Shea butter oil was purchased from open market in Gboko in Benue State. These oil samples were blended into different grades and were analyzed and characterized in Food Chemistry Laboratory of University of Agriculture, Makurdi in Benue State of Nigeria. Each oil blend was used to produce grease. The functional and mechanical properties of the grease samples were tested in Production Workshop of Benue State Polytechnic, Ugbokolo in Benue state.

2.2 Artificial neural network modeling

The neural model development for viscosity index and specific heat capacity was based on experimental data. The experimental phase was organized to provide the input and output quantities needed for neural network training, testing and validation.

The following steps were considered in modeling the wear rate and coefficient of friction [13]; (i) data generation (ii) definition of ranges (iii) data pre-processing, (iv) selection of neural network architecture (v) selection of training algorithms which includes selection of transfer function (iv) training the neural network, and (vii) testing or predicting, and data generator was the experimental design.

2.2.1 Input data and Output data

The neural model was developed to capture two groups of inputs data namely; materials formulation, and operating conditions. The effects of material formulation were represented by amount of thickener in the grease, additives, Free-fatty acid, density and cloud point. The influences of the friction materials operation conditions were represented by viscosity temperature coefficient, mechanical stability of the produced grease, kinematic viscosity and penetration. Input parameters identification and their numbers were done, prior to the important decision related to the ranges of inputs parameter. The input data related to the modeling of wear rate and coefficient of friction are shown on Table 1. Inputs data S_A-S_Z chosen outside the range of the experimental data were used for training the network while S_A-S_J for testing the capabilities of the artificial neural network for viscosity index and specific heat capacity prediction. The data for the neural network training was obtained from grease samples produced from 100% calabash oil and the blend of 50% Calabash oil and 50% Shea butter oil; 50% yellow oleander oil and 50% melon oil; 50% yellow oleander oil and 50% Shea butter oil ; 50% wild melon and 50% Shea butter. The synergistic effect of the influence of these nine (9) inputs parameters on viscosity index and specific heat as outputs are presented in Figure 1.

The output parameters viscosity index and specific heat capacity for the produced grease were presented to the network as shown in Table2. Viscosity index and specific heat capacity were obtained from experimental data.

2.2.2 Data pre-processing

Pre-processing of the inputs and output parameters was carried out before the neural network training. In neural network training, the input and output data set measured in different units need to be normalized into the dimensionless units to remove the arbitrary effect of similarity between the different data. Such difference normally decreases the convergence speed and accuracy within the network.

The nine (9) input parameters (presented in Table (1) from the material formulation and operating conditions were scaled within the range of 0-1 using the relation given in equation (1), while the two outputs (Table 2) were normalized using equation (2):

$$I_{Skal} = 1 + \frac{(I_{Curr} - I_{Max})}{(I_{Max} - I_{Min})} I_{Skal} = 1 + \frac{(I_{Curr} - I_{Max})}{(I_{Max} - I_{Min})} \quad (1)$$

$$O_{Lin} = 0.8 + 0.01 \times \frac{(O_{Curr} - O_{Min})}{(O_{Max} - O_{Min})} O_{Lin} = 0.8 + 0.01 \times \frac{(O_{Curr} - O_{Min})}{(O_{Max} - O_{Min})} \quad (2)$$

2.2.3 Network training

The best network's architecture for matching input/output relationship was found after series of a trial and error; since neural network's architecture and learning algorithm are always unknown in advance. The following networks architectures were investigated using MATLAB 7.9.0 (R20096); (i) one layered network 08 $9(4)_1$ **2,** 09 $(5)_1$ **2,** 09 $(6)_1$ **2,** 10 $(7)_1$ **2,** 12 $(8)_{1,}$ **2,** (ii) two layered network 08 $(6\text{-}4)_2$ **2,** 09 $(5\text{-}2)_2$ **2,** 09 $(7\text{-}4)_2$ **2,** 12 $(6\text{-}3)_2$ **2** (iii) three layered network 09 $(4\text{-}3\text{-}2)_3$ **2,** 10 $(5\text{-}4\text{-}2)_3$2. (iv) four layered network 09 $(7\text{-}6\text{-}3\text{-}2)_4$**2,** 09 $(5\text{-}4\text{-}3\text{-}2)_4$**2,** $10(8\text{-}6\text{-}4\text{-}2)_4$**2,**

The above networks architecture were trained using the following algorithms; Gradient descent with momentum back propagation GDM, Levenberg- Marquard (LM), Bayesian Regulation (BR), Resilient Back propagation (RB), Gradient decent back propagation, GD, Gradient descent with momentum and adaptive learning rule, and Scale conjugate gradient, SCG . The sigmoid function given in equation (3) was used between the input and the hidden layers and linear function was used between the hidden and output layer.

