Comparative analysis of the performance of cabinet solar dryer and open sun drying for Banana slices

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Abstract. Sun-drying is the traditional method of preservation fruits, crops and vegetables. It is also an alternative way to prevent the shortage of natural resources. But traditional sun drying causes damage to food quality and cannot prevent dust, any other insets and birds. For this reason, this paper represents the design calculation of cabinet solar dryer for 1kg of banana slices and the comparative investigation of cabinet solar dryer and open sun drying. The thickness of a banana slice is taken 4mm. After 14 hours of drying time in two days experiment, moisture content of banana slices inside of the cabinet dryer is 14% meanwhile open sun drying is still 40%. As a result, the desired moisture content of banana slice can be received quickly in cabinet solar dryer. And then, it can easily construct with locally cheap and environmentally acceptable, non-hazard materials. Cabinet solar dryer can also reduce the loss of food due to high temperature, insects, and birds. Hence, it is more effective than open sun drying.

1. Introduction
Drying is a method of dehydration of food products which means reducing the moisture content from the food to improve its shelf life by preventing bacterial growth [1]. Drying is the essential process to keep fruits, crops and paddy without spoilage for the desired time. Open sun drying is the cheapest and easiest way, but there was a lot of limitations such as the birth of microorganisms and mould due to its unstable temperature and weather conditions. In traditional sun drying, due to its unstable temperature, the drying materials loss their vitamins that are required for human health, their colour and texture. During off sunshine hours and cloudy days, it may encourage the birth of mould. The required temperature for drying food is the range from 30°C to 60°C [2]. In traditional sun drying, it needs labours to look after the drying materials for the prevention of damage by insects, birds, other herbivores, rain, dust and wind. In large scale preservation of food business, electrical drying machines are used. But farmers and households can’t afford to use this type of machines because of their large power consumption and expensive cost. In our country, Myanmar, a lot of agricultural products are spoiled every year by adverse climate conditions during the harvesting period. The solar dryer can maintain the required temperature of food. It reduces the spoilage of food by touching the direct sunlight, unlike open sun drying. Drying time is shorter than open sun drying. It prevents the damage of food by external enemies. Unlike electrical drying mechanisms, it is more economical because it has a low cost for power consumption. Some types of dryers have no cost for power consumption especially natural convection type and direct type solar dryers. For these reasons, a solar dryer is a suitable solution to solve these problems for farmers and small business. The paper described that the comparison between sun drying and solar drying and obtained that solar dryer generates high temperature, lower relative humidity, lower product moisture content and reduce spoilage during the drying process than
sunshine [3]. The drying time reduces about 20% and produces a better quality of drying products in the case of using a cabinet solar dryer and compare with open sun drying [4].

There are different types of solar dryers that are basically classified as natural convection type solar dryer, force convection type solar dryer, direct type solar dryer, indirect type solar dryer and mixed-mode solar dryer by various methods depending on the usage of mechanisms for airflow and how to exposure to sunlight whether directly or not [5]. In this present work, design considerations and comparative study of moisture content, relative humidity, the temperature of cabinet solar dryer for 1kg of the Banana slices with open sun drying. The recommended thickness of the banana slice to be dried is 4-5 mm [6]. In this paper, 4 mm of Banana slices were used.

2. Design Consideration

The amount of moisture to be removed, $m_w$ (kg)

$$m_w = m_p \left( M_i - M_f \right)/(100 - M_f) \quad (1)$$

where
- Initial moisture content of the material $M_i$
- Final moisture content of material $M_f$
- Initial mass of material(kg) $m_p$
- Moisture content dry basis, $M$

$$M = M_f / (1 - M_f) \quad (2)$$

- Water activity, $a_w$

$$a_w = 1 - \exp\left\{ -\exp\left\{ 0.914 + 0.5369 \ln(M) \right\} \right\} \quad (3)$$

- Equilibrium relative humidity, ERH

$$ERH = a_w \times 100 \quad (4)$$

- Average drying rate, $m_{dr}$ (kg of water/h)

$$m_{dr} = m_w / t_d \quad (5)$$

where $t_d$=drying time (hour)
- The mass flow rate of air, $m_a$ (kg of dry air /h)

$$m_a = m_{dr} / (w_f - w_i) \quad (6)$$

where,
- $w_i$ = initial humidity ratio (kJ/kg of dry air)
- $w_f$ = final humidity ratio (kJ/kg of dry air)

- The total heat energy required to remove moisture, $E$ (MJ)

$$E = m_a (h_f - h_i) \times t_d \quad (7)$$

where,
- $h_i$ =initial enthalpy of moist air (kJ/kg)
- $h_f$ =final enthalpy of moist air (kJ/kg)

