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EXPERIMENTAL STUDY WITH USING ANFIS TO EVALUATE THE PERFORMANCE OF A MODIFIED CLOSED WET COOLING TOWER

DR. QASIMSALEH MAHDI and **DR. HAYDER MOHAMMAD JAFFAL**
Dept. of Mechanical Engineering, University of Al-Mustansiriayah-Iraq

ABSTRACT

The present study involves experimental and computational analysis to investigate the thermal performance of modified closed wet cooling tower in perspective of first and second law of thermodynamics (analysis of energy and exergy) according to Iraqi weather. The experimental study includes design, manufacture and testing prototype of a modified counter flow forced draft closed wet cooling tower. The modification based on addition packing to the conventional closed wet cooling tower. To assess the thermal performance of cooling towera progression of tests was done at various operational and conformational parameters.The theoretical study included developed six models by an Adaptive Neuro-Fuzzy Inference System to anticipating various execution parameters of the tower including the cooling range, tower approach, thermal efficiency, cooling capacity, evaporation losses and exergy destruction. After simulating, three dimensional surface viewers obtained for future behavior of the thermal performance of cooling tower involves interactions between all operational parameters. Comparison of the output values obtained using the Adaptive Neuro-Fuzzy Inference System model and those obtained experimentally for other cases not included in the training data, indicates high compatibility with maximum percentage error of (5%).

KEYWORDS:Closed Wet Cooling Tower (CWCT), ANFIS, packing, exergy, thermal performance,heat exchanger

Nomenclature
A=total heat transfer area, m2
Cp=specific heat at constant pressure, kJ/kg ^{o}C
CR=cooling range,^{o}C
D=tube diameter, m
$E\dot{X}_D$=exergy destruction, kW
E_{loss}=rate of evaporation losses, kg/s
MRE=Mean Relative Error,%
$\dot{m}$=mass flow rate, kg/s
n=number of observations
o=output value
Q=volume flow rate, l/min
q=cooling capacity, kW
R^2=Coefficient of Multiple Determinations
RMSE=Root Mean Square Error
T=temperature,^{o}C
TA=tower approach,^{o}C
t=target value

Greek Symbols
η =thermal efficiency, %
ρ =density,kg/m^3
Φ=relative humidity,%
ω= humidity ratio, kg/kg$_{dry\ air}$

Subscripts
a=air
cw=cooling water
in=inlet
out=outlet
sw=spray water

INTRODUCTION

A cooling tower is a kind of warmth exchanger utilized to decrease the temperature of a water flow by extricating heat from water and transmitting it to the environment. Cooling towers utilize the vanishing of water to evacuate handleheat and cool the working liquid to close to the Air Wet Bulb Temperature (AWBT). Cooling towers can bring down the water temperatures more than gadgets that utilization just air to reject heat, similar to the radiator in an auto, and are in this manner more financially savvy and vitality productive. [1].

With respect to design of heat exchanger surface, there are two sorts of cooling towers:

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open and closed cooling towers. In open cooling tower, the air is in direct contact with the water at surface of packing. In conventional CWCTs recalculated water is showered over a horizontal bundle of tubes, while air is drawn over the tubes and cooling water is circulated in tubes and never contacts the outside air .Because of these advantages of the close cooling tower that restricted tainting dangers with airborne and erosion, extensive variety of uses in the fields of electrical power, chemical industry and building air conditioning. With more and more closed cooling tower applications, the study also received increasing attention [2]

STUDIES ON COOLING TOWERS

Much attention has been paid to issues on CWCTs relating to experimental studies and developed correlations of mass and heat transfer coefficients as a component of operating conditions. **Oliveira &Facao [3]**, 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. Design circumstances were a cooling limit of 10 kW, for temperature of water inlet 21˚C, a flow rate of cooling water 0.8 kg/s and an inlet AWBT of 16˚C .The area tower is 600 × 1200 mm and a height of 1550 mm. That tube package has 288 tubes of 10 mm external diameter in staggered array, for an aggregate transfer area of 8.6 m^2. Their results indicated that the efficiency increments with the increment in air and spray water flow rates while; efficiency diminishes with the increment cooling water flow rate.On the other side of argument, efficiency increases somewhat with increasing AWBT.**Shim et al. [4 & 5]** investigated experimentally the thermal performance of two heat exchangers in closed-wet cooling tower having anevaluated limitof 2RT. Both heat exchangers have multi-waythat is expendedas the passageway of cooling water and are comprising of bare-sort copper tubes of 15.88 mm and 19.05 mm. It may have been revealed that the cooling range of CWCT utilizing double ways is higher by around 20% than the single way. For working both tubes with two ways, cooling capacity per unit volume with 15.88 mm tube is nearly 27.5% and 41.01% higher than those with 19.05 mm when the inlet AWBT of CWCT were 24℃ and 28℃ individually.**Heyns& Kroger [6]** investigated the evaporative cooler thermal performance characteristics, which consist of 15 tube rows and 8 columns with 38.1 mm external diameter, excited steel tubes orchestrated in a triangular pattern of 76.2 mm. From the test results, coefficients of mass and heat transfer were correlated. Those test outcomes demonstrated that the flow rate of spray water has the best impact on the coefficient of heat transfer however this coefficient is likewise a stream's element of air and the temperature of spray water.

Many studies have been made on thecooling tower performance in view of exergy analysis.**QureshiandZubair [7]** presented theoretically a thermalexaminationof evaporative heat exchangers and counter flow wet cooling towers utilizing both the first and second law of thermodynamics. By applying an exergy balance on each of the systems, the variety of second-law efficiency and exergy destruction as a function of different information parameters such as inlet AWBT & inlet water temperature has been identified.**Mani and Rajagopal. (2008), [48]** formed a scientific model taking into account mass and heat transfer to find the outlet conditions of air and water in counter flow open type cooling tower. Their model has been solved using iterative method. Energy and exergy analysis infers that inlet AWBT was found to be most vital parameter than inlet water temperature. Thy showed that at lower inlet AWBT, the outlet temperature decreases which leads to higher water approach temperature and exergy destruction by decreases the second law efficiency.**Ramkumar and Ragupath.(2014), [8]** investigatedthermal performance of open type mechanical draft counter flow cooling tower using expanded wire mesh packing. Exergy analysis has been connected to concentrate the cooling tower capability of execution utilizing the psychometric gun technique.

