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Performance Analysis of Mixed-Mode Solar Dryer for Drying Vegetables

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Abstract

This work presents the design, fabrication and performance analysis of mixed-mode solar dryer for vegetables. In the dryer, the heated air from a separate solar collector will pass through a grain bed and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls and roof. The main components of the dryer are the solar collector (air heated), the drying, cabinets, drying trays. The results obtained during the analysis period shown that dryer and the solar collector was higher than the average ambient temperature during most hours of the day light. The rate of drying and efficiency of the system were found to be 0.75kg/h and 62.5% respectively. These, values obtained for the dryer exhibited sufficient ability to dry vegetables products to a safe moisture level and simultaneously ensured a superior quality of dry product.

1.0. Introduction

Drying is one of the oldest methods of food preservation [1-9]. Traditionally, drying is carried out openly in the field. Open air drying using direct sunlight has numerous draw backs which include subjection to adverse weather conditions like rain, dusts, wind, insects and sometimes rodents. This method slows down the drying rate, causing mold formation, for several thousand years, people have been preserving apricots, grapes, herbs, potatoes, corn, milk, meat and fish by drying [4,10]. Until canning was developed at the end of the 18th century, drying was virtually the only method of food preservation. Open sun drying has no quality control and also has a risk of contamination, creating a potential health hazard. The product's quality is seriously degraded, sometimes to the extent that they are inedible [10, 3, 8]. Food deterioration and spoilage is caused by the action of yeasts, bacteria and enzymes. The drying process removes enough moisture from food to prevent the growth and reproduction of microorganisms like bacteria, yeasts and molds causing decay. Food drying can reduce loss of a harvest surplus, allow storage for food shortages, and in some cases facilitate export to high value markets. To guide against the aforementioned demerits and also to speed up the rate of drying the product, control the final moisture content and elimination of microorganisms effect, various types of solar dehydrators can used [11]. Upon the subsequent development in the technical world, efforts are focused towards improve drying and this led to solar drying as an upgrade from sun drying.

Solar dryers are special drying enclosure that is used to dry food, produce and has numerous merits which include controlled drying rate, drying of higher temperature, lower relative humidity, and reduced moisture content of dried food [12]. Also it protects the produce against adverse weather conditions, pests and rodents [12]. In many parts of the world there is a growing awareness that renewable energy has an important role to play in extending technology to the farmer in development countries to increase their productivity [12]. However, to improve traditional drying, solar dryers which have the potential of substantially reducing the demerits of open-air drying, have received considerable attention over the past 20 years [2, 6, 5, 12, 1, 9]. Nowadays, several solar dryers designs exist in the market, and most of these designs require expensive materials and source of energy, which makes the prototype expensive and difficult to obtain for small scale producer [12, 13]. In this work we designed and fabricate a mixed-mode solar dryer which exhibit a sufficient ability to dry vegetable produce for domestic purpose

2.0. Materials and Methods

For this study, the research methodology covered the research design, selection of materials, design of the amount of moisture to be removed, quantity of air required to effect drying, Blower design and capacity, Quantity of heat required to effect drying, thermal efficiency of the dryer and drying rate.

2.1. Materials

The selection of materials for this study was guided by the design that was done, work they are expected to perform, the environmental condition in which they would function, their availability in the local market at cheaper costs. The body of the cabinet was made of plywood because it is a poor conductor of heat. Hence, heat loss from the cabinet would be greatly minimized. The inside of the cabinet was lined with aluminum sheet in order to reflect heat back to the cabinet also prevent decaying of the wood due to humid air, galvanized sheet metal also has outstanding advantages of toughness and ability to conduct and radiate heat, burnt bricks was used to build the wall of the heating unit because of its poor conductor of heat.