- Collector Area, $A_c$ (m$^2$)

$$A_c = E / I \times \eta \quad (8)$$

where $I$ = incident solar radiation (MJ/m$^2$)
- Collector efficiency $\eta$

- Volumetric airflow rate, $V_a$ (m$^3$/s)

$$V_a = m_a / \rho \quad (9)$$

where, $\rho$ =density of air (kg/m$^3$)
- Vent Area, $A_v$ (m$^2$)

$$A_v = V_a / v \quad (10)$$
where, \( v \) = wind speed (m/s)

2.1. Desired data for design calculation

Initial moisture content (\( M_i \)) 92.3%
Final desired moisture content (\( M_f \)) 14%
Ambient air temperature 30 °C
Ambient relative humidity 70%
Collector efficiency (\( \eta \)) 30%
Wind speed (\( v \)) 1 m/s

| Parameter | Value |
|-----------|-------|
| Daily average incident solar radiation in September for Myanmar (\( I \)) | 15.22 MJ/m² |
| Desired drying temperature (\( T_f \)) | 56°C |
| Drying time (\( t_d \)) | 7 hr |
| The thickness of a banana slice | 4 mm |
| Tilted angle (inclination angle of glass collector to cabinet) | 15° |

2.2. Results of Design Calculation

Table 1 shows the results of design calculation for cabinet solar dryer for 1 kg of banana slices. Design calculation based on the weather condition of Yangon Technological University, Myanmar. Figure 1 and Figure 2 describe the schematic diagrams of the cabinet solar dryer according to the design calculation results.

| Parameter | Value |
|-----------|-------|
| the initial mass of material, \( m_p \) | 1 kg |
| amount of moisture to be removed, \( m_w \) | 0.91 kg of water |
| moisture content dry basis, \( M \) | 0.15 |
| water activity, \( a_w \) | 0.59 |
| equilibrium relative humidity, ERH | 59% |
| average drying rate, \( m_{dr} \) | 0.13 kg/h |
| initial humidity ratio, \( W_i \) | 0.0185 kg of water/kg of dry air |
| \( h_i = \) initial enthalpy | 77 kJ/kg of dry air |
| \( h_f = \) final enthalpy | 104 kJ/kg of dry air |
| final humidity ratio, \( W_f \) | 0.0256 kg of water/kg of dry air |
| mass of airflow rate, \( m_a \) | 18.403 kg/h |
| the total heat energy to evaporate water, \( E \) | 3.4782 MJ |
| collector area, \( A_c \) | 0.761 m² |
| collector length, \( l_c \) | 1 m |
| collector width, \( b_c \) | 0.761 m |
| The density of air, \( \rho_a \) | 1.2 kg/m³ |
| volumetric airflow rate, \( V_a \) | 0.0245 m³/s |
| air vent area, \( A_v \) | 0.0245 m² |
Figure 1. Schematic diagram of cabinet solar dryer

Figure 2. Schematic diagram of cabinet solar dryer (Side View)

2.3. Components of Cabinet Solar Dryer

The top part of the cabinet solar dryer is covered by a glass plate. Most of the researchers suggested to use the glass thickness range from 4-5 mm and it should be a good transparent for solar radiation [1, 6, 7]. In this paper, 4mm thickness, 1 m x 1.067 m area of transparent glass is used. Some paper described the common materials used for the cover plate are plastic and polycarbonate. The tilt angle of the glass cover is 15° due south.

Absorber Plate is used to absorb the solar heat energy. Black painted of 1 mm thick aluminium plate is placed about 0.15 m height from the bottom of the dryer. It absorbs heat passing through the glass and re-emits heat to the passed inlet air inside the cabinet. Common materials for absorber plates are copper, galvanized steel sheet, aluminium sheet.

An insulating material is used to prevent leakage the emitted heat energy from the absorber plate to the surround of the cabinet. 2.54 cm thickness Styrofoam sheets are used to minimize the heat transfer from the walls of the drying chamber to the surroundings. All sides of the drying chamber and bottom of the absorber plate are covered by these Styrofoam sheets. Some other common insulating materials are thermocole sheets, fibreglass, foam, and sawdust.

The drying chamber is mostly made up of readily available materials especially plywood. Steel, iron, copper, plywood and aluminium can be also used. Plywood is a poorer heat conductor and cheaper than aluminium. But aluminium sheets are selected in this chamber to prevent the condition of being swollen during the rainy season.
The tray is used to spreading drying materials over it inside the drying chamber. The 1 cm x 1 cm iron mesh tray is used to allow the airflow inside the cabinet. And also, the measuring devices such as solar power meter, infrared thermometer, thermocouple, datalogger, hygrometer, air velocity meter are used to measure and collect the data during the experiment.

