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# Mixed Solar Drying System for Drying of pineapple

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**ABSTRACT**

In this study, a mixed solar dryer (MSD) was designed, fabricated, and evaluated for drying of pineapple. The dryer cabinet was modified from Lyes Bennamoum's dryer cabinet. Its performance was better with the angle of receive and reflect of radiation in dryer cabinet. It was found that the maximum temperature of the mixed solar dryer system without drying material was 67 °C while the environmental temperature was 34.5 °C. at 12:50 pm. (24/04/2018) For total drying time of 33 h was required for 1,060 g of pineapple with a size of 8-9 cm diameter, 1.3-1.5 cm thickness (cylinder shape) drying in the mixed solar dryer to reduce the moisture content from 87.46 % to 7.97% (the industry standard for dehydrated fruits and vegetables was ≤ 8.4%). The average temperature of the mixed solar dryer system was 45.7 °C while the average environmental temperature was 35 °C with 55.73 W/$m^2$ of the average intensity of solar radiation at 2:20 pm. (28/05/2018-03/5/2018) The percentage of moisture content could be reduced to 91.33 % and the efficiency of solar collector was 30%. Drying system efficiency of MSD was 13 %. The physical properties of dry pineapple were suitable for sale, nice color on skin, soft taste and sweet smell.

**Keyword:** Mixed solar dryer, flat plate collector, dryer cabinet, dry fruit

## 1. Introduction

Thailand is an agricultural country with so many agricultural products. Therefore, overproductions of agricultural products cause the problem. The farmers lose their profit. Especially pineapple, it is the tropical plant in Thailand that is an excellent edible fruit. The juice and flesh of them are used in cuisines all over the world. They are a lot and cannot sell out immediately at a high price. From these problems, the overproduction of pineapple is processed to add value. In this project, drying is one method to do with the Pattawia pineapple or Smooth Cayenne. [1] This process requires high energy input because of the high latent heat of water. Thailand is in the tropical zone which has the average solar energy (the average solar radiation intensity) 18.0 $MJ/m^3$day. [2] That mean Thailand has potential to do solar dryer. As known that drying is a process which high energy consumption. If we can substitute by using free solar energy and help to decrease the cost of the process, the research and the technology should be developed.

The aim of this study is design, construction and efficiency development of MSD for drying of pineapple. There are 3 types of solar dryer system; 1. Direct solar drying; DSD, the products are directly exposed to the solar ray. 2. Indirect solar drying; ISD, the ambient air is flowed and heated in flat plate collector then flow in dryer cabinet where products are stored. 3. Mixed solar drying; MSD, It is a combination of direct and indirect solar drying. Products will be dried with both of heat from directly and flowed from flat plate collector. In this project MSD is used, the design of the dryer cabinet, in order to reflect the solar radiation in the cabinet, was modified from Lyes Bennamoum. [3], and the flat plate collector to receive the solar radiation with natural convection was constructed. Guided by the principle of buoyancy of hot air into the dryer and the cold air from the bottom was replaced. Pattawia pineapple was dried in MSD to determine the efficiency of solar flat plate collector and drying system efficiency.

In the drying process, there are two basic mechanisms; 1. The transportation of moisture from the interior of an individual material to the surface. 2. The evaporation of moisture from the surface to the environmental air. The product drying is heat and mass transfer process which depends on external variables such as velocity, temperature, and moisture content of hot air stream, and internal variables such as characteristic of surface of drying product (smooth or rough surface), porosity, density, size, and shape of product and include chemical composition of raw material. (Starches, proteins, lipids, sugars, etc.) [4-5].

## 2. Materials and methods

### 2.1 Materials

In this study, a mixed solar dryer was designed, fabricated. (Fig.1). Mixed solar dryer system (Fig 1a) consists of 2 parts. The first part is the solar dryer cabinet section (Fig.1b) and the second part is the solar flat plate collector. (Fig.1c) The solar dryer cabinet section was developed to increase the efficiency of the solar dryer; the solar dryer cabinet is divided into 3 parts. The first part is inclined with 55°, in order to optimize the collection of radiation in winter. The second part is inclined with 15° to optimum captivated radiations during summer. The last is its floor contains bed paint in black used for the unfavorable drying condition as heat storage system [3]. The structure and frames of dryer cabinet and solar flat plate collector were fabricated from stainless steel thickness 0.2 cm. The dryer cabinet was made up of dimensions with length and width of 80 cm and height of 40 cm, covered with float glass in beside and polyacrylic on the top with 0.2 cm diameter of 8 holes of the vent. In the bottom of the cabinet is covered with 0.3 cm of black galvanized sheet thickness and screen mesh for drying material. Dimensions of solar flat plate collector (120 cm x 80 cm x 8 cm) were fabricated and covered with a transparent glass sheet thickness 0.3 cm. The galvanized sheet of 0.2 cm thickness with black paint was used as absorbing material.

