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A hybrid artificial neural network-genetic algorithm modeling approach for viscosity estimation of graphene nanoplatelets nanofluid using experimental data

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ABSTRACT

Predicting the viscosity of graphene nanoplatelets nanofluid with the help of multi-layered perceptron artificial neural network and genetic algorithm was the main aim of this study. In order to achieve the experimental results nanofluid which contains graphene nanoplatelets and deionized water at 20 to 60 °C and 0.025, 0.05, 0.075, and 0.1 wt% is used. Furthermore, genetic algorithm in artificial neural network is used to improve the learning process. In other words, different weights have been chosen for neurons' relations. Also, the bias preoccupation is based on improvements by genetic algorithm. On the other hand, for analyzing the accuracy of the presented model which gives us the nanofluid viscosity predictions MAPE, RMSE, R^2, and MBE indexes were used. The values of the presented indexes are 0.777, 0.086, 0.985, −0.0009 respectively. In case of comparison the results show that the presented model which is the combination of genetic algorithm and artificial neural network is compatible with experimental work.

1. Introduction

These days one of the most common propositions of researches and studies is increasing the efficiency of heating systems. Besides other solutions such as, surface, increasing, producing turbulence flow, adding metal and nonmetal particles to the fluid is introduced as one of the best methods. In other words, the thermal conductivity coefficient of metals and metal oxide is much more than fluids and oils [1]. A fluid that consists of metal particles of 100 nm diameter is called a nanofluid. It is important to say that, the term nanofluid was used for the first time by Choi [2] for sets of new fluid that contained rigid particles. By this time, the usage of nanofluid has become common for improving the heat transfer characteristics in different systems such as heat exchangers and solar collectors [3].

Thermophysical properties are very impressive in efficiency of heating systems. In other words, the main aim of adding nanoparticles to the fluids that are used in heat exchanging systems is improving the thermophysical properties. Also, the amount of these properties will change by adding them to the base fluid [4–8]. Among these properties the density, viscosity, thermal conductivity and specific heat capacity are citing factors. Researchers have different statements about the effect of adding nanoparticles to the water. In general, all these properties will increase by adding nanoparticles except for specific heat capacity which will decrease. The amount of growth depends on different parameters such as weight percentage of nanoparticles, nanoparticles' characteristics, base fluid characteristics and temperature [9–11].

Viscosity is one the most important thermophysical properties for calculating the pumping power and conductive heat transfer, which will be affected by dispersed nanoparticles. For this purpose, a multitude of researchers has surveyed nanofluids which lead them to report the fact that, nanofluids are a function of temperature and density [12–14]. On the other hand, it is really important to calculate the viscosity of nanoparticles and nanofluids in different situations and temperatures for designing different systems.

Undoubtedly, by using experimental methods and accurate laboratory tools for each discipline trustworthy and reliable results are achievable in our studies. Since the experimental methods require special equipment, and it would cost a lot of money and time, modeling methods and algorithms can be replaced by empirical methods. With regard to the proposed items, for predicting the property of nanofluid, viscosity modeling methods are usable. Today, artificial neural network is a tool for predicting and modeling the phenomena, that is inspired by the human brain functions.

Many studies have been done for viscosity determination. A.S. Dalkilic et al. [15] have predicted the viscosity of graphite nanofluid by means of artificial neural network. The experimental studies have

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been done for validating the presented ANN model. Furthermore, they have proved the measured dynamic viscosity values' accuracy by comparing them with literature. It is shown that the dynamic viscosity values of nanofluid in the study increase with decreasing temperature and increasing concentration as expected. Their volumetric concentrations are varied from 0 to 2% in pure water. The average proportional errors in achieved predictions are between 0.914% and 3.418%.

The prediction of thermal conductivity and dynamic viscosity of ferromagnetic nanofluid has been done by Hemmat et al. [16]. They have used experimental data for modeling and training the network. The input parameters presumed by them are, temperature, particle diameter and the density of the nanoparticles. The results show that, there is not much difference between experimental and modeling. The amount of error rate of thermal conductivity and viscosity are 2 and 2.5% respectively.

Artificial neural network modeling of the MWCNTs-SiO_2/AE40 nano-lubricant has been presented by Afrand et al. [17]. They have used 48 experimental dates in order to model and train the network. The results show that, the presented model has 1.5% conflict in case of comparison with experimental data. Also, in another study, prediction of nanofluid viscosity of multi walled carbon nanotube/water by using improved artificial neural network has been done. Furthermore, results show that, the presented model has 0.28% error rate in comparison with experimental data [18].

F. Yousefi et al. [19] have presented a model for demonstrating the viscosity of nanofluid by using diffusional neural networks. Also, the effective viscosity of nanofluid is determined as a function of the temperature, nanoparticle volume fraction, nanoparticle size and the base fluid physical properties. Moreover, the average absolute deviation for CuO-water that is achieved by ANN is 1.63.

