STEAM CONDENER PERFOMANCE EVALIATION BY USING NEURAL NETWORK

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ABSTRACT:

This work applied Artificial Neural Network (ANN) for performance evaluation of steam condensers which are widely used in power plants and refineries. Two condensers were experimentally investigated. Experimental data was obtained by use unit steam power from G.U.N.T Company and industrial condenser operates in Dura refinery. The commonly used Back Propagation (BP) algorithm was used to train and test network. Input of neural network include inlet water temperature, water flow rate, steam temperature and enthalpy difference. The exit water temperature represented output of the neural network. The maximum deviation between the predicted results and experimental data was less than 1%. It is recommended the (ANN) can be used to predicate the performance of thermal system in engineering applications, such as modeling 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 $m^{\bullet}_s$) based on software program built by Matlab language. Comparing the resulted from modeling with experimental data reveals a good agreement (-3% to 3%).

Keywords: Heat transfer, atmosphere condenser, Artificial Neural Network, Exit water temperature, Modeling, condensate.

تقييم أداء مكثف بخاري باستخدام الشبكة العصبية

الملخص:

يقدم هذا العمل تقييم أداء مكثف بخاري باستخدام الشبكة العصبية، تستخدم المكثفات بصورة واسعة في محطات التوليد والمصافي.تم استخدام مكثفين في الجانب العملي . للحصول على النتائج العملية تم استخدام مكثف مختبري من شركة G.U.N.T ومكثف يعمل في وحدة توليد قدرة داخل مصفى الدورة. اعتمدنا أشهر طريقة للتدريب وتعليم الخوارزمية وهي Back propagation algorithm. قيم الإدخال للشبكة العصبية هي درجة حرارة دخول الماء، معدل تدفق ماء التبريد، درجة حرارة البخار وفرق المحتوى الحراري.درجة حرارة خروج الماء تمثل مخرج للشبكة العصبية . يبلغ أقصى انحراف بين نتائج الشبكة والنتائج العملية اقل من 1%. ومن هذا يمكن اعتماد الشبكة العصبية للتنبؤ بالأداء الحراري لأغلب التطبيقات الهندسية مثل تمثيل الأداء الحراري للمكثفات. بعد ذلك تم استخدام نتائج الشبكة للحصول على معامل انتقال الحرارة بالحمل للماء ومعدل تدفق البخار بالاعتماد على برنامج تم بناءه باستخدام MATLAB ،مقارنة نتائج معدل تدفق البخار التي تم الحصول عليها من الموديل والجانب العملي أعطت نتائج مقبولة وبحدود (-3% to 3%) .

INTRODUCTION:

A steam 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.[R.S Khurmi(2008)] Since the steam condenser involves complex heat transfer processes, a large number of geometric variables and combined between thermodynamics and heat transfer correlations, it is difficult to simulate the condenser performance with high efficiency and accuracy.
A number of experimental and numerical researches on the steam condenser characteristics have been conducted for several decades. [M.M.Prieto(2003)] presented results of the usual design model "Standards for Steam Surface Condensers (SSSC)", for 2D model and 3D model. The SSSC model and the 3D model can complement one another in the design stage. Using the SSSC for the area estimation and improving the inner condenser geometry by means of the 3D model. Jinsong Tao[3] presented a study of condensers thermal efficiency with cooling tower and turbines working in steam power plant in paper mill. The result showed that the optimization model was practical and useful for paper mill. It can improve power plant efficiency and bring good economical performance for paper mill. [Konstantin Niktin(2008)] presented waste heat is recovered from steam condenser through cooling by liquid CO_2 instead of sea water . Experimental were performed to verify the model at a steam pressure range of 3.2-5 kPa and a CO_2 saturation pressure range of 5-6 MPa. Resulted obtained from the numerical model agree with the experimental data within $\pm 5\%$.
Several investigators have proposed (ANN) modeling with experimental or theoretical work for thermal engineering application. [Ling-Xiao Zhao(2010)] presented neural network approach to performance evaluation of the fin-and tube air-cooled condensers The multi-input multi-output (MIMO) neural network is separated into multi-input single-output (MISO) neural networks for training. The standard deviations of neural network models are less than 1.9%, and all errors fall into $\pm 5\%$. [G.N. Xie(2007)][6] presented Artificial Neural Network (ANN) for heat transfer analysis of shell-and-tube heat exchangers with segmental baffles or continuous helical baffles. Limited experimental data was obtained for training and testing neural network configurations. The maximum deviation between the predicted results and experimental data was less than 2%. Comparison with correlation for prediction shows superiority of ANN. [H.M. Ertunc(2006)] describes an application of artificial neural networks (ANNs) to predict the performance of a refrigeration system with an evaporative condenser. In order to gather data for training and testing the proposed ANN, an experimental refrigeration system with an evaporative condenser was set up. The ANN predictions usually agree well with the experimental values with correlation coefficients in the range of 0.933–1.000, mean relative errors in the range of 1.90–4.18% and very low root mean square errors.
The goal of this study is built (ANN) to find exit water temperature of steam condenser, experimental and practical data using to train and test the network. Using (ANN) to give more approach modeling with actual case. Afterwards, Connect (ANN) with Engineering Equation Solver (EES) and Matlab to find h_w and $m^{\bullet}{}_s$.

