Construction and Performance Analysis of a New Natural Convection Solar Dryer for Drying of Tomatoes and Green Chilies

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Abstract. Mechanical drying of farming items is a vitality expending activity in the post-gathering innovation. More prominent accentuation is given to utilizing sun powered vitality sources in this procedure because of the significant expenses and deficiencies of non-renewable energy sources. Therefore, an appropriate technology for drying of agricultural products has been developed and its performance of drying of tomatoes and green chilies was evaluated. A new solar dryer working on natural convection was developed. The point of this investigation is to assess dryer execution under natural convection methods of drying. In natural convection, air mass stream pace of 0.04849 kg/s was acquired. Heated sir stream reached on average drying temperature of 50.5˚C in characteristic convection. The outcome acquired from natural convection methods of drying were likewise contrasted with open sun drying. The shading, flavor and time required for drying is good in solar drying when contrasted with sun drying.

Keywords: Solar dryer; Natural Convection; solar collector; Performance Analysis of solar Dryer.

Nomenclature:

| Symbol | Description |
|--------|-------------|
| ηC     | Collector efficiency |
| ηDC    | Drying cabinet efficiency |
| cp     | Specific heat of air, kJ/kg.K |
| Tco    | Average temperature at collector’s outlet, (°C) |
| Tci    | Average temperature at collector’s inlet, (°C) |
| A      | Collector’s area, m² |
| I R    | Solar radiation intensity, W/m² |
| ṁ      | Mass flow rate of air, kg/s |
| mₑ     | Mass of evaporated moisture, kg |
| hL     | Water’s latent heat, kJ/kg |
| t      | Time (in seconds) |
| m₀p    | Initial mass taken of food product, kg |
| Mᵢ     | Initial moisture content in food material/product, % wb |
Mf  Final moisture content in food material/product, % wb

1. Literature Survey

Demand of energy is increases day by day with the increase in world population energy i.e. heat energy is also use to dry agricultural products after the farmers harvest them. Drying of agricultural products helps to increase the life of harvested products. The process of drying decreases the moisture content from the harvested product and these can be stored for long time without losing their flavor and smell. There are many methods of drying but all the methods needs some external power for drying except solar drying. Solar drying helps to decrease the mass and volume of the product being dried hence it become easy to pack the product, transportation cost and it also make possible to store product at the atmospheric temperature [1]. Several researchers have done the research in the development of solar drying. Many researchers have carried out experiments to see the effects of various factors on natural and forced convection solar dryers.

Ghahtrehsamani et al. [2] have carried out an experiment to see the effect of drying air temperature, drying air flow rate and bed depth on the drying walnut. They found that with the increase in drying air temperature, drying air flow rate and number of layers, moisture present in walnut is decreases from 37% to 9% in 3 hours. They also found that drying air temperature, drying air flow rate and layer depth of 41°C, 0.09 m³/s and 2 layers respectively gives the better drying. Alamu et al. [3] have designed and construct a domestic passive solar food dryer. They designed the solar dryer for the geographical location of Abeokuta (Nigeria) and used the meteorological data for design specification. Ghazanfari et al. [4] had done an experiment to study the feasibility of drying pistachio nut. They found that the major portion of the moisture present in pistachio was removed in first nine hours and then it decreases gradually. Pangavhane et al. [5] had designed and developed a new natural convection solar dryer and then do its performance testing. They developed the solar dryer having the capacity of producing average drying temperature of 50 to 55°C. Collector was having the efficiency of 26% for mass flow rate of 0.0126 kg/s and 65% for mass flow rate of 0.0246 kg/s. Kaivalya et al. [6] had studied the solar dryer coupled with flat plate collector. They found that the solar dryer coupled with flat plate collector gives the better efficiency than simple air dryer. Varun et al. [7] had constructed and do the performance analysis of an indirect solar air dryer integrated with solar air heater and found that the average drying temperature reaches 45°C in natural convection and 40°C in forced convection. They found that in natural convection, mass of tomatoes reduced from 1800 gm to 180 gm while 180 gm to 140 gm in forced convection for same time period. Many more researcher have also seen the effect of using nanofluid and nanocomposites in solar systems [8-13].

