# Design & Construction of Solar Dryer for Mango Slices

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**Abstract -** Different commodities are dried locally using different methods including natural drying in open area, solar drying. Different solar dryer designs can be found in various parts of India and a suitable design can be selected for the prototype depending on the type of drying contents, climatic conditions, etc. The purpose of this solar dryer was to study, design, fabricate and test a solar cabinet type of dryer for drying mango. Main emphasis was given in designing a simple dryer to be made from locally available materials and different products or materials are dried like cereals, legumes, condiments, fruits, vegetables, meat and fish mostly in open air or under shade. A prototype dryer was designed for 1kg of mango slices to be dried by means of direct solar heat in conjunction with an auxiliary heater.

***Key Words:*** **Design & construction of solar dryer.**

## 1. INTRODUCTION

Drying has been used to preserve food throughout the world since prehistoric times. When people learned that dried foods left out in the sun remain wholesome for long periods. The dried foods industry has greatly expanded after World War II but remained restricted to dried foods, including milk, soup, eggs fruits, yeast some meats and instant coffee etc. several mechanical drying units were built on experimental basis and a few commercial units were in operation primarily for dehydration of fruits, vegetables, and hay and seed corn. Much of the research in agriculture product up to 1955 was concerned mainly with field result. Since 1955 considerable research has dealt with theory and principles of drying in the design of farm level of commercial drivers. Drying in one of the oldest users of solar energy. The practice has been cheaply and successfully employed all over the world for thousands of years. The basic philosophy of drying foods is to remove water for prevention of microorganisms to grow and limit food enzymatic activity. It reduces an item to roughly 50% of its original volume and 20% of its original weight through gradual elimination of water. Three basic methods of drying are used today (i) sun drying, a traditional method in which foods dry naturally in the sun, (ii) hot air drying in which foods are exposed to a blast of hot air and (iii) freeze drying in which frozen foods are placed in a vacuum chamber to draw out the water. Removing the water preserves foods because microorganisms need water to grow and food enzymes cannot work without a watery environment.

### 1.1 Solar Drying Methods.

Recent work on solar drying has been devoted in two directions. There has been work on direct drying where in the material is exposed to direct solar heat and the product moisture is evaporated to the atmosphere to the other method of drying is indirectly accomplished by the use of some type of collector, which furnishes hot air to a separate drying unit . Since solar heat is not a constant source of heat due to weather conditions. Systems that are more effective are possible in some cases if a supplemental oil/gas or electric heater is used when the weather is cloudy.

Another method is to use trays stacked one above the other with their base of wire mesh. This process increases the drying rate and reduces the space needed for the crop spreading. Direct drying use dryers that consist of an enclosure with a transparent cover. The crops are placed on trays in the enclosure and elevated temperatures cause evaporation of water from crops. The moisture laden air through dryer. The design of direct dryers is such that the croup is directly beneath the transparent top cover that is sloped at the appropriate angle to collect maximum solar radiation. The recommended value of this angle is

$\alpha$ = latitude + 15°.

Indirect dryers however, use heated air in a solar air collector to dry out commodities without direct contact of solar energy with commodities. The heated air could be circulated using a fan or just natural convection.

**1.2 Objectives.**

To designed a natural convection solar dryer to dry mango slices. Solar dryer to be constructed to dry 1 kg of mango slices. Initial moisture content of mangoes is 85% & final moisture content desired is 6%.

**1.3. Material Thickness & Drying.**

The experimental solar drying of taro roots in slice and shredded forms indicated that the direct absorption dryer with plastic mirrors as reflectors and two mixed mode solar dryers were reasonably efficient in drying taro into stable forms of storage. With taro slices at loading density at 7.3 Kg/m$^3$ , the direct dryer with reflector was very efficient , the mixed mode dryer and the direct cage dryer were equally efficient, but slightly less than the direct dryer with reflectors, the indirect mode of solar drying was least efficient.

