EXPERIMENTAL INVESTIGATION AND NEURAL NETWORK PREDICTION OF THE PERFORMANCE OF A MIXED MODE SOLAR DRYER FOR COCONUT

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ABSTRACT

The shelf life of agricultural food products may be enhanced by reducing their moisture contents, by means of a drying process. The present work aims at drying coconut yielding copra. This paper presents the design, analysis of a mixed mode solar dryer for food preservation and energy saving. In the mixed mode solar dryer, the drying cabinet absorbs solar energy directly through the transparent roof and during the same time the heated air from a solar collector is passed through a tray. Various measurements like solar radiation, mass flow rate, and moisture content and relative humidity have been observed. From previous literature four different models (Newton, Page, Henderson & Pabis and Wang & Singh) are chosen for testing the performance of mixed mode solar dryer. Selected models are evaluated by using E_{MD}, E_{RMS}, R^2 and $\chi2$ and it is concluded that page model is more suitable for the fabricated cabinet solar dryer at air flow rate 0.009Kg/s based on the experimental analysis. The direct radiant solar energy and a convective hot air stream dry the products, resulting in longer life for the products which are also free from impurities. The experimental results are utilized to evolve a suitable mathematical model, among the different models that are chosen, for copra. This will help in designing suitable dryers for actual users. Also, a multilayer neural network approach has been used to predict the performance of a mixed mode solar dryer for drying coconut. The simulation of neural network is based on the feed forward back propagation algorithm.

Indexing terms/Keywords

Solar energy, mathematical model, drying capacity, copra, artificial neural networks

Academic Discipline and Sub-Disciplines

Mechanical engineering; renewable energy

SUBJECT CLASSIFICATION

Solar energy, heat transfer

TYPE (METHOD/APPROACH)

Experimental investigation

INTRODUCTION

Composition and properties of various food commodities vary according to their nature and group they belong [1]. The experimental data is used to fit a suitable form of characteristic curve using six models [2]. Society for Energy Environment and Development (SEED) has fabricated a solar cabinet dryer with forced circulation which is used for removal of moisture resulting in different products, with good market values, from locally grown fruits, vegetables, leafy greens and forest produce [3]. The application of a cross flow hot air cabinet dryer for carrot slices is reported in [4]. Generally, food products, especially fruits and vegetables require hot air in the temperature range of 45–60°C for safe drying. In order to maintain the quality of the product, the temperature and humidity of the air have to be controlled [5].

Many studies have been reported on solar drying of fruits and vegetables [6-10]. During the process, the grain temperature increases with the increase in length, breadth and tilt angle of the dryer tunnel [11]. According to the annual energy outlook [12], total world marketed energy consumption would grow from 4.32 × 1020 joules in 2000 to 6.035 × 1020 joules in 2015 and 7.596 × 1020 joules in 2035. Utilizing solar energy is a promising means of energy conservation because of the large amount of energy requirement. India is blessed with good solar radiation, with a mean value in the range of 5–7 kwhm^{-2} and more than 275 sunny days in a year [13]. Thin-layer drying characteristics for the samples of pumpkin are derived using a hot-air dryer. The data obtained on drying the pumpkin fruits are used to fit experimental, general exponential, page, logarithmic, parabolic model and the statistical validity of models tested are determined by non-

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linear regression analysis [14]. They Khalil et al. [15] studied the performance of the dryer for two types of fruits and vegetables. In this work, a dryer is designed, fabricated and its performance is evaluated for Coconut. Mohanraj et al. [16] carried out their works on the performance prediction of a direct expansion solar assisted heat pump using artificial neural networks. Their results showed that LM with 10 neuron in the hidden layer was the most suitable algorithm with maximum correlation coefficient 0.999, minimum root mean square value and low coefficient of variance. Ming et al. [17] had presented their work on design and optimization of a solar air heater with offset strip fin absorber plate. The optimal design maximizes the convection heat transfer in the air flow pass and minimizes the heat loss of the heater. Ilhan and Mustafa [18] had studied on the modeling of a hazelnut dryer assisted heat pump by using artificial neural networks. Many studies have reported on the drying kinetics of agricultural products [19-21].

