Design and analysis of a solar drier with a parabolic shaped dish type collector for drying peanut

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Abstract

Abstract
The present work deals with the performance evaluation of an active indirect solar dryer integrated with a parabolic dish collector to dry peanuts. Peanut is a widely available edible seed in India, obtained from a legume crop (Arachis hypogaea) which is used either directly in food or for extracting cooking oil. The system mainly consists of a parabolic collector which is provided with an insulator made of plywood with air gaps and aluminium foil wrapping, and a drier consisting of four trays where the peanuts are dried. The flow of hot air through the tray is maintained using an exhaust fan positioned at the top of the drier. The fan exhausts the moisture extracted from the product to make the flow of air without any localization. From the analysis it is found that the parabolic dish collector generates a maximum temperature of 79 °C at 12.30 PM and dries 1.5 kilograms of peanut in 5 hours of a day. Thus, hot air from the parabolic dish concentrator reduces moisture content of peanut by 21% more than obtained from open solar drying.

Keywords: Peanut, parabolic collector, solar dryer, trays

1. Introduction
The renewable energy has a vital role in the life of farmers in improvising the technology in farming which will increase the productivity. Lack of adequate infrastructure for processing of food and its storage in Asia-Pacific region leads to average wastage of 10 to 40% [1].

As a result of lack of processing technology availability in India, large quantity of food produced in the country is going to garbage, even when a numerous people are in need of their daily food. This leads to the formation of gap between the gross food production and its availability. Post-harvest losses should be minimized to improve the distribution of food to needy people [2]. Some of the conventional food preservation methods are bottling, canning, freezing, sugaring, salting (curing), drying, smoking, refrigerating, pickling and freezing. Among these methods, drying is one of the practical methods to preserve food at a very low cost and by means of renewable energy. Drying method not only an effective method, but also an ecofriendly to reduce postharvest losses and thus a solution to supply shortages. Drying process dehydrates the food products which enhances the shelf life by resisting the growth of bacteria [3]. Drying is a widely employed technology to dry crops, fruits, vegetables, herbs, woods, agricultural products and food stuffs that significantly contributes to the revenue developed by a country like India through agricultural technology [4]–[6].

Although drying of food under direct sunlight is economical, the dried products lack quality due to the contamination caused by dust, insects, birds and rain [7]. Moreover, direct sunlight drying is not only time consuming but also leads to loss of vitamins, nutrients and unpleasant colour change due to its exposure to direct ultraviolet rays. These problems pertaining to direct sunlight drying is eliminated through dehydrating using solar dryers. In addition, solar dryers generate a higher temperature, minimum relative humidity, lesser moisture content of the product and lower damage of drying components compared to direct solar drying [8].
Solar dryers remove the 20\% more moisture than open air drying to produce better quality of dried products [9]. Type of solar dryers include tunnel dryers, hybrid dryers, horizontal and vertical type dryers, multi-pass dryers and active and passive dryers [10]–[17].

On the basis of heating modes and utility of solar dryers, the solar dryers are classified as forced air circulation or active solar dryers and natural air circulation or passive solar dryers. Active or passive solar drying system is classified based on design or working principle of the dryer, mode of drying and product type to be dried as direct mode or integral type, distributed or indirect mode and mixed mode solar dryers, respectively. The direct mode of drying may affect the quality and property of a product to be dried, as an example, the chlorophyll may be damaged easily due to solar direct drying method. Indirect mode of drying is more preferred when there is less available space for drying large quantities of product. In this case, colour and the nutrients of the product undergoing drying is preserved. Moreover, forced convection dryers dries the product faster than natural convection solar dryer and those dried with forced convection has a higher quality than direct solar dryers [18], [19].

The quality of dried products using forced convection method can be further increased by the right choice of solar collector with appropriate solar tracking facility. Depending upon the concentration ratio of the collector, the solar radiation is amplified to generate more heat flux. When more heat is generated in the collector due to concentration ratio, the air can carry enough heat to the drying chamber to dry the product that requires higher temperature. This will considerably reduce the time of drying and hence efficiency of the dryer is improved.

Through there are many works carried out on the efficiency of parabolic solar dish collector, no studies are found to be reported in the moisture removal of the peanuts in a dryer with an efficient parabolic solar dish collector. In the present work, a solar dryer is designed with a parabolic dish collector to increase the concentration ratio of the solar radiation and hence carrying more heat in the air to remove the moisture of peanuts at a faster rate. Moreover, this works also demonstrates with the further improvement in solar radiation absorption rate with manual solar tracking collector which can rotate in one direction.

2. Materials and Method

Various steps are followed in designing a solar dryer. The first step involved is the study of climatic data and geographical nature of the location. Here, the study is conducted at Kalady, Ernakulam district. Second step is the study of insolation and calculation based on the size and configuration of the collector used in the dryer. Performance analysis of the drier is carried out by considering major design parameters pertaining to solar drier design [20]–[23]. When all the dimensions are determined for the design of dryer, an exhaust fan is chosen to mount at the top of the drying chamber to make the exhaust of air containing the moisture.

