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Technical Note

Simulation of turbulent convective heat transfer of γ-al_2o_3/water nanofluid in a tube by ann and anfis models

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ABSTRACT

In order to modeling and predicting heat transfer coefficient in nanofluids, artificial neural network (ANN) and Adaptive Neuro-fuzzy Inference system (ANFIS) were used in this study. In ANN and ANFIS, Input data are Reynolds number and nanoparticles volume fractions, and output data is heat transfer coefficient. Both of them could predict very well, and there is good agreement between experimental data and predicted data. In ANFIS coefficient of determination (R^2), average relative error and mean square error for train data are 0.99, 8.9×10^{-5} and 6.5476×10^{-5}, respectively, and for test data are one, zero and zero. According to results, by increasing the Reynolds number and volume fractions, the heat transfer coefficient increases. For base fluid in Re = 16300, heat transfer coefficient is 10961.38 W/m^2K, and for volume fraction 0.135, heat transfer coefficient is 13947.72 W/m^2K, therefore, heat transfer coefficient of nanofluids increased 1.27 time compared to that of base fluid. Results obtained from ANFIS are reliable, and can be used in prediction. Also, for ANN, ARE, MSE and R^2 value are, –0.003, 6.38264×10^{-5} and 0.99, respectively. So, there is good agreement between experimental data and ANN results too. According to errors, can conclude ANFIS is slightly better than ANN.

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INTRODUCTION

Today, since rising energy cost and environmental pollution, reduction and optimization of energy consumption in the various industrial process become important; using renewable resource energy[1] and alternative green fuel is necessary[2]. Heat transfer phenomena are one of the extensive areas of industrial processes. In general, at each industrial process, energy add to (or remove from) the process, and it has become the main task of industrial needs. Heat transfer enhancement leads to reduce process timing, operating and fixed costs due to reducing equipment size. There are several ways to encourage heat transfer performance in the process. Increasing the thermal conductivity

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of the working fluid, is one of the efficient methods to increase heat transfer performance. Almost in three last decades, nanofluids, which are superior heat transfer liquids[3], have been considered to apply for improving heat transfer in process.

Nanofluids are homogenous suspensions containing colloidal particles in the nanoscale. These fluids noticeable because of their promoted thermo-physical properties such as thermal conductivity compared to prevalent liquids[3]; and modified heat and mass transfer process [4]. One of the most important limitations of usual heat transfer fluids is their low thermal conductivity. Fotukian and Nasr Esfahany[4] measured heat transfer coefficient of γ-AL_2O_3/H2O nanofluid in the circular cooper tube with the inner diameter of 5 mm and 0.5 mm thickness. Their results showed that addition of small amount of nanoparticles to pure water could be improved the heat transfer performance significantly. Hojjat et al.[5] investigated γ-Al_2O_3, CuO and TiO2/carboxymethyl cellulose non-Newtonian nanofluids inside the stainless steel tube. They observed that heat transfer coefficient increased with Reynolds and Peclet number. At volume concentration of 0.5%, enhancement of heat transfer coefficient for suspension contain Al_2O_3 nanoparticle is more than two other nanofluids. Using a multichannel flat aluminum tube heat transfer of Al_2O_3– water nanofluids was investigated, showing that heat transfer enhancement was about 5.9% for Re=1732 and volume concentration 0.5% [6]. Alrashed et al.[7] had modeled the heat transfer and flow of CNT/water nanofluids in backwared-facing contracting channel. According to their results, surface temperature was reduced by enhancement of weight percentage of nanotubes and Reynolds numbers.

Computational intelligence which includes neeural network and fuzzy systems has become universal tools for many applications. Because of proximity and ability to learn, artificial neural networks widely used for simulation of dynamic processes, identification, prediction and control.

Vast investigations were done on intelligence modeling and simulation of heat transfer phenomena through other media expect nanofluids [8–10]. While little modeling studied was existed on heat transfer of nanofluids [11,12]. In this study, experimental data that have reported in [4] were used to simulate turbulent convective heat transfer of nanofluids γ-Al_2O_3 in a tube by ANFIS and ANN.

