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Comparative Study of Open Air Drying And A Medium Size Passive Solar Dryer Using Etfe As Glazing Material

[1]Aliyu, S., [1]Momoh, M.,[1]Garba M.M.,[1]Musa M,[2]Rikoto I.I.
[1]Department of Physics, Usmanu Danfodiyo Sokoto, Nigeria
[2]Sokoto Energy Research Centre of the Usmanu Danfodiyo University, Sokoto
Correspondence email address; sani.aliyu@udusok.edu.ng

Abstract: *Fresh okra was washed and sliced using a knife. The sample was weighed and divided into two equal parts of 0.625kg which was dried in a passive solar dryer and open air respectively for three days. A comparative analysis was carried out during and after drying on the medium sized passive solar dryer, which was constructed at the Sokoto Energy Research Centre of the Usmanu Danfodiyo University, Sokoto and open air drying. The results obtained showed that drying was faster with the solar dryer than with the open air. It was observed that while the okra in the dryer attained a final weight of 0.075kg representing 88% moisture loss (wb), the sample in the open air only attained a final weight of 0.150kg representing 76% moisture loss (wb) which shows that those in the solar dryer lost more moisture than the open air dried samples. The results also revealed that the average collection efficiency was 50.47% while the average system drying efficiency was 1.47%.*

Keywords: *Passive solar dryer, Fresh okro, moisture, open air, and efficiency*

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Nomenclature

ETFE	Ethylenetetrafluroethylene
V_a	Volume flow rate of air (m^3/s)
V	Average wind speed (m/s)
A	Area of the air gap or vent opening, m^2
n	Number of vent.
Ƞc	Collection efficiency
Ƞs	System drying efficiency
M_i	Initial moisture content (kg)
T	Drying time (s)
M_f	Final moisture content (kg)
ρ_a	Density of air (kg/m^3)
M_a	Mass flow rate (m3)
C_p	Specific heat capacity of the air at constant pressure ($Jkg^{-1}K^{-1}$)
ΔT	Elevation temperature (^0C)
I_c	The isolation on the collector (W/m^2)
A_c	The effective area of the collector facing the sun (m^2)
ML	Moisture loss (kg)
L_V	Latent heat of vapourization of water (2396.6kJ/kg)

I. Introduction

Drying is the process of removing water content from crops. Basically, the traditional way of drying farm produce is the open air method. The produce is spread directly under the sun, requiring large space, longer time for the produce to get dried and depending solely on the availability of sunshine as well as being the exposition to contamination by insects, pest, intrusion of animal and also weather dependent (Ahmad et al, 2012). These challenges faced by local farmers led to the innovation of an alternative source of drying that is, solar drying method. This method of drying is more efficient, produce better quality end product that retains its colour and flavour. These benefit led researchers to further studies on how to improve solar method. Many experimental studies have been reviewed on various methods of drying agricultural produce using solar drying systems. Eze (2010) designed and constructed a family sized cabinet dryer and its performance evaluated using cassava roots. In comparison with open air drying, he reported that cyanide and mould count of cassava reduced more on solar drying than open sun drying. The data obtained further showed that the colour and odour of the solar dried sample were preferred to those of the open air dried sample. A forced convection industrial food and vegetable dryer was designed and developed to reduce vegetable wastage. It consists of the following units; blower, drying chamber and heat exchanger. It was reported that the tomato weight decreased with increase in drying time (Ehiemet al.,2009). Dryer is one of the most important equipment in food processing industrieswhich had led to the development and improvement of solar dryers for drying agricultural produce to an improved storage condition.