3. Experiment Procedure
Cabinet solar dryer is set up at the unshaded place in YTU campus faced south. Two hygrometers are used to measure the relative humidity of the environment and inside of the cabinet. The inside temperature of cabinet and ambient temperature is measured by two thermocouples that connected to a data logger. The infrared thermometer is used to measure the absorber plate temperature. To measured solar irradiance, solar power meter (TES1333) is used. Figure 3 shows the inside view of cabinet solar dryer. Figure 4 shows the experimental set up for open sun drying for 1 kg of banana slices. Experiments were made at the same weather condition, at the same place and at the same time.

Figure 3. Inside view of cabinet solar dryer

Figure 4. Experimental set up for open sun drying

4. Experimental Results and Discussions
Solar radiation of the experimental site is measured hourly by solar power meter during drying time. Variation of solar radiation on each day is shown in Figure 5 and Figure 6. On the first day of the drying process, solar radiation gradually increases from 735.8 W/m² to 1007 W/m² between 9 am to 1 pm and then decreases to 63.6 W/m² at 4 pm. It was found that the solar radiation sharply decreases from 1 pm to 2 pm because of weather condition on that day. At the second day of the drying process, solar radiation slightly decreases from 304 W/m² and after that sharply increases to 1100 W/m² about noon and then dropdown. To be summarized, maximum radiation is obtained about (1000 to 1100) W/m² during 12 pm to 1 pm and it was found that the fluctuation of solar radiation was very high and it depends on weather condition.
Variation of the relative humidity of cabinet solar dryer and open sun drying are shown in Figure 7 and Figure 8 for the first and second day of the experiment. The relative humidity of open sun drying is always higher than cabinet solar dryer in all time of the experiment in two days. Because of this reason, the cabinet solar dryer is more effective in drying than open sun drying process. According to these
results, it was found that the relative humidity is a little bit high in the morning and afternoon and the lowest is at the afternoon both two days of the experiments.

**Figure 8.** Relative humidity on the 2nd day

**Figure 9.** Moisture content of Banana on the 1st day

**Figure 10.** Moisture content of Banana on the 2nd day
Variations of moisture content of banana slices for each day are shown in Figure 9 and Figure 10. In cabinet solar dryer, moisture content was fast removed than open sun drying at all of the drying time on the first day. After 7 hours of the first day, it can reduce the moisture content of banana about 93% to 29% in cabinet solar dryer meanwhile only reduce 93% to 70% in open sun drying. At the end of the experiment of two days, the moisture content of banana was 14% in cabinet solar dryer meanwhile only 40% in open sun dryer. It can be concluded that the removing of moisture content from the food is quite effective in cabinet solar dryer.

Figure 11 and Figure 12 describe the temperature distributions of the absorber plate, inside the cabinet and open sun outside. All of the three temperatures of the absorber plate, inside the cabinet and open sun outside, was maximum at 1 pm on the first day of the experiment. At the day, the temperature of all three conditions decreased at noon because of the weather condition. The temperature of the absorber plate is highest among them because the black painted absorber plate absorbed heat energy from the direct sunlight and emits heat energy inside of the cabinet solar dryer. It also clear that the temperature of the inside of the cabinet more than the outside temperature. It can dry the food faster inside of the cabinet solar dryer. From the figure 12, nearly stable maximum temperature could be obtained from 10 am to 12 noon on the second day of the experiment.

![Temperature distribution on the 1st day](image1)

**Figure 11.** Temperature distributions of Banana on the 1st day

![Temperature distribution on the 2nd day](image2)

**Figure 12.** Temperature distributions of Banana on the 2nd day
5. Conclusions
Cabinet solar dryer can reduce moisture content than open sun drying under the same weather condition even the cloudy hours without the aid of other heat energy source because the absorber plate absorbs heat during sunny hours and emits it. During 14 hours of drying time, cabinet dryer can reduce moisture from initial moisture content of 93% to final desired moisture content of 14% while the open sun can reduce 40%. For this reason, the desired moisture content of the food could be reached quickly in cabinet solar dryer without the use of any extra energy or electricity. And then, it can easily construct with locally cheap and environmentally acceptable, non-hazard materials. Cabinet solar dryer can also reduce the loss of food due to high temperature, insects, and birds. Hence, it is more effective than open sun drying.

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