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Research article

Exergetic performance prediction of solar air heater using MLP, GRNN and RBF models of artificial neural network technique

Harish Kumar Ghritlahre, Radha Krishna Prasad*

Department of Mechanical Engineering, National Institute of Technology, Jamshedpur, Jharkhand, 831014, India

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ABSTRACT

In the present study three different types of neural models: multi-layer perceptron (MLP), generalized regression neural network (GRNN) and radial basis function (RBF) has been used to predict the exergetic efficiency of roughened solar air heater. The experiments were conducted at NIT Jamshedpur, India, using two different types of absorber plate: arc shape wire rib roughened with relative roughness height 0.0395, relative roughness pitch 10 and angle of attack 60°, and smooth absorber plates for 7 days. Total 210 data sets were collected from the experiments. Mass flow rate, relative humidity, wind speed, ambient air temperature, inlet air temperature, mean air temperature, average plate temperature and solar intensity were selected as input parameters in input layer to estimate the exergetic efficiency. In the first part of study, MLP model has been used. In this model 10–20 neurons with LM learning algorithm were used in hidden layer for optimal model selection. It has been found that LM-18 is an optimal model. In second part, GRNN model was used. The GRNN model was simulated experimentally at different spread constants and found that keeping spread constant as 1.5, optimal results have been obtained. In the third part, RBF model was used. For optimal model, 1–5 spread constant at interval of 0.5 have been used. It has been found that by taking spread constant 3.5, best results are obtained. In the last part of the study, all neural models are compared on the basis of statistical error analysis. It has been found that RBF model is better than GRNN and MLP models due to lowest value of RMSE and MAE and highest value of R^2 and ME. After RBF model, GRNN model performs better results as compared to MLP model. It has been found that the values of RMSE, MAE and R^2 were 0.001652, 2.86E-04 and 0.99999 respectively for RBF model.

1. Introduction

Solar air heater (SAH) is a special kind of thermal system in the category of renewable energy systems, which is used for space heating in commercial and residential buildings and paper industries. In addition to this, it is used for crop drying, timber seasoning and various low temperature heating applications (Duffie and Beckman, 1991).

In solar air heating system the solar collector is the main component which collects the solar radiation in form of heat and transfers it to flowing air across it. Due to lower value of heat capacity and low thermal conductivity of air, the convective heat transfer coefficient between absorber plate and the air passing through it is low, and hence the major issue is to enhance the value of heat transfer coefficient. One of the best techniques for enhancement of heat transfer coefficient is to use artificial roughness on air-flow side of absorber plate. The use of roughness creates turbulence near the surface of absorber plate which increases the heat transfer coefficient. Several researchers have experimentally and analytically studied for improvement of performance of artificially roughened SAH (Bhushan and Singh, 2010; Chamoli et al., 2012; Sharma and Kalamkar, 2015).

The actual performance of SAH can be evaluated by the implementation of both energy and exergy analyses. The energy analysis alone does not give the direction of the process implementation and the information about the quality of various kinds of energies involved in the system. It also does not indicate the various internal irreversibilities. These problems are overcome by using exergy analysis (Ajam et al., 2005; Esen, 2008; Akpinar and Koçyigit, 2010; Alta et al., 2010; Bayrak et al., 2013; Panwar et al., 2012; Saidur et al., 2012; Kumar et al., 2012; Park et al., 2014). In view of this, in the present investigation, the exergy analysis of roughened SAH has been carried out.

ANN technique is very good as compared to other problem-solving technique, due to its fast processing speed and satisfactory results. It is mostly used where complex problems are not solved by other soft computing techniques. It has wide applications in the field of Thermal Engineering, specially for prediction of performance of thermal systems including the solar energy systems (Kalogirou, 2000; Farkas and Geczy-

* Corresponding author. ,
E-mail addresses: harish.ghritlahre@gmail.com (H.K. Ghritlahre), rkprasad.me@nitjsr.ac.in (R.K. Prasad).

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Table 1
Latest literature work on performance prediction using ANN technique.

