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Performance Evaluation of a Double Compartment Solar Dryer

Balogun, M.B., Anafi, F.O. and Kulla, D.M.
Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria

Abstract - *The performance characteristic of a solar dryer was carried out in Zaria located at North West Nigeria on latitude 11^o 13´ with an average solar radiation of 700W/m^2. This study presents the performance evaluation of the device, which aims at establishing more effective ways of utilizing the solar energy which is free and renewable. On the first and second days of the experiment, 350g of tomatoes were used to test the performance of the dryer from 9:15 am to 5:15 pm. Readings were taking at two hours intervals, and it was observed that the moisture content of the tomatoes reduced from 90 % to 26.7 % and 71.4 % to 10 % on the days of experiment respectively. Consequently, the open sun drying recorded a moisture content reduction from 90 % to 42.9 % and 72.4 % to 25 % on first and second days respectively. The dryer was found to perform above 75 % efficiency, which was the conceptual design target. An efficiency of 87.8 % was obtained and attained a maximum temperature of 58 ^{o}C for the absorber plate, which was able to dry the tomatoes in two days.*

Key words: *Solar energy, Dryer, Efficiency, Temperature, Tomatoes*

1.0 INTRODUCTION

Food drying is a very simple, ancient skill. It requires a safe place to spread the food where dry air in large quantities can pass over and beside thin pieces. Sun is often used to provide the hot dry air. Dry, clean air including dry cold air from any source will dehydrate food. Drying is an excellent way to preserve food and solar food dryers are an appropriate food preservation technology for a sustainable world". Draping food over branches or spreading it on wide shallow baskets on the roof is an old widespread tradition still in use around the world. Modem variations are to build special enclosed drying racks or cabinets to expose the food to a flow of dry air heated by electricity, propane or solar radiation (Barbara, 1998).

Drying of produce especially vegetables is one of the oldest forms of food preservation methods known to man. It is the removal of moisture from the product to an optimum level in order to prevent deterioration and preserve their nutritive values (Ehiem et al., 2009). Sun drying offers a cheap method of drying but often results to inferior quality of products due to its dependence of weather conditions and vulnerably to the attack of dust, dirt's, rains, insects, pests, and microorganisms. Solar drying is an alternative that offers several advantages over the traditional method and it has been developed for various agricultural products. Solar energy for crop drying is environmentally friendly and economically viable in the developing countries (Amer et al., 2010). In Nigeria, over the past three decades, several attempts have been made at developing simple dryers usually with mud or clay walls and incorporating very little imported technologies with some of this been successful. The use of concentrated energy from the sun (solar energy) offers considerable opportunities for grain drying (Bolaji, 2005).

Efforts are been geared towards the development of simple dryer which reduce the problem of cost, size, complexity and necessary operational preciseness commonly associated with grain drying technology. The need for crop drying in Nigeria is essential for agricultural products like maize, tomatoes, pepper, millets, sorghum, cowpeas, soya beans, groundnuts, rice, cassava etc, which are grown during the rainy season because the preservation facilities are inadequate or non-existent. Most of these crops may require drying after harvest for short or long-term preservation hence; drying of crop problem in Nigeria can therefore be over-come by harnessing the energy from abundant sunshine for the drying process. According to Folayan et al., (1988), excessive moisture affects a grain seed in two ways. Firstly, it encourages respiration, self heating and other chemical activities within the seed itself. Secondly, it provides suitable condition for growth of bacteria, mould, mites, and insects. The moisture content in percentages for safe storage of some crops are as follows; shelled maize 13%, crib maize 16%, sorghum and rice 12%, soya beans 10%, groundnut 8%, tomatoes 10%, okro 20%, onions 4%, carrots 5%, potatoes 13%, sweet potatoes 7%, apples 24%. Dried foods are tasty, nutritious, lightweight, easy-to-prepare, and easy-to-store and use. The energy input is less than what is needed to freeze or can, and the storage space is minimal compared with that needed for canning jars and freezer containers (Whitfield, 2000). Whitfield (2000), stipulated that the nutritional value of foods is only minimally affected by drying. Vitamin A is retained during drying