By training the experiment results with ANN, drying air velocities, moisture content of hazelnuts and total drying time were predicted for different air temperatures. Tayyeb et al. [22] had performed the optimization of a neural network topology using coupled response surface methodology and genetic algorithm for fluidized bed drying. This development could be used for determining the appropriate drying conditions of carrot cubes to reach the optimal energy efficiency in fluidized bed drying. Tayfun et al. [23] had carried out their work on the determination of freeze-drying behaviors of apples by artificial neural network. An artificial neural networks (ANN) has been developed for determination the prediction of drying behavior, such as MC, MR, DR, of apples in the freeze-drying process. Arijit et al. [24] had presented their works on enhanced extraction of rebaudioside-A: experimental, response surface optimization and prediction using artificial neural network. The experiments were performed in broad ranges of extraction time (15-75min), leaves to water ratio (2-5 % g/ml) and temperature (50- 80°C) to investigate their effects on Reb-A recovery. Ali et al. [25] had performed an energy and exergy investigation of microwave assisted thin-layer drying of pomegranate arils using artificial neural networks and response surface methodology. Energy utilization and energy utilization ratio increased with time, while exergy efficiency decreased with time.

Food fraud shows that this concept covers a wide variety of actions; food safety law is designed to protect consumers from substances and organisms not to fight food fraud [26]. Ramesh et al. [27] had found the experimental studies on the performance of a large-scale solar greenhouse dryer for banana in India. The parabolic dryer is used to drying the dried banana is obtained free from dirt and pests. Tripathy and Subodh [28] had analyses the neural network approach for food temperature prediction during solar drying. The important climatic variables namely; solar radiation intensity and ambient air temperature are considered as the input parameters for ANN modeling. Perez-Alonso et al. [29] had presented their work on the performance analysis and neural modeling of a greenhouse integrated photovoltaic system. In addition to this, an artificial neural network model has been developed to predict the electricity instantaneous production in the system. Rahman and Bala [30] had carried out their work on the modeling of jute production using artificial neural networks. The six input variables were represented by six neuron; Julian day, solar radiation, maximum temperature, minimum neuron, plant dry matter. Soares et al. [31] had investigated the utilization of artificial neural networks in the prediction of the bunches' weight in banana plants. The assessment of the correlations between variables allows the estimation of the changes in a character based on the changes in other characters. The aim of the study is to fit models for predicting surfaces using the response surface methodology and the artificial neural network for obtaining the maximum acceptability using desirability function methodology.

2 MATERIALS AND METHODS

2. 1. Experimental Setup

The experimental set-up consists of a centrifugal blower, solar energy collector, glass cover and drying chamber. A black coated plate with dimensions of 2000mm × 770mm× 1mm thick with insulation serves to absorb solar energy. The space below the absorber plate was filled with river sand for maintaining a steady temperature. The drying chamber has two layers for holding the commodities to be dried. The dimensions of the drying chamber are 488 mm× 595 mm. The materials required for the construction of a mixed mode solar dryer are easily available. Fig. 1 shows a sectional view of the set-up. The absorber plate material has high thermal conductivity, adequate tensile and compressive strength, and good corrosion resistance. The absorber plate is made of Aluminium, whose thermal conductivity is 204 W/m°C, and specific heat is 0.996 kJ/kg °C.
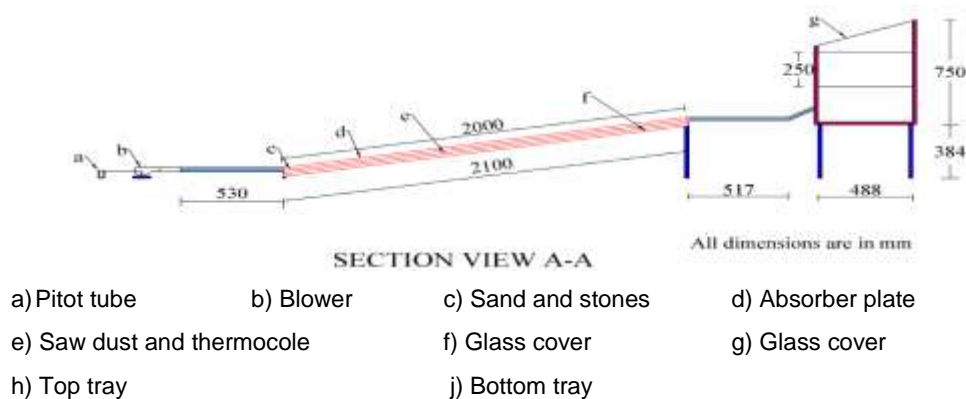

SECTION VIEW A-A

All dimensions are in mm

a) Pitot tube	b) Blower	c) Sand and stones	d) Absorber plate
e) Saw dust and thermocole		f) Glass cover	g) Glass cover
h) Top tray		j) Bottom tray	

