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Development of Solar Dryer with Thermal Energy Storage for Drying

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ABSTRACT

Drying is one of the most practical and traditional methods of preserving the quality of agricultural products. Solar dryer is the application of solar energy and numerous types of solar dryers have been designed and developed in various parts of the world, yielding varying degrees of technical performance. The problem with the solar energy is that it is intermittent and has a period of shinning. This problem makes most solar dryer ineffective and leads to moisture re-absorption and also prolong the period of drying, thereby affect the properties of the dried product. To solve this problem, granite stone painted black to absorb heat from the solar collector was provided to increase the drying period and improve product quality. This was placed immediately below the flat plate collector for storing the heat from the absorber. The heat stored by the rock was used later for drying when the solar energy is not available. The dryer was tested loaded and unloaded and the temperature of the cabinet and solar collector was measured with the help of k-type thermocouple connected to 12 channel temperature recorder at every hour. Tomatoes, sliced into 2mm thick were used when the dryer was loaded and the weight was measured at every one hour. Drying time was extended by 3 h and thereby reduces the drying period. Physical observation of dried tomatoes looks attractive. The drying chamber efficiency and overall system efficiency are 50.37% and 51.40% respectively.

1. Introduction

Renewable energy is energy that is generated from natural processes that are continuously easily replenished. Example of this energy are solar energy, wind energy, hydro energy, tidal, wave, geothermal, biomass etc. while non-renewable energy comes from sources that cannot be replenished. Examples of this energy are fossil fuels like coal, petroleum, and natural gas [1]. The sun is the most important source of heat and light in the world. In the early days when there was no electricity, the sun was majorly used as a source of heat and light in all their activities. Solar energy is one of the greatest source of renewable energy due to its increased affordability and it is referred to as the energy that comes from the sun‘s rays. Solar energy can be utilized in many ways, like, including heating houses, providing electricity, distillation of sea water and drying of agricultural products [2].

Drying is one of the most practical methods of preserving the quality of agricultural products and one of the traditional uses of solar energy has been for drying of agricultural products. Drying of agricultural products is one of the most attractive and cost-effective application of solar energy. The drying process removes moisture and helps in the preservation of the product. Traditionally, drying is done on open ground. The disadvantages associated with this are that the process is slow and that insects and dust affect the quality of the product. Thus, the use of dryer helps to eliminate these disadvantages. Drying can then be done faster and in a controlled fashion. In addition, a better quality product is obtained [3, 4]. Basically, there are four types of solar dryers; direct solar dryers, indirect solar dryers, mixed-mode dryers and hybrid solar dryers. There are two major classifications of solar dryer, direct solar dryer in which the item to be dried is exposed directly to solar radiation through a transparent material that covers the structure. The heat generated from the solar energy is used to dry the crops or food items and also heats up the surrounding. The second type is indirect solar dryer, which does not expose the crop directly to the sunlight. The solar radiation is absorbed and converted into heat by another surface (like a black top) usually called the collector. Air that will be used for drying is passed over this surface and gets heated, which is then used to dry the food item in the dryer. The main advantage of the indirect mode of drying is that the temperatures can be controlled. The sizes can vary from kilograms to metric tons, but it is expensive and more complex to construct when compared to direct solar dryers [5 -8].

To improve productivity in agriculture, preservation technique must be reliable and cheaper. The most readily available means of preservation of agricultural products are through sun drying, but sunlight, which is the source of energy is intermittent in nature. Therefore, how to store the energy so that drying can continue throughout the day and night is an attractive area of research. Energy storage is very important when the energy input is intermittent in supply like sunlight. However, to take care of the intermittent nature of sun, solar dryer can be enhanced by another source of energy such as electrical heater or solar collector being filled with paced rock beds, gravel, desiccant, water and phase change material [9-19].The selection of thermal storage system for an application depends on factors such as storage duration, economics, temperature supply and utilization requirements, storage capacity, heat losses and space availability. Thus, this experimental work has the objectives of comparing the drying

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period when thermal energy storage was used and when not used. Granite was used in this work as the thermal energy storage material because of its availability.

2. Methods

The dryer design was based on climatic condition of Ogbomoso which is the area of the experiment. Past designs of the dryer were studied and necessary parameters were determined. The performance of the dryer was analysed and the dryer dimensions were fixed. Ogbomoso Latitude and longitude are 8.13333 and 4.26667 respectively.

2.1 Design of System Components

Solar Collector

The flat plate absorber was made from corrugated roofing sheet and placed in a box made from aluminum and painted black for good absorption. The solar collector assembly consists of air flow channel enclosed by transparent cover made of glass. The metal sheet thickness of 0.8 mm was used for the construction. The dimension of the collector is 1 m by 0.5 m. The various collector components are as follows: A transparent glass top to allow solar irradiation into the collector unit and prevent loss of thermal energy. There is provision in the collector for thermal storage materials.

