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Estimation of dynamic viscosities of vegetable oils using artificial neural networks

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In this study, viscosities of raw sunflower and corn oils are measured at 1°C intervals between 0-100°C. Experimental results are fitted to six equations that are used in viscosity estimation and the correlation coefficients are determined. The best correlation coefficient is obtained using In(μ)=a+b/(T+c) equation with 0.99972 and 0.99974 for sunflower and corn oil, respectively. In addition to this, viscosity values are obtained using artificial neural networks and the results are compared to the equation leading to the best correlation coefficient. Using artificial neural networks, the correlation coefficients are obtained as 0.999907 and 0.999925 for raw sunflower and corn oil respectively.

Keywords: Dynamic viscosity, Vegetable oils, Artificial neural networks

Diesel engines have an important value for especially the transportation industry. Moreover, exhaust emissions originated from diesel engines considerably increase the environmental pollution just like the emissions from gasoline engines do. The future of diesel engines depends on the sustainability of fuels which are used as energy sources and generation of emissions that are environmentally acceptable. Therefore, importance is given to the research about internal combustion engines for decreasing fuel consumption and lowering emissions in exhaust gases. Decreasing reserves of petroleum based fuels which are used in internal combustion engines and increasing petroleum prices also cause concentration of research on renewable energy sources[1,2].

One of the renewable energy sources that could be used in internal combustion engines is vegetable oils. The use of vegetable oils (colza, flaxseed, cottonseed, soybean, sunflower, hint, coconut and palm oils) is not a new idea. In 1900, while Rudolph Diesel was introducing the new engine he had developed in Paris, he started one of his engines with peanut oil. In addition to this, during the World War II, varieties of vegetable oils were used in many vehicles in southern France. However, the most extensive research on the issue had started after the oil crisis of 1970s[3,4].

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Vegetable oils have advantages such as renewability, high calorific value, and low emission values[5-8]. Vegetable oils have a different chemical structures than that of petroleum based fuels. Therefore, direct use of vegetable oils on diesel engines causes various problems. Viscosity of vegetable oils is very high compared to that of diesel fuel. High viscosity causes problems on the injection of the fuel; it deteriorates atomization during injection and causes degradation of the combustion[9]. The most clear and simple method that can be used for decreasing the viscosity of vegetable oils is increasing the temperature of vegetable oils or blending them with diesel fuel at certain ratios[10]. There have been many studies conducted on operating engines with fuel obtained from vegetable oils or esters of these oils.

Kapseu *et al.*[11] investigated to the impact of solvents such as acetone, methyl ethyl ketone, methyl isobutyl ketone, hexane, and heptane on viscosity of cottonseed oil in the interval of 0-25°C. They conducted viscosity measurements by using capillary viscosity. The impact of solvents on decreasing viscosity of cottonseed oil is given as acetone, hexane, methyl ethyl ketone, heptane, and methyl isobutyl ketone in the descending order.

Noureddini *et al.*[12] measured the viscosities of many vegetable oils in the interval of 24-110°C and many oil acids in the interval of C_9-C_{12}.

They have fitted the experimental results with several equations. The correlation constants for the best fit are presented.

Lang *et al.*[13] measured the viscosities of refined, bleached, deodorized (RBD) and refined, bleached, winterized (RBW) canola oils in the interval of 4-100°C temperatures. They have modeled the viscosities of canola oil using an equation and determined the maximum error amount to be less than 1.6%.

Toro-Vazquez and Infante-Guerrero[14] used the Andrade equation and a multiple regression model to define the absolute viscosity changes of oils in the interval of 298-338 K. The best correlation coefficient (R^2) is obtained by using the Andrade equation (R^2>0.96). Besides, using a multiple regression model R^2≈0.93 is obtained.

Topallar and Bayrak[15] analyzed the impact of acetone on dynamic viscosity of sunflower oil in the interval of 25-50°C. They defined the impact of temperature on dynamic viscosities of oil solutions in the best possible way by using the $\text{In}(\mu)=a+b/(T+c)$ equation.

Gupta *et al.*[16] analyzed the impact of temperature on the viscosities of palm, rice bran, cottonseed, mustard, sunflower, and soybean oils, and developed an empirical correlation between viscosity and temperature.