$$f(x) = \frac{1}{1+e^{-x}} f(x) = \frac{1}{1+e^{-x}} \quad (3)$$

2.2.4 Neural network prediction

The neural network architecture BR 09 $[5\text{-}4\text{-}3\text{-}2]_4$**2** fitted the input/output relationship for the prediction of viscosity index and specific heat capacity; after series of training using different training algorithms mentioned above. The sigmoid function given in equation (3) was used between the input and the hidden layers and linear function f(x) = x was used between the hidden and output layer, where x is the value of weight used.

The statistical indicators for validation of the neural network model were carried out using four statistical criteria. The criteria used were, Nash-Scutcliffe efficiency (NSE), Root Mean square error (RMSE), Normalised mean square error (NMSE) , and Mean bias error (MBE), given by the equations (4), (5), (6) and (7) respectively.

$$NSE = 1 - \frac{\sum_{i=1}^{N} [\![(E]\!]_i - P_i)^2}{\sum_{i=1}^{N} (E_i - \bar{E}_i)^2} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (P_i - E_i)^2}{N}} \quad (5)$$

Where P_i, E_i are the predicted and observed values

III. RESULTS AND DISCUSSION

3.1 **Artificial Neural Network Modeling**

Tables 5 and 6 present predicted and experimental viscosity index and specific heat capacity of the grease samples respectively. While Figure 2 presents the comparison of experimental and predicted viscosity index of the grease samples, Figure 3 shows the correlation of predicted and experimental viscosity index of the same samples. Figure 4 shows comparison of experimental and predicted specific heat capacity while Figure 5 presents correlation of predicted and experimental specific heat capacity of the grease samples.

Bayesian Regulation (BR) neural network model architecture of BR 09 $(5\text{-}4\text{-}3\text{-}2)_4$ **2,** (9) neurons in the input layer, 4 hidden layers of 5, 4, 3 and 2 neurons each and an output layer of 2 neuron) was chosen for the modeling of viscosity index and specific heat capacity, after series of training using different network architecture and algorithm described in the methodology. Training performance indicated values of correlation coefficient R=0.9981 at epoch 12 out of 14 for training, R= 0.9064 for validation while the overall correlation coefficient (R) for training, testing, and validation was 0.9663. The neural model BR 09 $(5\text{-}4\text{-}3\text{-}2)_4$ **2,** was chosen because it gave the higher correlation coefficient for both training and testing compared with the other architectures and algorithms described in section 3. The neural model BR 09 $(5\text{-}4\text{-}3\text{-}2)_4$ **2,** was used to predict the values of viscosity index and specific heat capacity and the results were presented in Tables 5 and 6 respectively. The Tables also showed statistical analysis such Nash-Scutcliffe efficiency (NSE), Root means square error (RMSE), Normalized Mean Square Error, (NMSE) and Mean Biased Error (MBE) that were used for validating the ANN model.

The values of statistical indicators NSE, RMSE, NMSE, and MBE for model validation as presented in Tables 7 and 8 varied from 0.9060 to 1.0000, 0.0000 to 0.949, 8.2x10-7 to 0.0000 and -0.3610 to 0.0000 respectively. The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance, it indicates how well the plot of observed versus simulated data fits the 1:1 line. The higher values of NSE of 1.0000 for predicted values of 69, 216, 370, and 358 for viscosity index and 4.233, 2.797, 4.108 and 2.770 for specific heat capacity clearly showed that the model was successful. The RMSE is a commonly reported measure of residual error, and summarises the difference between the observed and modelled values, thus the values of 0.0000 were obtained at the predicted values of 69, 216, 370, and 358; and 4.233, 2.797, 4.108 and 2.770 for viscosity index and specific heat capacity respectively. Low values of RMSE are desirable, but few errors in the sum can produce a significant increase in indicator and this confirms the statement stated by [14] that a zero value for RMSE is desirable for model validation.

The Normalized Mean Square Error, NMSE, is an estimator of the overall deviations between observed and predicted concentrations. NMSE generally shows the most striking differences among the models. NMSE values of less than 0.0000 were reported for the prediction of viscosity index and specific heat capacity. Mean Biased Error (MBE) indicates the degree of over prediction (MBE>0) or under prediction (MBE<0) of the observed values. The MBE values of 2.0000, and 3.0000 clearly indicated that the model over predicted and -1.0000, -2.0000, showed that the model has under predicted. While the MBE values of 0.0000 obtained for prediction of viscosity index and specific heat capacity showed that the model predicted exactly as the experimental values. The slight disparity in some of the predicted and experimented values could be attributed errors in data arising from miscalculation.

