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Estimation of thermal conductivity of CNTs-water in low temperature by artificial neural network and correlation☆

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ABSTRACT

An accurate artificial neural network (ANN) model and new correlation are developed to predict thermal conductivity of functionalized carbon nanotubes (MWNT-10 nm in diameter)-water nanofluid based on experimental data. Experimental values of thermal conductivity are in six concentrations of nanoparticles from 0.005% up to 1.5%. The temperatures were changed within 10–60 °C. In order to estimate the thermal conductivity, a feed-forward three-layer neural network is utilized. The obtained results exhibited that the new correlation and ANN model have a good agreement with the experimental data. The maximum values of deviation and mean square error of neural network outputs were 2% and 8.2E−05, respectively. The findings illustrated that the artificial neural network can estimate and model the thermal conductivity of CNTs-water nanofluid very efficiently and accurately.

1. Introduction

Thermal conductivity of CNTs is noticeable compared to other nanoparticles [1]. Hence, many researchers eager to study the thermal conductivity behavior of nanofluids containing carbon nanotubes. Table 1summarized some experimental studies for the thermal conductivity enhancement of nanofluids containing CNTs.

Neural networks, genetic algorithms and fuzzy logic are the soft computing methods that could estimate the thermal conductivity of nanofluids, accurately. The thermal conductivity of MgO-EG nanofluids using the neural network method is obtained by Hemmat esfe et al. [17]. They modeled the experimental data using solid volume fraction of nanoparticles, temperature and diameter of nanoparticles as input, and thermal conductivity of nanoparticles as output of ANN. They concluded that neural network can be used as a powerful tool to predict the thermal conductivity of nanofluids. Also, in other studies, they reported ANN modeling and new empirical correlations to predict the thermal conductivity of various nanofluids base on experimental results [18–26]. Hojjat et al. [27] studied the three different types of nanofluids that were prepared by dispersing c-Al_2O_3, TiO_2 and CuO nanoparticles in a 0.5 wt.% of carboxymethyl cellulose (CMC) aqueous solution. They measured thermal conductivity of the base fluid and nanofluids with various nanoparticle loadings at different temperatures, experimentally. Also, they proposed neural network models to represent the thermal conductivity as a function of the temperature, nanoparticle concentration and the thermal conductivity of the nanoparticles.

A feed-forward three-layer neural network is proposed to predict conductivity (k) of pure gases which is done by Eslamloueyan et al. [28].Their results indicated that the proposed neural network outperforms other alternative methods, with respect to accuracy as well as extrapolation capabilities. Besides, conventional conductivity correlations are usually used for a limited range of temperature and components while the network method is able to cover a wide range of temperatures and substances.

In the present study, ANN is employed for modeling f-CNTs (MWNT-10 nm in diameter)/water nanofluid behavior and thermal conductivity. Input parameters consist of temperature and concentration of carbon nanotubes and output parameter is the effective thermal conductivity. Also, the new correlation base on experimental data [29] is proposed.

2. Artificial neural network

Numbers of simple processing elements called neurons constitute a neural network. In this network, each neuron is connected to others through direct communication links, each with an associated weight representing information being used by the network to solve

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Table 1
A summary of some experimental studies for the thermal conductivity enhancement of nanofluids containing CNTs.

Authors	Base fluid	Dispersed particles	Concentration	Maximum enhancement
Biercuk et al. [2]	Water	SWNT & VGCF	1.0%	125.0% & 45.0%
Choi et al. [3]	Olefin oil	CNT	1.75%	160.0%
Choi et al. [4]	Water	SWNT	0.89%	19.4%
Assael et al. [5]	SDS-water	CNT	1.05%	38.0%
Assael et al. [6]	CTAB-water	CNT	1.05%	34.0%
Amrollahi et al. [7]	EG	CNT	4.35%	20.0%
Han et al. [8]	Olefin oil	Hybrid sphere/CNT	0.45%	21.0%
Wensel et al. [9]	Water	MgO/Fe_2O_3-CNT	0.02%	10.0%
Hong et al. [10]	Water	CNT-Fe_2O_3	0.01%–0.02%	13.0%
Assael et al. [6]	CTAB-water	MWCNT	0.6%	34.0%
Hemmat esfe et al. [11].	Water	COOH functionalized MWCNTs	1.0%	36.0%
Jana et al. [12]	Water	Au and Cu/CNT	0.8%	34.0%
Jiang et al. [13]	R113	CNT	1.00%	104.0%
Chen et al. [14]	EG	CNT	0.01%	17.5%
Aravind et al. [15]	DIW & EG	MWCNT	0.03%	33.0% & 40.0%
Hemmat esfe et al. [16].	Water	DWCNTs	0.4%	7.41%

