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**Research article**

# Comparative study of open sun and cabinet solar drying for fenugreek leaves

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## Abstract

A cabinet solar dryer with variable width of chimney has indigenously fabricated for drying the leafy vegetable such as fenugreek leaves. In this work an attempt has been made to design development and evaluate the performance of cabinet solar dryer (CSD) and open sun drying (OSD) to dry the fenugreek leaves. The sample of one kg fresh leaves of fenugreek vegetable was dried in cabinet solar dryer and in open sun. The study showed that the sample dried in cabinet solar dryer took four hours while open sun took seven hours to dry at 87% (wb) moisture content. The temperature in cabinet solar dryer was found more than the surrounding temperature by about 20-22$^{0}$C during the clear sunny day. Results showed that the energy incident was found more in CSD. The rate of energy utilization was found 75% more in CSD as compared to OSD. Moreover, average efficiency of CSD was found 68.12% more in comparison with OSD. 

**Keyword:** Drying; Fenugreek; Energy; Temperature; Efficiency

## 1. Introduction

Though India stands second in vegetables and fruits production, hardly two percent of the produce is processed and 30 - 40 % is being wasted due to lack of processing and preservation infrastructure. The situation is worse for farmers in the rural areas of country. Most of the harvested vegetables and fruits are susceptible to deterioration due to poor preservation. The moisture content in the agricultural produce contributes greatly to the deterioration of vegetables and fruits. Therefore if the agricultural produce is to be stored for longer length of time, it is necessary to reduce its moisture level to certain well defined limit. This will prevent the production of undesirable chemical compositional changes in the produce by bacteria, mould and enzyme which will spoil the vegetables and fruits [1]. Drying is the reduction of moisture from the products and is the most important process for preserving agricultural products. Sun drying is a traditional method for drying vegetables and fruits. In this method vegetables and fruits are spread in a thin layer on the ground and exposed directly to solar radiation. It is the cheapest method but it has many drawbacks such as drying at uncontrolled temperature, uneven drying, and it takes more time. Moreover it is contaminated by dust, insect and rodents therefore dried vegetables become polluted.

Currently hot air drying is most widely used method in post-harvest technology of agricultural products. Using this method, a more uniform, hygienic and attractive coloured dried product can be obtained rapidly. However, it is an energy consuming operation, so more emphasis is given on using solar energy due to high prices and shortage of fossil fuels. Moreover, in rural India there is load shading due to scarcity of electricity. Cabinet solar dryers have potential to produce high quality dried products and can help to avoid problem of contamination [2].

In comparison to natural sun drying, solar dryers generate higher temperature, lower relative humidity, lower product moisture content and reduced spoilage during the drying process [3]. In addition, it takes less time and is relatively inexpensive. Hence cabinet solar drying is better alternative than the natural drying. In the present study a simple low cost cabinet solar dryer has been fabricated. The advantages of this dryer are- it is easy to operate, it requires no training and it is low cost since it is made by locally available materials. It is easy to build and requires semiskilled persons and limited facilities to fabricate.

## 2. Basic theory

Drying is a simple process of excess water removal from the agricultural produce. It is an energy intensive operation. Especially essential to reduce the moisture content from vegetables and fruits, as these have in general water content much higher than one suitable for long preservation. Solar dryers is usually classified in to four categories according to the mechanism by which energy is used to remove moisture [4]

i) Sun or natural dryers: The material to be dried is placed directly under hostile climate condition like solar radiation, ambient air temperature, relative humidity and wind speed to achieve drying.

ii) Direct solar dryers: In these dryers, the material to be dried is placed in an enclosure with transparent covers or side panels. Heat is generated by absorption of solar energy on the product itself as well as internal surface of drying chamber. This heat evaporates the moisture from drying product and promotes the natural circulation of drying air.

iii) Indirect solar dryer: In these dryers, air is first heated in a solar air heater then ducted to the drying chamber.

iv) Mixed type solar dryer: The combine action of solar radiation incident direct on the material to be dried and the air pre-heated in the solar air heater furnishes the energy required for drying process.