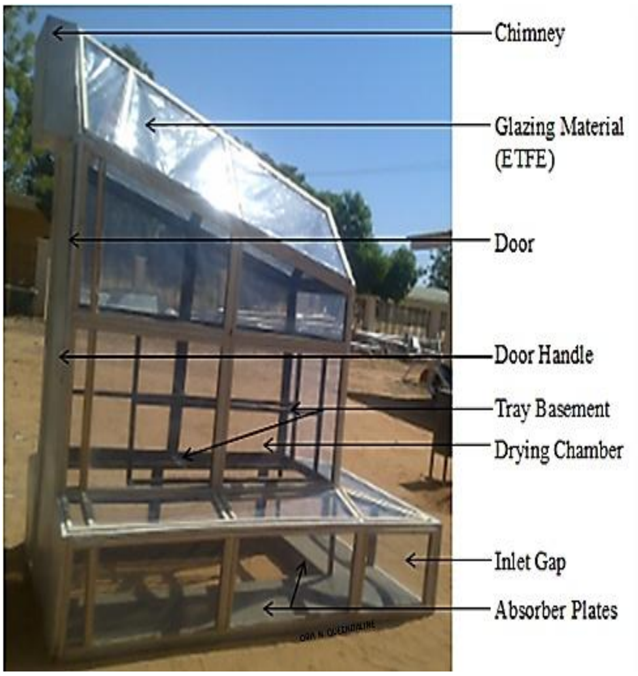

Figure1: Diagram of a Passive Solar Dryer

II. Materials And Experimental Procedures

The medium sized passive solar dryer was developed at Sokoto Energy Research Centre, Usmanu Danfodiyo University, Sokoto State The dryer was made up of: galvanized iron sheets, 1inch square pipes, ETFE foil, plywood, paints (black and white), nails, hinges, bolt and nuts. Fresh samples of okra (AlbelmoschusEscullentus) was purchased from KasuwaDaji, washed with tap water to remove the dirt and sliced longitudinally. The sample was weighed and divided equally into two parts of 0.625kg each for the dryer and open air analysis. The passive solar dryer was constructed with the absorber plate made of galvanized iron sheet. The absorber plate has an effective area of 1.38m x 0.62m x 0.3m dimension and 2mm thick. It was painted black to increase the solar absorption capacity of the system. The solar collector is enclosed with a transparent material (ETFE foil). The drying chamber and the frame of the solar dryer was fabricated with the 1inch pipe iron and was painted black to increase the temperature in the system. The roof and the sides of the dryer were covered with ETFE transparent foil which produces additional heat due to greenhouse effect. Moreso, the inlet vent was constructed with louvers frame and 6piece of louvers were fixed on the frames to regulate the air flowing into the dryer. The area of the inlet air vent is 1.40 x 0.41m.An outlet vent was positioned at the top back end of the dryer to enhance free exist of moist air from the chamber through the chimney to the environment. The chimney has a roof top fixed to prevent rain and excessive dust from entering into the drying chamber.

2.1 Operation of Drying

A passive dryer is one that does not have support or any of the auxiliary facilities. The solar radiation penetrates through the glazing materials to the absorber plate. The absorption of the solar intensity is enhanced by the inside surface of the collector and other frames that are painted black while the absorbed energy heats up the air inside the system. Ambient air from the surrounding enters through the inlet vent and hot air rises to the drying chamber, absorbs the moisture in the samples loaded in dryerand escapes through the outlet vent at the upper end of the chamber.

2.2 Dryer Performance Evaluation

The solar dryer was tested during Novermber and December period to evaluate its performance. The no-load test and load tests were carried out during which the ambient temperatures were measured using an infrared thermometer. A thermocouple thermometer with six channels was used to measure the following: glazing (ETFE), collector, inlet vent, outletvent and chamber temperatures respectively. The solar radiation was measured by the use of a pyrometer placed horizontally under the sun free from shade. Data were collected at intervals of 30minutes each from the hours of 9am to pm. The wind speed was also measured by a digital anemometer. The load tests were carried out using fresh okra which was weighed and divided equally into two parts of 0.625kg each for the dryer and open air analysis. The dryer performance was compared with open air drying. The sample took three days in the dryer to get to safe storage. Samples were measured before and at the end of each to determine the initial and final weights repeatedly. The collector and system drying efficiencies were evaluated using equations (7) and (8) as 66.9% and 1.5% respectively.

2.3 Basic Drying Theories

Drying is basically removal of water from sample that is being dried. That is, the reduction of the moisture content from such product by air. Therefore, the percentage moisture content of a product may be expressed on either the wet basis or dry basis. The percentage moisture content on wet basis expresses the moisture of the materials as a percentage of the weight of the wet material (kg/kg wet material).

