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Experimental Performance and Neural Network Modeling of a Large-scale Greenhouse Solar Dryer for Drying Natural Rubber Sheets

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Abstract: This paper presents experimental performance and artificial neural network modeling of a large-scale greenhouse solar dryer for drying of natural rubber sheets. The dryer consists of a parabolic roof structure covered with polycarbonate sheets on a concrete floor. The dryer is 9.0 m in width, 27.0 m in length and 3.5 m in height. Nine 15-W DC fans powered by three 50-W PV modules were used to ventilate the dryer. To investigate its performance, the dryer was used to dry six batches of natural rubber sheets. For each batch, 750 kg of rubber sheets were dried in the dryer. Results obtained from the experiments showed that drying temperatures varied from 32 ℃ to 55 ℃ and the use of the dryer led to a considerable reduction of drying time, as compared to the open air sun drying. In addition, the quality of the product from the dryer was high-quality dried products. A multilayer neural network model was developed to predict the performance of this dryer. The predictive power of the model was found to be high after it was adequately trained.

Key words: Solar energy, solar drying, natural rubber sheets, greenhouse solar dryer, ANN model.

1. Introduction

Natural rubber is one of the major agricultural products of Thailand. Since years 2006-2012, Thailand has been the number one producer and exporter of natural rubber with production capacity of 3.1-3.2 million tons per year, with 88-90% of total production capacity exported to foreign markets [1].

The natural rubber in the form of rubber sheets is widely produced in Thailand. To produce rubber sheets, the sheets need to be dried. Natural sun drying and the use of hot air from biomass burner are two methods usually employed in this country. With these drying methods, rubber sheets are usually subjected to the problems of non-uniform drying and spoilage due to adverse weather conditions.

Situated in the tropical area, Thailand receives abundant solar radiation [2]. Consequently, the use of solar dryers for natural rubber sheet drying is reasonable. Although several types of solar dryers have been developed in the last 40 years, most of them have small loading capacity [3-5]; hence, they could not meet the high demand of rubber sheets drying. As a result our research group has developed a large-scale greenhouse solar dryer to dry agricultural products in a commercial scale. It was successfully used for drying fruits and vegetable [6-7]. However, it has not been tested to dry non-food products. Therefore, the objectives of this research were to investigate the performance of the greenhouse solar dryer for drying natural rubber sheets and to develop an ANN (artificial neural network) model to predict the performance of this dryer.

2. Materials and Methods

2.1 Experimental Setup

The large-scale greenhouse solar dryer was installed at Nakhon Pathom (13.82◦N, 100.04◦E), Thailand.

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The dryer consists of a parabolic roof structure made form polycarbonate sheets on a concrete floor. The dryer has a width of 9.0 m, length of 27.0 m and height of 3.5 m. Nine DC fans operated by three 50-watt solar cell modules were installed in the wall opposite to the air inlet to ventilate the dryer. The pictorial view of the dryer is shown in Fig. 1.

Solar radiation passing through the polycarbonate roof heats the air, the products inside the dryer, as well as the concrete floor. Ambient air is drawn in through the air inlets at the bottom of the front side of the dryer and is heated by the floor and products exposed to solar radiation. The heated air, while passing through the products, absorbs moisture from the products. Direct exposure to solar radiation of the products and the heated drying air enhance the drying rate of the products. Moist air is sucked from the dryer by the nine DC-fans at the top of the rear side of the dryer. The structure of the dryer is shown in Fig. 2.

2.2 Experimental procedure

In this study, natural rubber sheets were dried in the large-scale greenhouse solar dryer to investigate its potentials for drying natural rubber sheets. Six experimental runs were conducted during the period of September 2013-February 2014, and 750 kg of natural rubber sheets were dried for each run.

Solar radiation was measured by a pyranometer (Kipp & Zonen model CM 11, accuracy ± 0.5%) placed on the roof of the dryer. Thermocouples (K type) were used to measure air temperatures in the different positions of the dryer (accuracy ±2%). A hot wire anemometer (Airflow, model TA5, accuracy ± 2%) was used to monitor the air speed inside the dryer. The relative humidity of ambient air and drying air was periodically measured by hygrometers (Electronnik, model EE23, accuracy ± 2%). The positions of all measurements are shown in Fig. 2.

Voltage signals from the pyranometer, hygrometers and thermocouples were recorded every 10 minutes by a multi-channel data logger (Yokogawa, model DC100). The air speed at the inlet and outlet of the dryer was recorded during the drying experiments using the hot wire anemometer. Before the installation,

Fig. 1 The pictorial view of the large-scale greenhouse solar dryer.

