DESIGN AND FABRICATION OF SOLAR DRYER BY NATURAL CONVECTION

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Abstract - *The world population is more than 8 billion and about 20-25 percent people does not have enough food to eat. It has been estimated that world as a whole more than 20-30 percent food grains and 30-50 percent vegetables, fruits etc. are lost before it reaches to the consumers. To overcoming spoiling problems of vegetables, food grains and fruit; various preserving methods are used and renewable sources are best for this purpose by which we can save energy for preservation and keeping the product in their natural flavor by drying it. Drying is a simultaneous heat and mass transfer energy intensive operation, widely used as a food preservation technique. Open air solar drying method is used frequently to dry the agricultural products. But this method has some disadvantages. Therefore to avoid disadvantages it is necessary to use the other solar drying methods. Different solar drying methods are direct solar drying, indirect solar drying, and mixed mode solar drying. The device used for drying process with application of solar energy called the Solar dryer. Solar dryers, also known as dehydrators, have been used throughout the ages to preserve grains, vegetables and fruits by removing moisture. Solar dryers can be made locally of any size and capacity and solar dryers are economical if cash crops are dried.*

***Key Words*:** Drying, Moisture , Higher temperature, Solar Energy, Natural Convection , Improved Efficiency

1.INTRODUCTION

The sun is the primal energy producer of our solar system. In addition, sun provides solar energy which is one of the most available type of alternative energy resource which can be used for overcome energy crises in coming years. Sun drying is still the most common method used to preserve agricultural products like grains and vegetables in most tropical and subtropical countries. Direct exposure to sunlight reduces the quality (color and vitamin content) of some fruits and vegetables Moreover, since sun drying depends on uncontrolled factors; production of uniform and standard products is not expected. Some of the problems associated with open-air sun drying can be solved through the use of a solar dryer which comprises of collector, a drying chamber and sometimes a chimney. Dryers have been developed and used to dry agricultural products in order to improve its life, by which variety of product and large volume reduction of products can be done. Most of these either use an expensive source of energy such as electricity *or a* combination of solar energy and some other form of energy.

2. DESIGN AND CALCULATIONS

2.1 DESIGN CONSIDRATION

- **Temperature -** The minimum temperature for drying food is 30°C and the maximum temperature is 70°C approx. Therefore 45°C and above is considered normal for drying vegetables, fruits, roots and some other crops.
- **Efficiency of solar dryer -** This is defined as the ratio of the useful output of a device to the input of the device.
- **Air gap/vent -** It is suggested that for hot climate passive solar dryers, a gap of minimum of 7cm should be created as air vent (inlet) and air passage. A chimney may be use for outlet for better ventilation or air flow through drier box.
- **Solar collector –** The metal sheet thickness of 0.8 – 1 mm (for example 27 gauge of aluminum) minimum approx. or copper tube of 1-3mm thick of 12 to 16 mm dia. minimum, the outer cover is glass for the collector. The efficiency of flat plate collector is 30% to 50% approximately assumed for further design calculations if used.
- **Dryer Trays –** Wooden frames made with net cloth or metal net painted with black color to reduce heat losses can be used as dryer trays to pass air circulation within the drying chamber. They are to be kept as minimum distance of 10cm to 15 cm between each other.
- **Drying Chamber –** The design of the dryer chamber making use of wooden wall sides and a glass top (tilted) protects the food to be placed on the trays from direct

sunlight. Roof at the top of box having a glass tilted at angle in order to have better drying of product, hence to aid the drying process and to keep the temperature within the drying chamber fairly constant due to the greenhouse effect of glass.

2.2DESIGN CALCULATIONS

- **Mass of water to be evaporated**

$M_e = (m_i-m_f)\ M_p$ ....(1)

100 – mf

Where, m_i= initial water content of product [%] wet basis

m_f= desired final water content of product [%] wet basis

M_e= mass of water to be extracted from the product [kg]

M_p= mass of product to be dried (after preparation) or initial feed mass [kg] (5-10 kg assumed as capacity of drying chamber)

- Moisture content in product which is to be feed in dryer (m_i)

Initial moisture content assumed :- 85%

- Moisture content in product which is to be achieved in the product as output (m_f)
Final moisture content to be achieved :- 15 to 20 %

➢ **Therefore, M_e= 4.1 Kg**

- **Energy required for evaporating water from product**,

$E_p=M_e*L_v$.....................................(2)

where, L_v = latent heat of vaporization of =2260KJ/kg

Therefore , **E_p= 9266 KJ/kg**

- **Energy required evaporating = Energy gain by air x time**

$E_p=E_a*t_s$ ....(3)