While preparing the taro roots into shredded from resulted in larger surface-to-volume ratio and could be useful for making flour after the shred were not necessarily effective for solar drying because the pieces tended to clump together thereby impending air passage through the shreds.

The quality of dried product was found was found acceptable to consumers and nutritionally satisfactory. The storage of dried product for 32 weeks at room temperature showed no adverse effect on the quality or change in chemical composition. The dried product had a moisture content of 10-13%

Drying experiments over two years showed that if the drying rate due to high air velocity, was too great the product tended to dry mainly from the surface layers and after being removed from the dryer, the surface become monist again.

Be at al conducted experiments on drying of onions in an indirect solar dryer using forced convection. Properties tested include taste cooler and general appearance of the dried onions. The maximum drying temperature was 50 to 55$^o$c. final moisture content of the product was about 5%. The collector and drying chamber were made of A-5 aluminum. The collecting surface was 2.32 x 1m with a cover glass thickness of 3 mm and insulation (6 cm of glass wool) on the sides and bottom of the collector. The drying chamber of three trays 15 cm apart each. The trays were made from 1 x 1 cm wire mesh to allow easy flow of air.

Measurements were taken every six minutes on temperature of air entering and leaving the collector. The glass plates the collector plate and the air entering and drying chamber and the global radiation with the use of a Hewlett data acquisition system.

**2. DESIGN & CONSTRUCTION OF SOLAR DRYER FOR MANGO SLICE.**

The area has Geographical & climatic condition is Suitable for solar dryer as like as the area Situated at 20 latitude (center) The average ambient conditions are 30°C air temperature 25 % Rh in month of summer with daily global solar radiation incident on a horizontal surface of about 20 MJ/m$^2$ per day.

**2.1. Design of Features of Dryer.**

The solar dryers has the shape of a home cabinet with tilted transparent top. The angle of the slope of the dryer cover is 37 °c for the latitude location it provided with air inlet and outlet holes at the front and back respectively. The outlet vent is higher level. The vents have sliding covers which control air and outflow. The movement of air through the vents, when the dryer is placed in the path of air flow, brings about a thermosiphon effect which creates an updraft of solar heated air laden with moisture out of the drying chamber.

**2.2. Solar Dryer Design Consideration.**

A solar dryer was designed based on the procedure described by temperature (1998) for drying dates ( a cabinet type) and procedure described by Bosnia Abe (2001) for drying rough rice (natural convection a mixed-mode type).The size of the dryer was determined based on preliminary investigation which was found to be 2.6 kg / m $^2$ (try loading ). The sample thickness is 3 mm as recommended by Bret et al. (1996) for solar drying of mango slices. The following points were considered in the design of the natural convection solar dryer system:

1. The amount of moisture to be removed from a given quality of wet mango/ orange.
2. Harvesting period during which the drying is needed.
3. The daily sunshine hours for the selection of the total drying time.

4. The quality of air needed for drying.
5. Daily solar radiation to determine energy received by the dryer per day. Wind speed for the calculation of air vent dimensions.

## 3. DESIGN PROCEDURE.

The size of the dryer was determined as a function of the drying area needed per kilogram of pulp of fruits. The drying temperature was established as a function of the maximum limit of temperature the fruits might support. From the climatic data the mean average day temperature in summer is 30 ° C and RH is 25% . From the psychrometric chart the humidity ratio is 0.0018kg $H_2O$/kg dry air. From the result of preliminary experiments on the croup, the optimal drying temperature was 74 ° C and final moisture content of the mango for storage is 6% w.b.

### 3.1. Construction of Prototype Dryer.

A natural convection solar dryer of a box – type cabinet is designed and constructed. The constructed dryer (cabinet – type) consisted of drying chamber and solar collector combined in one unit as shown in figure.

