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EFFECT OF SUCTION PRESSURE AND OTHER VARIABLES ON HEAT ABSORPTION AT EVAPORATOR OF SIMPLE VAPOUR COMPRESSION REFRIGERATION SYSTEM USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT

In this study, artificial neural networks (ANNs) with network type feed- forward back propagation used for performance analysis of single-stage vapor compression refrigeration system using refrigerant R134a, which does not damage the ozone layer. An experimental investigation was done to find the role of suction pressure and other variables like inlet temperature to the compressor, delivery pressure, outlet temperature to the compressor, to the heat absorbed at evaporator per kg of refrigerant. Experimentation has been performed under transient as well as steady condition as compressor speed changes due to the fluctuation of voltage and rate of cooling at condenser also varies due to day to day changes in environmental condition. Due to transient condition the conventional analytical approach involves more complicated analytical equation and theoretical assumptions , whereas experimental studies are more expensive and time-consuming , so in this paper an attempt has been made to train (ANNs) with network type feed- forward back prop with suction pressure, temperature inlet to compressor, delivery pressure, temperature outlet to compressor input parameter and heat absorbed at evaporator as output parameter, and network has been successfully trained to predict output, network resembles close to each other withR^2**=0.9999988,** RMSE = **0.201kJ/kg**, COV=**0.1089%**&ANNs with Network type -feed-forward back propagation, training function- TRAINLM, adaptation learning function – LEARNGDM, can be successfully applied in the field of performance analysis of simple vapour compression refrigeration system.

1. INTRODUCTION

Refrigeration is the process of removing heat from a lower temperature zone and discarding it to a higher temperature zone. Heat naturally flows from hot to cold. Refrigeration is, therefore, the opposite of the natural flow of heat. It has many applications in daily life including chilling, freezing, and air-conditioning.

Modern refrigeration systems operate using a vapor compression cycle. This cycle takes advantage of the following five fundamental physical principles:

- The natural flow of heat is from a hot to a cold zone.
- In order to change the state of a substance from liquid to gas through boiling or evaporation, heat energy is required.
- In order to liquefy or condense a gas into a liquid, heat must be removed.
- As the pressure increases, the boiling point or condensing point generally increases.
- As the pressure reduces, the boiling point or condensing point generally decreases.

The temperature at which a liquid boils varies with the pressure. As the pressure falls in a system, so does the boiling point. For example, at standard atmospheric pressure (1.013 bars), water boils at 100°C. If the pressure falls to 0.2 atmospheres, the boiling point of water will be approximately 60°C. For a given substance, the boiling point is limited by the critical temperature at the upper end, above which it cannot exist as a liquid, and by the triple point at the lower end, which is at the freezing temperature. At any point between these two limits, if the liquid is at a pressure below its boiling pressure, it will remain as liquid and will be sub-cooled below the saturation condition. When the temperature is higher than saturation, the substance will be a gas and superheated. If both liquids as well as vapor are at rest in the same enclosure, and no other volatile substance is present, the condition must lie on the saturation line. In order to operate the refrigerant at a lower temperature than the product or process that needs to be cooled, the refrigerant's boiling temperature is controlled by varying the pressure. Furthermost commercial refrigerants are selected to operate at a specified temperature and pressure bands. Typically they have boiling temperatures in the -10°C to -45°C range and saturation pressures in the 1 to 5-atmosphere range.

A simple vapor compression refrigeration system with simplest expansion device as a capillary tube is used in several of small or medium refrigeration applications like a domestic refrigerator, deep freezer, water cooler, room air conditioners, cooling cabinets and much more all over the world. The small scale refrigeration machines are produced in large numbers and have a substantial contribution to energy consumption. Energy conservation in refrigeration, air conditioning, and heat pump systems has a huge potential. The working conditions for a refrigerating system in steady operation depend on several factors: boundary conditions (ambient temperature, cold room temperature, compressor speed, and control settings), refrigerant type and refrigerant charge, system architecture and size, thermal loads. The performance is affected by matching of all these factors. Theoretical performance of the system deteriorates in real conditions due to internal and external irreversibility in the system, whereas experimental studies are more expensive and time-consuming.