2.2 Method:

i. **Collector (Air Heater)**

A flat plate collector is used since it is easy to fabricate and also economical. The collector was constructed using plywood, galvanized iron sheet, clear glass which were locally available with low cost. The collector is made up of wood. GI sheet of 27mm gauge is used as absorber as it is a good conductor and economical. It is painted black to increase the absorption of heat. The space between the inner box and outer box is filled with foam material of about 40mm thickness and thermal conductivity of $0.043Wm^{-1}K^{-1}$. The insulating material was selected to be plywood as it is a good insulator as well as environmentally friendly. It also does not have carcinogenic effects which other popular insulating materials like glass wool have. The collector glazing is a single layer of 4mm thick transparent glass sheet that has a surface area of 720mm by 980mm and of transmittance above 0.7 for the wave lengths in the range of 0.2 – 2.0 μm and opaque to wave length greater than 4.5 μm. One side of the solar collector has an air inlet vent of area $0.0888m^2$ which is covered by a galvanized wire mesh to prevent entrance of rodents while the other end opens to the plenum chambers.

ii. **Drying Cabinets.**

This is the place or space where drying of vegetable occur. The design of the drying cabinet was done to permit the user to use it as in –bin storage dryer. Since the dryer is a prototype and drying is to be done in racks, five racks were arranged at a distance of 100mm in drying cabinet the dimensions of the racks were taken as 370 x 370 x 100mm. the drying cabinet consisted of a square box dimension: 400 x 400 x 500mm. in order to minimize heat loss by conduction to the ambient environment; it was painted black both inside and outside to increase its heat absorption. The drying cabinet had in addition a digital thermometer/hygrometer inserted inside the drying cabinet in order to measure the temperature of the drying air and humidity in the drying cabinet. The mixed mode dryer isometric view is shown in Fig 1and Fig 2.

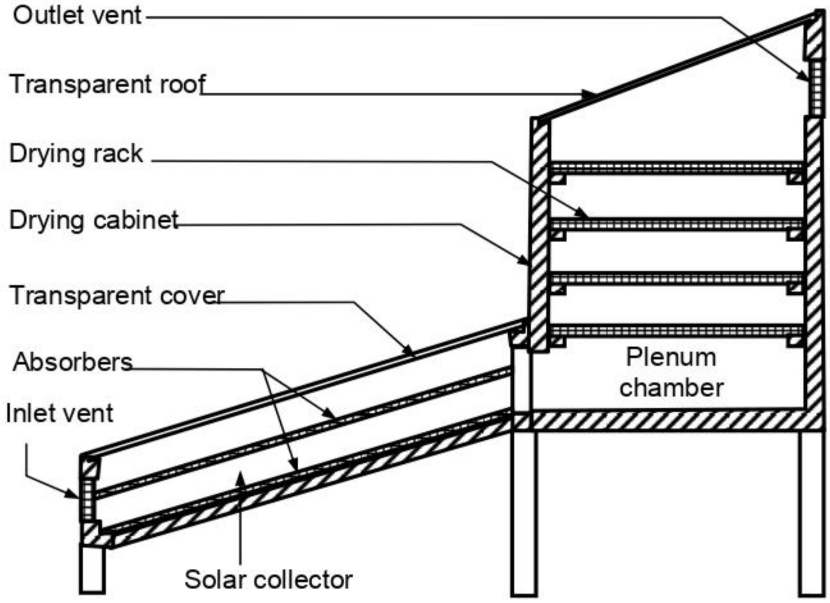

Fig. 1. Sectional view of the mixed-mode solar dryer.