There are many computational intelligencestudies on cooling tower. A utilization of an Artificial Neural Network (ANN) to prediction the thermal performance of cooling tower described by **YasarIslamoglu[10]**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, and the inlet AWBT are chosen as input variables, while the

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output is the coefficient of performance. It is inferred that a well-trained neural network gives quick, precise, and reliable results, making it a simple to utilize instrument for preparatory designing studies. **Hosozet. al. (2011),[11],** investigated the materialness of Adaptive Neuro Fuzzy Inference System (ANFIS) to foresee the execution of an R134a vapor –compression refrigeration framework utilizing a cooling tower for heat rejection. For this point, an exploratory refrigeration framework might be set under divers working conditions to acquire input-output sets. At that point, an ANFIS model for the system might have been formed to foresee its different performance parameters. **Jian. (2013)[12]** Have been developed physical model for analysis the operation of a cooling tower using fuzzy c-mean clustering algorithm. They investigated the effects of relative humidity and ambient air temperature and on the cooling capacity of a cooling tower. Their results demonstrated that the procured different models are profoundly precise in predicting the cooling water output temperature from the cooling tower

Muwafaq. (2015)[13] Predicted the thermal performance of NDWCT using computational method. Experimentally, three types of filling fills are investigated namely splash, honey cell, and trickle fill with different thicknesses such as (5, 10, 15, and 20 cm). The performance was investigated with the variation of different parameters such as (water mass flow rate, fill type, fill thickness, and cross wind velocity). Theoretically, ANN model using MATLAB program used to predicate experimental results through training, validation, and testing based on BP algorithm. A neural network with 8, 10, and 7 neurons at input, hidden, and output layers respectively was tested to investigate results.

In the applicable writing, no outcomes have been accounted for so far including the performance of CWCT with packing in view of energy and exergy analysis. The aim of this research is to evaluate thermal performance of modified CWCT in view of first and second law of thermodynamics (energy and exergy analysis) according to Iraqi weather.

EXPERIMENTAL SETUP

Description of Test Rig

A prototype of a modified counter flow CWCT was designed and constructed in which different operating parameters could be varied and tested in the laboratories of Environmental Engineering Department of Al-Mustansiriya University College of Engineering. The general arrangement of the equipment is shown photographically in Figure 1. In general, the apparatus consists essentially of cooling column and three major systems, Spray water, Cooling water and Air blowing.

The tower fabricated from galvanized steel sheet to provide protection from rusting and corrosion, each sheet of 1.5 mm thickness, connected together by screws and nuts as a rectangular box of external dimensions (700 mm×400 mm×2300 mm), mounted rigidly on a frame which is welded construction with a channel section at the base welded together from the rectangle. As exists in every forced cooling, the test section consists of three zones: spray, fill (cooling zone) and rain zone. Spray zone is at a height of 180 mm suitable to ensure water distribution uniformly to all points in the fill section. Fill zone at 1000 mm height and characterized as consisting of three places for sliding removable drawer rectangular boxes at the same dimensions, manufacturing for packing and heat exchangers to ensure change the locations and types of heat exchangers and height of packing to concentrate the impact of every oneofthese additions on the performance of the tower. The rectangular drawer made of galvanized steel with dimensions of 420 mm in width, 760 mm in depth and 280 mm in height. Six holes along the side of each (drawer) box were done to measure the water temperature, air relative humidity and dry bulb temperature. The rain zone at a height of 450 mm in the case of three boxes and it will be variable when lifting one or two packing's and increases as decreases the packing height.

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

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

Air from the atmosphere, enters the single stage centrifugal blower at a rate which is adjusted by the butterfly valve. The fan releases into the PVC pipe and entrance duct before entering the packed column. As the air flows through the heat exchanger and packing, its dampness content increments and the water in the heat exchanger are cooled.

From the load tank,hot water is pumped through the control valve and water flow meter to the heat exchanger placed inside test section of tower. Plain tube heat exchanger was designed and manufactured for the present work. The tubes were fixed horizontally in test section inside supported frame of rectangular drawer .Cooling water moves through the tubes while the spray water and air moves over the tubes in perpendicular direction. The tubes are arrays in staggered arrangement with tube pitch of $3D_{o.}$ The specification of heat exchanger shows in Table 1.

The water distribution system in the cooling tower should distribute the water uniformly over the tube bundle and packing inside the tower, to be the most coefficient method of uniformly water distribution in counter flow wet-cooling tower a pressurized spray system used. The spray water passes through the spray nozzles and constantly distributed at upper part of the test section, controlled by means of flow control valve globe type located downstream of the spray water pump. In the spray frame a header appropriates or isolates the deluge water into few courses or lateral branches. Spray water nozzles were fitted the end of each lateral branch.

Table (1): Physical dimension of heat exchanger

Heat exchanger configuration	Value	Unit
Length	690	mm
Height	166	mm
Width	381	mm
Tubes for coil	30	-
Vertical tube spacing	24	mm
Horizontal tube spacing	80	mm
Tube per row	5	-
Outside tube diameter	15.88	mm
Tube thickness	0.81	mm
Total heat transfer area	1032691.77	mm^2
Minimum free flow area	209148	mm^2

Test Procedure

In order to evaluate the thermal execution of cooling tower, a progression of analyses was done at various operational and conformational parameters. Operational parameters illustrate: air flow rate of (0.12-0.3) kg/s, spray water flow rate of (20,25,30,35,40,45) l/min, cooling water flow rate of(10,15,20,25,30,35,40,45,50) l/min, inlet cooling watertemperature of (35,40,45,50,55)˚C and inlet air wet bulb temperature of (7-24)˚C. Conformational parametersindicate: height of packing used (280 & 560) mm, location of packing (under heat exchanger and above heat exchanger).

