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Performance Analysis of a Hybrid Solar Dryer Incorporating Adaptive Glass Tilting

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Abstract

Solar drying is the most environmentally sustainable food drying method of agricultural products reducing post-harvest losses and enhancing food preservation. Although it is environmentally sustainable, the efficiency of the readily available low-cost solar dryers not high. One of the main causes is the ineffective design of the transparent glass cover, which is usually placed flat or at a fixed angle, which reduces the amount of solar radiation absorbed. We proposed tilting the transparent glass cover according to the sun's position to increase the solar radiation receiving capacity. This paper exhibits the performance of a prototype of a portable novel solar dryer equipped with an adaptive glass tilting mechanism and PV panel to drive. The dryer features a transparent glass cover that tilt following the sun's angle, a PVC body insulated with fiber wool, and an insulated interior with black-painted absorber walls to maximize heat absorption. The study aimed to build a solar dryer keeping the cost minimum considering the perspective of low-income farmers of Bangladesh, yet effective by using readily available material mostly. Experiments were conducted with two food samples which were potatoes and grapes and the dryer was tested in two different configurations: 1) traditional approach without glass tilting; 2) with adaptive glass tilting. The experimental investigation showed that the average air temperature of the drying chamber was 38.2 °C and 37.7 °C with tilting and without tilting configurations respectively. The weight loss for potatoes with tilting and without tilting configurations was 70% and 62%, respectively, and for grapes, it was 28% and 24% over 4 hours. The highest specific moisture extraction rate (SMER) was 0.47 kg of water/kWh with tilting configuration and 0.43 kg of water/kWh without tilting. The maximum drying efficiency was 31.54% with tilting and 29.12% without tilting.

Keywords: Solar dryer, adaptive glass tilting, absorber walls, energy efficiency.

1. Introduction

Drying of food products is a complex process that includes simultaneous mass and heat transfer. It is a method or process of food preservation in which food is dried by reducing the moisture contents (dehydrated or desiccated). This phenomenon inhibits the growth of bacteria and yeasts. [1] The solar drying system is mainly classified into two types: Active solar dryers and passive solar dryers. In active solar dryers, airflow is conducted in a forced method. The air in a passive solar dryer is heated and moved around by wind, buoyancy force or a combination of the two. Each solar dryer is further classified into three types: direct solar drying, indirect solar drying, and mixed-mode solar drying. A direct solar dryer uses the sun's heat to dry the products directly with a transparent cover. In indirect-type solar dryers, a solar collector is used to absorb the incident solar radiation and heat the air which passes over the drying chamber. Mixed-mode dryers are a combination of direct and indirect solar dryers. [2] [3] The solar dryer we used was an active direct solar dryer.

Drying potato is useful as it is Herbaceous in nature and the fourth most important food crop in the world after rice, wheat, and maize. [4] According to the results of the experiment conducted by Ammar et all, the average air temperature of the drying chamber is 50 °C, and the time required for drying potatoes starting at the initial moisture content (MC) of 84.17% until the final MC of 12.5% is 6h. The highest specific moisture extraction rate value was obtained as 1.074 g water/kWh. The drying efficiencies ranged from 20.37% to 34.01%. [5] Drying grapes is

also useful as Grapes have a high moisture content, so even in cold storage facilities, there is a greater risk of spoiling after harvest. Grapes' high sugar and moisture content encourage the growth of microorganisms, which in turn leads to grape deterioration. [6] According to Ilhem Hamdi et al., it is found that in grape drying using a solar dryer the moisture content of grape was reduced to 0.22 (g water/g dry matter) from its initial moisture content of 5.5 (g water/g dry matter) in 128 h. [7] A glass tilting mechanism is used to optimize solar energy capture. The primary aim is to increase the overall efficiency of the solar dryer by adjusting the angle of the transparent cover (glass) based on the sun's position. By tilting the glass at optimal angles throughout the day, more solar radiation can be trapped within the drying chamber, thus maintaining higher internal temperatures and accelerating the drying process. [8] The aim of our work is to focus on designing, fabricating and the performance investigation of simple cost-effective direct solar dryers suitable for Bangladesh. This study includes the careful examination of the dryer temperature, wet basis moisture extraction, specific moisture extraction rate and overall efficiency with the incorporation of adaptive tilting of the transparent cover which prove to be superior to the common method of solar drying.