THEORY

Adaptive Neuro-Fuzzy Inference System (ANFIS)

Fuzzy Inference System using if-then rules and can model the qualitative part of human knowledge and also predict the processes without employing a careful analysis. Takagi and Sugeno Fuzzy modeling were discovered first by systematically and finds applying application in control, predict and inference.

Neural Network

Neural networks is divided into two classification: artificial neural networks (ANNs) and natural neural networks (NNNs). ANNs are data processor system which have the same properties with NNNs. An ANN is a generalized mathematical model of human diagnosis based on neurobiology.

The neural network is made from a combination of simple elements operated in parallel. These elements obtain from natural neural systems.

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RESULT AND DISCUSSION

ANFIS model

In this study in order to simulation turbulent convective heat transfer of γ-Al_2O_3 nanofluids in a circular tube by ANFIS and neural network, experimental data from reference was used. In ANFIS and neural network, data conclude two parts: inputs and outputs. In this investigation, volume fractions and Reynolds number are inputs and heat transfer coefficient are output of networks.

In order to use ANFIS and ANN, input and output data should be normalized. After normalization, data randomly should be divided into two parts: train and test data. In this study, 75 percent of all data that means 33 data was chosen as train data and 25 percent of them (11 data) is test data. In the next step, type and number of membership functions specified in the middle layers and the bottom layer. Optimum membership function for both train data and test data are Gaussian membership function, and optimum number of membership function obtained for Gaussian is 5.

As can be seen in Figure 1, except for a small number of data, there is a good agreement between train and target data. In investigation agreement between test and target data, complete overlap between the data was observed. Base on Figure 1 and Figure 2 the best number and type of membership function has been chosen.

Figure 3 a and b show experimental data versus predicted data for train and test data, respectively. The coefficient of determination values (R^2), that shown in Figure 3, which quantifies the degree of agreement between experimental observations and numerically calculated values were found greater than 0.99 for all train output variables and equal one for test output.

Changing in heat transfer coefficient based on inputs in three dimensional shown in Figure 4. According to Figure 4 adding small amount of nanoparticles to base fluid, dramatically increasing heat transfer coefficient, and also heat

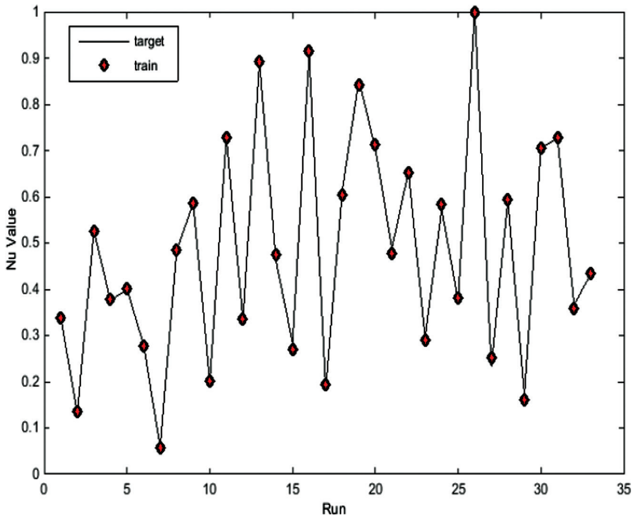

Figure 1. Overlap between target and train data.

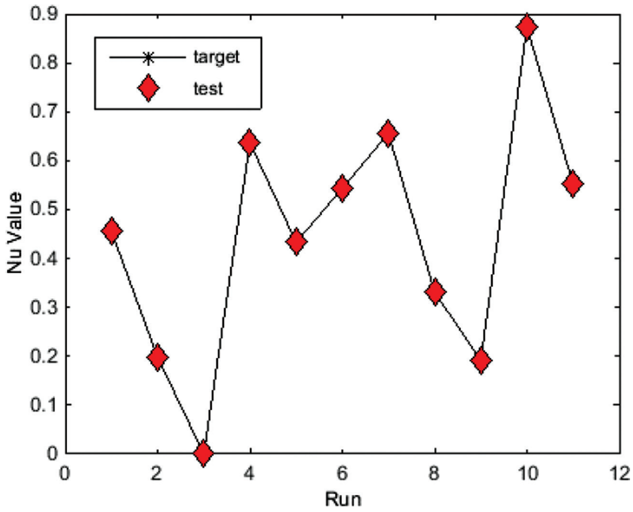

Figure 2. Overlap between target and test data.