Fig. 1. Sectional view of the drier

2. 2. Experimental Procedure

Experiments were carried out for the mass flow rate of 0.009 kg/s. Air was supplied to the system by a blower of 375 W powers. The air is heated by the collector which is passed through a tray, gaining additional solar energy through radiation directly through the transparent cover. Air velocity was measured using an anemometer. The hourly intensity of solar radiation on the collector was measured by solar energy radiation meter. The moisture content of the dried material was measured by weighing the selected specimen every hour. The experiments were done in the energy park of the National Engineering College at Kovilpatti (latitude of 9°11' North, longitude of 77°52'). The measuring instruments used in this work are as follows: Temperatures were measured using thermocouples of K type suitably calibrated, and connected to a digital multi-meter, the hourly intensity of the solar radiation on the collector was measured by the solar energy radiation meter and the velocity of air in the pipe was measured using a pitot tube. The relative humidity of air was derived from the measured values of wet and dry bulb temperatures using a psychometric chart. The kernels were separated from the shells at 40 % of moisture content and further dried without shells. The moisture content was measured using the equation (1).

The moisture content was found using the formula

$$m_{wb} = \frac{w_i - w_f}{w_i} \tag{1}$$

The thermal efficiency of the dryer is given by,

$$\eta = (m \times L)/(A \times I_S) \tag{2}$$

The moisture ratio MR is variable parameter due to changing climatic condition. The drying rate constants and coefficients of models were estimated using a nonlinear regression procedure. The experimental data obtained were fitted to the four well-known drying models given in Table 1. Thin-layer drying models given by various authors for drying curves are given below.

Table 1 Thin-layer drying mathematical models

Model name	Model	Reference
Newton	MR = exp(-k t)	Henderson [32]
Page	MR = exp(- k t^m)	Diamante and Munro [33]
Henderson and Pabis	MR = a exp(- k t)	Zhang and Litchfield [34]
Wang and Singh	MR = 1+ at +bt^2	Wang and Singh [35]

The statistical validity of the models were evaluated and compared by means of the coefficient of determination R^2, mean relative percent deviation EMD, root mean square error ERMS and reduced chi-square χ^2. These comparison criteria were calculated as follows Henderson [32].

$$E_{MD} = \frac{100}{N} \sum_{i=1}^{N} \frac{|M_{R,ex,i} - M_{R,pre,i}|}{M_{R,ex,i}} \tag{3}$$

$$E_{RMS} = \left[\frac{1}{N} \sum_{i=1}^{N} \left(M_{R,ex,i} - M_{R,pre,i} \right)^2 \right]^{1/2} \tag{4}$$

$$\chi^2 = \frac{\sum_{i=1}^{N} \left(M_{R,ex,1} - M_{R,pre,i} \right)^2}{N - Z} \tag{5}$$

$$R^2 = \frac{\sum_{i=1}^{N} \left(M_{R,exp,i} - M_{R,mean} \right)2 - \sum_{i=1}^{N} \left(M_{R,exp,i} - M_{R,pre,i} \right)^2}{\sum_{i=1}^{N} \left(M_{R,exp,i} - M_{R,mean} \right)^2} \tag{6}$$

Where $M_{R,ex,i}$ is the ith experimental dimensionless moisture ratio; $M_{R,pre,i}$ is the ith predicted dimensionless moisture ratio; N is the number of observations; and Z is the number of constants. R^2 is used as the primary comparison criterion for selecting the best model among the four models. Also, a model is considered better than another if it has a lower value of the EMD, ERMS and χ^2. During drying, water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated. The ease of this migration depends on the porosity of the substance and the surface area available. Other factors that may enhance drying are: high temperature, high air speed and low relative humidity. However, for drying the items like fish, meat, yam chips and plantain chips etc., excessive heating must be avoided, as it spoils their texture and quality.

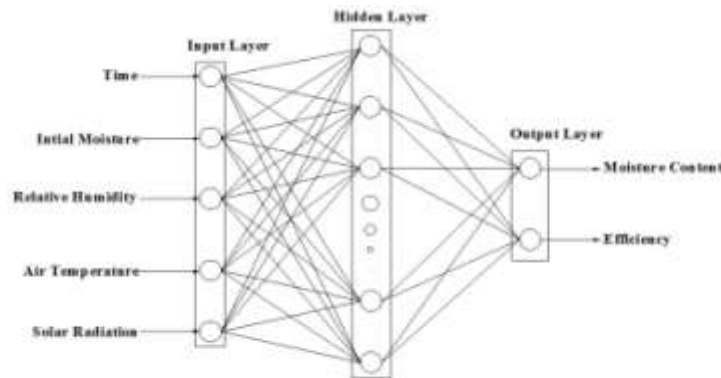# 3. Artificial Neural Networks (ANNs)