*Corresponding author Tel: +234-8098826282
Email: balo.muyi@gmail.com

because it is light sensitive. Therefore, food containing it should be stored in dark places. Yellow and dark green vegetables, such as peppers, carrots, winter squash, and sweet potatoes, have high vitamin A content. Vitamin C is destroyed by exposure to heat, although retreating foods with lemon, orange, or pineapple juice increases vitamin C content. Odunukwe (1988), designed a triple-row double column (TR-DC) tray solar bin dryer. The system comprised of two main sections, the solar air heater and the drying chamber connected by air duct. Both the solar air heater and drying chamber were effectively insulated to minimize loss of heat by heat conduction. The drying chamber has solar radiation enhancement effected by the transparent roof. This admits direct solar rays inside the chamber thereby compensating for any loss. The chimney effect completes the circulation of air through air heater, drying chamber and the outside air. Gbaha et al., (2007) designed and tested experimentally a direct type natural convection solar dryer for drying cassava, bananas and mango slices. This dryer is a simple design and can be manufactured by farmers from local materials. It has a relatively moderate cost and is easy to use. The thermal performance of the newly developed dryer was found to be higher compared to open sun drying for the selected food materials. Raju et al., (2013) succeeded in developing a natural convection solar dryer with a heat exchanger tube. For this system, there is an air vent (or inlet) with guide ways to the solar collector where air enters and is heated up by the greenhouse effect, the hot air rises through the drying chamber passing through the trays and around the food to remove the moisture content and exits through the air vent (or outlet) near the top of the shadowed side. Hence, this paper presents a report on the performance evaluation (moisture content reduction) of the sun energy in a solar dryer using a natural convectional airflow with aim of increasing heat transfer, temperature and efficiency with low friction losses in the system. Therefore, it is targeted at obtaining the lowest moisture content required for safe storage to reduce wastage of perishables.

2.0 MATERIALS AND METHODS

2.1 General Description

The double compartment solar dryer was designed and developed. It comprised of a flat plate air-cooled solar collector, a drying bin where the crops to be dried are kept, an aluminum absorbent plate and also a conventional natural opening made from the drying bin to provide a natural air circulation through the system thermal components. The flat plate collector was mounted in fixed position for maximum effectiveness, and also sloped at the latitude angle to the horizontal of "Zaria, Nigeria" location for maximum annual solar collection.

2.2 Operational Principle of the Developed Dryer

The basic principle of the solar dryer is that air is heated by the Sun in a collector and then passed over the produce, which is to be dried. The compartments of the solar dryer rely on the sun as its major source of energy. However, it differs from open air sun drying in that a simple structure, such as flat plate collector was used to enhance the effective collection of insolation and minimize loss of the collected sun energy to the environment. Thus the temperature above the crops inside the bin becomes higher. The collector serve one more purpose of reducing the direct convective losses to the ambient which further becomes beneficial for rise in crop and bin temperature respectively.

Tomatoes, which are the fruits to be dried in the solar dryer, were first weighed using electronic balance, sliced and then spread uniformly over the tray. When the moisture content is low, the tomato does not rot or go bad. This way, food preservation is achieved and its useful time will be prolonged. A pictorial view of the solar dryer is shown in Fig. 1.

Fig. 1: Pictorial view of the developed double compartment solar dryer during test

2.3 Experimental Procedure

Tomatoes were sliced transversely to a size of 20mm thick (Figs. 2 and 3) and weighted using an electronic balance. The initial weight of the tomatoes obtained was 350 g; this was spread uniformly on the solar dryer trays and used to test its performance. The openings to the dryer was closed and the tomatoes in all the trays were then left to dry over time. The same amounts of tomatoes were placed in open sun which serves as a control and readings were taken at two hours intervals. For the drying bin, this was done by rapidly removing the trays from the cabinet, weighing them on an electronic scale and returning them back to the drying bin. Moisture content at each weighing interval was then calculated from the initial mass of the tomatoes in each tray. Readings at the fresh air inlet entrance and air exit of the drying chamber were noted, measurement such temperatures, relative humidity using thermometer/hygrometer and the mass of water evaporated were continuously taken and recorded manually, then analyzed by means of data logging.

