Experimental study of a solar dryer with different flow patterns of air in the drying chamber

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Abstract. A novel aberrant sun based dryer is outlined and developed to ponder the regularity of drying in the drying chamber. The system is comprised of a Collector (Solar), drying chamber and a blower. Tests were conducted to compare the conditions when air is distributed through the bottom alone and when the air is distributed to each tray separately and adjudge the method that gave better drying. Dryer efficiency, drying rate, initial and final content of moisture of the green peas in two conditions and also temperature issued in each tray under the two conditions also studied. Mass of green pea, reduced from 120 grams to 66, 78 and 80 grams for trays T1, T2 and T3 respectively when air is distributed through bottom alone and it reduced to 52, 52 and 54 grams when air is distributed evenly to each tray. The average efficiency of the dryer in the first condition is 19.2% and that of the second condition is 22.6% which shows the second condition is a desirable option for the drying process. The temperature of drying air is the most vital factor during drying. Air velocity and air humidity is also an important factor for bettering the rate of drying.

Keywords. Solar Energy, Drying Chamber, Moisture Content, Green Peas

1. Introduction

In India, agriculture plays a very vital part in the growth of its economic system. About 30% of the cultivated crops are wasted every year due to lack of inexpensive methods to dry the crops which get destroyed due to the existence of contamination, insects, etc. Solar Drying is the better alternative to the industrial dryers as in the other case it uses expensive fossil fuels for its working. Though solar dryer makes use of solar energy which is a replenishable energy resource and is abundantly available it has certain drawbacks when it comes the drying technology. Solar Dryers have lower thermal efficiencies because of the deficiency of heat transfer from the plate to the air that is blown over it. Another issue is the mismatch between the radiation availability during the day time and the increment in the heat energy demand during night time which was studied by Qureshi et al [1]. In cabinet dryers, since the products are not bared to direct sunlight during drying, they have better color texture and more vitamins after the process of drying takes place. Studies have been conducted by Mahmood et al [2] and Sebai et al [3] with an aim of improving the efficiency of the collector by
incrementing the heat transfer area by addition of fins to the plate. Another method to better the purpose of solar dryers is by improving thermal functioning of the chamber which will lead to quality drying of a product. In a recent study, Ali and Ramin [4] used porous modeling approach had stated that while the air is sent from the bottom of the chamber, it is going through each tray one by one and there is drop in air pressure as it moves upwards. Different distributions of air inside the drying chamber are hardly looked into.

Here two modes of distribution of air inside the drying chamber are compared to see which methods provide better drying of the product.

One of the vital factors in the drying process is the humidity. One of the ideas for evaluating the standards of the process is by the content of humidity that is being taken out from the product. Effects of humid air on the product to be dried are explained by Zomorodian and Moradi [5] and Sadodin and Kashani [6].

Sreerag T.S. and Jithish K.S [7] conceptualized a solar dryer to make a study with and without PCMs. Here one is having low melting point and other is PCM with a high point of melting for the purpose of bettering efficiency. PCM stores the heat energy and then the air travels to the drying chamber the process of drying is taking office. Discharging from the PCM takes place, when the solar radiation level reduces. Thus, it decreases the shift in the energy and provides non-stop energy to the system.

Lingayat et al [8] built a indirect kind sunlight based dryer to dry agrarian items. An analysis was directed to think about drying attributes of banana. The subjective investigation for drying of banana showed that the dampness substance of banana was diminished from beginning estimation of 355% (dry basis) to conclusive dampness substance of 16.1%, 19.2%, 21%, 31%, and 43.76% (dry basis) for Trays T1, T2, T3, T4. The average thermal efficiency of the heater is found as 31.5% and that of drying chamber was 22.4%.