Artificial intelligence systems in refrigeration and air conditioning field are increasing gradually to solve the complicated problems. Artificial intelligence systems include areas such as expert systems, ANN, genetic algorithms, fuzzy logic and various hybrid systems, which combine two or more techniques [1,2]. The main advantages of ANN compared to other expert systems are its speed, simplicity, and ability to model a multi-variable problem to solve complex relationships between the variables and can extract the nonlinear relationships by means of training data [1,2]. ANN overcomes the limitations of conventional approaches by extracting the required information using training data, which has not required any specific analytical equations. ANN model can forecast the desired output of the system using limited training data.Ding [3] summarized the various simulation techniques for modeling and performance prediction of vapor compression refrigeration systems. ANFIS is an MLFFN consisting of nodes and directional links, that combines the learning capabilities of a neural network and reasoning capabilities of fuzzy logic [4].M. Mohanrajaet al.[5] has reviewed the performance of refrigeration, air conditioning and heat pump (RACHP) systems are analyzed in terms of the first law (energy analysis) and second law (exergy analysis) of thermodynamics using conventional approaches (analytical and experimental methods).Practically a refrigeration system has to work under transient conditions. Steady or transient conditionANN can be successfully applied for study in the design and balancing of components of a "vapor compression refrigeration system" for optimization of its performance.The values calculated from the ANN formulations were found to be in good agreement with the actual values. This method will help the engineer to obtain a very accurate and fast forecast of system performance.

2. REVIEW OF LITERATURE

A summary of ANN applications for vapor compression systems is listed in Table 1.

Table 1 -Applications of ANN for vapor compression systems

Authors [references]	Network architectures	Year	Equipment
Hosoz and Ertunc [6]	MLFFN	2006	Cascade refrigeration system
Yilmaz and Atik[7]	MLFFN	2007	Mechanical cooling system

Performance of refrigeration systems

Hosoz and Ertunc[6] studied the suitability of using MLFFN-Multi-layer feed forward network to predict the performance of a cascade refrigeration system. The inputs to the network are water mass flow rate and evaporator load, while the outputs are evaporating temperature, compressor power in the lower circuit, COP for the lower circuit, compressor power in the higher circuit and overall COP for cascade refrigeration system. The network using Levenberg–Marguardt (LM) variant was optimized for a 2-4-5 (neurons in input-hidden–output layers) configuration. ANN predicted results were reported to be closer to experimental values having correlation coefficients of 0.996, 0.994, 0.97, 0.985, 0.953 for evaporating temperature, compressor power in lower circuit, COP for lower circuit, compressor power in higher circuit and overall COP of a cascade refrigeration system, respectively with corresponding mean relative errors of 0.2%, 3.6%, 3.6%, 3.9% and6%.

A Multi-layer feed forward network with one neural in input layer (condenser water flow rate) and four neurons in output layer (input power in cooling and heating mode, COP of the system in both cooling and heating modes) was developed for predicting the performance of a variable cooling capacity mechanical cooling system [7]. It was reported that ANN (using 1-6-4 configuration) predicted results were closer to experimental results with average relative errors of 1.37%, 4.44%, 2.05%, 1.95% for input power, heating power, heating COP, and for coolingCOP, respectively. The R2 values for predicting the input power, heating power, heating COP and cooling COP are 0.992, 0.972, 0.988 and 0.990, respectively.

3. ARTIFICIAL NEURAL NETWORK: AN OVERVIEW

Artificial neural networks (ANNs) are a computational model used in computer science and other research disciplines, which is based on a large collection of simple neural units (artificial neurons), loosely analogous to the observed behavior of a biological brain's axons. Each neural unit is connected with many others, and links can enhance or inhibit the activation state of adjoining neural units. Each individual neural unit computes using summation function. There may be a beginning function or limiting function on each connection and on the unit itself, such that the signal must surpass the limit before propagating to other neurons. These systems are self-learning and trained, rather than explicitly programmed, and excel in areas where the solution or feature detection is difficult to express in a traditional computer program.