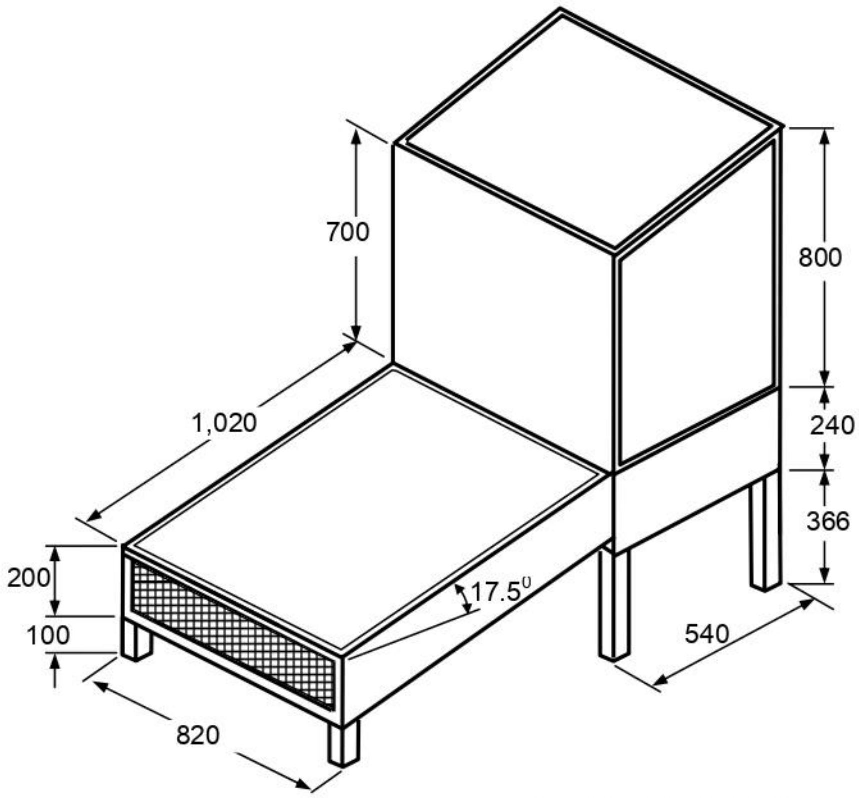

Fig. 2. Isometric drawing of the mixed-mode solar dryer.

iii. Drying Trays

The drying trays are contained inside the drying cabinet and were constructed from galvanized wire mesh with a fairly open structure to allow drying air to pass through the vegetable

2.3. **Determination of the Tilting Angle for the Solar Collector**

The tilting angle for the solar collector was determined from [14]

$$\beta = 10^0 + Lat\phi \quad (1)$$

Where,

β = Tilting angle

$Lat\phi$ = Latitude angle of the Solar collector location

The latitude angle of Uromi where the dryer was designed and fabricated is 7.5^0N, Substituting into equation (1) gives

$$\beta = 10^0 + 7.5^0 = 17.5^0$$

The flat plate solar collector is normally tilted and oriented in such a away that it receives maximum solar radiation in the desired season of use. The best stationary orientation is due South in the Northern hemisphere and due North in Southern hemisphere. The Solar collector for this work was therefore oriented facing the South and tilted at 17.11^0 to the horizontal.

2.4. Experimental Setup and Approach

The test was conducted between the period of 5th of March, 2023 and 13th March, 2023.

An initial test was first conducted for six bright days to evaluate the thermal profile of the solar collector from 6.00am to 6.00pm. The ambient air conditions were noted and recorded by the use of a digital thermometer, as well as their corresponding drying cabinet temperature. The vegetables used were bought from a Uromi Market to determine the maximum amount of vegetable that can be handled per batch for optimal drying base on the quality of heat produced as well as the drying time. A maximum of 0.4kg of vegetable were sufficiently dried. At the start of the solar drying test, the fabricated solar dryer was positioned at the front of Mechanical Engineering Department such that a shadow will not be cast in order to prevent shading effect. The dryer was positioned to align with the North-South axis and with solar collector tilted to face the South Pole. The moisture content of the vegetables was determined by weighing the fresh vegetables and drying them until no significant weight loss was observed. The weight was measured and recorded in one hour intervals with the use of an electronic weighing balance.

Before the staring of solar drying test, the mass of the vegetables was recorded. Then the weighed tagged vegetables was put into the drying cabinet, the starting time was recorded. The temperature in the solar collector cabined and the ambient air temperature was measured with a digital thermometer and hygrometer respectively. At the end of the test which lasted for 4-6 hours, the moisture content was calculated as a percentage of the initial dried mass of the vegetable and the difference between the initial mass and the hourly measured mass was used to calculate the percentage weight loss for vegetable.

2.5. Performance and Data Analysis

2.5.1. Collector Efficiency

Collector efficiency measures the thermal performance, i.e the useful energy gain of the collector. Not all of the solar radiation from the sun incident on the collector surface is converted to heat. Part of the radiation is reflected back to the sky and the other component is absorbed by the glazing. Once the collector absorbs heat and as a result temperature gets higher than the surrounding, there will also be a heat loss to the atmosphere by convection and radiation.