Mghazli et al [9] performed the drying of rosemary leaf in an indirect solar dryer with a distinct SC and drying unit. The drying energy were considered for 4 diverse air temperatures (50, 60, 70 and 80 °C) and two wind currents drying for a surrounding temperature in the scope of 26-37 °C. The drying time variety as per the drying wind current rate is imperative for low temperatures, yet not huge for high temperatures. The observational outcomes are employed to decide the trademark curve drying.

In the current study uniform air distribution to each tray has resulted which has led to uniform drying of the product. Trials for two conditions at the steady mass stream rate has been directed which comprises of a condition where air is gone through the base of the drying chamber (vertical) alone and in another condition air is distributed equally to every tray which incorporates a mix of horizontal and vertical development of air inside the chamber which is a more latest idea in the research area. The horizontal motion of air is made available by the inclusion of vertical UPVC pipes that has holes facing each of trays. Moisture removal rate, dryer efficiency, drying rate, initial and final content of moisture of the green peas in two conditions and also temperature issued in each tray under the two conditions also studied.

2. Raw Material

The chosen raw material was green peas, which are a versatile spring or fall crop. 120 grams of green peas were placed in each tray for the initial experiment. The drying temperature of product is 55°C. The reason behind the preference of this raw material is that we will get about 115 calories from 1/2 cup of split dried green peas, according to the U.S. Department of Agriculture.
3. The Experimental Set Up

The experimental setup consists of three major components- solar air collector, drying chamber and a blower. For measurement purpose Data Logger, Anemometer, Pyranometer, Hygrometer and a separate temperature indicator is used. The studies are directed to examine the thermal characteristics of a drying chamber for different variations of air distribution.

3.1. Solar Air Collector

The SAC is consisting of components like insulation material, absorber plate, glass and coating material. The plate is consisting of aluminum with thickness of 1 millimeter and the area of 1 m² which is used for absorbing solar energy. The material for insulation purpose that is given in the proposed model is foam with the thickness of 40 mm which is used to decrease the heat losses. The important material that is used in the experiment is glass with thickness of 5 mm. The solar air heater consist of inlet 25mm diameter and outlet of 38.1 mm diameter. The coating material used in the plate is black paint to take in energy more efficiently.

![Figure 1. Solar Air Collector during Fabrication](image1.jpg)

3.2. Drying Chamber

The drying cabinet is constructed from plywood material on the exterior and its dimensions are 0.57x0.54x0.82 m. The insulation material is glass wool of 30 mm thickness which is use to reduce the heat loss. Insulating material is covered with 2 kinds of materials. The interior material is aluminium plate of 1 mm thickness and the outside material is plywood with 12mm thick. Three trays made of mesh and stainless steel are used in the drying chamber to control the drying products. Each tray is placed 150 mm from each other and a mild steel tray is present on the underside to hold the PCM material that is to be used for further experiment. Three Thermocouples are attached to each of the trays and connected to a data logger which hourly temperature data in the drying chamber. Along the back of the Chamber, three vertical pipes and one horizontal UPVC pipe are fitted to provide air flow in the chamber. The horizontal pipe at the bottom is attached to the SAC outside. The front aspect of the drying chamber during fabrication is given in the image below.
3.3. Blower

A metal blower is used for blowing air at a required velocity to the air collector. The blower used here is a metal blower with a maximum speed of 2800 rpm and 2.4 Hp and 180 watts. The velocity of air at the inlet of the solar air collector can be controlled using a regulator.

4. Methodology

The experimental model of the solar dryer which basically consists of Solar Air Collector and Drying Chamber is tested by using a small amount of green peas. Firstly the skin over the green peas is peeled and three sets of green pea, which are of 120 gm each are kept in three of the trays. The experiment is conducted from 10 A.M to 2 P.M on two separate days which had similar amounts of solar insolation. To get to a steady state condition the experimental measurement is started one hour prior to the actual readings taken. On the first air is distributed through bottom of the chamber alone and holes in the vertical pipes are closed to avoid any air reach the tray other than the bottom source. And on the next day all the holes in the UPVC pipes are kept open such that air can be sent to each tray separately.

