DESIGN, FABRICATION AND ANALYSIS ON NOVAL SOLAR DRYER

G Venkatraj [1], Varun kumar S [2], RakeshkumarPurad [3],Giridhar M [4], Ningappa D Kunabeva[5]

[1] *Student, Mechanical Engineering, Rajarajeswari College of Engineering, Karnataka, India*
[2] *Student, Mechanical Engineering, Rajarajeswari College of Engineering, Karnataka, India*
[3] *Student, Mechanical Engineering, Rajarajeswari College of Engineering, Karnataka, India*
[4] *Student, Mechanical Engineering, Rajarajeswari College of Engineering, Karnataka, India*
[5] *Assistant Professor, Mechanical Engineering, Rajarajeswari College of Engineering, Karnataka, India*

ABSTRACT

Solar energy is the most promising of the renewable energy sources. An indirect solar dryer, environmentally friendly, low-cost solar dryer was designed to dry various agricultural products. The dryer was built by locally available, biologically degradable and low-cost materials. The dryer consists of solar collector /air heater and a solar drying chamber confining rack of three trays both being integrated together and electrical heater. Banana is the chosen to crop for the experimentation since it's terribly high in production and additionally has substantial loss in India. Also, the dried bananas are having good nutritive value which makes it as essential diet. The experiments were conducted to dry food and to check its drying characteristics like rate of drying and quality of dried in terms of taste, color and shape.

Keyword: - *Solar drying, Design on solar dryer, design calculation, analysis, Moisture content, Temperature*

1. INTRODUCTION

Food drying is a very easy, ancient skill. It's one of the fore-most accessible and therefore the foremost widespread process technology. Sun drying of fruits and vegetables remains practiced mostly unchanged from ancient times. Traditional sun drying takes place by storing the product under direct daylight. Sun drying is just potential in areas wherever, in an average year, the weather permits foods to be dried instantly after harvest.

The quality of sun dried foods can be improved by reducing the scale of items to achieve quicker drying and by drying on raised platforms, covered with color or netting to safeguard against insects and animals. Because of the present trends towards higher price of fossil fuels and certainty relating to future price and availability, use of solar energy in food processing will probably increase and become a lot of economically possible within the close to future

In several parts of the world, awareness is growing about renewable energy that has a very important role to play in extending technology to the farmer in developing countries like India to increase their productivity. Poor infrastructure for storage, processing and selling in several countries of the Asia-Pacific region results to a high proportion of waste, which average between 15 and 40 % [1]. Although Indiais a major producer of agriculture crops, several Indians are unable to get their daily demand of fruits and vegetables and also the human development index (HDI) is extremely low. Considerable quantities of fruits and vegetables produced in India visit waste due to improper post harvest operations and lack of processing [1]. Drying may be a technique of dehydration of food products which means reducing the wetness content from the food to improve its time period by preventing microorganism growth [2]. It is still used in domestic up to small commercial size drying of crops, agricultural product and foodstuff like fruits, vegetables, aromatic herbs, wood etc. contributing thus considerably to the economy of small agricultural communities and farms[3,4,5] . Gain drying Grain drying is process of drying grain to prevent spoilage during storage. Overview Hundreds of millions of tons of wheat, corn, soybean, rice and other grains as barley, oats, etc., are dried in grain dryers [6].

The most extensively investigated solar thermal systems include solar water and air heaters, solar cookers, solar stills and solar dryers [7]. Indian horticulture database 2013 [8] shows that banana is the most important fruit crop in India, accounting for 32.6 % of the whole fruit production. Almost the complete production is used fresh, and hence, the complete production is subjected to the post harvest losses of 17.87 %. Banana is the chosen to crop for the experimentation since its high in production and additionally has substantial loss in India. Also, dried bananas are having smart nutrient worth that makes it as essential diet [9, 10 and 11].