2.1. Climatic and geographical data

Kalady is a place in Ernakulam district of Kerala state, India. It is located at a latitude of 10.1710° N and longitude of 76.4468° E. Solar radiation (Insolation) on the surface of Kalady is 855.3876 W/m² [23]. The angle at which the solar collector should be tilted is determined from the declination angle (Ψ).

2.2. Declination (Ψ)

Elevated angle between equatorial plane and sun’s direction (Ψ) [21] is formulated using the day ‘i’ in the year, where i varies from 1 to 365.

\[
Ψ = 23.45 \sin \left[ 0.9863(284 + i) \right] \tag{1}
\]

General equation for optimum slope of collector of the solar collector (β) with respect to horizontal is defined with the declination of (Ψ), and latitude(θ) of Kalady [21]. The solar collector is tilted at an angle (β) of 11.8686 South.

\[
β = Ψ + \text{latitude angle (θ)} \tag{2}
\]

The solar radiation on 12° tilted surfaces is calculated as 867.43 W/m².
2.3. Design consideration
As solar drying method has a higher drying rate than open sun drying, solar drier with the collector having manual solar tracking system is implemented for drying of the peanut. The dryer has a parabolic dish shaped collector made of galvanized iron sheet with a clear glass cover of 5 mm thickness [5] and an exhaust fan at the exit of the drying chamber. The inner portion of parabolic dish shaped collector is first coated with a copper and then it is painted black over it [24], [25] to provide maximum absorption of heat from the sunlight. The recommended air gap is 5 cm [26] for a tropical climate is also maintained. Collector surface is insulated by providing an air gap using a plywood material cut in the circular shape to reduce thermal losses.

![Diagram of solar dryer](image_url)

**Figure 1.** Schematic diagram of solar dryer with dish shaped parabolic collector and drying chamber

The reason for choosing plywood is that it is an ecofriendly material. Heat loss by radiation and damaging of plywood due to moisture absorption is prevented by wrapping an aluminum foil over it [19]. The axial flow exhaust fan assures the constant air flow through the drying chamber at a flow rate of 2 m/s. For this study, 500 grams of peanut is spread over the trays in the drying chamber. The hot air from the outlet of the solar collector is fed to trays in the drier chamber through the inlet holes drilled just below it. In drying chamber, slots are made in the drying chamber with a clearance between them to hold the trays. The clearance between the slots in the chamber helps to keep the trays separated from one another, so that the peanut placed for drying will be exposed to adequate hot air. This arrangement will speed up the drying process. Heat from the solar collector is carried to trays, where the crops are placed for drying, through a connecting pipe that connects the solar collector and the drier chamber.

A parabolic dish shaped collector has a diameter of 1.5 meter and area of 1.77 m$^2$ is selected. The major function of collector is to convert the solar radiation into useful heat energy. A thermal analysis is performed for calculating heat gain and losses when the air is flowing between glass cover and absorber plate, which is called as a top flow, while air flow between absorber plate and bottom insulation which is called as bottom flow [3]. It is observed that more heat is lost through upper portion of the collector than the bottom flow portion as the bottom portion has less temperature difference with ambient air.

2.4. Efficiency of the drier
Efficiency of a solar drier ($\eta_d$) is calculated as the ratio of product of mass of moisture in a crop (m) and the latent heat of vaporization ($h_{fg}$) to the product of area of collector ($A_c$), and insolation ($I_c$) falling on the collector and time duration of drying (t).

$$\eta_d = \frac{mh_{fg}}{A_c I_c t}$$ (3)
The parameter that controls the efficiency of a drier is the time period of drying.

\[
Q = m \times h_{fg} = \rho C_p V (T_c - T_a) \begin{cases} 
T_c - T_a = T_b & \text{Ideal case} \\
T_c - T_a > T_b & \text{When losses are considerable}
\end{cases}
\]

The amount of moisture removal can be related to the hot air flowing from the collector outlet is by equating mass of the moisture to be removed from the crop (m) times the latent heat of vapourization of water \( (h_{fg}) \) to the heat required \( (Q) \) to remove the crop moisture (eqn.4). However, in case of air, the amount of heat carried by the air \( (Q) \) can be formulated (eqn. 4) by multiplying density of air \( (\rho) \) with Specific heat capacity of air, Volume flow rate of the air \( (V) \) and the difference between the temperature carried by the air from the collector \( (T_c) \) to the ambient temperature \( (T_a) \). There are two cases (eqn. 4) to be dealt with: (1) ideal case and (2) when losses are considerable. In the ideal case, it is assumed that there is no loss of heat happens when the air carries heat from collector to the drying chamber. In this ideal case, the difference between the air at the outlet of collector and the ambient temperature should be equal to the required temperature \( (T_b) \) in the drying chamber. The required temperature in the drying chamber is the temperature required for drying a particular crop, here it is peanut.

