THERMAL ANALYSIS OF A HYBRID SOLAR TUNNEL –MICROWAVE, DRYER FOR DRYING CULTIVATED BANANA

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ABSTRACT

This research aims to design and develop a hybrid dryer between solar energy and microwave for drying cultivated banana. The solar collector uses black painted steel sheets to absorb the sun's radiation covered with a clear acrylic sheet to prevent heat loss from convection and hot air is sent to the drying cabinet equipped with a 6 inch diameter electric fan. The size of solar collector is 0.56 meters width and 1.2 meters length. The drying cabinet is made of stainless steel with a volume of 0.2035 cubic meters. There is a set of electrical control cabinets for adjusting and controlling the inside temperature of the cabinet. A magnetron head set for microwave generator was installed at the back of the cabinet. Dried samples were evaluated for rehydration ratio, drying time and drying rate when the dryer is completely fabricated, the banana drying experiment was conducted for comparing the drying rate in 2 cases. The results showed that when drying banana with microwave mode the average drying rate was 29.167 g water/kg d.s/min m² and when using the solar collector mode, drying can be achieved by convection heat transfer. The average drying rate was 13.778 g water /kg d.s/min m². Therefore, this hybrid dryer should be used in the proper conditions and gain the most energy efficient and suitable. In case of using solar and microwave, mix-mode, should be used for continuous dehumidification and can be used as an auxiliary mode during the night time without sunlight or assist in increasing the temperature in the cabinet to reduce the duration time of drying products.

KEYWORDS: Hybrid Dryer; Solar Tunnel Drying; Thermal Performance; Microwave Drying & Cultivated Banana

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1. INTRODUCTION

Thai government supports and encourages communities to have production and product processing within the community to increase the income for people in the community. Being able to be self-reliant according to the philosophy of sufficiency economy and being immune regardless of economic changes, however, the community group Thirteen Canal Pathum Thani Province need to join a group to learn about food production, which generates income for the elderly in the community and housewives with no income need academics and researchers to develop the production potential of the community in order to be able to learn how to produce dried fruit such as dried bananas for generating income for their family. Pathum Thani Province has a lot of farmer who grow bananas. The research team therefore has the idea to conduct a research and develop a hybrid dryer with solar and microwave. To conduct an experiment with the energy-saving bananas dryer, which can operate both day and night time. The developed small dryer is suitable for drying dried fruit products, which can be produced in the household, reducing production costs, saving time, reducing the import of food drying technology and equipment from foreign countries. This will help to improve the economic status, society, well-being and the ability to be self-reliant in a sustainable manner. Thailand is located in equator area, therefore this country received a quantity of solar radiation quite high throughout the year. Total average solar radiation daily is 18.2 megawatts per square