1.1 METHODS OF SOLAR DRYING TECHNOLOGIES

Direct Solar Drying

Direct solar drying is the conventional way of drying the product. In this method the product are directly exposed to the solar radiation and reduce the moisture content to atmospheric air.
It is broadly classified into 2 categories:
(1) The outdoor open air solar drying.
(2) Through a transparent cover which protects partly the foodstuff from rain and other natural phenomena i.e. a passive solar drying technique.
This technique involves the thin layer of product spread over larger area to expose to solar radiation. This process for a long time until the product will dry to a required level. The surface floor made from the concrete or particular space of soil is making applicable for Outdoor direct sun drying. This type of drying method is useful for grains. Material is led on outdoor floor for a long time, usually 10-25 days.

It is easiest method products drying but it has following disadvantage

(1) It depends on climate conditions and requires a large surface and long time of exposure to the sun.
(2) Product may loss quantity wise on attack of birds, animals and rodents.
(3) Product may expose to all kinds of weather changes.
(4) Drying rate is very low for direct solar drying.
(5) The direct exposure to sunlight can greatly reduce the level of nutrients such as vitamins in the dried product.

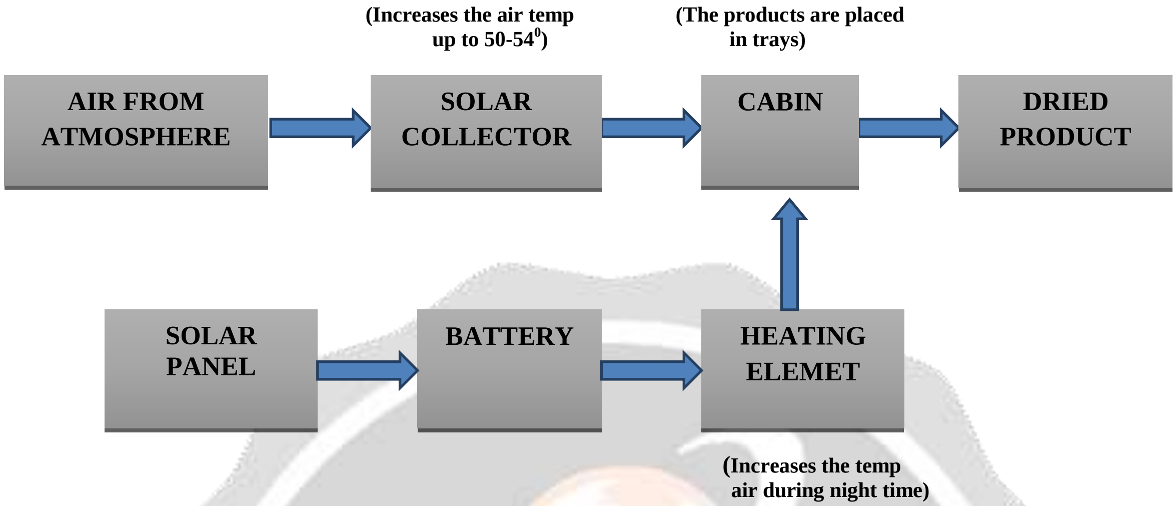
Indirect Solar Drying

Indirect solar drying is the new technique of product drying. It is very efficient method than the direct type of solar drying. In this method the atmospheric air is heated in flat plate collector or concentrated type solar collector. The heating process is either passive or active. This hot air then flow in the cabin where products are stored. Therefore moisture from the product may lost by convection and diffusion. This method of drying is used to avoid direct exposing to the solar radiation.
This method mainly reduces the disadvantages of direct solar drying.

Advantages and Disadvantages of Indirect Solar Drying:

(1) Drying rate in indirect solar drying is high as compare to direct solar drying.
(2) Final condition of products after drying can be controlled scientifically.
(3) Losses in product are avoided on the circumstances of natural phenomena.
(4) Floor surface space required is very low for the same quantity of material in direct solar drying.
(5) Same dryer can be used for different seasonal products.
(6) Main disadvantage of indirect solar drying is the high initial cost.

2. EXPERIMENTAL SETUP



SOLAR DRYER BLOCK DIAGRAM

Drying is that the method of wet removal from the product within the sun drying method, products is heated by radiation for making a better vapor pressure in product. The drying rate of a particular product relies on each air temperature and air rate of flow.