The experiment was ran for two days to achieve the 10% moisture content or less which is specified as safe for storage (Raju et al., 2013). The tomatoes which were not completely dried were packed from the solar dryer and the open sun and covered at the end of the first day. This led to a slight increase in moisture content of the tomatoes because the reabsorbed moisture. So the drying process continued on the second day 9:15 am to 5:15 pm and readings were also taken at two hours intervals. After completion of drying, the dried tomatoes samples were collected, cooled in a shade to the ambient temperature and then sealed in plastic bags. The sliced tomatoes shown in pictorial views are the fresh and dried samples.

Fig. 2: Sample of fresh sliced tomatoes

Fig. 3: Sample of dried sliced tomatoes

2.4 Calculation of Solar Dryer Efficiency

The collector useful energy is given as (Santos et al., 2005);

$Q_u = A_c F_R [\tau \alpha I_t - U_L (T_{ai} - T_a)]$ (1)

Q_u = Collector useful energy gained, W

I_t = Incident solar radiation on the collector cover surface, W/m^2

$\tau \alpha$ = effective transmittance absorptance product

A_c = Collector area, m^2

U_L = Overall collector heat loss coefficient, W/m^{2}K

T_{ai} = Mean temperature of the collector absorber surface, ^{o}C

T_a = Mean ambient temperature, ^{o}C

F_R = Collector heat removal factor

While the heat gain by the dryer is given by (Santos, 2005);

$Q_d = A_d \tau \alpha I_t$ (2)

A_d = Dryer area, m^2

From design calculations, the values for each parameter were determined thus:

I_t = 700 W/m^2

$\tau \alpha$ = 0.76

U_L = 5.4 W/m^2 ^{o}C

F_R = 0.89 (Single fiberglass collector)

Lastly, the collector area was determine as, A_c = 0.5960 m^2, then from (Equation 1) above, Q_u becomes;

$Q_u = 0.5690 \times 0.89 [0.76 \times 700 - 5.4 (45 - 44)]$

Q_u = 279.3297 W

While the heat gained by the dryer becomes;

$Q_d = A_d \tau \alpha I_t$

$Q_d = 0.5978 \times 0.76 \times 700$

Q_d = 318.0296 W

The efficiency of the solar dryer was calculated as (Santos et al., 2005);

$$\eta = \frac{Q_u}{Q_d} \times 100\% \quad (3)$$

$$\eta = \frac{279.3297}{318.0296} \times 100\%$$

$$\eta = 87.8\%$$

3.0 RESULTS AND DISCUSSION

3.1 Variation of Moisture Content and Temperature with Time

The experiment was conducted within the month of January 2010 under the Nigerian dry season condition with ambient air ranging from 25 ^{o}C to 34 ^{o}C to evaluate the performance of the solar dryer and open-air sun drying for first day, (07/01/2010). Fig. 4 presents the variation of moisture content with time. From the Fig., the moisture content of the tomatoes, which was uniformly, spreads in the solar dryer reduced rapidly. Variations of air temperatures on the two trays at the beginning of drying temperature were low and increased slowly and then sharply with the increase of solar radiation. The reason can be attributed to the initial stage of drying where moisture content of the tomatoes was initially high (about 90%) and more moisture was evaporated from the tomatoes surface with increase in temperature and time. As shown in Fig. 4, a reduction of 90% to 26.7% moisture content was obtained for the double compartment solar dryer while that of open air-drying reduced from 90% to 42.9%. This demonstrates the efficiency of the solar dryer as compared to open air sun drying. After 8h of drying, there was no significant different of temperatures among the trays but outlet air temperature was low due to the effect of reduced environmental temperature. This result is in agreement with research conducted by Amer et al., (2010), where the capacity of the dryer in their study dried about 30 kg of banana slices for 8 hrs on a sunny day from an initial moisture content of 82% to the final moisture content of 18%. The study concluded that the colour, aroma and texture of the solar dried products were better than the sun drying products.

