Performance Investigation on Solar Dryer Using Flat Plate Collector

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Abstract
Solar Drying is one of the important processes required for the preservation of food and agricultural products. Bacterial growth and moisture are removed in this process. It helps for preserving the food products for more long time. Solar drying is an effective method used for drying food products. The device used to preserve food products using solar energy is called a solar dryer or solar dehydrator. The solar dryer is classified based on the drying mode, air circulation, type, and arrangement of a cabinet of solar air collectors. The preserved raisin is a favorite dry fruit in India. Traditionally the drying of raisins mainly exposes natural sunlight and requires about 21 days. This experiment used a comparative study between natural sun drying and solar drying using a flat-plated collector dryer from 29th March 2020 to 19th April 2020. The incident area of solar radiation on the collector was $0.9m^2$, with a black rough surface aluminum plated absorber of $1.8m^2$ attached below the covered acrylic glazing used in the collector body. It was found that the latitude inclination of 19.5° had a maximum temperature of 69°C during 01:00 PM – 02.00 PM hours. The result found that drying raisins naturally takes up to 21 days, and comparatively, it takes 7 days to dry using the solar dryer. Thus, the drying period is reduced by 14 days.

Key Words: Solar Drying, Raisins, Agriculture Products, Natural Sunlight.
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I. INRODUCTION
The drying of grapes to form into raisins usually relies on direct sunlight exposure. This drying method requires more periods and lower quality of dried products. Drying of grapes is usually conducted under low temperatures, and thus, the use of solar dryers for dehydrating grapes is one of the best alternatives. Due to energy crises, most of the food processing and food preservation activities in the industries are depends upon non-renewable energy sources. It needs to check for alternatives for non-renewable and polluting fossil fuels. The use of renewable energy sources like solar energy is one of the best solutions for reducing the usage of non-renewable sources. The sun produces its energy through many thermonuclear reactions which create a large amount of heat and electromagnetic radiation which is easily available throughout the earth. This solar energy is trapped by heat exchanger devices called solar collectors. By comparing solar drying with traditional drying, solar drying has advantages such as better quality of food products, reduction in wastage of food products, a better market price can be achieved the product can be protected against flies, rain, and dust, the product can be left in the dryer overnight during rain, since dryers are waterproof, prevent fuel dependence and reduces the environmental impact, it is more efficient and cheaper [7].
The chosen raw material was grapes, which is a versatile spring crop. We kept 500 grams of grapes in the tray for the initial experiment. Grapes required drying temperatures ranging from 20°C to 60°C. The reason behind the selection of grapes as a raw material is the prices of dried grapes or raisins is much higher than the prices of fresh grapes available in the market, also per 100 gram of fresh grapes contains 81% of the water in it and the nutrition value we get is, 18% carbohydrates, 1% protein, 69Kcal energy and a moderate amount of vitamin K (14% of daily value) which can get from only 29 gram of split dried raisins (dried grapes), according to USDA (US department of agriculture) [1-3]. The effect of environmental conditions plays a vital role in the performance of solar dryers. The minimum temperature required to use the solar dryer system for processing food is 15°C [1]. The performance is affected by the use of material quality such as Aluminium sheets at the inner side give better results in drying foods. It also acts as a good absorber [2]. The parameters that decide the results are moisture, solar radiation, wind speed, and humidity. The addition of a fan/blower to introduce indirect forced convection will help to enhance performance as well as reduce heat loss during the operation [9]. The flow of air at the inner side may be unidirectional or bidirectional which is generally affected by external air wind speed [8]. While the shape and geometry of collectors are the research area in which work can be tested by changing parameters. However, the performance of solar dryers varies around 10-15% in terms of efficiency and the general achieved temperature range is 50+°C with 15-22% of Relative Humidity [11].

II. EXPERIMENTAL SETUP
The experimental model consists of major components like a flat plate collector and drying chamber which are connected by the flexible pipe for the transfer of drying high-temperature air from the collector to the drying chamber. A flat plate collector is designed as per a multi-stage pattern to achieve more heat and it consists of layers of insulator and absorber in it, which are air securely covered by an acrylic sheet to convey solar radiation to the absorber. The

