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Estimating The Efficiency Of Okra Drying Mixed-Mode Solar Dryer

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Abstract: The business of using solar energy in crops drying has been in existence from the primitive man. This plays a significant role economically to famers and governments the world over. As important as this is, there has always been a quest to improve the method with increasing population and the need for more food production and better methods of storage. The dryer concentrates the available solar energy on the crops to be dried and by this reduces the length of time of drying, increasing the shelve life of the dried product and its quality. This work specifically focused on the design and construction of a mixed mode solar dryer from locally sourced materials for drying okra. The highest ambient air temperature recorded was 33 ^{0}C corresponding to the highest solar insolation of 450 W/m^2 at 14:00 hrs. In all, the overall dryer efficiency was about 65.5%

Keywords: Solar energy, shelve life, mixed mode, dryer efficiency.

1. INTRODUCTION

Crops drying by solar energy plays a significant role economically to famers and governments the world over. Many depend mainly on solar energy for the preservation of their crops agains microbial and fungal attacks. In Nigeria, during the harvest periods coincide with raining periods but the good thing is the country lies along the zone that is blessed abundantly with solar irradiance throughout the year. To effectively utilize the full potential of the abundant solar energy, proper solar dryer design for this purpse can notbe overemphasized. In drying these crops using the designed dryers removes both moisture and transfers heat [5]. Since the peak period of grains harvest fall within the peak rainy period, most grains are poorly dried with the attendant spoilage of the grains thereby always leading to shortage of food and the grains for the planting season. Solar drying is grouped into three classes - direct, indirect and mixed-modes. With the first class of direct solar dryers, the dryer is designed such that the collector or air heater contains the grains with a transparent glass cover where heat can be absorbed through it by the grains. Solar radiatione essentially required for the drying falls on the upper transparent cover and is conducted to the grain bed. The indirect dryers work slightly different from the first class by collecting the solar energy by a separate collector which in turn heats the air that filters along the grain bed. The working substance here is the heated air. In the mixed mode arrangement, heat energized air travels from separate solar collector through the dryer bed and symultaneously, the transparent walls or roof absorb solar energy directly [6]. Rural famers simply use open air drying where the grains are exposed to animal attacks, contamination, sometimes rains fall on them with the attendant poor finishing which often result in spoilage [7]. The uses of well designed solar dryers have obvious advantage of low temperature drying which enebles the grains to be dried without cracking. Another advantage is that it prevents growth of fungi on the grains and wastage due to bacterial attacts. This method is adaptable for bulk drying [5]. Fabrication of this mixed mode solar dryer from locally sourced materials to dry okra was the sole aim of this research.

2. BASIC THEORY

Standard energy balance equations of the flat plate collectors on fenestration information had been documented in texts [1, 2].

The following quantities have been computed from measured parameters using standard equations [7] for the dryer.

2.1 The angle of declination (δ)

The angle the sun makes in its direction with equatorial plane is known as declination [7], given as:

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right] \qquad (1)$$

where (n) is a day in the year and varies from n = 1 to n = 365.

2.2 Hour Angle, (H)

$$H = \frac{360T}{24} = 15T \qquad (2)$$

where T is the time of the day.

2.3 Solar Altitude (β)

This is the altitude at which optimum irradiance falls on the collector, determined from

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$\sin\beta = \cos L \cos H \cos\delta + \sin L \sin\delta$ (3)

where L = latitude; H = hour angle; (δ) = angle of declination for that location.

2.4 Direct Normal Solar (I_{DN}) Intensity

$$I_{DN} = \frac{A}{e^{\beta}/\sin\beta} \text{ (w/m}^2\text{)} \quad (4)$$

where A = collector area

2.5 Collector Thermal Efficiency (η)

This is computed from,

$$\eta = \frac{\rho V C_p \Delta T}{A\, I_C} \quad (5)$$

where (ρ) = density of air (kg/m^3); (I_c) = insolation on the collector; (ΔT) = temperature elevation; (C_p) = the specific heat capacity of air at constant pressure (J/kg K); (V) = volumetric flow rate (m^3/s); (A) = the effective area of the collector facing the sun (m^3).

2.6 Dryer Daily Efficiency (η_d)

This is given by [7],

$$\eta_d = \frac{Ml}{A\tau\, I_C} \quad (6)$$

where (l) = latent heat of vaporization of water, (J/kg); (M) = mass of the substance, (kg); (τ) = time of drying (s).