- **Energy gain by air from Radiation**,

$E_a=I_c*A_c$*(Efficiency Of collector) ....(4)

Where, I_c= Solar intensity (W/m²)=450 w/m2 (average assumed)

A_c= collector area (m²)

Efficiency of collector assumed=(maximum) 40%,

because as any collector acts like heat transfer exchanger so assumed it is 40% rather than 50% maximum

- Therefore Ac can be known from equation 2, 3 &4,

➢ **Ac= 1.7 m² = 1.497m x 1.1m(approx)**

- **Heat gain by air**,

$E_a=I_c*A_c$*(Efficiency Of collector)$=M_a*C_{pa}*\Delta T$

Where, (C_{pa}) air = 1.006 kJ/kgK

ΔT=45-27= 18 degree Celsius(◦C)=291 Kelvin(K)

So, **M_a= mass flow rate of air=1.04 (Kg/s)** is obtained from above calculations

- **Volume of air required to be circulated**,

Ma = density of air x V_a

Where, V_a= volume rate of air

density of air =1.18Kg/m³

➢ Therefore **V_a=0.88(m³/sec)**

➢ **Volume of solar collector = 1.5m x 1.12m x 0.1m=0.168 m³ (lxbxh)**

- Now, $M_{dr}= M_e/t_s$ =4.1/12=0.341

M_{dr}= 0.341 (kg/hr)

Where, M_{dr} = average drying rate (Kg/hr)

M_e= mass of water to be extracted from the product[kg]

t_s= time required for drying

= 5 to 6 hrs of daytime is required means its takes 1 day of daytime to dry the product as per requirements.

2.3 MATERIALS USED FOR SOLAR DRYER

- **Wood**: - The casing (housing) of the entire system; wood is selected being a good insulator and relatively cheaper than metals. Having low thermal conductivity than other materials, so heat transfer is less.

- **Glass**: - The solar collector cover and the cover for the drying chamber. It permits the solar radiation into the system but resists flow of heat energy out of system. It is having a higher transmissivity than other materials.

- Mild steel or galvanize or aluminum sheet or copper tubes of 1mm approx. thickness painted black for maximum absorption of solar radiation.
- Net cloth (cheese cloth or metal mesh) and wooden frames for constructing the trays are painted black for reducing heat losses.
- Nails and glue as fasteners and adhesives.
- Insect net at air inlet and outlet - to prevent insects from entering into the dryer.
- Hinges and handle for the dryer's door.
- Caster wheels are used for moving the setup easily.
- **Paint**:- Black and any other color for the solar dryer outlook

3. EXPERIMENTAL SETUP WITH SPECIFICATION OF PART

3.1 EXPERIMENTAL SETUP

1) Here we are going to prepare MIXED MODE TYPE of solar drying dryer having application of both direct and indirect solar drying

2) The cabinet is a large wooden or metal box and the product is located in trays or shelves inside a drying cabinet. If the chamber is transparent, the dryer is named as integral-type or direct solar dryer. If the chamber is opaque, the dryer is named as indirect solar dryer. Mixed-mode dryers combine the features of the integral (direct) type and the distributed (indirect) type solar dryers. The combined action of solar radiation incident directly on the product to be dried and hot air provides the necessary heat required for the drying process.

3) The air is warmed during its flow through a low pressure drop solar collector and passes through air ducts into the drying chamber and over drying trays containing the product. The moist air is then discharged through air vents or a chimney. It should be insulated properly to minimize heat losses and made durable (within economically justifiable limits).

