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A Review Paper on Solar Dryer

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Abstract— In many countries of the world, the use of solar thermal system in the agricultural area to conserve vegetables, fruits, coffee and other corps has shown to be practical, economical and the responsible approach environmentally. Solar heating system is used to dry food and other corps which can improve the quality of product while reducing the waste product. We are going to do an analysis of the parameters that are concerned with cost and efficiency of solar dryer. We are also going to make a design of solar dryer which would be having a critical low cost or have less cost/kg for drying and maximum efficiency by varying some parameters.

Keywords— Solar Dryer; Forced Convection; Indirect type; Temperature; double pass polycarbonate; Velocity; Pressure; Humidity.

I. INTRODUCTION

Solar drying is in practice since the time in memorable for preservation of food and agriculture crops. This was done particularly by open sun drying under open the sky. This process has several disadvantages like spoilage of product due to adverse climatic condition like rain, wind, moist, and dust, loss of material due to birds and animals, deterioration of the material by decomposition, insects and fungus growth. Also the process is highly labor intensive, time consuming and requires large area. With cultural and industrial development artificial mechanical drying came into practice. This process is highly energy intensive and expensive which ultimately increases product cost. Solar energy is one of the most promising renewable energy sources in the world compared to nonrenewable sources for the purpose of drying of agriculture and industrial products.The concept of a dryer powered by solar energy is becoming increasingly feasible because of the gradual reduction in price of solar collectors coupled with the increasing concern about atmospheric pollution caused by conventional fossil fuels used for drying crops. Thus solar drying is the best alternative as a solution of all the drawbacks of natural drying and artificial mechanical drying.

Solar dryers used in agriculture for food and crop drying ,for industrial drying process, dryers can be proved to be most useful device from energy conservation point of view. It not only save energy but also save lot of time, occupying less area, improves quality of the product, make the process more efficient and protects environment also. Solar dryers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus reducing the total amount of fuel energy required.

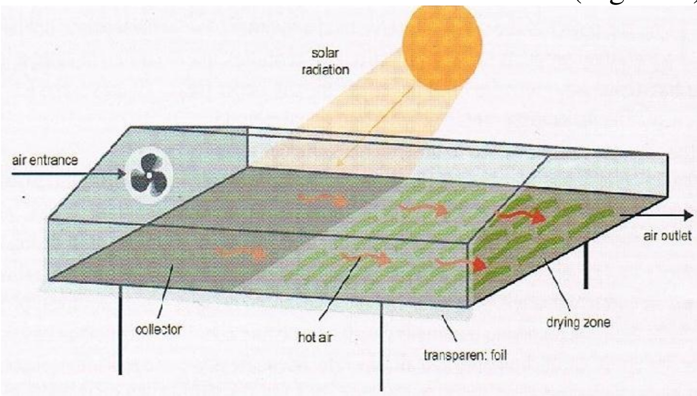
Solar dryer is a device which removes water content from food. In different food water content is different. So requirement of solar Dryer is also different and drying time also different as per moisture content. If moisture content is less then drying time is less and if the moisture content is high then drying time also high.

II. PRINCIPLE OF SOLAR DRYER

The basic principles employed in a solar dryer are:

- Converting light to heat: Any black on the inside of a solar dryer will improve the effectiveness of turning light into heat.

- Trapping heat: Isolating the air inside the dryer from the air outside the dryer makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted heat, a plastic bag or glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days.
- Moving the heat to the food. Both the natural convection dryer and the forced convection dryer use the convection of the heated air to move the heat to the food. (Figure-1)



"Figure 1. Schematic view of solar dryer"

III. TYPES OF SOLAR DRYER

Basically, there are two different types of solar dryer:

1. Direct type.
2. Indirect type.

3.1 Direct type Solar Dryer

In a direct mode solar dryer the crop is directly exposed to solar radiation. For this to occur the structure containing the crop must be covered with a transparent material. The solar radiation passes through the glazing and is absorbed by the crop and its immediate surroundings. Most of the solar radiation is converted into heat, thus raising the temperature of the crop and its surroundings.

