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An RBF-based Artificial Neural Network for Prediction of Dynamic Viscosity of MgO/SAE 5W30 Oil Hybrid Nano-Lubricant to obtain the best performance of energy systems

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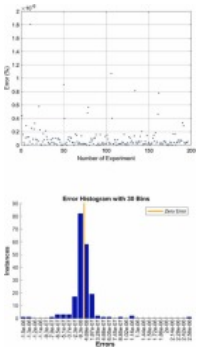
Abstract

Technological progress and complications in microfluidics usage have led researchers to use nanomaterials in different scientific fields. The properties and characteristics of hybrid Nanofluids are more enhanced compared to nanofluids based on single nanoparticles and conventional liquid. Recently, modeling methods have replaced most common statistical methods. Due to the high accuracy of the response and generalizability in various conditions, artificial neural networks (ANNs) to estimate nanofluids' viscosity and thermal conductivity have become common. Dynamic viscosity (μ) (estimation analyzes one of the key factors in determining the hydrodynamic behavior of nanofluids. In this manuscript, an RBF-ANN is used to simulate the input-output relation of dynamic viscosity of the MgO- SAE 5W30 Oil hybrid nanofluid versus three important parameters, including volume fraction of nanoparticles, temperature, and shear rate. The results show that for this nanofluid, by increasing temperature and shear rate, the dynamic viscosity is decreased. In contrast, the volume fraction of nanoparticles directly affects the output, although this consequence can be neglected. By increasing the temperature from 5 to 55 °C, the dynamic viscosity would decrease. Also, changing the shear rate from 50 to 1000 rpm decreases the dynamic viscosity from 400 cP to 25 cP. It is worth mentioning that the obtained trends and deviation of dynamic viscosity for MgO-SAE 5W30 Oil hybrid nanofluid versus temperature, the volume fraction of nanoparticles, and shear rate can be used by the academic community as well as an industrial section to obtain the best performance of energy systems based on this nanofluid.

Graphical abstract



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Introduction

Technological progress and the occurrence of complications in microfluidics usage, including equipment damage, sedimentation in ducts, extreme fluid pressure drop, and improper particle suspension in fluid, have led researchers to use Nanomaterial in different scientific fields [1]. Recent studies on nanofluids have introduced an advanced fluid classification with enhanced thermal properties called hybrid nanofluids, obtained by dispersing nanocomposites or nanoparticles of various metals in a base fluid such as water, ethylene glycol, or oil [2]. Hybrid nanofluids' properties and characteristics are more enhanced than nanofluids based on single nanoparticles and conventional liquids [3]. Researchers have proven that metal oxide particles such as CuO, MgO, and TiO_2 have an effective role in improving the properties of nanofluids due to their high elastic modulus, oxidation resistance, corrosion resistance, and high temperature tolerance [4]. Hemmat Esfe et al. [5] investigated the effects of increasing temperature and concentration of copper and titanium oxide nanoparticles in the various temperature ranges of 65 to 95 °C and up to a volume fraction of 2%. The fluid was also a hybrid and a mixture of water and ethylene glycol. This study showed an increase in the thermal conductivity to 44% at 65 °C and the volume fraction to 2%. Vafaie et al. [6] also investigated the effect of hybrid nanoparticles of carbon nanotubes and MgO on the thermal conductivity of ethylene glycol. This study shows that by increasing the number of nanoparticles and increasing the temperature, the thermal conductivity increases by 29%.

Recently, modeling methods have replaced most common statistical methods due to their high efficiency, reliability, and flexibility. Due to the high accuracy of the response and generalizability in various conditions, the use of ANNs to estimate the viscosity and thermal conductivity of nanofluids has become common [7]. The results showed that the ANN with this training algorithm could predict the Nusselt number with high accuracy. Also, in terms of calculation time, this method calculates the results quickly. For example, Tian et al. [8] investigated the influence of temperature and volume fraction of nanoparticles on the thermal conductivity of Graphene oxide-Al_2O_3/Water-Ethylene glycol hybrid nanofluid. The results showed that ANN was well trained using the trainbr algorithm and had a correlation coefficient of 0.999 for thermal conductivity. Finally, the results showed that increasing the nanofluid temperature has less effect on improving the thermal conductivity than the volume fraction of nanoparticles. Hemmat Esfe et al. [9] investigated the thermal conductivity of MgO/ethylene glycol (EG) nanofluids in the temperature range of 25-55 ° C and a volume concentration of up to 5%. It has been observed that the neural network can be used as a powerful tool to predict the thermal conductivity of nanofluids.

