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Development of a Direct-Active Desiccant Tomato Dryer

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Abstract: *A direct-active desiccant solar dryer of capacity 1kg was designed and fabricated in an attempt to solve the challenge of solar drying in humid tropical regions using research and development design method. The dryer consist of a dc fan powered by a solar panel and battery, a rock bed which served as a heat storage system and slabs of desiccant material for air dehumidification.The performance of thedryer was evaluated using 1kg of tomato in three replications and compared to open air sun drying which served as the control. The desiccant material used is a combination of Rice Husk Ash (RHA) and calcium chloride held together with cement in the ratio of 1:1:1 by weight. Analysis of variance (ANOVA) at $p \leq 0.05$ was used to determine if there was any significant difference between the dryer and open air sun drying. The drying rates were 0.12kg/h and 0.03kg/h for the dryer and open air sun drying,and drying time of 7 and 29 hours for dryer and open air sun drying respectively. The test result shows that the desiccant dryer performed better by reducing the moisture of the tomato sample from 92.1% to 12.1% within 7 hours while the open air sun drying took 29 hours. The appearance of the products dried with the dryer were quite attractive, while the sample dried in the open sun went off colour and were highly contaminated. It was concluded that based on the evaluated performance of the dryer, it can be used for drying other vegetables. The direct active desiccant tomato dryer is recommended for use in humid tropical locations.*

Keywords: *Tomato, Desiccant, Dryer, Humid tropic, Performance, Solar.*

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I. INTRODUCTION

One of the major problem of postharvest tomato in Nigeria and elsewhere is deterioration during storage, distribution and marketing due to its high moisture content and susceptibility to damage (batu, 2004; Agamy et al., 2013). Deterioration of fresh produce can also result from natural ripening process, respiration, water loss, temperature injury, or invasion by microorganisms (Babalola et al, 2008). Consequently, this usually results in high postharvest losses with figures as high as 20-50% reported for tomatoes(Sahel research, 2015).

These losses have direct negative consequences on food security which seems to be far from being achieved. To remedy the threat posed on this product, there is need to reduce it moisture content which consequentially deter the action of micro-organisms. When the moisture content of a product is reduced below a certain limit, metabolic activities ceases and micro-organisms cannot survive, Such a product can then be stored (Mujumdar, 2007). This is achieved through sun drying method. However, solar drying offers the advantages of faster drying than regular sun drying, greater retention of vitamins especially vitamin A and C, and minimizing the damage from incessant rains. Traditional solar fruit drying however is often a slow process impeded by the high humidity, haze, and intermittent clouds experienced in tropical regions (Ringeisen, Barrett &Stroeve, 2014). In Arid regions drying can be accomplished without a solar dryer due to the low relative humidity of air in such regions, crop drying is a relatively simple process as the hot and dry air quickly removes moisture from fruits. Although directly exposing fruits to sunlight will most often be sufficient for drying, solar crop dryers are often utilized to protect fruits from contamination, insects, and dirt (Tiwari and Jain, 2016).

In humid tropical climates, however, drying can be impeded (Forson et al., 2007). With the humid air's reduced capacity to absorb moisture from the drying fruits, using a solar crop dryer coupled with a solid organic desiccant helps to improve the drying rate by increasing internal dryer temperature and radiation.This modified desiccant dryer will address the problem of drying in humid tropical regions and contribute in reducing the problem of postharvest losses of fruit and vegetables especially tomatoes in Nigeria.

II. MATERIALS AND METHODS

1.1 Material Selection Consideration.

For the purpose of this design, glass and medium density fibreboard wood were the major materials used for the construction of the dryer. This is because glass is useful for the greenhouse effect and heat needed for drying; the wood used on the other hand was suitable to retain the heat generated in the dryer and thick enough to eliminate any need for additional insulation. All materials used were readily available.

1.2 Description of the Designed Direct Active Desiccant Dryer

The dryer consists of a solar flat plate collector, a pre-heater unit, two rock-beds, drying chamber, two desiccant units, turbo dc fan and a voltage generator. The voltage generator comprises a photovoltaic panel, a solar charge controller and a horizontally placed deep-cycle battery. The photovoltaic panel is connected to the solar charge controller, then to a dc battery which is in turn connected to the dc fan through a switch which is positioned in front of the dryer.

