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PERFORMANCE EVALUATION OF NATURAL CONVECTION INDIRECT SOLAR DRYER FOR DRYING WHITE YAM SLICES

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ABSTRACT

This paper presents the performance evaluation of a natural convection indirect solar dryer for drying white yam. Drying is the process of removing enough moisture from food to prevent decay and spoilage. Large quantity of yams are produced, therefore, there is need for drying the yams to minimize wastage. This study mainly tried to solve the problem of post harvest-loss using natural convection indirect solar dryer for drying white yam. The dryer was made from plywood with 10 mm thickness and consists of a solar collector and drying chamber which houses three trays with an upper vent for the exit of air. The result of no load showed that the dryer temperature could rise up to 60℃. The average collector temperatures recorded from no load tests were 71.1 ºC and 75.11 ºC. The collector efficiency was found to be 53.1% and dryer efficiency was 10.5%. The drying rates for the load tests were found to be 0.081 kg/hr and 0.095 kg/hr. It was found that, the required 7.6% moisture content was obtained within 18 hours of drying. Therefore, farm products with an initial moisture content of 71.3% can be dried using this dryer.

Keywords: Post harvest, Collector, Moisture, Dryer

INTRODUCTION

Solar drying is an excellent way for preserving food for a sustainable development. Drying crops by solar energy is of great economic importance all over the world, especially in Nigeria where most of the crops and grains harvested are lost to fungal and microbial attacks (Gatea, 2011). Traditional open sun drying is common and widely used method for drying of agricultural product including fruits, vegetables and cash crops. The agricultural product exposed to the open sun air may sometimes be seriously degraded and become uneatable which resulted in loss of food quality. Some of the problems associated with open-air sun drying can be solved through the use of a solar dryer, which comprises of collector, a drying chamber and sometimes machinery (Kalenya, Madhlop and Jones, 2002). Agricultural wastages could easily be prevented by proper drying, which enhances storage of crops and grains over long period of time. Nigeria lies close to the equator and is blessed with abundant solar energy almost all year around. This solar energy can easily be harnessed by the proper design of solar dryers for crop drying. This method of drying requires the transfer of both heat and water vapor (Forson *et al.*,2007). EL-Sebaii and Shalaby (2012) designed, constructed, and investigated an indirect-type natural convection solar dryer under Tanta prevailing weather conditions. The dryer consists of a flat plate solar air heater connected to a cabinet acting as a drying chamber. In order to improve the drying process the air heater was designed in such a way that various storage materials could be used at bottom of solar air heater. Drying experiments were conducted with and without storage materials for different spherical fruits, such as seedless grapes, figs and apples, as well as vegetables, such as green peas, tomatoes and onions. They noted the equilibrium moisture content for seedless grapes was reached after 60 h when drying system was used with storage and 72 h when it was used without storage material. Yahya and Umar (2011) designed, fabricated and evaluated an indirect solar dryer for drying 5 kg of fresh beef. The dryer consist of collector, air duct and drying chamber. The collector has a dimension of (2400 mm × 800 mm) and the air duct has a gap of 100 mm. The absorber plate was constructed with aluminum sheet of thickness of 2 mm and the cover glass has a thickness of 4 mm. The solar collector was tilted to an angle of $12 \cdot 05^{\circ}$(the latitude of Kano). The final moisture content of meat was 7% and the meat was dried for 9 hours. Food losses are the major problem of the worlds especially for developing nations were 25% of the food is lost by mishandling, spoilage and pest infestation (Vipin, Kumar and Prashant, 2014).Agricultural researchers have found that, preservation of food by drying reduces wastages but open sun drying is the most commonly used method for drying of agricultural products in Nigeria. The major disadvantages of open sun drying include: uncertain weather, contamination, damage by rodents, insects, slow or intermittent drying and long period of time at drying. The direct rays from the sun mostly discolour the crop and reduce the market value of the crop. Therefore, indirect dryers are the best option which save crops from such problems and also maintain the nutrients value of crop. Yam suffers a high degree of post-harvest loss due to it's high water content between 65 and 85% of weight of tuber (Adelaja, Asemota and Oshiafi, 2010). Therefore, the purpose of the research was to solve the problem of post-harvest loss of yam using natural convection indirect solar dryer.