The cabinet solar dryer is composed of mainly two parts. The cabinet where the air is heated by solar radiation and the sample were exposed; other is chimney which assists the exhaust of moist air while using buoyancy effect. The latent heat of vaporisation used to remove the moisture from the sample is provided by the hot air in the cabinet.

The air flow in the cabinet solar dryer plays an important role in the drying process and is responsible for moisture transport by enhancing convective transfer of water vapour from the fenugreek leaves to the surrounding air. The moist air located just above the fenugreek leaves is carried away by the air flow.

The energy balance of water evaporation can be used to estimate the total energy utilised for drying the given quantity of sample given by the following equation [5].

$$M_w L_v = m_a C_p (T_i - T_f) \quad (1)$$

Where $M_w$ is mass of water evaporated from the sample (Kg), $L_v$ is the latent heat of vaporisation (KJ/Kg), $m_a$ is the mass of drying air (kg), $C_p$ is the specific heat of air at constant pressure (kJ/kg $^0$k), $T_i$ and $T_f$ initial and final temperatures of the drying air respectively.

## 3. Material and method

### 3.1. Cabinet Solar Dryer

The cabinet solar dryer consists mainly of two parts such as cabinet and chimney. The cabinet was made by waterproof plywood. An opening was provided at the bottom of the cabinet to suck the air inside the dryer. Inner side of cabinet was polished by black paint. Inside the cabinet at mid position perforated tray was placed. Further the flatten chimney was attached to the cabinet. The chimney was also made of waterproof plywood and its inner surface was painted black. The front sides of cabinet and chimney were covered with transparent glass. The temperature of chimney was more than the temperature of cabinet and the temperature of the cabinet was more than the surrounding and hence the natural convection is set up in the dryer. The schematic diagram is shown in following figure1. The temperature inside the cabinet can be set according to drying temperature of vegetables by adjusting the width of chimney mechanically. For fenugreek leaves required temperature for drying was 45$^0$C to 60$^0$C. [6] This temperature was maintained in the cabinet by adjusting the width of chimney.

### 3.2. Sample collection

One kg fenugreek leaves sample was collected from the one farm only to ensure the uniformity and to avoid the effect of soil variation on the nutrient content of the sample. The fresh and green fenugreek leaves were selected and discoloured, as well as wilted leaves removed to avoid bad odour and loss of nutrients after dehydration.

### 3.3. Sample preparation

The fenugreek leaves were cut from the stem in order to make them free of soil and dirt. The leaves were washed with ample of fresh and clean water number of times. After washing, the leaves were air dried at room temperature to eliminate the residual moisture in the sample. Any non leafy part present in the sample was then removed to get a homogenous collection of fenugreek leaves which was then separated in two equi-weighted quanta for open sun drying (OSD) and cabinet solar drying (CSD). The sample weight was recorded before the actual experimental drying was started. The OSD & CSD were carried out in an open space on the terrace of building with GPS location 19$^0$ 35'at North latitude and 74$^0$ 11' at East longitude. Both the drying systems i.e. CSD & OSD have the same surface area of the mesh used to spread the sample. The temperature, insolation, humidity and loss of mass in OSD and CSD were recorded at an interval of one hour.