2.7 Heat energy Q needed by the dryer for crop drying

This is calculated from

$$Q = M_w l = \rho_w V C_p (T_a - T_b) \quad (7)$$

where l = latent heat of vaporization of water, (J/kg); M_w = mass of crop before drying, (kg); ρ_w = water density, (kg/m^3); T_a = temperature of ambient, (K); T_b = temperature of dryer, (K).

2.8 Determining the Moisture content (M.C)

This is calculated from:

$$M.C\ (\%) = \frac{(M_i - M_f)}{M_i} \times 100\% \quad (8)$$

where M_i = mass of sample before drying, (kg); M_f = mass of sample after drying, (kg).

2.9 Determining the Moisture Loss (ML)

The moisture loss is given as:

$$ML = (M_i - M_f) \text{ (kg)} \quad (9)$$

where Mi = mass of the sample before drying; M_f = mass of the sample after; l = latent heat of evaporation of water.

3. EXPERIMENTATION

The box-type mixed-mode solar dryer with four drying trays [9] was constructed using local, cheap and readily available materials. See Fig.1 for a section of the solar crop dryer. The main four main parts of the dryer are: (1) Box-type absorber of solar air collector of size 25mm x 50mm. (2) The drying chamber, size31mm x 76mm x 40mm which is designed to bearing in mind the required finished product to be dried, drying air speed, the prevailing relative air and the quantity of product to be dried. (3) The rack, of size 30mm x 75mm x 8mm and (4) two electric fans. In figure 2 is shown the design features of the solar crop-drying system.

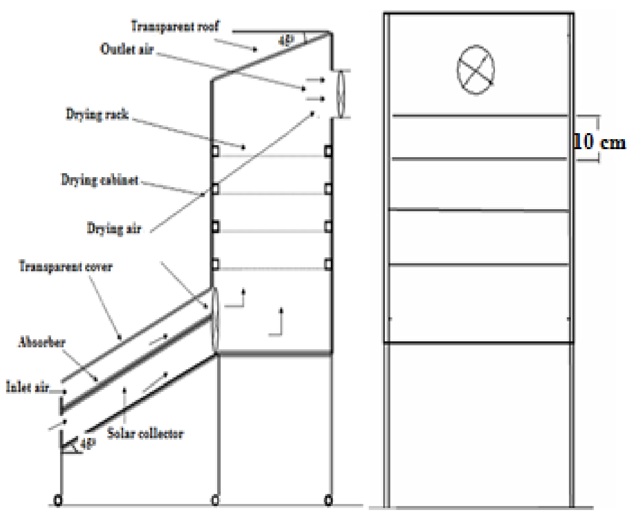

Figure 1: Features of the solar crop-drying system

3.1 Collector (solar air heater)

The heat absorber was fabricated from a black color coated galvanized plate of I mm in thickness to improve its solar absorptivity; the sun facing surface was also painted with black paint for the same reason [4]. This collector was packed with 5 cm thick insulating materials on all sides. Rock wool of thermal conductivity 0.04 Wm^{-1}K^{-1} was used for this purpose.

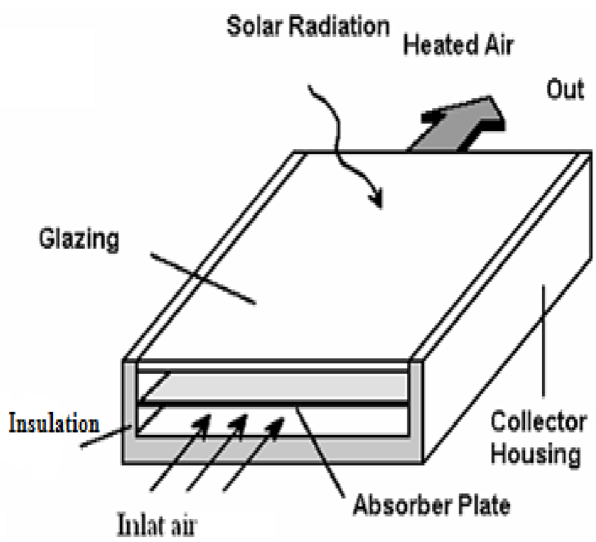

Figure 2: Typical solar air collector

The collector assembly encloses air passage which is in turn covered by a glazed transparent cover. It is a 4 mm thick single transparent glass layer of transmittance above 0.86 and measures 0.82 cm x 1.2 cm in area.

3.2 The Racks and Cabinets

The drying chamber houses four drying racks placed 10 cm equidistance from each other. The trays whose dimensions are as shown below are placed 20 cm evenly apart within the cabinet from each other carrying the product to be dried.