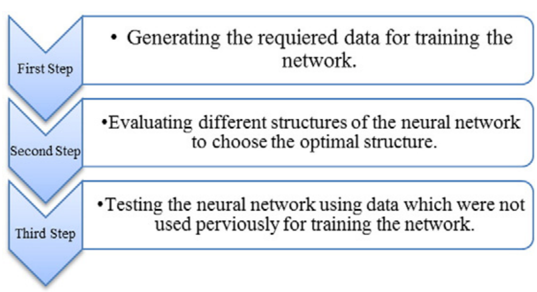

Fig. 1. Steps in modeling an artificial neural network.

the problem. The output of a neuron is computed from the following equation:

$$Out_j = f\left(\sum_{i=1}^{n} W_{ij}X_i + b_j\right) \quad (1)$$

where Out_j = output of jth neuron, f = activation or transfer function, b_j = bias of jth neuron, W_{ij} = synaptic weight corresponding

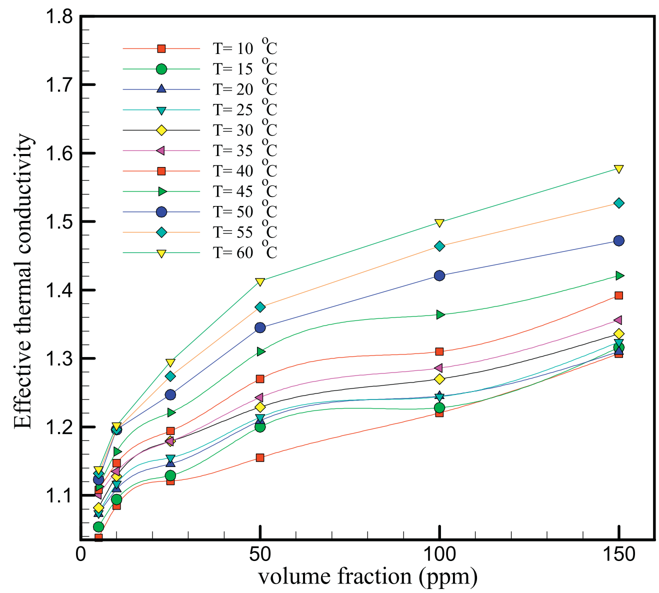

Fig. 3. Effective thermal conductivity versus volume fraction at different temperatures.

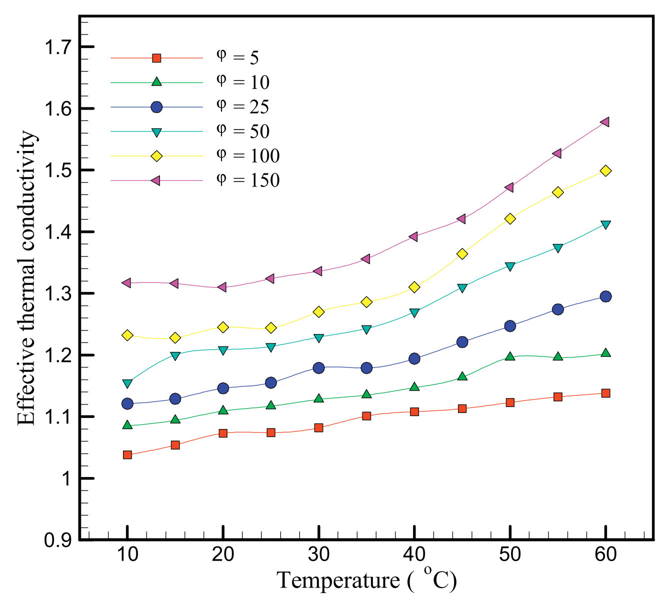

Fig. 4. Effective thermal conductivity versus temperature at different volume fractions.

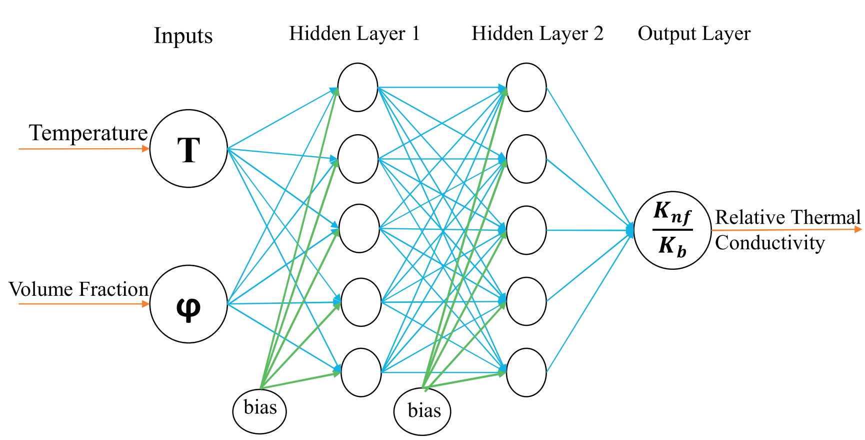

Fig. 2. The optimal multi-layer perceptions (MLP)-feedforward network.