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Abstract

About 33.3% of global food production is lost to spoilage every year. At current rates, that amount is adequate for feeding an average of 300 million people around the world. This huge loss can be decimated to 13.17% if food spoilage is avoided or managed better. One technique for minimizing food waste is solar drying. West Africa and locations around the equatorial plane are described by average daily insolation of about 4-6 kWhm^{-2}. In effect, this energy source could be applied to curb the problem of food spoilage and wastage. Another side attraction of drying with solar is that, it offers year-round availability of food crops. In this study, solar drying is investigated with the principle of blackbody radiation using an electronic data logger coupled with the Arduino Uno, SD Card Module, DHT22 Temperature and Humidity Sensor, SD Card, and Connecting wires to record temperature and humidity data. The output was 56.3°C and 46.8°C for the upper and lower limit of temperature respectively, yielding an average difference of about 10°C. The interaction of sensible blackbody radiation within a four-tier rock bed was crafted into a novel solar dryer design. With this relatively high-temperature gradient between the upper and lower, a blackbody solar dryer constructed was suitable to preserve the both quality and shelf life of agricultural produce.

Keywords: Solar energy, Solar dryer, Thermal energy storage, Rock bed

1. Introduction

In accordance with United Nation Sustainable Development Goals 1 and 2, no poverty and zero hunger. Local farmers utilize direct sun drying of their crops as a cheap and readily available option. In all, solar drying units are usually employed in the preservation of limited amounts of grains, dairy products, assorted fruits, vegetables, meat, and fish. [1-5]. All Solar dryers are either grouped under direct or indirect categories. The distinction lies in whether the products to be dried are directly or indirectly exposed to insolation. Amidst the repertoire of solar drying

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techniques, preservation of material is paramount consideration. Consequently, the material could be dried by hot air circulation atypical of industrial settings, air-driven fans may provide the air drift in passive systems. Others belong to the distributed indirect regime, while another subset is of the mixed mode variant [6]. Other advantages such as minimal acreage requisition, and short drying intervals are compensations that still lure low- and middle-income farmers to open drying. This is largely because drying food products industrially by burning fossil fuel is uneconomical and out of reach financially for small-scale farmers. In general, of the myriads of drying techniques for agricultural products, each method has its own merits and demerits [7-9]. For instance, exposing food products to direct open-air sunlight for preservation causes deterioration in the food products [10]. Food products also become prone to spoilage due to adverse effect of wind, dust, and rain, and they also get infected or eaten up by birds, rodents, and insects. Burning fossil fuels is not environmentally friendly, electricity is scarce in rural developing countries and so is not a readily available option. The drying unit design assume different shapes and construction types such as a Cabinet dryer which comprises a box, produced from readily sourced materials [11]. These include sheets of aluminum, brick, plywood, concrete, or even galvanized iron, which gives insulation at its base and sides. It is typically a rectangular container roofed with a single or double layer of transparent solid. Bored holes allow fresh air to ventilate the cabinet. Outlet vents positioned at the upper, lateral, and hinder sides of the cabinet, ensure the exit of hot gases as temperature increases using natural convection [12].

A variation to the simple cabinet type is an indirect solar cabinet dryer in which a traditional air heater and collector are incorporated. Air circulation however is through natural convection, only effective for small scale dying conditions [13]. A consensus lies in the probability of localized overheating and long drying times in the simple integral solar dryers. In order to solve this problem, a solar chimney is coupled to produce air buoyancy. It has been recorded to reduce air drying time by more than one-fifth percent [14]. Current designs feature passive air heating solar collectors, solar chimney in a transparent drying chamber. In solar greenhouse dryers, a larger degree of control over the drying process eliminates the problem of over drying and it has capacity for large scale drying. Another perspective to solar drying is given by solar PVT dryers wherein thermal conversion of moisture occurs strictly through heat absorbed by collectors and heated air. In a particular case, DC solar powered fans were used to circulate air with an outstanding thermal efficiency of 61.6% [15-17]. In another development, a hybrid-type greenhouse PVT solar dryer capable of multi-tasking was introduced. Forced air circulation was by DC fans powered by PV modules, absorbed heat transfers to the drying cabinet followed after, and thirdly, PV was arraigned to shield produce from direct glare of the sun to enhance product quality. When used for tomatoes, initial moisture content was reduced from 91.9 to 22.3% in just 44 hours. In addition, the product quality was improved simultaneously as de-coloration was reduced [18-19]. Research is ongoing for cutting -edge solar drying technologies. However, in forced solar drying, since shading induced chlorophyll breakdown, immature fruit are prone to substandard appearance if dehydrated [20].

2. Materials and Method

The following components were used for the construction; fasteners, gravel (rock-bed), tarpaulin, plastic material, mesh, plywood, metal trays, digital thermometer, data logger, SD Card Module, Arduino UNO, connecting wires and sensors.