2. Materials and Method

2.1 Description of the Solar Dryer

The solar dryer projected as in Figure 1 and Figure 2 was constructed with two layers of PVC board of 3mm thickness with insulation of fiber wool between both layers. The length of the dryer was 19.75cm with heights of 12cm and 18cm respectively. The inlet and exit, both having a diameter of 10.5cm for airflow, were cut out along the width (14.5cm) of the dryer. A plastic dust filter was used in both inlet and exit and a 12 DC fan was mounted on the exit which was driven by a 20W PV panel for active flow. MS sheets, painted black, placed inside the dryer were used as additional solar absorbers which helped in capturing further heat. A 3mm thick glass panel (19cm×12cm) was used as a transparent cover to trap heat which rested on the shaft that was driven by an SG-90 servomotor controlled by an Arduino UNO microcontroller. The shaft was further supported by two bearings(8mm×22mm×7mm). Polythene sheets were wrapped around the glass to eradicate heat loss through openings around the glass panel. The dryer housed a tray (16cm×12.3cm) which contained the necessary samples for testing.

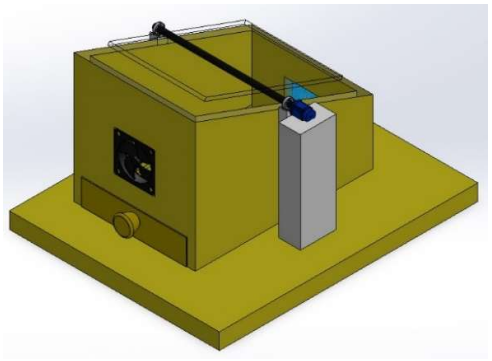


Fig. 1: 3D view of the solar dryer

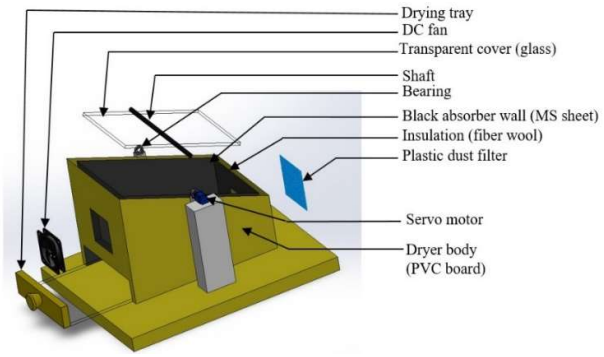


Fig. 2: Exploded view of the solar dryer

2.2 Instruments for Measurement of Drying Performance Parameters

The output current and voltage were taken with a multimeter (model: DT-9205A, voltage: accuracy: ±0.5%, range: 200mV-1000V, current: accuracy: ±2%, range: 20μA-10A). The wind velocity through the 12V DC fan was recorded by a Reed rotating vane anemometer (model: LM-81AM, accuracy: ≤ 20m/s: ±3%FS; >20m/s: ±4%FS, range: 0.4-30m/s). The temperature of the dryer and surroundings were measured by Hanna pyrometer (model: HI 8757, accuracy: ±0.5%, range: -50ºC - 1350ºC, auto ranging: 0.1ºC: -50ºC - 199.9ºC; 1ºC: 200ºC - 1350ºC). The solar intensity was measured by a Hukseflux pyranometer (model: LI-19, calibration uncertainty: 0.1%). The sample weights were recorded using a R.P.S King digital balance (capacity: 0-40kg, division: 2g, accuracy: ±0.01g).

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2.3 Experimental Setup and Procedure

The potatoes were thinly sliced, the grapes were peeled and 100g of both samples were taken as initial mass. 50g of both samples were laid out on the drying tray and another 50g were laid out directly under the sunlight. The PV panel was placed along the dryer to provide stable power to the DC fan and a laptop was used to drive the microcontroller. On the first day, the tilting configuration was tested, therefore, the servo motor was coded to rotate at an angle of 15 degrees an hour. But on the second day, with fresh samples, the dryer was tested without tilting so no power was given to the servomotor and the glass was placed at the default position. In both cases, the testing continued form 10:20 am through 2:30 pm. All essential data were recorded at roughly 30 minutes intervals.