Sun drying of leaves, flower, fruits, vegetables, roots and tubers needs the application of the following principles:

- Drying starts at the bottom of the bin, which is that the initial place air contacts. The dry air flows through a layer of wet grain. Drying happens during a layer of 1 to 2 feet thick, that is named the drying zone
- The usual drying times vary from 1 h to 4 h depending on what quantity water should be removed, variety of grain, air temperature and also the grain depth
- The drying zone moves from the bottom of the bin to the top, and once it reaches the best layer, the grain is dry
- Preparation of the material for food consumption (washing, sorting, peeling ...) to avoid spoilage
- Catching the maximum amount as possible of sun radiation by acceptable absorbers (black plates perpendicular to the sunbeams)
- Increasing the circulation of air around the product
- Avoiding heat loss (insulation of areas not exposed to the sun)
- Facilitating quick drying by increasing the exposed surface of the products (dicing' slicing' spreading-out of products)

3. DESIGN AND FABRICATION

3.1 Design Consideration

1. Temperature - The minimum temperature for drying food is 35°C and therefore the maximum temperature is 60°C, therefore. 45°C and above is considered average and normal for drying fruits, vegetables, roots and tuber crop chips, crop seeds, etc.
2. The design was created for the optimum temperature for the dryer. T0 of 65°C and therefore the air inlet temperature or the ambient temperature of dryer was T1 = 30°C (approximately outdoor temperature).
3. Efficiency - this is defined as the ratio of the useful output of a product to the input of the food product.
4. Air gap - it's suggested that for hot climate passive solar dryers, a gap of 7.5 cm should be created as air vent (inlet) and air passage.
5. Glass and flat plate solar collector – It suggested that the transparent glass covering should be 4-5mm thickness. During this work, 4mm thick transparent glass was used. It additionally prompts that the metal sheet thickness should be of 0.2 – 1.0mm thickness; here aluminum of 0.2mm thickness was used.

6. Dimension – it's recommended that a constant exchange of air and a roomy drying chamber should be attained in solar food dryer design, so the look of the drying chamber was created as spacious as possible of average dimension of 34 × 34× 38cm with air passage (air vent) out of the cabinet of 10 × 10cm2.
7. Dryer Trays – net (metal) was designated as the dryer screen or trays to aid air circulation inside the drying chamber. 2 trays were fabricated from metal net. The tray dimension is 12 × 12cm.

Fig -1 solar dryer

3.2 Design calculations

1. **Solar Collector/Air Heater Angle of Tilt (β).**

The angle of tilt (β) of the air heater should be

$\beta = 10° + \text{lat } \phi$

Were lat ϕ is the latitude of the collector location; the latitude of Bangalore where the dryer was designed is latitude 12.6° N.

Hence, the suitable value of angle of tilt (β) use for the collector:

$\beta = 10° + 12.6° = 22.6°$

2. **Insulation on the Collector Surface Area.**

The value of solar radiation for Bangalore i.e. average daily radiation H on horizontal surface as;

$H = 666.635 W/m^2$

And avg effective ratio of solar energy on tilted surface to that on the horizontal surface R as;

$R = 1.017$

Thus, the insulation on the collector surface was obtained as

$I_c = HT = HR = 666.635 \times 1.017 = 677.96 W/m^2$

3. **Determination of volumetric flow rate and mass flow rate of air**

The mass flow rate of air Ma was determined by taking the average air speed Va = 0.2m/s.

The air gap height was taken as 7.5cm = 0.075m and the width of the collection assumed to be 29cm = 0.29m.