Fig. 2. Schematic illustration of artificial neural netwok

Fig. 2 shows the Schematic illustration of artificial neural network. In this work, different combinations of neutrons were tried. Finally a three layered network is selected for good performance which consists of an five input, hidden and two output layer as shown Fig. 2. MATLAB version 2010a is used for design, implementation and simulation of the networks with feed forward back propagation algorithm. Back propagation networks are multilayer networks with the hidden layer of sigmoid transfer function and linear layer output layer. The log-sigmoid or tan sigmoid transfer functions transfer functions may be used for hidden layers and should be differentiable thus, either is typically used .In this study,the tan-sigmoid transfer function, tansig and purelin transfer function are used for hidden layers and output layer, purelin is a linear transfer function which is used to calculate a layer's output from its net output. Each hidden and output layer is made of artificial neutrons, which are interconnected through adaptive weights. The Selected network training function is trainlm. Trainlm is a network training function that updates weight and bias values according to the Lavenberg – Marquardt algorithm.

3. 1. Training and Prediction

Among 66 experimental sets 46 data sets were alloted for training, 10 for validation and 10 for testing. In this network training function that updates weight and bias values according to the lavenberg marquardt algorithm,the performance is conformed through mean square error. The training,validation and testing have been continued until it reaches the minimum mean square error. The network structure 5-22-2 gives the minimum mean square error, So this structure is finally used for ANNs prediction system, making full use of the domain knowledge stored in the trained networks, which show the relationship of thermal property(moisture content, efficiency). The results predicted through the proposed ANNs model are compared with the experimental value Fig. 3 , it is evident that even with a very small number of apoch (1000) the network attains an accuracy of 3.4806e-12.
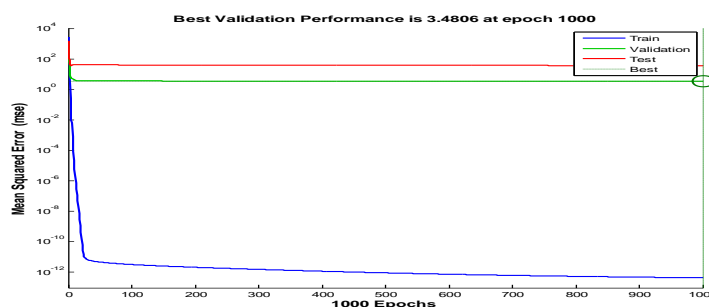

Fig. 3. Ann training, validation and testing performance system

4. RESULTS AND DISCUSSION

The variations of solar radiation and ambient relative humidity during the period of experiment are shown in Fig. 4. For the mass flow rate of 0.009 kg/s, a maximum solar intensity of 1060 Wm^{-2} was observed. The ambient relative humidity varied between 35% and 80% with an average of about 65%. Temperature variations of the drying air and ambient air and absorber plate temperature are shown in Fig. 5. For the mass flow rate of 0.009 kg/s, the average drying air temperature recorded at the drier was 44°C. The maximum drying air temperature recorded during peak sun shine hours was 71°C. The top tray temperature increased to 72°C at noon. Fig. 5 shows the variation in temperatures of theoretical and experimental set-up values for absorber plate. It is seen that the air could achieve the nearest temperature of theoretical value 52°C. The variation in the moisture content (wet basis) with drying time is shown in Fig. 6. The moisture content and the moisture removal process are fully dependent upon the temperature and air flow rate. The air velocity was 3 m/s and the speed of air was increased at the drying chamber in order to increase the moisture removal rate. The moisture content was reduced from 55 % to 8.7 % within the period of 85 hours, the moisture content reduced from 55 % to 7 % during the period of 67 hours.The moisture reduction during the first and the second day of drying was found to be between 30 % and 10 % respectively. Dried copra is showed in the Fig. 7.
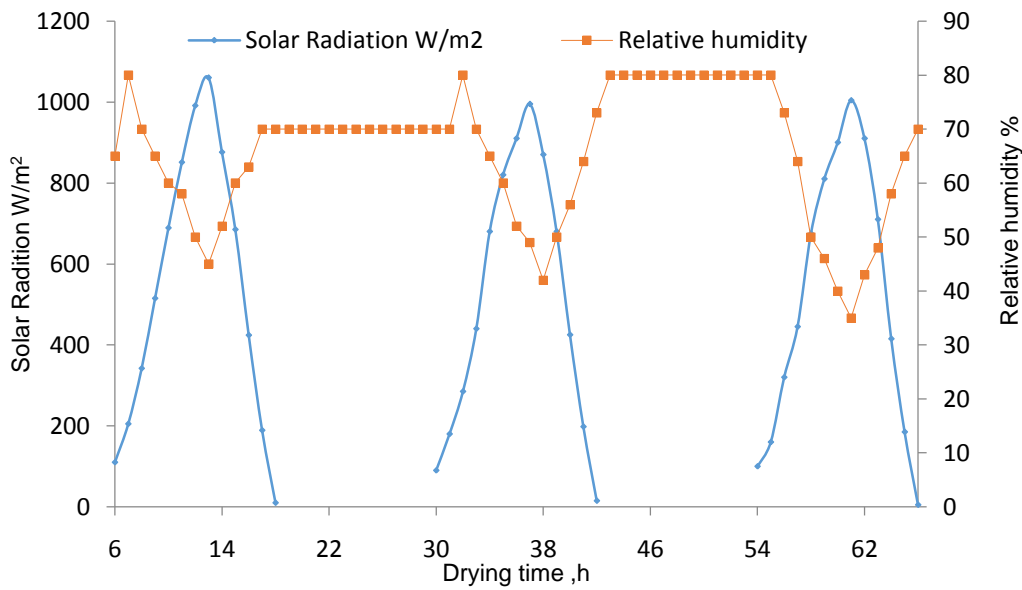