NEURAL NETWORK BASICS

Neural network, as a non-parametric approximate is used to fit curves through given data without being provide a predetermined function. Many types of neural network have been invented and well-developed.

Typically, neural networks are adjusted, or trained, so that a particular input leads to a specific target output. **Fig. (1)** Illustrates such a situation. There, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically, many such input/target pairs are needed to train a network. [Malik M.ALI, (2010)]

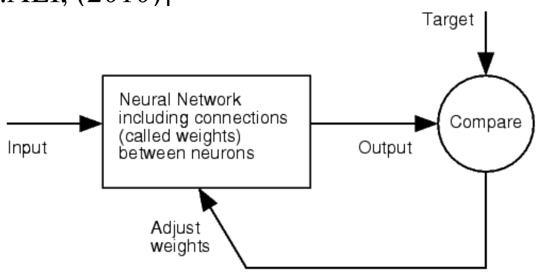

Fig.(1) A schematic of an artificial neural network

ANN comprise of a great number of interconnected neurons. Fig.(2) illustrates a typical full-connected network configuration. Such an ANN consists of a series of layers with a number of nodes. The nodes (circle points in Fig. (2)) sometimes called neuron are the basic processors of neural network. Each connection between two nodes with a real value is called weight. Nodes are gathered together into a column called layer. For each node, there exist activation and a bias associated it. Among various types of ANNs, the feed forward or multilayer perception neural network is widely used in engineering applications. The input information is propagated forward through the network, while the output error is back propagated through the network for updating the weights. As shown in Fig. (2), the first layer with six nodes and last layer with one nodes are called input layer and output layer respectively, while the others in the middle are called hidden layers.[G.N. Xie(2006)]

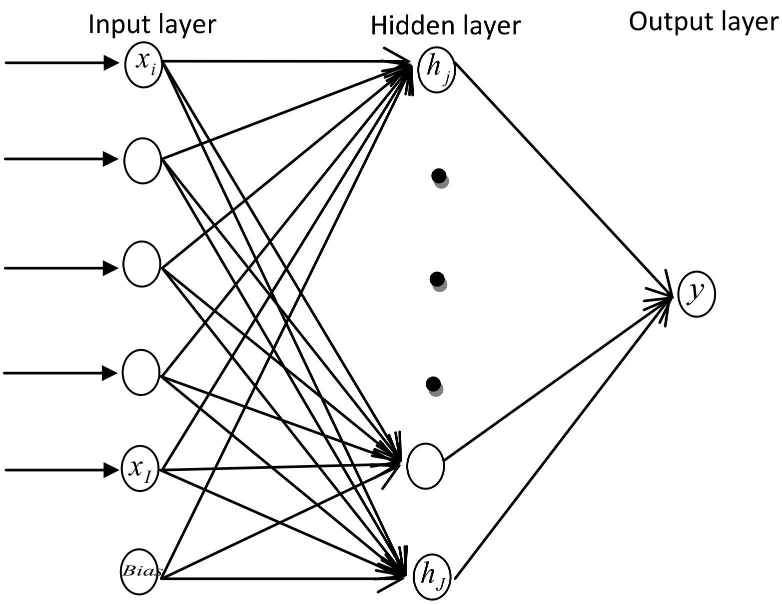

Fig. (2): Architecture of three layer preceptron network

CONDEMSER DATABAS MODELING

Sufficient data samples are necessary for NN model development. It is almost need to take more accuracy data from actual cases to represent any model. Condensers work with little efficiency in local steam power plants because of the bad conditions and old life of work. Unit steam power plant from G.U.N.T Company was intended for training purpose of worker staff.
Experimental devices were carried out to validate the sufficient data for NN modeling. **Fig. (3)** show the overall experimental set up of first unit steam power plant (ET 810). The experimental setup consisted of feed water tank, feed pump, gas-heated boiler(flame tube-flue tube) for generation of steam, a double-acting single cylinder piston steam engine with generator, Micromotor as engine load, Atmospheric condenser , Measurement of temperature – pressure - flow rate - speed , and safety equipment . Transfer area of condenser ($80\ cm^2$) and maximum cooling water consumption ($100\ L/h$).[G.UN.T manual (2008)]