In this study, dynamic viscosities of raw sunflower and corn oils are measured in the interval of 30-100°C. Experimental data are fitted with six equations that are used in viscosity estimation and correlation coefficients are determined. Viscosity estimations are also conducted using artificial neural networks and the results are compared to the most appropriate equation.

Material and Methods

Experimental procedure

In this study, raw sunflower and corn oils, which are widely used for cooking oil production, are used. Raw sunflower and corn oils are provided by Oruçoğlu Oil Industries and Trading Inc. which has production facilities in Afyonkarahisar. Properties of diesel fuel, sunflower oil and corn oil were given in Table 1[17].

Viscosity measurements are performed using a Brookfield DV-II+ Pro rotary viscosity-meter which can measure in the interval of 0.01-200 rpm speed. Experiments are conducted under 20°C ambient temperature. Temperature measurements are realized using an RTD temperature probe which is capable of conducting measurements in the interval of -100°C to 149°C with 0.1°C sensitivity. The experiments are conducted under constant speed of 100 rpm with RV2 spindle. Prior to the experiments, oils are heated up to 110°C using a magnetic stirrer with heater. Dynamic viscosities of oils were measured from 110°C to 30°C. Thermostat was used in the test. During the tests, sunflower oil, corn oil and diesel fuel were subject to self-cooling.The measurements are realized in the interval of 100°C to 30ºC and the data are recorded in 5 s intervals by using a Wingather VII software program.

Artificial neural networks (ANNs)

Artificial neural networks (ANN) are data processing structures which are developed by inspiration from human brain data processing technology. ANN is developed by inspiration from the working principles of biological nerve cell system. Nerve cells used in ANN include neurons and these neurons form a network by connecting to each other in various styles. ANNs have the capability of learning, memorizing, and revealing the relationship among data. In this study, dynamic viscosities of vegetable oils are estimated by using an ANN. In the application, Neural Network Fitting Tool of MATLAB® software is used. Using neural network fitting tool, it is possible to graphically construct ANNs, select input and target data, select what percentage of the experiment data is going to be used for training-validation-test, and finally train the ANN that is built according to the specified data and calculate the performance of the training results by using mean square error and regression analysis methods. For sunflower, 457 of 653 data are used for training the ANN and 98 data are used for testing purposes (Table 2).

Table 1—Properties of diesel fuel, sunflower oil and corn oil

Fuel Properties	Density at 15ºC (kg/m^3)	Kinematic viscosity at 40ºC (mm^2/s)	Lower calorific value (kJ/kg)	Cetane number (-)
Diesel Fuel	837	3	42,700	50
Sunflower oil	920	34	36,500	37
Corn oil	915	35	36,300	38

A three-layer feed-forward network with sigmoid hidden neurons and linear output neurons is used as the network. Levenberg-Marquardt backpropagation training algorithm is used to train the network. The present study is given in Fig. 1 with feed forward Levenberg-Marquardt backpropagation network. The input and output layers have 1 neuron where hidden layer has 7 neurons.

In the history of artificial neural networks, an important development has occurred in feed-forward artificial neural networks. In the feed-forward networks, neurons are aligned from input towards output in ordered layers and transmission from one layer to another is only available for the next layer. Input data is transferred first to the input layer then to the hidden layer and finally to the output layer where they are processed and the results are communicated to the outer world. It has been proven that a three layer feed-forward ANN can approximate any continuous function at the desired accuracy level provided that a sufficient number of neurons are included in the hidden layer.

Table 2—Number of data used in ANN

Oil type	Training (%70)	Validation (%15)	Testing (%15)	Total
Sunflower oil	457	98	98	653
Corn oil	603	129	129	861

Results and Discussion

Experimental and modeling results

Vegetable oils are very important for cooking, soap, cosmetic, and pharmaceutical industries. Viscosity and density estimations of vegetable oils are considerably important for design of units such as distillation, heat exchanger and reactors[18].