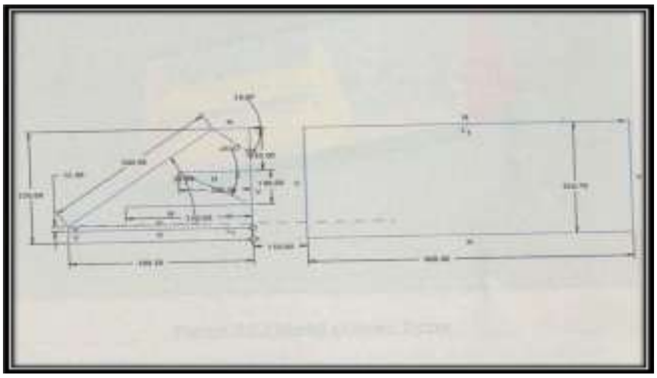

**Fig -1:** 2D Layout of Solar Dryer.

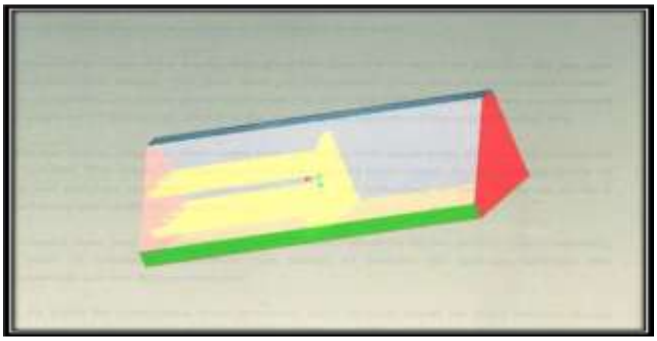

**Fig-2:** Model of Solar Dryer.

A simple box frame 90cm long, 51 cm wide and 34cm high at the back and 10 cm high in front made of mild steel plates (16 gauge ) 1.6mm was fabricated. Sheets of mild metal sheet 0.16cm thick were welded onto three sides and bottom of the fabricated frame. Glass wood was used as insulator with a thickness of 1 cm and placed the bottom mild metal sheet.

Try holders made of angle iron were welded in such a way to hold try inside drying chamber. The lower holder was 15cm above the absorber glass wool and the upper was 15. Asbestos sheet of 0.3 cm thick were used as insulator and fitted to the three inner sides of the frame. Aluminum foil sheets were glued to asbestos sheet and used as a moisture barrier and to reflect incident solar radiation to absorber from sides.

One panel of a 5-mm thick transparent glass (84.5 cm x 44.5 cm ) was glued to the top part of the frame with sealant. The glass used is toughened glass, low in iron content (water white glass) because of its good transitivity for solar radiation. The glass was inclined at an angle of 37° due south, which is the angle of the experimental site.

In side the drying chamber there were four movable wire mesh trays that can be placed on their hiders. The frame of each try was constructed from wood. Each tray was made of wood and stainless steel wire mesh. For loading and unloading of material to be dried, a hinged door was made for this purpose.

The hinged door was constructed from M.S. metal sheet (0.16 cm thick), 0.3 cm asbestos was used as insulator. The door was sealed to prevent air leakage between the surrounding and drying chamber.

Two air vents for ventilation were provided. Intel air hole (front air vent) located above the base of absorber plate; 60cm length and 6 cm width, provided with adjustable cover that was two levels of operating; full and half opening for dryer temperature control.

The outlet vent (rear air vent); 60 cm x 6 cm was locked top edge and provided with adjustable cover for dryer temperature control. It has two levels of opening; full and half opening.

**3.2. Design Calculations.**

To carry out design calculations and size of the dryer, the design condition or assumption are applicable as Follows: It can dry the 1 Kg Mango a single time. The Initial Moisture content at Harvest i.e. $M_i$ is 85% w.b. & the Final Moisture content at storage i.e. $M_f$ is 0.6% w.b. The Ambient Air temperature ($T_{am}$ ) & Ambient relative humidity ($Rh_{am}$) is 30 $^o$/c & 20% respectively; Specifically this solar dryer is designed for Mango fruit with the thickness 3 mm of slice of mango. It takes 10 hour time to done this process with maximum allowable temperature 74 $^o$/c .