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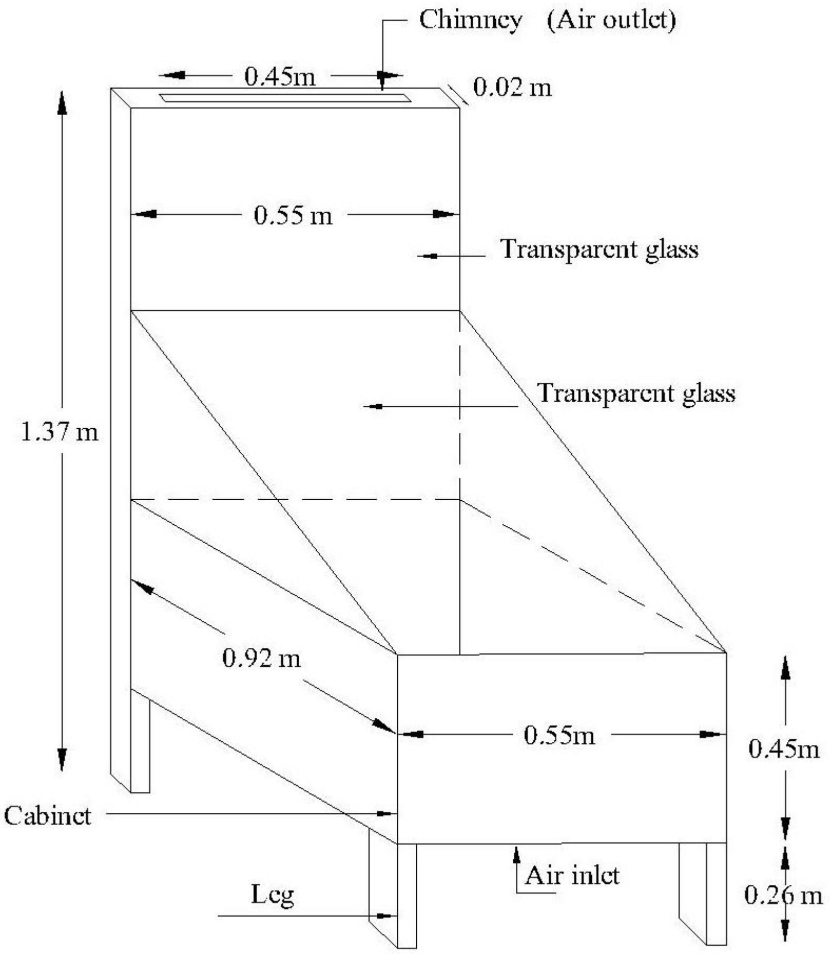


**Figure 1.** Cabinet Solar Dryer

### 3.4. Open sun drying

For OSD the leaves were uniformly spread on a mesh kept at a 0.35m height from the ground. The intention of such system was to avoid the contamination of dust. In OSD the temperature and the heat content depends solely upon the amount of incident radiation from the sun. The leaves were kept in open sun from 10:00 a.m. till the leaves were sufficiently dried up to the 13 % moisture content.

### 3.5. Cabinet solar drying

For CSD the air dried leaves were uniformly placed over the mesh; which has same dimension as used for OSD. Mass of leaves, cabinet temperature, surrounding temperature, and insolation were measured periodically till the required moisture content was obtained.

### 3.6. Energy incident rate

The energy incident rate on OSD and CSD is given by

Energy incident (J/s) = $I \times A$ (2)

Where I = Insolation (Watt/$m^2$), A = Exposure area of fenugreek leaves into solar radiation ($m^2$)

### 3.7. Energy utilised

The amount of energy utilised is given by following formula [7]

Energy utilised (J/s) = $M_a \times L_v / t$ (3)

Where $M_a$ = Mass evaporated (kg), $L_v$ = Latent heat of vaporisation of water (kJ/kg)

t = time (second)

### 3.8. Efficiency

The quantity of heat energy required to evaporate the moisture inside the product is called drying efficiency. Drying efficiency was calculated by following formulae

#### 3.8.1. Efficiency of OSD

$$\eta_d (\%) = \frac{ML}{A_c \times I_c \times t} \times 100 \quad (4)$$

Where, M = Mass evaporated (kg), L = Latent heat of vaporisation of water (kJ/kg),

$I_c$ = Insolation (Watt/m$^2$), $A_c$ = Collection area (m$^2$), t = Time(s)