Many studies are conducted about estimating viscosities of vegetable oils with respect to temperature. In these studies, a total of 6 equations

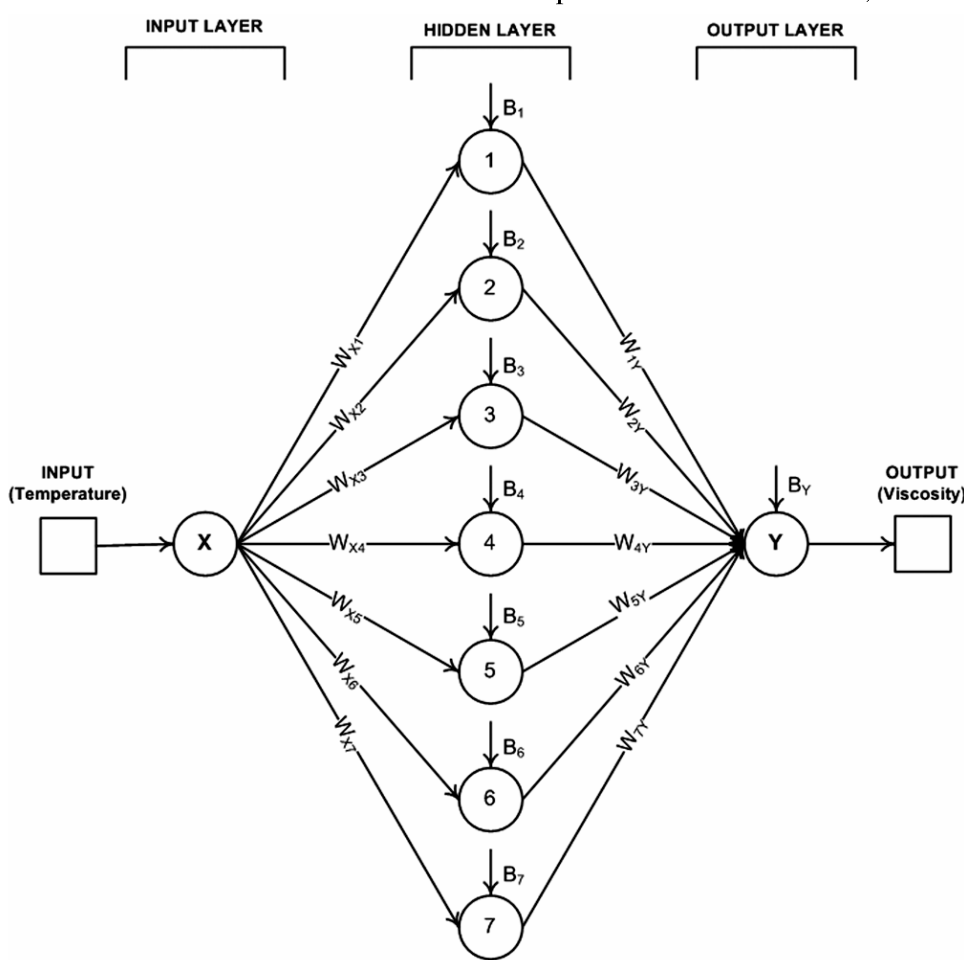

Fig. 1—Structure of the artificial neural network used

with either two constants or three constants are used for estimating dynamic viscosities[15,16]. These equations are;

$$\ln(\mu)=a+b\ln(T) \qquad \ldots (1)$$

$$\ln(\mu)=a+b/T \qquad \ldots (2)$$

$$\ln(\mu)=a+b/(T+c) \qquad \ldots (3)$$

$$\ln(\mu)=a+b/T+c/T^2 \qquad \ldots (4)$$

$$\ln(\mu)=a+b/T+cT \qquad \ldots (5)$$

$$\ln(\mu)=a+bT+cT^2 \qquad \ldots (6)$$

In these equations T (K) is absolute temperature and a, b, and c are constants. In Fig. 2, the change in In (μ) values of diesel fuel, raw sunflower and corn oils with respect to temperature is given. At 303 K temperature, In(μ) values of sunflower and corn oils are 1.518 and 1.508 times that of diesel fuel, respectively. In(μ) values of diesel fuel, sunflower oil and corn oil are decreasing by increasing temperature.

In Table 3, the correlation coefficients and constants obtained by the equations which are used for sunflower and corn oils are given. Among these equations, viscosity values which are calculated using Eq. (3) are found to be in considerable agreement with the experimental results. As it is also indicated in the literature, the most appropriate equation obtained has three correlation constants which are a, b, and c. In the study conducted by Topallar (15) as well, Eq. (3) was determined to be the most appropriate equation.