Fig. 4. Variation of solar intensity and ambient relative humidity
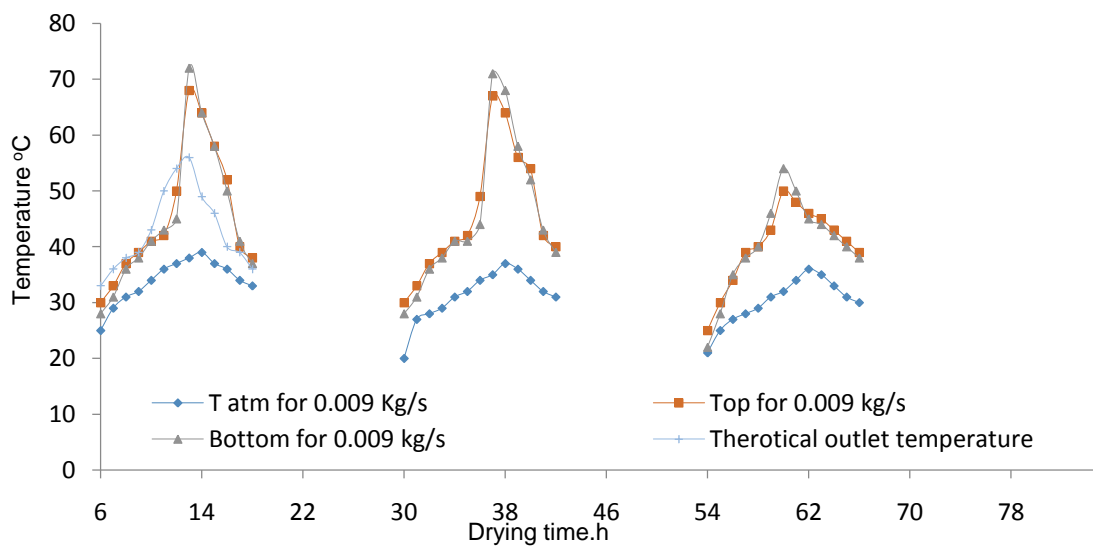
Mass flow rate and 0.009 kg/s

Fig. 5. Variation of the temperature between the trays Mass flow rate 0.009 kg/s and absorber plate temperature and Comparison of theoretical outlet temperature with actual temperature
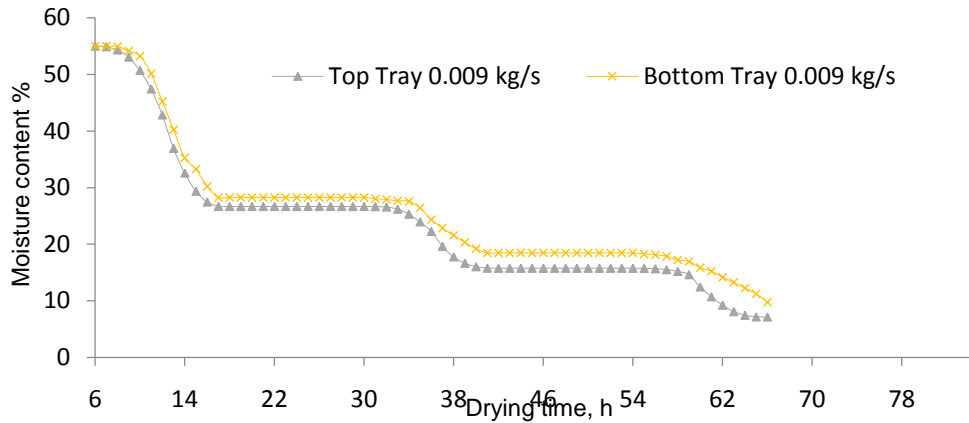
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Fig. 6. Variation of the moisture content Mass flow rate 0.009 kg/s