#### 3.8.2. Efficiency of CSD

$$\eta_d (\%) = \frac{ML}{A_c \times I_c \times t \times \tau} \times 100 \quad (5)$$

Where, M = Mass evaporated (kg), L = Latent heat of vaporisation of water (kJ/kg),

$I_c$ = Insolation (Watt/m$^2$), $A_c$ = Collection area (m$^2$), t = Time(s), $\tau$ = Transmittance

## 4. Results and discussion

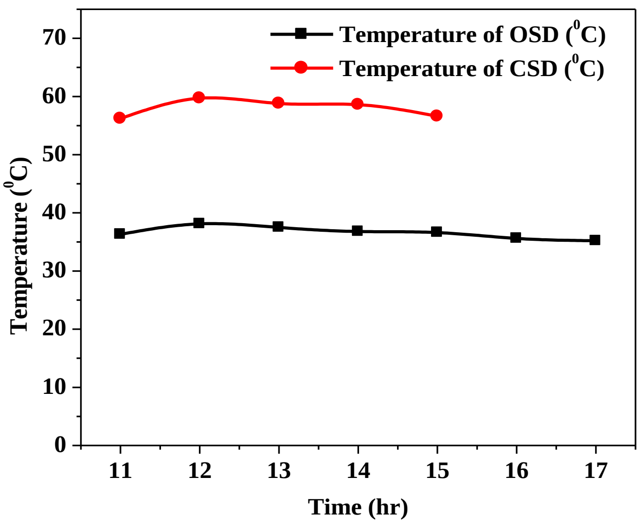


**Figure 2.** Temperature variations of CSD and OSD

From figure 2 it is observed that the cabinet solar dryer attained a maximum temperature of 59.7$^0$C at 12:00 noon with a minimum of 56.2$^0$C at 11:00 a.m. with the ambient temperature of 38.8 $^0$C and 36.2 $^0$C respectively.

This difference in air temperatures of surrounding and cabinet solar dryer is responsible for buoyancy effect which causes air flow [1, 3-4, 8-14].

In both the process, temperature increases from morning and attained maximum at noon and then declined. This happened because at morning insolation is lower and at noon it is maximum. From figure2 it can be seen that as surrounding temperature increased then temperature inside the cabinet solar dryer also increases and vice versa.

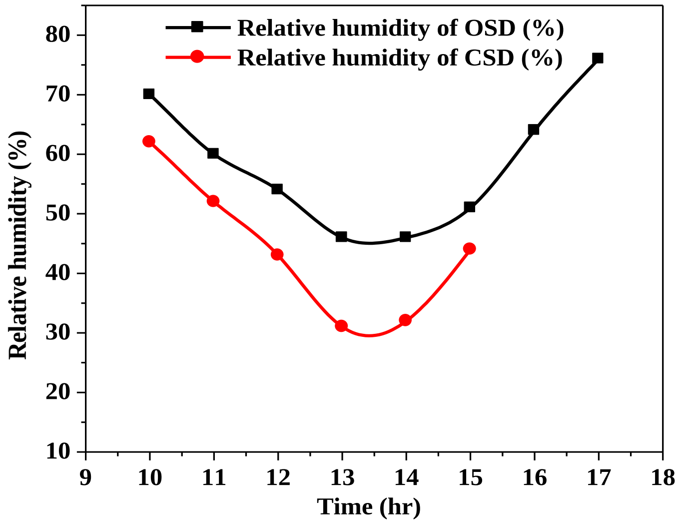


**Figure 3.** Relative humidity of OSD and CSD

The curves in fig. 3 show change in relative humidity during day time in both the processes. The relative humidity decreases with time in CSD and OSD during the first half of the day. This is caused by increasing the temperature in CSD and OSD; hence it increases the water holding capacity of the drying air. For the latter half of the day, relative humidity is increased as temperature in both CSD and OSD is lower. Furthermore, the relative humidity of air inside the dryer is always less than that of ambient air since temperature inside the dryer is more than the surrounding. Thus the time of the day with more potential for solar drying is between 10:00 a.m. and 16:00 p.m. Moreover, the air leaving dryer has lower relative humidity than that of the ambient air, which indicates the exhaust air from drying, still has drying potential.

