Nanomed. J. 5(4): 217-221, Autumn 2018

RESEARCH PAPER

Applying GMDH artificial neural network to predict dynamic viscosity of an antimicrobial nanofluid

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ABSTRACT

Objective (s): Artificial Neural Networks (ANN) are widely used for predicting systems behavior. Group Method of Data Handling (GMDH) is a type of ANNs which has remarkable ability in pattern recognition. The aim the current study was to propose a model to predict dynamic viscosity of silver/water nanofluid which could be used as antimicrobial fluid for several medical purposes.

Materials and Methods: In order to have precise model, it is necessary to consider all influential factors. Temperature, concentration and size of nanoparticles are used as input variables of the model. In addition, GMDH artificial neural network is applied to design a proper model. Data for modeling are extracted from conducted experimental studies published in valuable journals.

Results: The dynamic viscosity of Ag/water nanofluid is precisely modeled by using GMDH. The obtained values for R-squared is equal to 0.9996 which indicates perfect precision of the proposed model. In addition, the highest relative deviation for the model is 2.2%. Based on the values of these statistical criteria, the model is acceptable and very accurate.

Conclusion: GMDH artificial neural network is reliable approach to predict dynamic viscosity of Ag/water nanofluid by using temperature, concentration and size of particles as input data.

Keywords: *Dynamic viscosity, Irrigant, Medical, Nanofluid*

How to cite this article

Mohamadian F, Eftekhar L, Haghighi Bardineh Y. Applying GMDH artificial neural network to predict dynamic viscosity of an antimicrobial nanofluid. Nanomed J. 2018; 5(4): 217-221. DOI: 10.22038/nmj.2018.05.00005

INTRODUCTION

Nanotechnology is widely applicable in several fields of science [1,2] some of them are more influential such as temperature, size and type of nanoparticles and volumetric concentration. In this study, artificial neural network as well as least square support vector machine (LSSVM) were used. By applying nano-based materials, it is possible to achieve high efficiency, compact sizes and appropriate mechanical properties [3]. Several studies have focused on the applications of nanotechnology in engineering systems to obtain better working conditions [4,5]. Several parameters are influential in the properties of nanomaterials such as their size, manufacturing process, working temperature and etc. These factors must be considered in modeling their properties to have accurate and proper output.

In addition to engineering systems, nanotechnology is applicable in medical and dental fields. By using nanofluids, such as nano-irrigant, effective disinfection is achievable. Based on a study conducted by Akbarianrad *et al.* [6], nanotechnology has been utilized in dentistry for different purposes such as root canal irrigation and photosensitizer for photodynamic therapy. There are various researches focused on using nanofluids, which are prepared by dispersing nano-sized particles in base fluids. Atai *et al.* [7] performed a study on nano-porous nano silica, which was thermally sintered, as filler in dental composite. The properties of the composite contained the nano filler were compared with the composites with micro fillers and the conventional available nanocomposite. Elastic module and their strength were evaluated by applying various models. In the study, nano-silica particles with 12

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Note. This manuscript was submitted on July 10, 2018; approved on August 18, 2018

nm diameter were thermally sintered to obtain nanofiller particles. The investigated material was a mixture of 70% (wt) of the nanofiller and Bis-GMA and TEGDMA. The microfiller utilized in the study contained micro-sized filler made of glass. Based on the obtained results, the composite with nano-sized materials had higher mechanical strength, and modulus of elastic compared with the composite filled with the micro-sized material.

Some nanoparticles such as silver, have antimicrobial property which can be utilized in medical treatments [8–10]. Silver nanoparticles are broadly utilized in various medical and dental applications due to their antibacterial and anti-inflammatory influences [11]. In addition, these nanoparticles are used in dental practice and integrated with restorative materials and agent to prevent formation of biofilms and decrease caries [12].

In order to simply use these nanoparticles, dispersing them in a base fluid such as water is an appropriate idea. Rodrigues *et al.* [13], synthesized silver/water nanofluid.

In the synthesis procedure, lactulose was utilized as reducing and stabilizing agent. Results revealed that the nanofluid had excellent antimicrobial performance.

Nanofluids properties depend on several factors such as temperature, synthesis process, concentration of solid phase, and size of nano particles. Several studies have focused on finding comprehensive relationship between these factors and nanofluids properties [2,3].

Since dynamic viscosity of fluids affects the flow, pressure loss and wall shear stress, this property is considered in the current study. Size of silver particles, temperature of nanofluid and concentration are among the most influential factors in the determination of dynamic viscosity. Therefore, dynamic viscosity of the nanofluid can be predicted based on the values of these parameters.

Artificial neural networks are accurate approaches to model systems based on variables influencing on their performance [14]. Group Method of Data Handling (GMDH) artificial neural network is a powerful approach for system recognition and modeling.

This method is applied in various systems and shows its high accuracy as a predictive model. In the present study, GMDH is utilized to predict dynamic viscosity of Ag/water nanofluid as a function of temperature, size and concentration.