The solar collector chamber was constructed with galvanized iron metal of dimensions 4 x 2 x 1 feet coupled with 2 mm sized bolt and nuts. The length and breadth along the parallel sides were covered with plywood. A rock-bed consisting of medium sized gravel was packed half-full inside the solar collector box with a total height of ½ feet. A drying chamber constructed with metal of 5 x 2 x 2 feet was fastened with 2mm bolt and nut. It was divided into layered trays positioned for drying within the given space. The entire solar cabinet dryer was enclosed with black tarpaulin of about 1 cm thickness to prevent direct solar energy influx into the chamber.

A novel addition, an electronic data logger was assembled and connected together with the Arduino Uno, SD Card Module, DHT22 Temperature and Humidity Sensor, SD Card and Connecting wires to record temperature and humidity data. The consequent performance constitutes the fundamental study of the blackbody solar dryer first with, and secondly, without thermal storage. The cabinet solar dryer's data-logger was powered with solar panel of the following parameters; (8 watt) and charge controller (12V/24V 30A) and battery (12V, 18Ah). An illustration of the set-up is as shown in Figures 2.1 (a) and (b). A solar collector was mounted and tilted at an angle commensurate with the earth inclination for optimal collection of solar energy [20]. A plywood support was provided to hold the rock-bed, and a perforated mesh encased the solar cabinet or chamber to create free flow of hot natural air. In effect, thermal energy hitting the solar collector chamber creates convectional air flow patterns geared to dry the agricultural products. A unique aftermath of this design is the possibility for continuous drying of agricultural products during cloudy days.

Figures 2.1 (a) and (b): Inside the Blackbody Solar Dryer and Connection of data logger powered with solar cell

3. Results and Discussion

Figures 3.1 to 3.6 represent the temperature at the four layers inside the blackbody solar dryer taken manually, using Mercury Thermometer on six different days, Dy 1 – Dy 6. A differentiation of the temperature with respect to tiers is as illustrated in the Figures 3.1 to 3.6.

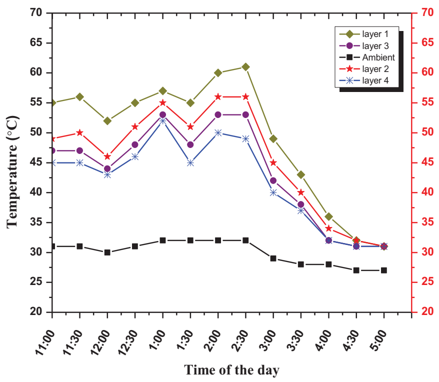

Figure 3.1: Four tier on Dy 1; 18/06/21

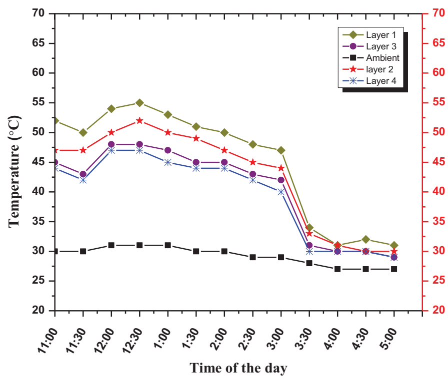

Figure 3.2: Four tier on Dy 2; 21/0/21

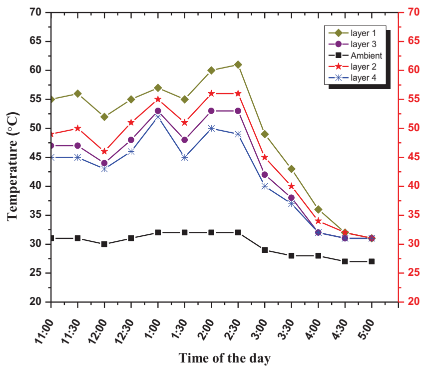

Figure 3.3: Four Tier on Dy 3; 21/06/21

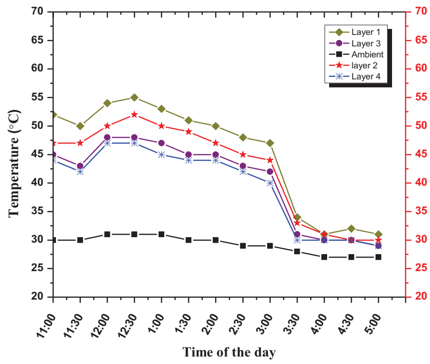

Figure 3.4: Four Tier on Dy 4; 05/07/21

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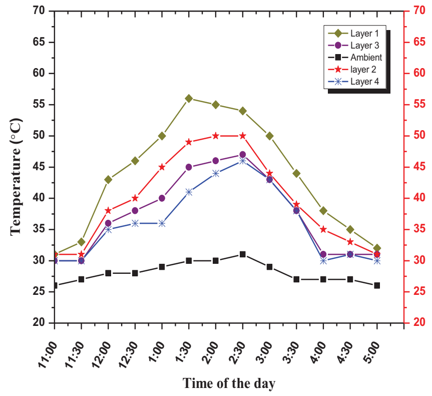