During the experiment, temperatures at the inlet and outlet of air heater, five points on the aluminium absorber plate, inlet and outlet of the chamber, tray 1, tray 2 and tray 3 temperatures were noted. Along with this relative humidity of the drying chamber and velocity of drying air was also measured. Temperature was measured using RTD thermocouple connected to data logger (Agilent Make) and these thermocouples were attached to the trays in the drying chamber and each tray had three thermocouples attached to it and average of the temperatures were taken for the study. Velocity measured using anemometer and here the velocity is retained constant around 12 m/s and a pyranometer is used to measure the solar radiation.
5. Result and Discussion

![Completed Experimental Set Up](image1)

![Completed Experimental Set Up](image2)

Readings are taken at two days by considering two conditions that are based on the motion of air inside the drying chamber. That is on first day air was distributed through bottom of the chamber alone. And in second case, Air was blown through bottom and also passed to each tray separately using pipe connections. The solar radiation varies from 600 W/m² in the morning to 920 W/m² in the noon. Heater inlet had the minimum temperature reading and the aluminium absorber plate had the maximum temperature that ranged around 75-80˚C during peak timings. On both days a total of 360 grams of green peas was taken, out of which 120 grams were placed in each of the trays and their weight was checked after everyone hour interval.

Table 1. Radiation and Ambient Temperature during Feb 1 and Feb 3

| Drying Time | February 1 (Radiation Data) (W/m²) | February 3 (Radiation Data) (W/m²) | Ambient Temperature (˚C) February 1 | Ambient Temperature (˚C) February 3 |
|-------------|----------------------------------|----------------------------------|--------------------------------------|--------------------------------------|
| 9 A.M       | 562                              | 581                              | 29.6                                 | 28.5                                 |
| 10 A.M      | 626.73                           | 658.14                           | 30.2                                 | 30                                   |
| 11 A.M      | 769.76                           | 813.63                           | 31.9                                 | 31.4                                 |
| 12 A.M      | 841.85                           | 841.32                           | 32.7                                 | 32.9                                 |
| 1 P.M       | 846.11                           | 851.97                           | 33.1                                 | 33.5                                 |
| 2 P.M       | 897                              | 899.98                           | 34.8                                 | 34.7                                 |
| 3 P.M       | 663.47                           | 675                              | 33                                   | 32.9                                 |
| 4 P.M       | 334.9                            | 395.34                           | 31.4                                 | 30.5                                 |
| 5 P.M       | 155                              | 175.65                           | 30.2                                 | 29.1                                 |

Table 1 shows the variation in the radiation corresponding to the drying time. On February 1, the air was distributed through bottom only and on February 3, air was distributed to each tray separately. Figure 4 shows the variation of radiation on the two days w.r.t the drying time. It is seen that the radiation is ranging from 600 W/m² to 925 W/m² during both the days and also the variation of radiation is similar on both the occasions. Usually the radiation level passes 1000 W/m² in the TN Region during summer season.

Figure 5 and Figure 6 show the variation of tray temperatures according to the drying time. In this study of the drying chamber the concentration is put on the disparity of air distributed inside the
drying chamber. In figure 5, the air is moved through the bottom alone and the air is moving from bottom to top in a vertical movement. Tray 1 gets the maximum amount of heat which is used for drying of green peas and then the air moves on to the other trays. So the bottom tray has maximum temperature and there is 3-5°C temperature difference between first, second and third tray.

![Figure 4. Drying Time Vs Radiation And Ambient Temperature](image1)

In figure 6, the air is sent from the bottom and also separately to each tray through the holes in the vertical UPVC pipes. In the beginning itself there is a uniform air distribution inside the drying chamber and variation of temperature is also uniform that is not seen in the first case.