3. Performance Analysis

This study focused on the examination of the following parameter:
Wet Basis Moisture Content: This indicates the moisture content removed per unit weight of the sample. In other words, wet basis moisture provides an image of the quality of the output of the solar dryer.
Specific Moisture Extraction Rate (SMER): SMER demonstrates the moisture that is extracted through the supply of unit energy to the dryer.
Overall Drying Efficiency: Efficiency offers the idea of the ratio of the total output to total input. In this case, the total energy extracted to the energy supplied. This gives a clear view of the drying performance.
These parameters are used to evaluate and optimize the drying process of the solar dryer under study.

3.1 Wet Basis Moisture Content

The moisture content of the potato and grape samples were measured using a wet basis method. It is expressed as the amount of moisture removed per initial weight of the samples. The wet basis moisture content can be found using the following equation. [9]

$$W_{wb} = \frac{W_f - W_i}{W_i} \quad (1)$$

Where,
W_{wb} = Wet basis Moisture Content (kg)
W_f = Final weight of the drying specimen (kg)
W_i = Initial weight of the drying specimen (kg)

3.2 Specific Moisture Extraction Rate (SMER)

The specific moisture extraction rate (SMER) is defined as the moisture extracted per unit of energy incident on the dryer. The total energy consumption equates to the sum of the total solar energy incident on the dryer and the energy consumed by the p-v panel as noted in the equation. [10]

$$SMER = \frac{W_{extracted}}{Pt + Ai} \quad (2)$$

Where,
$W_{extracted}$ = Weight of the moisture extracted from all drying specimens (kg)
P = Power supplied to the fan (kW)
i = Solar intensity (W/m^2)
A = Effective surface area (m^2)
t = Drying time (hours)

3.3 Overall Drying Efficiency

The overall efficiency is defined as the amount of relative energy required to dehydrate the sample to the amount of total energy supplied. The energy incident remains the same as equation (2) as the following equation portrays. [10]

$$\eta = \frac{W_{extracted} \times h_{fg}}{Pt + A} \times 100\% \quad (3)$$

Where,
η = Overall Drying Efficiency
h_{fg} = Latent heat of vaporization (kJ/kg)
t =Drying time (seconds)

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4. Result and Discussion

4.1 Variation of solar intensity and dryer (tilting and non-tilting) temperature with time

Figure 3 illustrates the solar intensity for both days of testing. The first day of the test showed a steady trend at first but faced a massive decrease in intensity (226 W/m2) around 1:00 pm as the weather became cloudy and the sun was barely visible and as Figure 4(a) and Figure 4(b) show the temperature around this time also dropped but the dryer with tilting setup retained its temperature to around 40oC and maintained a higher temperature at all times. On the contrary, the next day of testing showed a stable trend of both solar intensity (avg. 753.25 W/m2) and temperatures (dyer avg. 37.7oC; ambient avg. 37.125oC) which increased till 12:00 pm but started to drop then and reached a minimum of (537 W/m2, 36.2oC ambient) at 2:00 pm. The dryer held out a greater temperature for both setups at all times due to its practical design.