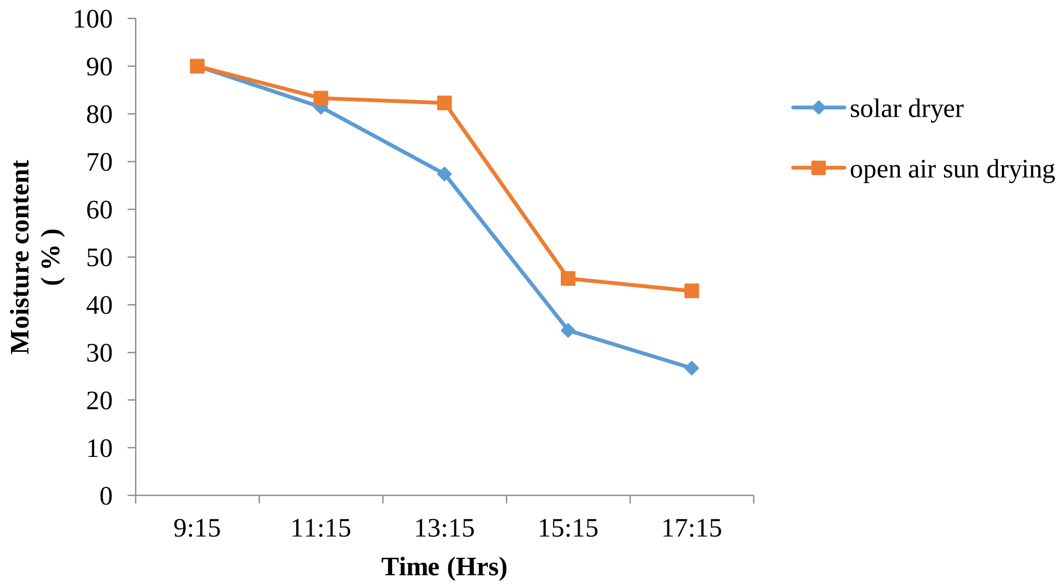

Fig. 4: Variation of moisture content against time of day 1

Fig. 5 depicts the performance of the dryer bin absorber plate temperature against that of open-air sun drying. It can be deduces that the absorber plate played a vital role in the drying of the tomatoes in the drying bin. As shown from Fig. 5, at the beginning of drying, the absorber plate temperature increases with the increase of solar radiation and it reached a peak in the noon and then decreased at slower rate in the late afternoon with the decrease of solar radiation. During this drying period, the maximum absorber plate temperature achieved was 58 ^{o}C, which was 14 ^{o}C above the ambient temperature. The result as shown in Fig. 5 corroborates with the study conducted by Amer et al., (2010), that conducted research on design and performance evaluation of a new hybrid solar dryer for banana. The study reveals that at the beginning of drying, collector air temperature as well as absorber temperature increased with the increase of solar radiation and reaches its peak at noon with average collector air temperature of 54.31 ^{o}C, which was 27 ^{o}C above the ambient temperature. Also, it corroborate with the study of Bolaji, (2005), where the maximum average temperature obtained during the day light inside the collector and drying chamber were 64 ^{o}C and 57 ^{o}C respectively, while maximum ambient temperature observed was 33.5 ^{o}C, the study concluded that temperature inside the dryer was higher than the ambient by an average of 15.3 ^{o}C throughout the daylight.

