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Performance prediction of a thermal system using Artificial Neural Networks

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Abstract:- Condenser is a device in which heat is transferred from one medium to another across a solid surface. The performance of condenser deteriorates with time due to fouling on the heat transfer surface. It is necessary to assess periodically the condenser performance, in order to maintain at high efficiency level. Industries follow adopted practices to monitor but it is limited to some degree. In this paper, performance monitoring system for a condenser is developed using artificial neural networks (ANNs). Experiments are conducted based on full factorial design of experiments to develop a model using the parameters such as temperatures and flow rates**.** ANN model for overall heat transfer coefficient of a design/ clean condenser system is developed using a feed forward back propagation neural network and trained. The developed model is validated and tested by comparing the results with the experimental results. This model is used to assess the performance of condenser with the real/fouled system. The performance degradation is expressed using fouling factor (FF), which is derived from the overall heat transfer coefficient of design system and real system. It supports the system to improve the performance by asset utilization, energy efficient and cost reduction in terms of production loss.

Keywords:- Condenser; Full factorial design of experiments(DOE):Artificial neural networks (ANNs); overall heat transfer coefficient; Fouling factor(FF).

I. INTRODUCTION

A condenser has two main advantages: The primary advantage is to maintain a low pressure (atmosphere or below atmosphere pressure) so as to obtain the maximum possible energy from steam and thus to secure a high efficiency, The secondary advantage is to supply pure feed water to the hot well, from where it is pumped back to the boiler.

It is recommended the (ANN) can be used to predict the performance of thermal system in engineering applications, such as modelling condenser for heat transfer analysis. Afterwards, ANN resulted used to find thermal parameters (convection heat transfer coefficient of water side h_w and steam flow rate *m s*) based on software program built by Matlab language[1], The prediction of fouling in condenser is heavily influenced by the periodic fouling process and dynamics change of the operational parameters, to deal with this problem, a novel approach based on fuzzy stage identification and Chebyshev neural network is proposed[2], This model is used to assess the performance of heat exchanger with the real/fouled system. The performance degradation is expressed using fouling factor (FF), which is derived from the overall heat transfer coefficient of design system and real system[3], The multi-input multi-output (MIMO) neural network is separated into multi-input single-output (MISO) neural networks for training. Afterwards, the trained MISO neural networks are combined into a MIMO neural network, which indicates that the number of training data sets is determined by the biggest MISO neural network not the whole MIMO network [4]. The author present and discuss a stochastic approach to the analysis of fouling models. In view of the performance indicator (U/Uc) of the heat exchangers, a maintenance strategy for planned maintenance schedules is presented. Various scenarios of reliability based maintenance strategy are introduced. The strategy is explained in terms of the scatter parameter (α) of the time to fouling distribution corresponding to a critical level of fouling, and the risk factor (p) representing the probability of tubes being fouled to a critical level after which a cleaning cycle is needed[5]. The author presents an analytical and computational modelling of the effect of the space surrounding the condenser of a household refrigerator on the rejected heat. The driving force for rejecting the heat carried by the refrigerant from the interior of a refrigerator is the temperature difference between the condenser outer surface and surrounding air[6]. Due to the fouling deposit on the heat transfer surfaces, the thermal resistance between refrigerant and water gradually increases. The fouling resistance depends on several factors such as heat exchanger geometry, heat flux, water quality and water flow rates [7].

From the above literature survey, it is identified that the performance prediction of condenser is analysed by applying various techniques which involves complexity and difficult procedures. To mitigate these limitations, In this paper ANN is used in a simpler way to predict the performance of a condenser as follows.

II. PROBLEM DEFINITION

In this paper, a monitoring system is developed for a condenser using measurements namely the temperatures and flow rates of the hot and cold fluid .Neural network system is developed to investigate the performance of condenser. ANN is applied to model the heat exchanger with experimental data. The input parameters to develop a model for condenser are inlet temperature and flow rate of shell and tube side fluids and output is overall heat transfer coefficient (UDesign). The overall heat transfer coefficient of real/fouled system (UReal) is calculated using online measured values such as inlet temperature, outlet temperature and flow rate of shell and tube side fluids. The condenser performance is assessed by comparing the results of clean/design and fouled/real system. Any deviation from the result of design/clean system indicates that the performance is degraded due to fouling. Its degree is derived from fouling factor (FF) using UDesign and UReal.