Viscosity is a critical physical property of nanofluids in particle heat transfer applications. No broad model is able to exactly forecast nanofluid viscosity in a wide scope of powerful parameters. E. Heidari et al. [20] have presented 1490 experimental information focused on relative viscosity of various nanofluids which have been gathered by a thorough search in literature. At that point, a feed forward back propagation multilayer perceptron artificial neural system was produced and tried by means of utilizing Levenberg Marquardt preparing calculation keeping in mind the end goal to anticipate nanofluid thickness in expansive scopes of working parameters. In this research the attained correlation coefficient is 0.99998 and the percentage of average absolute deviation is 6.44%.

Prediction of dynamic viscosity by using neural network has been done by M. H. Esfe et al. [21] the viscosity of the aqueous nanofluid has been modeled. They have used a network with one hidden layer and 4 neurons. The regression coefficient obtained was 0.9998. Moreover, the maximum error for a wide range of nanoparticle mass fractions was 0.5%. On the other hand, the maximum deviation obtained for modeling the neural network was 2%. In order to achieve the viscosity of nanofluids S. Atashrouz et al. [22] have used a hybrid group method of data handling (GMDH) type neural network system. Furthermore, the estimation of viscosity has been done for nine different nanofluids based on water. Moreover, the percentage of average absolute relative deviation for all systems was 2.14% with a correlation coefficient of 0.9978. Also, the obtained result has been compared with various theoretical models and empirical equations. Obtaining relative viscosity of nanofluids by a grand polynomial correlation function of temperature, particle diameter and volume fraction was the main point in that study.

N. Zhao et al. [23] have used a different method for achieving the viscosity of water based nanofluids. The radial basis function neural network was a tool in their study. Two radial basis function (RBF) neural networks are proposed, one with 5 input variables, the other with 4 input variables. Both models take into account the effects of nanoparticle volume concentration, nanoparticle diameter, nanoparticle density and the viscosity of base fluid, while the 5-input model also considers the effect of temperature. The results for water nanofluid viscosity are root mean squared error (RMSE) $= 9.078 \times 10^{-5}$, mean absolute percentage error (MAPE) $= 2.673\%$, sum of squared error (SSE) $= 4.327 \times 10^{-6}$ and, for the CuO-water nanofluid viscosity are RMSE $= 3.623 \times 10^{-5}$, MAPE $= 1.067\%$ and SSE $= 2.572 \times 10^{-7}$.

For improvement in modeling genetic algorithm is a considerable approach. This algorithm is based on Darwin's theory about nature and survival of the fittest. Improvement function is one of the most common usages of genetic algorithm. This algorithm is an accidental and a directional method for improving that gradually moves toward the optimal point. In case of comparison with other algorithms, genetic algorithm can resolve any problem without any information and there is no limitation for type of variables. Also, it has proven performance in finding the global optimum. When the classical methods are inapplicable or receivable optimal and generally uncertain, the ability of these methods to solve complex optimization problems comes in [24]. By using the artificial network back-propagation and genetic algorithm Karimi et al. [25] have investigated the density of four nanofluids in temperatures of 273–323 K and the results of their study show the proper accuracy by absolute deviation of 0.13% and with a high correlation coefficient ($R \geq 0.98$). In another study Karimi et al. [26] have predicted the nanofluid characteristics by using artificial neural network and genetic algorithm. They have used experimental data of 8 nanofluids for modeling. The results of their study show that the accuracy of the presented model is acceptable by an absolute deviation of 2.48% and a correlation coefficient of 0.98.

Salehi, H. et al. [27] have shown that, the hybrid modeling of neural network and genetic algorithm for predicting the heat transfer of silver nanofluid by using the two-phase closed thermosyphone has accurate results. The investigation into genetic algorithm along with artificial neural networks for predicting the characteristics of nanofluids leads us to measuring the viscosity of nanofluid which contains graphene nanoplatelets and deionized water by experimental approaches. Furthermore, in this study modeling has been done with the help of genetic algorithm and artificial neural networks.

2. Experimental method

2.1. Materials and methods for preparing nanofluids

Graphene with a diameter of <2 μm and a thickness of 2 nm has been used in this study. Besides, 750 m^2/g was used as a magnifying factor which is the product of "XG Sciences, Inc., Lansing, MI, USA" grade C. On the other hand, the base fluid used to disperse the nanoparticles, is deionized water.

Purvey of stable nanofluids with uniform particle distribution is one of the factors affecting thermo-physical properties. Among the available methods for the preparation of nanofluid, the two-step method has been chosen. In this process, for dispersing the nanoparticles by 0.025, 0.05, 0.075, 0.1 wt% the ultrasonic probe "Q700 Sonicator, Qsonica, LLC., USA" that has 700 W and 20 kH frequency has been used. Required ultrasonic time for building samples by 95% power is 1 h and for overheating prevention, the mixture was changed into passive ultrasonic.

2.2. Method of investigating the properties

Nanofluid is a mixture of nanoparticles and base fluid. Due to the nature of this fluid, the physical properties of a nanofluid are as a function of the properties of its ingredients. Therefore, knowledge of the properties of nanoparticles and base fluid is a necessity. In this research for analyzing the materials and investigating the structure of nanoparticles two methods have been used. In the first one, the morphological study of graphene nanoplatelets has been done by the electron microscope model "TEM, EM900, Zeiss, Germany". The acceleration voltage of electrons is 80 kV and it is illustrated in Fig. 1.