ANNs Results

Minimum error value is obtained with an ANN that has 7 neurons in its hidden layer and that is trained using Levenberg-Marquardt algorithm. Activation functions of ANNs are generally selected to be non-linear functions. In the application, sigmoid activation function is used in the hidden layer and linear activation function is used in the output layer. Activation function for neurons in a multi-layer feed-forward network can be linear or non-linear. Sigmoid activation function is

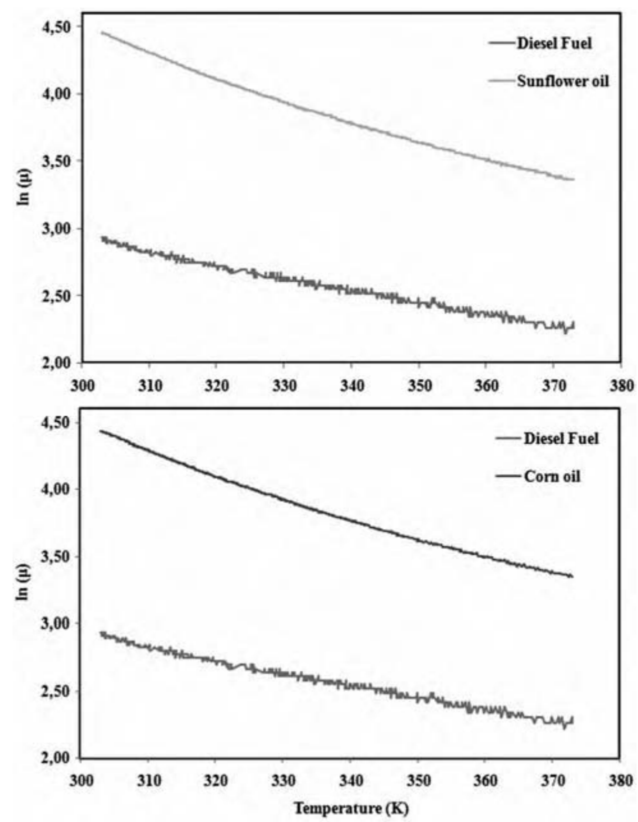

Fig. 2—In(μ) values of sunflower and corn oils

Table 3—The correlation coefficients and constants obtained for sunflower and corn oils

Oil type	Properties	ln (μ)= a+b*ln (T)	ln (μ)= a+b/T	ln (μ)= a+b/(T+c)	ln (μ)= a+b/T+c/T^2	ln (μ)= a+b/T+c*T	ln (μ)= a+b*T+c*T^2
Sunflower oil	a	35.32	-1.497	0.7595	2.329	-9.004	18.33
	b	-5.41	1793	609.7	-741.3	3034	-0.07056
	c	-	-	-137.3	$4.184\ 10^{+5}$	0.01131	$8.157\ 10^{-5}$
	R^2	0.99539	0.99823	0.99972	0.99971	0.99968	0.99959
	RMSE	0.019449	0.012048	0.0048026	0.0049045	0.0051031	0.0058079
Corn oil	a	34.88	-1.452	0.7644	2.304	-8.878	18.18
	b	-5.332	1782	609.2	-726.9	3020	-0.06956
	c	-	-	-138	$4.178\ 10^{+5}$	0.0111	$7.996\ 10^{-5}$
	R^2	0.99557	0.99832	0.99974	0.99974	0.99973	0.99967
	RMSE	0.019574	0.012051	0.0047413	0.0047564	0.0048372	0.0053058

Table 4—A three-layer feed-forward network weight values

			Sunflower Oil				
W_{X1}	W_{X2}	W_{X3}	W_{X4}	W_{X5}	W_{X6}	W_{X7}	
-9.7475	-8.5279	6.0899	-5.1083	-4.2141	2.9038	-9.6980	
W_{1Y}	W_{2Y}	W_{3Y}	W_{4Y}	W_{5Y}	W_{6Y}	W_{7Y}	
0.0927	0.0830	-0.1241	0.1208	-0.4314	0.1685	0.0684	
B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_Y
8.6803	5.5180	-2.3726	0.5926	-0.8182	1.9682	-9.1105	0.0654
			Corn Oil				
W_{X1}	W_{X2}	W_{X3}	W_{X4}	W_{X5}	W_{X6}	W_{X7}	
-8.9933	7.6921	1.2239	-4.4403	-5.7372	-4.5044	-7.7621	
W_{1Y}	W_{2Y}	W_{3Y}	W_{4Y}	W_{5Y}	W_{6Y}	W_{7Y}	
0.0196	-0.0224	-0.7200	0.04107	0.04292	0.1932	0.1300	
B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_Y
8.7232	-5.9859	-0.2918	-0.6058	-1.8767	-2.8999	-7.1348	-0.0380

