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Parametric study of closed wet cooling tower thermal performance

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Abstract. The present study involves experimental and theoretical analysis to evaluate the thermal performance of modified Closed Wet Cooling Tower (CWCT). The experimental study includes: design, manufacture and testing prototype of a modified counter flow forced draft CWCT. The modification based on addition packing to the conventional CWCT. A series of experiments was carried out at different operational parameters. In view of energy analysis, the thermal performance parameters of the tower are: cooling range, tower approach, cooling capacity, thermal efficiency, heat and mass transfer coefficients. The theoretical study included develops Artificial Neural Network (ANN) models to predicting various thermal performance parameters of the tower. Utilizing experimental data for training and testing, the models simulated by multi-layer back propagation algorithm for varying all operational parameters stated in experimental test.

1. Introduction

Many of researches and studies concerning the cooling towers conducted due to the use in wide applications in the industrial sectors, which led to draw the attention of researchers to develop different aspects of engineering studies including theoretical aspects, which included various trends of analysis and design methods as well as the practical aspects of those applications. Oliveira & Facao, [1], designed a new CWCT in order to examined effects of the operating parameters on the saturation efficiency for a CWCT modified for use with chilled ceilings in buildings. Thermal performance of tow evaporative cooled heat exchangers, investigated by Hasan & Sirén, [2]. They studies two heat exchangers; plane and plat-finned circular tube types occupy the exact volume and the ratio of total area (finned tubes /plate tubes) is four. Shim et al., [3&4] investigated experimentally the thermal performance of two heat exchangers in closed-wet cooling tower. Both heat exchangers have multi path that is consumed as the entrance of cooling water and are consisting of bare-type copper tubes of 15.88 mm and 19.05 mm. Heyns & Kroger, [5] investigated the thermal performance characteristics of an evaporative cooler, which consist of 15 tube rows with 38.1 mm outer diameter galvanized steel tubes arranged in a triangular pattern of 76.2 mm. There are many computational intelligence studies on cooling tower. A utilization of an ANN to prediction the performance of cooling tower described by Yasar Islamoglu, [6] examined the ability of an ANN model to assess the thermal performance of a cooling tower. The network is trained with the accompanying trial values: the ratio of the water flow rate to air flow rate, the inlet and outlet water temperatures are chosen as input variables, while the output is the coefficient of performance. Ming Gao et al., [7] predicted performance parameters of Natural Draft Wet Cooling Tower (NDWCT) by ANN model. This model adopts the improved Back Propagation (BP) algorithm, the input parameters are: Froude number, spray water density, temperature of inlet water and relative humidity of inlet air, the outlet parameters are: air velocity, cooling efficiency, temperature difference, heat and mass transfer coefficients. Qasim and Muwafaq, [8] Predicted the performance of NDWCT using computational method. The performance was investigated with the variation of different parameters such as (water mass flow rate, fill type, fill thickness, and wind velocity). The focus of this study is to predicting the thermal performance of modified forced draft counter flow Closed Wet Cooling Tower (CWCT) using Artificial Neural Network (ANN) simulation.

2. Experimental and artificial neural network modeling

A modified CWCT was designed and constructed in which different operating parameters could be varied and tested in the laboratories of Al- Mustansiriyah University Faculty of Engineering. [9], describes experimental work and results recorded from experimental test rig shown in Figure (1).

Figure 1a. Photographic picture for experimental apparatus (lateral view).

Figure 1b. Photographic picture for experimental apparatus (front view).

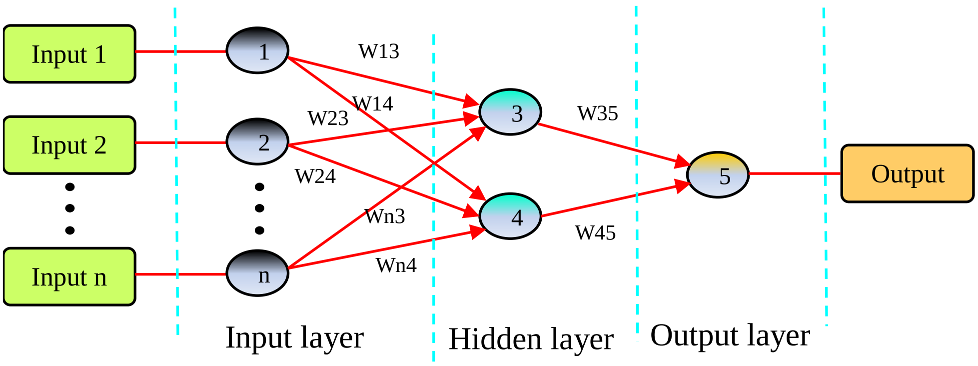

Figure 2. Multilayer network.