4) Following is the 2D design of our mixed mode solar dryer setup is as below,

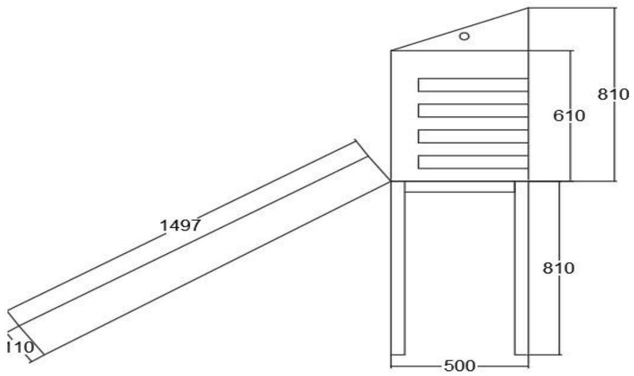


Fig 1:- 2D Design of Experimental Setup

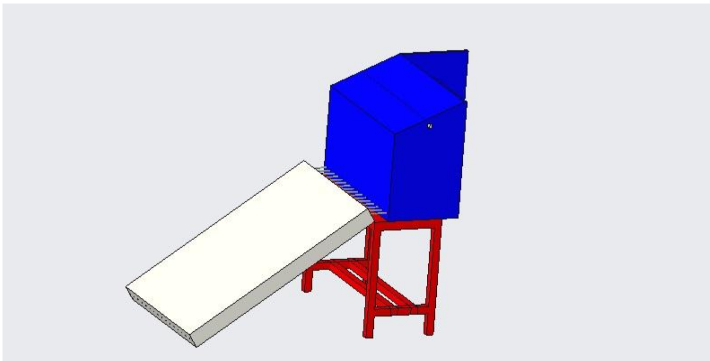


Fig 2 :- Cero 3D design model of Experimental Setup

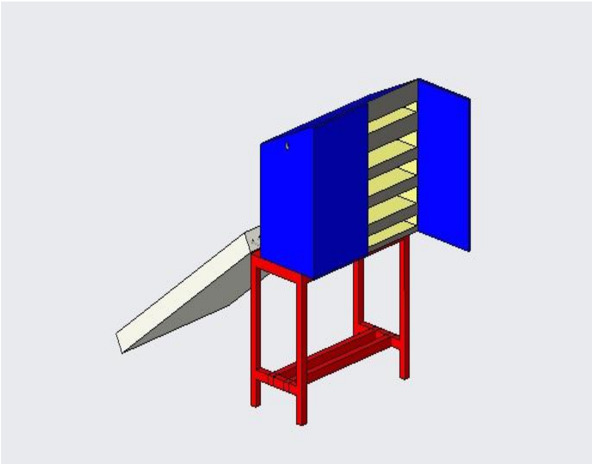


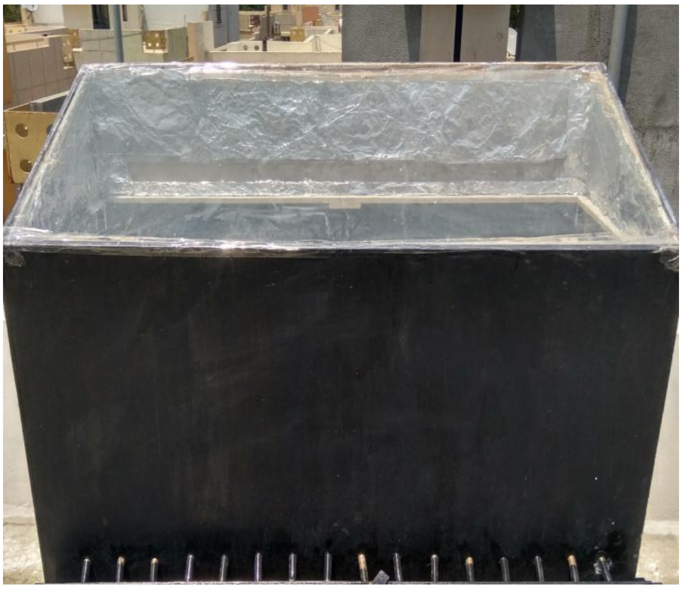
Fig 3:- Cero design model of Experimental Setup

3.2 Different Parts Specification in Experimental Setup

1.) Solar Collector

- Dimensions : 1.497 m x 1.1 m x 0.11m
  Holes at bottom of 6mm dia. and above of 12mm dia.
- Material used : Wood
  Transparent Glass
  Glass Wool as Insulation
  Aluminum Sheet and aluminum foil as Primary and secondary heating sources