Collector Efficiency, $\eta_c = \frac{Ma(To - Ti)Cp}{IcAc}$ (2)

2.5.2**. Moisture Content**

Moisture content was taken at the beginning and at the end of each drying day drying and calculated using the following equation

Moisture content $M_c = \frac{Mi - Mf}{Mi} x100$ (3)

2.5.3. **Drying Rate**

Drying rate is the amount of evaporated moisture over time

Drying Rate $D_R = \frac{Mi - Md}{t}$ (4)

2.5.4. **Drying Efficiency**

Drying efficiency is the ratio of the energy needed to evaporate moisture from the material to the heat supplied to the dryer. This term is used to measure the overall effectiveness of a drying system. But it may not be used for comparing one dryer with another due to different factors such as the particular material being dried, the air temperature and mode of air flow may differ for various dryers.

System efficiency can be expressed mathematically as

$\eta_d = \frac{M_L}{I_t A_c}$ (5)

2.5.5. **Amount of Moisture to be removed**

The formula to calculate the total amount of moisture to be removed (Mw) is given by [14]

$M_m = \frac{W_w (Mi\ \% - M_f\%)}{I - M_f}$ (6)

2.5.6. **Amount of heat required to remove moisture content is given by**

$Q_R = (M_m \times h_{fg}) + (M_m \times h_f)$ (7)

3.0. Results and Discussion

The day results of hourly variation of the temperatures in the Solar collector and drying cabinet compared to the ambient temperature. The dryer is hottest about 13.00 hour when the sun is usually overhead. The temperatures inside the dryer and solar collector were much higher than the ambient temperature during most hours of the day light.

The temperature rise inside drying cabinet was up to 25^0c (75%) for about three hours immediately 13.00hour and this indicates prospect for performance than open-air sun drying.

The variation of the relative humidity of the ambient air and drying chamber is shown in fig 4. Comparison of this figure with fig 3 shows that the drying processes were enhanced by heated air at very low humidity.

Fig 5 shows the drying curve for vegetable in mixed mode solar dryer. It was observed that the drying rate increased due increase in temperature between 10.00hours and 14.00hours but decreased thereafter which shows the earlier and faster removal of moisture from dried vegetables.

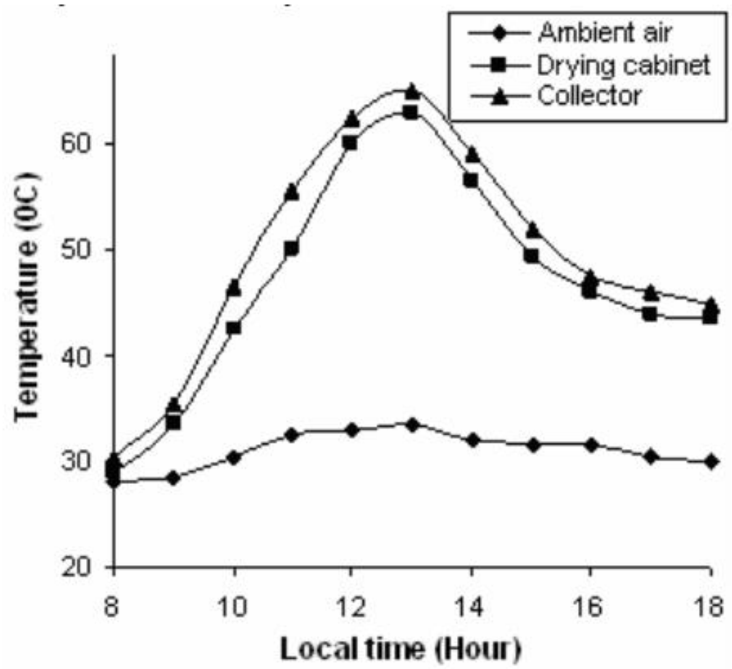

Fig. 3. A typical day results of the diurnal variation of temperatures in the solar dryer.