Figure 3.5: Four Tier on Dy 5; 06/07/21

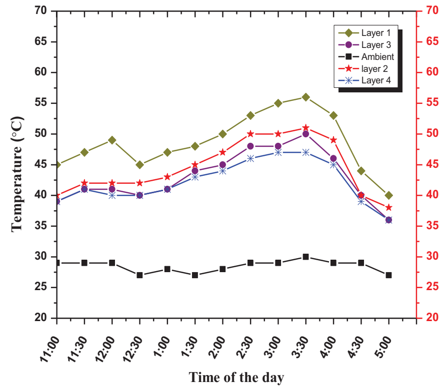

Figure 3.6: Four Tier on Dy 6; 07/07/21

Figures 3.1-3.6: The temperature at the four layers inside the blackbody solar dryer taken manually using mercury thermometer

On day 1, the initial average temperature gradient observed between the four layers varied between 56.3°C and 46.8°C, yielding average difference of about 10°C. Average drying temperature for most agricultural products vary between 35°C and 55°C. This validated the effectiveness of the blackbody solar dryer. The sudden drop in temperature at the later recording was due to sudden change in weather. On day 2, the initial average temperature gradient fluctuated between 51.1°C and 43.9°C, yielding average difference of about 7.2°C. On day 3, the initial average temperature gradient observed between the four layers varied between 50.7°C and 40.6 °C, yielding average difference of about 10.1°C. It was also confirmed in the literature that agricultural product dries at this array of temperature. The temperature drop in the four layers was due to cloud cover, the period coinciding with the raining season. Despite the weather, the blackbody solar dryer still maintained the temperature range for the drying of agricultural products.

The correlation between the electronic sensor data and the mercury thermometer data was calculated to be 0.9083 which is about 90.8% on day 1. This correlation shows that electronic sensor has high percentage of adaptability. Another variant in correlation between the electronic sensor data and the mercury thermometer data was calculated to be 0.8103 which is about 81.0%. In this correlation the electronic sensor sustained its high accuracy in recording the temperature for day 2. On day 3, the correlation between the electronic sensor data and the mercury thermometer data was calculated to be 0.8774 which is about 87.7%. Comparison of ambient temperature concurrently with that within the solar dryer for its four layers were observed ranging from 31°C and 61°C, 31°C and 56°C, 31°C and 53°C, 31°C and 50°C respectively for the first, second, third and fourth layers. In general, ambient temperature ranged from 27°C to 32°C.

A comparison of the blackbody solar dryer with open air-drying reveals that blackbody solar dryer dries faster than open air drying, reduces exposure of drying crops to rainfall, insects, rodents and air contamination. Figures 3.7 to 3.12 show the variation of humidity with temperature inside the blackbody solar dryer for six different days. Blackbody solar dryer is less expensive, making it readily affordable to small scale farmers as an option for drying their agricultural products. In addition, it is environmentally friendly as it causes no pollution to the environment. The use of blackbody solar without thermal storage shows that the first layer and second layer dry faster than the third and fourth layers of the blackbody solar dryer. Also, the blackbody solar dryer with thermal storage shows the importance of the thermal storage where there was enough heat circulating from thermal storage chamber to the drying layers of the solar dryer. This is graphically represented for days 1 to 6 in Figures 3.7 to 3.12.