Authors	Neural model	Model type	Learning algorithms	Used in area/system
Kalogirou (2000)	13-5-1, 14-7-2	MLPNN	BP	Solar water heating unit.
Farkas and Geczy-Vig (2003)	3-7-1	MLPNN	TRAINLM	Flat plate solar collector.
Facao et al. (2004)	ANN: 8-9-1, 9-3-1, 9-6-1 RBF:9-84-1	MLPNN, RBFNN	BP, RBF learning algorithm	hybrid solar collector
Sozen et al. (2008)	7-20-20-1	MLPNN	BP	flat plate solar collector
Esen et al. (2009)	6-4-2, 6-5-2	ANN, WNN	ANN:LM, SCG,CGP WNN: LM	Three different types of SAH
Varol et al. (2010)	5-7-1	MLPNN	LM	solar collector with PCM materials
Caner et al. (2011)	8-20-1	MLPNN	LM	Two different types of solar air collector
Benli (2013)	8-3-1	MLPNN	LM	Two types of solar air collector
Dikmen et al. (2014)	4-12-1	FFNN, ANFIS	LM	evacuated tube solar collector
Yaïci and Entchev (2014)	10-20-8	FFBP	LM, SCG	solar thermal energy system
Cakmak (2014)	5-10-1	MLP, MLR	LM	solar cooker
Citakoglu (2015)	2–6 input variables in different combinations are used for one output variable	MLP, ANFIS and MLR	LM, hybrid learning algorithms	Prediction of the monthly solar radiation.
Mashaly and Alazba (2016)	9-12-1	MLP and MLR	LM	solar still
Wang et al. (2016)	6 input parameters and one output parameter	MLP, RBF, GRNN and IBC	LM, RBF learning algorithms	Predict the solar radiation.
Ghritlahre and Prasad (2017a)	4-5-3	MLP	LM, SCG, CGP, OSS	unidirectional flow porous bed solar air heater
Ghritlahre and Prasad (2017b)	6-6-2	MLP	LM	Investigate the energetic and exergetic efficiency of solar air heater
Mashaly and Alazba (2017)	7-8-1	ANN and SWR	BP	Solar still
Ghritlahre and Prasad (2018a)	6-6-1,6-7-1	MLP	LM, SCG	Roughened solar air heater
Ghritlahre and Prasad (2018b)	7-7-5	MLP	LM,SCG,CGP	Predict the exergetic performance of roughened SAH

Vıg, 2003; Facão et al., 2004; Sözen et al., 2008; Esen et al., 2009; Varol et al., 2010; Caner et al., 2011; Benli, 2013; Dikmen et al., 2014; Yaïci and Entchev, 2014; Çakmak, 2014; Citakoglu, 2015; Mashaly and Alazba, 2016; Wang et al., 2016; Ghritlahre and Prasad, 2017a; b; Ghritlahre and Prasad, 2017a; b). The recent literature related to application of ANN technique for estimating the performance of systems are presented in Table 1.

The literature review indicates that ANN model is used to predict the performance of solar energy systems. However, only MLP model was used to predict the thermal performance and exergetic performance of solar air heaters. The applications of GRNN and RBF models have not been used in the past. In the present work, three different types of neural models (MLP, GRNN and RBF) have been used to predict the exergetic performance of arc shaped wire roughened SAH and to find out the appropriate model on the basis of comparative study. This is the novelty of the present study.

In view of the above, MLP, GRNN and RBF models of ANN technique have been applied. To achieve this aim, experiments have been conducted using two different types of solar collectors: roughened and smooth, and collected 210 data sets. Eight parameters are used in input layer and one parameter is used in output layer for all models. The objectives of the present study are: (1) To develop MLP, GRNN and RBF models for prediction of the exergetic performance of SAH. (2) To select the most appropriate model based on the criteria of best performance.

2. Materials and methods

2.1. Experimental study and data collection

The detailed diagram of experimental setup is shown in Fig. 1. It consists of inlet section, test section, exit section equipped with Galvanized Iron (GI) pipe, flange coupling, orifice plate, U-tube manometer, digital thermometers, suction blower and control valve. A photographic view of experimental setup has been shown in Fig. 2. The rectangular duct is dimensions 2300 mm x, 330 mm × 35 mm, in which the length of test section is 1200 mm. The absorber plate is made up of 1 mm thick GI sheet. The photographic view of Roughened and Smooth absorber plates have been shown in Fig. 3. The test section has been covered by 4 mm glass cover on the top. A 5 cm glass wool was used as insulation on the bottom of the duct covered by 5 mm plywood. The wooden duct has connected with 2.5 inch diameter GI pipe. To measure the mass flow rate of air, an orifice meter has been fitted to the pipe. The pressure drop was measured by using a U-tube Manometer, fitted across the orifice plate. A 5 HP -3 phase suction blower was used to suck ambient air. The intensity of solar radiation was measured with digital pyranometer. For measuring the temperature at various sections of plate, thermocouples were used and for air temperature, digital thermometers were used. The experiments was conducted in the clear sky at Jamshedpur (India), having latitude and longitude of 22.77° N & 86.14° E respectively in the month of February 2017. The data has been collected from 9:00 to 16:00 Hours. Total 210 data sets were collected by using two different types of absorber plates, whose specification is given in Table 2.

The uncertainty analysis as proposed by Kline and McClintock (1953) was used to calculate the uncertainty associated with experimental results, based on the observations in the measured values used in calculating the result. The uncertainty values of various measuring instruments are shown in Table 3.

In the view of relative uncertainties in the individual factors denoted by x_n, the uncertainty calculation was carried out using the following equation (Holman, 2007)

$$U = [(x_1)^2 + (x_2)^2 \ldots\ldots\ldots\ldots\ldots (x_n)^2]^{0.5} \quad (1)$$

The uncertainties occurred in the mass flow rate and useful heat gain were ± 0.876% and ± 3.36% respectively.

2.2. Exergy analysis of SAH

The analysis of exergy of a system is the most useful concept for optimal use of energy. This analysis can be used to design thermal

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