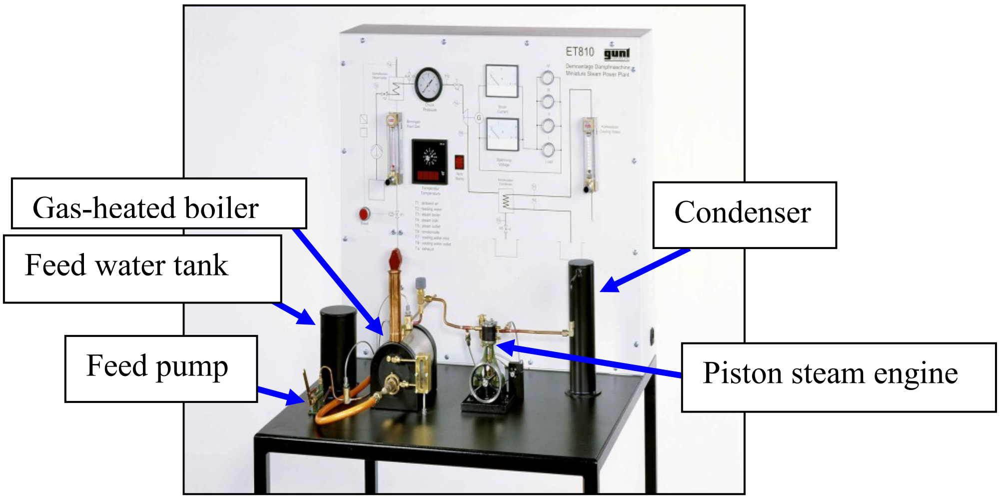

Fig. (3) Single cylinder steam engine from G.U.N.T. comp.

When the system has reached to a steady state the following measurements was taken: temperature of outlet Steam engine, condensate temperature, cooling water inlet and outlet temperature, cooling water flow rate, amount of steam condensate and period of time using stop watch to calculate steam flow rate based on following equation:

$$m^{\bullet}_{s} = \frac{\rho_w * V_w}{\Delta t} \qquad (1)$$

After a few minutes the pressure of boiler is adjusted using the steam valve and repeat reading more than ones for the same measuring points.
Fig.(4) show a surface condenser consisted of straight-tube design ,two- pas condenser with shell expansion joint and hot well, operating in power generation department of Dura refinery. Transfer area ($4.2\ m^2$), pressure loss ($0.157 bar$) the

maximum cooling water pressure ($3bar$), maximum admissible pressure and temperature in shell side ($2\ bar$, $120\ ^{\circ}C$) respectively, maximum admissible pressure and temperature in tube side ($6bar$, $80\ ^{\circ}C$) respectively.

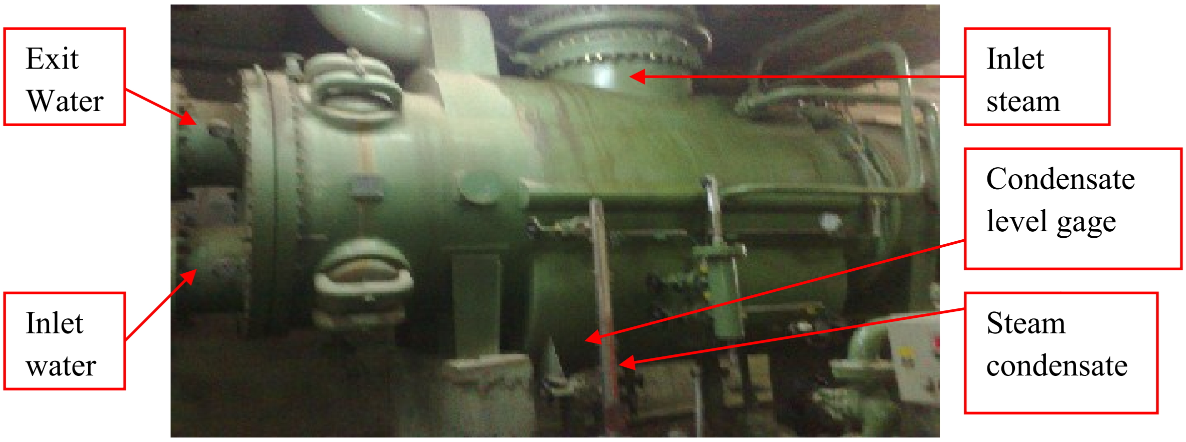

Fig. (4) Steam condenser operation in Dura refinery

When the system has operating in different days the following measurements was taken: temperature of outlet Steam turbine, condensate temperature, cooling water inlet and outlet temperature, cooling water flow rate, amount of steam condensate .The data range from experimental and practical devises used for neural network training is listed in **Table (1)**.