Fig. 7. Dried Copra at Mass flow rate 0.009 kg/s

4. 1. Curve fitting

Table 2 lists the estimated parameters and comparison statistics of the four drying models for mixed mode solar drying of copra. For mixed mode solar drying, all the models other than the Page model provided adequate fit with the experimental data with a value of 0.962939 for R^2.

Table 2 Statistical results of different models for mass flow rate 0.009 kg/s

Model Name	Constant	R^2	EMD	ERMS	χ^2
Newton	K = 0.013988	0.96074	8.1933	0.04262	0.000184
Page	K= 0.001225 m= 2.3106	0.96293	7.5318	0.04140	0.001772
Henderson& Pabis	a= 0.92707 K= 0.011464	0.95188	10.900	0.04718	0.002302
Wang& Singh	a= 11.87284 b= -0.29484	0.96032	9.02435	0.04352	0.001958

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From the above results, it is observed that all model values are found to be less as compared with page models and the page model is suitable for the determination of grater in the coefficient of R^2 values for the case of lower air flow rate model.

4. 2. Thermal Efficiency of the Dryer for Copra

The thermal efficiency of the dryer was calculated using the equation (2). The thermal efficiency of the mixed mode solar dryer while drying the copra with a mass flow rate of 0.009 kg/s was around 23.25 % on the first day of the experiment, and 7.243% on the second day and 5.461 % on the third day. Fig.8 indicates the comparison of the thermal efficiency of the dryer during the drying of copra with a mass flow rate of 0.009 kg/s. It is observed that, solar dryer had higher efficiency for drying the copra with this mass flow rate.
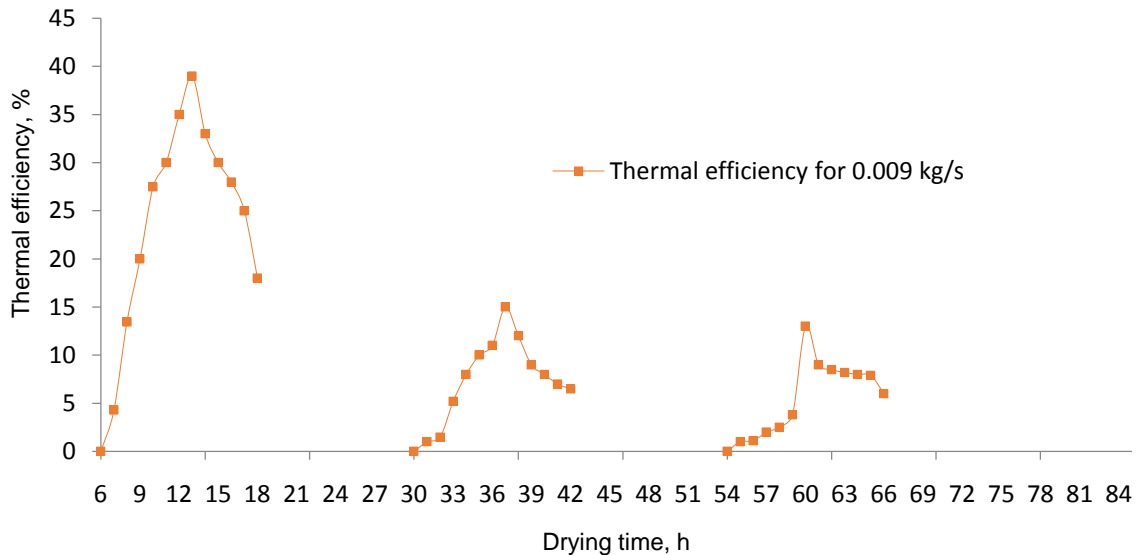