Thus, volumetric flow rate of air

$V'_a = V_a \times 0.075 \times 0.29$

$V'_a = 0.2 \times 0.075 \times 0.29 = 4.3 \times 10^{-3} m^3/s$

Thus mass flow rate of air

$M_a = V'_a \times \rho_a$

Density of air ρa is taken as $1.28 kg/m^3$

$M_a = 4.3 \times 10\text{-}3 \times 1.28 = 5.504 \times 10 kg/s$

4. **The solar collect area (Ac) in m2**

The solar collect area (Ac) was calculated from the following equation as given by

$A_c = (V_a * \rho_a * \Delta T * C_p) / I\,\eta = 0.71 m^2$

Where;
I = Total solar radiation on the horizontal surface during the drying period. The mean value of global radiation of Bangalore is given as 666.635W/m^2
η_c = the collector efficiency, 30 – 55%
Cp = specific heat of air (1005J/Kg.K)
ρa = Density of air (1.28kg/m^3)
Va= volumetric flow rate of air ($4.3 \times 10^{-3} m^3/s$)

5. **Total energy required**

The total energy required for drying a product is given as
$E=Ma\ (H_2-H_1)$
Where; Ma = mass flow rate of air (kg / sec)
H_2 = Enthalpy of warm air (KJ / kg dry air)
H_1 = Enthalpy of ambient air (KJ / kg dry air)
Enthalpy of the air can be calculated using
$H=1006.9T+H_r\,(2512131.0+1552.4T)$
Where; Hr = Humidity ratio, Kg H20 / Kg dry air (from psychometric chart)
T = air temperature, °C

6**. Calculation of Heat Losses from the Solar Collector (Air Heater).**

Total energy transmitted and absorbed is given by
IcAcτα = Qu + Q_L + Qs …………………… (6.1)
where Qs is the energy stored which is negligible,
IcAcτα = Q_u + Q_L ……………………… (6.2)
Thus QL the heat energy losses
Q_L = IcAcτα - Qu …………………………... (6.3)
Since
Q_u = maCp (T0 – Ti) = maCpΔT ……………… (6.4)
and
Q_L= U_LAcΔT …………………………… (6.5)
then
U_LAcΔT = IcAcτα - maCpΔT ………………. (6.6)
U_L = (IcAcτα - mCpΔT)/(AcΔT) …………. (6.7)
α was taken as 0.9 and τ = 0.86
Ta = 0.774
U_L = (592.91×0.71×0.774–5.504×10-3×1005×30)/(0.70×30)
U_L = 9.839W/m^2°C
Therefore,
Q_L = 9.839× 0.57 × 30 = 168.251W
Heat loss includes the heat loss through the insulation from the sides and the cover glass.

7. **Amount of moisture removed**

The amount of moisture removed from a given quantity of wet product to bring the moisture content to a safe storage level in a specified time was calculated using the following equation described by

$$M_n = ((W_w-W_d)/W_w) \times 100$$

Where; M_n = moisture content (%) of material in
W_w= Wet weight of the sample
W_d= weight of the sample after drying

8. **Quantity of heat required to remove the moisture (Ea) in KJ**

The quantity of heat required to evaporate the moisture was calculated as follow;
Quantity of heat required to evaporate the moisture = heat energy to raise the temperature to 60°C + latent heat to remove moisture

$$Ea=M_p*C_t*\Delta T + M_w*L_v$$

Where; C_t= Specific heat capacity of product (3.676KJ/kgK)
ΔT = Change in temperature of the drying chamber 30°C to 60°C
L_v = Latent heat of vapourization of water at s.t.p 2257KJ/kg

9. **Power** = Quantity of heat/ time (sec)

$$Power = E_a/td$$

Where; td= time of drying

10. Determination of the efficiency of the dryer

$$\eta = (W*L)/ IA + P_h$$

Where;

η = efficiency of the dryer

W = weight of water evaporated from the product when drying (kg)

I = solar radiation (W/m^2)

A = area of collector (m^2)

L = latent heat of water (J/kg)

P_h = energy consumption of hater (J)

The drying rate which was the quantity of moisture removed from the product in a given time was computed as described by

Drying rate= quantity of moisture removed / total drying time

3.3 Material used

The following materials were used for the development of the domestic solar dryer:

1. Wood — wood was selected for collector casing, because it is lightweight in weight, easily available and cheaper in price then other material

Fig.2. Wood

2. Glass — we choose the glass for upper covering of the air heater chamber because it's simply allowed the rays to travel inside and heat the sheet and it resists the heat to travel outside.