drying chamber cabinet is isolated with insulator material and contains two trays of size 600 mm X 600 mm for carrying the food hub for drying. For measurement purposes Arduino based smart data logging system is used which contains DHT22 & DHT11 respectively temperature and humidity sensors have a range of Temperature -40°C to 100°C and humidity 0% to 100% which are further connected with Arduino UNO motherboard and 16 X 2 character Alphanumerical display for showing the temperature and humidity values of sensors which kept in locations of a setup like Temperature & humidity at ambient, Temperature & humidity at absorber surface of collector, Temperature & humidity of air exhaled from the collector, Temperature & humidity inside the drying chamber[1-3]. The RTC (Real-time clock) device is used to indicate and manipulate the temperature and humidity data concerning time. The SD card logger is used to store the daily data of temperatures and humidity at different conditions. The model is programmed as per auto ON & OFF of the system from 10.00 AM to 06.00 PM. This study is conducted to examine the thermal characteristics of the solar dryer with a flat-plated collector.

A. Flat-plated Solar Air Collector

The flat plate solar air collector consists of components like a layer of insulation material, charcoal black painted absorber plates, airflow passages, acrylic glass, and coating material.

Fig.1 Flat-plated Solar Air Collector

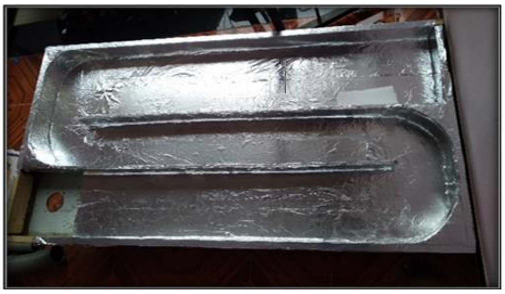


Fig.2 Solar Collector with Absorber Surface

The cabinet body of the flat plate solar collector is made up of wooden plywood of inner sizes of 1500 mm X 600 mm X 120 mm and has a thickness of 12MM.the material for insulation of the collector body is polystyrene foam sheets and Aluminum foil having lower thermal conductivities of 0.033 W/mK & 0.06 W/mK respectively used to reduce the heat loss.

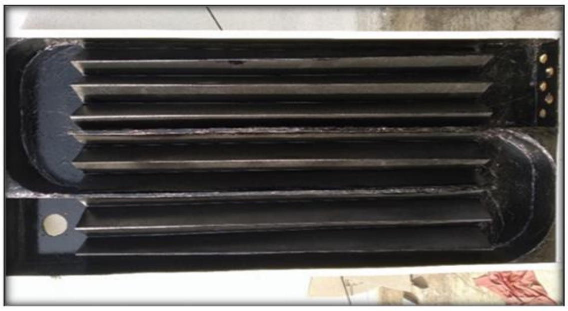


Fig.3 Solar air collector insulation

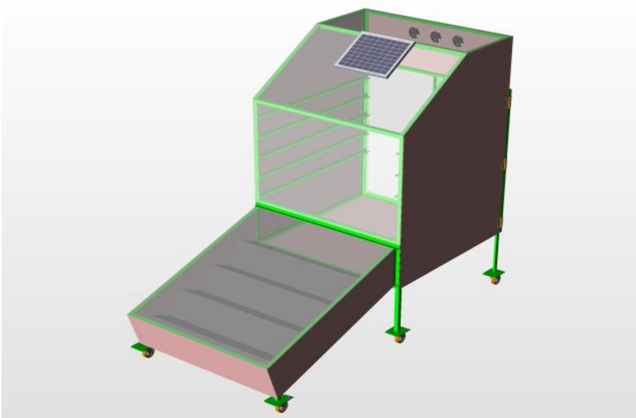


Fig.4 Complete Experimental Assembly of Setup

The absorber element used for absorbing solar radiation is the rough texture of an aluminum sheet of 0.5 mm thickness in a conical harmonic shape for providing more surface area for absorber plates. These absorber plates are painted black with charcoal-activated paint. The important material used in the collector body is the acrylic glass sheet of thickness 3 mm. The solar collector is mounted and supported on a heavy-duty mild steel structure which is durable and adjustable concerning latitude angle and can be set up into standard angles like 15°, 20°, 35°, 40°, and 45° as per investigation performance at different latitude angles.

B. Drying Chamber

The drying chamber cabinet is constructed from wooden plywood material to reduce heat losses. The dimensions of the drying chamber are 600 mm X 600 mm X 600 mm with a thickness of 12 mm. The drying chamber is insulated by a polystyrene foam sheet and aluminum foil from the interior to reduce heat losses. Two trays made up of meshed steel structures are used inside the drying chamber to contain food products for the drying process. Both trays are placed at 250 mm distinct from each other. The drying chamber is constructed with a chimney at the top for sweeping out humid air from the drying chamber. The collector and the drying chamber are connected utilizing a flexible pipe of diameter 2 inches.