MATERIALS AND METHODS

GMDH artificial neural network is a predictive tool which is widely used for pattern recognition and modeling of systems. This type of neural network is self-organizing and one-directional which contains several layers with some neurons. All the neurons have similar structure with two inputs and one output. Each neuron process between input and output data via 5 weights and one bias as shown in Fig 1 and equation 1.

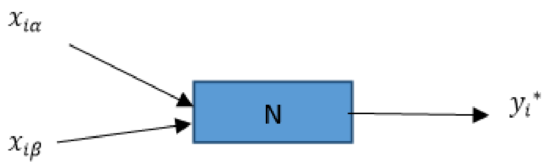

Fig 1. neuron structure in the network

$$y_{ik}^* = N(x_{i\alpha}, x_{i\beta}) = b^k + w_1^k x_{i\alpha} + w_2^k x_{i\beta} + w_3^k x_{i\alpha}^2 + w_4^k x_{i\beta}^2 + w_5^k x_{i\alpha} x_{i\beta} \quad (1)$$

$i = 1,2,3, \dots, N$

Where N refers to input and output data, $k = 1,2,3, \dots C_m^2$ and $\alpha, \beta = \{1,2,3, \dots, m\}$. m is the number of neurons in the previous layer. The weights are obtained based on the linear least squares and utilized as constants in each neuron. In this network, neuron in previous sections or layers generate neurons. Some of these neurons will be removed to prevent divergence of the network. The criterion for eliminating and selecting the neurons in each layer is defined based on equation 2.

$j \epsilon \{1,2,3, \dots, C_m^2\}$

$$r_j^2 = \frac{\sum_{i=1}^N (y_i - y_{ij}^*)^2}{\sum_{i=1}^N y_i^2} \quad (2)$$

In the above equation, *m* is the number of selected neurons in the previous layer. In order to correlate the input and output data, Volterra functional series is applied as [15]:

$$y = a_0 + \sum_{i=1}^n a_i x_i + \sum_{i=1}^n \sum_{j=1}^n a_{ij} x_i x_j + \sum_{i=1}^n \sum_{j=1}^n \sum_{k=1}^n a_{ijk} x_i x_j x_k + \cdots \quad (3)$$

The utilized structure for the neurons is represented in equation 4:

$$y_i = G(x_{ip}, x_{iq}) = a_0 + a_1 x_{ip} + a_2 x_{iq} + a_3 x_{ip} x_{iq+} a_4 x_{ip}^2 + a_5 x_{iq}^2 \quad (4)$$

The constants in above equations are obtained based on the below relationships:

$$Min \sum_{k=1}^N [(f(x_{ki}, x_{kj}) - y_i^2)^2] \quad (5)$$

The above equation can be represented as:

$$Aa = Y \quad (6)$$

$$a = \{a_0, a_1, a_2, a_3, a_4, a_5\} \quad (7)$$

$$Y = \{y_1, y_2, y_3, \dots, y_M\}^T \quad (8)$$

The unknown vector is denoted by a, Y stands for the output vector, and A refers the two neurons belongs to each of M equation.

$$\begin{bmatrix} 1 & x_{1p} & x_{1q} & x_{1p}x_{1q} & x_{1p}^2 & x_{1q}^2 \\ 1 & x_{2p} & x_{2q} & x_{2p}x_{2q} & x_{2p}^2 & x_{2q}^2 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & x_{Mp} & x_{Mq} & x_{Mp}x_{Mq} & x_{Mp}^2 & x_{Mq}^2 \end{bmatrix} \quad (9)$$

More details on GMDH procedure are represented in Refs [15–17].

RESULTS AND DISCUSSION

Based on the literature review, three main factors significantly affect dynamic viscosity of nanofluids. Studies have shown that increase in temperature results in lower dynamic viscosity of nanofluids which is attributed to higher energy of molecules and intermolecular distances [18]. Concentration of nano particles is another influential factor. Due to existence of solid phase, increase in concentration leads to higher viscosity [19]. In Fig 2, the effects of concentration and temperature on dynamic viscosity of the nanofluid is shown.

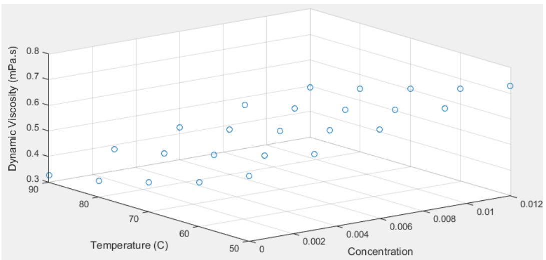

Fig 2. Effect of temperature and volumetric concentration on dynamic viscosity of Ag/water [20]

Table 1. Ranges of input variables

Variable	Min	Max
Size (nm)	40	63
Temperature (℃)	20	90
Volumetric Concentration	0	0.012

Size of nano particles is another factor which has impact on the thermophysical properties of nanofluids. Based on a comprehensive review study conducted by Koca *et al.* [21], it was concluded there is discrepancy about the influence of size of nano particles on the dynamic viscosity of nanofluids. The aim the current study is determining the dynamic viscosity of Ag/water nanofluid as a function of temperature, concentration and size of nano particles. Data are extracted from experimental data represented in Refs [20,22–24]. The ranges of input variables are represented in Table 1.