Fig.3 Glass

3. Net used for constructing the trays for placing the food product within the drying chamber.
4. Electrical heater
5. Battery(12v)
6. Solar panel
7. Paint (black)
8. Aluminum sheet of 1mm thickness use to extend the temperature of air passing through the air chamber painted black with tar for absorption of radiation.

Fig.4 Aluminum sheet

4. RESULTS AND DISCUSSION

Results from experimental tests performed in the dryer with electrical heater showed that the dryer can be used to dry up to 3kg of bananas. The thermal characteristics of the drying air were relatively stable, providing a final product good quality.
Experimental runs for drying of banana slices were performed. Banana slices were exposed to natural sun drying and in the dryer with electrical heater and in dryer without electrical heater were compared.
Results showed that the time required by the samples to reach the desired final moisture content was lower in the natural sun drying when compared with the dryer without electrical heater and with the dryer with electrical heater, to similar outlet air temperatures.

4.1 Variation of the temperatures in the indirect solar dryer with heater and indirect solar dryer without heater compared to the ambient temperature.

The ability of the dryer to maintain the outlet airflow temperature in 50˚C was evaluated in the experimental test performed. The dryer was supposed to maintain this temperature, regardless external ambient conditions. The capacity of the dryer was determined based on the outlet airflow mass. This test was carried out on May 8th, from 08:00 to 18:00. The ambient air temperature and the outlet air temperature of the dryer over time are shown in Fig. 2. From the results in this figure, it is seen that the ambient air temperature varied from 23.8˚C (at the beginning of the test) to 33.5˚C at 14:30. The outlet air temperature varied from 37˚C to 54˚C.

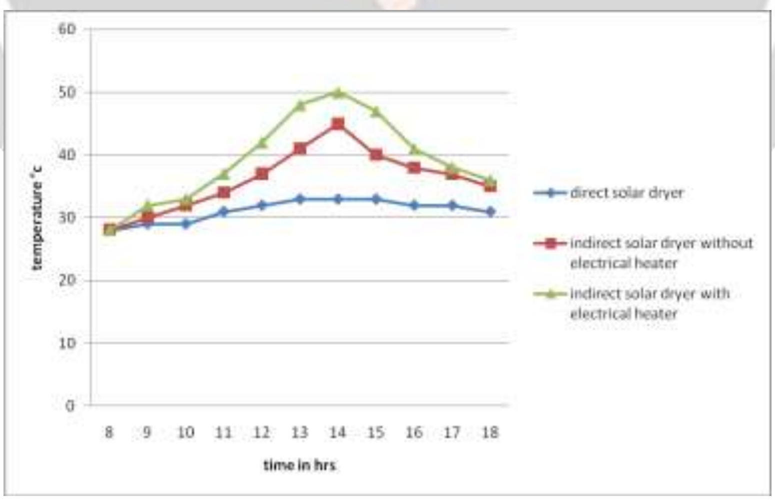


Chart-1 temperature vs time

4.2 Analysis of moisture content of banana.

The moisture content of bananas reached 25% (wet basis) from an initial value of 71% (wet basis). It is seen that the desired final moisture content was reached in 6hr (on MAY 8th) by the bananas inside the dryer with electrical heater, and in 8.5hr (MAY 12th) by the banana inside the dryer without electrical heater and while the bananas exposed to natural sun drying did not achieve this content in a 10hour period. The faster drying of bananas inside the dryer with heater is due to the higher volume flow and temperatures obtained in the dryer which reduced significantly the drying time.