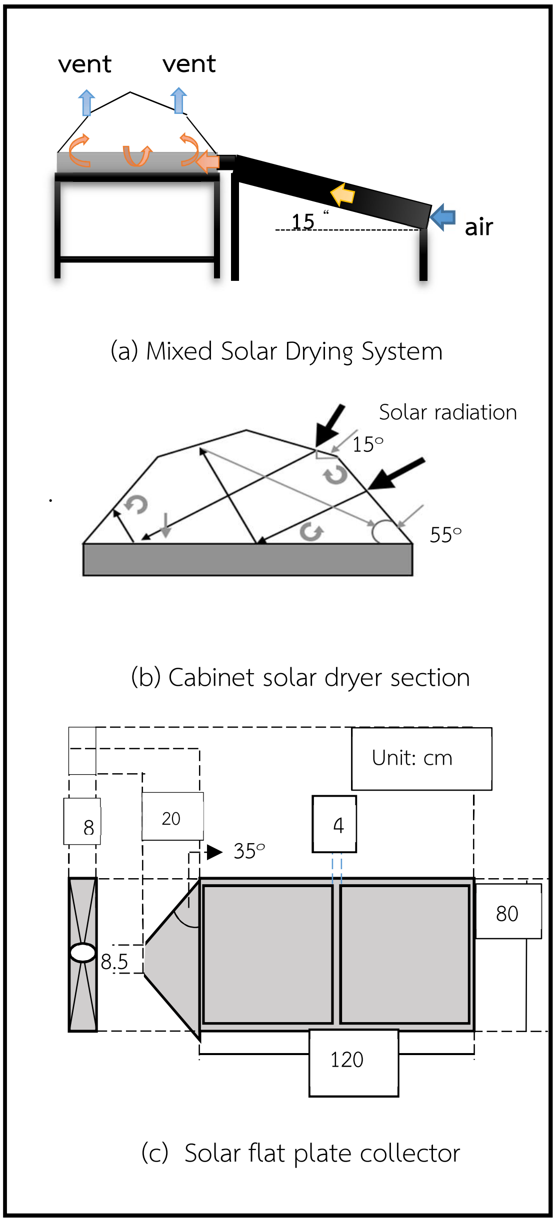


Fig. 1 Mixed Solar Drying System

**2.2 Methods**

After designed and constructed the MSD, the experiment will be done with 3 steps. 1. Determine the maximum temperature of the solar dryer cabinet, solar flat plate collector, and environment temperature. 2. The moisture content of pineapple in an electric oven, and 3. Drying of pineapple in the MSD. In order to determine the maximum temperature, the experiment was started in May with the empty solar dryer system. Fig. 2 was shown the position of the temperature detector. Three thermometers have been placed at position number 1-3 to detect the temperature at the inlet, center, and outlet portion of air in flat plate collector. Another two thermometers have been positioned to measure the temperature of the solar dryer cabinet at position number 4, and 5. Thermometer at the position number 6 has been placed to measure the temperature of the environment during the experiment. The Data were collected every 30 min started from 9.20 a.m.- 8.20 p.m. for 3 days. The average temperature of the solar dryer cabinet, solar flat plate collector, environment air, and time were plotted. The storage solar radiation on the surface and thermal efficiency of solar flat plate collector was calculated by the equation below; [6]

$$I_t = \frac{I_0 \square T}{2\beta(T_b - T_c)} \quad (1)$$

$$\eta_d = \frac{MwL_t}{I_t A_t t} \quad (2)$$

Where $I_t$ is the average storage solar energy on surface ($W/m^2$), $I_0$ is the average solar energy per day (18.0 $MJ/m^3day$), $\Delta T$ is the different temperature between drying and environment (°C), $\beta$ is a parameter of F.K. Forson (0.2), $T_b$, $T_c$ is the boiling point and cooling point of water. $\eta_d$ is the thermal efficiency of solar flat plate collector, $M_w$ is the mass of remove water from product (kg), $L_t$ is the latent heat of vaporization of water (2.257 J/kg), $A_t$ is the storage area of solar flat plate collector($m_2$), M is the mass of the crop, and t is the time of drying