III. CASE STUDY

In this present work, Nagarjuna agrichem taken as a case study. It is located in chilakapalem, srikakulam district, Andhra Pradesh, India. Nagarjuna agrichem which produces the pesticides, insecticides, fungicides, etc, the outlet from the reactor containing hot gases and vapors will be sent to tube side of the condenser, where as cold water enters the condenser at shell side. Hot vapors from reactor will condense by rejecting heat to water. The condensate will be sent to collecting tank. The remaining undissolved gases in the condenser will be passed over to vacuum pump which drains them out to atmosphere. Both vapour and water flow in counter current direction so as to attain maximum heat transfer rate.

A. Condenser setup in industry

Figure 1. Condenser setup in industry

B. Specifications of condenser

Condenser Type	Shell and Tube in Counter current mode
Shell material	SS 316
Tube material	Copper
Shell diameter	360mm
Tube length	3000 mm
Number of Tubes	144
Tube Outer Diameter (OD)	22 mm
Tube Inner Diameter (ID)	19.05 mm
Baffle no’s	6

C. Data obtained from industry

Three process parameters namely hot vapor inlet temperature, cold water flow rate and hot vapor flow rate were selected and their data was taken at 3 different levels.

Parameter	Level1	Level2	Level3
Cold water Flow rate(LPH)	350	375	400
Hot vapor Flow rate(LPH)	230	250	270
Hot vapor inlet temperature(°C)	56	59	62

D. Taguchi method

Taguchi method is a statistical method developed by Taguchi and Konishi. It involves identification of proper Orthogonal Arrays (OA) are used to conduct a set of experiments. L27 Orthogonal Arrays (OA) is used in this work. Full factorial design of experiments (DOE) is used and their combinations of process parameters such as temperatures and flow rates were used for calculations Experimental design using full factorial design of experiments and their outputs [8].

E. Equations used and methodology of calculations

The performance of the condenser is assessed by computing overall heat transfer coefficient. The overall heat transfer coefficient is calculated using log mean temperature difference (LMTD) approach because the inlet temperature, outlet temperature and flow rate of the cold and hot water are known. The overall heat transfer coefficient of condenser is calculated by using below equations.

Qh = mh Cph (Thi – Tho) in kW (1)

(or)

Qc = mc Cpc (Tco – Tci) in kW (2)

where

Qh - Heat transfer rate of hot vapor side
Qc - Heat transfer rate of cold water side
mh - Mass flow rate of hot vapor in kg/hr
mc - Mass flow rate of cold water in kg/hr
Cph – Specific heat capacity of hot vapor in kJ/kgK
Cpc – Specific heat capacity of hot water in kJ/kgK
Thi – Hot vapor inlet temperature in °C
Tho - Hot vapor outlet temperature in °C
Tco - Cold water inlet temperature in °C
Tci - Cold water outlet temperature in °C
A - Heat transfer Area in m2.

LMTD for Counter current flow =

$$((T_{hi}-T_{co})-(T_{ho}-T_{ci})) / \ln ((T_{hi}-T_{co}) / (T_{ho}-T_{ci})) \qquad (3)$$

U = [Qh or Qc] / [A*LMTD] in W/m2.°C (4)

Where U is Overall Heat transfer Co-efficient.

Initially the heat transfer rate (Q) of the water or vapor was calculated based on secondary measurements such as temperatures and flow rates using equation (1) or (2). Then the heat transfer area of the heat exchanger (A) was calculated based on the geometrical parameters. LMTD for counter-current flow of vapor and water was computed with inlet and outlet temperatures of cold and hot water using equation (3). Based on the calculated values of Q, A, and LMTD the overall heat transfer coefficient was calculated using equation (4). The overall heat transfer coefficient of design/clean condenser is computed and it varies from 4.21-7.31 w/m^2k.

IV. DESIGN AND DEVELOPMENT OF PERFORMANCE ASSESSMENT SYSTEM FOR CONDENSER USING ANN

A. Design of performance assessment system

In this an ANN is used to develop the model for predicting the overall heat transfer coefficient (U_{Design}) of the design system using secondary measurements temperature and flow rates. Inputs of the developed network were temperature of hot vapor inlet T_{hi}, flow rate of cold water F_{ci} and flow rate of hot vapor F_{hi} and output was U_{Design}. Data acquired from the design of experiments were used for training, validation and testing the ANN model. Heat transfer coefficient of real system (U_{Real}) is derived using secondary measurements such as T_{ci}, T_{hi}, T_{co}, T_{ho}, F_{ci} and F_{hi}.