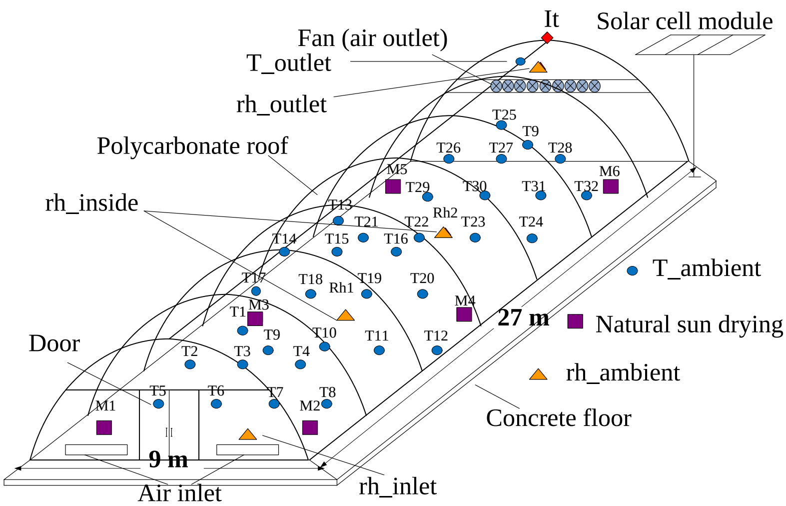

Fig. 2 The structure of the large-scale greenhouse solar dryer and the position of the thermocouples (● T), hygrometer (▲ rh), solar radiation (◆ I_t) and product samples ■ M).

Fig. 3 The natural rubber sheets dried inside the dryer.

the pyranometer was calibrated against a pyranometer recently calibrated by the manufacture. The hygrometers were calibrated using standard saturated salt solutions.

Natural rubber sheets dried in each drying test was 750 kg. The pictorial view of rubber sheets being dried in the dryer is shown in Fig. 3.

Natural rubber sheets were hung on arrays of racks inside the dryer. Each day, the experiment was conducted during 8:00 am-6:00 pm. The drying was continued on subsequent days until the desired moisture content was reached. Product samples were placed at various positions in the dryer and were weighed periodically at two-hour intervals using a digital balance (Kern, model 474-42, accuracy ± 0.1g).

To compare the performance of the dryer with that of natural sun drying, a control sample of rubber sheet was placed near the dryer and dried simultaneously under the same weather conditions. The moisture content during drying was estimated from the weight of the product samples and the estimated dried solid mass of the samples. At the end of the experimental drying, the exact dry solid mass of the product samples was determined by the oven method (103 ℃ for 24 hours, accuracy ±0.5%).

2.3 Neural Network Modeling

The neurocomputing methods are shaped after biological neural functions and structure. As a result, they are generally known as ANN. Similar to biological neural network, the function of ANN are developed not by programming them, but by exposing them to given sets of input and output data on which they can learn how to perform a required task. In such modeling approach, a formulation of analytical description of a process is not required. Instead, a black-box process model is created by interacting the network with representative samples of measurable quantities characterizing the process.

In this work, a multilayer ANN model of the greenhouse solar dryer for drying the natural rubber sheets was developed. The model has a four-layered network. This network consists of a large number of processing elements, called neuron (Fig. 4). The input layer of the model comprises five neurons which correspond to solar radiation (I_t), airflow rate ($\dot{m}$), air relative humidity (rh), air temperature (T), and initial moisture content (M_i). The output layer has one neuron which represents the final moisture content (M_f). A selection of the number of neurons for hidden layers is optional. A large number of neurons can represent the system more precisely but it is more complicated to obtain proper training of the network. In this work, the selected number of neuron in hidden layers 1 and 2 of the model are 10 and 5, respectively.

ANN is able to modify its behavior in response to its environment. Unlike analytical model, the structure of ANN cannot represent the system behavior, unless it is properly trained. The aim of training the network is to adjust the weights of the interconnecting neurons of the network so that an application of a set of inputs produces a desired set of output. Initially, random values are given as weights. One input-output set can be referred to as a vector. Training assumes that each input vector is paired with target vector representing the desired output and these are called a training pair. In general, a network is trained over number of training pairs.