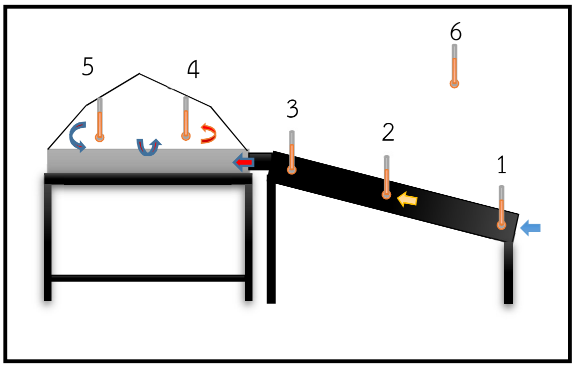


Fig. 2 The position of the temperature detector

Pineapple preparing and processing: drying material was the Pattawia pineapple or Smooth Cayenne was obtained from the East of Thailand. They were cut to 8-9 cm in diameter, 1.3-1.5 cm in thickness and 260 grams in weight before drying in an electric oven at 60 °C until constant weight (5 days), then the equilibrium moisture content was assumed reached. The initial moisture content (% wet basis) is determined by the following equation:

Assume for wet weight basis

$$M_w = \frac{m_i - m_f}{m_i} \times 100 \qquad (3)$$

Where $m_i$ and $m_f$ are the initial and final of material mass (kg), $M_w$ is moisture content (% wet basis).

The 1,060 g of the Pattawia pineapple as mentioned above were dried in MSD, laid on screen mesh in solar dryer cabinet as shown in Fig. 3 and 4. The distance between 2 pieces of pineapple was 2 cm, and 1 cm from the wall. The solar flat plate collector is setup front to the south with incline 15 ° to the horizontal. It was carried out within the period from 28/05/2018-30/5/2018 (3 days). The equilibrium moisture content was assumed reached when the weights of the Pattawia pineapple did not change significantly during the drying period. At drying process, water from the Pattawia pineapple was evaporated until it reached equilibrium weight.

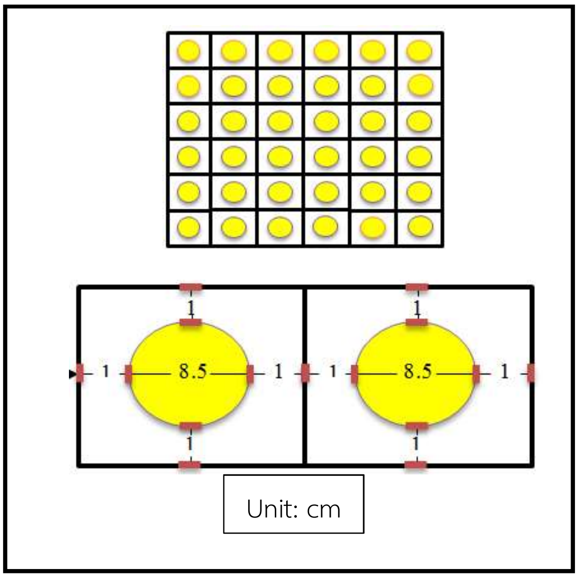


Fig. 3 The arrangement of pineapple in the solar dryer cabinet

Drying system efficiency ($\eta_{ds}$): Total efficiency of MSD system was consumed in evaporating water from pineapple and heat which was consumed in rising up the temperature of pineapple. [7] It is given by the following expression.

$$\eta_{□□} = \frac{□□+□_{□}\ □_{□}\Delta□}{□□_{□}□} \qquad (4)$$

Where $m$ is released vapor mass (kg), $L$ is the latent heat of evaporation (2,260 kJ/kg), $m_p$ is mass of pineapple determine at time $t$ in seconds, $C_p$ is the specific heat of pineapple (3.68 kJ/kg °C), $A$ is the area of the solar dryer cabinet

Fig. 4 drying of pineapple in the solar dryer cabinet

## 3. Results and discussion

Figure 5 shows the completed mixed solar dryer, which is two parts. The first part is the solar dryer cabinet section (80 cm x 80 cm x 40 cm) and the second part is solar flat plate collector (120 cm x 80 cm x 8 cm)

The temperature distribution on a day during the no-load operation is as shown in Figure 6. The X-direction is time and the Y- direction is the

Fig. 5 The completed mixed solar dryer

temperature in degree Celsius. It shown that the temperature of environment air range from 30 °C to 40 °C, while the temperature of flat plate collector varied from 35 °C to 62 °C and the solar dryer cabinet temperature was from 36 °C to 67 °C at the average intensity of solar radiation was 55.73 W/m$^2$. In a solar drying system, the intensity of the solar radiation received affects the efficiency of the system. If more solar radiation received, more heat will be obtained in the solar drying system [8].