Artificial neural networks (ANN) try to mirror the brain functions in a computerized way by restoring the learning mechanisms the basis of human behavior. ANN can operate like a black box model, which requires no detailed information about the system or equipment. ANN can learn the relationship between input and output based on the training data. The structure of an artificial neuron is illustrated in Fig.1 and Fig 2. ANN is a nonlinear informational processing device, which is built from interconnected elementary processing devices called neurons. Each input is multiplied by a connection weight. The product and biases are summed and transformed through a transfer function (consists of algebraic equations) to generate a final output. The process of combining the signals and generating the output of each connection is represented as weight. Most commonly used network architectures in the field of RACHP are

(i) Multi-layer feed forward,

(ii) Radial biased function network,

(iii) Generalized regression neural networks and

(iv) Adaptive neuro-fuzzy system

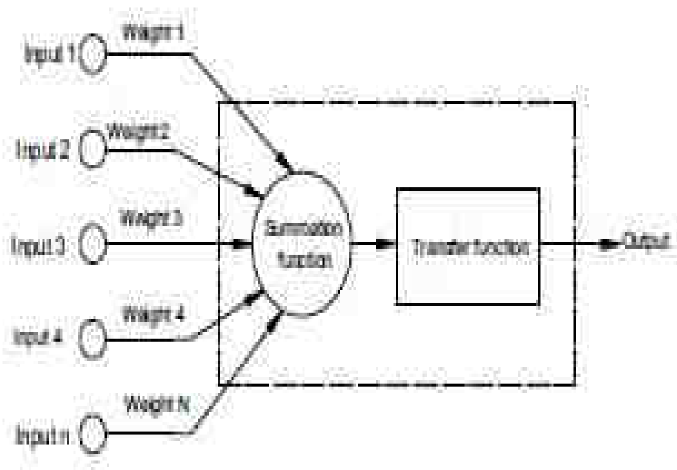

Fig. 1. structure of an artificial neuron [5]

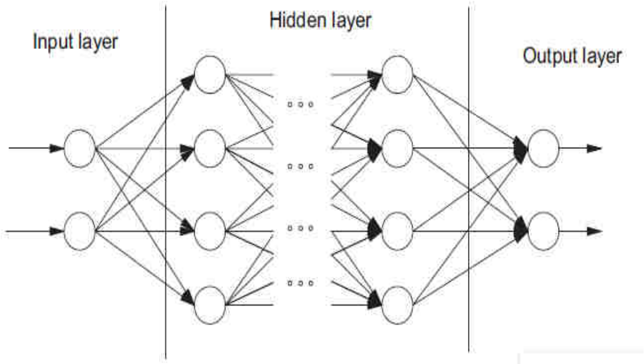

Fig 2 Layers of Network [5]

4. METHODOLOGY

1. Details of the mechanical model (Experimental setup) of refrigeration system Fig 3.

Fig.3 Experimental setup

By above mechanical model, we can collect following experimental data

- p_1Suction pressure.
- p_2Delivery pressure.
- Mass flow rate of refrigerant.
- Can expand refrigerant from the different capillary length.
- Can use with/without an internal heat exchanger.
- Current (Amp).
- Voltage (Volt).
- T_1 Temperature at the inlet to the compressor.
- T_2 Temperature at the outlet of the compressor.
- T_3 Temperature at the outlet to the condenser.
- T_4 Temperature outlet of the expansion valve.

- T_5 Temperature inlet to a heat exchanger (suction line).
- T_6 Temperature outlet to a heat exchanger(suction line).
- T_7 Temperatureinlet to a heat exchanger (delivery line).
- T_8Temperatureoutlet to a heat exchanger(delivery line).
- T_9 Temperature of brine inlet to the evaporator.
- T_{10}Temperatureof brine outlet to the evaporator.
- T_{11}Temperature of brine.