Thermocouples type K inserted before and after the cooler coil to measured cooling water temperature. To measure the spray water temperatures at intermediate locations inside test section, specially channels have been manufacturing to insert thermocouples through holes .These holes are closed by rubber stoppers through which thermocouples are inserted to measure the temperature profile. The variations of air relative humidity and dry bulb temperature along the test section as well as at the tower inlet and outlet were measured by humidity meter,which combined temperature/humidity sensor. The humidity meter model TH-305 has a temperature and relative humidity measurement range from 0 to 60˚C and 20 to 95% respectively. The sensor probe handle is placed directly in the air stream and connected to display.

Performance Parameters

Energy Analysis

In viewpoint of energy analysis, the parameters utilized to evaluate the thermal performance of cooling tower are:

1-Cooling range: is the difference temperature between the inlet and exit waterstates.

$$CR = T_{cw,in} - T_{cw,out} \quad (1)$$

2-Tower approach: is the distinction in temperature between the outlet temperature of cooling water and the inletAWBT:

$$TA = T_{cw,out} - T_{awb,in} \quad (2)$$

3-Thermal efficiency: The thermal efficiency for the closed circuit cooling towers was defined as [3&14]:

$$\eta = \frac{T_{cw,in} - T_{cw,out}}{T_{cw,in} - T_{awb,in}} \quad (3)$$

4-Cooling capacity: is the heat dissipation, given by:

$$q = \dot{m}_{cw} C_{p,cw}\, CR \quad (4)$$

5-Rate of waterevaporation losses:The amount of water evaporated into air is given by:

$$E_{loss} = \dot{m}_a(\omega_{out} - \omega_{in}) \quad (5)$$

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Exergy Analysis

In this study, the exergyinvestigation of the CWCT in light of the Exergy Destruction Method (EDM) was carried out in the simplified system appeared in Figure 2, where the dray air enters the test section from the bottom at the input conditions and crosses the test section at the output conditions while spray water opposed the air direction, on the other hand, cooling water enters the test section inside the heat exchanger perpendicular to the direction of both air and spray water and come out the opposite of entering heat exchanger.

For steady state conditions (operating cooling tower), neglecting the effect of kinetic and potential energy, an exergy balance is formulated for all components of the CWCT were presented in figure 2.

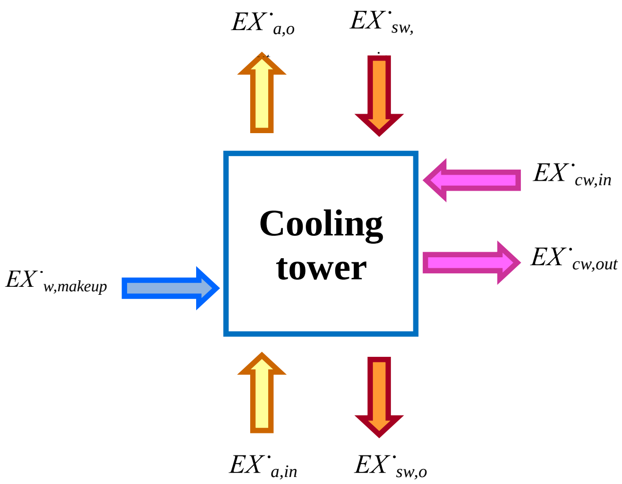

Fig.(2): Exergy balance of the cooling tower

1-Exergy of water

Exergy of water can be obtained by **Bejan** as flows [15]:

$$EX_w^{\circ} = m_w^{\circ}\left[(h_{fw} - h_{fo}) + T_o(S_{fw} - S_{go}) - R_v T_o \ln \emptyset_o\right] \quad (6)$$

Neglected the mechanical exergy of water comparing with chemical exergy, so the exergy of water for ideal gas law, Eq . (13) Becomes:

$$EX_w^{\circ} = m_w^{\circ}\left[C_{Pw}(T - T_o) - T_o C_{Pw} \ln\frac{T}{T_o} - R_v T_o \ln \emptyset_o\right] \quad (7)$$

2- Exergy of humid air

The total exergy in the psychometric process such as in operating mechanismofthe cooling tower, without the impact of potential and kinetic energy,on the bases of dray air and water vapour as an ideal gas while ignoring the pressure change through the cooling tower in the steady state –can thus be generally represented presented in **Bejan[15]:**

$$EX_a^{\circ} = m_a^{\circ}\left[(C_{Pa} + \omega C_{Pv})\left(T - T_o - T_o ln\frac{T}{T_o}\right) + R_a T_o\left((1 + 1.608\omega) ln\frac{1 + 1.608\omega_o}{1 + 1.608\omega} + 1.608 w ln\frac{\omega}{\omega_o}\right)\right] \quad (8)$$

3-Exergy distraction

An exergy balance states that the total exrgy increases or decreases inside the system boundary in additiontheexergy destruction inside a similarboundary parallels the distinctionbetween the total exergy transfers in and out over the boundary. Exergy destruction represents by the difference between exergy change of water and exergy change of air.

$$\sum EX_{in}^{\circ} - \sum EX_{out}^{\circ} - EX_D^{\circ} = 0 \quad (9)$$

The exergy destruction can be determined by:

$$EX_D^{\circ} = \left(EX_{a,in}^{\circ} + EX_{sw,in}^{\circ} + EX_{cw,in}^{\circ} + EX_{w,makeup}^{\circ}\right) - \left(EX_{a,out}^{\circ} + EX_{sw,out}^{\circ} + EX_{cw,out}^{\circ}\right) \quad (10)$$

4 ANFIS MODEL DESCRIPTION

ANFIS models were initially created by **Jang (1993)[16]** and fuse FL with ANN to encourage the learning and evolving adjustment. As being what is indicated, ANFIS utilizes the fuzzy IF-THEN rules including reason and ensuing parts of Sugeno-sort FIS. To portray this system,basic ANFIS architecture shown in Figure 3 is essentially accepted that interface framework has two inputs x and y and one output *f* [16&17].