C. Fans (Air Exhauster)

At the end of each stage, a pair of DC fans are used in solar collectors with a discharge of 35 CFM and a total power rating of 12V 0.18 W for each fan. The velocity of air can be controlled with the help of a DC regulator.

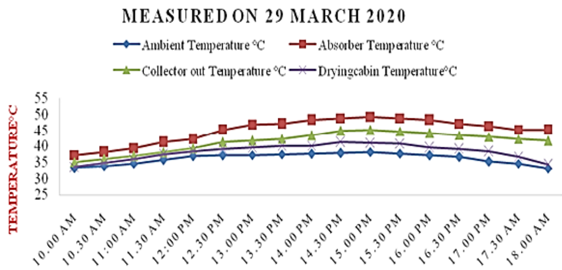
III. METHODOLOGY

The performance investigation is carried out in two experimental procedures. In the first experiment, an amount of 500-gram fresh grapes were kept directly in an open atmosphere for drying. This study is based on a daily record of the amount of weight drop and change in color of the grape converting into perfect raisins. The second experimental project model of a solar dryer which consists of a flat-plated multi-stage air flowing collector and drying cabinet chamber is tested by using a measured number of fresh grapes of 500 grams which were kept in the solar dryer for testing and investigation of weight drop i.e. moisture removal. The experiment is conducted from 10.00 AM to 06.00 PM for a few couples of days. To achieve a steady-state condition the trial of experimental measurement started one hour before the actual measurements were taken. At the end of the day, the color appearance and the weight drop were recorded daily. During the trial of the experiment temperature and humidity at ambient conditions, temperature and humidity at the absorber plate, temperature, and humidity at collector air discharge, and temperature and humidity at the dryer chamber are measured and recorded by the smart Arduino system and further saved into an SD Card. Temperatures and humidity were measured using DHT22 & DHT11 digital sensors which were further connected to the data logging system and LCD screen for continuous monitoring of data points. The velocity of the flow of air is regulated by the fan controller and measured by the anemometer. Also, the pyrometer is used to measure solar radiation.

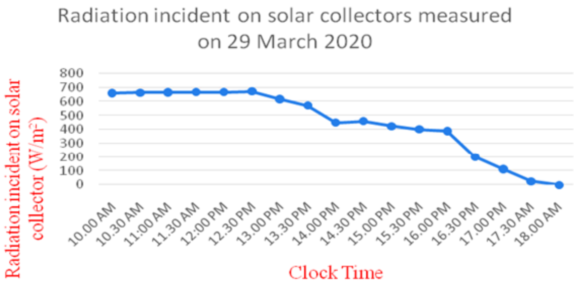
IV. RESULTS AND DISCUSSION

Thermal Performance of the Device

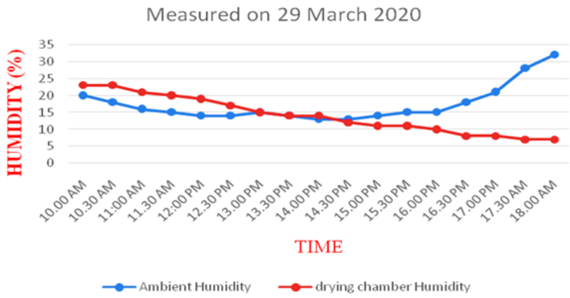
Graph No.1 represents the variation of time concerning temperature present in the atmosphere, the temperature inside the collector body, the temperature at the absorber surface, and the temperature inside the drying chamber on the first day of drying. (29th March 2020) which is typically a sunny day. Exactly at 10.00 AM, the drying of grapes started. After 30 minutes, the temperature rise in the drying chamber is observed. The temperature inside the drying chamber is noted maximum from 03.00 PM to 03.30 PM as 41°C.



Graph No.1 variations of temperature present in the atmosphere, temperature inside the collector body, temperature at the absorber surface, and temperature inside the drying chamber.