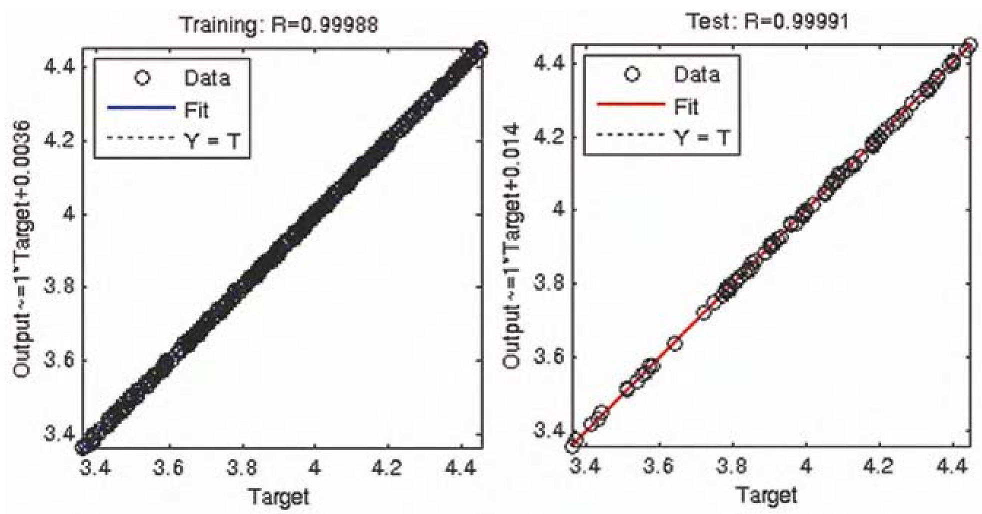

Fig. 3—Comparisons between training, test results, and target data for sunflower oil

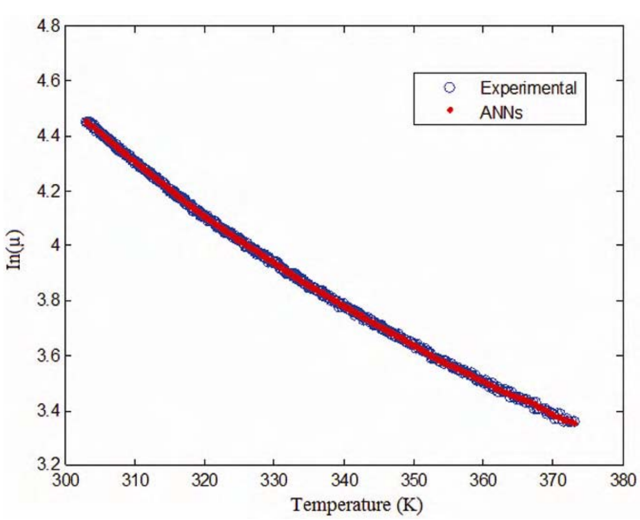

Fig. 4—Experimental and ANN estimation results for sunflower oil

Table 5—Comparison of the results of Equation 3 and ANN

Oil type	Properties	In (μ)= $a+b/(T+c)$	ANNs
Sunflower oil	R^2	0.99972	0.999907
	RMSE	0.0048026	0.0038405
Corn oil	R^2	0.99974	0.999925
	RMSE	0.0047413	0.0040806

a widely used non-linear activation function whose output lies between zero and unity[19]. Back-propagation algorithm is an ANN algorithm based on updating the weights to form outputs for obtaining a special functional characteristic from the input data set. Before the network is trained, the weights have random values and after the network is trained they have significant values. The weight values obtained as a result of training the ANN are given in Table 4. The results of Eq. (3),