One of the most important properties of nanofluid is dynamic viscosity, that affects the flow and pumping power of the fluid and its thermal behavior. In most cases, the viscosity of the nanofluid is higher than that of the base fluid. Viscosity estimation analyses are key factors in determining the hydrodynamic behavior of nanofluids [10]. Nanofluid viscosity depends on temperature, particle size, nanoparticle volume fraction, and shear rate [11]. The obtained results from the study of dynamic viscosity of MWCNT-carbon/SAE 10 W40-SAE 85W90 showed that the effect of temperature on dynamic viscosity is dominant compared to the shear rate and concentration. In this study, the temperature and concentration of nanoparticles were defined as the input of the ANN. The recommended R^2 value of ANN was 1, which showed good performance in predicting dynamic viscosity [12]. The results of the researchers showed that another factor influencing the dynamic viscosity is the shear rate. In some models, this parameter was considered as an input variable. For example, Toghraie et al. [13] considered temperature, shear rate, and concentration as inputs and influential factors for predicting the dynamic viscosity of Tungsten Oxide (WO_3)-MWCNTs/Engine Oil hybrid nanofluid in the ANN model. The R^2 value of the ANN model in this study was 0.9948, which indicates the accuracy and good performance of the model. Hemmat et al. [14] predicted the dynamic viscosity of Al_2O_3-engine oil nanofluid using an ANN. Their results showed that the use of ANN leads to better results. Using the RBF-ANN model, the effect of volume percentage and temperature on the viscosity of Al_2O_3/Water nanofluid was investigated, which is well consistent with experimental data [15].

A review of previous research has shown that no research was conducted on a hybrid nanofluid consisting of SAE5W30 as the base fluid and MgO. Also, due to the complex mechanism and structure of nanofluids, in this study, the data obtained from the viscosity of the nanofluid are simulated with artificial RBF ANNs. In addition, the effects of volume fraction, temperature, and shear rate on the viscosity of the hybrid nanofluid are investigated. Finally, an attempt will be made to propose an optimal model to evaluate the dynamic viscosity of this nanofluid.

Section snippets

Radial Basis Function Network

Recently, modeling using machine learning and artificial intelligence methods have replaced most common statistical methods due to their high efficiency, reliability, and flexibility [18], [19], [20], [21], [22], [23]. Artificial Neural Networks (ANNs) are currently the most widely used Machine Learning techniques which are used in different applications [24], [25], [26], [27], [28]. Radial basis ANNs consist of a vast number of radial basis functions [29], [30]. There are two variants of…

RBF network training procedure

The training process of an RBF network has consisted of the following steps:

- **Data Preprocessing:** The input data was preprocessed by normalizing the features to ensure consistent ranges. We used MATLAB's built-in function, normalize, to perform this step.…
- **Selecting RBF Centers:** To determine the centers for the RBF neurons, the K-means clustering algorithm available in MATLAB's Statistics and Machine Learning Toolbox is used.…
- **Computing RBF Activations:** the activation values of each RBF neuron are…

…

Results and discussion

After training, the performance of the network can be computed using the function of *perform*. The main information of created network is summarized in Table 2.

To better understand the deviation of dynamic viscosity versus each input parameter, boxplots of dynamic viscosity are depicted versus each input parameter in Fig. 4, Fig. 5, Fig. 6.

Looking above figures, several points can be drawn. First of all, the volume fraction of nanoparticles directly affects the output, while the temperature and…

Conclusion

In this manuscript, an RBF ANN is used to simulate the input-output relation of dynamic viscosity of the MgO- SAE 5W30 Oil hybrid nanofluid versus three important parameters, including volume fraction of nanoparticles, temperature, and shear rate. The range of parameters is as follows: in 7 levels, 9 levels, and 11 levels. By combining the above values for the input parameters, 196 samples were obtained and for each case, the dynamic viscosity is examined and computed. Then an RBF-ANN is fitted …

Uncited reference

[17]…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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