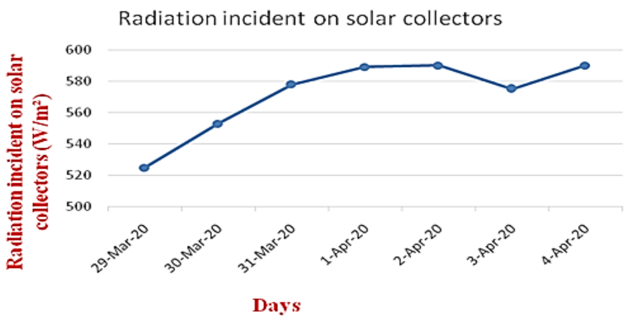


Graph No.2 shows the variation of solar radiation incident on the flat plate collector on 29th march 2020, it is noted that the peak radiation amount is 673 W/m² from 12.30 PM to 01.00 PM.



Graph No.3 variations of relative humidity (%) present in the atmosphere and present inside the drying chamber concerning time.

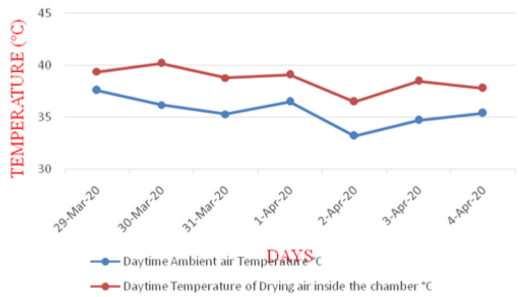
As shown in Graph No. 3 the relative humidity at the beginning of the drying test was almost the same. The incident solar radiations during the start were 660W/m² and the recorded atmospheric temperature was 33.3°C. After a time of 2 hours, solar radiation is raised with 13W/m² which results in a reduction of humidity inside the drying chamber by 4%. After 04.00 PM the humidity in the atmosphere raised by 18% in just two hours, but it does not raise the humidity and moisture content inside the drying chamber. Due to heat trapped by the collector body and absorber surface, the dehumidification continued and reached up to 7% relative humidity.



Graph No.4 variation of solar radiation incident on flat plate collector daily at 02.00 PM

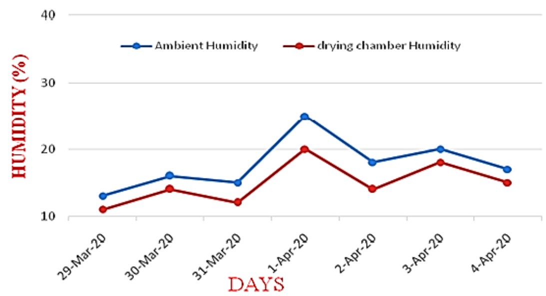
Graph No 4 shows radiation incidents on solar collectors. As per the Nashik altitude collector set as the angle of 19⁰.

Which gets maximum solar radiation in collectors. In experimental processes, solar radiation gets increases on a sunny day.



Graph No.5 temperature in the atmosphere and temperature inside the drying chamber of the solar dryer daily at 02.00 PM

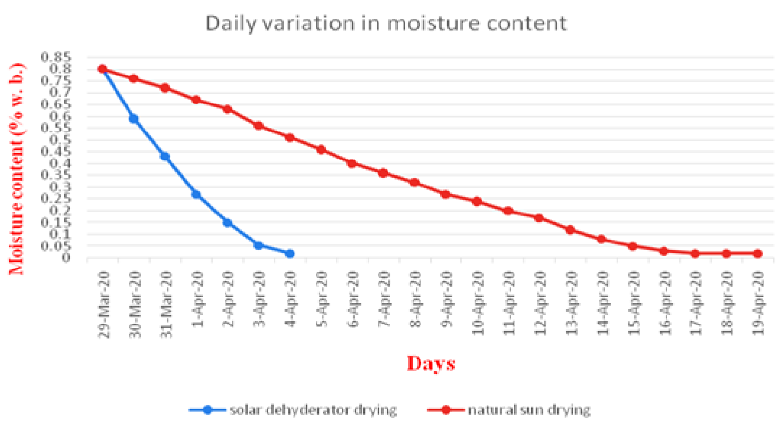
Graph No. 5 shows the variation in temperatures in ambient temperature and inside the drying chamber during the period of grapes drying in the solar dryer. As shown in the graph, on 29th March, 1st April and 4th April, due to cloudy weather the temperature gradient between the drying cabin and atmospheric temperature was low as 1.8°C, 2.6°C, 2.4°C but during the sunny days like 30th March and 3rd April the temperature difference between the drying cabin and atmospheric temperature was 3.8°C to 4.2°C.



Graph No.6 Relative Humidity in the atmosphere and Relative Humidity inside the drying chamber of solar dryer daily at 02.00 PM.