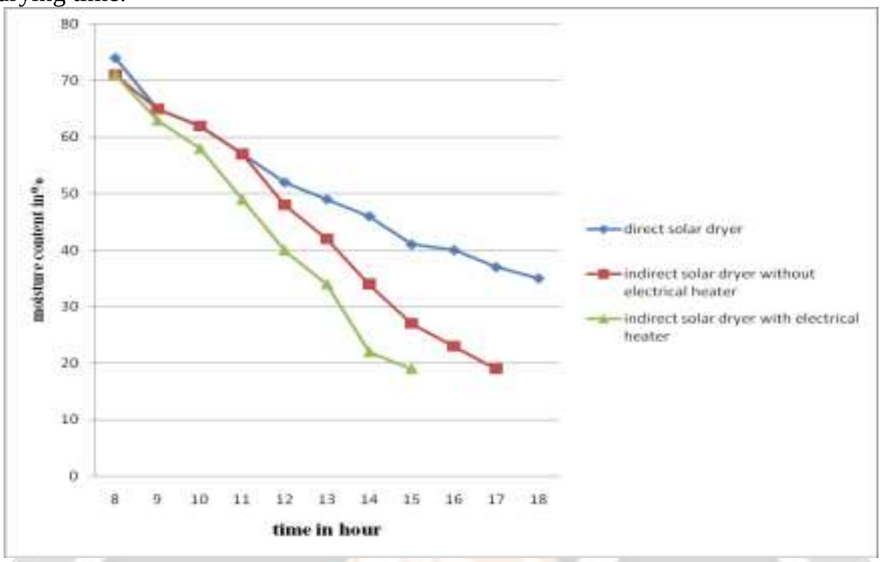


Chart -2 time vs moisture content

Fig Dried slices of banana using solar dryer Without heater

Fig Dried slices of banana using solar dryer with heater

5. CONCLUSIONS

Results from experimental tests performed in the dryer with electrical heater showed that the dryer can be used to dry up to 5kg of bananas. The thermal characteristics of the drying air were relatively stable, providing a final product good quality.

Experimental runs for drying of banana slices were performed. Banana slices were exposed to natural sun drying and in the dryer with electrical heater and in dryer without electrical heater were compared.

Results showed that the time required by the samples to reach the desired final moisture content was lower in the natural sun drying when compared with the dryer without electrical heater and with the dryer with electrical heater, to similar outlet air temperatures

6. ACKNOWLEDGEMENT

We are thankful to the Principal, Rajarajeswari College of Engineering, Head of the Department, and Mechanical Engineering for their support throughout the work. We are thankful to Assistant Professor Ningappa D Kunabeva for sharing with us the technical knowledge and helping us to achieve the results

7. REFERENCES

[1]. Rosa Rolle S. (2006) Postharvest management of fruit and vegetables in the Asia-Pacific region. Asian Productivity Organization, Tokyo, Japan

[2]. Garg H P, Prakash J. (1997) solar energy fundamentals and applications. Tata McGraw Hill, New Delhi, India

[3]. Emad Almuhanna A (2012) Utilization of a solar greenhouse as a solar dryer for drying dates under the climatic conditions of the eastern province of Saudi Arabia. J Agric Sci 4(3):237–246

[4]. Ghaly AE, MacDonald KN (2012) An effective passive solar dryer for thin layer drying of poultry manure. Am J Eng Appl Sci 5(2):136–150

[5]. Manoj M, Manivannan A (2013) Simulation of solar dryer utilizing greenhouse effect for cocoa bean drying. Int J Advanc Eng Technol 4(2):24–27

[6]. Fellows, P. Guidelines For Small-Scale Fruit and Vegetable Processor s, FAO Agricultural Services Bulletin 127, FAO of the United Nations, Rome, 1997.

[7]. Singh S, Kumar S. New approach for thermal testing of solar dryer: development of generalized drying characteristic curve. Solar Energy 2012;86:1981–91.

[8]. Rajendra Kumar Tiwari, Mistry N C, Brajendra Singh, Chander Gandhi P. (2014) Indian Horticulture Database 2013. National Horticulture Board, Ministry of Agriculture, Government of India

[9]. Thilagavathi T (2013) Nutrient content of banana varieties dehydrated by various methods. Int J Innovative Res Stud 2(11):225–231

[10]. Kostaropoulos AE, Saravacos GD (2006) Microwave pre-treatment for sun-dried raisins. J Food Sci 60(2):344–347

[11]. Schirmer P, Janjai S, Esper A, Smitabhindu R, Mühlbauer W (1996) Experimental investigation of the performance of the solar dryer for drying bananas. Renew Energy 7(2):119–129

[12]. Solar Radiation Handbook (2008) Solar Energy Centre. MNRE Indian Metrological Department, New Delhi, India