However, if the heat loss when the air carries the air from the collector to the drying chamber is considered, then the difference between the temperature of collector \( (T_c) \) and ambient temperature \( (T_a) \) should be greater than the temperature in the drying chamber. If only this constraint is met, the temperature loss while carrying the hot air from collector to the drying chamber can be compensated, and required air can be delivered to the drying chamber.

The percentage of moisture removal from the peanut (eqn. 5) is calculated as the ratio of the difference between the initial mass of the crop \( (M_i) \) and the final mass \( (M_f) \) of the peanut after drying to the initial mass of the peanut \( (M_i) \).

\[
\text{Moisture (\%)} = \text{Moisture drop in the crop (\%)} = \left( \frac{M_i - M_f}{M_f} \right) \times 100
\]

3. Results and Discussion

The solar radiation, insolation \( (I_c) \), falling on the exposed surface of the dish type solar collector is in the range 540 to 760 W/m\(^2\). As a result of this insolation falling over the surface of the solar collector, the temperature of the air \( (T_{ci}) \), ambient air temperature, entering the inlet of the solar collector is in the range from 31\(^0\) C to 37.5\(^0\) C and the temperature of the air exiting through the outlet of the collector \( (T_{co}) \) is in the range of 59 \(^0\) C to 79 \(^0\) C.

![Figure 2. Variation of temperatures of solar insolation with respect to time](image-url)
Collector inlet temperature, collector outlet temperature and the solar insolation falling on the collector is plotted against time of exposure of collector from 9 AM to 2 PM on a hot day in figure 2. The maximum solar radiation is incident on the solar collector during the noon 12 hours 30 minutes, which is 760 W/m$^2$ and the minimum solar radiation falling on the collector is at 9 A.M. morning, which is 540 W/m$^2$. The ambient air drawn into the solar collector is heated by the radiation of sunlight falling on the absorber to a maximum temperature of 79$^\circ$ C, for 760 W/m$^2$, and the hot air is taken out of the solar collector to the drying chamber.

Figure 3. Reduction in the moisture content and solar insolation with time

Figure 3 shows a comparison of natural and solar drying. The crop is openly exposed to sunlight for natural drying, whereas dish collector solar drying system is utilized for drying the crop under solar drying method. For comparison between natural and solar drying method, solar dryer is exposed to same insolation or solar radiation as in figure 3. It is evident from the figure 3 that the crop having 68% of moisture is reduced to 14% when dried for 5 hours, where 35% of moisture is still exist in the crop after natural drying. Hence, the solar drying with solar dish collector is more effective and capable of removing 21% of extra moisture when compared to natural drying method.

Figure 4. Collector exit temperature ($T_{co}$), tray temperatures ($T_1$, $T_2$, $T_3$ and $T_4$) and moisture removal rate (%) with time
In the solar drying system, the hot air from the collector is delivered to the trays through the vents just below the trays. As hot air passes through these four trays, Tray 1, Tray 2, Tray 3 and Tray 4 have temperature $T_1$, $T_2$, $T_3$ and $T_4$ respectively. In figure 4, tray 1 has a temperature of 61 °C, whereas tray 2 has 60.5 °C, tray 3 has 59.5 °C and tray 4 has 67.5 °C. Tray 4 is exposed to highest temperature because tray 4 is placed in the bottom most position, and as a result the hot air first reaches tray 4 and in addition to the supplied heat to the tray 4, the hot air coming through the vents of other trays will also add heat to the tray 4. Though the insolation is 660 W/m² at 11 AM on the day of testing, tray 4 is subjected to highest temperature in this time period. However, for an insolation of 760 W/m² and collector outlet temperature of 79 °C at 12.30 PM, the hot air reaching the tray 4 has only a temperature of 63.5 °C which is attributed to heat loss between collector and the tray. As the tray 4 is subjected to enough temperature, the moisture level of the crop placed for drying on this tray is drastically reduced from 68%

4. Conclusions
Peanut is dried using a solar dryer with a parabolic dish type collector and the moisture reduction over a time period of 5 hours in a day is analysed. The study reveals that the lowest tray in a dryer chamber, for which an air hole is provided, dries the peanut at a faster rate than other trays because of the highest air temperature to which it is exposed. Moreover, solar drying method extracted a higher percentage of moisture from the peanut than the open sun drying method. Although the slope of the drying curve is steep at peak hours of temperature in a day, the increase in temperature does not reduce the drying time drastically. The parabolic dish collector generated a maximum temperature of 79 °C at 12.30 PM and dries 1.5 kilograms of peanut in 5 hours of a day. Application of parabolic collector in solar dryer improved the moisture removal by 21% when compared to direct solar drying.
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