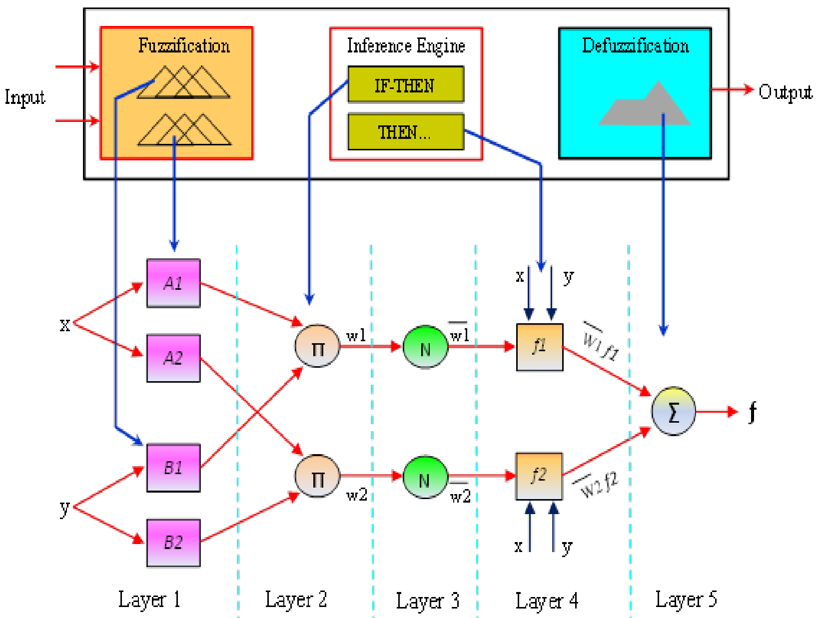

Fig.(3): Architecture of ANFIS [17]

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An ordinary standard fuzzy set with tworules IF-THEN for a first fuzzy model demand of Sugeno can be communicated as:

$$1 - IF\ x\ is\ A_1\ \ and\ y\ is\ B_1, THEN\ f_1 = p_1x + q_1y + r_1$$
$$2 - IF\ x\ is\ A_2\ \ and\ y\ is\ B_2, THEN\ f_2 = p_2x + q_2y + r_2$$

wherelinear parameters in the resulting part are: p_1,p_2,q_1,q_2,r_1 and r_2 are and nonlinear parametersare: A_1,A_2,B_1 and B_2.

The structural planning of the ANFIS framework comprises of 5 layers, to be specified, the fuzzy layer, item layer, standardized layer, de-fuzzy layer and aggregate output layer. The model capacities in the similar layer are of the same capacity family as depicted by **Jang** in the accompanying [16&18]:

Layer 1: this is fuzzy layer. The customizable hubs in this layer are spoken to by square hubs and stamped by A_1, A_2, B_1 and B_2 with x and y outputs.A_1, A_2, B_1 and B_2 are the etymological marks (little, substantial, etc.) utilized in the fuzzy hypothesis for separating the MFs. The hub capacities in this layer that determinates the membership connection among the data and yield capacities can be given as:

$$Q_{1,i} = \mu_{A_1}(x)\ \ , i = 1,2 \qquad (11)$$

$$Q_{1,j} = \mu_{B_1}(y)\ \ , j = 1,2 \qquad (12)$$

where $Q_{1,i}$ and $Q_{1,j}$ signify the yield capacities, and μ_{Ai} and μ_{Bj} mean the suitable MFs. For example, if the Bell-shaped MF is used $\mu_{Ai}(x)$ is given by:

$$\mu_{A_i}(x) = \frac{1}{1 + \left[\left(\frac{x - c_i}{a_i}\right)^2\right]^{b_i}} \qquad (13)$$

wherethe parameters of the MF are: a_i, b_i and c_i,overseeing the Bell-shaped capacities in like manner.

Layer 2: this is the item layer and each hub is altered stamped by a circle hub and marked by ∏. Theweight elements of the following layer arethe outputs w_1 and w_2. The yield of this layer, $Q_{2,i}$, is the information's results of the information flags and given by

$$Q_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y)\ \ , i = 1,2 \qquad (14)$$

The yield sign of every hub, w_i, speaks to the terminating quality of the rule.

Layer 3: this layer is the standardized layer and in this layer each hub is altered node, stamped by a circle hub and named by N. The hubs standardize the ascertaining so as terminate quality the proportion of terminating quality for this hub to the entirety all ending quality, i.e.

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$$Q_{3,i} = \overline{w_i} = \frac{w_i}{w_1 + w_2}\ , i = 1,2 \qquad (15)$$

***Layer 4**:* this layer is de-fuzzy layer having versatile hubs and stamped by square hubs. By a non-fuzzy comparison,the hub capacity in this layer is presented

$$Q_{4,i} = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i)\ , i = 1,2 \qquad (16)$$

whrer$\overline{w_i}$ is the standardized terminating quality yield from the past layer commercial {p1,qi,ri} is the parameter set of this hub. These parameters are direct and alluded as resulting parameters of this hub.

Layer 5this layer is the final layer that basically processes the general framework yield as the summation of each approaching sign. Each hub in this layer is altered hub, stamped by circle hub and named by Σ. The model capacity is given by:

$$Q_{5,i} = \sum_i \overline{w_i} f_i = \frac{\sum_i \overline{w_i} f}{\sum_i \overline{w_i}}\ , i = 1,2 \qquad (17)$$

Not that, the framework output is the weighted whole of the guidelines. By the quantity of hubs in layer 1, the amount of fuzzy sets is dictated .In other ward, the measurement of layer 4 decides the quantity of fuzzy rules principles utilized the structural planning that demonstrates the intricacy and adaptability of the ANFIS architecture. At the end point when contrasted with the neural systems, likeness the neurons fuzzy rules can be considered [16].There are two versatile layers can bewatchedin ANFIS construction, modeling, in the particular the first layer and fourth layer. There are three modifiable parameters in the first layer {a_i, b_i, c_i}, which are identified with the info MFs. These parameters are alleged reason parameters. In the fourth layer, there are additionally three modifiable parameters {p_i, q_i, r_i}, relating to the first requast polynomial. These are alleged ensuring parameters [18].

ANFIS SIMULATION RESULTS AND DISCUSSION

Theoretical Results

In this part, the performance of cooling tower has been assessed with the presence of ANFIS. The fuzzy logic toolbox of **MATLAB R2011.a** was utilized to train the ANFIS and obtain the outcomes. In order to accomplish the maximum prediction accuracy for ideal training, the diverse ANFIS parameters were tried as preparing parameters. Six models are constructed by 5 inputs and 1 output for each one. The inputs parameter for each model are air flow rate,coolingand spray water flow rates, inlet temperature of cooling water and inlet AWBT whereas the output parameter for each one are cooling range ,tower approach, thermal efficiency, cooling capacity , rate of water evaporation losses and exergy destruction .