It is mathematically given by Yusuf et al, (2013) as:

% Moisture Content (MC):

Wet Basis (wb) = $\frac{Mi - Mf}{Mi}$ X 100 ………………………………………………………………. (1)

Likewise,

Dry Basis (db) = $\frac{Mi - Mf}{Mf}$ X 100 ……………………………………………………………….. (2)

The amount of moisture evaporated from the sample is known as the moisture loss (ML) and is mathematically written as (John et al, 2015):

ML = $(M_i - M_f)$ (kg) …..……………………………………………………………………… (3)

The drying rate, which is the quantity of moisture removed from the sample in a given time, is given by John et al, (2015) as:

% DR = $\frac{Mi - Mf}{t}$ X 100..…….………………………………………………………………. (4)

The higher the air flow rate, the higher the collector dryer efficiency in terms of heat transfer from the absorber plate to air. Thus, the air flow rate can be calculated (Ezekoyeand Enebe, 2006)using:

V_a= v x A x n …...…………………………………………………………………………. (5)

The density of air ρ_a is given as the ratio of mass to volume. The mass flow rate of air (m_a), therefore, is expressed (Ezekoyeand Enebe, 2006) as:

$M_a = \rho_a x V_a$ ……………...……. ………………………………………………………………..(6)

The collection efficiency (η_c) is the ratio of the heat received by the drying air to the solar insolation upon the absorber plate surface and is expressed(Ezekoyeand Enebe, 2006) as:

$\eta_c = \frac{\rho V C p \Delta T}{I c A c}$ ………………………………………………………………………………. (7)

The system drying efficiency (η_d) is the amount of heat required to evaporate the moisture inside the product and is computed from (Ezekoyeand Enebe, 2006):

$\eta_d = \frac{ML v}{I c A t}$…….……………………. …………………………………………………………..(8)

III. Results And Discussion

The variation of temperatures and solar radiation with time in day was shown in figure 2. The highest temperature of 53.50^{0}C was recorded as the dryer's collector temperature while the solar radiation was 798W/m^2 when the ambient temperature was 32.70^{0}C. The ETFE temperature was recorded as 40.00^{0}C. While the inlet air temperature was 34.00^{0}C, the outlet temperature of 46.30^{0}C was recorded. The dryer's chamber attained a temperature of 47.30^{0}C when the air velocity was 1.33m/s all at this same time of 13.30Pm.

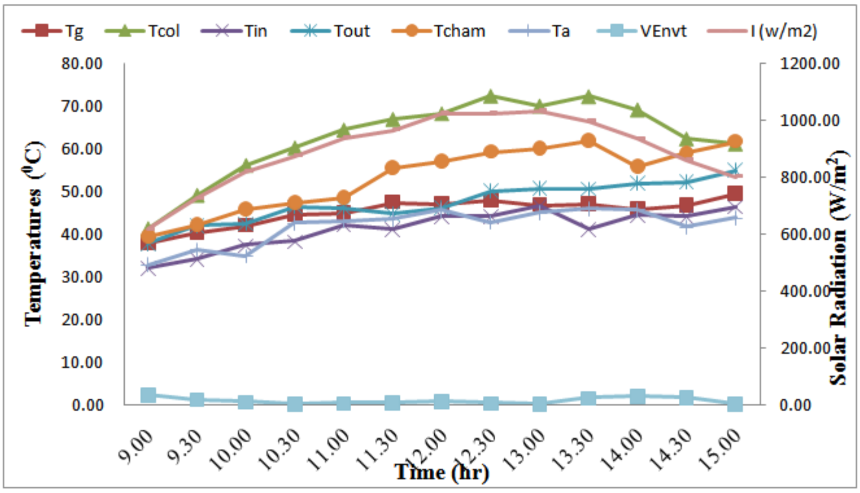

Figure 2: Day One Stagnation Test.