Drying Chamber

The drying cabinet was built from galvanized sheet metal which is reliable in strength and has low weight and good ability to withstand corrosion and atmospheric attack and most importantly has good thermal conductivity. An outlet was provided at the top of the cabinet. This facilitates and controls the movement of moisture out of the dryer. Access door to the inner part of the dryer was also provided at the front of the cabinet.

The drying chamber of length 0.3m and width of 0.1m and a thickness of 0.036m was made. The sides of the chamber are insulated using a 10 cm thick foam material to prevent loss of heat energy. The various properties of the drying air were to be measured along the duct. The measuring devices were inserted into an inlet made in the duct for the measurement of temperature, relative humidity, and the air-flow rate.

Thermal Storage

Granite was selected as a means of heat storage because it has good thermal properties and was painted black to enhance its absorbtivity performance. It was put in the absorption chamber to prolong the drying period. Thermal conductivity of granite at room temperature is 1.6 – 7.7 W/mK and air is 0.03W/mK [20].

The drying tray

There are three drying trays inside the chamber with the dimension of 0.498m by 0.488m and are made of wooden frame and wire mesh with a fairly open structure to allow drying air to pass through the food items and to allow for circulation within the drying chamber.

Plate 1. Side view of Dryer

2.2 Performance Evaluation

The dryer is a passive system in the sense that it has no moving parts. It is energized by the sun’s rays entering through the collector glazing. The trapping of the rays is enhanced by the inside surfaces of the collector that were painted black and the trapped energy heats the air inside the collector. The flat plate solar collector is always tilted and oriented in such a way that it receives maximum solar radiation during the desire season of used. The air flow inside the dryer is achieved by natural convection.

Both no load and load situation was considered during the testing of the dryer. Variations in temperature and solar radiation were observed at every one hour. The temperature at the inlet and the temperature falling on the collector was measured by laboratory type mercury bulb thermometer while the temperature inside the chamber was measured by using 12channel temperature recorder. The solar radiation was measured throughout by means of (solar power meter) Pyrometer.

Relative humidity was also measured by using thermo hygrometer. In the case of loading, i.e. when sliced tomatoes were loaded in the dryer, to test the performance of the dryer. Digital weight balance was used to measure the initial weight of tomatoes and subsequent weight was taken at intervals of one hour throughout the drying period.

2.3 Experimental Procedure

Fresh tomatoes purchased from new Wazo market located in Ogbomoso North local government, Oyo state. They were washed and the good ones were separated from bad ones. The good ones were cut into 2mm tick each and were placed in the dryer during the experiment. The experiments were repeated three times and the results are presented in tables 1 to 4.

Part of the performance evaluation of the dryer apart from measuring some parameters directly during experiment involves determination of the following parameters [21, 22]:

Moisture content: the moisture in tomato was determined after each hour of drying using equation 1. The moisture content after each hour of drying was determined by taking initial weight and weight loss after each hour with the help of electronic balance (model EPS-3001, 3000gx 0.1g).

$$M_c = \frac{M_i - M_d}{M_i} \times 100 \qquad (1)$$

Drying rate: The drying rate was formed by decrease of the water concentration during the time interval between two subsequent measurements divided by this time interval as in equation 2

$$R_d = \frac{M_i - M_d}{t} \qquad (2)$$

Collector efficiency: A measure of collector performance is the collector efficiency and it is defined as the ratio of useful heat gain over any time period to the incident solar radiation over the same period as in equation 3.

$$\eta_c = \frac{Q_u}{IA_c} \qquad (3)$$

Drying chamber efficiency: It can be defined as the ratio of difference between the drying chamber inlet and drying chamber outlet temperature to the difference between the drying chamber inlet and ambient as in equation 4

$$\eta_d = \frac{(T_1 - T_2)}{(T_1 - T_2)} \quad (4)$$

Overall system efficiency is the ratio of the energy required to evaporate moisture from the product to the heat supplied to the dryer. The system drying efficiency is a measure of the overall effectiveness of a drying system as in equation 5.

$$\eta_s = \frac{m_w h_g}{IAt} \quad (5)$$

Where; W_o is the mass of moisture evaporated; L is the latent heat of vaporization of water at the dryer temperature; I is the total global radiation on the horizontal surface during the drying period; kJ/m^2; Ac is the solar drying system collector area, m^2; m_w is mass of water in tomatoes

3. Results and Discussions

The result of effect of stone in the solar collector during no load period is presented in table 1. The table shows the variation in the solar radiation and ambient temperature and their effects on the collector and dryer temperatures. It was observed that the dryer has the highest temperature of 64.5°C when the collector temperature is 70°C and solar radiation was 803.2 W/m^2 at 1pm. The dryer temperature was higher than ambient temperature till 8pm in the night, which shows that drying period can be extended till night. This is due to the retention ability of the granite in the collector. This is desirable for a good drying system.

