International Communications in Heat and Mass Transfer 74 (2016) 125–128

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Estimation of thermal conductivity of Al_2O_3/water (40%)–ethylene glycol (60%) by artificial neural network and correlation using experimental data☆

Mohammad Hemmat Esfe [a,*], Wei-Mon Yan [b,*], Masoud Afrand [c,*], M. Sarraf [d], Davood Toghraie [a], Mahidzal Dahari [d]

[a] Young Researchers and Elite Club, Khomeinishahr Branch, Islamic Azad University, Isfahan, Iran
[b] Department of Energy and Refrigerating Air-Conditioning Engineering, National Taipei University of Technology, Taipei 10608, Taiwan, ROC
[c] Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[d] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Available online 13 April 2016

Keywords:
Nanofluid
Thermal conductivity
Artificial neural network

ABSTRACT

In this work, the estimation of thermal conductivity of Al_2O_3 nanoparticles in water (40%)–ethylene glycol (60%) has been investigated. An empirical relationship has been proposed based on experimental data and in terms of temperature and volume fraction. Besides, a model has been presented using feedforward multi-layer perceptron (MLP) artificial neural network (ANN). The presented correlation relationship estimates empirical data very well. However, artificial neural network has a higher regression coefficient and lower error compared to the presented relationship. After examining different structures of neural network with different transfer functions, a structure was selected with two hidden layers and 5 neurons in the first and second layers and tangent sigmoid transfer function for both layers. The results indicate that artificial neural networks can precisely estimate the experimental data of thermal conductivity of Al_2O_3/water (40%)–ethylene glycol (60%) nanofluids.

1. Introduction

Nanofluids are colloidal suspensions in which particles in nano size are dispersed in pure fluid. Recently, to improve the heat transfer, one way is increased, the thermal conductivity of base fluids with adding solid particles to these fluids. First, Choi [1] suspended metal nanoparticles of copper in water and reported thermal conductivity enhancement. After that, a great number of researches have been conducted on different nanofluids from different aspects [2–8]. These particles include different types of oxides such as copper oxide [9–11], aluminum oxide [12–14], titanium oxide [15,16], and so on. The other nanoparticles used in nanofluids preparation are metal particles like silver nanoparticles [17]. From different nanoparticles, CNT is considered a good one for nanofluids preparation. Choi et al. [18] reported 150% increase in thermal conductivity of poly (α- olefin) by adding 1% volume of multiwall nanotube (MWCNT). Similarly, Yang et al. [19] reported 200% increase in thermal conductivity by adding 0.35% multiwall carbon nanotube (MWCNT). Hemmat Esfe et al. [20] investigated aquatic nanofluids of carbon nanotube and examined thermophysical properties and pressure drop in two-tube transformers. Amiri et al. [17] have produced stable nanofluids by the synthesis of carbon nanotubes decorated by silver particles and examined their thermophysical properties. The heat transfer of MWCNT oil nanofluids inside horizontal flattened tubes was performed by Ashtiani et al. [21]. Baghbanzadeh et al. [22,23] have examined the thermal conductivity and viscosity by preparing hybrid MWCNT/SiO_2 nanofluids and different combinations. Also, Chen and Xie [24] examined the effect of PH on zeta potential of one- and two-wall nanofluids and measured their thermal conductivity.

While using nanofluids, we should remember that the effective viscosity of nanofluid can be four times as much as that for base fluid. Therefore, increase in viscosity would enhance pump power and thus increase energy consumption [25]. Definitely, several different aspects of nanofluids have not been revealed up to now, and using these fluids in industrial applications requires more extensive researches. One of the new subjects used in transformers heat analysis in recent years is artificial neural network [26]. Hojjat et al. [27] in an article have used MLP neural networks for modeling their empirical data. Hemmat Esfe et al. [28,29] have modeled different empirical data by using neural networks. Karimi and Yousefi [30] have modeled the results of nanofluids density by using a combination of neural network and genetic algorithm. Neural networks are able to model the complex patterns well by using simple computations and a parallel processing similar to what takes place in human brain.

☆ Communicated by: W. J. Minkowycz
* Corresponding authors.
E-mail addresses: M.hemmatesfe@gmail.com (M. Hemmat Esfe), wmyan@ntut.edu.tw (W.-M. Yan), masoud_afrand@yahoo.com (M. Afrand).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2016.02.002
0735-1933/

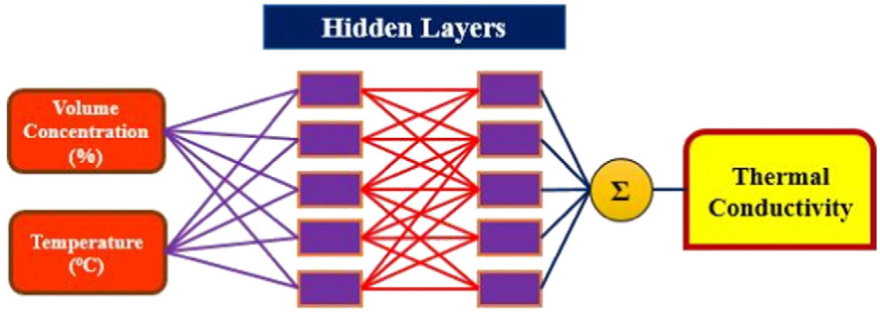

Fig 1. ANN structure with 2 hidden layers.