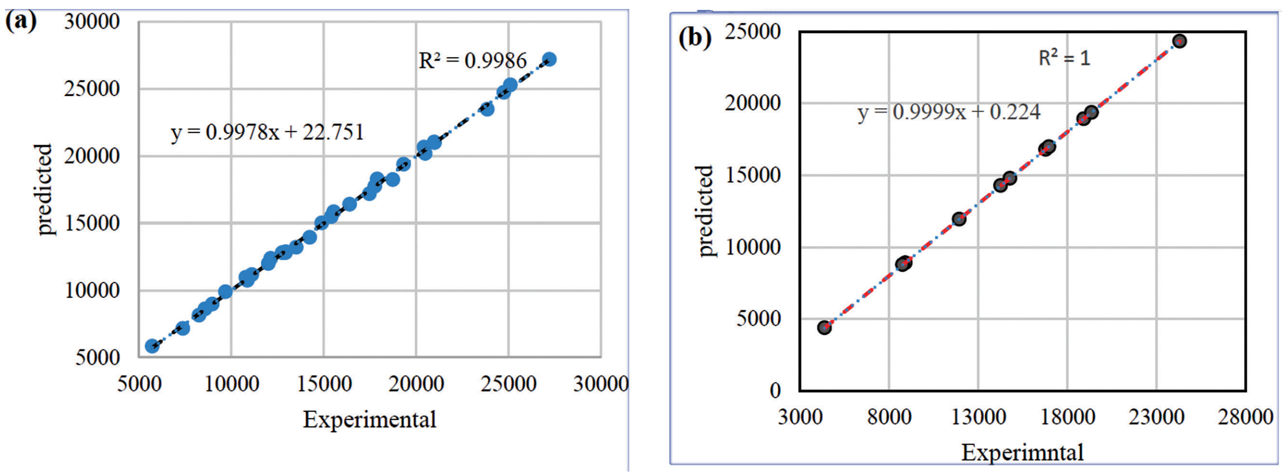

Figure 3. Predicted data versus experimental data by ANFIS, **(a)** train data, **(b)** test data.

transfer coefficient increasing due to increase Reynold number.

Table 1 reports average relative error (ARE), Mean square error (MSE) and R^2 value for train and test data. R^2 value should be near one and ARE and MSE value should be near zero. According Table 1 acceptable they have values.

ANN model

In the neural network, Parameters such as the number of hidden layers, the percentage of training, test and validation data are determined. By changing the parameters values and comparing the error values and coefficient of determination can be achieved optimal values for them. The number of hidden layers major impact on the accuracy of prediction by the neural network. After trial and error, hidden layer, percentage of train data, test data and validation data were obtained.

The results were summarized in Table 2.

Predicted results respect to experimental data are shown in Figure 5. According to this figure, relation between predicted data and experimental data is linear and coefficient of determination value is 0.99. Ideal value for R^2 is one, so this prediction is good because the R^2 value is close to one.

Error value unlike R^2 should be zero. In neural network, ARE error equal –0.003. It is very close to zero so prediction has a good result. Where MSE and R^2 are 6.38264×10^{-5} and 0.99 respectively.

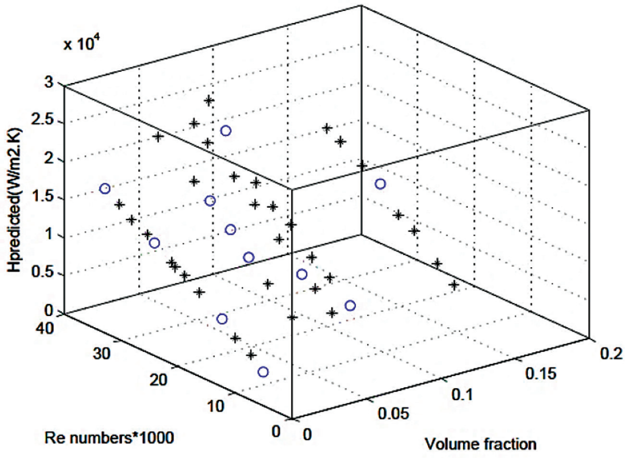

Figure 4. Heat transfer coefficients versus inputs (Re, Vol. fraction).