Two sets of solid Calcium chloride ($CaCl_2$)-based, organic desiccant slabs are attached in-between the pre-heater and the solar absorber and another in-between the solar absorber and the drying chamber. The equipment is a structure with frames made of wood and metal stand. It has a dc fan attached to one end and has openings at the other end to allow moisture escape to the surrounding. The side frames constitute the length of the dryer and attached to the equipment is the photovoltaic cell, solar charge controller and a deep cycle battery. It incorporates a transparent glass cover at the top for the greenhouse effect and thus the heat needed for drying operation. The attached desiccant material has the capacity to dehumidify the humid ambient air. The rock-bed is capable of absorbing heat during sunshine hours to release the stored heat during off sunshine hours. The equipment has no external insulation as the thickness of the frame material is considered to provide reasonable insulation.

The solar drying equipment works on the principle of forced convection. The dryer's turbo dc fan delivers ambient air to the pre-heater unit where it is pre-heated by the rock-bed and thereafter desiccated by the first desiccant unit (DU1). The desiccated air is further heated by the solar absorber plate and desiccated a second time as it passes through the second desiccant unit (DU2) before coming in contact with the food material on the mesh trays. There is convective heat transfer to the product resulting in the vaporization of water in the product. Thus, it is a simultaneous heat and mass transfer process. The mass (water) is then transferred to the hot dry air thereby causing it to be humid. At this point, the humid air leaves the dryer by the action of the fan through the openings at the other end of the dryer to the environment. Figure 1 presents the schematic diagram of the prototype dryer with its essential components.

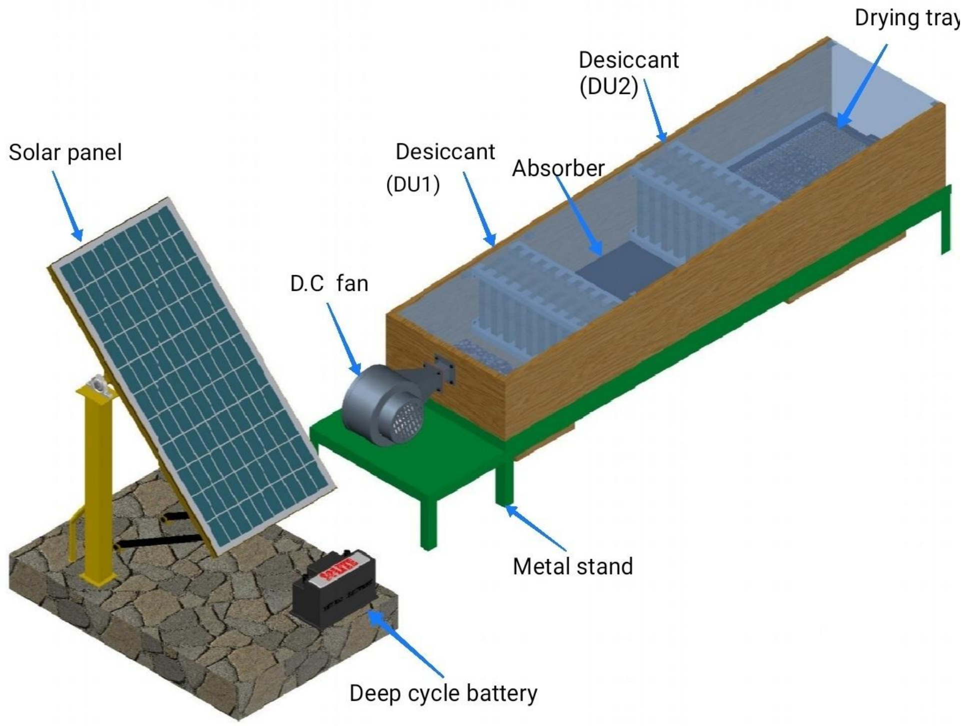

Figure 1 Schematic diagram of the prototype dryer

1.3 Design Consideration

Primarily, the following were put into consideration:
i. Physical features of the dryer
ii. Dryer area and dimension
iii. Arrangement of desiccant in desiccant unit
iv. Fan capacity.
v. Drying temperature
vi. Rock-bed to improve efficiency
vii. Amount of moisture to be removed
viii. Availability of the needed materials
ix. Quantity of air needed for drying.
x. Environmental conditions of the test location