**1). The amount of moisture to be removed from the product**

$m_w$ was calculated using the following equation:

$m_w=m_p(M_i-M_f)/(100-M_f)$ --------------------- (1)

Where :

-$m_p$ is initial mass of product to be dried, kg ;

-$M_i$ is the initial moisture content, % wet basis,

-$M_f$ is the final moisture content, % wet basis.

$m_w$ = 1(0.85-0.06)/(100-0.06)

=0.79 kg of water /kg of mango.

**2). Final Or Equilibrium Relative Humidity;**

Final relative humidity or equilibrium relative humidity was calculated using sorption isotherms equation for mango given by Hernandez et al (2000) as follows:

$a_w$ =1-exp[-exp(0.914+0.5639lnM)] -----------------(2)

where

$a_w$ =water activity, decimal

M =moisture content dry basis, kg water/kg dry solids

=0.85 kg water/kg dry mangoes

$a_w$ =ERH/100 ------------------------------------------- (3)

0.89729=2.610 x RH/100

Rh = 34.37

**3). Quality of heat needed to evaporate the $H_2O$;**

The quantity of heat required to evaporate the H2O would be:

Q =mw x h f g ------------------------------------------ (4)

**=** 079 x 23255.74= 18372.0346 KJ

Where : Q = the amount of energy required for the drying process, k J

$m_w$ =mass water , kg

$h_{fg}$ =latent heat of evaporation, kJ/kg $H_2O$

The amount needed is a function of temperature and moisture content of the croup. The latent heat of vaporization was calculated using equation given by Youcef- Ali et al. (2001)as follows:

$h_{fg}$=4.186 x (597 – 0.56($T_{pr}$)) ------------------ (5)

=4.186 x (597 – 0.56(74))= 232555.74 kJ/kg.

Where: $T_{pr}$= product temperature, °C=74 °C

Moreover, the total heat energy, E (kg) required to evaporate water was calculated as follows:

E = m' ($h_f$-$h_i$)t --------------------------------------------- (6) **=**6.475(78.18-29.764) x 10=3.1349 MJ

Where:

e =total heat energy, kj

m =mass flow rate of air, kg/hr.

$h_f$ and $h_i$ = final and enthalpy of drying and ambient air respectively, kJ/kg dry air.

$t_d$= drying time, hrs= 10 hrs.

The enthalpy (h) of moist air in J/kg dry air temperature T(°C)can be approximated as (Brooker at 1992);

H = 1006.9T + w [2512131.0 + 1552.4T] ………………… (7)

$h_i$ =1006.9 x 25 + 0.0018[2512131.0 + 1552.4 x 25]

=29.729kJ/kg dry air.

$h_f$ =1006.9 x 55 + 0.0014[2512131.0 + 1552.4 x 55]

=88.13 kJ/kg dry air.

**4). Average drying rate**

Average drying rate, $M_{dr}$, was determined from the mass of moisture to be removed by solar heat and drying time by the following equation:

$M_{dr}$ =mw/td ------------------------------------------------(8) =79/10=0.79 kg of water/hr.

The mass of AIR needed for drying was calculated using equation given by sodha et al. (1987) as follows:

$M_a$ = $M_{dr}$ / [ $W_f$–$W_i$ ] -------------------------------------------(9) = 0.079 / ( 0.014 – 0.0018)= 6.475 kg of air / hr.

Where:

$M_{dr}$ = average drying rate, kg/hr

$W_f$ & $W_i$ = find and initial humidity ratio, respectively , kg $H_2O$ / kg dry air

From the total useful heat energy required to evaporate moisture and the net radiation received by the tilted collector, the solar drying system collector area Ac, in $m^2$ can be calculated from the following equation.