Table (1) Data value of input and output parameters

	$T_w)_i$ $^{\circ}C$	$m^{\bullet}{}_w$ kg/s	T_s $^{\circ}C$	$m^{\bullet}{}_s$ kg/s	$h_1 - h_2$ kJ/kg	$T_w)_e$ $^{\circ}C$
Experimental data	**25**	**0.0153**	**47**	**1.7*10^-4**	**2150.2**	**29**
	25	0.0153	57	2.5*10^-4	2128.4	31
	25	0.0153	71	3.2*10^-4	2097.8	34
	25	0.0153	84	4.4*10^-4	2068.3	36
	25	0.0153	88	5.4*10^-4	2059.5	39
	25	0.0153	94	5.1*10^-4	2045.2	40
	25	0.0153	102	6*10^-4	2026.5	44
	25	0.0153	106	6.2*10^-4	2011.6	46
	25	**0.0181**	**47**	**1.8*10^-4**	**2150.2**	**28**
	25	0.0181	57	2.7*10^-4	2128.4	29
	25	0.0181	71	4*10^-4	2097.8	33
	25	0.0181	84	5.1*10^-4	2068.3	35
	25	0.0181	88	5.9*10^-4	2059.5	38
	25	0.0181	94	6.2*10^-4	2045.2	39
	25	0.0181	102	7.15*10^-4	2026.5	42
	25	0.0181	106	7.6*10^-4	2011.6	44

	25	**0.021**	**47**	**2.5*10^-4**	**2150.2**	**26**
	25	0.021	57	3.1*10^-4	2128.4	28
	25	0.021	71	4.6*10^-4	2097.8	29
	25	0.021	84	6*10^-4	2068.3	33
	25	0.021	88	6.5*10^-4	2059.5	35
	25	0.021	94	7.1*10^-4	2045.2	36
	25	0.021	102	8*10^-4	2026.5	40
	25	0.021	106	8.7*10^-4	2011.6	42
	$T_w)_i$ $^\circ C$	$m^\bullet{}_w$ kg/s	T_s $^\circ C$	$m^\bullet{}_s$ kg/s	$h_1 - h_2$ kJ/kg	$T_w)_e$ $^\circ C$
Practical data	28	50	80	.0069	2108.9	31
	28	50	82	.0071	2103.2	33
	28	50	89	.0084	2085.8	37
	29	50	77	.0068	2118.9	31
	29	50	83	.0073	2101.2	34
	29	50	91	.0087	2080.6	41
	30	50	88	.0082	2088.9	37
	30	50	90	.0086	2081.2	42

CONDENSER MODELING

Condenser model being developed in this study based on four steps; first using (EES) to find enthalpy difference ($h_1 - h_2$) based on steam conditions. Afterwards, using the data from experimental set up to train and test neural network NN model, then using neural network results in engineering equation solver (EES) to find the following properties of water $\mu_w, cp_w, k_w, \Pr_w$ dynamic viscosity, specific heat, thermal conductivity and prandtl number respectively, finally calculate other thermal parameters (h_w and $m^\bullet{}_s$) based on software program built by Matlab language.

CONDENSER NEURAL NETWORK MODELING

The type of neural network used in this approach is the multilayer neural network (MLNN) with learning process called back propagation**.** Standard back propagation is a gradient descent algorithm, as is the learning rule to multiple-layer networks and nonlinear differentiable transfer functions. Input vectors and the corresponding target vectors are used to train a network until it can approximate a function. Here the network is supplied with series of input and corresponding correct (desired) output. The network then tries to set its own parameter until it can approximate an unknown function that can associate input data with corresponding desired output. There are generally four steps in the training process:[Bart Kosko ,(1997)]

1- Assemble the training data.
2- Create the network object.
3- Train the network.
4- Simulate the network response to new inputs.

A three – layer network is capable of approximating any function with a finite number of discontinuities, which is used in the present work. The three layer network consists of one input layer, one hidden layer and one output layer. All of the processing elements at input layer are connected to each of the middle layer processing elements via interconnections, which are weighted and represented by ($w_{j,i}$) and mathematically expressed as below.[Ling-Xiao Zhao, (2010)]

$$h_j = g_{hidden}(\sum_{i=1}^{I} u_{j,i} x_i + b_{1,j}) \quad (j = 1,......, J) \tag{2}$$

The output and the middle layer elements also connected similarly and the connection weights are represented by ($w_{k,j}$) and mathematically expressed as below. [Ling-Xiao Zhao, (2010)]

$$y_k = g_{out}(\sum_{j=1}^{J} w_{k,j} h_j + b_{2,k}) \quad (k = 1,......, K) \tag{3}$$

Proper selection of input and output parameters is the first step of NN model development, which should reflect the condenser performance without missing necessary parameters. Input parameters for condenser neural network modeling include inlet water temperature $T_w)_i$, steam temperature T_s , water flow rate $m^\bullet{}_w$, Steam enthalpy difference between inlet and outlet condenser $h_1 - h_2$. Usually, tube material is constant. (EES) use to find steam enthalpy difference based on steam condition from experimental device. Once steam and cooling water entering states are given, the condenser performance indexes including the exit water temperature can be figured out by laboratory tests or numerical modeling.

NEURAL NETWORK TRAINING

The entire database is used to training NN. The proper size of training data base, best-fit transfer functions and appropriate number of neurons in the hidden layer should be determined through a trial and error NN training process to balance the training efficiency, accuracy and possible over- fitting risk.