Tables 2 and 3 shows no load experiment when granite alone and flat plate collector was used. From table 2, the highest temperature in the dryer and collector are 59°C and 64.2°C while that of table 3 is 58°C and 50.5°C respectively. From table 2 the temperature inside the dryer was higher than that of the ambient at 8pm while for flat plate collector could not go beyond 6pm when the there was no solar radiation.

Table 4 shows the drying process of tomato. It was observed that maximum tray temperature is 58.8°C and 51.2°C for top and bottom tray, which is good for drying process. There was a progressive reduction in the weight of the tomatoes as drying progresses as shown in figure 1 until the weight was constant. It was also observed that the temperature was well distributed in the dryer during the drying period. Drying was done until 9pm for the two days that the drying was done just to confirm that inclusion of granite in the dryer elongate the drying period thereby making the drying faster. This will also improve the quality of the tomato. The total drying period for tomato in the experiment is 16 hours. Humidity values also confirm that water is being removed from the drying material. The results of the analysis show that drying chamber has an efficiency of 50.37% and overall system efficiency was found to be 51.40 which is good for the drying process.

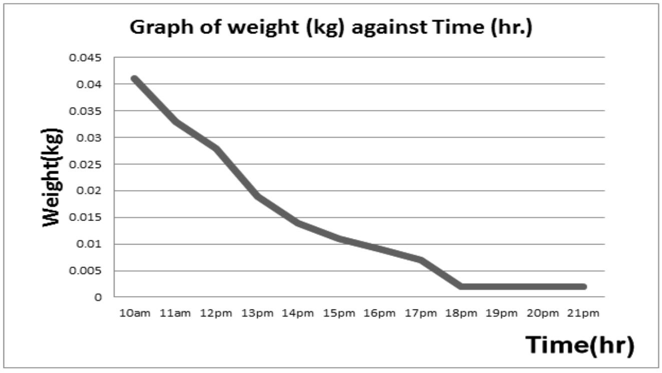

Figure 1. Graph of weight (kg) against Time (hr).

Table 1.No load test for collector and stone.

Time (hrs)	Solar rad. (W/m^2)	Ambient Temp.(°C)	Temp. inside the chamber(°C)	Temp. of the collector(°C)
9 am	535.0	30.0	32.0	34.4
10am	725.9	32.5	37.0	39.0
11 am	760.5	33.0	45.0	52.5
12pm	775.4	35.5	60.0	68.5
1 pm	803.2	36.0	64.5	70.0
2 pm	731.0	34.5	54.0	60.0
3 pm	772.8	34.0	50.0	52.0
4 pm	773.3	34.0	40.0	42.0
5 pm	734.2	32.0	35.0	37.5
6 pm	720.1	29.5	30.0	32.5
7 pm	595.1	27.5	28.1	28.8
8 pm	320.5	27.5	28.0	28.5

Table 2. No load testing for stone only.

Time(hrs)	Solar rad. (W/m^2)	Ambient Temp.(°C)	Temp. inside the chamber(°C)	Temp. of the stone(°C)
12pm	754.6	35.5	43.5	55.0
1 pm	768.3	34.0	55.0	50.0
2 pm	779.5	36.5	59.0	62.0
3 pm	805.3	38.0	57.0	64.2
4 pm	725.6	35.0	45.5	55.2
5 pm	702.3	32.5	40.0	45.0
6 pm	699.1	30.2	33.5	35.2
7 pm	344.2	28.5	28.2	29.0
8 pm	120.4	27.9	28.0	28.2

Table 3. No load testing for collector only.

Time (hrs)	Solar rad. (W/m^2)	Ambient Temp. (°C)	Temp. inside the chamber(°C)	Temp. of the chamber(°C)
11pm	706.7	29.0	40.5	40.0
12pm	699.5	30.5	42.0	42.0
1 pm	778.5	31.0	45.5	45.5
2 pm	798.0	33.5	58.5	50.5
3 pm	792.5	32.5	55.0	64.5
4 pm	786.2	30.0	52.0	58.5
5 pm	701.0	27.0	50.5	55.0
6 pm	688.5	25.5	37.5	40.5