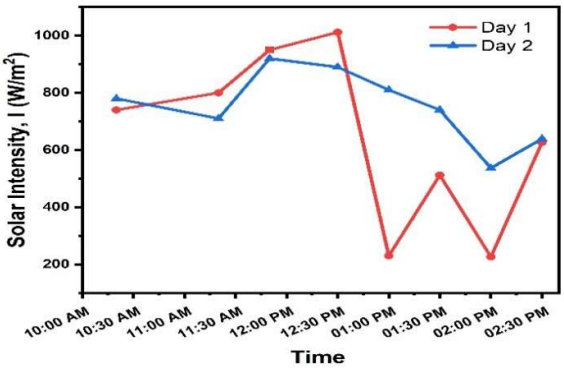


Fig. 3: Variation of solar intensity with time

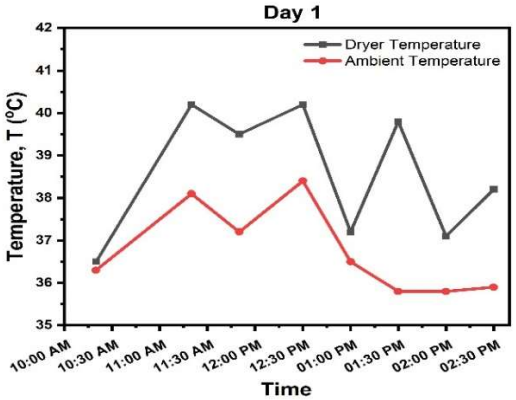


Fig. 4(a): Variation of dryer (with tilting) temperature with time

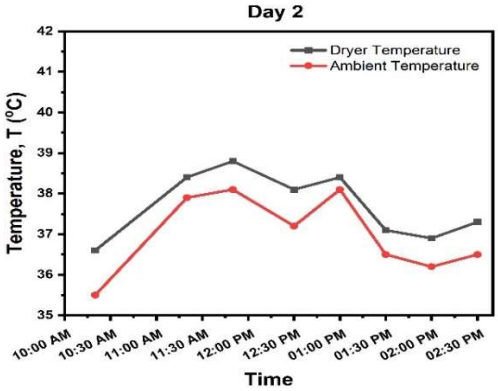


Fig. 4(b): Variation of dryer (without tilting) temperature with time

4.2 Variation of wet basis moisture content of potato and grape with time

Figure 5(a) and Figure 5(b) illustrate the wet basis moisture extraction of both potato and grape samples. It is found that the tilting configuration has a higher yield than all cases with a maximum wet base moisture of 0.7 in the case of potatoes and 0.28 in the case of grapes as the adaptive tilting helped in providing greater heat to the interior for vaporization of water particles on samples. Without adaptive tilting, the dryer lost around 11% and 14% of its yield for potatoes and grapes, respectively, with their maximum wet base moisture being 0.62 and 0.24. Under direct sunlight, almost a quarter of the drying potential was lost with the values decreasing to 0.52 (potatoes) and 0.22 (grapes). If the surrounding condition could be kept the same for both setups of the dryer a more rational and accurate observation could be recorded with the result being more appropriate. Nonetheless, without any dynamic parts, the dryer still holds a higher yield than direct sunlight drying but the greater moisture than all cases

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by the adaptive tilt configuration proves the superior ability of this enhancement.