And with suitable modification, other necessary data can be collected. From experimental data performance parameter will be calculated using peace software [8] and then ANN will be applied for further analysis and optimization of the system.

5. TRAINING Of ANN

Experimental data has been collected for refrigerant R134a and for different suction pressure p_1 in kPa (kilo Pascal) value of suction temperature i.e temperature inlet to compressor T_1in ^{0}C (degree centigrade), temperature outlet to compressor T_2in ^{0}C (degree centigrade) and delivery pressure p_2 in kPa (kilo Pascal) is recorded and with the help of other parameter heat absorbed per kg of refrigerant is calculated .enthalpy value are calculated using peace software[8] out of huge experimental data few steady state data are selected for different suction pressure out of which 65 data is used to train network and after training it is tested with the 05 test data which are excluded while training the ANN network1.The performance of the ANN is measured by the absolute fraction of variation (R^2), Root mean square error (RMS) and coefficient of variance (COV), which can be calculated by using following equations (1),(2),(3) recommended by [5].

The fraction of absolute variance is given by

$$\mathbf{R^2 = 1 - \frac{\sum_{m=1}^{n}(y_{pre,m} - t_{mea,m})^2}{\sum_{m=1}^{n}(t_{mea,m})^2}} \quad (1)$$

The root mean square value is calculated by

$$\text{RMS}=\sqrt{\frac{\sum_{m=1}^{n}(y_{pre,m} - t_{mea,m})^2}{n}} \quad (2)$$

Coefficient of variance is calculated by the following equation

$$\mathbf{COV = \frac{RMS}{\sum_{m=1}^{n}(t_{mea,avg})} \times 100} \quad (3)$$

Here, n is the number of data patterns in the independent data set, $Y_{pre,m}$ indicates the values predicted by ANN, $t_{ea,}$ is the measured value of one data point m and $t_{ime,\ Avg}$ is the mean value of all measured data points. Here in this paper R^2, RMSE, COV is calculated for data used to test the network.

Training the artificial neural network is done MATLAB software using neural network toolbox.Input to the network are suction pressure p_1 in kPa (kilo Pascal), suction temperature i.e temperature inlet to compressor T_1 in ^{0}C (degree centigrade), delivery pressure $p_2$in kPa (kilo Pascal) and temperature outlet to compressor T_2 in ^{0}C(degree centigrade) .output parameter is hear absorbed kJ (kilo Jule)per kg of refrigerant65set of data is used to train network.For this new worksheet is opened rename it as input and input data is saved.Similarly, another worksheet named target is opened and experimental output data is saved as a target. Out of 05set of experimental data used to test the network, the input value is saved in the worksheet named as a sample as shown in fig 4.Predicted output of network has been saved as network_1outputsample.

In command prompt typed into land after pressing enter key followed new window appeared and we imported input sheet from MATLAB as input data sample sheet as input data and target sheet as target data then closed the window as shown in fig 5.