With the end goal of selecting the best values for numbers of hidden layers and also number of neurons trial and error is implemented. Distinctive numbers of neurons and number of layers are tried factual pointers are computed. At that point keeping in mind the end goal to check, how well the input and output data are fitted in the network, regression plot is used.

During training, 85 percent of gave data are only utilized for training network and remaining 15 percent data sets are utilized for testing the network. Thus regression plot will generally have four graphs appearing for training, validation, and test and combining all. Regression plot for this network in appeared in Figure 3.

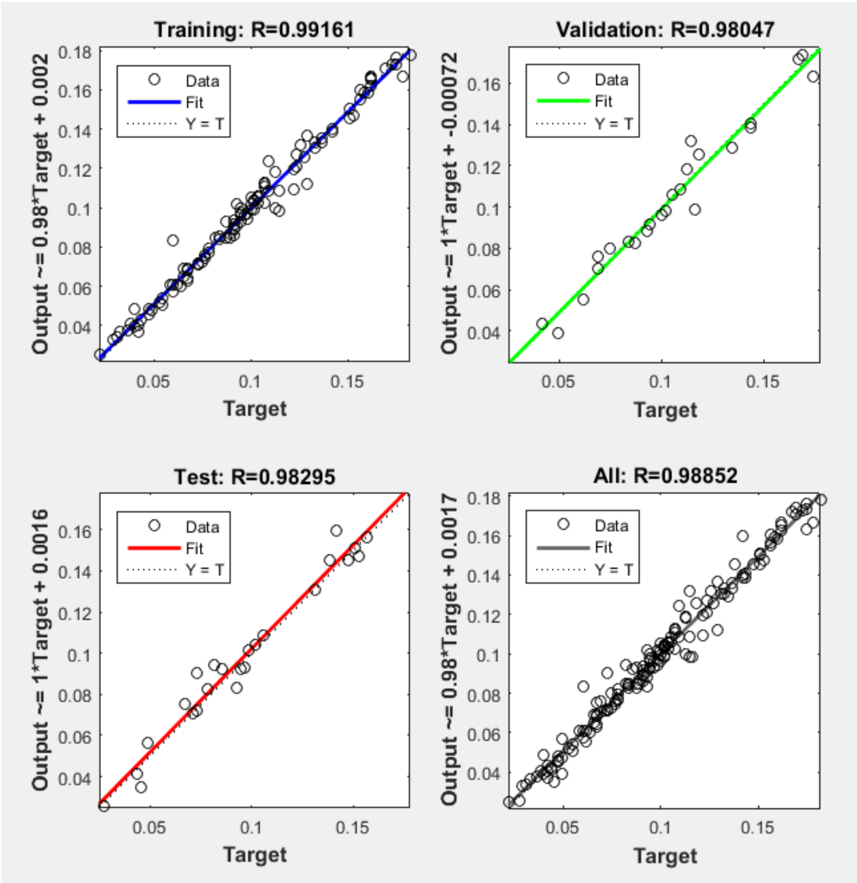

Figure 3. Neural Network plot regression graph.

Through this graph, we can observe that all data sets are appropriately fitted to the line. It showed our neural network structure is right. Furthermore, it can be utilized for predicting the output for other input data sets. After completing network structure analyzing, it is then used to predict the performance of the system for various data set of input, which were not used while training the network. It is then compared with experimental data set.

3. Results and discussion

As specified earlier ANN are trained by using a back propagation learning algorithm with varieties LM, 10 neurons in the hidden layer and logistic sigmoid transfer function. Once the ANN is made ready, by utilizing remaining 27 experimental data sets, thermal performance of cooling tower are predicted. From the models developed, the performance of the models is validated considering their performance in terms of experimental and ANN predicted outputs. This will be achieved by a scatter plot for actual and forecasted outputs by the six models developed. On the other hand, for comparison of the prediction of the models, the Root Mean Square Error (RMSE), Mean Relative Error (MRE) and Coefficient of Multiple Determinations (R^2) between experimental and predicted values were tested to verify the good prediction of the models. The RMSE, MRE and R^2 were calculated using the following formulas [11]:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{j=0}^{n}\left(t_j - o_j\right)^2}{n}} \tag{1}$$

$$\mathrm{MRE} = \frac{1}{n}\sum_{j=0}^{n}\left|100 \times \frac{t_j - o_j}{t_j}\right| \tag{2}$$

$$R^2 = 1 - \left(\frac{\sum_{j=0}^{n}(t_j - o_j)^2}{\sum_{j=0}^{n}(o_j)^2}\right) \tag{3}$$

where t is the target value, o is the output value and n is the number of observations. Figure (4) scatter plot of the ANN predictions as a function of experimental values for the cooling range. The performances of these models in terms of RMSE, MER, and R^2 are listed in Table 1.