This work will be founded on the significance of a solar based dryer which is dependable and low in cost, to develop a solar based dryer simple in design utilizing locally accessible materials and to assess the performance of this solar dryer.

2. Illustration of Solar Dryer

Sun situated drying insinuates a methodology that utilizes sun controlled radiation to change over it into nuclear power needed for drying purposes. Most sun based dryers use sun oriented based air radiators and the warmed air is then experienced the drying bureau (containing food material) to be dried. The air moves its essentialness to the material causing scattering of dampness of the material. The pictorial view of the sun based dryer is appeared in Figure 1. The test set-up of dryer is created from wood which is effectively accessible and comprised of the accompanying two fundamental segments: the sun oriented collector and the drying chamber. These fundamental parts are depicted beneath.
Figure 1. Fabricated Solar Dryer

2.1 Collector (Air Heater)

Solar collector is simply a box made of wood open at the top. The solar collector assembly consists of air flow channel enclosed by transparent cover (glazing). The collector part of the dryer is made inclined so that the collector can get the maximum solar intensity or solar energy. The angle at which the collector is inclined is given by the relation $(S-10^\circ) \leq (S+10) [14]$. Solar collector in this work is tilted at 27°. The collector itself comprises of three important parts as collector plate or absorber plate, cover plate (glazing) and insulation. A GI sheet is used as collector plate which is painted with black paint. A passage is formed between the absorber plate and the lower glazing plate to trap the air for heating by solar radiation transmitted by the glazing plate or sheet, so the collector plate is placed 35 mm below than that of lower cover plate. Cover plate or glazing plate is simply the transparent window glass sheets having high transmissivity as its performance depends on its transmissivity. A pair of cover plate is used with 10 mm gap between them so that they can decrease the amount of heat from escaping. These cover plates encloses the absorber plate from top and to minimize the heat loss from the system the collector plate is insulated beneath with thermocol sheets and glass wool. The edges are also covered with clay minimize the heat loss. The total thickness of insulation (glass wool + thermocol sheets) is 50 mm. The design parameters of solar collector are illustrated in Table 1.

Table 1. Solar Collector Specifications

| Design Parameters | Value                        |
|-------------------|------------------------------|
| Collector Box material | wood                        |
| Area($m^2$)            | 0.65$m^2$                   |
| Length(m)               | 1 m                         |
| Width(m)                | 0.65 m                      |
| Collector plate          | 0.4 mm black painted GI sheet |
| Cover plate              | Transparent window glass ( 2 sheets) |
| Inclination of collector | 27 degree(latitude)         |
| Flow area                | 0.023 $m^2$                 |
| Insulation               | 50 mm thick                 |

2.2 The Drying Cabinet

The drying cabinet together with the basic edge of the dryer was worked from all around prepared woods which could withstand termite and climatic assaults. An outlet vent was given toward the upper end at
the rear of the cabinet to encourage and control the convection stream of air through the dryer. Access entryway to the drying chamber was additionally given at the rear of the cabinet. Two drying trays are provided in the cabinet to lay down food items to be dried. The drying plate are contained inside the drying chamber and were developed from a twofold layer of fine chicken wire network with a genuinely open design to permit drying air to go through the food things. The design parameters of drying cabinet are given in Table 2.

| Table 2. Drying Cabinet Specifications |
|----------------------------------------|
| **Design Parameters** | **Value** |
| Dryer Cabinet Box material | wood |
| Area (m²) | 0.195 m² |
| Length (m) | 0.65 m |
| Width (m) | 0.3 m |
| Height | 0.6 m |
| Number of Trays | 2 |

3. Experimental Details

3.1 Food Materials
Fresh tomatoes and chilies were bought from neighborhood advertise. Fresh samples were arranged outwardly by hues and size. Oven method [15] is used to determine the initial moisture content in tomatoes and green chilies at 105°C for 4 hours and were found 95% (wb) and 84% (wb) respectively. The drying process completes in two steps or moreover can say in two step mechanism as follows:

- First the moisture present in the interiors of the food material migrates on to surface of the material.
- Secondly the moisture evaporation from the surface to the encompassing air. The drying item is a mind boggling heat and mass exchange process which relies upon outside factors, for example, temperature, humidity and speed of the air stream and inside factors which rely upon parameters like surface attributes (harsh or smooth surface), compound synthesis (sugars, starches, and so on.), physical structure (porosity, thickness, and so forth.), and size and state of item.