meter per day. [1] The use of solar radiation drying technology for agricultural crops, it is possible both in terms of techniques and economics of dryer development. The solar radiation energy drying of the past researchers, most of the solar collector are used as heat sources for product drying. Produce heat in the drying chamber by means of heat convection with direct air or convection with hot water. Many researchers reported relate to energy utilization, solar radiation used in drying agricultural crops for example, C Phanlek et al. [2] have improved Longan dryer performance by installing a solar radiation panel in the size of 5 square meters, which provides an average efficiency of 40 percent in drying, 80 percent of hot air is recovered. The new dryer has a 19 percent increase in performance. In drying paper from banana pulp with the solar dryer. Solar radiation energy drying for industries in households using direct air convection principles carried out by B. Prasit et al. [3] with the drying machines in the thermal efficiency of 34.7 percent. Formerly, he develops a solar radiation drying machine together with energy from the gasifier for drying mulberry leaves, thermal efficiency of 23.6 percent. T. Kiat Siriroet et al. [4] have developed a drying system. From the study of Tomas Funebo and Thomas Ohlsson (1998) [5] a microwave oven combined with hot air system was used for dehumidification of apples and mushrooms fragrant. The product was good quality in color, close to the fresh products and can reduce the drying time to 50 and 75 percent for drying apples and drying shiitake mushrooms respectively, compared to drying with only hot air oven. Jirawat Kankriangwong and others (2006) [6] studied dried chili production by a microwave vacuum chamber. The spin drum using a microwave frequency of 2450 MHz and 1.18 kW electric power. The vacuum pressure was 60 millimeters of mercury. The drying time was 44 minutes. The optimum conditions resulting in drying chillies with unique characteristics was not the same as dried peppers in the market, with bright red, scalloped pellets. The surface is smooth, hard, sequin. It has a brightness (L^*), red (a^*) value. The remaining color (b^*) equals 34.14 ± 1.27 , 32.84 ± 1.94 and 23.10 ± 0.69 , respectively, the volume of dried chilies obtained equal to 1.63 ± 0.09 cubic centimeters / tablet moisture equal to 6.73 ± 0.64 percent and activity water equals to 0.444 ± 0.001 , which is lower than chili. The sensory market found that dried chilli that manufactured from a rotary vacuum microwave oven, available in red more crispy and crisp fragrance and more spicy than dried peppers in the market. [7] Cumnueng Vatayota (2010) conducted a study on the rubber block drying by using microwave oven combined with hot air. The height of the rubber layer was 10 and 15 cm when using the heated air temperature 100 degrees Celsius, providing energy consumption. The low specificity is 11.67 and 11.96 mega joules per kilogram evaporated water, respectively. Suchada Chaisawat and Surachai Kaewbunruang (2009) [8] conducted the comparative study on drying methods with a hot air dryer and vacuum dryer by comparing 2 baking methods which are using vacuum and hot air dryers, tom yum products were dried for testing. Looking for the microbial quantity, the microbial quantity decreased from 106 colony forming unit per gram, remaining 102 colony forming unit per gram in both conditions. The method of drying the Tom Yam machine by drying in the oven. Vacuum drying was better than the hot air drying method because of the short drying time, but also spent higher cost of production. [9] Banana is the greatest significant tropical fruit. Bananas and plantains are the fourth most vital food harvest in the world. Nevertheless, only few cultivars are cultivated on great scale. In some countries bananas are basic food. There are wide variations reported in different banana cultivars for Vitamins (riboflavin, folate, & vitamin C), Carotenoids (β -carotene, α -carotene, lutein, & zeaxanthin) minerals (P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, & B).

2. SOLAR HYBRID DRYER AND SOLAR TUNNEL DRYER

Drying is a superb method to reserve food and open sun drying is the eldest agricultural practice to preserve food. [10] According to Kumar et al. [11], solar drying has the capability to meet the rising demand for natural foods in addition to providing income in a sustainable way. Moreover, solar dryers involve suspicious design and research to decide the drying