The visual assessment of the predicted viscosity index as shown in Figure 5 showed that almost all the viscosity index predicted by ANN model matched with the experimental values. This was confirmed by the regression of the predicted and experimental wear rates as shown on Figure 6. There was high correlation between the predicted and experimental wear rates with R^2 of 0.977. Hence, the visual checking of predicted and experimental viscosity index confirms that the ANN model was successful. In the same vein, visual assessment of the predicted specific heat capacity, as shown on Figure 7 showed that almost all predicted specific heat capacity values by ANN model matched with the experimental values. This was also confirmed by the regression of the predicted and experimental coefficient of friction shown in Figure 8, with higher correlation coefficients of R^2 = 0.9074. This also indicated that the ANN model was successful in predicting specific heat capacity.

IV. CONCLUSION

The artificial neural model developed for the prediction of Viscosity index and Specific heat capacity from experimental data of performance evaluation of greases produced from selected oil seeds and blends was successful with insignificant network errors. Influence of other parameters like pour point, flash point on performance evaluation of grease from natural oil seeds can be modeled using artificial neural network.

Table1: Input Parameters used for Training and Testing

Parame ters	**Training data set. S_A-S_Z**				**Test**	**Data**	**Set**				
		S_A	S_B	S_C	S_D	S_E	S_F	S_G	S_H	S_I	S_J
Material formulation											
Thickener (g)	50-300	70	50	65	70	100	80	120	200	140	180
Additives		12	18	20	20	25	40	30	26	30	40
Free-fatty acid (%)	2.5-6	3.4	3.4	2.6	2.82	3.5	3.7	3.8	3.4	4.0	4.25
Density (kg/m^2)	0.70-0.10	0.0879	0.909	0.875	0.925	0.885	0.881	0.890	0.890	0.910	0.900
Cloud point (^{0}C)	6-15	13	8	8	8	9	9	9	11	11	12
Operating conditions											
Viscosity temperature coefficient(^{0}C	0.20-0.300	0.2381	0.2400	0.2400	0.2418	0.2265	0.2290	0.2274	0.2288	0.227	0.228
Mechanical stability (g)	25-50	35	40	30	45	40	41	32	45	39	40
Kinematic Viscosity at (100 ^{0}C))	15-120	21	71	65	50	111	109	109	108	108	108
Penetration (mm)	160-400	179	270	315	235	230	325	185	360	360	190

Table 2: Output Parameters

Parameters	S_{OA}	S_{OB}	S_{OC}	S_{OD}	S_{OE}	S_{OF}	S_{OG}	S_{OH}	S_{OI}	S_{OJ}
Viscosity Index	70	236	216	165	370	362	362	358	359	**358**
Specific heat capacity (kJ/kgK)	3.756	3.745	2.663	4.233	2.797	4.228	4.052	4.108	2.770	2.674

Table 3: Scaled Values of Input Parameters

Parameters				**Test**	**Data**	**Set**				
	S_A	S_B	S_C	S_D	S_E	S_F	S_G	S_H	S_I	S_J
Material formulation										
Thickener (g)	1.860	0.000	0.100	0.130	0.330	0.200	0.460	1.000	0.600	0.860
Additives	0.000	0.970	0.280	0.280	0.460	1.000	0.640	0.500	0.640	1.000
Free-fatty acid (%)	0.460	0.460	0.000	0.100	0.530	0.650	1.280	0.460	0.840	1.000
Density (kg/m2)	0.000	0.980	0.940	1.000	0.960	0.950	0.970	0.970	0.980	0.970
Cloud point (^{0}C)	1.000	0.000	0.000	0.000	0.200	0.200	0.200	0.600	0.600	0.800
Operating conditions										
Viscosity temperature coefficient(^{0}C)	0.750	0.880	0.880	1.000	0.000	0.1600	0.050	0.150	0.030	0.090
Mechanical stability (g)	0.330	0.660	0.000	1.000	0.660	0.730	0.130	1.000	0.600	0.660
Kinematic Viscosity at (100 ^{0}C))	0.000	0.560	0.500	0.320	1.020	1.000	1.000	0.990	0.990	0.990
Penetration (mm)	0.000	0.500	0.750	0.300	0.280	0.800	0.030	1.000	1.000	0.060