The direct absorption of solar radiation by the crop is the most effective way of converting solar radiation into useful heat for drying. The final dried quality of some crop is also enhanced by direct exposure to solar dryer.(Figure 2)

3.2 Indirect type Solar Dryer

In an indirect mode solar dryer, the crop is not directly exposed to the solar radiation. The incident solar radiation is absorbed by the some other surface- usually a solar dryer collector – where it is converted into the heat. The air for drying flows over this absorbed and is heated. The warmed air is then used to transfer to the crop located within an opaque structure. (Figure 3)

High and controllable temperature can be achieved in this type of dryer if a fan is used to move the air through the solar collector. The main disadvantage of an indirect mode solar dryer are

"Figure 2. Schematic view of direct type solar dryer"

"Figure 3. Schematic view of indirect type solar dryer"

the additional cost and complexity involved in construction. Like direct mode dryers, the capacity can range from kilograms to several metric tons.

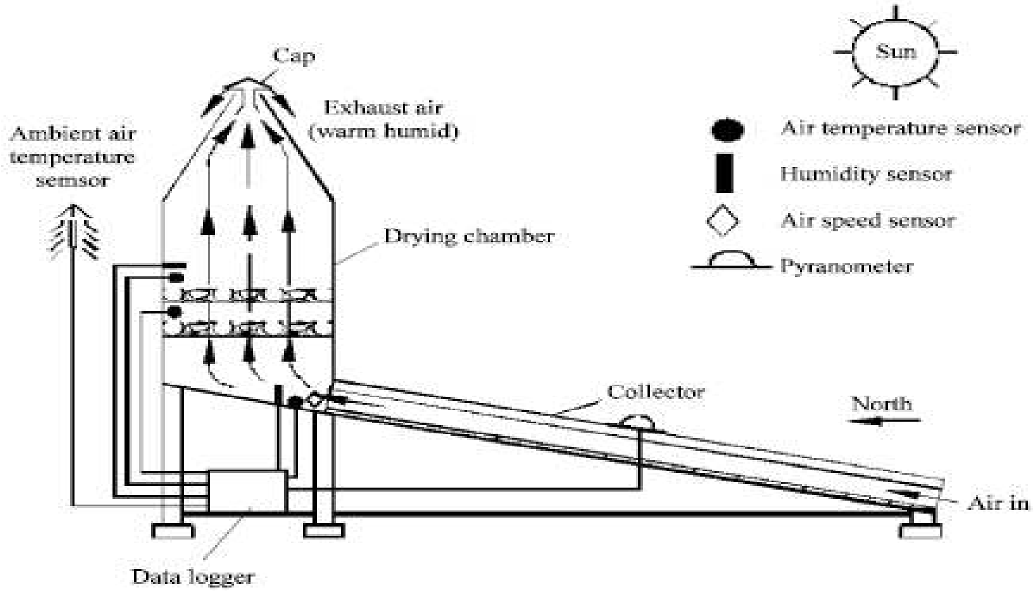
IV. METHODS OF SOLAR DRYING

Basically, there are two different types of solar dryer:

1. Natural Convection solar drying
2. Forced Convection solar drying

4.1 Natural Convection Solar Drying

In this method no fan or blower is used, air flows naturally. It takes more time for drying the food, compare to active type. As the air flow is natural, there is no need of external power supply.It's drying rate is limited. It plays vital role in drying sector because of its low cost. It has became more popular.

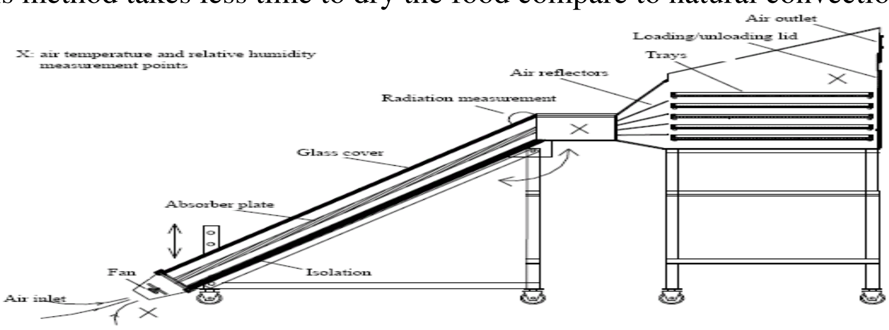


"Figure 4. Natural convection schematic diagram"