This system imitate the real time system and used for performance assessment (fouling) of the system. Measured values of Tci, Thi, Tco, Tho, Fci and Fhi are used to predict the value of UDesign and compute the value of UReal.

FF value is computed with the predicted value of UDesign and the computed value of UReal. It is used to identify the performance degradation or degree of fouling of the condenser. If the FF value is greater than or equal to the set value (allowable) of design condenser, warning message will be given for cleaning or maintenance of condenser.

B. NN model development

FF value is computed with the predicted value of U_{Design} and the computed value of U_{Real}. It is used to identify the performance degradation or degree of fouling of the condenser. If the FF value is greater than or equal to the set value (allowable) of design condenser, warning message will be given for cleaning or maintenance of condenser.

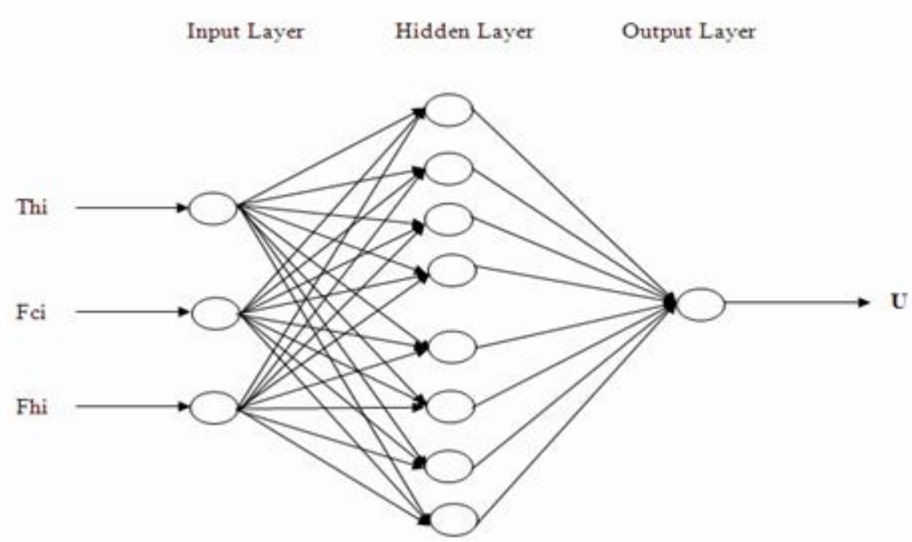

Figure 2. Topography of developed ANN Model (3-10-1) for U_{Design}

The network architecture or features such as number of neurons and layers are very important factors that determine the functionality and generalization capability of the network. For the model, a standard multilayer feed forward back propagation hierarchical neural network is designed with MATLAB NN Toolbox. The networks consist of three layers: the input layer, hidden layer, and output layer. In order to determine the number of hidden layers and neurons we go for trial and error method. The neural networks for U_{Design} has three neurons in the input, corresponding to each of the three process input parameters T_{hi}, F_{ci} and F_{hi} and one neuron in the output layer, corresponding to the process response U_{Design}. The topography of the ANN model (3-10-1) for U_{Design} is shown in Figure 2. In this one hidden layer with ten neurons is found to be most suitable for model development by trial and error method. For networks, linear transfer function 'purelin' and tan sigmoid transfer function 'tansig' is used in the output and hidden layer respectively. Industry data set are used to train, validate and test the U_{Design} network. In this, nineteen data set are used for training, four data set are used for validation and remaining four data set is used for testing the network. The training of ANN for 19 input-output patterns has been carried using 'trainlm' algorithm. The learning factors are set as goal of 10^{-10} and epochs of 1000. The variation of MSE during the training is shown in Figure 3 In the present study, the desired MSE is achieved after 11 epochs.