2.) Drying Chamber/Cabinet

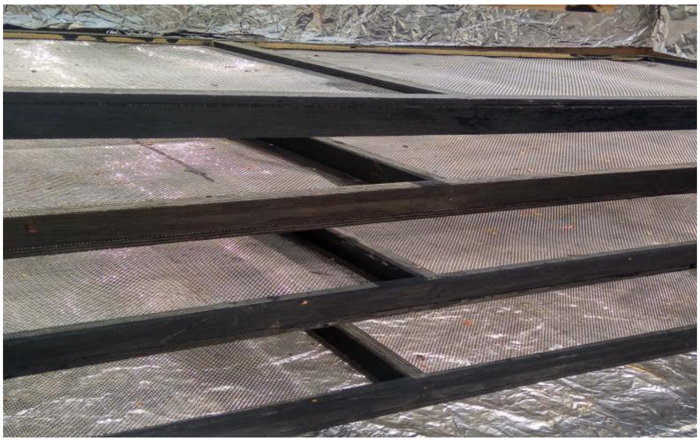


- Dimensions : 0.51m x 1.1 m x 0.81m
  Holes at bottom of 12mm dia
- Material used : Wood
  Transparent Glass
  Glass Wool as Insulation
  Aluminum foil for heat loss reduction

3.) Copper Pipe

- Dimensions : For Holes connecting between drying cabinet of 12mm dia. and collector of 12mm outer dia. having thickness of 2 mm.
- Material used : Copper

4.) Drying Trays (inside drying cabinet)



- Dimensions : 0.41m x 1.09 m x 0.035m
- Material used : Wood
  Steel Cloth

3.3 FINAL MODEL OF SOLAR DRYER BY NATURAL CONVECTION

3. RESULT AND CONCLUSION

1) Results of Drying temperature Achieved after performing Practical

Table of Drying temperature(°C) achieved in the project is mentioned as below :

Table1 : Drying Temperature(°C) achieved for drying various things

Local Time (hrs)	Top trays in drying chamber temperature (°C) achieved	Bottom trays in drying chamber temperature (°C) achieved	Collector temperature (°C)
9	50.2	48	52.3
10	54.9	51.3	57.7
11	59.4	52.7	61.1
12	62.6	54.9	70
13	64	55.3	75.5
14	66.4	56	78.4
15	68.7	59.1	80.8
16	72.6	60.9	82.3
17	62.4	53.7	73.8
18	52.3	49.4	60.4

2) Results of Drying temperature achieved after performing Practical for Forced Convection Drying

Table of Drying temperature (°C) achieved in the project for forced convection drying (i.e. performed practical by using forced circulation of air with the help of fan) is mentioned as below:

Table 2 :Drying Temperature (°C) achieved for drying various things for forced convection drying

Local Time (hrs)	Top trays in drying chamber temperature (°C) achieved	Bottom trays in drying chamber temperature (°C) achieved	Collector temperature (°C)
9	55.7	53.4	57.6
10	58.9	54.9	62.6
11	64	57.3	65.3
12	67.9	59.7	75.4
13	69.5	60.8	80.3
14	72.7	63.4	84.2
15	74.9	65.6	86.4
16	78.6	71.2	89.6
17	76.4	68.9	87.8
18	70.4	62.1	78

3) Results of Drying temperature achieved after performing Practical by using mirror attachment for drying by Natural Convection

Table of Drying temperature (°C) achieved in the project for by using mirror for drying by Natural convection drying is mentioned as below :

Table 3 : Drying Temperature(°C) achieved for drying various things by using mirror for drying by Natural convection dryi3G.

Local Time (hrs)	Top trays in drying chamber temperature (°C) achieved	Bottom trays in drying chamber temperature (°C) achieved	Collector temperature (°C)
9	53.7	51	55.3
10	59.3	55.8	63.3
11	62.7	56.7	66.4
12	66.1	60.5	74.7
13	68.8	62.9	79.7
14	73.3	65.8	81.8
15	74	67.6	84.2
16	77.4	70.5	88.5
17	68.8	66.3	83.8
18	64.2	59.6	78.1

3.1) Comparison of temperatures achieved in the solar dryer by using different methods used for drying

Below figure shows how a typical day results of the hourly variation of the temperatures in the the drying cabinet achieved in the solar dryer by using different methods used for drying.

Here below in graph comparison is shown of drying temperatures (°C) achieved in top trays of drying cabinet by using different temperatures stated as below ,

- Blue color – Natural Convection in mixed mode type solar dryer (Project)
- Green color – Forced Convection (Practical performed with help of fan inducing forced draft)
- Red color – Mirror attachment used for performing the practical having used Natural Convection

Here below in graph points located are as per below table for plotting graph :-

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Table 4: Drying Temperature(°C) achieved for drying various things by using different methods used for drying things