However, natural convention has a limited capacity. (Figure 4)

4.2 Forced Convection

Fan or the blowers are the main object that are used in forced convection type solar dryer. This method is not used in many countries as it needs electricityto run the fans..It has many advantages. This kind if solar dryer is more appropriate for drying food in ambient temperature. Power designed a solar forced convention dryer which is fuel efficient and yields products with better quality than those processed through open sun drying.It also takes less solar assisted drying segmentation process that uses most attractive and cost effective materials or commonly used in agricultural and marine sectors.They are highly efficient.Air and water based collectors are used in this system. This method takes less time to dry the food compare to natural convection. (Figure 5)



"Figure 5. Force convection diagram"

V. IMPORTANT PARAMETERS THAT ARE CONCERNED WITH SOLAR DRYER.

Following are the important parameters that are concerned with solar drying system.

1. Temperature
2. Humidity
3. Velocity of air
4. Solar collector area
5. Sunshine hours
6. Pressure drop between inlet and outlet of air flow.
7. Drying Force
8. Constructonal material
9. Sun radiation
10. Air flow rate

5.1 Temperature

Each fruit and vegetable has a critical temperature above which a scorched taste develops. The temperature should be high enough to evaporate moisture from the food, but not high enough to cook the food. During the drying process, at first the air temperature is relatively high, that is, 150 degrees to 160 degrees F. (65 degrees to 70 degrees C.), so that moisture can evaporate quickly from the food. Because food loses heat during rapid evaporation, the air temperature can be high without increasing the temperature of the food. But as soon as surface moisture is lost (the outside begins to feel dry) and the rate of evaporation slows down, the food warms up. The air temperature must then be reduced to about 140 degrees F. (60 degrees C.).Toward the end of the drying process the food can scorch easily.

5.2 Humidity

The higher the temperature and the lower the humidity, the more rapid the rate of dehydration will be. Humid air slows down evaporation. If drying takes place too fast, however, "case hardening" will occur. This means that the cells on the outside of the pieces of food give up moisture faster than the cells on the inside. The surface becomes hard, preventing the escape of moisture from the inside.Moisture in the food escapes by evaporating into the air. Trapped air soon takes on as much moisture as it can hold, and then drying can no longer take place. For this reason, be sure the ventilation around your or in your food dryer is adequate.

5.3 Humidity Velocity of air

Velocity is inversely proportional to the drying time. In the solar dryer velocity is high then drying time is less but, if velocity is high then it will take less time to dry the product. In solar dryer at starting where the fan is provided, velocity of inlet air is high but after covering some distance velocity of air reduces.

5.4 Solar Collector area

Collector area is depends to product quantity. If product quantity is more then, large collector area is needed, but we can design it like maximum area of product comes in contact with air.

5.5 Sunshine hours

Sunshine hours means maximum of daytime duration for a given location. On an average normal day, there are up to 8 to 6 sunshine hours, but it is different in different season. In summer sunshine hour is more than compare to monsoon and winter.

5.6 Pressure drop between inlet and outlet of air flow.

It is defined as the difference in pressure between two points of a fluid carrying network. Pressure drop occurs when frictonal forces, caused by the resistance to flow, act on a fluid as it flows through the tube. In case of solar dryer when air enters in the dryer it is dry and its pressure is high. After covering some distance it becomes wet because of absorbing the moisture from the product, so the pressure of air reduces. High flow of velocities result in a larger pressure drop across a section of object. Low velocity will result in lower or no pressure drop.

5.7 Dryng force

Air is commonly used in drying processes for heat and vapor transport.The heat required to evaporate water from the product may be transferred from heating coils in the dryer to the drying product by continuously circulation air. Evaporated water vapor from the product is removed by replacing some of the circulating air with fresh make up air with a lower specific moisture content..

The drying force is the difference between the vapor pressure in the air and the saturation pressure at the same temperature.

The drying force can be expressed as:

$$DF = P_{ws} - P_w \quad (1)$$

Where,

DF = Drying Force (mbar)

P_w = vapor pressure (mbar)

P_{ws} = saturation vapour pressure at the actual dry bulb temperature (mbar)

5.8 Constructonal material

Constructional material is different in different dryer but selection of material is also important because in direct type solar dryer covering material should have high transmissivityso it can transmit more amount of solar radiation and temperature air in dryer can become high as much as possible .