1.4 Design Analysis

Design analysis of the dryer was undertaken to determine specific design parameters like the power rating of the d.c fan, number of modules to power the d.c fan, volume of the pre-heater unit, collector area, size of rock-bed in the dryer unit and number of batteries, as shown in Table 1

Table 1: Design parameters

	Parameter	Factors considered
1.	Power rating of d.c fan	Resistance to the flow of air offered by the desiccants Distance from the fan to the exit of the dryer
2.	Number of PV modules to power the d.c fan	Power rating of the d.c fan
3.	Volume of the pre-heater unit	Volume of the rockbed Thermal properties of the rockbed
4.	Collector area	Desired temperature elevation Quantity of heat required for drying
5.	Size of rock-bed in the dryer unit	Desired temperature elevation Quantity of heat required to reduce the moisture content of the tomato
6.	Number of batteries	Number of PV modules Depth of discharge (DoD) of the selected battery

1.5 Desiccant Preparation

Based on the research work of Itodo, Ijabo, Charles, Ezeanaka andAkpa(2019), the reseacher prepared a low cost, solid organic desiccant consisting of rice husk ash, commercial grade calcium chloride ($CaCl_2$) powder and cement mixed in the ratio of 1:1:1 by weight for use in this work. Equal weight of each of the Rice Husk Ash (RHA), $CaCl_2$ and cement were mixed manually in an open tray. A hand trowel was used and water was added to the mixture to obtain a good consistency. The pastes were then poured into 18 wooden molds. The top was smoothened off using a gauging trowel and allowed to set as described by Itodoet. al., (2019). The molds measure 0.2 m x 0.2 m with a thickness of 0.03m. The dry desiccants were then removed from the molds and put in the tray that is placed in the desiccant units of the dryer.

III. EXPERIMENTAL PROCEDURE

2.1 Data Collection

Fresh tomatoes obtained in a local market in Makurdi, Benue State-Nigeria were washed and sliced into small thickness. 1 kg of the tomato was weighed and arranged on the drying tray and then placed inside the dryer. The dryer was switched on for the drying process to begin. At the same time another 1kg of sliced tomatoes was placed on an open tray for sun drying which served as the control. The procedure was replicated three times each to get average measurements of temperature, moisture loss of the produce, relative humidity, drying period and drying rate from the dryer and control.

The temperature and relative humidity at the pre-heater unit, collector unit and the drying chamber were measured by a digital thermometer and hygrometer before loading the dryer with the tomato. The weight of the tomatoes to be dried and that of the desiccant were measured by a digital weighing scale. Hourly measurement of the weight of the moisture removed, temperature and relative humidity of the pre-heater, collector and drying unit were recorded. Hourly measurements of the weight of the desiccant were also taken to determine the moisture absorption rate.

2.2 Data Analysis

The generated data were analyzed using the software Statistical Package for the Social Sciences (SPSS) version 25. Analysis of Variance (ANOVA) at $p \leq 0.05$ was employed to determine if there was any significant difference between the dryer and open air sun drying.

III. RESULTS AND DISCUSSIONS

3.1 Temperature Variation Results and Analysis

To determine the temperature variation of the dryer, hourly air temperatures of the ambient and dryer environment were obtained using temperature sensors which were placed at different locations inside the dryer. The transient temperature distribution in each of the following parts of the dryer was recorded (the pre heater area, the absorber, the drying area and the ambient). The mean results of the three replications obtained were 40.94^{o}C from the ambient, 48.14^{o}Cfor the pre heater, 48.33^{o}Cfor the absorber and 48. 35^{o}C from the drying area of the dryer respectively.

The trend of the graph in Figure 2 show that the temperature from both the ambient and solar dryer starts to increase in the morning and reaches its peak value in the afternoon when the sun insolation is highest and starts to decrease again in the evening when the sun sets. Overall the dryer performed well by increasing the drying temperature by 18.12% from the ambient.