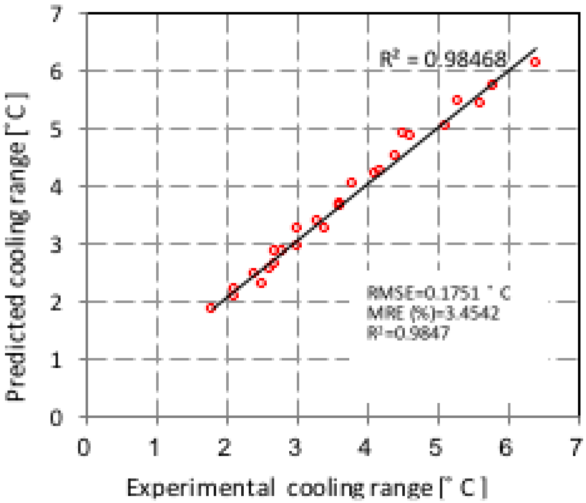

Figure 4. Scatter plot of experimental and ANN predicted cooling range

Table 1. Performance indication for all models.

Model	RMSE	MRE (%)	R^2
Cooling range	0.17510˚C	3.45420	0.9847
Tower approach	0.65885˚C	1.22051	0.9676
Thermal efficiency	0.04812 %	6.01440	0.9654
Cooling capacity	1.0590 kW	4.60805	0.9129
Mass transfer coefficient	0.03674Kg/m^{2}s	4.94678	0.9438
Heat transfer coefficient	W/m^2 K 17.667	2.54661	0.9461

ANN predicted data and experimental data are compared in figures (5) to (10).

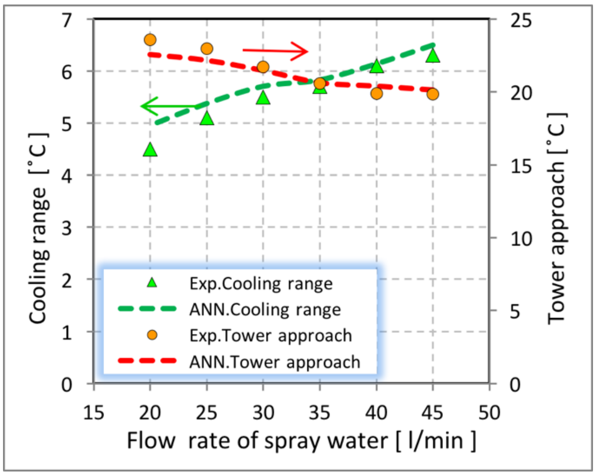

Figure 5. Variation of cooling range and tower approach with spray flow rate.

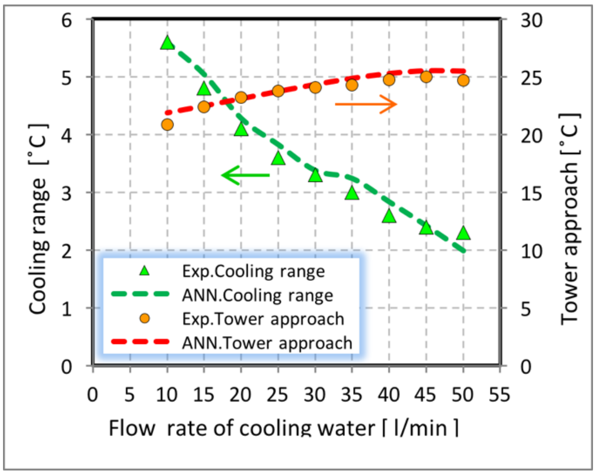

Figure 6. Variation of cooling range and tower approach with cooling water flow rate.