The maximum temperature of the solar dryer cabinet is 67 °C, while the maximum temperature of solar flat plate collector and environment are 62 °C and 40 °C respectively. The temperature of the solar dryer cabinet was always higher than the temperature of the environment air throughout the period of the experiment. That means it confirmed that MSD could raise the temperature of the dryer cabinet for effective drying. Thus the temperature of the

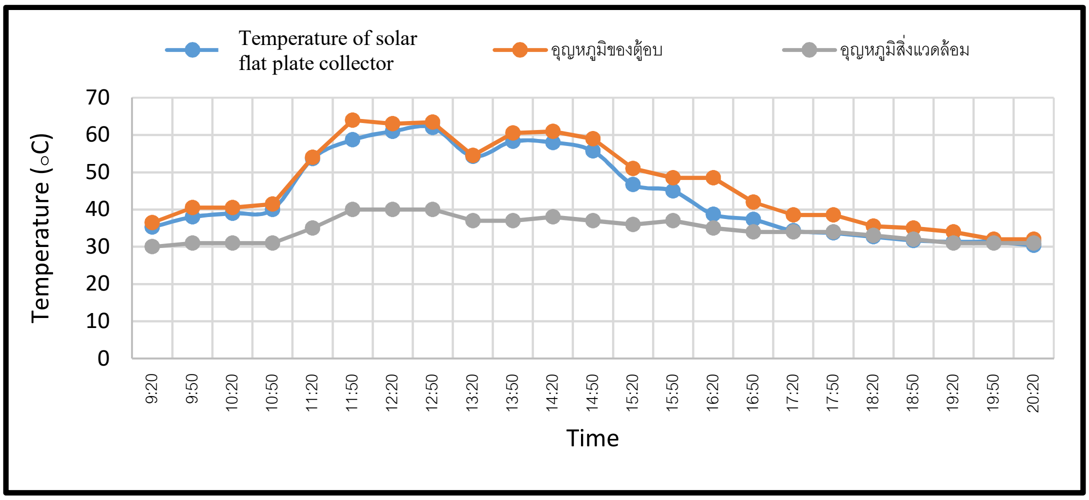


Fig. 6 Temperature of solar dryer cabinet, solar flat plate collector and the environment represented VS. Time

solar dryer cabinet is important in drying efficiency. If it becomes higher, the drying process will be fast, then making the drying time shorter.

The average storage solar energy on the surface which was calculated from Equation (1) is 55.73 W/$m^2$ and thermal efficiency of solar flat plate collector from equation (2) is 30%. It was noted that it had rained in some days,so the maximum temperature of the solar dryer cabinet was not so high.

The initial moisture content of pineapple versus drying time in the electric oven is as shown in Figure 7. The X direction is a time in the day units and the Y direction is moisture content in percentage. The initial moisture content of pineapple from the electric oven (wet basis) according to Equation (3) is 87.46 wt% within 5 days

For drying of pineapple in MSD within the period from 28/05/2018-30/5/2018 (3 days), the

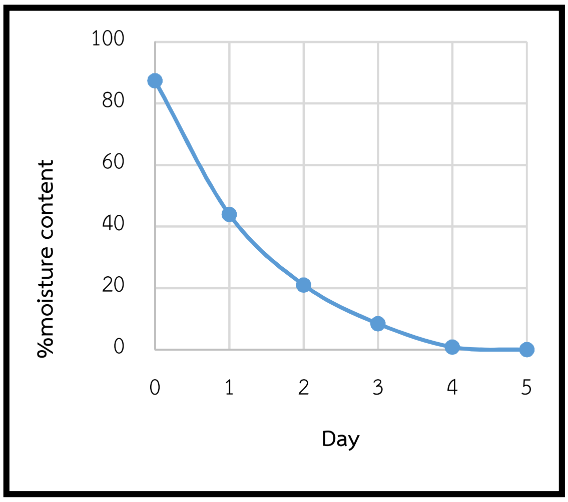


Fig. 7 The initial moisture content of pineapple

initial mass of pineapple 1,060 g with 87.46 %wt basis of initial moisture content is dried. The weight of pineapple after drying and moisture content versus days were represented in Figure 8 and 9 respectively. In day 3, the weight of pineapple was reduced from 1,060 g to 300.84 g and the final moisture content of pineapple is