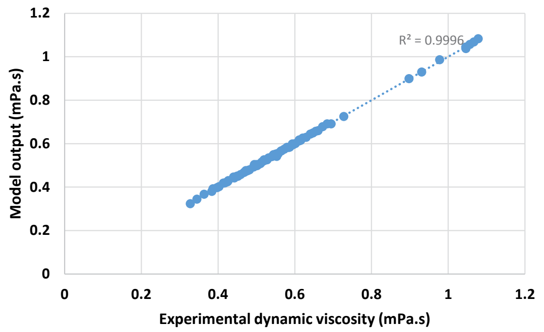

Fig 3. Experimental data vs model output

In order to model the dynamic viscosity of Ag/water nanofluid, 72 data sets were utilized. Approximately 80% of them used for training the network and 20% of them were applied for testing the model. The obtained correlation between input and output data by applying GMDH artificial neural network is represented in equation 10.

$$\text{Dynamic Viscosity} = 2.06061 + \text{size} * \text{temperature} * 0.000944779 + \text{concentration} * \text{temperature} * (-0.00626814) + (\text{temperature})^2 * 3.45634 * 10^{-5} + \text{Size} * \text{concentration} * (-0.22393) + (\text{concentration})^2 * (-442.965) + (\text{size})^2 * (-0.000303035) + \text{temperature} * (-0.0698069) + \text{Concentration}\ 35.0541 + \text{size} * 0.00175957 \quad (10)$$

comparison between obtained results by model and actual data is represented in Figure 3.

As shown in Figure 3, the obtained R-squared value for the proposed model is equal to 0.9996 which shows excellent accuracy of the model.

The experimental value and model output for each data index are illustrated in Fig 4.

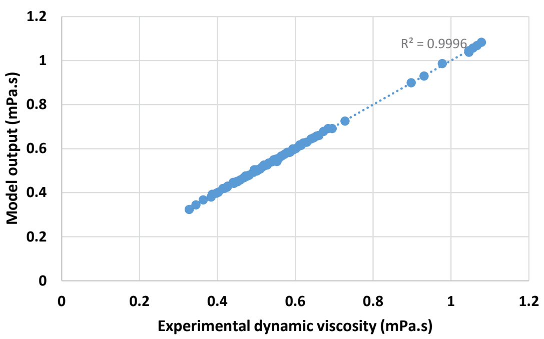

Fig 3. Experimental data vs model output

Another criterion for evaluation the precision of the predictive model, is relative deviation between

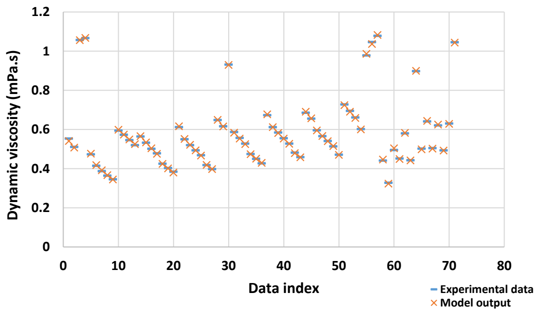

Fig 4. Dynamic viscosity vs data index

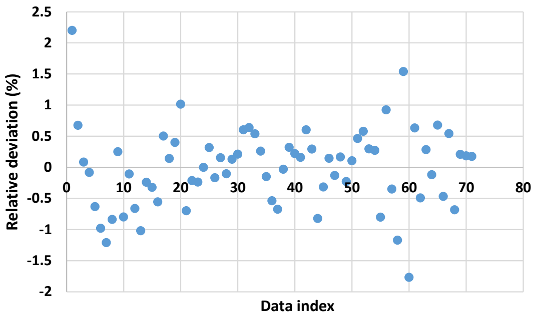

Fig 5. Relative deviation vs data index

actual data and model output. Relative deviation for each data index is represented in Fig 5.

As shown in Fig 4, the highest relative deviation is equal to 2.2% which demonstrate that the model is able to predict the dynamic viscosity precisely.

The accuracy of the designed model can be attributed to the selection of appropriate and influential factors affecting dynamic viscosity of the nanofluid.

Moreover, since the utilized data are selected from several experimental studies with different specifications, the model is comprehensive and cover wide range of input variables.

CONCLUSION

In the current study, dynamic viscosity of Ag/water nanofluid, applicable as an antimicrobial fluid, is modeled by using GMDH artificial neural network.

In order to have precise and comprehensive model, temperature, size of nano particles and concentration are selected as input variables. Results revealed that GMDH is an accurate method to predict dynamic viscosity of silver/water nanofluid.

The R-squared value of the model was 0.9996 and the highest relative deviation was equal to 2.2%.

ACKNOWLEDGMENTS

The authors would like to thank M. Zeinali for his helpful comments.

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