Fig. 8. Comparison of thermal efficiency of the dryer during drying of Copra with a mass flow rate of 0.009 kg/s
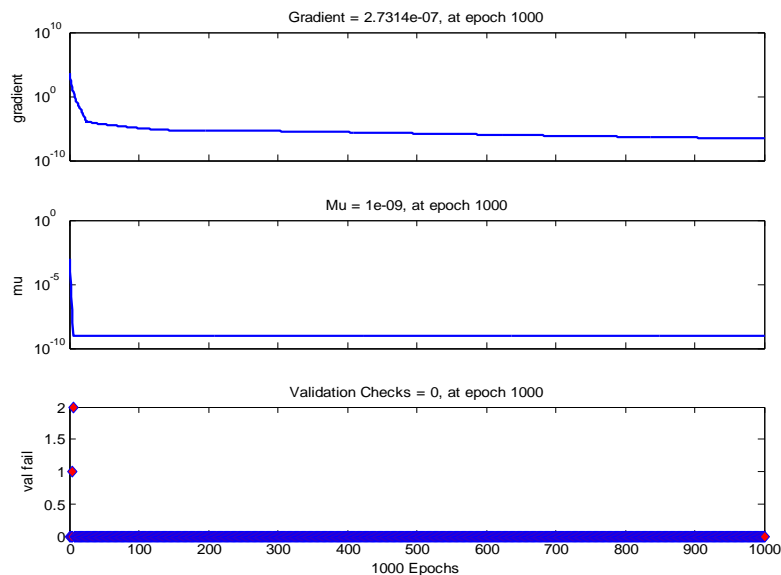
4. 3. Performance Analysis

Fig. 9a. Curve of SSE to training subset and test subset for moisture content

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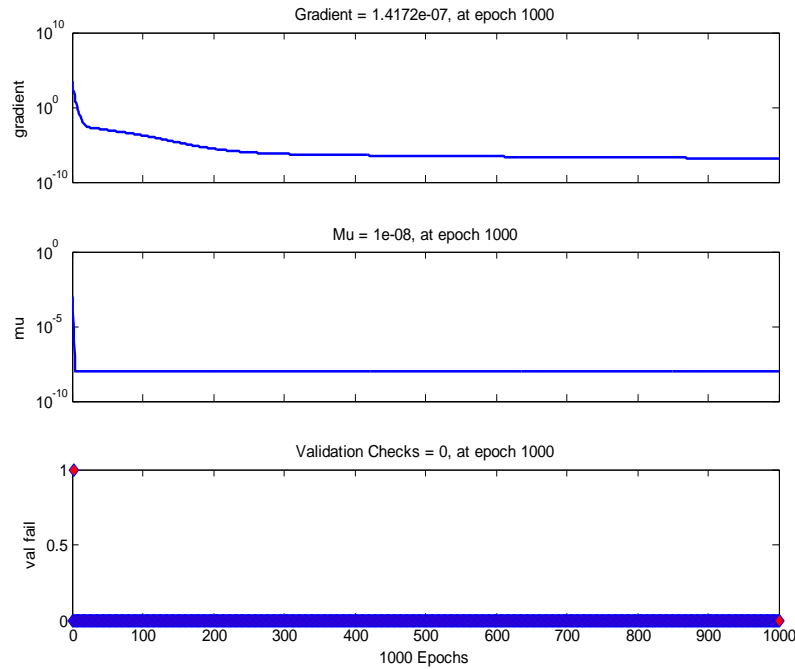J o u r n a l o f A d v a n c e s i n c h e m i s t r y

Fig. 9b. Curve of SSE to training subset and test subset for moisture content

Five factors, time, initial moisture, relative humidity, air temperature and solar radiation, were used as each unit of inner layer. The outer layer was composed of two response variables, the moisture content and efficiency. A set of factors was used for training the network into the computer several iterations were conducted with different number of neurons of hidden layer in order to determine the optimal artificial neural network structure. It was started with two neurons and increased up to twenty two. The least MSE value and a good prediction of the outputs of both training and test sets were obtained with twenty two neurons in the hidden layer. Fig. 9a and 9b shows values obtained for the moisture content and thermal efficiency using trained artificial neural networks.
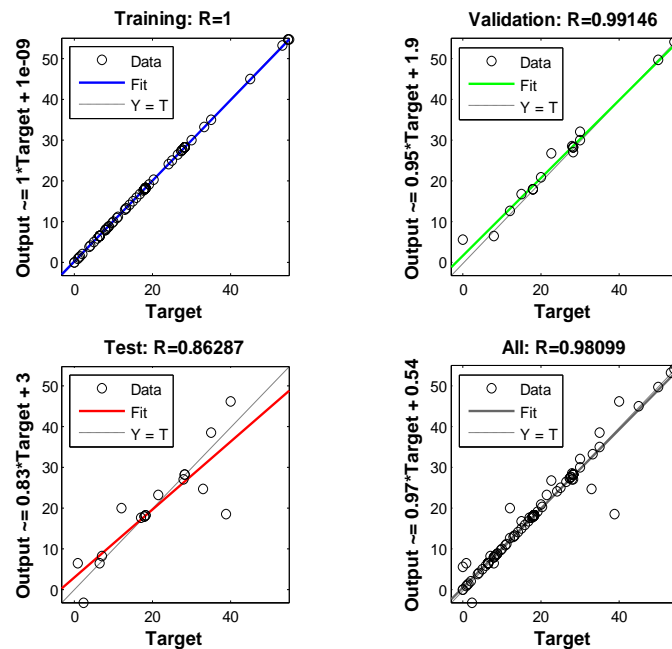

