Experimental analysis of agricultural solar dryer

G Ravikumar Solomon, K Ilayaperumal, R Balaji, B Chellappa

1Department of Mechanical Engineering, Hindustan Institute of Technology & Science, Chennai-603103

2Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai 600124

*E-mail: sridharabalaa@gmail.com

Abstract: The drying process is simply the moisture extraction process of a product. It can be achieved with different approaches. In these processes, thermal drying is most widely used for drying agricultural products. This drying systems are normally divided into low and high temperature dryers according to their working temperature levels. In low temperature drying systems, natural-circulation greenhouse model dryers seem the most desirable method for use in remote regions. There are operationally and competitive economically to natural open sun drying. Here solar collector of dimensions (1.25m×1m×0.2m) with area of 1.25m² has been painted black to absorb solar radiation and the solar drying cabinet that is divided into 3 number divisions separated by four removable shelves. Each shelf is 0.3m wide and 0.5m in length and is composed of a wooden boundary framed nylon wire mesh. For loading and unloading purposes, both sides of the drying chamber walls are sealed with wood and a shutter on the back. During this research, grapes were dried. In the four days after drying, the grapes' moisture content was decreased from 81.7% to 36.7%. The drying air flows naturally through the commodity. The operating modes are discussed in this research. The results were discussed for designed solar agricultural dryer. Also it involves with the design and fabrication of agriculture solar dryer that can be manufactured in rural areas in an economic way.

Keywords: Solar Dryer, Agricultural purpose, Solar Dryer Design, Chamber, Grapes dryer

1. Introduction

In the majority of countries agriculture represents the biggest part of their economy. Countries like India, Iran and Africa use traditional method for drying. Sun drying method is more efficient when compared with other drying method [1]. They have their own merits and demerits. The main drawback when using the traditional Sun drying method is when drying takes place in open atmosphere the risk of getting contamination by dirt, insects, bacteria and losses in drying process due to the rainfall or monsoon. These are tolerated as it is inherits the procedure of the processing technique [2]. In order to save the products from the mentioned disadvantages and decrease the drying time of the process, controlling the moisture of the product, and reduce the wastage by using a fully closed agriculture solar dryer [3]. The most important concern in designing an agricultural solar dryer for drying is the total system cost. This research is therefore focused on a economical agricultural solar dryer that can be constructed in rural area from the available materials and with less manpower [4].
Thermal drying is the structure most usually utilized for drying agrarian items. Diverse warmth sources are utilized for the thermal drying of agrarian products, the most well-known being petroleum products, power, and solar energy. In any case, in numerous country areas in most agricultural nations, network-associated power and supplies of other non-renewable wellsprings of energy are either inaccessible, temperamental, or, for many farmers, excessively costly. Accordingly, solar energy dryers show up progressively to be alluring for rustic ranchers [5]. In solar drying, solar energy is utilized as either the sole wellspring of the necessary warmth or as a supplemental source. The wind stream can be produced by one or the other characteristic (normal course solar dryer) or constrained convection. This strategy requires the harvest to be spread thinly on the uncovered ground or on a raised stage [6]. Solar energy occurrence on the yield disintegrates its water content, and surrounding moving air gets this dampness and diverts it. The traditional open sun drying that rural farmers usually use is, however, limited: high crop loss caused by insufficient drying, fungal attacks, and invasion by insects, birds and rodents, unexpected rainfall and other long-term impacts [7]. Any of these problems leads to a dry object of poor quality and post-loss. Regular solar power dryers seem the most desirable option for use in distant rural areas considering the fact that it is commonly anticipated. They are more operational and commercially serious than typical open-to-sun drying. The upsides of normal flow solar energy dryers that empower them to contend economically with customary drying procedures [8].

Drying in the open sun in regions with a high relative moisture levels is very difficult. Thus, two separate types of greenhouse crop dryers in natural circulation method were designed, built in and tested in this investigation for their efficiency [9]. Without a product (not filled or empty), a product (piped), chimney or chimney, the drying systems were experimented. Furthermore, in open sun drying the same substance was dried to equate the greenhouse dryers. The findings indicate that the dryers in greenhouse are 2.5 times more effective than drying in open air. In addition, the use of the black and chimney area increases the dryer efficiency [10]. The research aims at increasing the efficiency of an agricultural dryer by using solar energy. An effort is being made by using eco friendly materials and a blower for accelerating the flow of air in to the dryer. Analysis has been done and the result shows considerable improvement in efficiency. The objectives of the research are to solve the problems like moisture condensation, discoloration of crop and rise in temperature affecting moisture removal. Comparison studies of various software analysis of dryer at an inlet temperature have been done to study the improvement.