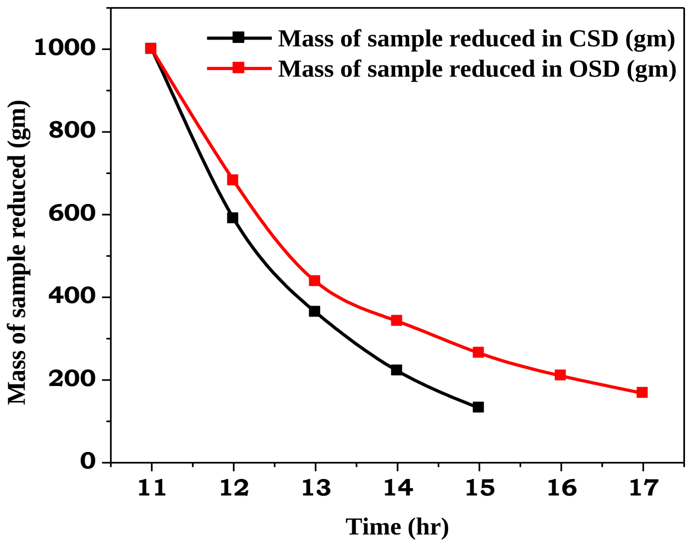


**Figure 4.** Mass of sample reduced in CSD and OSD

The curves in fig. 4 give the variation in mass of the samples with time. The initial mass of the fenugreek leaves (at the time when they were subjected to drying process) was 1000 gm and was found to reduced to 132 gm in CSD in the time span of 240 minutes; whereas the equal loss of mass in OSD was observed in 420 minutes [15, 14]. The reduction of higher moisture takes place during the initial stages of drying in both OSD & CSD was observed due to evaporation of free moisture from the outer surface layers and then gets reduced to internal moisture migration from the inner layers to the surface [16]. The cabinet solar dryer showed a quicker moisture removal than that in open sun.

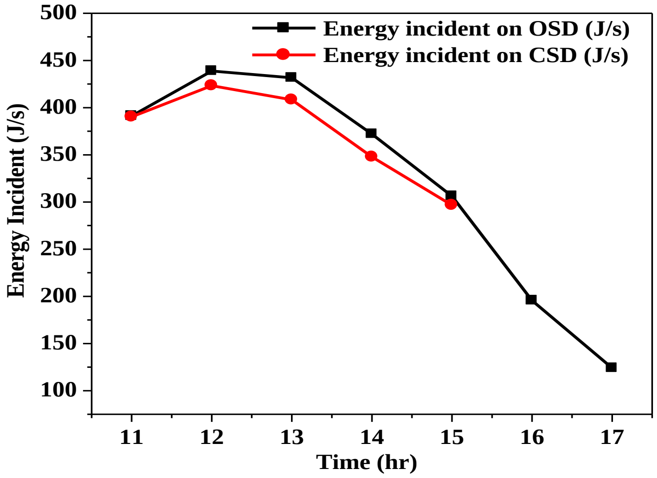


**Figure 5.** Energy incidents in CSD and OSD

The curves in fig. 5 shows energy incident rate in both CSD and OSD. The rate of energy incident in both CSD and OSD increases from morning and attains maximum value at 12:00 noon and then decreases [13]. The maximum amount of energy incident is obtained at 12:00 noon since sun is at overhead position and ultimately insolation is maximum [3]. Furthermore, energy incident rate of CSD was larger as compared to OSD as transparent glass cover inclined at an angle of $20^0$. This high energy incident rate is responsible for higher efficiency and faster drying rate of CSD [3, 12, and 17].