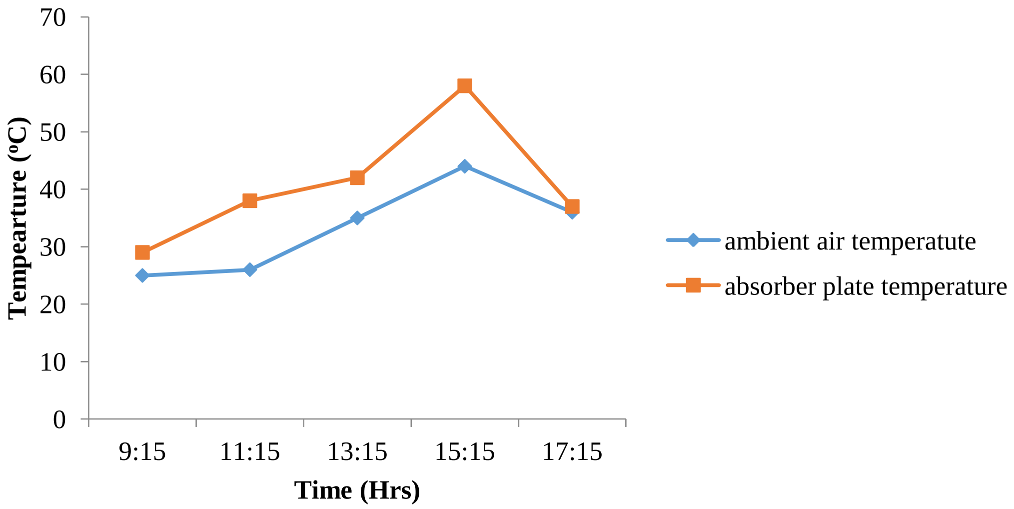

Fig. 5: Variation of temperatures against time of day 1

As the experiment continues for the second day, (08/01/2010), the drying rate of the double compartment solar dryer was much faster compare to the open air-drying. The variation of moisture content of the double compartment solar dryer and that of open-air sun drying is giving in Fig. 6. As shown from Fig. 6, the moisture content of 10% was achieved for the double compartment solar dryer due to rapid drop of the moisture from 50% to 12% at noon, which was attributed to improved mass flow rates and high heat transfer of the working fluid in addition to high solar radiation. The produce subjected to open air-drying moisture content dropped from 68% to 34% and further dropped to 30% at end of the drying. Furthermore, at 15:15hrs, the required moisture content level of 10% safe for storage of tomatoes was accomplished for the double compartment solar dryer due to improved moisture loss as compared to open air drying and this is in agreement with the research of Raju et al., (2013), that designed and fabricated an efficient solar dryer to dry 20 kg sliced tomatoes with an initial moisture content of 81.4% to a final moisture content of 13% for 10 hrs. Additionally, their work recommended double slope passive solar dryer to attain higher efficiency. Subsequently, the result is in agreement with that of Gbaha et al., (2007), whose study was on experimental investigation of a solar dryer with natural convective heat flow. The designed natural convective solar dryer permits the reduction of the moisture content of cassava and sweet banana approximately 80% in 19 hrs and 22 hrs respectively to reach the safety threshold value of 13%. The study concluded that this value permits the conservation of these products for about one year without deterioration

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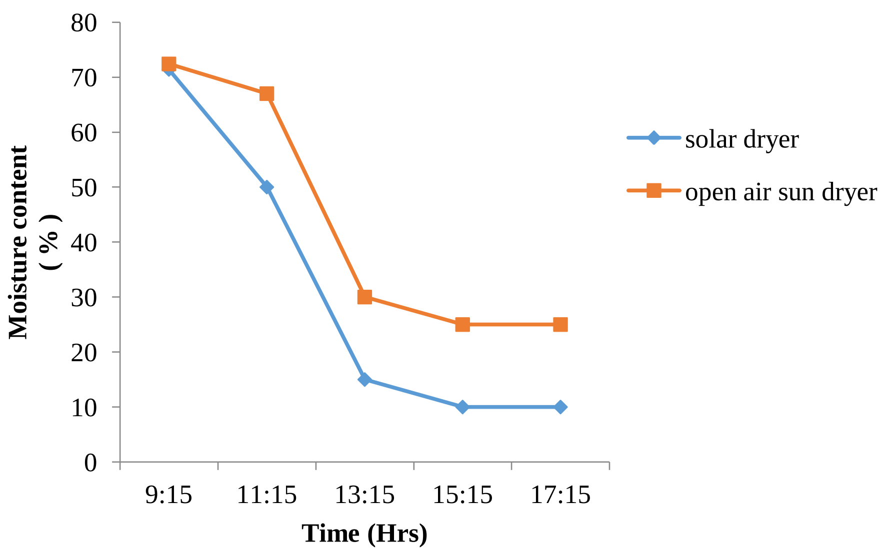