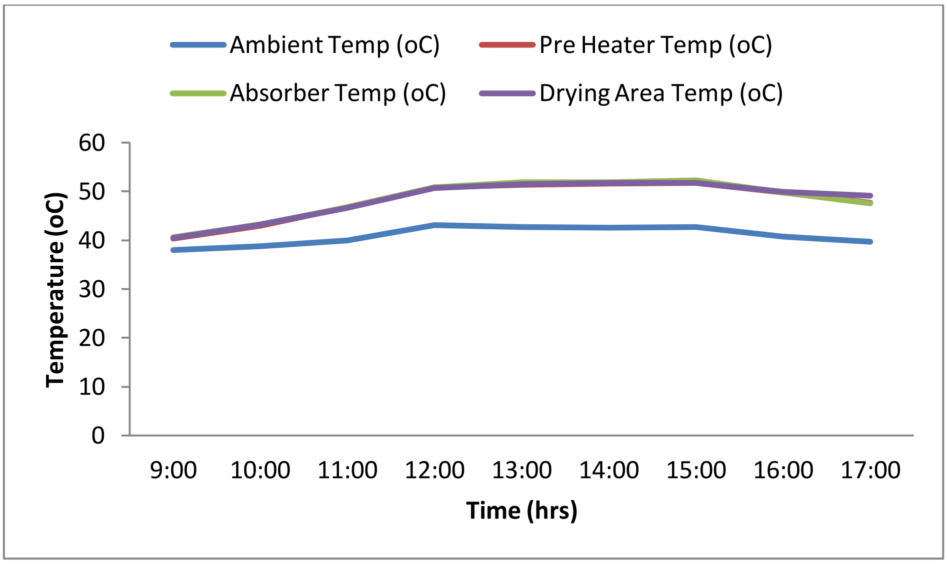

Figure 2: Temperature variation in dryer and open sun

3.2 Relative Humidity Variation Results and Analysis

The relative humidity of the ambient, the pre heater area, the absorber and the drying area of the dryer were measured using digital hygrometers. The data obtained from the mean relative humidity replication results of dryer and presented in figure 3 show that the relative humidity were 25.29% for ambient, 22.85% for pre-heater unit, 18.33% for solar absorber and 18.15% for the drying area respectively.

The result showed that relative humidity of the ambient air entering into the pre-heater of the dryer was reduced by 9.85% and further reduced by 7.54% as the heated air stream passed through the first desiccant and finally by 1% as it passed through the second desiccant slabs before coming in contact with the tomato being dried. The desiccant therefore had a great influence in the humidification of the air stream that dried the tomato in the dryer units of the dryer.