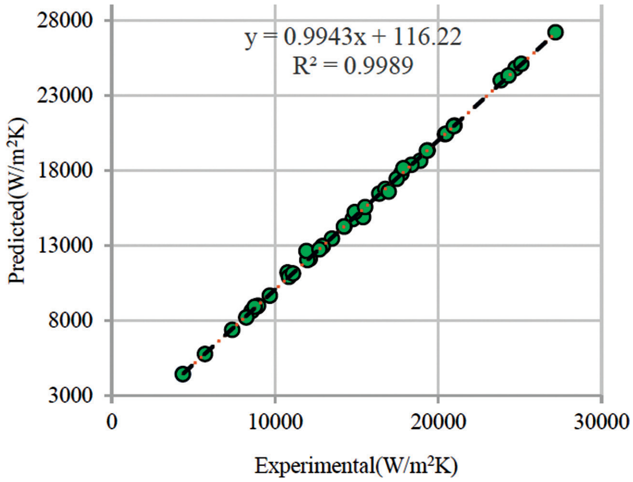

Figure 5. Predicted data versus experimenta.

Table 1. R^2 and ARE and MSE values for train and test data

	ARE	MSE	R^2
Test	0	0	1
Train	-8.9×10^{-5}	6.5476×10^{-5}	0.99

Table 2. Results of ANN

Number of hidden layers	15
Percentage of train data	75%
Percentage of test data	15%
Percentage of validate data	10%

Table 3. Compression between ANN and ANFIS results

Parameters	ANN		ANFIS	
R^2	Train	0.998	Train	1
	Test	0.998	Test	0.988
R	Train	0.99	Train	1
	Test	0.99	Test	0.99
ARE	–0.003		0.001	

Comparison of ANN and ANFIS Model

The results that were obtained from ANFIS and ANN are reported in table 3. Determination coefficient of train data in ANN are slightly lower than that in ANFIS, but for test data it become revers. For both ANN and ANFIS can be considered equal to the value of the correlation coefficient. On the other hand, error value for ANFIS simulation is lower than ANN simulation, so the result in ANFIS is slightly better than ANN.

CONCLUSIONS

Heat transfer coefficient is an important issue in industrial, so increasing that is important too. There is several ways to increase this coefficient but newest way is using nanofluids as working fluids. Researchers testing any kind of nanofluids experimentally, but experimental spend many money and time. In this study, in order to reduce cost and time of experimental, heat transfer coefficient of γ-AL_2O_3 nanofluids in tube was simulated and investigated by ANFIS and ANN. The results of ANFIS and ANN compared with experimental data. Coefficient of determination, average relative error and mean square error were used to investigation agreement between experimental and ANFIS and ANN results. R^2, ARE and MSE for train data are 0.99, -0.000089 and 6.5476×10^{-5}, respectively. For test data, R^2, ARE and MSE are one, zero and zero, respectively. It can conclude ANFIS and ANN models are reliable. When plot experimental data versus predicted data, all data is on straight line and focus on it. Because of these conclusions, ANFIS and ANN can be used to predict arbitrary data. The heat transfer coefficient changes by changing the Reynolds number and volume fraction. According to ANFIS and ANN results, heat transfer coefficient of nanofluids increase with Reynolds number and nanoparticles volume fraction. Increasing the volume fraction also results in an increase in the heat transfer coefficient.

NOMECLATURE

ANFIS Adaptive Neuro-fuzzy inference system
ANN Artificial neural networks
ARE Average relative error

MSE Mean square error
Nu Nusselt number
R^2 Coefficient of determination values
Re Reynolds number

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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