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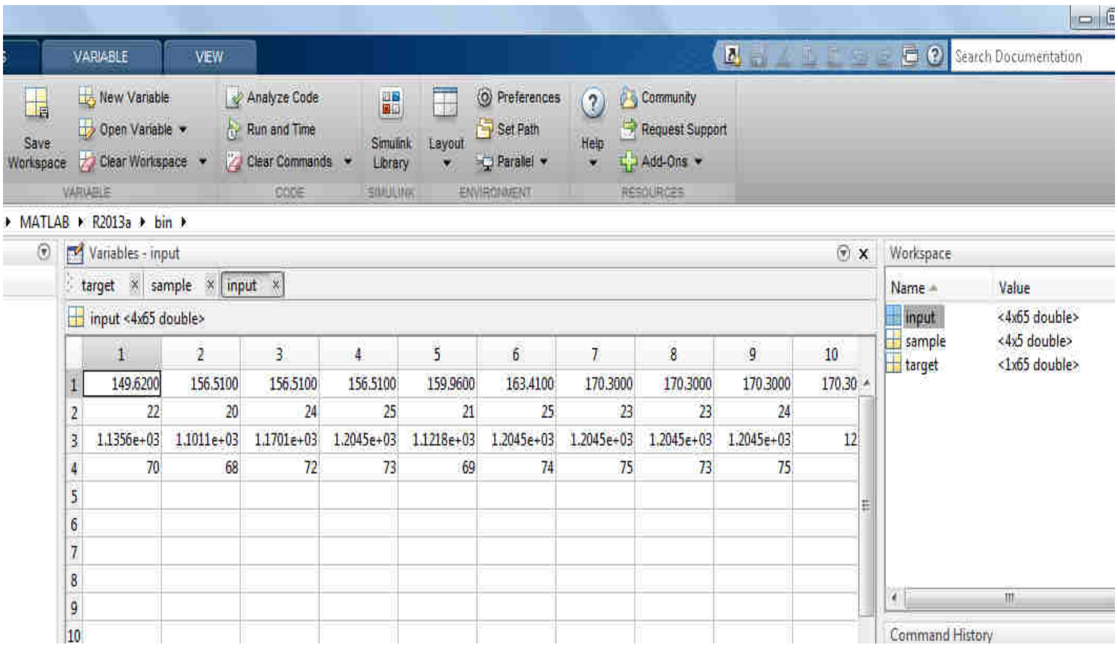

Fig 4 Spreadsheet of MATLAB

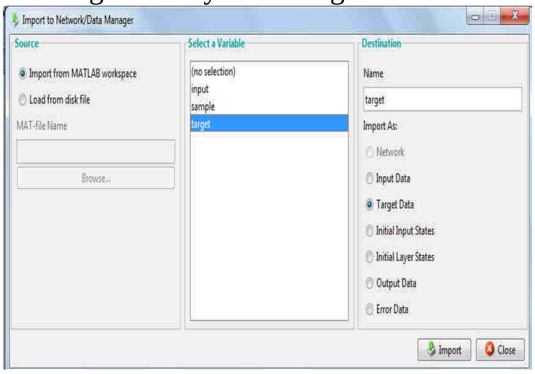

Fig 5 MATLAB Importing of data.

Then generated new network by pressing new tab and renamed it as network_1 as output parameter for this network is heat absorbed in evaporator here and after so many trail finally selected Network property as shown in fig 6 as network type –feed forward back propagation ,input data as input, target data as target ,training function as TRAINLM,adaptation learning function as LEARNGDM,performance function as MES number of layer 1, no of neuron as 8 ,transfer function LOGSIG,and viewed network shown in fig 7.

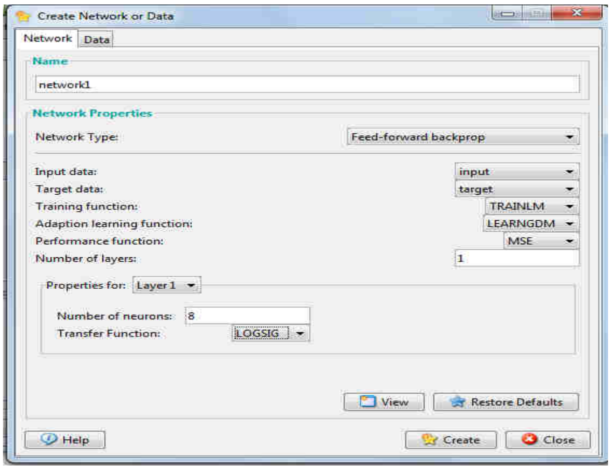

Fig 6 screen shot of MATLAB showing network property.

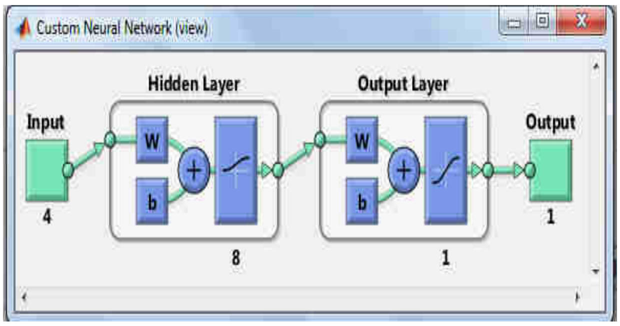

Fig 7 screen shot of MATLAB showing view network while training ANN.