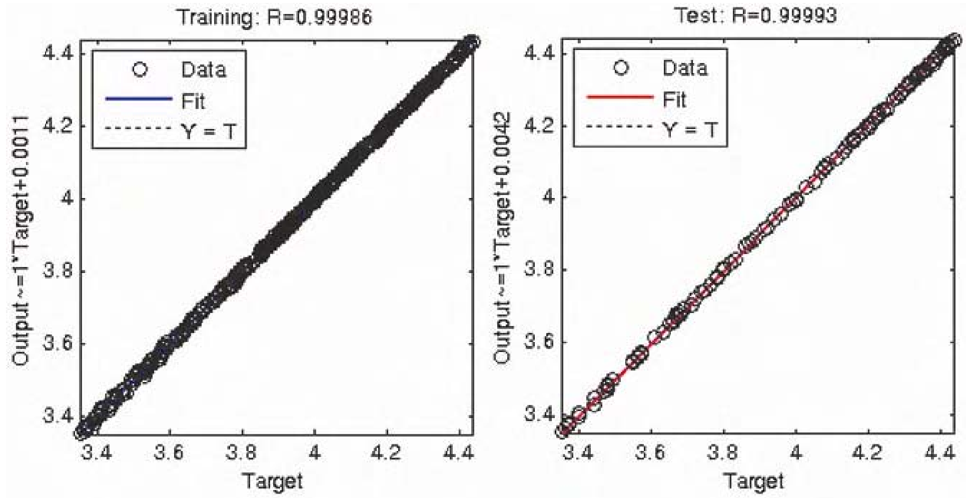

Fig. 5–Comparisons between training, test results, and target data for corn oil

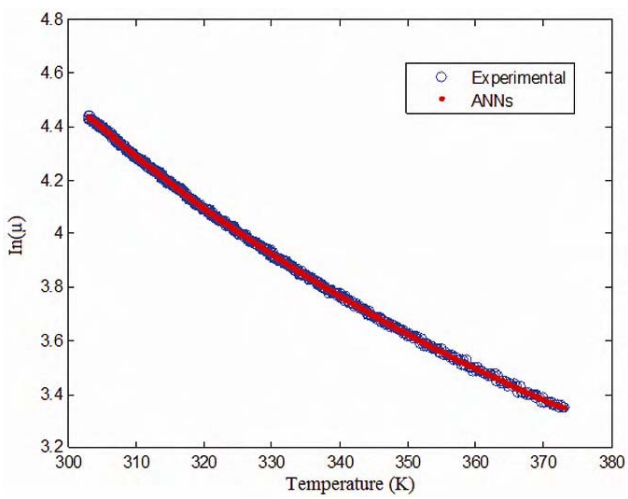

Fig. 6—Experimental and ANN estimation results for corn oil

which gives the closest values to experimental results, and the result of ANN are given in Table 5. A comparison of experimental results to the ANN results is given in Fig. 3-6. It is observed that experimental results and the data obtained with ANN are very close to each other. Besides, the correlation coefficients (R^2) and root mean squared error (RMSE) values obtained by the ANN are very good when compared to those values obtained by Eq. (3) which is used for viscosity estimation. Mean squared error is the average squared difference between outputs and targets. Lower values are better. The formula used for calculating MSE and RMSE values of ANN is given in Eq. (7).

$$\mathrm{MSE} = \frac{1}{Q}\sum_{k=1}^{Q} e(k)^2 = \frac{1}{Q}\sum_{k=1}^{Q}\left(t(k) - a(k)\right)^2 \quad \textit{and} \quad \mathrm{RMSE} = \sqrt{\mathrm{MSE}} \qquad \dots (7)$$

Conclusions

Vegetable oils are widely used in many sectors. Viscosity is substantially important in transportation, storage and packaging of vegetable oils. In this study, dynamic viscosities of raw sunflower and corn oils are measured and using the six equations, which are commonly used for viscosity estimation, the equations are fitted and the correlation coefficients are determined. Using Eq. (3), the best the correlation coefficient, i.e., 0.99972 and 0.99974 are obtained for raw sunflower and corn oils, respectively. Moreover, viscosity estimations are conducted by using artificial neural networks. With this approach, the correlation coefficient of 0.999907 and 0.999925 are obtained for raw sunflower and corn oil, respectively. The comparison of artificial neural network model with Eq. (3) shows that the use of artificial neural networks in viscosity estimation is considerably successful.

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