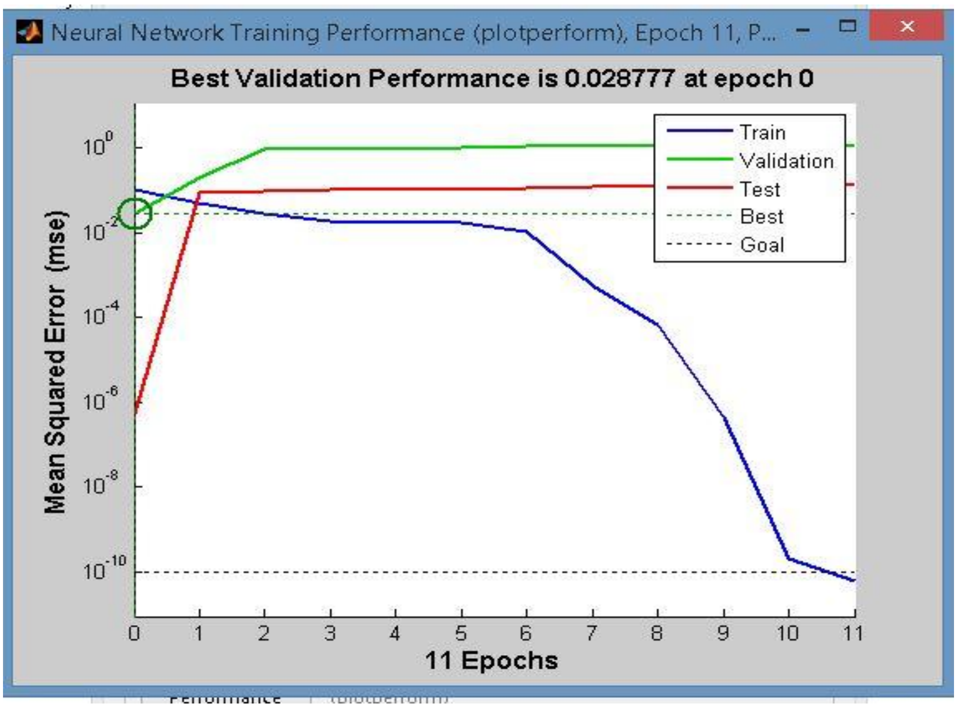

Figure 3. Training graph of developed ANN model for U_{Design}

The trained ANN is initially tested by presenting 19 input patterns, which are employed for the training purpose. For each input pattern, the predicted value of overall heat transfer coefficient is compared with respective output data and absolute percentage error is compared, which is given as

$$\% \text{ Absolute error} = \left| (Y_{i,exp} - Y_{i,pred})/(Y_{i,exp}) \right| X100 \qquad (5)$$

where, $Y_{i,\ exp}$ is the measured value and

$Y_{i,\ pred}$ is the ANN predicted value of the response for i^{th} trial.

The performance capability of network is examined based on the absolute error percentage between the network predictions and the experimental values. It is found that the predicted and experimental values are very fairly close to each other. The error of overall heat transfer coefficient for 19 input trials of training patterns are 10.3%. Another way of measuring the performance of a trained network is by performing a regression analysis between the network response and the corresponding targets. This is carried out by using 'postreg' function in MATLAB. The graphical output of 'postreg' is shown in Figure 4 for U_{Design}. The correlation coefficient (R) between the outputs and targets is a measure of how well the variation in the output is explained by the targets. If R value is 1 then it indicates perfect correlation between the target (T) and predicted outputs (A). In this case, the R value of the output overall heat transfer coefficient is 0.89685, it indicates that the model had good correlation.

In validation, four new data set are used, which do not belong to the training data set. For this validation data set, the overall heat transfer coefficient is predicted using the ANN model and then compared with the actual (real) values. It is observed that predicted values of U_{Design} are very closer to the actual values that are shown in Figure 4. It is also found that maximum absolute error of U_{Design} is 7.41 %. This indicates that the model accuracy for predicting the process responses is adequate.

For testing, other four new data set are used which do not belong to the training and validation data set. For this testing data set, the overall heat transfer coefficient is predicted using the ANN model and then compared with the actual values. It is observed that predicted values of U_{Design} are very closer to the actual values that are shown in Figure 4. It is also found that maximum absolute error of U_{Design} is 0.14%. This indicates that the model for predicting the process responses is well adequate for generalization. NN model for U_{Design} is developed to study the performance degradation by estimating the fouling of the condenser.