Custom neural network window opened and it shows trend of input and output data as the trend is matched we created the network called network1 and added to network/data manager. Created network is selected and followed in neural network/data manager window and shown in fig 8.Network1proceed by selecting train tab to set training information, and under training data, the input is selected as input and target as a target as shown in fig 9.

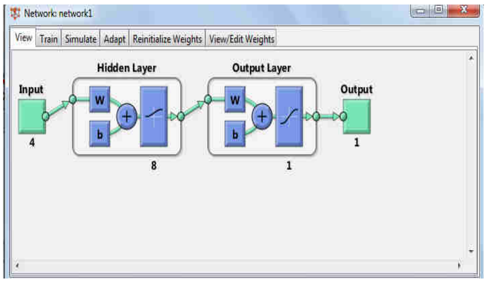

Fig 8 Network by ANN

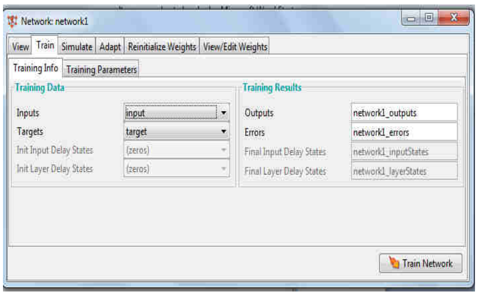

Fig 9 Training data by ANN

Under training parameter after so many trails finally selected as shown in fig 10 which gives training of network in fig 11and regression analysis as shown fig 12