3.2 Procedure, Instrumentation and measurement
Solar dryer is placed under direct radiation of sun to carry out the experiments on open rooftop of GLA University, Mathura (UP), India. The collector part is tilted at an angle of 27 degree due south being the latitude angle of place where experiments are performed. The tomatoes were cut into slices of uniform thickness after cleaning them with fresh water. The mass of these slices taken to carry out the experiments was 600 gm, kept in two trays inside the drying cabinet of solar dryer i.e. 300 gm of tomato slices in each tray (upper tray and lower tray). Similarly 300 gm of green chilies were taken and kept in two trays in equal amount i.e. 150 gm in each tray. The experiments for tomatoes and green chilies were carried on different dates. The experiment was carried out between 10:00 am to 5:00 pm in the month of March. Different data is recorded during the experiment like solar irradiance, ambient temperature, ambient humidity, collector plate temperature, drying cabinet temperature and mass of tomato and green chilly slices. The temperatures were estimated with the assistance of thermocouple which operates on Seebeck effect that a voltage is produced when a temperature difference exist between two dissimilar conductors and this voltage is recorded by millivoltmeter. The thermocouple sensor are place on different places like in drying cabinet, on collector plate for measurement of temperature of absorber plate , hot air and inside drying cabinet. The all out occurrence sun oriented radiation was estimated by utilizing a digital pyranometer with an error of 2%. Air speed was estimated by utilizing a hot wire anemometer and the surrounding air relative moistness and exit air relative humidity were estimated with the
assistance of advanced hygrometer. The mass of the drying food material is measured by electronic balance machine with 0.02 gm precision.

4. Performance Evaluation
The collector efficiency indicates the utilized heat against the heat input in the form of solar insolation. Performance of solar dryer is evaluated in terms of efficiency, moreover in term of efficiency of solar dryer’s two major parts i.e. efficiency of solar collector and the efficiency of drying cabinet, and to calculate these efficiencies following formula’s [7] are used:

4.1 Efficiency of solar collector

\[ \eta_c = \frac{m_e c_p (T_{co} - T_{ci})}{AI_R} \]  

4.2 Drying Cabinet efficiency

\[ \eta_{dc} = \frac{m_e h_t}{AI_R} \]  

Where \( m_e \) is given by:

\[ m_e = \frac{m_{f p} (M_f - M_f)}{(100 - M_f)} \]  

5. Results and Discussion
Figure 2 shows the variation in temperature at different points in solar dryer i.e. over the collector, ambient temperature and drying cabinet temperature variation at a gap of 1 hour from 10:00 am to 5:00 pm over a day in month of March. The average outside atmosphere temperature was found ranging from 33°C-43°C while solar collector and drying chamber average temperature was ranging from 67°C-94°C and 46°C-55°C respectively.

![Figure 2. Temperature behavior of Solar Dryer](image)

The average solar insolation in Mathura as measured with a pyranometer is shown in Fig. 3. It was noticed that during the day the solar insolation rises during 10 to 11 am and reaches maximum insolation and then a slight drop in insolation is noticed from 11 to 12 pm and after that it starts to drop continuously. The maximum radiation received was 950 W/m² at 11 am, whereas minimum radiation received was 523 W/m² at 5 pm.
Figure 3. Solar Radiation Intensity over the days of experiment

The percentage of moisture removed from the tomatoes and green chilies has been analyzed below. The initial moisture content in tomatoes and green chilies is generally 95% and 84% respectively. The results obtained from the experiment for tomatoes on day 1 are shown in table 3 and for green chilies in table 4 below:

Table 3. Temperature, Weight, Moisture Removed and Solar Intensity in different conditions when Tomatoes are dried on Day 1.