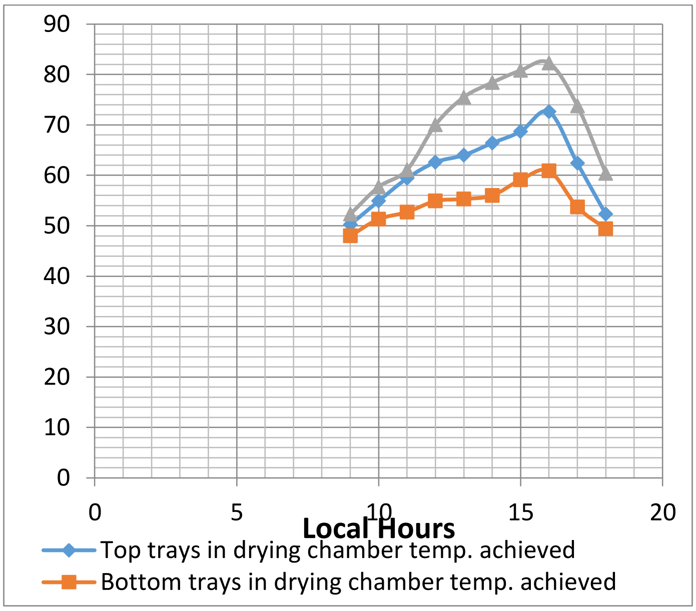
Local Time (hrs)	Natural Convection	Forced Convection	Mirror Attachment
9	50.2	55.7	53.7
10	54.9	58.9	59.3
11	59.4	64	62.7
12	62.6	67.9	66.1
13	64	69.5	68.8
14	66.4	72.7	73.3
15	68.7	74.9	74
16	72.6	78.6	76.4
17	62.4	76.4	68.8
18	52.3	70.4	64.2

By comparing various methods used for drying stated above in which temperature achieved maximum is 78.6°C in forced convection method but in which with the help of electrical energy fan is used for inducing forced draft of air in the dryer which causes a cost extra for using it and even too buying fan for it also causes additional cost of the dryer and it does not reduce that much time taken for drying, though we tried to manage to do with the help of mirror attachment making increase efficiency of the solar collector with the help of laws of refraction which helps in increasing overall drying temperature up to 76.4°Cby making use of mirror attachment of costing around 5000 to 7000 more than the natural convection drying of which our project is made of causes increase in overall cost and moreover it becomes difficult to handle the mirror with attachment as it is fragile thing which tends to break easily with some amount of force.

At the least, we conclude that our model of solar dryer of mixed mode type using natural convection process for drying is more beneficial in overall cost wise and does not requires other external energy which affects overall cost and moreover its does requires more drying time than other two methods stated above but its nominal to be bearable as per time requirement with respect to manufacturing cost by consumer's point of view which at the end is beneficial to both consumer and manufacturer also.

3.2) Variation of the temperatures in the solar collector and the drying cabinet comparatively

Below graph how a typical day results of the hourly variation of the temperatures in the solar collector and the drying cabinet comparatively. The dryer is hottest about mid-day when the sun is usually overhead. The temperatures inside the solar collector were much higher than the ambient temperature and drying chamber's temperature during most hours of the daylight. The temperature rise inside drying cabinet was up to 72.6°C for about a hour (noon). This indicates prospect for better performance than open-air sun drying.



Analytical Graph of Drying Temperature achieved in the practical VS Local time (hrs) taken for drying

3.3) Analyze the Result and Discussion

This project presents the design, construction and performance of a mixed-mode solar dryer for food preservation. In the dryer, the heated air from a separate solar collector is passed through a copper pipe to drying chamber, and at the same time, the drying chamber absorbs solar energy directly through the transparent walls and roof. The results obtained during the test period revealed that the temperatures inside the dryer and solar collector were much higher than the ambient temperature during most hours of the day-light. The temperature rise inside the drying cabinet was up to 72.6 °C for about a hour. The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product

3.4) Conclusion

From the test carried out, the following conclusions were made. The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The product inside the dryer requires less attentions, like attack of the product by rain or pest (both human and animals), compared with those in the open sun drying. Although the dryer was used to dry tomato and chilly mostly here in practical, it can be used to dry other crops like yams, cassava, maize and plantain etc. There is ease in monitoring when compared to the natural sun drying technique. The capital cost involved in the construction of a solar dryer is much lower to that of a mechanical dryer.

Also from the test carried out, the simple and inexpensive mixed-mode solar dryer was designed and constructed using locally sourced materials. The hourly variation of the temperatures inside the cabinet and air-heater are much higher than the ambient temperature during the most hours of the day-light. The temperature rise inside the drying cabinet was up to 72.6^{o}C for about a hour. The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product

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