MATERIALS AND METHODS

Methods

Determination of Initial Moisture Content of White Yam

The initial moisture content of white yam was determined using weight method. 5 kg of yam sample was sliced and placed in an empty Ten-aluminum can. The weight of the empty can was recorded before placing the yams on can. Similarly, the weight of the yam and can was also recorded. Thereafter, the weight of yam was obtained by subtracting the weight of can from the weight of yam and can. The can with the yam were then placed into an electric oven to dry and later removed and transferred into desiccators to cool down. After cooling, the cans containing yams were removed and weighed using sensitive balance. After weighing, they were immediately placed into the oven at temperature 105 ℃. The weight losses of the sample in the oven were measured at an hour interval. This experiment was done in Department of Agricultural Engineering, Faculty of Engineering, Bayero University, Kano. The moisture contents of the samples were then calculated using the following equations given by Fudholi *et al*. 2011.

$$Moisture\ content\ (wet\ basis) = m = \frac{w - d}{w} \times 100 \quad (1)$$

$$Moisture\ content\ (dry\ basis) = M = \frac{w - d}{d} \times 100 \quad (2)$$

m = Moisture content, wet basis in percentage
M = Moisture content, dry basis in percentage
w = Weight of fresh sample of yam in g
d = Wight of dried yam sample in g

Experimental setup

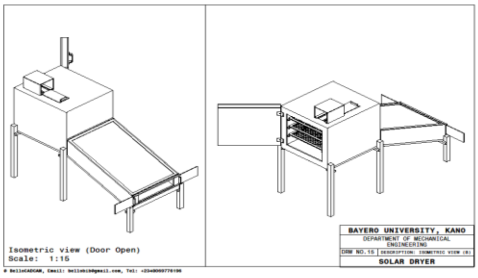

Figure 1: Isometric drawing of natural convection indirect solar dryer


Figure 2: Fabricated Solar dryer

Figure1 shows isometric drawing of the natural convection indirect solar dryer and figure 2 shows experimental set-up of the constructed solar dryer. The dryer consist of a solar collector, absorber plate, glass cover insulator and drying chamber. The performance of the natural convection indirect solar dryer was evaluated in the months of April and November 2019 under no load and load conditions. During the tests, thermocouples were positioned to measure the inlet and outlet air temperatures, collector temperature, glass temperature and dyer temperature. A combination of hydrometer and thermometer was used to measure the ambient relative humidity, ambient temperature and the exhaust relative humidity. Digital anemometer was used for measuring air flow rate and air velocity during the experiment.

No load tests

The constructed natural convection indirect solar dryer shown in figure 2 was used for the No load tests. The tests were carried out without yam slices in the drying chamber. The ambient temperature, inlet temperature, collector temperature, outlet temperature, dryer temperature and solar radiation were recorded every one hour interval. The no load test was carried in two days. In the first day the test started at 8: 00 am and ended at 18:00 pm while the second test started at 9:00am and ended at 17:00 pm. The tests were conducted on 11thApril, 2019 and 1st November, 2019. The no load tests helped in knowing the maximum possible temperature rise in the drying chamber as compared to the corresponding ambient temperatures (Tibebu, 2015).

Load tests

Two batches of load tests were conducted, the first test was conducted from 12th to 17th April, 2019, and second test from 2nd to 7th November, 2019. In each test, the prepared yam slices were blenched in boiled water at 70 ℃ for a period of 30 minutes and then drained the water using a plastics sieve. The initial and final moisture contents of white yam were found to be 71.3 % and 7.6 % respectively.

Sample Preparation

Fresh white yams were obtained from Yankura market in Kano city. The purchased yam was washed to get rid of dirt and debris using clean water. It was further peered using a clean stainless knife and then cut into 5mm thickness. The yam slices were then weighed using a weighing balance and later soaked in boiled water at 70 ℃ for a period of 30 minutes. After that, the blenched yam slices were drained using a plastic sieve and then placed on the drying trays of the dryer. The same procedure was used to prepare the yam slices for both no load and load experiments.