Usually increase number of layer and neuron is used to give good precision in network. Relation between layer and neuron is important, so if the number of layer is low, neural network can't reflect non liner mapping for input and output. On the other hand, if they are more than required, the network produces nonlinear mapping with unsatisfactory performance.

Here, the neural network with 1-3 layers (hidden layer), 1-14 neurons is studied and results error are provided in **Table (2)**. It 'is clear that 3 layers with 4 neuron ($T_w)_i$, T_s , $m^\bullet{}_w$ and $h_1 - h_2$) in input layer , 14 neurons in hidden layers ,and 1 neuron in output layer have less error approach to zero.

Table (2) results of neural networks

No. of layer / No. Of neuron	1	2	3
1	3.61*10^-2	2.8*10^-4	2.16*10^-8
2	5.1*10^-3	4.14*10^-5	5.15*10^-9
4	5.9*10^-3	4.21*10^-7	3.38*10^-11
6	4.3*10^-4	3.14*10^-8	2.5*10^-12
8	4.21*10^-4	3.05*10^-10	5.18*10^-13
10	3*10^-5	2.99*10^-12	6.28*10^-14
12	2.19*10^-6	3.82*10^-14	7.16*10^-15
14	3.03*10^-7	2.33*10^-16	9.936*10^-17

The goal of training is to find an optimum answer of network. **Fig.(5)** show the training graph of developed network with 3 layers and 14 neurons. The graph resulted show a very good performance (small error between predicted and desired value) after 349 attempts. **Fig.(6)** illustrate the good agreement between NN predictions and the data used for training.