1.1 Drying

Drying is the method of removing moisture from the product, or grape in this case. Normally grape can either absorb or de-absorb moisture from its surroundings depending on the difference in pressure, humidity transferred from a higher to the lower pressure. In the agriculture sun drying process, the grapes are heated by radiation from the sun and thus creating a higher pressure in the air surrounding the product. In the similar manner, the drying process starts when the grape is heated (by conduction) when the air flow inside the chamber gets heated, the air has the advantage of reducing the boundary layer of the grapes, thereby increasing the heat transfer coefficient of the grape, as well as increasing the rate of moisture movement from grape to the surrounding air. Therefore, the drying rate of a specific kind of product (Grapes) depends on both air temperature and air flow rate [11].
1.2 Indirect Solar Drying (ISD)

In this case, the crop is directly exposed to solar radiation to minimize discoloration and cracking on the surface of the crop. Under a convective heat losses from the absorber is mounted the cylindrical reflector, fitted with the glass cover, on the aperture. Selectively, the absorber is coated at 45 degrees from the horizontal, the inclination of the glass cover is applied for strongest radiation. The absorber area and the glass cover is the same as the drying chamber surface. The cylindrical reflexor reflects solar radiation to the absorber after its transmission through the glass cover. Since absorbing, the glass cover is partially lost in the ambient and the remainder is convected to the transferred air above it. The following air is thus heated and passes through the crop placed in the drying chamber. The crop is heated and moisture is removed through a vent provided at the top of drying chamber [12].

1.3 Solar Drying

In the current trend due to higher cost of natural fuels and uncertainty of its availability and regarding future cost. On the contrary use of solar energy for processing the food will probably increase the efficiency of the process and could become more cost-effective and viable in the future. Solar drying method has various advantages are compared with sun drying when designed correctly. This process can give quicker drying rates by heating the air above the ambient temperature, which results in the moment of the air throughout the dryer, by reducing its humidity and prevents insects. Drying faster increases the quality of the product and gives a higher output, and thus reducing the area required for the drying of the product [13].

On the other hand careful inspection is needed when drying fruits and vegetables to prevent quick drying thus avoiding complete drying and case hardening. Solar dryer’s method protects product from dirt, insects, birds and animals. The construction of the solar dryer can be
made from the materials available locally with relatively low capital cost and there is no additional cost for fuels. Thus, they could be very useful in rural regions where electricity and fuel are expensive. They are helpful by heating the air for artificial dryers and reduce fuel costs. The land space required for the solar drying less and more expensive when compared to sun drying method [14]. Solar drying method can be used in frequently many areas but based on the rate the food dried are affected by various variables, in particular the quantity of sunlight and humidity level. In a typical solar dryer they drying process can take 1 to 3 days of time depending on the relative humidity, movement of the air flow, sun and type of the food item that needs to be dried. In drying relative and total humidity are of great importance, taking that into consideration is the key principle behind the design of solar dryers. The following factors are too considered: Air can take only up to a limit of the moisture in the product. Absolute humidity in the maximum limit and it totally depends on temperature. To produce a high-quality economically product, the drying process must be fast without using too much of heat, which could degrade the product’s quality. Products drying time can be easily reduced by two main actions: first is to elevate the products temperature so that the moisture can be vaporized, at the same time removing the humid air constantly [15]. The second course of action is to treat the product is to minimize the water migration paths so that the products can be dried easily.

1.4 Solar Dryer Description

The fundamental method of product drying process is the transfer of heat and moisture between the material and the air i.e. in our case it’s between grapes and air. The heat is transferred from the sun to the surface of material by conduction and to the adjacent air through convection to the product being dried. If the hot air is passes through the grapes with relative humidity of less than moisture content in grapes, as the result the air will absorb moisture from the grapes while increasing its relative humidity. A prototype unit was designed, built and evaluated to validate the experiment conducted.