The weights of 3 empty trays were determined using an electric weighing balance. In the first test, 800 g of yam slices were laid on tray number one (bottom tray), 700 g on tray number two(middle tray) and 800 g on tray three (top tray). In second test, 880.38 g of yam slices were spread on tray number one, 814.31 g on tray number two and 880.52 g tray number three. The ambient temperature and humidity, dryer temperature, collector temperature, glass temperature, inlet and outlet temperature of collector, velocity of air, flow rate and solar radiation were recorded every one hour interval while the weight of produce in the drying chamber were measured every two hours interval.

Drying rate

The following equation was used to determine the drying rate for the two tests conducted under load conditions (Dhanushkodi *et al*. 2014).

$$Drying\ rate\ (DR) = \frac{M_i - M_d}{t} \times 100 \quad (3)$$

Where: M_i = mass of sample before drying
M_d = mass of sample after drying
t = drying period

Collector Efficiency

The following equation adopted by (Struckmann, 2008) was used to determine the collector efficiency.

$$Collector\ efficiency = \eta_c = \frac{v\rho\,\Delta T\,C_p}{I_c\ A_c} \times 100 \quad (4)$$

where:
V is the volumetric flow rate of air = 0.0144 m^3/s, ρ is the air density = 10059 kg/m^3, C_p= Specific heat capacity at constant pressure = T_a = 41.1818 ^oC, T_c = 50.4545 ^oC; I_c is the Insulation collector surface = 702.545 w/m^2 ; Collector area = 0.35 m^2

Collector efficiency $= \frac{0{\cdot}0144 \times 10059(50{\cdot}4545 - 41{\cdot}1818)}{702{\cdot}545 \times 0{\cdot}36} \times 100 = 53.1$

Dryer Efficiency

Dryer efficiency is the ratio of the energy needed to evaporate moisture from the material to the the heat supplied to the dryer. This term is used to measure the overall effectiveness of a drying system (Dhanushkodi *et al.* 2014).

$$Drying\,efficiency = \eta_d = \frac{M_w\,L}{I_c\,A_c\,t} \times 100 \quad (5)$$

where:

M_w is the mass of moisture evaporated in kg

L is the latent heat of vapourization of water (at temperature of dryer) in kJ/kg

t is the drying time

Amount of Moisture removed

The amount of moisture removed was calculated using the following equation (Abdurrahman, 2013).

$$M_w = \frac{W_w(M_i - M_f)}{1 - M_f} \quad (6)$$

Where: M_w is the amount of moisture to be removed

W_w is the initial total weight of material to be dried

M_i is the initial moisture on wet basis

M_f is the final moisture content on wet basis

RESULTS

Figures 1 and 2 present the variation of temperatures with time for no load tests I and II while 3 and 4 for load tests I and II. The variation of moisture contents with time for load tests I and II are presented in figures 5 and 6.