ANFIS Model Designing

The hybrid ANFIS technique as in ANN and FL in architectural structural contains a number of parts that can be selected to find the best solutions, these parts of the optional determine the type and number of membership functions used in the input data representation, and same this choice also exists in FL model representation. Also, the ANFIS model architecture representation of the simulation process technology for input new data.

The data of experimental tests for CWCT with packing (560 mm) height located under heat exchanger with staggered tubes arrangement and

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jet spray nozzle type used to design six ANFIS models for preparingand testing. The preparingdata set the was utilized to prepareANFIS, while testing data set was utilized to confirm

the precision and the adequacy of the prepared ANFIS display for the computation data quality evaluation. The ANFIS model designing steps are: data loading, generate FIS, train FIS and test FIS.

In order to start modeling ANFIS, 186 data sets are partitioned into two independent subsets: training and testing subsets. To cover all operational parameters,the training subset incorporates 159 data samples and testing data subset has remaining 27 data samples are used to test the validation of the model (the best test set is 10 - 15% of the training set). For cooling range ANFIS model, the tanning data loading from the workspace as shown in Figure 4.

Data Loading

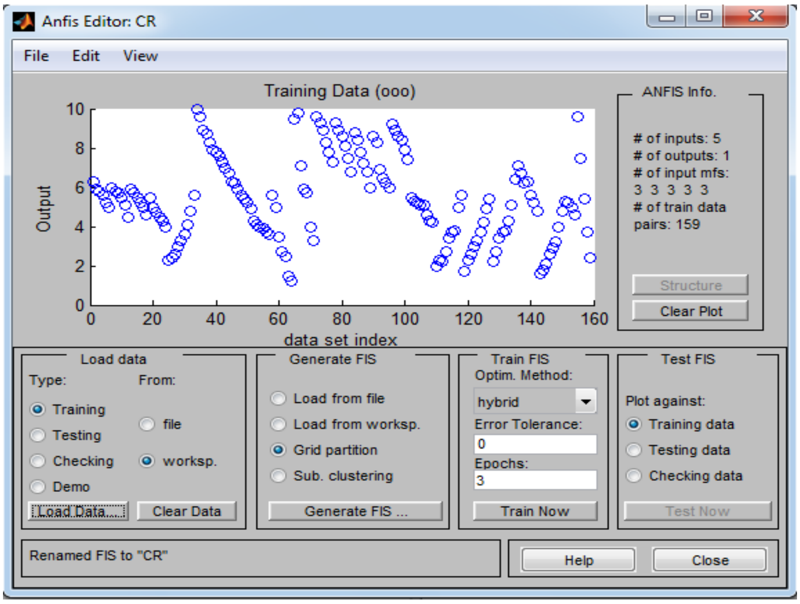

Fig.(4): Loading the training data set in ANFIS model for cooling range

Generate FIS

In the ANFIS editor,the FIS was created by picking the fitting number of MF and their shape and by stacking the information from the workspace. Figure 5. Shows the Sugeno FIS in fuzzy logic tool box gives a FIS editor. The FIS editor shows the input variables, the derived membership function and the output variable.Once the FIS was delivered, the ANFIS must be prepared appropriately by choosing a legitimate calculation withreasonable number of epochs.

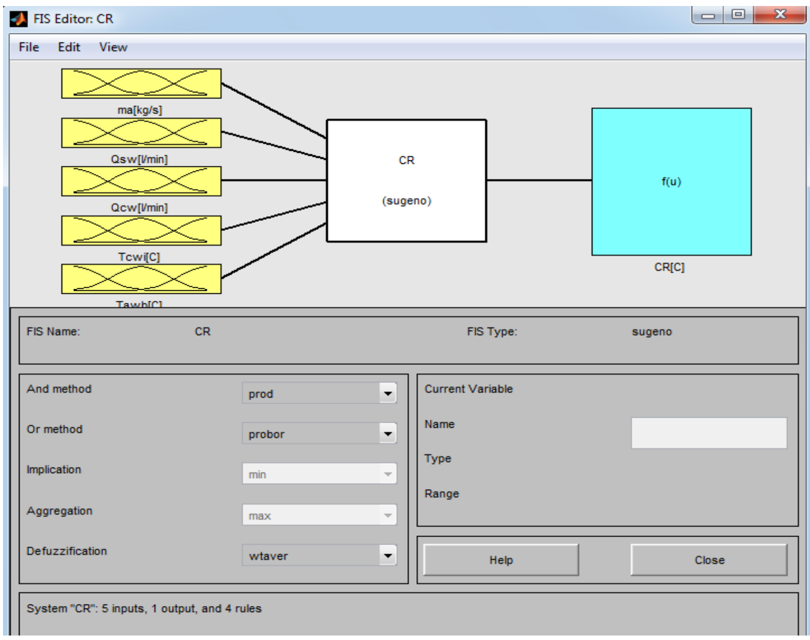

Fig. (5): ANFIS fuzzy inference editor for cooling range model

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Train FIS

By utilizing the training data, the ANFIS was trained using either back propagation or a hybrid system which contains a combination of the least-squares-typeandback propagation methods. The MTLAB implements the ANFIS in two methods to recognize the inference parameters, namely grid partitioning and subtractive clustering. ANFIS training process minimizing the error gradually until reaching the situation of error constancy which represents the smallest obtainable error.In this study, for the cooling range ANFIS model, by trial and error, the total iterations to select ANFIS parameters are listed in Table 2.After training, final configuration for the FIS is selected, the specifications of the proposed cooling range ANFIS model tabulated in Table 2.The input dataset is clustered using subtractive clustering; the radius used in ANFIS for clustering the data is 0.8. Numbers of epochs assigned are 12. The created ANFISstructure with 6 total neurons5 neurons for input and 1 neuron for output,four number of hidden layers used : input MF, rule base, MF, and aggregate output as shown in Figure 6. In Figure 7, it is presented the ANFIS error curve for 30 epoch's .The minimal Root Mean Square Error (RMSE) reached by using clustering with Gaussian MF within 8 epochs is 0.33122˚C.