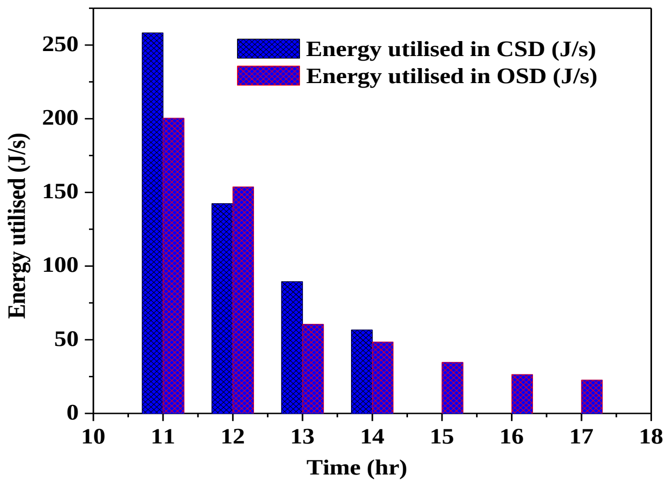


**Figure 6.** Energy utilised in CSD and OSD

The fig. 6 shows the energy utilised during the day time. Except 12:00 noon the energy utilised in CSD is more than the OSD; since at noon there is small wind stream (0.4 $m/s^2$ recorded on anemometer) in the atmosphere. The average heat energy used in CSD sample was 136.71 J/s and that in OSD was 78.12 J/s [12, 18 and 19]. Thus, the amount of heat energy used in CSD was found more compared to OSD [3]. The higher amount of heat energy used in CSD leads to the faster drying rate of CSD and also leads to higher efficiency. The energy used was found maximum at 11.00 a.m. and lower at 14.00 p.m. in CSD while in OSD it was found maximum at 11.00 a.m. and lower at 17.00 p.m

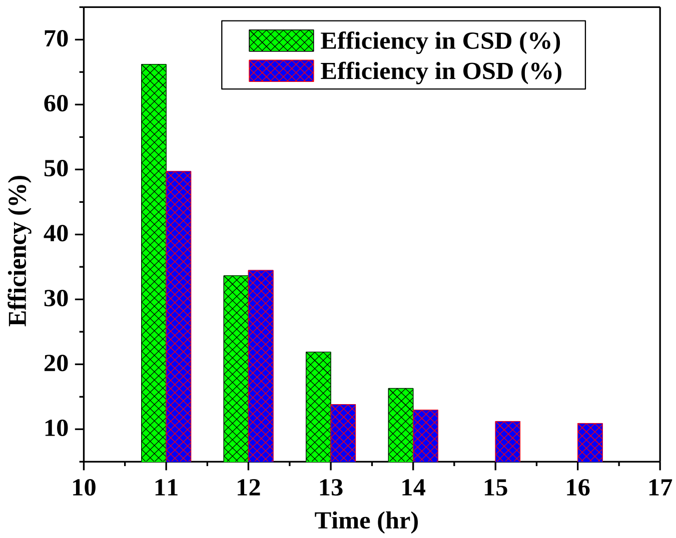


**Figure 7.** Efficiency in CSD and OSD

The efficiency of CSD and OSD during drying period is shown in figure 7. The average efficiency of CSD sample during the drying period is 34.50% and for OSD it is 20.52%. The efficiency of CSD sample was larger compared OSD sample as energy utilization is more in CSD than in OSD as shown in figure 6. Due to higher efficiency of CSD, the drying period of CSD is reduces.

## 5. Conclusions

The observation in the present study implies that the temperature of cabinet solar dryer is higher than that of open sun drying. Cabinet solar drying is faster than open sun drying. The performance of solar drying system was highly dependent on solar radiation and ambient temperature. Moreover energy incident, energy utilization and efficiency of cabinet solar dryer is higher than that in open sun.

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