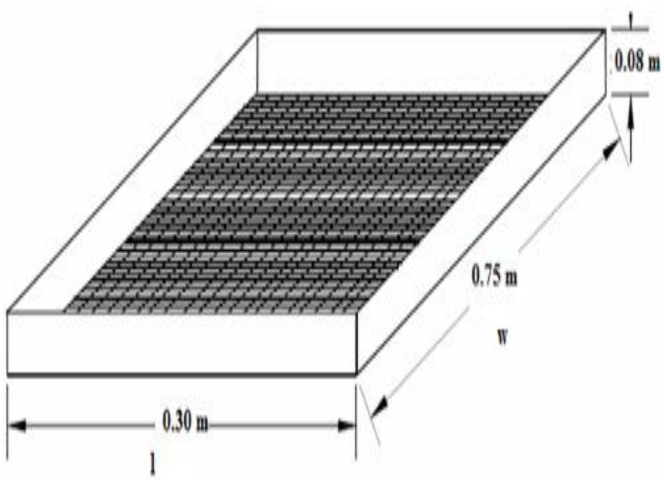

Figure 3: The tray showing its dimensions

The tray, (Figure 3) was fabricated with 3mm^2 aluminum wire mesh attached to it.They are fitted with handle for easy manipulation or sliding through the chamber. The drying chamber was lined with 5 cm thick foam insulation material to prevent heat loss.

3.3 Drying Process

In the drying process, heat is required to evaporate moisture from within the substance and air current helps in convection of the evaporated moisture away. The two basic mechanisms involved in the drying process are: 1) the migration of moisture from the interior of an individual material to the surface, and 2) the evaporation of moisture from the surface to the surrounding air [11]. The drying of a product is a non-linear and complex heat and mass transfer process which depends on external variables such as temperature, humidity and stream of air current and internal variables which depend on parameters like physical structure (porosity, density, etc.

3.4 Measurement of Physical Quantities

Two thermocouples accuracy of ±1 were fixed to record the air inlet and outlet portion of the air heater. Four other thermocouples were each placed on trays 1 to 4 to record their temperatures. Mercury in glass thermometers were used to measure the ambient air conditions during the experiment. Makurdi, Nigeria (latitude 33.27° northwards) was the location of the experiment and the orientation of the solar collector was inclined at 45^0 South direction which was found to give maximum insolation throughout the period of the month of March 2011. The solar radiation was measured directly using SL200 solarimeter inclined at the same angle with the collector and was controlled to take measurements at one hour interval. A cup anemometer was used to measure the air velocity and the set up was place away from trees shadows.

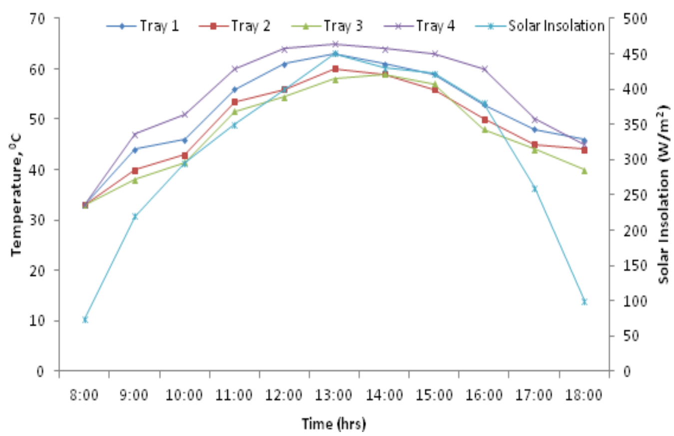

Figure 4: Temperature variation of ambient air, drying air on each tray and insulation