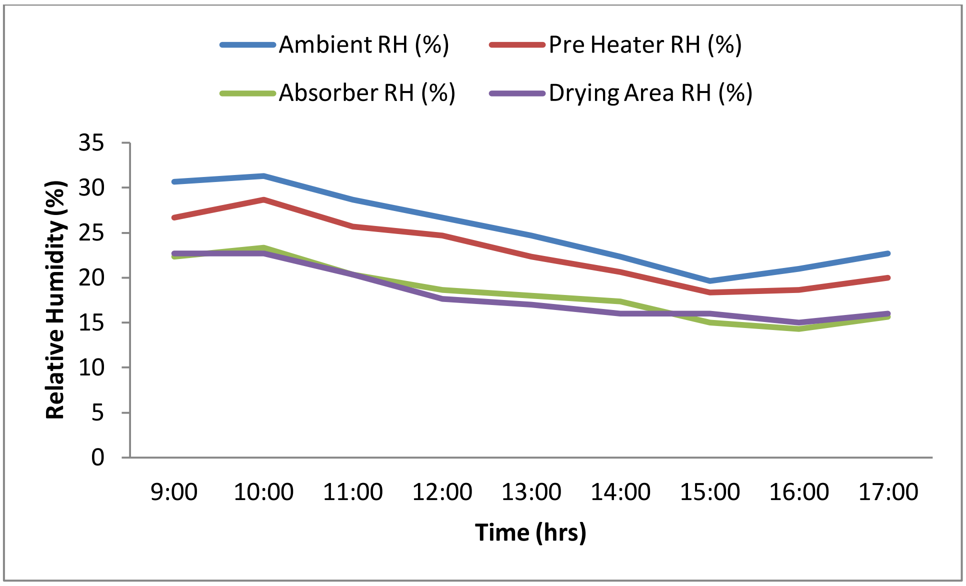

Figure 3:Relative humidity of dryer and open sun

3.3 Weight Loss Analysis with Time

To determine the weight loss of the drying tomato, product from the dryer and open air drying was first weighed with a weighing balance to determine its initial weight and thereafter hourly weights were taken from both the dryer and open sun drying until there was no further weight loss. Results of mean weight loss shows that dryer reduced 1kg of tomato to 0.18kg in 7hours compared to 30 hours that the same weight of 1kg tomato reduced to 0.20kg in the open sun.The observation of tomato moisture loss recorded during the testing of the dryer as illustrated in figure 4 showed that there was a sharp and consistent loss of moisture content in the tomato from the 3rd hour of drying until equilibrium moisture was attained on the 7th hour. The tomato in the open sun drying on the other hand experienced slow and irregular moisture loss and took 30 hours to reach equilibrium moisture content. The 7 hours drying time obtained in this research signifies a huge reduction in drying time over previous research reported by Alonge and Eke (2011) whose direct mode passive solar tomato dryer took 58 hours to dry.

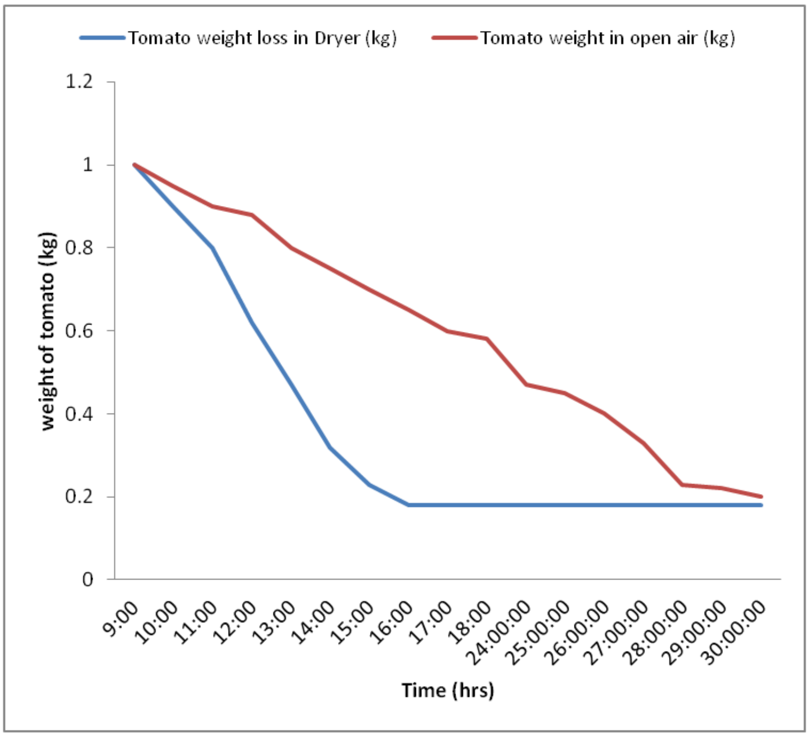

Figure 4: Moisture loss of tomato in dryer and open sun drying

IV. CONCLUSION

A force convection desiccant integrated solar tomato dryer was designed and evaluated, it was observed that the optimum drying rate was 0.12kg/h and drying time was 7hrs for 1kg of tomato slices. The test also showed a reduction of relative humidity within the dryer to 15% and a maximum dryer temperature of 53^oC. From the dryer test performance it can be concluded that the direct active desiccant dryer achieved significant reduction in the relative humidity of air and this accounts for the high drying rate obtained.

Based on the evaluated performance of the dryer, it can be used for drying other vegetables since even tomato that is known with high moisture content was dried to a shelf stable range in 7 hours.

Conflict of interest

There is no conflict to disclose.

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