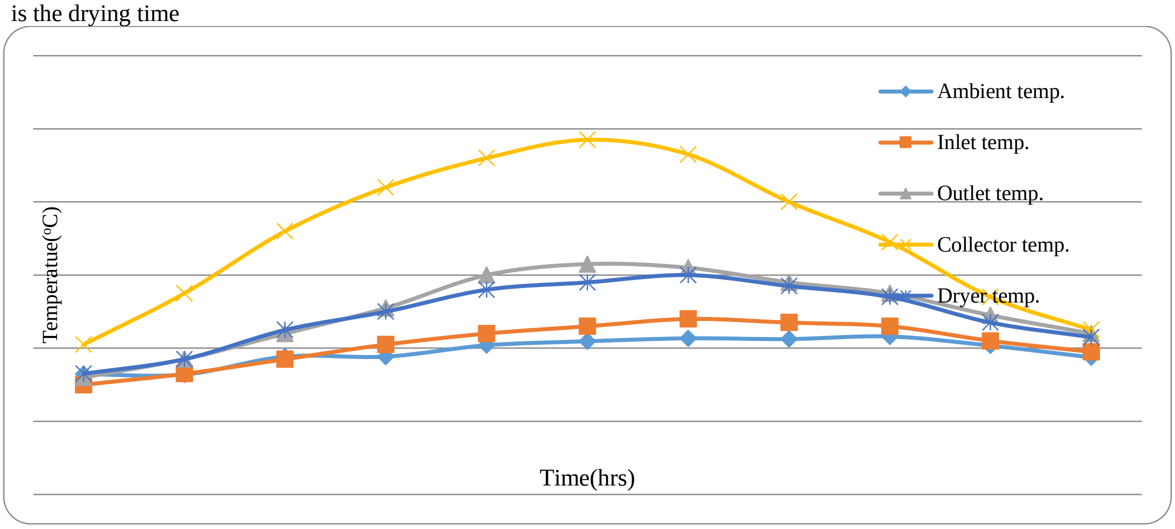

Figure 1: Variation of temperatures with time for no load test I in April 2019

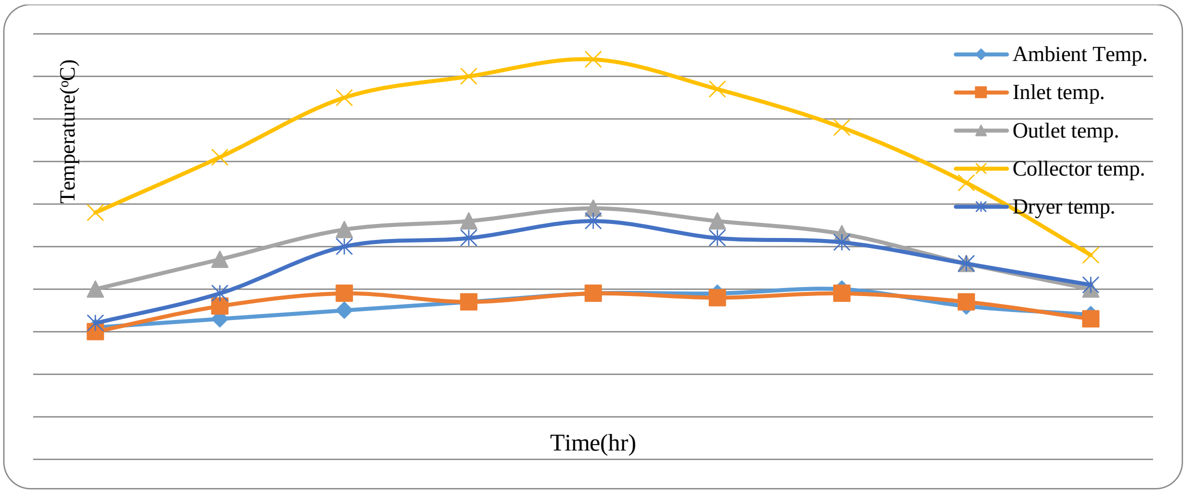

Figure 2: Variation of temperatures with time for no load test II in November, 2019