![Solar Agricultural Dryer]

Figure 3. Solar Agricultural Dryer

The collector employed in this research is made of a 25mm wooden frame (1.2m long * 1.0m wide * 0.16m high), insulated with polyster foam. The insulator was fitted with black painted rock for sun radiation absorption and thermal energy storage. The collector was coated with a fibreglass layer in order to minimise heat loss.
Figure 4. Top view of the model

Figure 5. Side view of Dryer
Air enters the lower end of the box and is hot as it passes through the painted rocks. The hot air outlet is connected to the lower front of the collector's chamber. The chamber dimensions are the following: Wide by 0.3m long, 1m high x 0.5m. Four removable 0.5m length x 0.5m wide and composed of nylon wire mesh framed in the wooden boundary, the drying product is dispersed, are transferred by solar heated air. The rear of the drying chamber contains a door for easy insertion and removal of the trays. A ventilator is mounted on the dryer roof to increase the air flow volume.

1.5 Design Considerations

Enclosed Container Basic Design Fruit dehydration is performed at a temperature not much above the ambient air and thus an intricate solar collector is not essential. A solar panel is a unique form of heat exchange that converts radiant solar energy into heat. Sun collectors differ from more standard heat exchangers in many ways. The energy transmission occurs in a heat exchanger at a very high rate at the interface between fluid and fluid, making it insignificant for radiation. In the other side, solar gatherers use the sun to pass it to a remote source of radiation. The maximum flux from the radiation incident to the sunlight is 1100 W/m². The sun radiation's wavelength range is from 1.3 - 3 μm. The radiation released by most energy consuming surfaces is considerably shorter. It is based on the principle of the flat plate collector (FPC). Such a design has many advantages. T The main advantage is that flat collectors will use both the laser and the diffuse radiation to work on clear cloudy days. Radiation from the beam is described as radiation from the sun without being dispersed into the atmosphere. Conversely, diffuse radiation is the energy received from the sun after its direction has been changed by scattering in the atmosphere.

2. Experimentation

The drying unit consists of a collector and a drying chamber. The collector basically a wooden frame insulated with a polyester form. The stones were placed on the collector to absorb the solar radiation and store the thermal energy. The collector is covered by a tempered glass cover. The fig. shows a schematic diagram of the experimental set up.
The air enters through an inlet channel provided at the bottom of the collector box and gets heated while flowing over the gravels. The exit of the collector box is connected to the lower end of the drying chamber. The drying chamber holds removable trays through which hot air passes. The pictorial representation of the experimental set up is shown in figure. The wooden frame of the collector box is 1.2m long × 1.0m wide× 0.16m high. The dimensions of the chamber are 1.5m high, 0.5m wide and 0.3m long. The drying temperature is measured using a thermometer and the weight loss of the grapes is measured every one hour time. The experiment is carried on the same grapes for 2 days and then the stones in collector box are painted black and the experiment is repeated for next 2 days to perform the comparison study of the drying the grapes with unpainted stones and black painted stones. The trays with suitable porosity has been selected for appropriate air flow and placed inside the dryer chamber. A door has been provided to prevent heat loss to surroundings. An exhaust fan has been installed on top of the chamber to increase the hot air circulation inside the chamber, which ensures quick drying of grapes inside the chamber. The black grapes were weighed and loaded into the trays of solar drier chamber. For experimentation, the temperature inside the chamber, air inlet temperature, ambient temperature and the weight of grapes were measured at equal intervals of one hour [15]. The experiment was repeated for two days and the graphs were plotted for temperature and moisture content. Initially the experiment was conducted using unpainted stones inside the absorber plate. Then to increase the absorbability, stones were painted black and were placed inside the absorber plate. The experiment was repeated with new set of grapes weighing the same and procedure was repeated for two days.

![Experimental setup](image)

Figure 7. Experimental setup

The grape weighing 1 kg is kept in the dryer chamber. The stones are placed in the collector, exposed to sunlight throughout the day. The fan is switched on the reading were taken from 8 am to 5 pm for 4 days consequently. The ambient temperature, the dryer inside temperature, the collector temperature and the weight were measured at an interval of 1hour, in the first two days the experiment investigation is done on the unpainted stone in the collector and in the next two day the experiment is repeated with stones painted in black in the collector.