Ac =E/Iή ------------------------------------------- (10)

=3.134/20 x 0.35=0.447 $m^2$

Length of collector = 0.9 m

Width of collector =0.5 m

Where :-E is the total useful energy received by the drying air , kj; is the global radiation on a horizontal surface during period, kj /$m^2$ =20 kj /$m^2$ & ή is the collector efficiency , 35 % (sodha et al.,1987)volumetric airflow rate, was obtained by dividing ma by density of air which is 1.2 kg/ $m^3$

**Table-1:** Values of Design Parameters.

| Parameter Used | Value |
|---|---|
| Initial Humidity Ratio, $W_i$ | 0.0018 Kg $H_2O$/Kg dry air |
| Initial Enthalpy, $h_i$ | 29.76 KJ/Kg dry air |
| Equilibrium Relative Humidity, $Rh_f$ | 34.37% |
| Final Enthalpy, $h_f$ | 78.18 KJ/Kg dry air |
| Final Humidity Ratio, $W_f$ | 0.014 kg $H_2O$/Kg dry air |
| Mass of Water To be Evaporated, $m_w$ | 0.79 kg of air/hr |
| Average Drying rate, $M_{dr}$ | 0.079 Kg $H_2O$/hr |
| Air Flow Rate, $M_a$ | 6.475 kg of air/hr |
| Volumetric Air Flow Rate, $V_a$ | 5.396 $m^3$/hr |
| Total Useful Energy, E | 3.1349 MJ |
| Solar Collector | 0.45 $m^2$ |

**3.3. For Forced Calculations.**

DC brushless fan was used of following section;

Size :- 80 x 80 x 25

Voltage :- 12 V

Bearing :- sleeve

Current :- 0.12 mA

RPM :- 2500

Air flow rate :- 32CFM

An electric heater as backup with thermostat controller was used. The specification was as followed:0.5 kw, U-tube finned type.

**4. CONCEPT OF DRYING WITH SUN'S WARMTH.**

Imagine a closed heated space in which a fruit or damp agriculture croup has been stored two things happen;

- The crops warned by the heat from the stove of fire
- Air around the heat source is heated up – whereby it can take up a great deal of moisture – and rising, is continually replaced.

As the crop is warmed up, including the air between the plant fibers , the water it contains quickly evaporates. Pretty soon the air within and surrounding the croup is saturated with water vapour. Fortunately the air moving alongside, warm and unsecured can take up this moisture and transport it away. A small fan will of course help this process, but it is not strictly necessary.

At a certain moment the air in the room has taken up so much moisture from the croup that the windows suddenly mist up (though this will depend on the outside temperature ); the air against the could window has been cooled to below the 'dew point'. In this way the water in the croup is transferred to the window panes, where it can be wiped off, or allowed to fall into a gutter which leads outside the room.

If in this account 'heat source' is replaced by sun, a solar drier has effectively been described. The 'cold window' (which works as a condenser) is sometimes encountered in indirect drying, where the warming of air drying of the croup are separated, if the product has been stacked too high or too together.

Solar drying is a technique particularly suited the warmer parts of the world since:

- There is abundant sunlight.
- The air temperature is high and relatively constant over the whole year.

A high and stable air temperature is actually just as important as the sunshine itself, since it limits loss of generated warmth. It allows a simple solar drier to maintain the temperature of the drying fruit crop the day around 40°C.

**3. CONCLUSIONS**

In such drying, the product is spread thinly over the ground directly exposed to solar radiation. Solar heat vaporized the water in the product and ambient air with allow relative allow relative humidity carry this moisture to the atmosphere. No doubt, the method is cheap but there are problems associated with sun drying which often result in quality of dried commodities. For example, no control over the drying process, possible contamination of the product by dirt, dust storms, rains, rodents, animals, infestation by insects and moulds, and possible contamination from environmental pollution. Improvements could possibly be brought about in the traditional sun drying mats and drying trays placed over the ground.

By using this Special propose design Solar Dryer for mango slice is used in some Humidified Area to control moisture percentage from 85% w.b. up to 0.6% w.b. in limited time with 3mm mango slice thickness.

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