Load tests

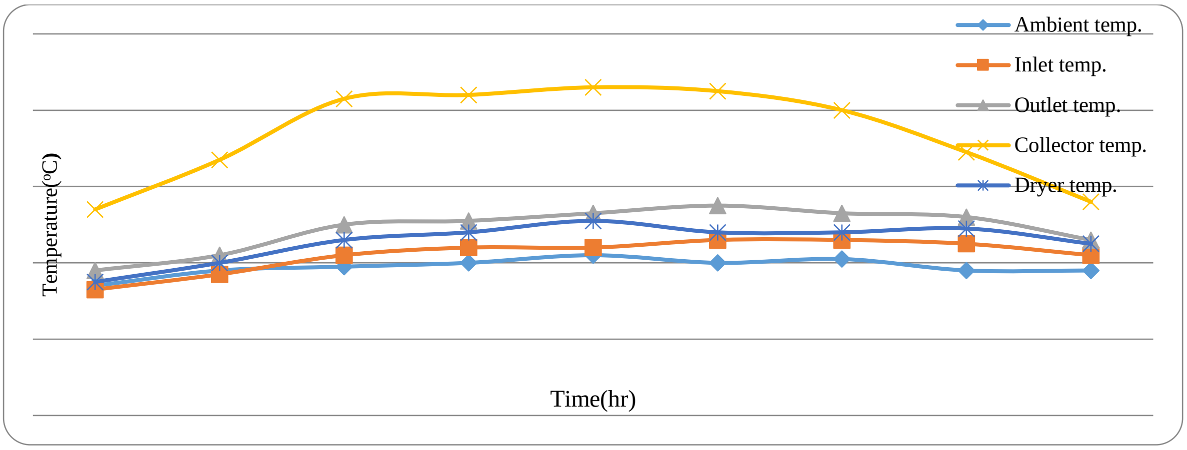

Figure 3: Variation of temperature with time for load test I in April, 2019

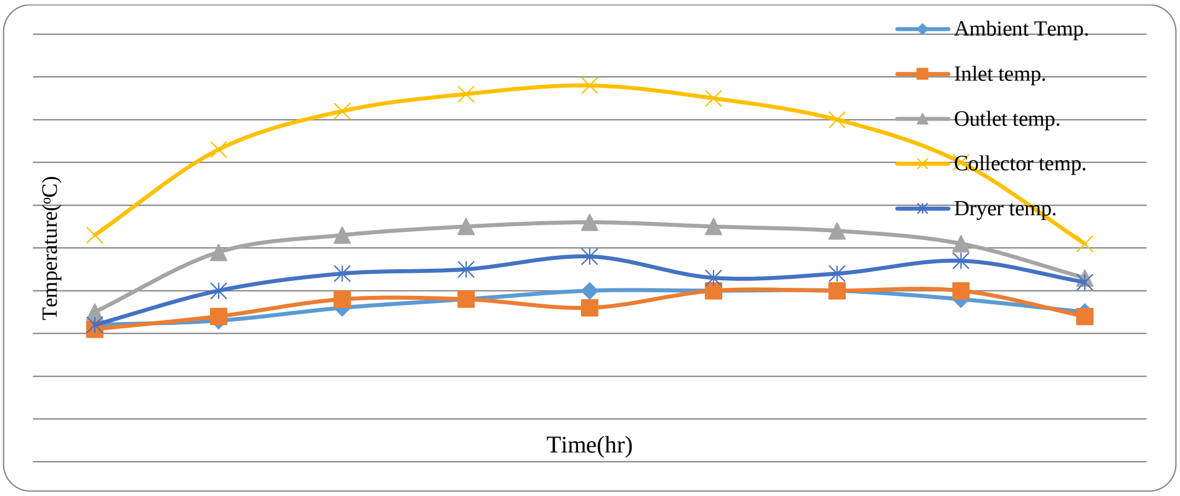

Figure 4: Variation of temperature with time for load test II in November, 2019

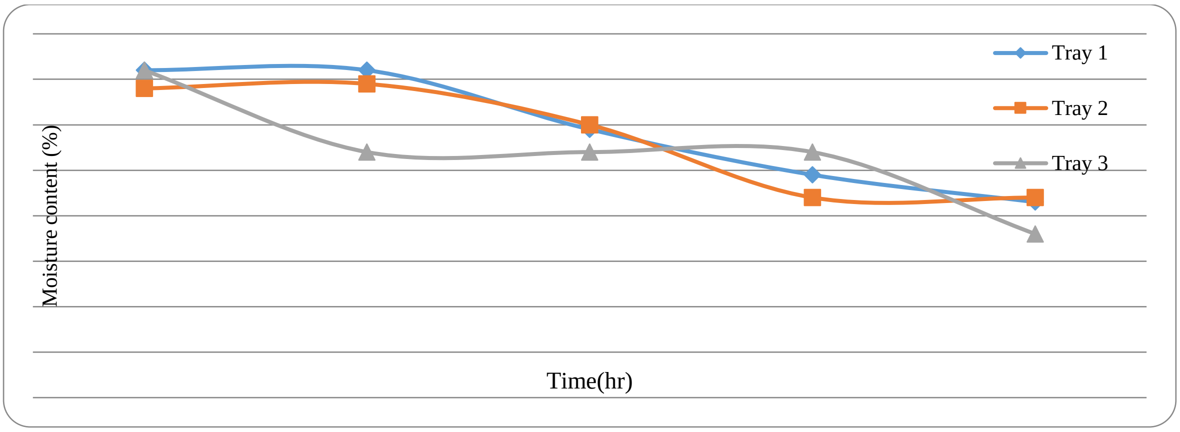

Figure 5: Variation of moisture content with time for load test I