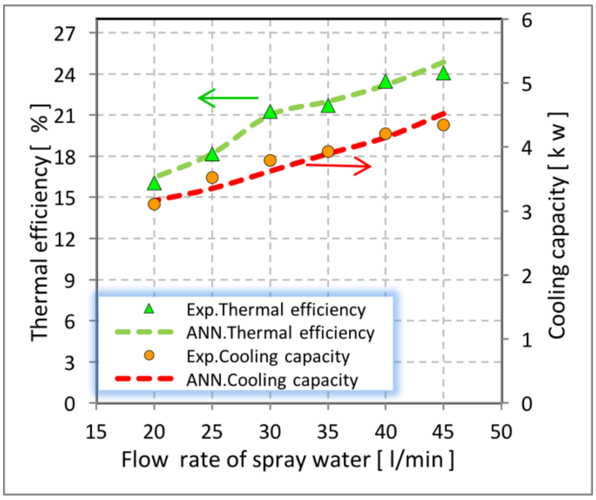

Figure 7. Variation of thermal efficiency and cooling capacity with spray flow rate.

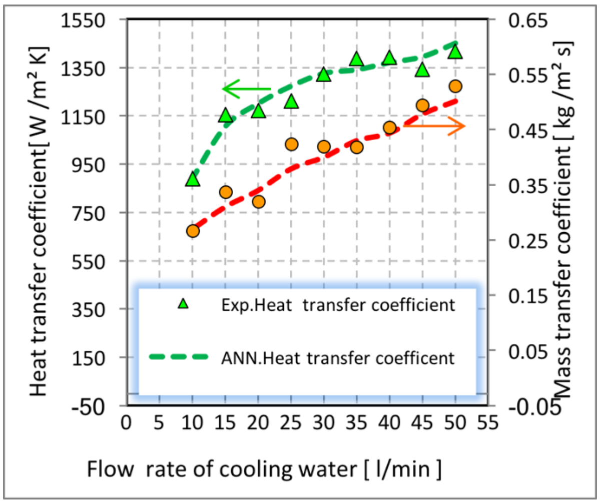

Figure 8. Variation of thermal efficiency and cooling capacity cooling water flow rate.

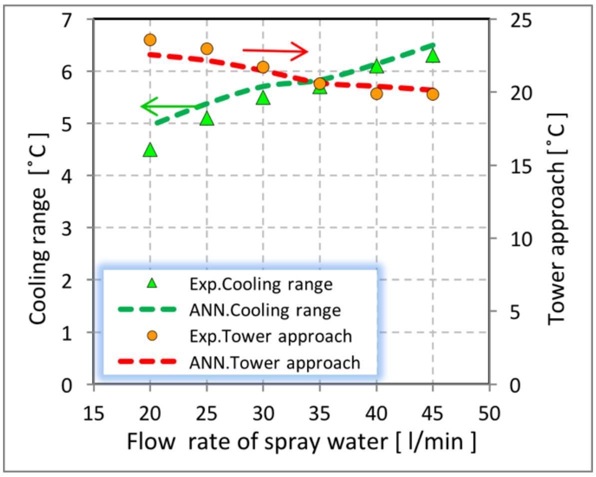

Figure 9. Variation of heat and mass transfer coefficients with spray flow rate.

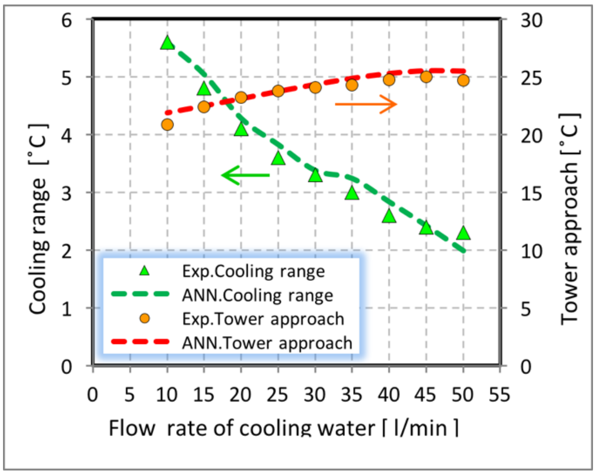

Figure 10. Variation of heat and mass transfer coefficients with cooling water flow rate.

4. Conclusions

In the present paper, ANN algorithm with feed-forward BP learning algorithm was presented to predict and optimize the thermal performance of CWCT. The cooling range, tower approach, cooling capacity, thermal efficiency, heat and mass transfer coefficients are predicted by using an ANN models. The effect of different influencing factors such as air flow rate, spray and cooling water flow rates, inlet cooling water temperature and inlet on the performance of CWCT are investigated. Comparison was made between the output values obtained using the ANN models and those obtained experimentally for other cases not included in the training data, this comparison indicated high compatibility with maximum MRE of (5%).

5. References

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