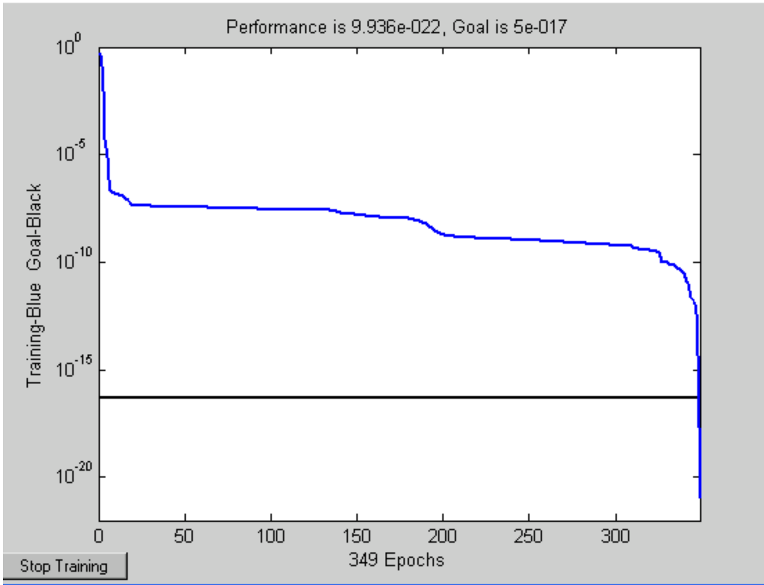

Fig.(5) best training

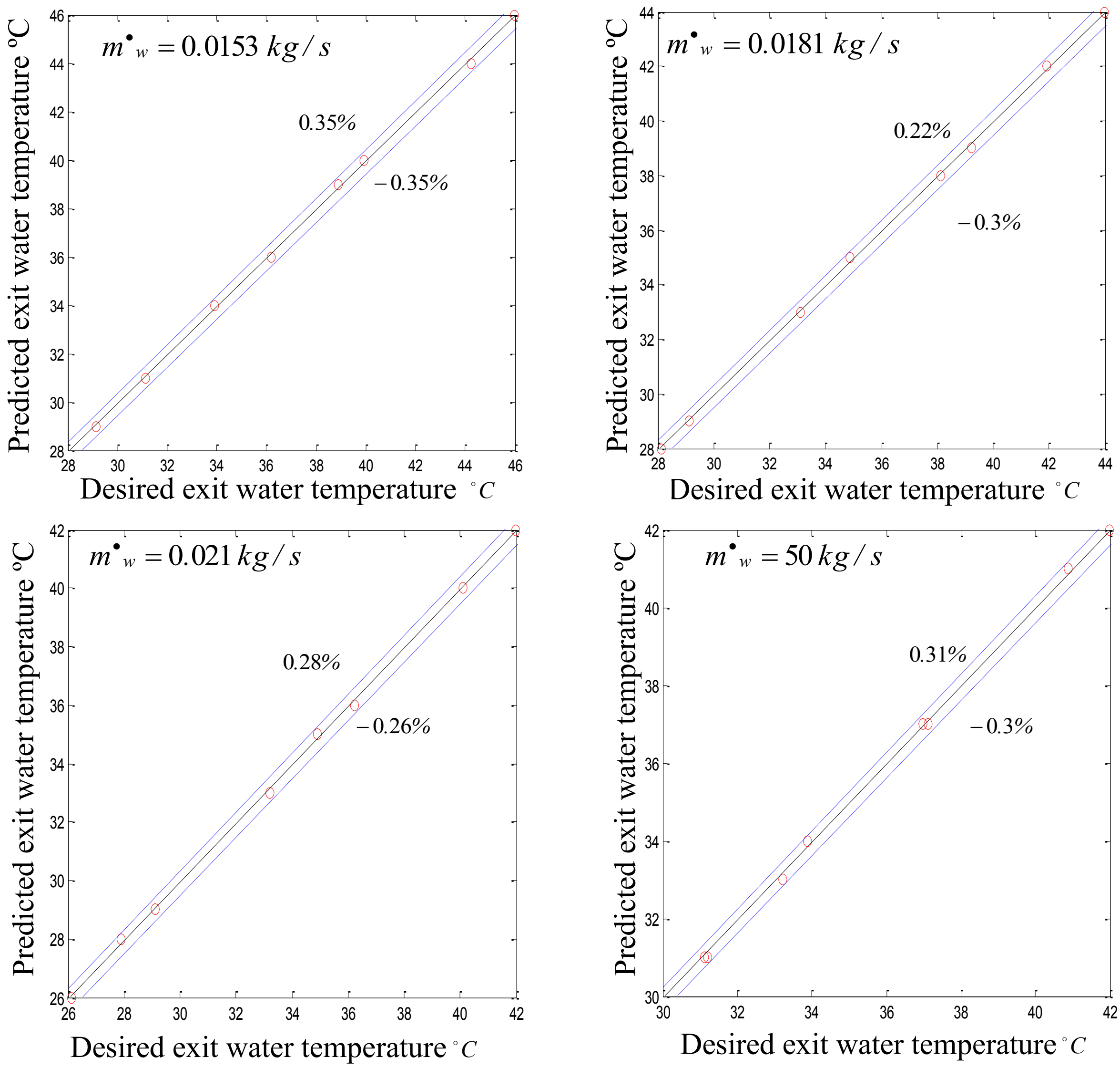

Fig.(6) Desired and predicated output data for training neural network

NEURAL NETWORK TESTING

A good performance results was observed as shown in **Fig.(6)** when NN training based on variation data shown in **Table (1)**. This study used another experimental and practical data shown in **Table (3)** to test NN and the results shown in **Fig (7)** illustrate the good agreement.

Table (3) Data value of input and output parameters

	$T_w)_{in}$ $^{\circ}C$	$m^{\bullet}{}_w$ kg/s	T_s $^{\circ}C$	$m^{\bullet}{}_s$ kg/s	$h_1 - h_2$ kJ/kg	$T_w)_e$ $^{\circ}C$
Experimental data	25	0.0153	78	3.7*10^-4	2081.5	35
	25	0.0153	98	5.7*10^-4	2035.4	42
	25	0.0153	112	7*10^-4	2002.2	49
	25	0.0181	78	4.5*10^-4	2081.5	34
	25	0.0181	98	6.7*10^-4	2035.4	41
	25	0.0181	112	7.8*10^-4	2002.2	47
	25	0.021	78	5.5*10^-4	2081.5	32
	25	0.021	98	7.7*10^-4	2035.4	38
	25	0.021	112	9.7*10^-4	2002.2	45
Practical data	28	50	93	.0087	2060.1	40
	29	50	86	.0079	2098.5	37.5
	30	50	78	.00692	2113.9	32
	30	50	80	.00705	2108.9	34