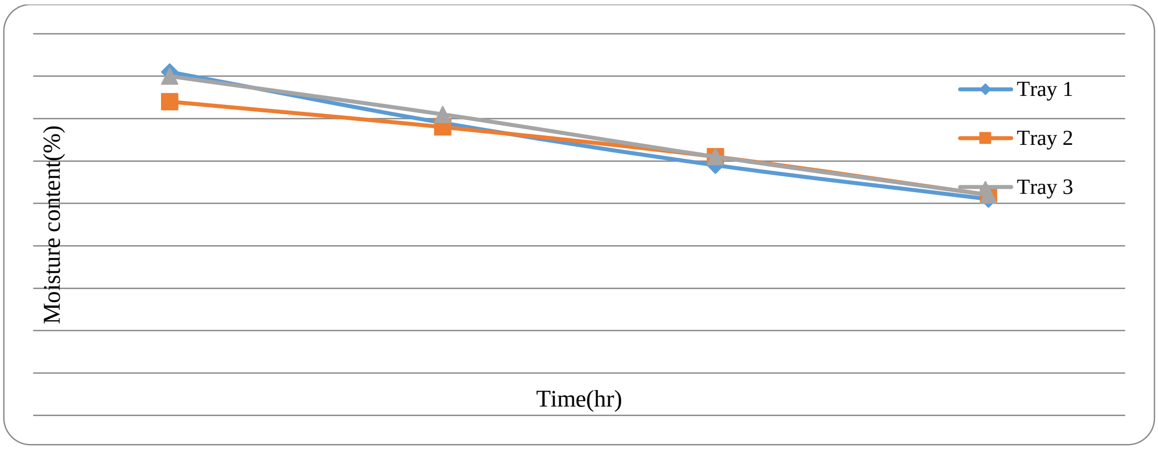

Figure: 6 Variation of moisture content with time load test II

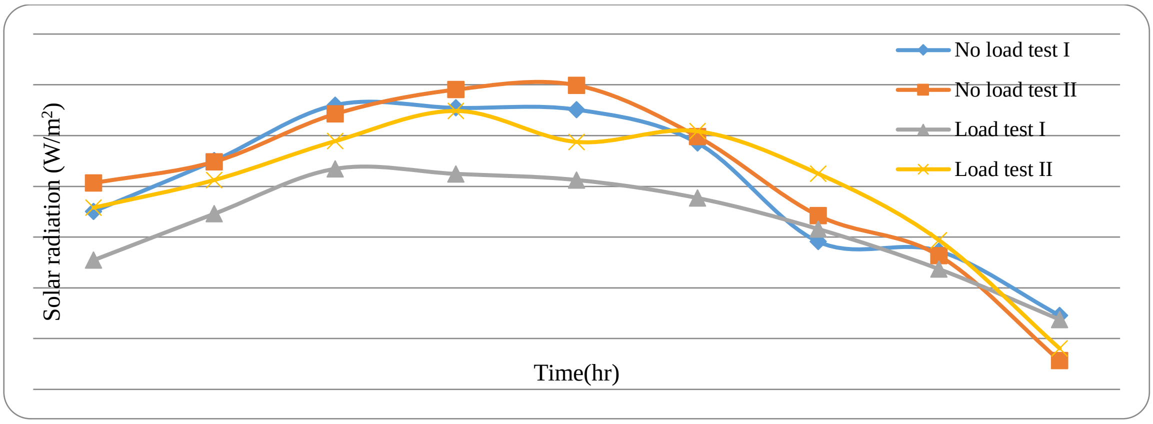

Figure 7: Variation of solar radiation with time for no load and load tests

The above figure 7 presents the results of variation of solar radiation with time for both no load and load tests.