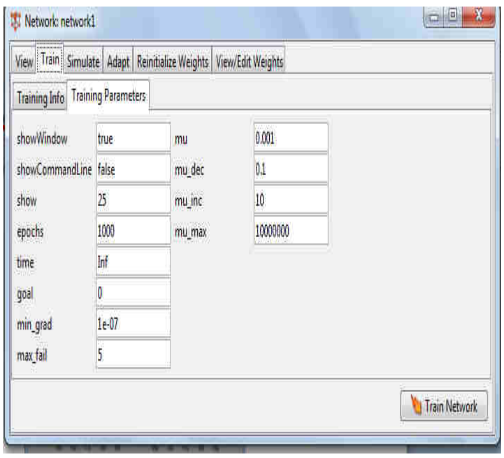

Fig 10 Training parameter

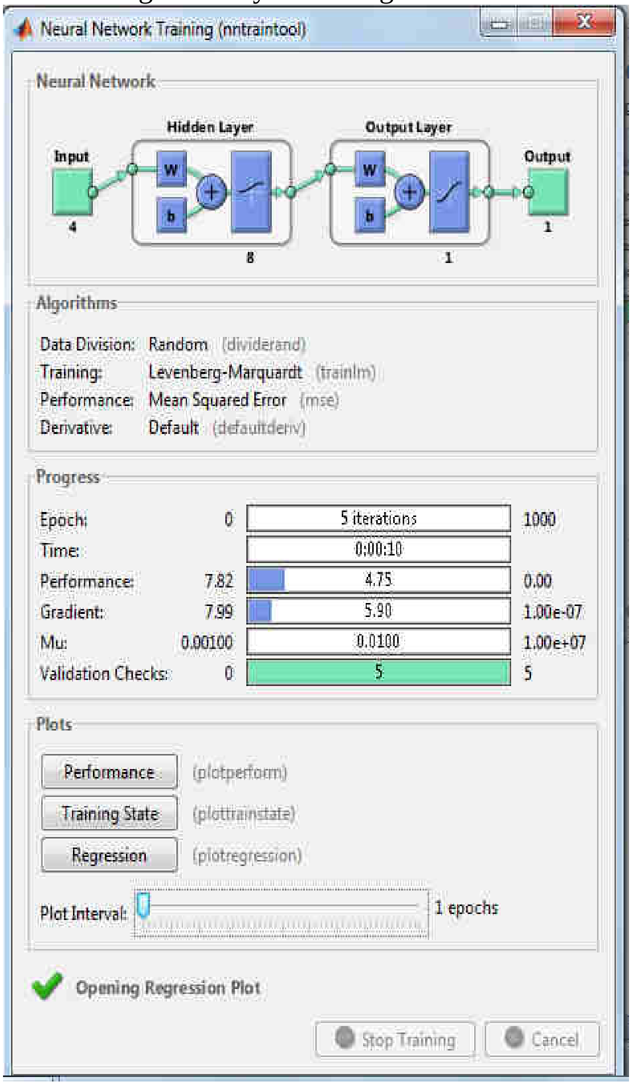

Fig 11 Network Training

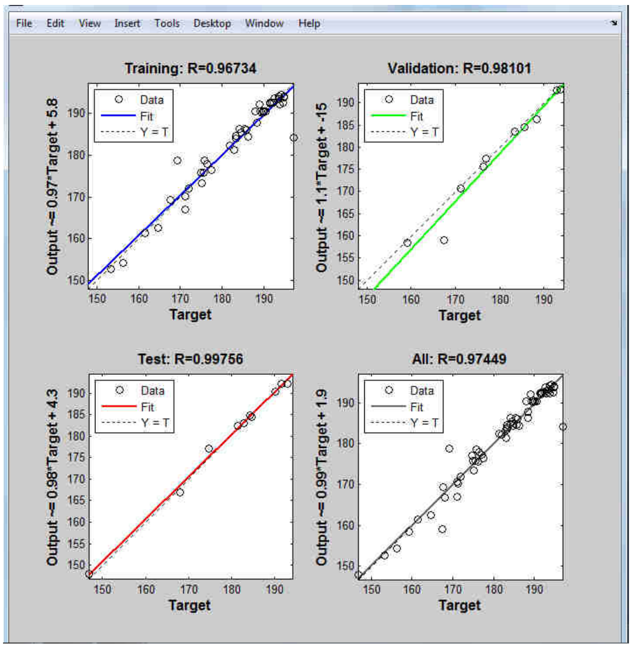

Fig 12 Regression analysis

Then trained network is simulated as shown in fig 13 with simulation data input as sample and output as network1_outputsample then result in i.e output /predicted data is stored in network /data manager as shown in fig 14. Fig 15show network1_outputsample value which is exported to worksheet and compared with an experimental output which resembles each other as shown in table 2.