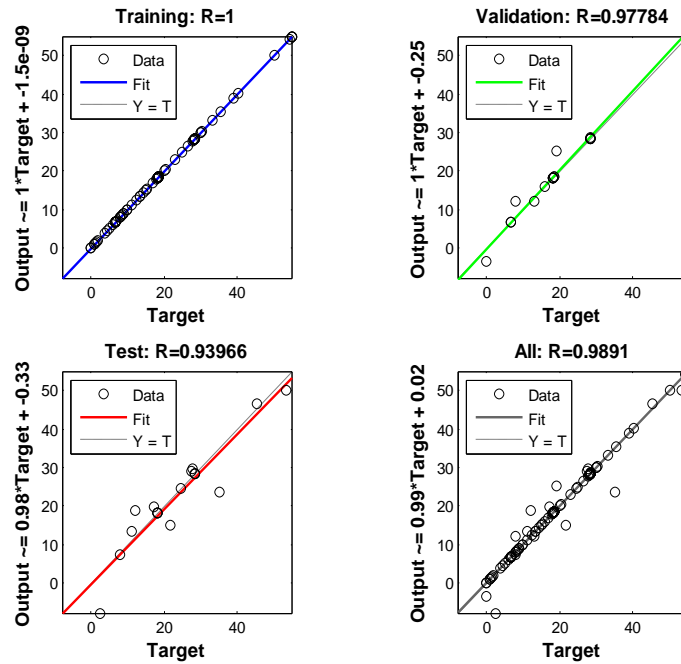**Fig. 10a.** Results obtained for the moisture content

Fig. 10b. Results obtained for the thermal efficiency

Fig. 10a and 10b show the comparisons made between the experimental and predicted data set of training, validation, testing and combined set; among 66 experimental set, 46.2 data set was allotted for training 9.9 for validation and remaining 9.9 for testing and all the data sets were visible in the respective graph. Fig. 10a and 10b correspond to the output parameter of moisture content and efficiency. All the above mentioned output having good coincidence exists between the experimental and predicted output. Also Fig.10a and 10b confirm that all the data have good fit due to the fine training. So the trained network system gives the output with minimum percentage of error and also may be used to predict the unknown value in future. It is noted that high values for R and adequate accordance to the linear regressions which were related to the network for outputs in the design points on the lines target is equal to the output was other reasons for nicety of this artificial neural network. In case if the R value is very less then we have to increase the neurons in the hidden layer to increase the R value.

5. CONCLUSION

This work presents the performance of a mixed-mode solar dryer for the purpose of preservation and energy saving. Also it presents the literature review, methodology, and theoretical analysis for solar air dryer. The design, fabrication and experimental analysis of the system are explained. The moisture content and efficiency during drying of coconut were investigated as functions of time, initial moisture, relative humidity, air temperature and solar radiation were analyzed. The parameters were determined at 66 experimental points. According to the theoretical analysis, the system can achieve a maximum temperature of $52^{o}C$ at the outlet of the drier at noon. The drying rate increases with the decrease in the mass flow rate. Such solar driers are more suitable for drying copra for small farmers. It is seen that mass flow rate of 0.009 kg/s is the most suitable one for drying Copra; Page model Diamante LM and is suitable for the mixed mode solar dryer with a maximum of 23.32 % thermal efficiency. This model is very much useful to design a dryer to suite the desired parameters for the actual users in the field. The contour plots related to fitted functions using response surface methodology described effect of the factors on values of each response individually and cumulatively. A neural network with 5 inputs and 2 outputs was found to be able to predict the operation of the dryer after it was adequately trained. The prediction of the model has been found to be excellent. It can be used to predict the potential of the dryer for different location, and can also be used as a predictive optimal control algorithm.

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