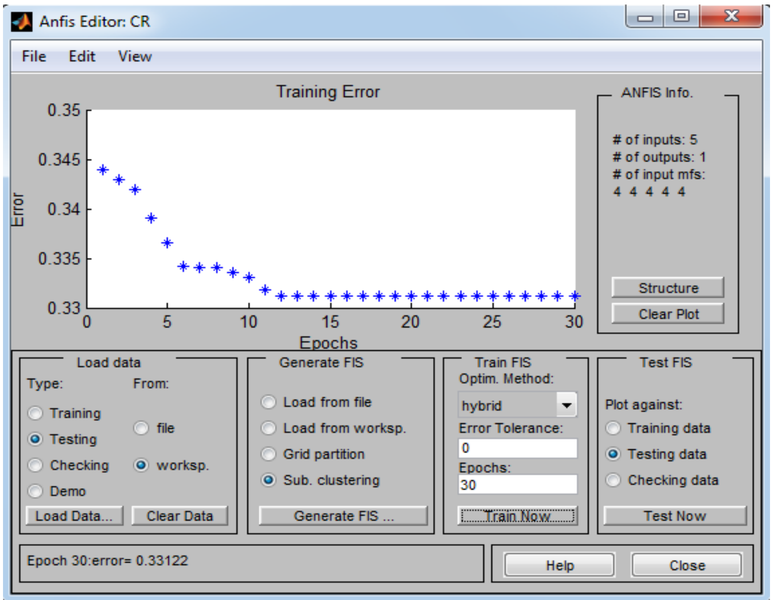

Fig.(6): The RMSE during the training of cooling range ANFIS network

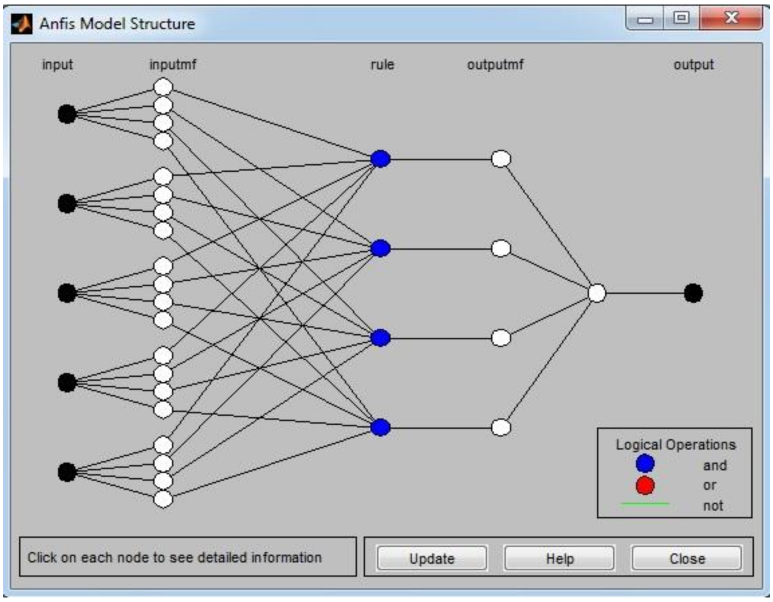

Fig. (7): General ANFIS model structure for cooling range prediction showing all the 5 layers in the ANFIS architecture

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Table(2): Specifications of the proposed cooling range ANFIS model

ANFIS parameter type	Value
Defuzzification method	Centroid
Number of membership functions	4
Type of membership functions	Gaussian
Number of fuzzy rules	4
Output functions	Linear
Learning algorithm	Hybrid learning
Number of training epochs	12
Number of training data pairs	159
Number of testing pairs	27
Number of nodes	56
Number of linear parameters	24
Number of nonlinear parameters	40
Total number of parameters	64

Test FIS

Figure 8.shows tested parameters for cooling range ANFIS model .As can be seen from figure the actual data good conference with predict data and the testing RMSE is 0.19485˚C.

InFigure9., for the cooling range ANFIS model, the first five columns from left side presents inputs to the system, which are air flow rate, spray and cooling water flow rates, inlet temperature of cooling water and inlet AWBT. The final column presents the output from the system, which is cooling rang for 4 fuzzy rules. For example, when air flow rate is 0.19 kg/s , flow rate of spray water is 32.5 l/m,flow rate of cooling water is 30 l/min, inlet cooling water temperature is 45℃ and inlet AWBT is 15.8 ℃ cooling range becomes 3.31℃ as shown in this figure.