DISCUSSION

No load tests

Figures 1 and 2 present the results of no load tests for the natural convection indirect solar dryer conducted on 11th April and 1st November, 2019. No load test was performed without anything inside the drying chamber. The parameters studied include ambient temperature, inlet air temperature, collector temperature, outlet air temperature and drying chamber temperature. The values of the parameters were recorded at every one hour interval. It was observed that, the maximum temperature in the dryer was 60 ℃ at 14:00 h for test I and 48 ℃ at 12:00 h for test II. The minimum temperatures were found to be 33 ℃ at 8:00 and 32 ℃ at 9:00 for test I and II respectively. The relative humidity for the corresponding temperatures was 37 % for test I and 23.7 % for II .. The maximum and minimum ambient temperatures for test I were 42.7 ℃ and 32.8 ℃ while that up test II were 41 ℃ and 30 ℃ respectively. Hence there was an increase in temperature of about 17.3 ℃ and 7 ℃ for tests I and II as compared to the outside temperature. The no load test helped to know the maximum possible temperature rise in the drying chamber as compared to the corresponding ambient temperature value as recommended by Tibebu (2015). Figure 7 presents the variation of solar radiation with time for the no load and load tests. It was observed that, the average solar radiation for no load test I was 702.55 W/m^2 and that up test II was 683.78 W/m^2. The average ambient humidity for no load test I was 23.75 % and 31.81 % for no load test II.

Load Tests

Figures 3 and 4 show the hourly variation of temperatures for load test I while 5 and 6 for load test II. It was observed that, the average ambient air temperature for the first test varied from 34 ℃ to 42 ℃ and for the second test ranged between 32 ℃ – 40 ℃. Also, the average solar radiation for first test ranged between 257 – 869 W/m^2 and for the second test ranged between 161 - 1097 w/m^2. A closed examination of figure 7 shows that the solar radiation attained it peak between 11:00 and 12:00 hours. It was also observed that the solar radiation started decreasing after 13:00 hours. As the solar radiation decreases also the ambient temperature, collection temperature, glass temperature and dryer temperature decrease. However, ambient relative humidity and inlet relative humidity started increasing at this point. This shows that the temperatures of collector, ambient and dryer are significantly dependent on the degree of intensity of the solar energy. The maximum average wind speeds recorded at each of the tests were 0.53 m/s and 0.41 m/s. These values were less than 1.7 m/s obtained by Abdulrahman (2013) using a mixed mode solar dryer. The maximum average drying chamber temperatures recorded were 51 ℃ and 48 ℃ for tests 1 and II respectively. A critical observation shows that there was a great difference between the values of collector temperature and outlet temperature of the collector. This shows that, the transfer of heat energy from the collector to the drying chamber was characterized by low speed of drying air.

From the graphs it was observed that the drying temperatures were higher than the ambient temperatures. This shows that the amount of heat energy transferred to the drying chamber was more than the ambient heat. Hence, the heat energy was sufficient to increase the vapour pressure of the moisture confined within the product which is in line with the research of Tiwari (2016). The desired moisture content of 7.6 % for first and second tests was reached within 18 hours of drying.

Drying rate

The drying rates obtained after the tests were found to be 0.081 kg/hr and 0.095 kg/hr. These values were lower than the recommended value of 0.25 per hour for solar dryers by Fellows (2000). Therefore, the result indicated that either the air temperature or air speed was too low or the relative humidity is too high. In this research, it was observed that, the speed of drying air was too low.

Collector efficiency

The collector efficiency of the natural indirect solar dryer under no load test was found to be 53.1%. This value was higher than the collector efficiency of 46% reported by Saravanan *et al*. (2014) but lower than 74 % reported by Yahya and Umar (2011) for an indirect solar dryer.

Dryer efficiency

The dryer efficiency was found to be 10.5 %.This value was within the range recommended by Madhlopa and Ngwlo (2007) which suggested that typical value of drying efficiency should be between 10 – 15 % for the natural convection solar dryer (Edmund, 2015).

CONCLUSION

The performance of a natural convection indirect solar dryer was evaluated. The hourly variation of temperatures inside the dryer and collector were much higher than the ambient temperatures under no load tests. The average collector temperatures for the two tests were 71.01℃ and 63.44 ℃ while that of the dryer were 49.09 ℃ and 42.67 ℃. The maximum air temperatures inside the dryer were found to be 60℃ and 48℃ and the drying rates for the tests were found to be 0.081 kg/hr and 0.095 kg/hr. It was found that, the dryer exhibited sufficient ability to dry yam slices to a safe moisture level and therefore, farm products with an initial moisture content of 71.3 % can be dried using this dryer.

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