time, solar radiation, and achievable air conditions such as temperatures, relative humidity, and air speed for optimum drying in order to obtain a good quality product. B.M.A. Amer a, et al [12] conducted the design and performance assessment of an innovative hybrid solar dryer for a banana. The main objective of the study was to design and investigate constantly hybrid solar dryer (day time and night time) by storing the solar energy in water tank during the sunshine period to decline the drying cost, attain the quality of the dried products, and to escape the microbial growth while drying. A hybrid solar dryer was designed, constructed and tested at Institut fur agrartechnik Potsdam-bornim, Germany during the dated of 2005–2006. There are many parts of solar dryer such as: solar collector, drying cabinet, heat exchanger and storage unit. A hybrid solar dryer was designed and fabricated using solar energy and microwave. The dryer comprises of solar collector, reflector, magnetron tube, and drying chamber. The drying chamber was located at the back of the collector. The dryer was operated during regular sunny days as a solar dryer, and during cloudy day as a hybrid solar dryer. The solar dryer was tested for drying of cultivated banana slices. The capacity of the dryer was dried about 30 kg of banana slices in 8 hours on a sunshiny day from an initial moisture content of 82% to the final moisture content of 18% (wb). In the same time it reduced to only 62% (wb) moisture content in open sun drying method. The main limitation of other hybrid solar dryer for a banana is the huge and complex of the system, which is not practical in operation, so the author conducted the appropriate size of the hybrid solar tunnel –microwave, dryer for drying cultivated banana test. Arjoo et al [13] carried out performance evaluation of a solar tunnel dryer for around the year use. The study was assess the performance of a walk-in type solar tunnel dryer for around the year use. Full loading was done with garlic, chili, fenugreek and aonla candy depend on their seasonal availability in Hisar, India. During full load, the dryer decreases the moisture content of garlic from 65% (w.b.) to 8.5% (w.b.) in 8 days, chilli from 77%(w.b.) to 7% (w.b.) in 7 days, fenugreek from 86% (w.b.) to 7.2% (w.b.) in 5 days and aonla candy from 44% (w.b.) to a moisture content of 16%(w.b.). The thermal efficiency of the dryer was between 8.89% to 17.63%. A temperature of 15-30 °C higher than the atmospheric temperature was recorded inside the dryer. Dried products were hygienic and their sensory assessment indicated that they were of good quality and acceptable. Yogesh P.Gandhimutha and Mahesh G. Bhongto [14] performed a performance analysis of solar tunnel dryer for drying various agricultural product under Nasik (Maharashtra) weather condition. The dryer consist of 6 ft long and 3 ft wide with 1 mm thick polycarbonate sheet. Capacity of onion drying in the dryer was 4 kg. Onion was dried from an initial moisture content of about 85% to 15% in solar tunnel dryer in 11 hours while by open sun drying it required 18 hours also temperature achieved inside the dryer is above 30°c to 40°c than outside temperature with the average thermal efficiency of about 53.1%. Isaac Nyambe Simate, and Sam Cherotich [15] tested the design and testing of a natural convection solar tunnel dryer for mango. The system comprising of three major units, a solar collector unit, a drying unit, and a vertical bare flat-plate chimney. No-load tests with a horizontal configuration of air entering the collector resulted in a 2-directional air flow. To correct this undesirable situation, an air guide at the collector was incorporated to ensure that air entered in a vertical direction. Drying experiments with mango were carried out at the University of Zambia. The results showed the solar radiation was between 568.4 and 999.5 W/m², air temperature was 65.8°C. The average relative humidity values were 30.8%, 6.4%, and 8.4% for the ambient, collector, and drying unit, respectively. Under these conditions, mango with an initial moisture content of 85.5 % (wet basis) was dried to 13.0% (wet basis) in 9.5 hours. The collector, drying, and pick-up efficiencies were found to be 24.7%, 12.8%, and 35.0%, respectively. The average temperature difference between the chimney air and ambient air was 12.1°C. Ihaddadene and Ihaddadene [16] conducted the effect of distance between double glazings on solar thermal collector performance. Experimentations were carried out on an active solar energy system. The results reveal that the efficiency of double glazing solar collector declines with increasing the distance splitting the two glasses.

3. STEPS AND METHODS FOR FORMING A PROTOTYPE DRYER

In this work the cultivated banana drying was conducted by using heat energy, which come from solar and microwave. In order to achieve good quality of products, the appropriate conditions of the dryer should be determined, such as the size of the solar panel. The size of the drying cabinet, the size of the fan, the size of the magnetron head, heat transfer rate in the cabinet, and the initial moisture content of banana. The solar collector uses black steel sheets for absorbing solar radiation covered with a clear acrylic sheet to prevent heat loss from convection. The advantage of using this collector type is because of its low thermal losses [16, 17]. Therefore, this research has designed and built a hybrid dryer, solar and microwave for drying cultivated bananas, consisting of the main equipment: wave generator sets, cabinet and control panel. Sun exposure magnetron sets, such as magnetron tubes, are generally characterized as shown in Figure 1, which consists of a filament and a cathode.

Figure 1: Magnitron Tube.