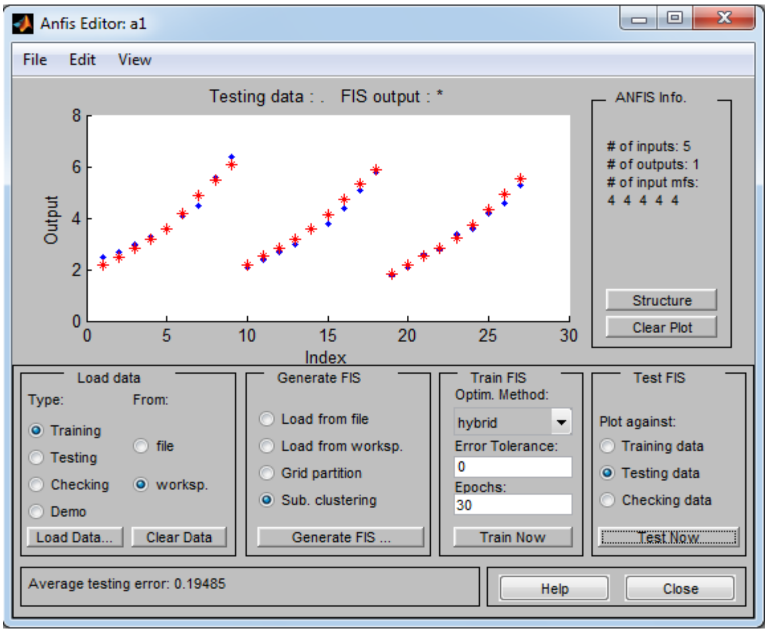

Fig.(8): Testing the trained cooling range ANFIS model

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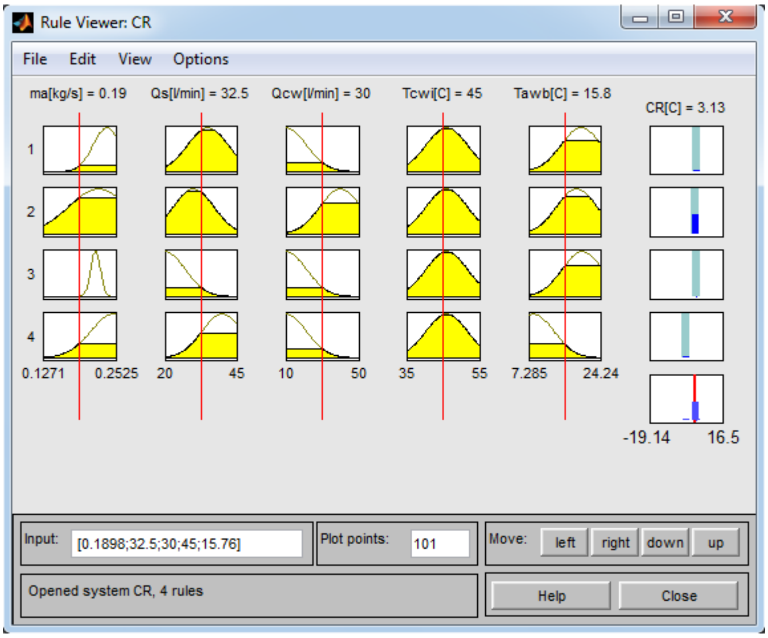

Fig. (9): Rule viewer of designed ANFIS model

Validation of the Models

From the models developed, the performance of the models is validated considering their performance in terms of experimental and ANFISpredicted 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 forecast of the models.The RMSE, MRE and R^2 were calculated using the following formulas [19]:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{j=0}^{n}(t_j - o_j)^2}{n}} \qquad (18)$$

$$\mathrm{MRE} = \frac{1}{n}\sum_{j=0}^{n}\left|100 \times \frac{t_j - o_j}{t_j}\right| \qquad (19)$$

$$R^2 = 1 - \left(\frac{\sum_{j=0}^{n}(t_j - o_j)^2}{\sum_{j=0}^{n}(o_j)^2}\right) \qquad (20)$$

Where t is the target value, o is the output value and n is the number of observations.For

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example, in table 3, the values of RMES, MER and R^2 for cooling range model are 0.19485 ˚C, 4.4564 % and 0.9771 respectively.

Table (3): Performance indication for all models

Model	RMSE	MRE (%)	^{2}
CR	0.19485˚ C	4.4564	0.977
TA	0.33268˚ C	1.2683	0.974
η	0.91858 %	4.9496	0.963
q	0.4168 kW	3.9052	0.901
E_{losses}	0.0001532 kg/s	2.4455	0.847
	0.0377798 kW	3.6169	0.815

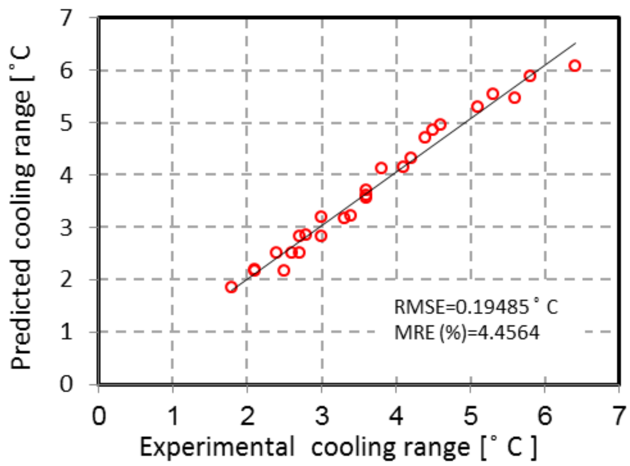

Fig.(10): Scatter plot of experimental and ANFIS predicted cooling range

Figures 10 shows scatter plots of the ANFIS forecasts as a function of test values for the cooling range.

Surface Viewer Analysis (Models Prediction)

The most important advantage of using ANFIS model is to predict the behavior which shows the interactions between the output and two inputs by surface viewer. In this section the three dimensional surface viewers obtained by simulating Sugeno-type of FIS for the cooling range, tower approach, thermal efficiency, rate of evaporation losses and exergy destruction are discussed. The surface viewer displays both the presentations lines and faces of the surface in color. Figures 11 to 16. Shows selected three dimensional output surface viewers of performance parameters relating to five ANFIS networks.

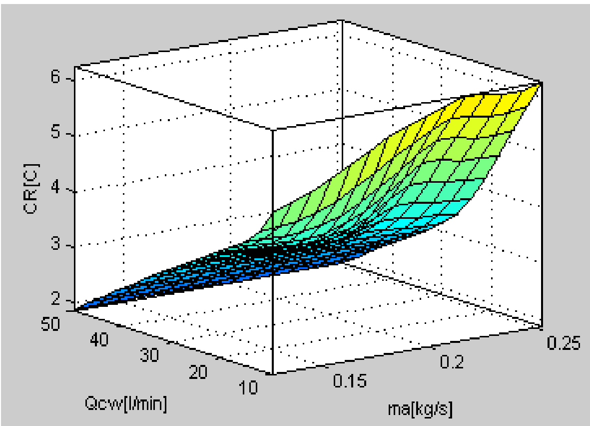

Fig. (11): ANFIS surface viewer showing the relationship of cooling range with cooling water & air flow rates

Figure 11.indicates the surface viewer between cooling water and air flow rates for cooling range. It shows that the value of cooling range increments significantly with the diminishing of cooling water and increment in air flow rate. Figure 12.indicates the surface viewer between air and spray water flow rates for tower approach. When the both values of air and spray water flow rates decrease, the tower approach increase.