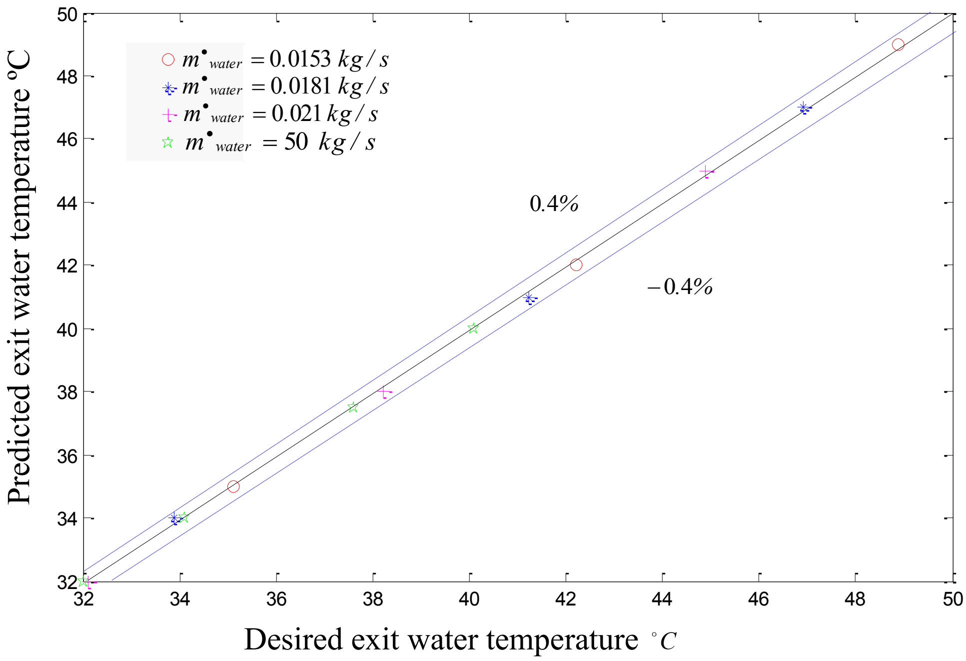

Fig.(7) Desired and predicated output data for testing neural network

CONDENSER EES MODELING

EES automatically identifies and groups equations that must be solved simultaneously. This feature simplifies the process for the user and ensures that the solver will always operate at optimum efficiency.EES provides many built-in mathematical and thermophysical property functions useful for engineering calculations. The large data bank of thermodynamic and transport properties built into EES is helpful in solving problems in many engineering applications.[Sanford Klein , (2008)]

After calculation $T_w)_e$ from NN modeling. Enter the functional relationships with lookup tables, with internal functions written with EES, to calculate the properties $\mu_w, cp_w, k_w, \Pr_w$ based on $T_w)_{ave.}$. After this EES transfer to externally compiled functions written in Matlab.

$$T_w)_{ave.} = \frac{T_w)_i + T_w)_e}{2} \tag{4}$$

CONDENER MATLAB MODELING

To develop an intermediate complexity model, the following assumptions are made: [Kwang kook Jeong(2010)]
*The heat transfer to the cooling water is the sum of sensible and latent heat of steam condensate
* The thermal resistance due to the condensate film is negligible since it contributes only about 1-3% of the total thermal resistance.
* The heat transfer area based on the tube outer diameter.
* Flow in pipe is turbulent.[Yunus A(2002)]
Heat balance equation can be written as below.

$$m^{\bullet}{}_w * cp_w * \Delta T_{average} = h_w * A * \frac{\Delta T)_e - \Delta T)_i}{ln \frac{\Delta T)_e}{\Delta T)_i}} = m^{\bullet}{}_s .(h_1 - h_2) \tag{5}$$

The Nusselt number relations used in several references are fairly simple, but they may give errors as large as 25 percent. This error can be reduced considerably to less than 10 percent by using more complex but accurate relations such as below. [Yunus A(2002)]

$$Nu = \frac{(f/8)(\text{Re} - 1000)\Pr_w}{1 + 12.7(f/8)^{0.5}(\Pr_w{}^{2/3} - 1)} \tag{6}$$

For smooth tubes, the friction factor (f) can be determined from the equation shown below: [Yunus A(2002)]

$$f = (0.79 \ln \text{Re} - 1.64)^{-2} \tag{7}$$

From defined Nusselt Number we can write convection heat transfer coefficient as below:

$$h_w = \frac{Nu * k_w}{D} \tag{8}$$

MATLAB TESTING

Matlab programming was built in this study to find h_w by use eqs.(6,7,8) and $m^{\bullet}_s$ by use eq.(5) based on NN modeling results . Comparing the $m^{\bullet}_s$ resulted from modeling with experimental and practical data for each value of water flow rate, the results shown in **Fig.(8)** show a very good agreement (-3% to 3%). The comparisons prove to accuracy of NN and Matlab modeling of steam condenser.