In this work, thermal conductivity of Al_2O_3 in water–EG (40–60%) base fluid has been studied by using empirical data [31], correlation relationship, and neural network. The effect of different parameters on regression coefficient of correlation has been investigated and the best relationship with the least error would be presented. Also, different structures of neural network have been examined and an optimal structure has been used for modeling empirical data.

1.1. Artificial neural network

Artificial neural network is a new subject in which computer scientists have become interested and on which they have spent a great deal of time and money to make more advances in computer sciences. The study of artificial neural networks was greatly inspired from natural learning systems in which a complex series of connected neurons are involved in learning. Fig. 1 shows the neural network structure in which has two hidden layers, each of which has 5 neurons. For each of these layers, transfer function of tansig has been considered that brings about the best results. In the output layer, transfer function of purelin has been used. Tansig function that has been used for the data is shown as follows:

$$f(z) = \frac{1}{1 + e^{-z}} \qquad (1)$$

2. Results and discussion

To understand the iterations on mean squared error, the improvement in network's performance for each training, validation, and test set is shown in Fig. 2. The best response of validation set is selected to be the output in this work. Fig. 3 shows the results of the thermal conductivity of nanofluids under various volume fractions and temperatures for experimental data and the obtained model for neural network. This graph has been plotted for 5 different temperatures ranging from 20 to 60 °C. It is clearly found that the neural network can estimate experimental data with an acceptable precision.

Another method that can be used to measure the agreement between the neural network and the data is the regression plot. The regression plot for all samples is presented in Fig. 4. It is noted in Fig. 4 that the actual outputs of the network in terms of the associated values. The linear fit to the relationship precisely divides the plot's top-right and bottom-left corners and shows that the network agrees with the data well. Otherwise, additional training, or training a network including more hidden neurons, is recommended. Table of parameters of neural network modeling for training, validation, and test data and also the general performance of network is disclosed in Table 1. In Table 1, μ is the mean of error and σ is the standard deviation of neural network outputs.

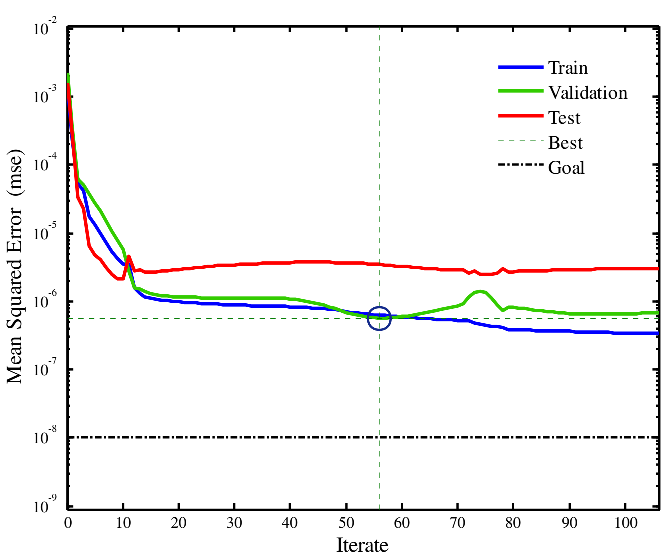

Fig 2. Validation performance.

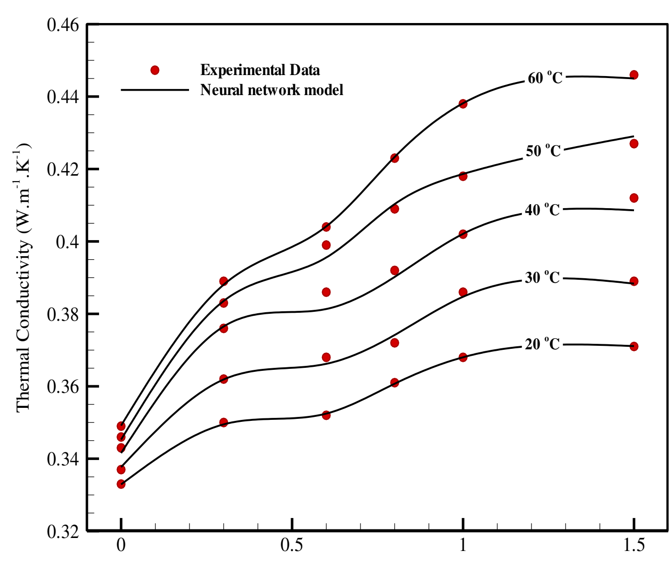

Fig. 3. Comparison between experimental data and ANN at different volume concentrations.