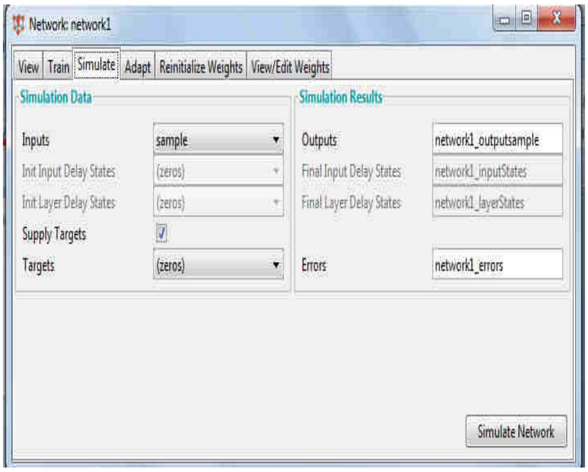

Fig 13 Simulation training on ANN

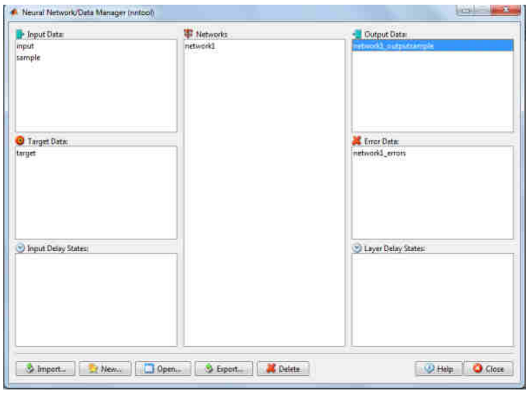

Fig 14 Outputsample on ANN

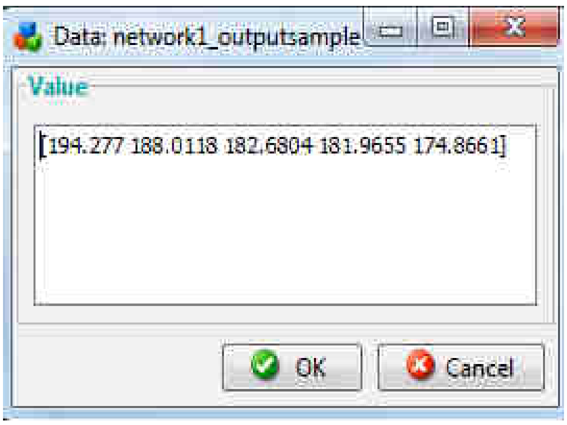

Fig 15 Predicted Result

Table 2 Response Data by ANN

	DATA TO TEST TRAINED NETWORK									
	INPUT				**OUT-PUT**	**Ann output**				
S.NO	**p_1 kPa (kilo Pascal)**	**T_1 (°C) -Inlet to Compressor**	**p_2 kPa (kilo Pascal)**	**T_2 (°C) outlet to compressor**	**h_1-h_4 (heat absorbed) kJ/kg**	**h_1-h_4 (heat absorbed) kJ/kg**	**Measured output –predicted output**	**R^2**	**RMSE**	**COV**
1.	156.51	20	1135.57	70	194.30	194.28	0.02	0.9999988	0.201 kJ/kg	0.1089 %
2.	177.20	28	1273.47	77	188.13	188.01	0.12			
3.	204.78	26	1349.31	84	183.00	182.68	0.32			
4.	232.35	24	1342.42	75	182.10	181.97	0.13			
5.	266.83	31	1514.79	80	174.61	174.87	-0.26			

6. RESULT:

Result is shown in Table2 as experimental output and Output parameter predicted from network resembles close to each other withR^2= **0.9999988,** RMSE = **0.201kJ/kg**, COV= **0.1089%**& can conclude ANNs with Network type -feed- forward back prop, training function- TRAINLM, adaptation learning function –LEARNGDM, can be successfully applied in the field of performance analysis of simple vapour compression refrigeration system. Actual performance of the network is evaluated using test data since these were not used for training and table 2 shows that $R^2$is very close to 1 for test data and RMS error is very small**0.201kJ/kg.** It is clear that ANN (network1) gives a very accurate representation of statistical data over the full range of operating condition and indicates that network1 may predict heat absorbed at evaporator for given input very accurately. Evaluation of these result suggests that heat absorbed are predicted within acceptable error (they have a small error).

7. CONCLUSION

The ANN model developed in this study has been made to analyze performance analysis of vapor compression refrigeration system to find out the role of the input parameter to the output parameter. Input parameter is suction pressure, inlet temperature to the compressor, delivery pressure and outlet temperature to the compressor which gives the effect of the output parameter heat absorbed at evaporator per kg of refrigerant.

So in this paper an attempt has been made to train (ANNs) with network type feed-forward back propagation with suction pressure, inlet temperature to compressor, delivery pressure and temperature outlet to the compressor as input parameter and heat absorbed at evaporator as an output parameter.ANN has been successfully trained as experimental output and Output parameter predicted from network1 resembles close to each other with $\mathbf{R^2=0.9999988}$**,** **RMSE**=**0.201kJ/kg**, **COV**=**0.1089%**. This way can conclude ANNs with Network type feed-forward back prop, training function-TRAINLM, adaptation learning function–LEARNGDM, No of a neuron as 8 and transfer function LOGSIG as network1, can be successfully applied in the field of performance analysis of simple vapor compression refrigeration system.

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