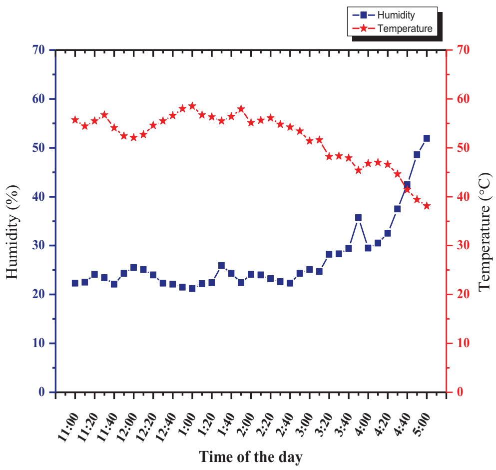

Figure 3.7: 18/06/21

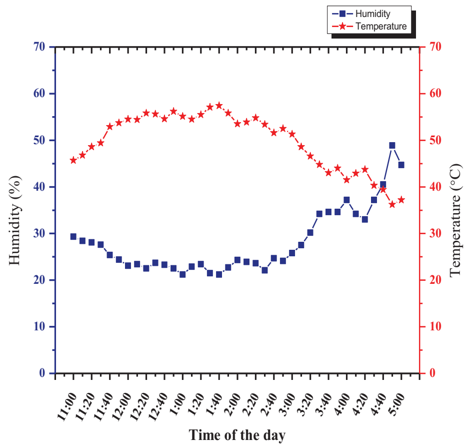

Figure 3.8: 19/06/21

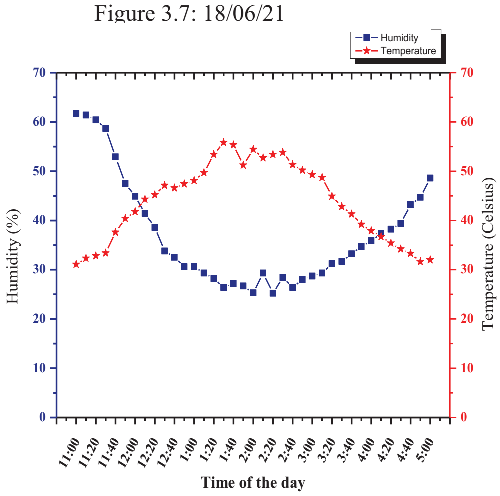

Figure 3.9: 21/06/21

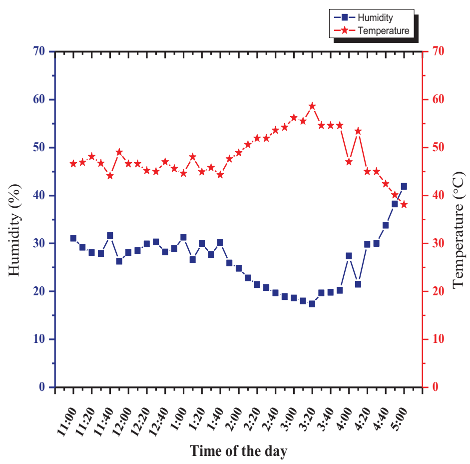

Figure 3.10: 05/07/21

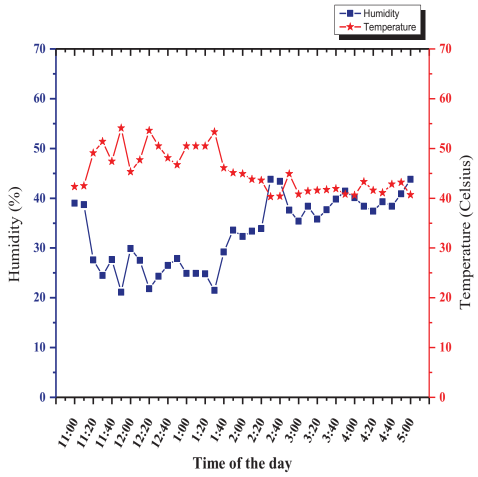

Figure 3.11: 06/07/21

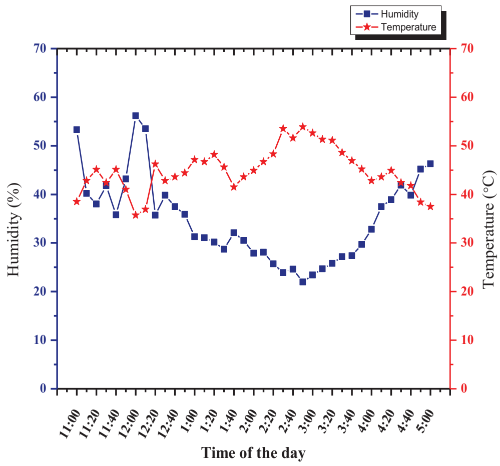

Figure 3.12: 07/07/21

Figure 3.7-3.12: The graph of temperature against humidity inside the blackbody solar dryer using electronic sensor

Conclusions

The significance of this result is that relative to the average drying temperature for most agricultural products which ranges between 55ºC to 35ºC respectively, from a difference of about 20°C, the effectiveness of the blackbody solar dryer has been validated. This implies that the quality and shelf life of agricultural produce is improved by an integral factor. Drying using multiple layers offers optimal condition for not over-drying agricultural produce. The solar dryer enjoys both the heat generated by blackbody through the solar energy from the sun and from the thermal storage which is effective enough to dry agricultural product faster. The blackbody solar dryer will improve the quality of dried agricultural products which will boost income generation for the farmers. Determination of thermal performance of blackbody solar dryer is recommended to be carried out using appropriate software application to bench mark experimental drying curves and to obtain better drying time estimates.

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