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Designing an artificial neural network to predict dynamic viscosity of aqueous nanofluid of TiO_2 using experimental data☆

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ABSTRACT

In this research, the viscosity of the aqueous nanofluid of TiO_2 has been modeled by artificial neural networks using experimental data. Artificial neural networks are able to estimate the pattern of dynamic viscosity variation along with temperature and nanoparticles mass fraction with a high precision. A network with one hidden layer and 4 neurons has been used. The regression coefficient was obtained 0.9998 in this modeling, which shows very high precision of neural network with a very simple structure. In addition, a relationship in terms of mass fraction and temperature was presented in order to predict the viscosity of this nanofluid. This correlation can estimate the viscosity of TiO_2–water nanofluid in a wide range of nanoparticles mass fraction with a maximum error of 0.5 %.

1. Introduction

By adding nanoparticles to the base fluid, an increase in viscosity is inevitable. Increase in nanofluids viscosity should not make increase in fluid thermal conductivity or heat transfer coefficient ineffective. Increase in viscosity leads to a pressure drop in system, and a greater amount of power is required to compensate for the pressure reduction. Therefore, nanofluids viscosity as well as thermal conductivity is considered a very significant parameter for investigating nanofluids efficacy.

Different parameters affecting nanofluids behavior have been mentioned in a review paper by Nwosu et al. [1]. Also, different parameters affecting viscosity have been investigated by researchers in separate studies. Temperature [2–11], volume fraction [12–17], packing fraction [18], thickness of nano layers [19,20], particle shape [21,22], and aggregation radius [23] are some of the most important parameters affecting viscosity that have been summarized in Table 1.

As is observed in Table 1, many parameters affect nanofluids viscosity. Some researchers have investigated nanofluids numerically [24–27].

The purpose of this article is modeling the viscosity of TiO_2-water nanofluids [28] by using artificial neural networks. To do this, different structures of neural network have been investigated, and experimental data and modeling results have been compared in different graphs. Also, a relationship in terms of temperature and nanoparticles mass fraction has been presented to predict these nanofluids viscosities.

2. Artificial neural network

The new point of view on neural networks based on brain performance emerged in the 1940s. The first practical application of neural networks appeared by introduction of perceptron network in the late 1950s. In the last 10 years, thousands of articles have been written on neural networks and these networks are widely used in different sciences. What currently can be said is that in future neural network will have an important role as a scientific tool to solve special problems. At present, the information available on the performance of brain is limited and the most significant advances in neural network will be obtained in future when more information on performance of brain and biological neurons is available.

The applications of neural networks in different sciences include application in aerospace industries as auto-pilot, in transportation industries as orientation systems, in defensive affairs as pursuing moving targets and many other applications. The application of neural networks in the sciences mentioned above is increasing and a new application of these networks is mentioned in articles by researchers every day.

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Table 1
Summary of some researchers conducted on the parameters affecting nanofluid dynamic viscosity.

Author(s)	Range of temperature and volume fraction	Research method	Nanofluid	Results
Tavman et al. [2]	20–60 °C 0–4 vol.%	Experimental	SiO_2/water Al_2O_3/water	Increase in relative viscosity by increase in volume fraction
Pastoriza-Gallego et al. [3]	280–325 K 1–5 wt.%	Experimental	CuO/water	The effect of particle size cannot be ignored. The greatest amount of potential *Z* is in pH 2 and pH 13.
Mariano et al. [5]	283.15–323.15 K Up to 25 wt.%	Experimental	Co_3O_4/EG	Intense variations of temperature–nanofluid Newtonian behavior increase of 20–30% in thermal conductivity at 6 vol.%
Hemmat Esfe et al. [7]	26–55 °C Up to 3 vol.%	Experimental	Fe/EG	The smaller the particle size lead to the higher thermal conductivity and viscosity; 40 nm nanoparticles have a thermal conductivity 11% higher than 100 nm nanoparticles.
Yiamsawas et al. [8]	15–60 °C 1–4 vol.%	Experimental	TiO_2/water EG Al_2O_3/water EG	The viscosity of Al_2O_3 nanoparticles is 130% greater than TiO_2 nanoparticles.
Abdellahoum et al. [13]	1–4 vol.% 10^4<Re<10^5	Numerical	Al_2O_3/water	Pak and Cho model shows the maximum value of friction.
Vajjha et al. [15]	1–6 vol.% 3000 < Re < 8000	Numerical	Al_2O_3/water EG CuO/water EG	The average heat transfer coefficient over the base fluid for a 3% volume fraction of Al_2O_3 nanofluid is 36.6% and that for a 3% volume fraction of CuO nanofluid is 49.7%.
Zhao et al. [16]	Present two ANN with 4 and 5 inputs.	Numerical	Al_2O_3/water CuO/water	Modeling by using neural network through radial basis function
Srivastava [21]	1–5 vol.%	Numerical	Al_2O_3/water	Particle shape deviation from spherical leads to an increase in viscosity.
ZHAO et al. [23]	Diameter of nanoparticles from 7 to 40 nm 0.1–2 vol.% *T* = 20, 25, and 30 °C	Experimental	SiO_2/DI-water	The amount of viscosity relate to the size of agglomerate overdependence of viscosity of nanofluids or 7 nm nanoparticles to PH