![Figure 5. Drying Time Vs Tray Temperatures(Air passed through the bottom of the chamber)](image2)  ![Figure 6. Drying Time Vs Tray Temperatures (Air passed to each tray evenly)](image3)

Figure 7 and Figure 8 shows the variation in the Drying rate of the green peas with respect to the drying time for both the conditions. The drying rate is varying from 0 to 0.021 kg/hr in both the conditions but the drying rate is not uniform when the air passes through bottom alone.
Figure 7. Drying Rate Vs Drying Time (Air passed through bottom of Chamber)

Figure 8. Drying Rate Vs Drying Time (Air passed to each Tray evenly)

The drying rate is uniform in the second case when the air is distributed evenly to each tray so in this condition the moisture removal rate also becomes uniform as moisture removal and drying rate is interconnected. The drying rate shows how much moisture is removed from the product per hour.

Figure 9. Moisture Content Vs Drying Rate (Air Passed through bottom of Chamber)

Figure 10. Moisture Content Vs Drying Rate (Air passed to each Tray evenly)

Moisture content is an important aspect in the drying process. A weighing machine was used to measure the initial and final mass of the green peas. The initial moisture content can be calculated using the following equations:

\[ M_{\text{dry basis}} = \frac{w_{\text{initial}} - w_{\text{final}}}{w_{\text{final}}} \]  

\[ M_{\text{wet basis}} = \frac{w_{\text{initial}} - w_{\text{final}}}{w_{\text{initial}}} \]  

It is noticed that at the beginning green peas has 80% of water (approximately). Fig 9 and Fig 10 shows the variation of the drying rate with respect to the moisture content on dry basis. It is seen that there is no uniformity in the drying rate in Fig 9 which leads to different initial moisture content in each trays i.e. tray 1, tray 2 and tray 3 have an initial moisture content of 81.8%, 53.84% and 50% (db) respectively whereas in the Fig 10 variation of drying rate with respect to moisture content is similar in all the trays. In Fig 10 where the air is passed evenly to each tray, tray 1, tray 2 and tray 3 are having an initial moisture content of 130.76%, 130.76% and 122% (db) respectively which are similar.
Figure 11 and Figure 12 shows the variation of drying time compared to the moisture content. Here also it can be seen that moisture content is greatly varying in all the trays during the drying period of 5 hours. Moisture removal rate is high in the bottom chamber as it is getting maximum amount of heat energy compared to the other trays. In figure 12 as all the trays are getting even amount of heat energy the change in the moisture content is uniform in all the trays. The relative humidity ranges between 50-60% during the drying time which is good as low humid air has better capacity to absorb more moisture.

Dryer Efficiency is calculated by using the following equation:

$$\eta_{\text{dryer}} = \frac{(m_{\text{water, h}})}{(A_c.I_t)}$$  \hspace{1cm} (3)

The initial mass of green peas was 120 gm in each tray. In the first condition where air was passed through the bottom alone, the mass of green peas in tray 1, tray 2 and tray 3 was reduced to 66, 78 and 80 gms respectively whereas in the second case where air was passed evenly to each tray, the mass of the sample in tray 1, tray 2 and tray 3 got reduced to 52, 52 and 54 gms respectively which shows the second condition is better compared to the first one.

6. Conclusion

An Indirect type solar dryer was constructed and fabricated to dry the green peas. The thermal performance of the drying chamber was studied in two conditions, one where air was passed through the bottom of the chamber alone and in the second case the air was passed to each tray separately. It was found that the second condition is more effective compared to the first. It is observed that the dried product is free from undesired contaminants. Mass of green peas reduced from 120 grams to 66, 78 and 80 grams for tray 1, tray 2 and tray 3 respectively when air was distributed through bottom alone and the mass reduced to 52, 52 and 54 grams when air was distributed evenly to each tray. This shows that the second condition is more efficient than the first condition. The average efficiency of the dryer in the first condition was found to be 19.2% and the average efficiency of second condition was found to be 22.6% which shows the second condition is a better option for the drying process. Future studies are also planned to improve the performance of drying chamber by the inclusion of PCM, Desiccant and a combination of both.
7. References

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