One of the tubes is contained in a vacuum chamber where the surrounding wall acts as an anode. The generated microwave is sent outside by the magnetron. In the operation of the magnetron tube, the magnetron lamp will be supplied with 3-4 volts of low-voltage alternating current, 10 amps at the incandescent lamp which will create a hot tube and release the electrons and when supplying high voltage electricity to one pole of the incandescent lamp, which is acting as cathode compared to anode cause the electrons to be forced to move under the influence of electric and permanent magnetic fields. When the potential difference is high, a magnetron lamp can emit microwaves. The frequency of the microwave wave is determined by the internal structure of the vacuum channel between the cathode and anode. This makes it suitable for the magnetron tubes emit waves at the frequency of 2.45 GHz to create a combined energy dryer with solar and microwave. Materials used are stainless steel sheet, steel oven, box, structure, the bottom of the cabinet is equipped with 4 wheels and a 6-inch electric fan to the cabinet was installed as shown in figure 2-4.

Figure 2: Installing a Magnetron Set on the Drying Cabinet.

Figure 3: Solar Collector Fabrication in the Workshop.

Figure 4: The Hybrid Solar Dryer Combine Microwave and Solar Energy for Drying Cultivated Bananas.

4. THE MATERIAL AND METHOD

The performance of a solar tunnel dryer for banana drying was evaluated by conducting banana drying load test. The dryer is lined up on a North-South axis. Hot air with the constant flow rate is used as a heat transfer fluid. 470-gram of banana was dried in 1 day (6 hours). The bananas were weighed before and after drying in order to calculate the rate of evaporation of water from the product. The air temperature throughout the experiment was measured and recorded. The air temperatures in the tunnel dryer, and in the drying chamber were measured as well. The K-type thermocouples attached to the collector on both inlet and outlet sides. An ambient temperature was collected by a data logger at all six points as shown in Fig. 1, which is recorded at the end of one day as well as the temperature of the outside air (glass type thermometer was used). To measure the radiation of the sun (I), a direct solar radiation in the units of W/m^2 was measured by a pyranometer and shading rings in every 1 minute. Then plot the relationship between the temperatures of every tested point and time (temp-time of the day). The performance of a solar tunnel dryer, and the overall thermal efficiency of the combined heat, solar dryer were calculated by the equation 1. In the drying unit, parameter was assessed, that is the drying efficiency. For natural convection solar dryers, the drying efficiency is given by [18].

$$\eta_{\text{drying}} = W \cdot hfg \cdot I \cdot \Delta T_{\text{ec}} \quad (1)$$

$$\eta_{\text{system}} = (m_w \times hfg) / (m^\circ \cdot C_p \Delta T) \times 100 \quad (2)$$

Where;

m_w = Evaporated water in kg

hfg = Latent heat of water in $kJ/kg.K$

m° = Air mass flow rate in kg/s

ΔT = Temperature different in K

Where; η_{drying} is the drying efficiency; W is the total moisture removed, kg; hfg is the latent heat of water vaporization at the dryer air temperature, J/kg; IST is the total solar radiation received during the drying period, J/m². For a dryer that receives only direct radiation on the product, A_{ec} can be taken as the area of the drying tray.

And the performance of the drying system can be determined from the amount of heat used to evaporate water from all materials. The amount of heat of the air in the drying room by the thermal efficiency of drying can be calculated from the equation 2 [19].

The experimental setup consists of a solar tunnel dryer for cultivated banana drying, 5 points of K-type thermocouple, a pyranometer for direct solar radiation measurement, and a data logger for data recorded as shown in Fig. 5-6. Three selected clear sky days were considered for the test. The experiments conducted on June 29-30 and July 1, 2019 at Faculty of Industrial Technology, Vallaya Alongkorn Rajabhat University Pathum Tani, Thailand. The cultivated banana was weighted for starting an initial mass and put on the product's shelf in the drying cabinet drying at 40 degrees Celsius 45 50 55 and 60 degrees Celsius with each temperature will use the drying time of 16 hours by weighing of cultivated banana every 1 hour. Recorded various data from the collector receive solar radiation every 1 minute by using a data logger GRAPHTEC model GL800 (accuracy setting $\pm 0.2\%$ of full scale) and recorded temperature and relative humidity of the outside air and in the drying cabinet, including electric power after drying and then take the cultivated banana out to find moisture with the AOAC standard method. [20]

Figure 5: Solar Tunnel Dryer Experimental Study.