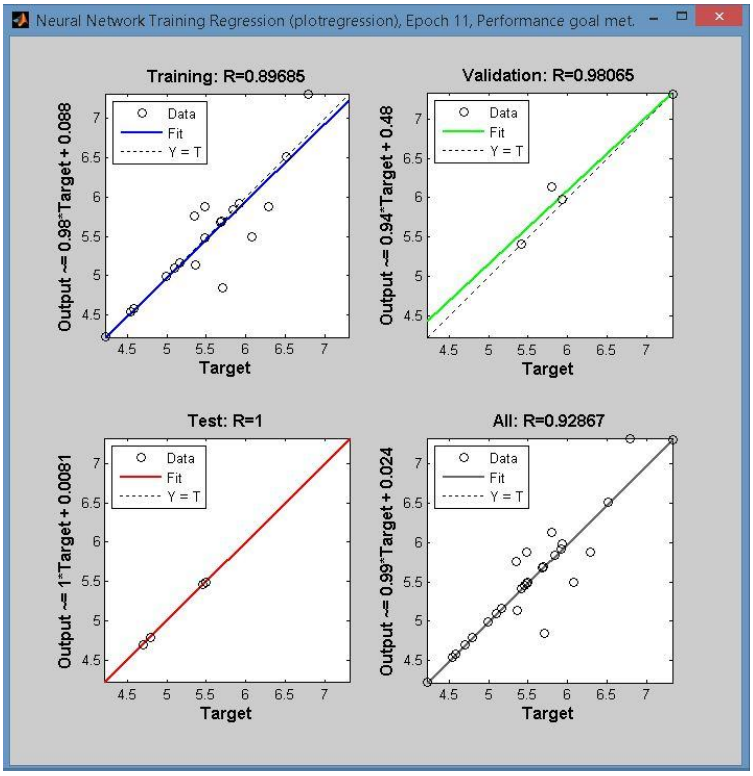

Figure 4: Output value graph of developed ANN model for U_{Design}

F. Performance assessment

Condenser's performance will degrade with the time from design to real conditions. The rate at which this will occur is dependent on the application of condensers. Fouling detection is able to present the degradation of condenser performance, which is responsive for changes in the FF across the heat transfer surface. Effective and majorly applied method for fouling detection is to compare the U_{Design} and U_{Real}. It cannot be measured directly and it uses the secondary measurements such as flow rates and temperatures as inputs from the industrial data to estimate it.

From the measured values such as T_{ci}, T_{hi}, T_{co}, T_{ho}, F_{ci} and F_{hi} the performance of the condenser is assessed. T_{hi}, F_{ci} and F_{hi} were used to predict the value of U_{Design} using developed ANN model. U_{Real} value is computed using LMTD approach with T_{ci}, T_{hi}, T_{co}, T_{ho}, F_{ci} and F_{hi}. The performance of condenser is assessed by comparing the U_{Real} value with U_{Design} value. The decrease in U_{Real} value indicates the degradation of performance by formation of fouling.

In this, performance degradation or fouling is estimated using FF approach and this will indicate the degree of fouling. The degradation in performance is expressed by the FF, as calculated by the equation:

$$FF=[(1/U_{Real})-(1/U_{Design})] \qquad (6)$$

The FF value of condenser is calculated using the equation (6). In design stage, the allowable Fouling resistance i.e. FF is specified for all the condensers by manufacturer's to avoid frequent cleaning or maintenance.

V. RESULTS AND DISCUSSIONS

The system initially predicts the U_{Design} value with ANN model and computes the U_{Real} value through the observed input values. We manually calculated the FF value using U_{Real} and U_{Design} values. Based on the FF value the system gives the information to the operator. The FF range for our industrial equipment is 0.0003-0.0008. From the results it is identified that the condenser performance is within the tolerance value (set by field engineer/maintenance engineer) of FF, there is no need for maintenance If the performance of the condenser is above the tolerance value of FF, it needs immediate maintenance or corrective action to recover the heat transfer efficiency. This gives intimation to the operator for planning maintenance well ahead to minimize operational disturbance due to unplanned shutdowns.

The advantage of this system is that it could be easily implemented in the industries to get performance assessment/fouling effect by simple and effective manner. This gives comprehensive information to field engineers for improving the performance of condenser by asset utilization, energy efficient and cost reduction in terms of production loss and maintenance.

VI. CONCLUSION

In this work, Data were taken for a condenser with different flow rates of cold water and hot vapor, and hot inlet temperature to assess the performance of the system. The data was incorporated into the ANN model development. A feed forward neural networks model was developed to predict overall heat transfer coefficient U_{Design} of the design condenser system and the model was trained, validated and tested for generalization. Good agreement was identified between the predictive model results and the manually calculated results. It was found that the maximum error of validation and testing data set for overall heat transfer coefficient U_{Design} of the design system were 0.17 % and 7.41 % respectively. NN model was used to predict the value U_{Design} and U_{Real} was derived from measured values. FF is found from the predicted U_{Design} and U_{Real} value. From the estimated FF value, the performance degradation/fouling effect was within the tolerance limit (margin). Based on the results, further it needs intelligent approach to do fouling analysis and maintenance decisions.

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