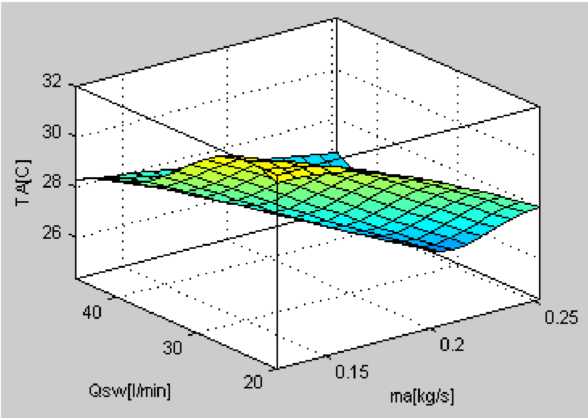

Figure 12. ANFIS surface viewer showing the relationship of tower approach with air& spray water flow rates

The thermal efficiency surface viewer with both cooling and spray water flow rates are appeared in Figure 13. The figure depicts that the value of thermal efficiency increases with decreasing in flow rate of cooling water flow rate and increasing in flow rate of spray water. Therefore, maximum thermal efficiency achieved at the minimum value of cooling water flow rate and maximum value spray water flow rate.

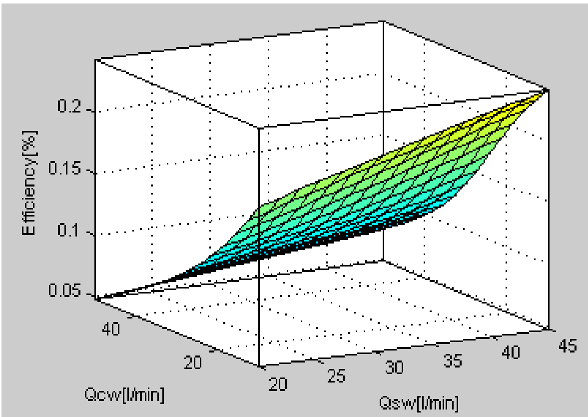

Fig. (13): ANFIS surface viewer showing the relationship of thermal efficiency with spray & cooling water flow rates

In Figure 14., the surface viewer between air flow rate and temperature of inlet cooling water for cooling capacity is illustrated. It shows that the temperature of inlet cooling water has significant effect in determining the value of cooling

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capacity. Also, the cooling capacity increases with increase air flow rate.

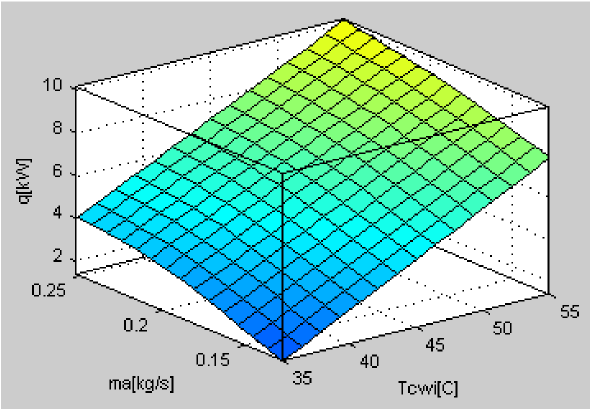

Fig. (14): ANFIS surface viewer showing the relationship of cooling capacity with air flow rate & inlet cooling water

In Figure 15., the surface viewer between inlet AWBT and cooling water flow rate for rate of water evaporation losses is illustrated. It shows that the evaporation losses increasing with increase in both inlet AWBT and cooling water flow rate.

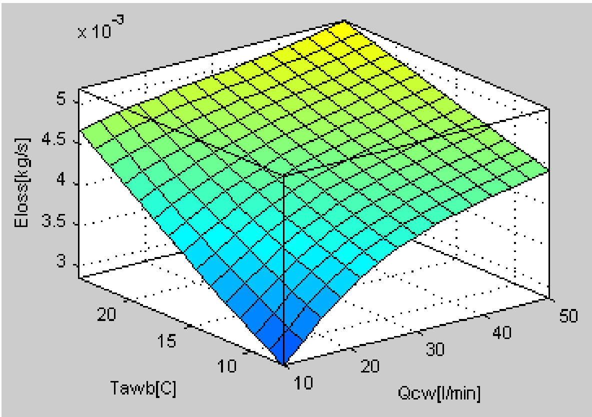

Fig. (15):. ANFIS surface viewer showing the relationship of evaporation losses with inlet AWBT &cooling water flow rate

The exergy destruction surface viewer for temperature of inlet cooling water and flow rate of spray water for exergy destruction is shown in Figure 16. The figure depicts that the value of exergy destruction increments with the diminishing the flow rateofspray water and the increment in temperature of inlet cooling water.

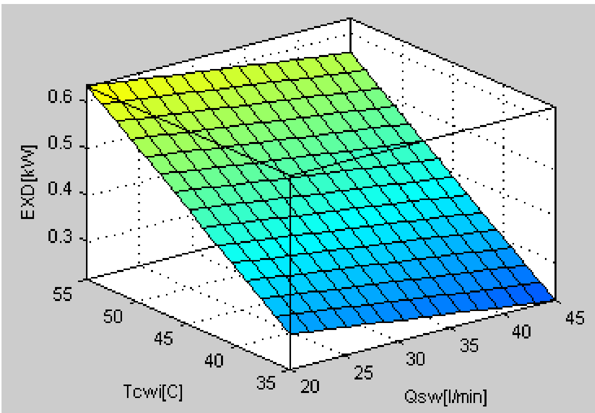

Fig. (16): ANFIS surface viewer showing the relationship of exergy

CONCLUSIONS

It is vital to assess the execution of cooling tower in view of first and second law of thermodynamics. In this paper, thermal performance of modified CWCT thermodynamics were analyzed in view of first and second law of in order to enhance its performance. Operational parameters have direct effects on the cooling tower performance. So the best operational conditions achieved for higher cooling rang, thermal efficiency, cooling capacity and for lower tower approach, evaporation losses and exergy destruction.Comparison of the output values obtained using the ANFIS models and those obtained experimentally for other cases not included in the training data, indicates high compatibility with maximum percentage error of 5 %. Through the ANFIS simulation, the contribution of interdependent parameters obtaining the output might easily provide from the surface viewer without utilizing gigantic computations.

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