Temperature and solar radiation recorded by a data logger model graptec gl 820 as shown in figure 6.

Figure 6: Temperature Acquisition.

Preparing wet banana by slicing into 3 mm thickness and weighing initial weight before drying as shown in figure 7.

Figure 7: Sliced Banana Weight Measurement.

To dry bananas from a hybrid dryer and collected data such as temperature at various points in the drying cabinet. Data such as the heat inside the oven and time were collected by using an internal thermometer. The outside the drying room temperature, drying time were collected as well. Measure the solar radiation by using a pyranometer. Collecting the data used the data logger and save the data to the computer. The wet and dry weight of cultivated bananas was used to calculate, shown in tables and graphs to compare variation from the average and used to calculate the efficiency of the solar dryer. Microwave system efficiency data obtained by using the software package for statistical analysis were percentage, mean, and data were used to summarize the results of the experiment and research. Drying in all 2 cases, including 1. Drying with the sunlight 2. Drying with solar and microwave. The drying rate in different cases was compared.

Microwave Drying

The pretreated banana chips were dried in a microwave oven as shown in figure 8. Drying was carried out in the 800W microwave power. The sample of banana chip design was dried simultaneously, in order to ensure uniform drying conditions. Then the dried banana chips were analysed for different physicochemical analysis.

Figure 8: Sliced Banana with Microwave Dehydration.

Determination of Moisture Content

AOAC-Method was used to determine the moisture content of banana chip samples

Procedure

The instrument used for moisture determination was hot air oven. 5g of the prepared sample was weighed and taken in the

moisture dish. Placed the dish in the oven maintained at the 110 ± 5 °C for overnight. Cooling in the desiccators was done and weighted.

$$\text{Percent moisture content} = \frac{\text{Loss in weight}}{\text{Initial weight of sample}} \times 100$$

The moisture content for the sample was computed using the following equations.

$$\text{Moisture content (wet basis)} = \frac{(M_1 - M_2)}{M_1} \times 100 \quad (3)$$

$$\text{Moisture content (dry basis)} = \frac{\text{M.C. (wet basis)}}{100 - \text{M.C. (wet basis)}} \times 100$$

$$\text{Rate of drying} = \frac{\text{M.C. Lost}}{\text{Time difference}}$$

Where,

M.C. = moisture content of sample (% w.b. and d.b.)

M_1 = weight of sample before oven drying (g)

M_2 = weight of sample after oven drying (g)

Determination of Drying rate (DR)

Drying rate is the loss of moisture from the wet solid per each unit of time.

$$\text{Drying rate} = \frac{\text{Amount of moisture removed (g)}}{\text{Time taken (min)}}$$

Rehydration Ratio

5 g of dehydrated sample was taken into a small container and 120 ml of distilled water added to it. Cover the container with a watch glass and boil the water. Boil the water gently for 15 minutes. Turn out the sample onto a white dish and cover the surface with a piece of filter paper to soak the excess water and recorded the weight of the sample. Rehydration ratio calculated by the following formula

$$\text{Rehydration ratio} = \frac{B}{A}$$

Where,

B = weight of sample (g) after rehydration

A = weight of sample (g) before rehydration

5. RESULTS AND DISCUSSIONS

The banana was dried in solar tunnel dryer in 3 selected days. The results show that the average solar tunnel dryer efficiency was 14.59 %. The relation of the temperature and time are shown in figure 9.

Figure 9: Temperature Measurement At Various Times.

Solar intensity data on the test day was measured by using a pyranometer as shown in figure 10. The average intensity was 923.16 W/m^2 , which was suitable for drying product.

Figure 10: Solar Intensity Data Measurement.