3. RESULTS AND DISCUSSIONS

3.1 Dryer Temperature

The ambient temperature and the solar temperature for the four days of the experiment is measured at an interval of 1 hour from 8 am to 5 pm. The variation of ambient temperature and solar temperature for the first two days where un-painted rocks is used in the collector is given in the Table. 1.
Table 1 The variation of ambient temperature and solar temperature for day1 and day 2 with unpainted stones

| Time | Ambient Temp day 1 | Solar Temp day 1 | Ambient Temp day 2 | Solar Temp day 2 |
|------|--------------------|-----------------|--------------------|-----------------|
| 08   | 28                 | 35              | 30                 | 38              |
| 09   | 30                 | 38              | 31                 | 42              |
| 10   | 32                 | 44              | 32                 | 46              |
| 11   | 32                 | 53              | 33                 | 59              |
| 12   | 34                 | 58              | 34                 | 61              |
| 13   | 34                 | 62              | 35                 | 64              |
| 14   | 34                 | 64              | 34                 | 68              |
| 15   | 34                 | 54              | 33                 | 57              |
| 16   | 34                 | 46              | 32                 | 49              |
| 17   | 33                 | 38              | 32                 | 42              |

The ambient temperature and solar temperature for the second two days painted rock is used in the collector. The variation of ambient temperature and collector temperature with respect to time is plotted for the two days of experiment in when unpainted rocks is used in the collector box is shown in Fig.8.

![Figure 8. Temperature variation for solar dryer with non-painted stones](image)

The solar collector temperature and ambient temperature were measured at an interval of 1 hour from 8 am to 5 pm with the painted rocks is given in Table 7.2
Table 2 The variation of ambient temperature and solar temperature for day 1 and day 2 with unpainted stones

| Time | Solar Temp day 1 | Ambient Temp day 2 | Solar Temp day 1 |
|------|------------------|--------------------|------------------|
| 08   | 36               | 28                 | 39               |
| 09   | 39               | 31                 | 43               |
| 10   | 42               | 33                 | 45               |
| 11   | 52               | 33                 | 57               |
| 12   | 56               | 34                 | 63               |
| 13   | 60               | 34                 | 66               |
| 14   | 62               | 33                 | 69               |
| 15   | 53               | 33                 | 58               |
| 16   | 45               | 32                 | 45               |
| 17   | 41               | 32                 | 41               |

The variation of ambient temperature and collector temperature with respect to time is plotted for the two days of experiment in when painted rocks is used in the collector box is shown in Fig 9.

Figure 9. Temperature variation for solar dryer with black painted rock

The variation of inside temperature of the dryer and the ambient temperature for solar collector with unpainted stones is shown. The maximum temperature of 64°C has been observed at 01.00 PM for the corresponding ambient temperature of 34°C. The temperature pattern has been observed in an increasing trend from 8:00 AM to 03:00 PM then there was a gradual reduction till
From these figures, it is very clear that, the maximum temperature was observed at 02:00 PM with a temperature of 69°C for the corresponding ambient temperature of 33°C. The usage of solar collector with high absorptive black painted stones and usage of exhaust fan to draw the hot air from collector to inside of dryer chamber increases the temperature of the dryer chamber and the drying rate.

3.2 Moisture Content

Moisture content determines the amount of water present in a sample. In case of solar dryer, the moisture content manifests the drying efficiency. It was calculated for two separate days, for both non-painted and black painted stones. It is clear from the figure 5 that the variations of moisture content in the sample with normal stone is lower than that of the sample in the collector with black stones on the first day of experimentation. During the initial hours, the reduction in moisture content was found to be lesser than that observed during afternoon hours. In the evening hours the drying rate reduces significantly. Figure 6 shows the variation of moisture content for second day, and the same pattern was observed as that of the first day.

To decide the proportions of different materials are to be mixed together in making compost, the resulting mixtures moisture is one of the critical factors to be considered. The subsequent steps provide a guide line how to design the initial mix so that it will be in a suitable moist level for optimal composting. In the industry, the rule is to report moisture level on a wet or total weight of the product, the following formula indicates the calculation of moisture. The physical properties of the fruit to be dried are needed to determine the appropriate size of the collector. Calculate the % moisture for each of the materials plan to compost.