Fig. 6: Variation of moisture content against time of day 2

The dryer chamber outlet and inlet air temperatures, heat removal factor, collector area and incident solar energy, make it possible to determine the thermal effectiveness of the double compartment solar dryer. An efficiency of 87.8% was attained for this study, which is attributed to strident increase of solar radiation with swift increase of working fluid, absorber plate and drying chamber temperatures that implies approximately 87% utilisation of the incoming solar energy.

Fig. 7 shows the variation of temperature of the absorber plate with the ambient air temperature of the last day of the experiment. Maximum temperature of 58 ^{o}C for the absorber plate of the double compartment solar dyer was recorded throughout the experiment over the open-air sun drying. It can deduced from the (Fig. 7), that rapid rise in temperature of the absorber plate was noticed from 27 ^{o}C to 42 ^{o}C at early hour of the day and this can be attributed to sharp increased of solar radiation. In comparison to ambient air temperature, which was from 25 ^{o}C to 30 ^{o}C, this clearly indicates that the solar dryer efficiency is at maximum. However, toward the late noon, a slight drop of 1^{o}C in the temperature of the absorber plate was observed compared to ambient air temperature.

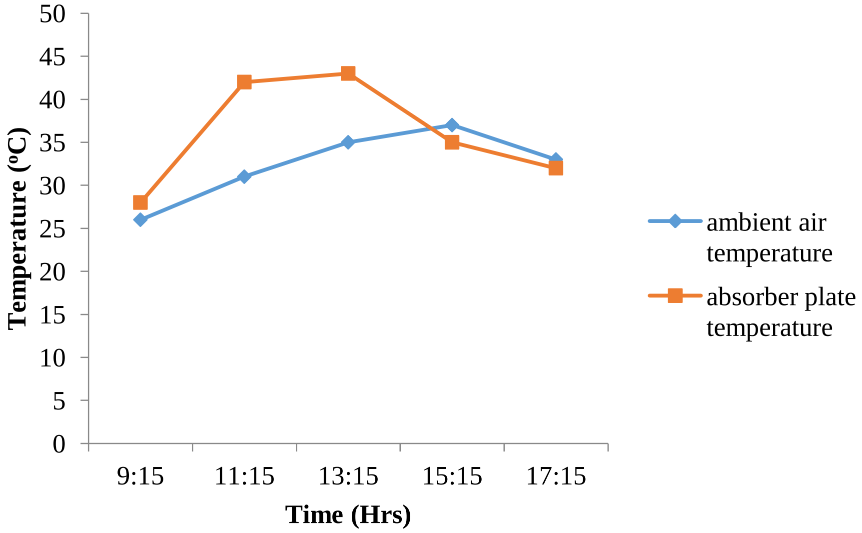

Fig. 7: Variation of temperatures against time of day 2

4.0 CONCLUSION

The study has shown the specific method of utilization of energy from the sun has high potentials in agricultural field for purpose of preservation of crops. The effect of thermal storage was properly observed from the fresh tomatoes with 90% moisture content in the drying bin at 9:15am from solar dryer and same quantity of tomatoes with 90 % moisture content was spread in an open-air sun drying, the double compartment solar dryer offers the advantage of faster drying rate than open air drying. It further offers protection of the tomatoes from weather and other forms of contaminations that would normally accompany a drying process.

Furthermore, in designing the system factors such as cost, availability and some properties of materials were taken into consideration and this reveals that the solar dryer is easy to construct, no running cost during operation since its source of energy is free and constructed from locally available materials. The benefit derived from its use justifies the effectiveness of the device. It is suitable for both urban and rural/remote locations

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