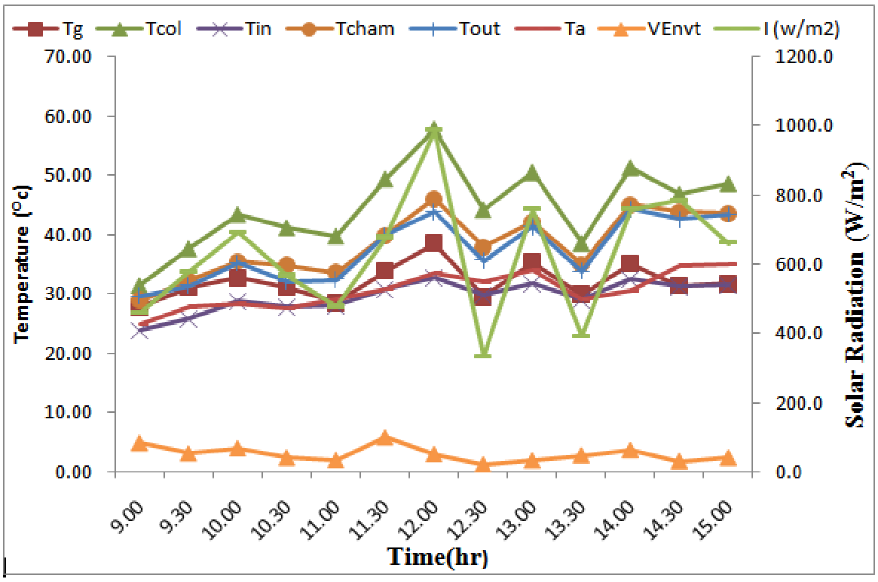

Figure 3: Day one drying of okra.

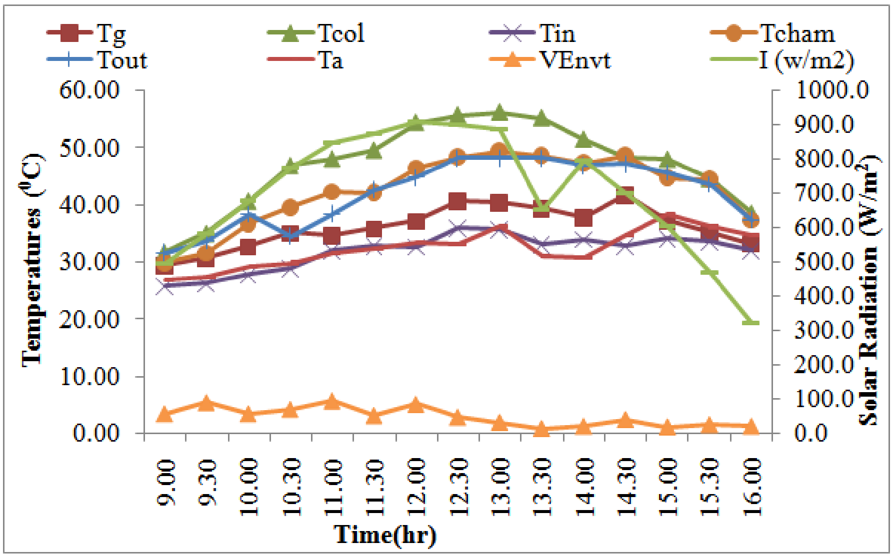

Figure 4: Day two drying of okra.

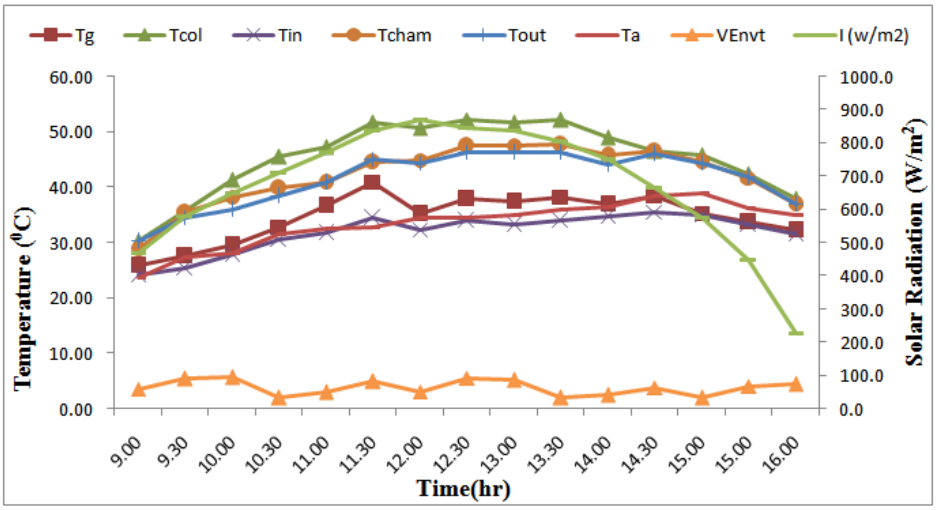

Figure 5: Day three drying of okra.