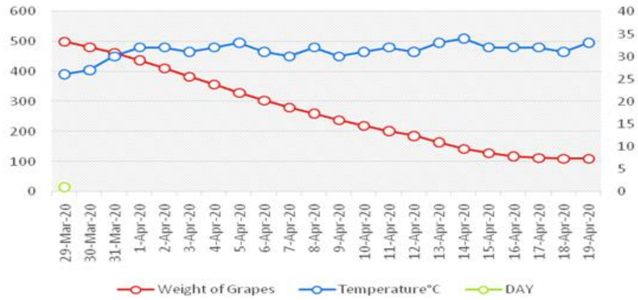
Graph No. 6 shows relative humidity in the atmosphere and inside the drying chamber. Reading takes at 02.00 PM every day. On 1st April 2020, humidity is high. Humidity, as compared to the atmosphere, is less in the drying chamber which increases the moisture removal rate.

B. Drying behavior of the device



Graph No. 7 Daily variation in moisture content using the solar dryer and without using the solar dryer (Conventional method)

Graph No. 7 shows the daily variation of moisture content of two groups of grapes in which one is kept inside the solar dryer and the other is dried conventionally. Compared to natural drying solar drying required 7 days for complete drying. In natural drying quantity and quality is low due to uneven drying processes.



Graph No.8 variation of temperature and weight of raisins concerning days (Conventional drying)

Graph No. 8 shows that the conventional method of drying grapes takes 21 days to convert into raisins. The initial moisture content of grapes was 81%. As the moisture content of grapes reduces, the weight is also reduced. The sample weight of the grape bunch was 500 grams which were reduced to 110 grams. At this stage, it is converted into perfect raisins since the weight drop was stopped after 110 grams.

Fig.5 shows the weight drop from 500 grams to 110 grams and the physical and aesthetical changes of grapes.

Nomenclature:

Ac : Area of the collector (m2)
Hi : Latent heat of vaporization of water (kl/kg)
IR: Solar radiation (w/m^2)
Mw: Mass of water removed (kg)
M: Moisture content of the sample at any time (kg/kg)
C: Specific heat of air at constant volume (J/kg°C)
T: Time (hour)
To: Outlet temperature of air (°C)
Ti: Inlet temperature of air (°C)
mo: Initial total mass (kg)
mi: Initial moisture content sample(kg)
mf: Final moisture content in the sample(kg)
ΔW: difference in weight loss in 1 hour (kg)
ΔT: difference in time (hour)
ηdryer: Efficiency of the dryer
ηc: Thermal efficiency of solar collector

A. Solar Dryer Efficiency:

The Thermal efficiency of a solar dryer system ηdryer is the ratio of the heat required to extract the moisture from food products to the energy required to run the solar dryer

$$\eta d = Mwhi / Aclt \qquad (1)$$

Here, the prior measured mass of the grape sample was 500 grams, converted into a final mass of 110 grams, resulting in 0.390 kg of water being removed from a sample of 0.5 kg. For measuring the unit mass of 1 kg from the sample 0.78 kg of water is removed. The 9.14% thermal efficiency was found in the drying chamber cabinet.

B. Moisture Removal Rate:

$$Mw= (Wi-Wf)/Wi *100 \qquad (2)$$

We measure the sample's moisture removal rate by taking the sample's initial weight of 500 grams, which was converted into 110 grams. From the above formula, we get the moisture removal rate is 78%.

C. Mass of Water Evaporate from the sample:

$$W= mo(mi-mf)/100-mf \qquad (3)$$

For measurement mass of water evaporate total mass taken is 1 kg which initial moisture content of about 80% after drying we get moisture on the sample is 22% is reaming, therefore the mass of water evaporating from the sample is around 70%.

D. Drying Rate:

$$DR = \Delta W/ \Delta T \qquad (4)$$

The weight of the sample we get is 1 kg after a 1-day drying process weight loss is up to 226 grams. The drying process conducts 6 hours a day which means in 1-hour weight loss of 37.66 grams. Therefore, the drying rate of 37.66 grams/hour.

V.CONCLUSION

A flat-plated indirect-type flat-plate collector solar dehydrator was developed to investigate the performance of drying grapes. The following conclusions have been drawn from the results: The temperature inside the drying chamber cabinet remains higher than the ambient temperature. The result of grapes drying is shown that the mass of 500-gram grapes converted into 110 grams of perfect raisins. The maximum output temperature of 59°C can be achieved. The average thermal efficiency of the solar dryer using a flat plate collector is 9.14%.

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