The comparison of deviation of the moisture content of treated banana in a solar tunnel dryer for banana drying with microwave drying was conducted in a typical run on May 29-30 and June 1, 2019. Processed banana was dried in the solar tunnel dryer. The moisture content of the product was found by oven drying method. After every 1 hour, samples of the product were taken and weighed. Then they were placed in the moisture boxes that were located in the hot air oven at temperature of 105°C for 24 hours. It was observed that the initial moisture content of material in the middle-tray in ambient air was 82 % d.b. whereas, at the end of the day, the moisture content of material in the middle-tray was reduced to 35.25 % d.b. The graphic illustration of moisture content and time inside the solar tunnel dryer is shown in figure 11.

Figure 11: The Drying Rate Curve of the Cultivated Bananas Compared with the Moisture Ratio of Solar Tunnel Dryer.

Figure 12: Temperature and Time Graph of Dried Slices Banana using the Microwave in Various Positions in the Cabinet.

From the graph above, the drying test for banana with 800 W microwave showed that water temperature in the glass (T_w) was at the highest in 180 seconds at 61 °C, the average temperature of the bananas in the oven from 5 positions was 42.95 °C, the highest temperature inside the oven (T_n) in the period of 180 seconds was 69 °C.

Figure 13: Dehumidification of the Banana with 800 W Microwave.

From figure 13, the drying test for drying banana with microwave was found that the heat increased rapidly at the magnetron head temperature from 29° C to 230° C within 1 minute, the temperature inside the dryer increased accordingly, the moisture content of bananas from the moisture ratio of 336.50 g water / g product continuously reduced to 124.00 g water / g product level within 180 seconds. The linear equation is $y = -1.2536x + 348.03$ ($R^2 = 0.985$).

The drying rate curve of the cultivated bananas compared with the moisture ratio of microwave is shown below.

Figure 14: The Drying Rate Curve of the Cultivated Bananas Compared with the Moisture Ratio of Microwave.

The combined heat banana dryer was found to be the best among the natural convection solar dryers for drying banana but the low capacity rate of drying is considered to be improved. In the next research, should vary the microwave power, which may provide energy from 300 watts to 800 watts, etc. and should increase the range of drying with the temperature of hot air to a wider range from 40 degrees Celsius to 70 degrees Celsius. The nutritional value of the dried banana products by using microwave with hot air such as finding vitamin C content antioxidant substances phenolic compounds, etc., should be studied. The effect of using microwave techniques for drying bananas in the next study, should use more ripe bananas, which will be more than 60 percent because it will make sweeter taste and more acceptable to consumers and can be used for commercial.

6. CONCLUSIONS

The purpose of banana drying by using microwave and hot air from the solar tunnel dryer was to find the suitable conditions for producing dried banana by using microwave and hot air energy derived from the sun. The hybrid solar tunnel-microwave dryer for banana drying was tested at Faculty of Industrial Technology, Vallaya Alongkorn Rajabhat University Pathum Tani, Thailand. The load tests show that the average banana drying temperature was 43.13 °C. The banana moisture content was considered in a decreasing from 82 to 35.25 MC (% w.b.) in 6 hours. The heated air was around 526.20 W, with the incoming heat in the solar tunnel dryer of 923.16 W/m². The thermal efficiency of a solar tunnel dryer was on the average of 14.5 %. After using the solar collector mode, drying can be achieved by convection heat transfer. The average drying rate was 13.778 g water /kg d.s/min m². The drying test for banana with 800 W microwave showed that the average temperature of the bananas in the oven from 5 positions was 42.95 °C, the highest temperature inside the oven (T_n) in 180 seconds was 69 °C. At the initial stage of drying, moisture content was high and more moisture was vaporized from the outside surface. As the drying stage continued, the free moisture available on the surface reduced and fewer evaporation occurs and later drying rate suggestively declined with drying time as well as moisture content. When drying banana with microwave mode with solar mode the average drying rate was 29.167 g water /kg d.s/min m². The drying time could be decline by one second for banana for the same level of last moisture content without affecting any considerable change in the quality of the dehydrated product.

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