| S.No | Time  | Temperature (°c) | Collector Inlet | Collector Mid | Collector Outlet | Dryer Inlet | Dryer Outlet | Upper Tray Weight (gm) | Lower Tray Weight (gm) | Moisture Content removed (%) | Solar Radiation W/m² |
|------|-------|-----------------|----------------|--------------|----------------|-------------|-------------|------------------------|------------------------|--------------------------|---------------------|
| 1.   | 10:00 | 76              | 74             | 86           | 86            | 89          | 89          | 49                     | 51                     | 52                       | 300                 |
| 2.   | 11:00 | 79              | 77             | 89           | 89            | 92          | 92          | 52                     | 54                     | 55                       | 285                 |
| 3.   | 12:00 | 83              | 77             | 93           | 90            | 94          | 93          | 53                     | 53                     | 53                       | 238                 |
| 4.   | 13:00 | 82              | 77             | 92           | 89            | 92          | 92          | 52                     | 52                     | 52                       | 204                 |
| 5.   | 14:00 | 81              | 77             | 91           | 88            | 91          | 91          | 51                     | 52                     | 53                       | 161                 |
| 6.   | 15:00 | 78              | 76             | 89           | 87            | 89          | 88          | 49                     | 50                     | 52                       | 123                 |
| 7.   | 16:00 | 74              | 73             | 85           | 83            | 87          | 88          | 48                     | 48                     | 50                       | 101                 |
| 8.   | 17:00 | 67              | 66             | 76           | 75            | 78          | 78          | 46                     | 46                     | 48                       | 90                  |

Table 4. Temperature, Weight, Moisture Removed and Solar Intensity in different conditions when Green Chilies are dried on Day 2.

| S.No | Time  | Temperature (°c) | Collector Inlet | Collector Mid | Collector Outlet | Dryer Inlet | Dryer Outlet | Upper Tray Weight (gm) | Lower Tray Weight (gm) | Moisture Content removed (%) | Solar Radiation W/m² |
|------|-------|-----------------|----------------|--------------|----------------|-------------|-------------|------------------------|------------------------|--------------------------|---------------------|
| 1.   | 10:00 | 76              | 75             | 86           | 87            | 89          | 89          | 50                     | 52                     | 53                       | 150                 |
| 2.   | 11:00 | 77              | 78             | 89           | 89            | 92          | 93          | 53                     | 55                     | 56                       | 134                 |
| 3.   | 12:00 | 81              | 78             | 92           | 91            | 93          | 94          | 54                     | 53                     | 54                       | 117                 |
| 4.   | 13:00 | 83              | 79             | 93           | 88            | 92          | 90          | 53                     | 53                     | 53                       | 117                 |
| 5.   | 14:00 | 82              | 78             | 90           | 87            | 91          | 90          | 52                     | 53                     | 53                       | 105                 |
| 6.   | 15:00 | 77              | 76             | 88           | 88            | 88          | 88          | 50                     | 51                     | 52                       | 86                  |
Percentage of moisture removed on the per hour basis inside the drying cabinet for tomatoes is shown in Fig. 4 and for chilies in Fig. 5. The lower tray and the upper tray curves represent moisture content removed in % inside the drying cabinet during the drying of tomatoes and chilies on Day 1 and Day 2 respectively. Obtained graphs represents the removal of moisture content on percentage basis with respect to time. Since the solar based drying doesn't give steady temperature because of climatic condition; so the dampness % removed movements un-reliably with time and the varied temperature.

Figure 4. Drying Rate of Tomatoes

Figure 5. Drying Rate of Green Chilies

During night, entirely irrelevant decrease in the mass of tomatoes was watched. The drying time was diminished by 62% for same moisture evacuation when contrasted with open sun drying. Fig. 6 represents the physical appearance of Tomatoes and Green Chilies after 7 hours of drying each for one day.
6. Conclusion

After study it was found that the solar dryer supplies around three to four times heat inside the cabinet than that of the atmosphere. For 7 hours of consistent drying under the equivalent climatic condition, 70% (upper tray) and 63.8% (lower tray) moisture content removed from tomatoes and it removed 70% (upper plate) and 65.3% (lower plate) dampness content from green chilies individually. On the contrary at outside there is only average 25% moisture content was removed. In experiment for first when tomatoes were dried the dryer efficiency was found to be 13.4% and collector efficiency 33% and for second day for green chilies the dryer efficiency was found to be 13.9% and collector efficiency 33.8%. The average moisture content removed for selected samples as tomatoes and green chilies were found 66.9% and 67.65% respectively. All the readings were measured for two days for 7 hours each.

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