Table 4. Load testing for tomatoes considering weight loss

Initial weight of Tomatoes used=0.110kg

Time (hrs)	Solar rad (W/m^2)	weight (kg)	Amb. Temp (℃)	C_1 (℃)	C_2 (℃)	C_3 (℃)	C_4 (℃)	C_5 (℃)	C_6 (℃)	C_7 (℃)	C_8 (℃)	C_9 (℃)	C_{10} (℃)	C_{11} (℃)	C_{12} (℃)	H. (%)
2pm	799.1	0.110	33.3	48.8	48.5	40.1	51.1	47.4	49.2	48.7	70.0	61.5	53.3	48.8	72.5	47
3pm	784.6	0.095	32.9	47.1	47.2	37.5	48.0	47.3	47.5	47.1	56.5	55.6	51.2	42.3	55.9	48
4pm	775.1	0.074	32.3	46.8	46.2	39.2	50.1	48.4	47.7	47.8	69.0	59.4	52.3	47.3	72.4	49
5pm	760.0	0.056	32.2	45.2	46.0	38.8	48.5	48.2	47.5	47.2	52.0	54.5	50.0	42.1	68.9	51
6pm	550.2	0.049	29.6	40.1	41.1	40.0	42.7	42.3	39.2	39.9	49.2	51.1	48.2	39.8	54.2	54
7pm	320.1	0.045	26.9	32.2	33.1	30.9	31.4	32.8	31.1	30.1	33.1	35.1	34.1	31.0	30.1	73
8pm	85.9	0.042	26.7	26.8	26.9	27.0	27.5	28.1	29.3	26.9	28.0	30.1	29.1	27.1	28.2	75
9pm	53.0	0.040	26.0	26.1	26.5	26.9	27.1	27.2	27.0	26.0	26.4	28.5	28.4	26.8	27.0	83
10am	602.1	0.039	26.8	28.3	28.3	29.4	29.7	29.6	29.8	30.1	27.3	26.8	28.3	31.7	31.9	80
11am	641.6	0.033	29.0	35.8	36.1	35.9	39.1	38.7	39.5	39.9	30.7	32.4	34.9	45.9	49.7	69
12pm	791.5	0.028	30.2	48.9	49.4	48.9	48.0	51.1	50.6	52.8	78.8	36.7	45.9	59.0	71.6	53
1pm	832.0	0.019	31.3	51.3	58.8	50.0	51.3	52.5	53.7	55.8	76.5	45.1	49.1	52.3	76.6	47
2pm	824.3	0.014	32.0	50.6	52.2	50.2	50.7	50.0	51.0	54.2	41.4	43.9	48.5	43.1	70.7	48
3pm	725.4	0.011	31.8	50.5	52.4	52.5	52.4	50.5	50.6	51.7	64.3	42.4	49.6	41.8	73.2	44
4pm	718.7	0.009	32.2	47.8	48.9	51.7	49.5	48.6	48.9	50.3	38.8	38.8	47.3	40.3	64.7	45
5pm	705.2	0.004	31.3	42.7	42.9	49.1	42.8	42.0	41.6	43.7	36.0	35.1	42.3	35.6	47.6	50
6pm	655.8	0.002	30.4	36.7	36.5	38.9	37.0	37.0	36.9	35.5	32.8	32.2	38.0	32.1	36.0	62
7pm	624.5	0.002	28.5	26.9	30.6	27.8	25.5	30.2	27.3	29.4	26.7	30.5	25.4	30.0	29.0	79
8pm	125.2	0.002	25.6	25.9	27.4	26.9	25.1	28.3	26.5	27.3	26.0	27.0	25.2	25.5	26.0	81
9pm	18.9	0.002	24.9	25.2	25.9	24.5	24.8	25.1	25.6	24.9	24.8	25.2	25.0	25.9	25.7	85

Amb. Temp= Ambient Temperature in (℃).
Hum. = Humidity in (%)
C_1= Temperature at the top tray inside the chamber in (℃).
C_2= Temperature at the bottom tray in (℃).
C_3= Temperature at the door surface (inside) (℃).
C_4= Temperature on the left surface inside the dryer (℃).
C_5= Temperature on the left surface inside the dryer (℃).
C_6= temperature at the back surface inside the dryer (℃).
C_7= temperature at the top of the dryer inside (℃).
C_8= Temperature on the absorber (℃).
C_9= Temperature on the glass surface (℃).
C_{10}= Temperature of the granite (℃).
C_{11}= Temperature on the right side of the dryer (℃).
C_{12}= temperature on the top surface of the dryer (℃).
W = weight at measured at different hours in kg.

4. Conclusion

A solar dryer with thermal energy storage was designed and constructed and its performance was evaluated using tomatoes. Savings in time were achieved as against the ordinary collector for drying as the extension of heat inside the chamber was up to 3 hrs which was not so for ordinary collector. Since the developed dryer does not use electricity, it can be used by farmers in rural communities. Physical observation of dried tomatoes looks attractive. The drying chamber efficiency and overall system efficiency are 50.37% and 51.40% respectively

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