The structure of neural network used in this research has been shown in Fig.1. This structure is the simplest one among the investigated structures (Table 1) that has the highest regression coefficient. Evaluation and optimal structure of artificial neural network takes place through trial and error. As can be seen, a one layer with 4 neurons has been used as optimal structure for modeling nanofluid dynamic viscosity.

Table 2 shows that increasing hidden layers and the number of neurons do not necessarily increase the network precision in estimating the data. As was mentioned previously, by considering the values of R and MSE, the best selection for artificial neural network architecture in order to model the data of viscosity has been chosen a network with one hidden layer and 4 neurons and tansig transfer function has been used.

3. Correlation

In order to obtain the relative viscosity of TiO_2 aqueous nanofluids, a correlation has been presented in terms of temperature and nanoparticles mass fraction.

$$\frac{\mu_{nf}}{\mu_f} = 1.431 - 0.01864T + 0.6073\omega + 0.01334T^2 + 0.02586T.\omega + 0.3092\omega^2 + 0.006043T^3 + 0.005644T^2.\omega + 0.03323T.\omega^2 + 0.08318\omega^3 \quad (1)$$

Where mean 313.1 and SD 20.37 are used to normalize *T* (temperature). Also, mean 16.5 and SD 12.85 are used to normalize ω (mass fraction), and coefficients are 95% confidence bounds. This relationship

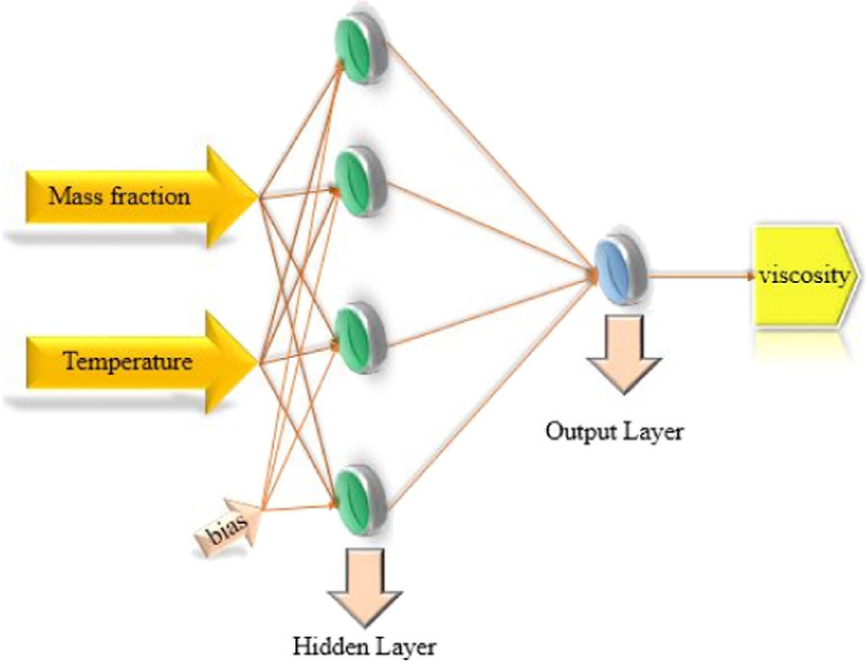

Fig. 1. Optimal structure of neural network.