Figure 6: Open air Drying Sample **Figure 7:** Sample in the Solar Dryer

Figure 3 shows the variation of temperatures and solar radiation with time on the first day of loading the okra into the dryer. The highest temperature was recorded as 57.70^{0}C which depicts the dryer's collector temperature at 12.00Pm. During this same time, the ambient temperature was 33.50^{0}C while the inlet and outlet temperatures of 32.70^{0}C and 43.70^{0}C were recorded respectively. The ETFE temperature was recorded as 38.40^{0}C while the dryer's chamber attained a temperature of 59.30^{0}C and a solar radiation of 985W/m^2 when the air velocity was 2.90m/s at this same time. The results revels that the temperatures and solar radiation increased with increase in time.

The variation of temperatures and solar radiation with time in day was shown in figure 4. The highest temperature of 56.10^{0}C was recorded as the dryer's collector temperature while the solar radiation was 883W/m^2 at 13.00Pm when the ambient temperature was 36.40^{0}C. The ETFE temperature was recorded as 40.40^{0}C when the inlet air temperature was 35.60^{0}C. The outlet temperature of 48.10^{0}C was recorded. The dryer's chamber attained a temperature of 49.30^{0}C when the air velocity was 1.80m/s at this same time.

Figure 5 shows the variation in temperatures and solar radiation with time in day. The highest temperature was recorded as 52.30^{0}C which depicts the dryer's collector temperature at 12.30Pm. During this same time, the ambient temperature was 34.60^{0}C while the inlet and outlet temperatures of 34.00^{0}C and 46.40^{0}C were recorded respectively. The ETFE temperature was recorded as 37.90^{0}C while the dryer's chamber attained a temperature of 47.50^{0}C and a solar radiation of 844W/m^2 when the air velocity was 5.60m/s at this same time. The results revels that the temperatures and solar radiation increased with increase in time.

The daily moisture content (wb) for the three days of okra drying was computed from equation (1) as 36%, 33%, 50% for the passive solar dryer and 38.9%, 33.3%, 66.7% for the open air respectively. The average moisture loss for the three days of okra drying was computed from equation (3) as 0.55% for the passive solar dryer and 0.48% for the open air respectively. The average drying rate for the three days of okra drying was computed from equation (4) as $7.2x10^{-6}kgs^{-1}$ for the passive solar dryer and $6.2x10^{-6}kgs^{-1}$ for the open air respectively. The collectionefficiency (η_c) wascomputed from equation (7) as 66.9% while the daily system drying (η_d) efficiencies werecomputed from equation (8) as 2.6%, 1.0% and 0.8% respectively.

IV. Conclusion

A comparative analysis was carried out during and after drying on the medium sized passive solar dryer, which was constructed at the Sokoto Energy Research Centre of the UsmanuDanfodiyo University, Sokoto and open air drying. It took three days for each the 0.625kg samples in the dryer and open air to attain the weight of 0.075kg and 0.150kg respectively. The results obtained showed that drying was faster with the solar dryer than with the open air. It was observed that while the okra in the dryer attained a final weight of 0.075kg representing 88% moisture loss (wb), the sample in the open air only attained a final weight of 0.150kg representing 76% moisture loss (wb). It was also observed that the average drying rate for the three days of okra drying was $7.2x10^{-6}kgs^{-1}$ and $6.2x10^{-6}kgs^{-1}$ for the solar dryer and open air respectively which shows that those in the solar dryer lost more moisture than the open air dried samples. The result also revealed that the average collection efficiency was 50.47% while the average system drying efficiency is 1.47%.

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