5.9 Sun radiation

Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy.About half of the radiation is in the visible short-wave part of the electromagnetic spectrum.The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum.

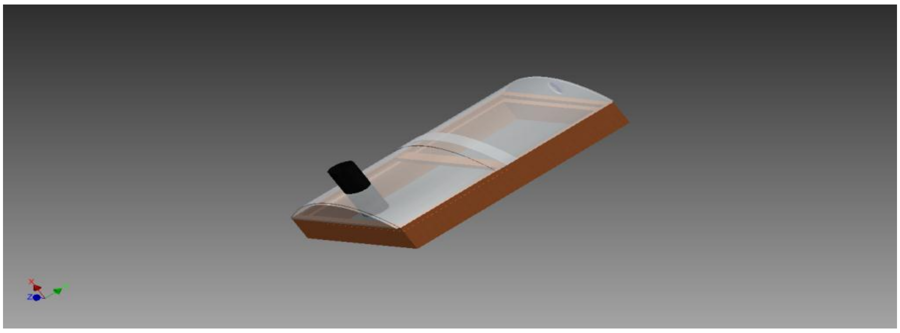
5.10 Air flow rate

The airflow or air flow is a measurement of the amount of air per unit of time that flows through a particular device.The amount of air can be measured by its volume or by its mass. Typically it is measured by volume, but for some applications it is necessary to measure it by mass, as air is a gas and therefore its volume can vary with temperature.

$$Air\ flow\ rate(Q) = Velocity \times Area$$

IV. TUNNEL TYPE SOLAR DRYER

In the force convection type solar tunnel dryer, air is heated inside the dryer due to greenhouse



"Figure 6. Schematic of tunnel type solar dryer"

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effect by natural means. Increased drying process takes place by hot air flow, and the passage of an air mass around a product represents a complex thermal process where unsteady heat and moisture transfers occur simultaneously. Heat and moisture transfer removal rate depends on air velocity and temperature of the circulating drying air. In force convection type dryer, air velocity depends on created draft because of temperature difference.

VII. DESIGN OF TUNNEL TYPE SOLAR DRYER

7.1 Quantity of Water to Be Removed

- Mass of initial water content was calculated using following equation:

$$M = \frac{(m_1 \times x)}{100}$$

- Mass of bone dry product was calculated as follows:

$$M_d = x - M$$

- Initial moisture content (db) was calculated as follows:

$$M_1 = \frac{m_1}{100 - m_1} \times 100$$

- Final moisture content (db) was calculated as follows:

$$M_2 = \frac{m_2}{100 - m_2} \times 100$$

- The mass of water to be removed during drying was calculated using following equation:

$$M_w = \frac{m_1 - m_2}{100} \times x$$

7.2 Total Energy Required for Drying

- Total energy required for drying was calculated using following equation:

$$Q = M_d \times C_d \times (T_2\text{-}T_1) + M \times C_p \times (T_2 - T_!) + M_w \times \lambda$$

- Energy required per hour for drying was calculated using following equation:

$$Q = \frac{Q}{t}$$

7.3 Drying Rate

- Drying rate was calculated as follows:

$$k = \frac{Mw}{t}$$

7.4 Collector Area of Solar Tunnel Dryer Required for Drying

It has been found that about 68 per cent area of hemispherical shaped solar tunnel dryer towards south is able to receive sunlight whereas remaining 32 per cent area toward north is from the sun . It is assumed that the overall thermal efficiency of solar tunnel dryer is 40 per cent. Collector area of solar tunnel dryer required for drying was calculated using the following equation:

$$A_c = \frac{Q_t}{I \times \eta \times 0.68}$$

7.5 Dimensions of Solar Tunnel Dryer

- Area of solar collector equals area of hemicylindrical shape of solar tunnel dryer.