7.97 wt%. (The industry standard for dehydrated fruits and vegetables was ≤ 8.4 wt%), so the percentage of moisture content was reduced to 91.33 within 3 days. It was noticed that the MSD system, moisture content was faster and lower contents than dried under the direct sunlight. The high moisture content of the samples also affected the temperature of the drying chamber causing the heated air to become moist and reduced the temperature of the air too.

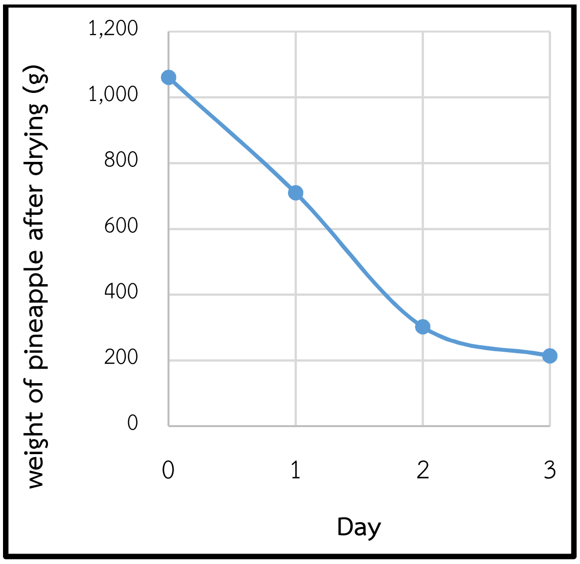


Fig. 8 The weight of pineapple after drying 3 days

In the MSD process, the direct solar radiation passed through the top, front, back, and side of the dryer cabinet is important together with the heated air from flat plate collector. The average temperature obtained for 3 days of drying period was 40-45.7 °C. The average temperature of solar dryer cabinet was 35.9 °C -45.7 °C whereas the average temperature of flat plate collector was 40.8 °C -62.0 °C. The decrease in temperature in the dryer cabinet was due to the vent outlet on the top part of the cabinet, and the high moisture content of the Pattawia pineapple had affected the temperature of the solar dryer cabinet. It was resulting in the hot air become humid while lowering the temperature in the cabinet. In addition, the average storage solar energy on the surface was 55.73 W/m$^2$, so that the useful gain of heat was very low.

Drying system efficiency of MSD was determined to follow to the Equation (4). It was found that the total drying system efficiency of MSD was 13 %

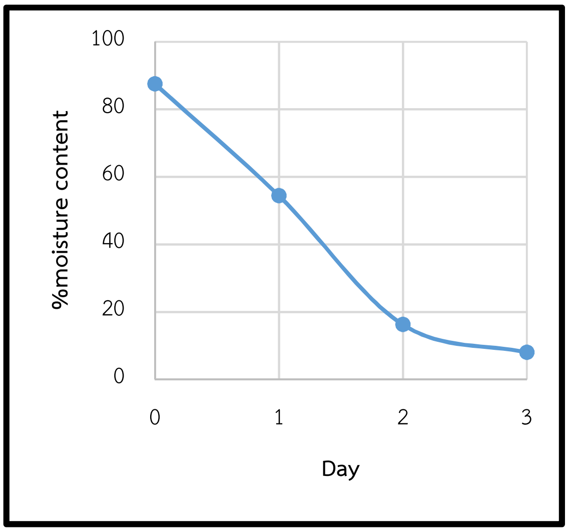


Fig. 9 The moisture content of pineapple

## 4. Conclusion

A mixed solar drying system for drying of pineapple, the dryer cabinet was modified from Lyes Bennamoum to increase the performance of MSD. The moisture content was faster and lower content than dried under direct sun radiation. The physical properties of dry pineapple were suitable for sale, nice color on skin, soft taste and sweet smell. (The industry standard for dehydrated fruits and vegetables was ≤ 8.4%) The percentage of moisture content could be reduced to 91.33 wt%, the efficiency of the solar collector and drying system efficiency of MSD were 30 % and 13 % respectively. It will be more efficiencies of solar dryer cabinet and solar flat plate collector when the MSD is operated on a sunny day.

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