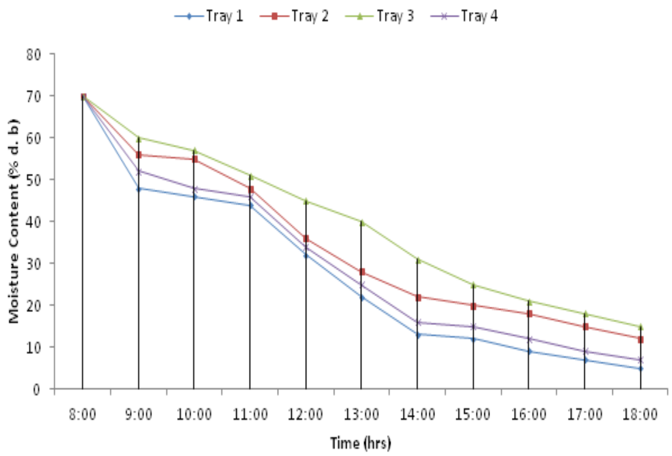

Figure 5: Variation of moisture content in okra from each tray with time

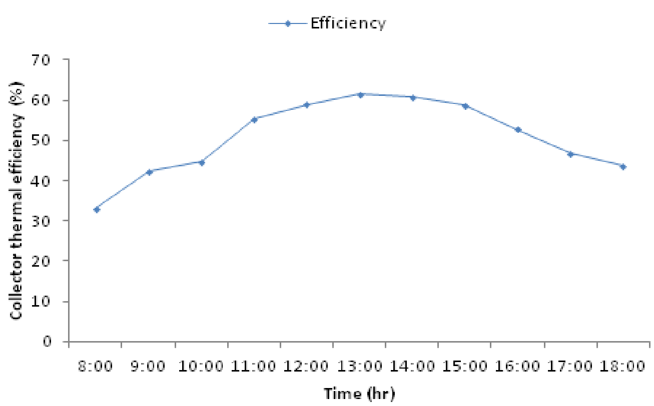

Figure 6: Variation of collector thermal efficiency with time

4 RESULTS AND DISCUSSION

Table 1: Mean Input Data

			Chamber Temperature					Moisture Content (% d. b)			
Time	Insolation	Ambient temp.	Tray 1	Tray 2	Tray 3	Tray 4	Air Vel.	Tray 1	Tray 2	Tray 3	Tray 4
hr	W/m^2	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	m/s	kg	kg	kg	kg
8:00	74	30	33	33	33	33	1.0	70	70	70	70
9:00	220	31	44	40	38	47	0.5	48	56	60	52
10:00	295	32	46	43	41.5	51	0.5	46	55	57	48
11:00	350	32	56	53,5	51.5	60	1.0	44	48	51	46
12:00	400	33	61	56	54.5	64	1.0	32	36	45	34
13:00	450	33	63	60	58	65	1.0	22	28	40	25
14:00	430	31	61	70	59	64	1.0	13	22	31	16
15:00	422	31	59	58	57	63	1.4	12	20	25	15
16:00	380	30	53	50	48.5	60	1.0	9	18	21	12
17:00	260	29	48	45	44	50	1.0	7	15	18	9
18:00	100	29	46	44	40	45	1.0	5	12	15	7

4.1 Indicated Collector Performance

It was observed from the results that the highest recorded solar insolation was 450 W/ m^2 which occurred at the hour of 13:00 and the lowest of 74 W/m^2 at 8:00 from the start of experimentation. This solar insolation was high enough to generate the necessary energy for drying process. Figure 4 shows plots of the mean temperature variation of outlet and ambient air, absorber and insolation against time. The working fluid (air) absorbed enough energy to raise its temperature to generate air current across the collector to carry out the drying process. The highest recorded ambient and tray temperatures occurred at 13:00 when the solar irradiance was highest showing the dryer thermal efficiency is dependent on the irradiance. The average air velocity stood at 1.0 m/s. Moisture loss from the product was also when the dryer temperature was highest.

4.2 Dryer Performance

Its performance is a function of many factors, chief of which is the solar intensity, the resultant inlet air temperature and its speed of entering. The highest ambient air temperature recorded was 33 ^{0}C corresponding to the highest solar insolation of 450 W/m^2 at 14:00 hrs.

4.3 Variation of Moisture Content in the Trays

Figure 5 shows that from 70% moisture content loss to (5, 12, 14 and 7%) respectively on dry basis through 10 hours according to (trays 1through 4).

4.4 The collector Efficiency

It is dependent on the inlet air mass flow, the temperature change between the inlet air and that at each tray and the intensity of the solar radiation.

5 CONCLUSION

At the end of the study, the following conclusion was drawn: 1) 65 °C was recorded as the maximum drying temperature; 2) 12 % of moisture was retained over the 10 hrs of drying. This shows that the drying is adequate for moisture extraction. Air temperature and its flow rate were the determining factors in the drying process; 3) Drying time of the product depended on the climatic conditions (solar radiation, relative humidity, ambient temperature and wind speed). 4) The highest thermal efficiency of the solar collector was 61.58% at 14:00 hrs.

COMPETING INTEREST

All authors declared that there is no competing interest

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