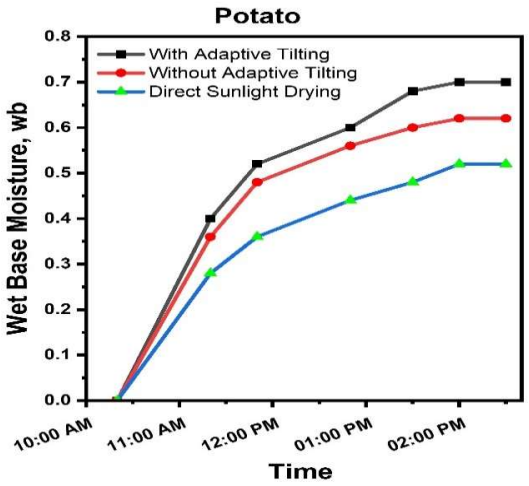


Fig. 5(a): Variation of wet basis moisture content of potato with time

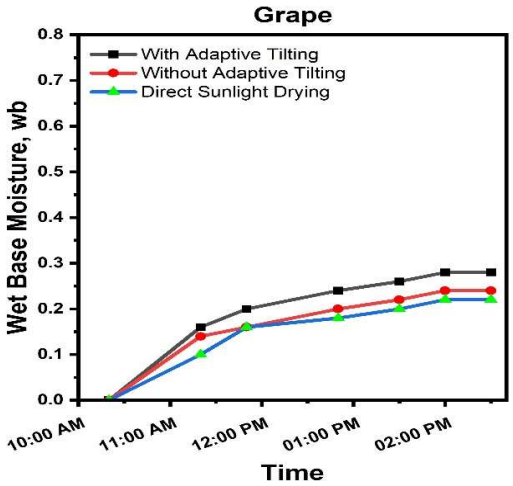


Fig. 5(b): Variation of wet basis moisture content of grape with time

4.3 Variation of SMER and overall drying efficiency with time

Figure 6 shows the specific moisture extraction rate for both configurations of the dryer. Whereas Figure 7 shows the overall drying efficiency. Both curves follow a similar downward trend as they are governed by almost identical equations noted by equations (2) and (3). From Figure 6 it can be observed that Specific Moisture Extraction Rate followed a steady downward slope up until 1:30 pm where it saw a notable spike with its value reaching 0.26 for the case of adaptive tilt. The reason behind this can be an increase in solar intensity and

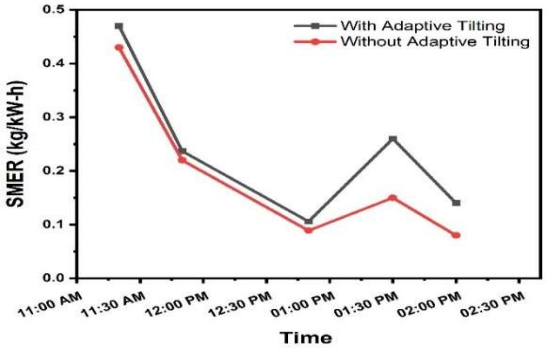


Fig. 6: Variation of SMER with time

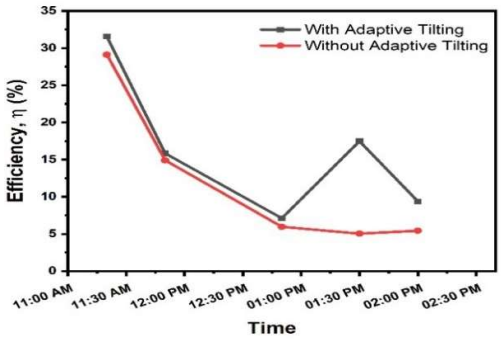


Fig. 7: Variation of overall drying efficiency with time

temperature around the same time which are visible in Figures 3, 4(a) and 4(b). A similar fashion is also recorded for the case of the overall efficiency (17.48% at 1:30pm) because of the same reasons. The moisture extraction rate reduced as the testing hours progressed and the samples lost their moisture which is the root of the downward trend of SMER and efficiency curves. Overall, the adaptive tilting setup held a better performance with a maximum SMER difference of 0.11 kg/kW-hr and an efficiency difference of 12.44%. This setup showcased an SMER range of 0.106-0.47 and an efficiency range of 7.11-31.54%. The setup without any tilting also portrayed a reasonable SMER range of 0.08-0.43 and an efficiency range of 5.04-29.12%.

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5. Conclusion

In this study, an improved direct solar dryer with adaptive glass tilting was prototyped and proposed as an alternative against the conventional direct solar dryer (without glass tilting) and direct sunlight drying. The materials utilized in the proposed solar dryer were very inexpensive and readily accessible in the local market. Due to certain limitations, tests for both setups could not be conducted on the same day with same intensity and wind velocity. The authors plan to continue future research on with limited varying surroundings. If the noted limitations could be overcome, the overall feasibility of the system would increase considerably. Based on the results, the average air temperature of the drying chamber was 38.2 °C and 37.7 °C for the tilting and without tilting configurations, respectively. The weight loss for potatoes with tilting and without tilting configurations were 70% and 62%, respectively, and for grapes, they were 28% and 24% over 4 hours. The highest specific moisture extraction rate (SMER) was 0.47 kg of water/kW-hr for the tilting configuration and 0.43 kg of water/kW-hr without tilting. The maximum drying efficiency was 31.54% for the tilting configuration and 29.12% without any tilting. Therefore, the incorporation of a tilting mechanism offers a simple, cost-effective enhancement to solar drying systems, making them more competitive with traditional, energy-intensive drying methods over any conventional solar drying method. Future research should investigate automated tilting systems to further increase drying efficiency.

6. Acknowledgement

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