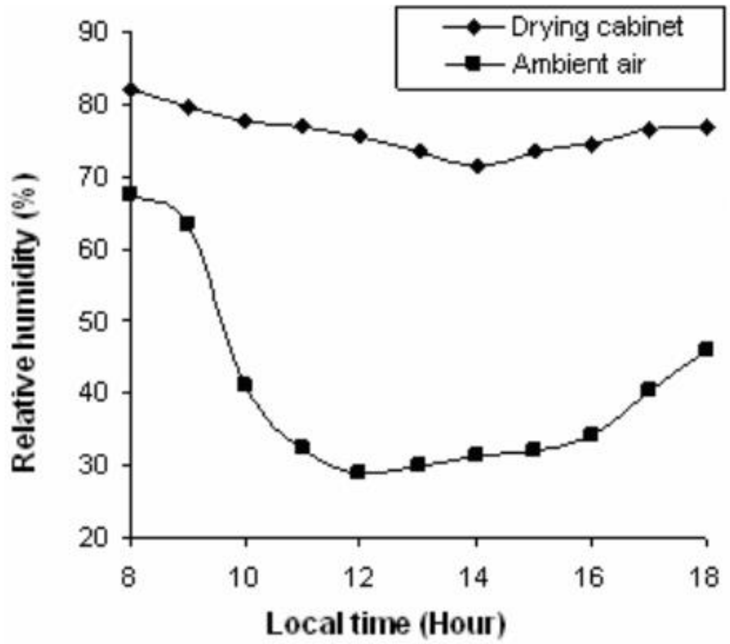

Fig. 4. A typical day results of the diurnal variation of relative humidity in the dryer.

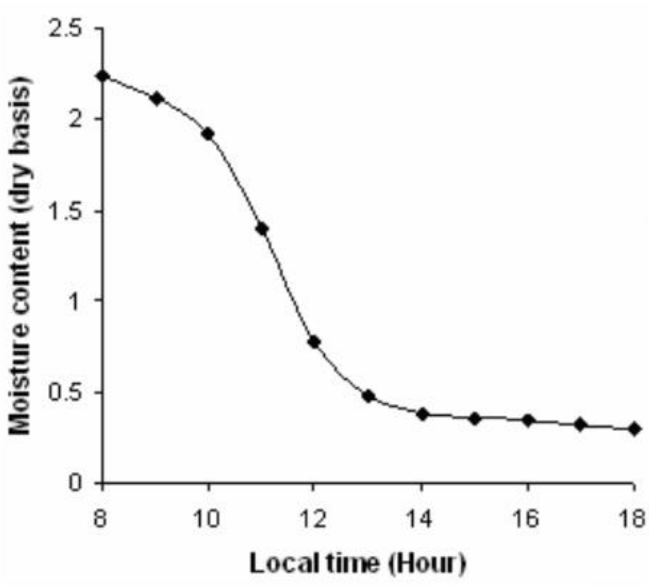

Fig. 5. Drying curve for **Vegetable**

The dryer was able to remove 85.4% of moisture, dry basis, from 7.5kg of vegetable in one day of 10.00 hour drying time, which is about 0.75kg/h drying rate.

The collector efficiency of the mixed-mode solar dryer during the test period was found to be 63.2%.

4.0. Conclusion

An easy and low cost mixed mode solar dryer was designed and fabricated using locally sourced materials. The hourly variation of the temperature inside the cabinet and air-heater are much higher than the ambient temperature during the most hours of the day light. The temperature rise inside the drying cabinet was up to 25% (75%) for about three hours immediately after 13.00hour. The drying rate, collector efficiency and percentage of moisture removed from drying vegetable were 0.75kgh^{-1}, 63.2% and 85.4% respectively. The dryer exhibited sufficient ability to dry vegetables reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried vegetable.

Nomenclature

T - air Temperature elevation, ^{0}C
I_e - insolation on collector surface, W/m^2
A_c - Collector Area, m^2
M_E- Mass of vegetable slides before drying
R_e - Collector efficiency
M_c -Moisture content
DR – Drying rate
M_d- Mass of sample after drying
E - drying period
η_d – System efficiency
M -Mass of moisture evaporated per second (Kg/s)
L - Latent heat of evaporation of water (KJ/kg)
I_t - Insolation on tilted collector surface (W/m^2)
A_c - Collector area (m^2)
M_m – Amount of moisture to be removed
M_w -amount of moisture removed

W_w- initial total weight
β - Tilting angle
Lat ϕ - Latitude angle of the solar collector location

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