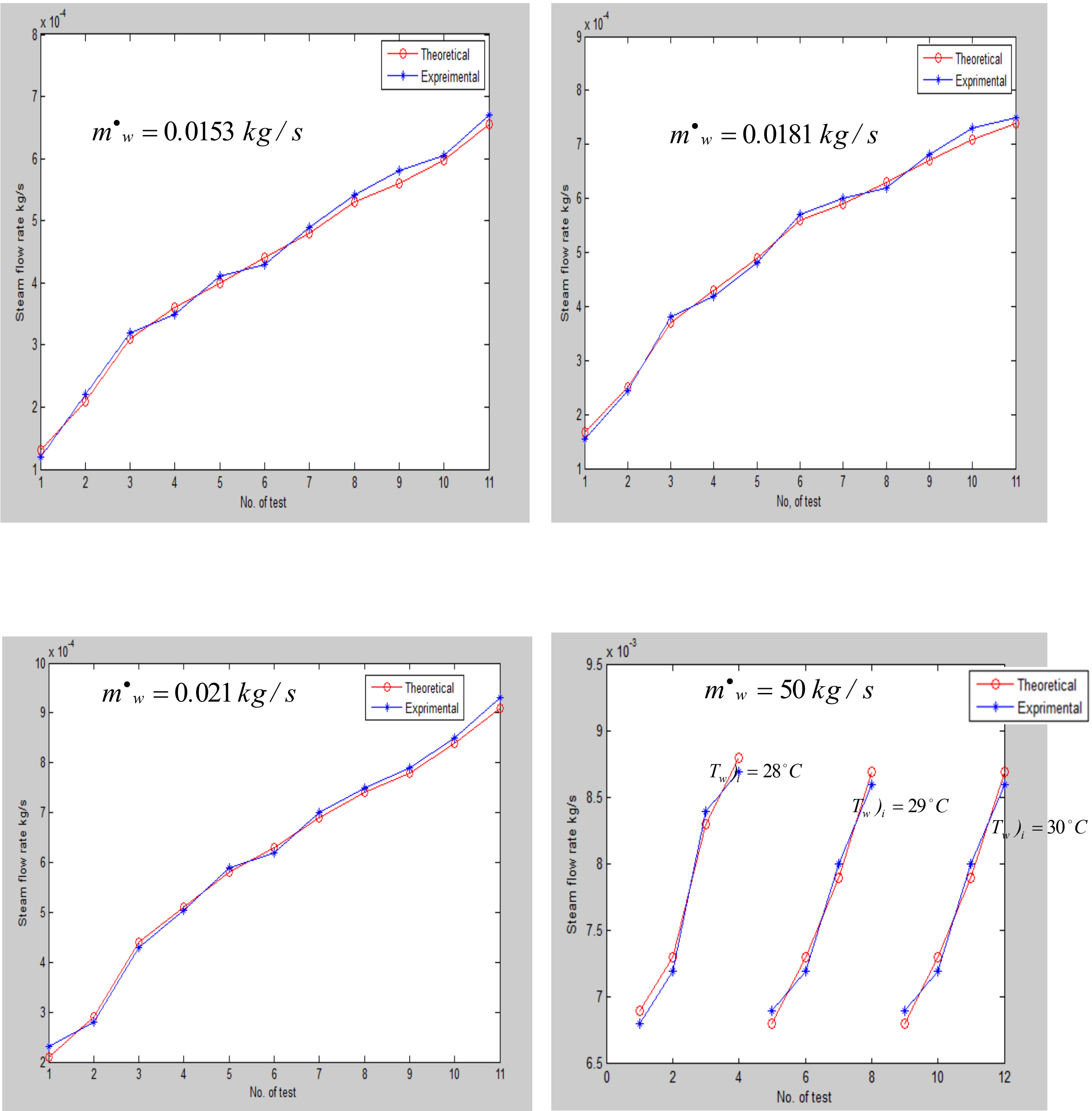

Fig.(8) Comparison of predicated by Matlab modeling and experimental work

CONCILUSION

This paper presents (ANN) modeling approach to the steam condenser performance. Experimental were carried out to validate the ANN model .EES use to find steam enthalpy difference and water properties. After the construction of the network by use of back propagation algorithm, the training and testing of the results are carried out and the output of network is created.

After study 1-3 layers with 1-14 neuron, three layers with 14 neurons has the best answer and used in this paper.

The trained NN model can approach desired values with height accuracy. Compared with experiment results the exit water temperature drops predicted by the trained NN is $\pm 0.35\%$ of training data and $\pm 0.4\%$ of testing data. All deviation falls into $\pm 1\%$.

The research shows change of exit water temperature with change of input parameters. The results were used in Matlab programming built in this paper to find steam flow rate and convection heat transfer coefficient of water. Comparison between Matlab modeling and experimental results show a very good agreement (-3% to 3%).

With artificial NN exit water temperature can be found without need to condenser analysis. Matlab modeling can be use to find any parameters needed to study the condenser performance by adding necessary equation.

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MODEL VARIABLES (NOMENCLTURE)

Variable	Description
A	Surface area (m^2)
b	Bias of neuron
cp_w	Specific heat of water $(kJ/kg.^\circ C)$
f	Friction factor
g	Transfer function
h	output of the hidden layer
h_w	Convection heat transfer coefficient of water $(W/m^2.^\circ C)$
h_1	Inlet steam Enthalpy (kJ/kg)
h_2	Exit steam Enthalpy (kJ/kg)
I	Neuron number of the input layers
J	Neuron number of the hidden layers
k	Neuron number of the output layer
k_w	Thermal conductivity of water $(W/m.^\circ C)$
$m^\bullet$	Mass flow rate (kg/s)

NU	Nusselt Number
Pr_w	Prandtl number
Re	Renold number
t	Time (s)
T	Temperature $(^{\circ}C)$
T_w	Water temperature $(^{\circ}C)$
T_{wall}	Wall temperature $(^{\circ}C)$
u	Connection weight between input and middle layers
V_w	Volume of condensate (m^3)
w	Connection weight between middle and output layers
x	Input of neural network
y	output of neural network

Greek symbols

Variable	Description
μ_w	Dynamic viscosity of water (kg.m/s)
ρ_w	Density of water (kg/m^3)
Δ	difference

Subscripts

Variable	Description
ave.	Average
e	exit
i	inlet
s	steam
w	water