- weigh the container in which the product is going to be dried.
- Weigh the container with 10 g of the product (grapes) to be dried.
- Dry the 10 g sample for one day in a controlled environment of 105-110 °C for example oven.
- Reweigh the product sample at the end of the day; by subtracting the weight of the container we get the weight of the product. The moisture content is determine using the following equation:

\[ M_w = \frac{(W_w - W_d)}{W_w} \times 100 \]  

(1)

| Table 3 Experiment taken with Unpainted Stone |
|-----------------------------------------------|
| **Day 1 Weight (Grams)** | **Day 2 Weight (Grams)** | **Moisture ratio Day1** | **Moisture ratio Day2** |
|--------------------------|--------------------------|--------------------------|--------------------------|
| 1027                     | 837                      | 0.5842259                | 0.71684588                |
| 1021                     | 831                      | 0.78354554               | 0.96269555                |
| 1013                     | 823                      | 1.38203356               | 1.70109356                |
| 999                      | 809                      | 2.1021021                | 2.59579728                |
| 978                      | 788                      | 3.16973415               | 3.93401015                |
| 947                      | 757                      | 3.90707497               | 4.88771466                |
| 910                      | 720                      | 4.17582418               | 5.27777778                |
| 872                      | 682                      | 1.83486239               | 2.19941349                |
| 856                      | 667                      | 0.81775701               | 1.1994003                 |
The variation of moisture content for the normal stones and black stones with respect to drying hours is shown in the Fig 10.

![Graph showing variation of moisture content with duration](image)

**Figure 10.** Variation of moisture content with duration for the first day

The second experiment is taken with the painted stone in the solar air collector. The moisture content in day 1 and day 2 was taken. The moisture ratio for the painted stone is given in the table 4.

| Day 1 Weight (Grams) | Day 2 Weight (Grams) | Moisture ratio Day 1 | Moisture ratio Day 2 |
|----------------------|----------------------|----------------------|----------------------|
| 1027                 | 826                  | 0.77896787           | 0.72639225           |
| 1019                 | 820                  | 0.88321884           | 1.2195122            |
| 1010                 | 810                  | 1.78217822           | 2.22222222           |
| 992                  | 792                  | 2.82258065           | 2.9040404            |
| 964                  | 769                  | 3.31950207           | 4.03120936           |
| 932                  | 738                  | 4.29184549           | 5.4200542            |
| 892                  | 698                  | 4.37219731           | 5.73065903           |
| 853                  | 658                  | 1.992966             | 3.03951368           |
| 836                  | 638                  | 1.19617225           | 1.56739812           |

The variation of moisture content for the normal stones and black stones with respect to drying hours is shown in the fig 11. Weight of the grapes in equal interval of time in day 1 and day 2, is mentioned in column 1 and 2. The moisture removal from the product is mentioned in column 3 and 4. The difference between the moisture content is taken from the above equation. From the above table can get the moisture content graph of painted stone respectively.
The variation of moisture content of painted and unpainted stone are mentioned on the above graph. It is noted that the painted stone have more efficient that the unpainted stone for removing moisture content of grape that is used here for drying product.

4. CONCLUSION

A forced convention solar dryer was designed, fabricated and tested for black grapes. It can be concluded that forced convention black painted solar drier is most suitable for producing high quality of agricultural products.

The feasibility of drying grapes in a solar agricultural dryer has been experimentally investigated and the following conclusions were obtained:

- Solar agricultural dryer is more suitable for producing high quality dried grapes than the conventional open sun drying method.
- In a drying time of 16 hours, the moisture content removal of about 35% and 38% has been achieved when unpainted stones and black painted stones were used respectively.
- The moisture content is found to be reduced at a faster rate for the black painted stones compared to that of the unpainted stones.
- Compared with the unpainted rock it is observed that the drying time required for the painted is shortened. In general, the black painted solar dryer is 2-5 times more effective than open-sun dryers and much higher efficiency than open-sun dryers. It has been concluded, that these dryers can successfully be used in a large variety of farm produce to prevent spoilage and maintain nutritional value of the material, particularly fruit and vegetable products.
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