Table 4: Scaled Values of Output Parameters

Parameters	S_{OA}	S_{OB}	S_{OC}	S_{OD}	S_{OE}	S_{OF}	S_{OG}	S_{OH}	S_{OI}	S_{OJ}
Viscosity Index	0.000	1.360	1.290	1.120	1.810	1.780	1.780	1.770	1.780	1.770
Specific heat capacity (kJ/kgK)	1.500	1.490	0.810	1.180	0.890	1.800	1.690	1.730	0.870	0.810

Table 5: Predicted and Experimental Viscosity index

S/N	**Experimental Viscosity index**	**Predicted Viscosity index**	**NSE**	**RMSE**	**NMSE**	**MBE**
1	70	69	1.0000	0.3160	1.0x10-6	-1.0000
2	236	238	0.9980	0.6320	4.0x10-8	2.0000
3	216	216	1.0000	0.0000	0.0000	0.0000
4	165	168	0.9999	0.9490	1.05x10-5	3.0000
5	370	370	1.0000	0.0000	0.0000	0.0000
6	362	362	1.0000	0.0000	0.0000	0.0000
7	362	360	0.9985	0.6320	1.0x10-6	-2.0000
8	358	361	0.9999	0.9490	1.05x10-5	3.0000
9	356	259	0,9985	0.9490	1.05x10-5	3.0000
10	358	358	1.0000	0.0000	0.0000	0.0000

Table 6: Predicted and Experimental specific heat capacity

S/N	**Experimental Specific heat capacity (kJ/kg/K)**	**Predicted Specific heat Capacity (kJ/kg/K)**	**NSE**	**RMSE**	**NMSE**	**MBE**
1	3.756	3.755	0.9960	0.0003	8.2x10-7	-0.0010
2	3.745	3.789	0.9800	0.0139	1.5x10-5	0.0440
3	2.663	2.302	0.9060	0.1145	0.00106	-0.3610
4	4.233	4.233	1.0000	0.0000	0.0000	0.0000
5	2.797	2.797	1.0000	0.0000	0.0000	0.0000
6	4.228	4.301	0.9920	0.0730	0.0005	0.068
7	4.052	4.051	0.9990	0.0003	8.2x10-7	-0.0010
8	4.108	4.108	1.0000	0.0000	0.0000	0.0000
9	2.770	2.770	1.0000	0.0000	0.0000	0.0000
10	2.674	2.691	0.9990	0.0054	2.3x10-6	0.0170

Plate 12: Neural Network Architecture
Plate 12: Neural Network Architecture
Figure 2: Comparison of experimental and predicted viscosity index
Figure 3: Correlation of predicted and experimental viscosity index.
Figure 4: Comparison of experimental and predicted specific heat capacity
Figure 5: Correlation of predicted and experimental specific heat capacity

Table 7: Predicted and Experimental Viscosity index

S/N	Experimental Viscosity index	Predicted Viscosity index	NSE	RMSE	NMSE	MBE
1	70	69	1.0000	0.3160	1.0x10-6	-1.0000
2	236	238	0.9980	0.6320	4.0x10-8	2.0000
3	216	216	1.0000	0.0000	0.0000	0.0000
4	165	168	0.9999	0.9490	1.05x10-5	3.0000
5	370	370	1.0000	0.0000	0.0000	0.0000
6	362	362	1.0000	0.0000	0.0000	0.0000
7	362	360	0.9985	0.6320	1.0x10-6	-2.0000
8	358	361	0.9999	0.9490	1.05x10-5	3.0000
9	356	259	0,9985	0.9490	1.05x10-5	3.0000
10	358	358	1.0000	0.0000	0.0000	0.0000

Table 8: Predicted and Experimental specific heat capacity

S/N	Experimental Specific heat capacity (kJ/kg/K)	Predicted Specific heat Capacity (kJ/kg/K)	NSE	RMSE	NMSE	MBE
1	3.756	3.755	0.9960	0.0003	8.2x10-7	-0.0010
2	3.745	3.789	0.9800	0.0139	1.5x10-5	0.0440
3	2.663	2.302	0.9060	0.1145	0.00106	-0.3610
4	4.233	4.233	1.0000	0.0000	0.0000	0.0000
5	2.797	2.797	1.0000	0.0000	0.0000	0.0000
6	4.228	4.301	0.9920	0.0730	0.0005	0.068
7	4.052	4.051	0.9990	0.0003	8.2x10-7	-0.0010
8	4.108	4.108	1.0000	0.0000	0.0000	0.0000
9	2.770	2.770	1.0000	0.0000	0.0000	0.0000
10	2.674	2.691	0.9990	0.0054	2.3x10-6	0.0170

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