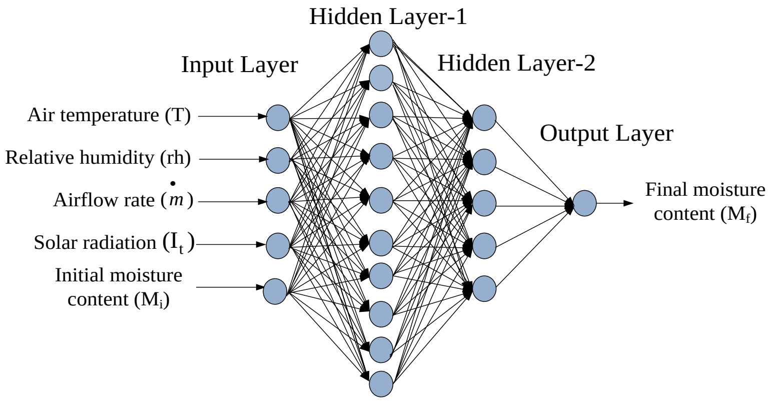

Fig. 4 The structure of the artificial neural network of the large-scale greenhouse solar dryer for drying rubber sheets.

In this work, the ANN model of the greenhouse solar dryer was trained by the back propagation algorithm [8].

The procedure of the training are as follows: (1) an input vector was applied; (2) the output of the network was calculated and compared to the corresponding target vector; (3) the difference (error) between the calculated and the target outputs was fed back though the network; and (4) weights were changed. This procedure was repeated over the entire training set until the error was within an acceptable value or until the outputs did not significantly change any more. The ANN model was programmed in C++.

3. Results and Discussion

3.1 Experimental Results

Drying experiments of natural rubber sheets in the large-scale greenhouse solar dryer were carried out between September 2013-February 2014. Six batches of experimental runs were carried out. The typical results are shown in Figs. 5-8. It was observed that solar radiation was strongly fluctuated on the first, second and fourth days of the experiment because there was clouds on those days (Fig. 5). On the third and fifth days, solar radiation was low due to rain.

For comparison, air temperature at five different locations inside the dryer and the ambient air temperature were measured. The pattern of temperature change in different positions was comparable for all locations inside the dryer (Fig. 6). Temperatures in different positions at these five locations varied within a narrow band. In addition, temperatures at each of the locations differed significantly from the ambient air temperature.

Relative humidity at two different locations inside the dryer and ambient air relative humidity during solar drying of natural rubber sheets was measured. Relative humidity decreased over time at different locations inside the dryer during the first half of the day while the opposite is true for the other half of the day (Fig. 7). No significant difference was found between relative humidity of different positions inside the dryer. However, there was a significant difference in relative humidity for all locations inside the dryer compared to the ambient air. The relative humidity of the air inside the dryer was lower than that of the ambient air. Hence, the air leaving the dryer had lower relative humidity than that of the ambient air, and this indicated that the exhaust air from the dryer still had drying potential for recirculation to dry the product.

The moisture content of natural rubber sheets in the greenhouse solar dryer was reduced from an initial value of 24-30% (wb) to a final value of 0.4-3.9% (wb) in five days. The decrease of mean moisture content of the rubber sheets being dried in the dryer, as compared to the open air sun drying is shown in Fig. 8.

To determine the quality of natural rubber sheets, the dried samples of rubber sheets were analyzed following the standard test [9]. It was found that the quality of all samples met the requirement of the

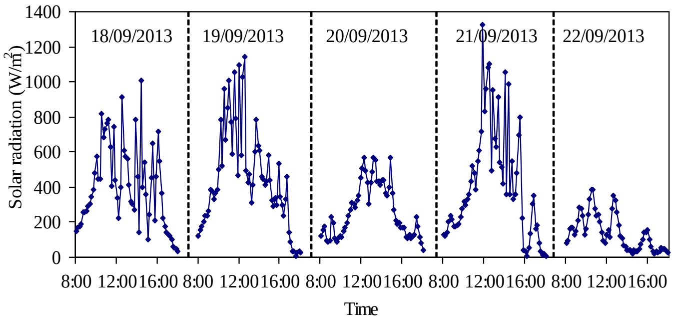

Fig. 5 Variation of solar radiation with time of the day during drying of natural rubber sheets.

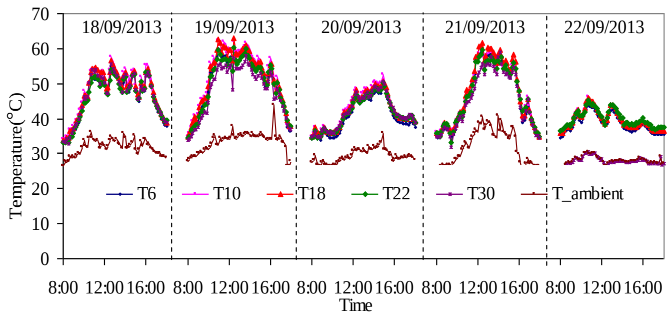

Fig. 6 Variation of ambient temperature and the temperature at different positions inside the dryer during drying of natural rubber sheets.

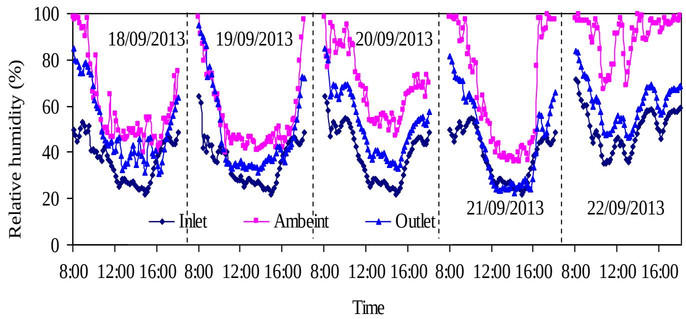

Fig. 7 Variation of ambient relative humidity and relative humidity inside the dryer with time of the day during drying of natural rubber sheets.

standard. In addition the colour of the dried rubber sheets was measured by a chromometer (CR-400 Minota, Japan) and results indicated that rubber sheets dried in the dryer had better colour than that of dried in open air and the quality of dried rubber sheets obtained from the dryer corresponded to high-quality dried product.

3.2 Performance prediction by ANN model

The ANN model of the greenhouse solar dryer developed for natural rubber sheets drying was trained with the experimental data from five experiments. The data from the sixth experiment were reserved for testing the model. After 100,000 times of iteration step of training, the square sum of difference (error) between the observed and the predicted output reached a significant low level. The comparison between the model-predicted and measured moisture contents of the dryer is shown in Fig. 9.

From Fig. 9, it is found that the agreement between the predicted and measured moisture contents is good and the root mean square difference (RMSD) is 9.8% with respect to the mean measured value. Thus, if the model is adequately trained, it can appropriately

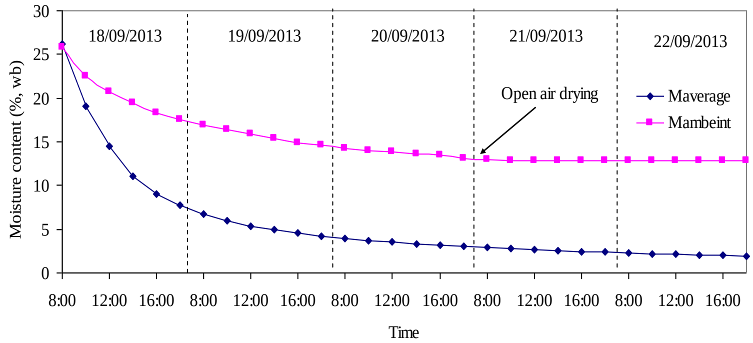

Fig. 8 Comparison of the mean moisture content of rubber sheets inside the dryer with moisture content of the sample dried by the open air drying.

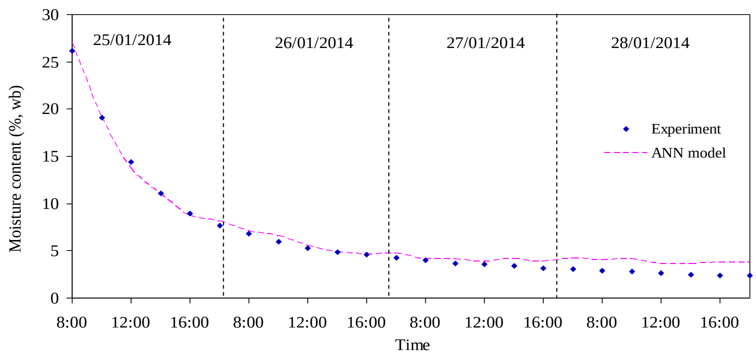

Fig. 9 Predicted and measured moisture contents of natural rubber sheets.

predict the performance of the greenhouse dryer for drying natural rubber sheets.

4. Conclusion

The performance of the greenhouse solar dryer for drying natural rubber sheets has been experimentally investigated. It was found that the use of this dryer led to considerable reduction in drying time in comparison of that of sun drying. An ANN model for this dryer has also been developed. This ANN with five input, one output and two hidden layers was found to be able to predict accurately the moisture content of rubber sheets. It is expected that this ANN model can be used to predict the potential of this dryer for other locations.

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