Area of hemicylindrical shape of solar tunnel dryer was calculated as follows:

$$a = \Pi \times r \times (r \times L)$$

- Diameter (d) of solar tunnel dryer 3.75 m is kept as constant for easy entry and other convenience. Radius of solar tunnel dryer was calculated as follows:

$$r = \frac{d}{2}$$

- Length of solar tunnel dryer was calculated as follows:

$$L = \frac{a - \pi r^2}{\pi r}$$

- Floor area (drying area) of solar tunnel dryer was calculated as follows:

$$A = L * d$$

7.6 Design of North Wall

- Total area of transparent cover was calculated as follows:

$$a_1 = \Pi * r * (r + L)$$

- Since 32 percent of collector area toward north has to protect.So, total area of north wall to be protected was calculated as follows:

$$a_P = 0.32\, a_1$$

- Arc width of cover through which energy losses was calculated as follows:

$$W = \frac{a_P}{L}$$

- Perimeter of solar tunnel dryer was calculated as follows:

$$p = \Pi * r$$

- Since perimeter (p) covers diametrical length, $m = d * l$
- Therefore, arc width will cover diametrical length was calculated as follows:

$$d_l = \frac{d * w}{p}$$

- Hence, required height of protector was calculated as follows:

$$h_p = \sqrt{w^2 - {d_l}^2}$$

7.7 Design of Chimney

Since airflow in the dryer takes places due to the draft caused by the density difference between outside cold air and inside hot air, a natural draft uses the basic law that warm air rises. Air as it is warmed expands and becomes lighter in mass. Colder, heavier air pushes in under it and forces it up. This causes a draft. Mass of air needed for removing □□, kg of water was calculated using the following equation:

$$q_a = \frac{(M_w \times \lambda)}{C_a \times (T_3 \quad - T_1)}$$

- Mass of exit air was calculated as follows:

$$q = (M_w + q_a)$$

- Density of inlet air was calculated as follows:

$$\rho_i = \rho_0 \times \frac{T_0}{T_1}$$

- Produced draft in chimney (Height of chimney assumed by 3.75 m) (five numbers of 0.75 m)

$$D_p = H \times g \times (\rho_i - \rho_e)$$

- But actual draft was calculated as follows:

$$D_a = 0.75 \times D_p$$

- Velocity of exit air was calculated as follows:

$$V = \sqrt{\frac{2D_a}{\rho_e}}$$

- Volume of exit air was calculated as follows:

$$V_e = \frac{q}{\rho_e}$$

- Rate of exit air was calculated as follows:

$$Q_a = \frac{Q_a}{n}$$

Thus if assumed this exit air is being carried by n number of chimney.

- Rate of exit air for single chimney was calculated as follows:

$$Q_c = \frac{Q_a}{n}$$

- Area of chimney was calculated using following equation:

$$a_c = \frac{Q_c}{V}$$

- Diameter of chimney was calculated as follows:

$$d_c = \sqrt{\frac{4 \times a_c}{\pi}}$$

VIII. BENEFITS OF TUNNEL TYPE SOLAR DRYER

- Dried foods are tasty, nutritious, the nutritional value and flavor of food is only minimally affected by drying
- Dried foods are high in fiber and carbohydrates and low in fat, making them healthy food choices
- Vitamin A is retained during drying.
- Storage space is minimal, easy-to-store.
- Transportation costs are reduced; dried Products weigh only about 1/6 of the fresh food product.
- The energy input is less than what is needed to freeze or can.
- Easy-to-prepare; solar food drying is a very simple skill.
- Protection of the drying products from contamination by animals or insects.
- Protection of rain.
- Protection of pollution by dust etc.
- Reduction of drying time (reduces changes through spoilage).
- Good product-quality.
- You can have up to 50% more productivity in agriculture.
- Longer storage of dried products (because of more complete drying).

IX. DISADVANTAGES OF TUNNEL TYPE SOLAR DRYER

- Drying can be performed only during sunny days, unless the system is integrated with a conventional energy-based system.
- Due to limitations is solar energy collection, the solar drying process is slow in comparison with dryers that use conventional fuels.
- Normally, solar dryers can be utilized only for drying at 40-50oC.

X. CONCLUSION

A force convection solar tunnel dryer was designed and constructed based on preliminary investigation of industrial product (dibasic vegetables) drying under controlled conditions. The designed dryer with a collector area of 35 m^2 is expected to dry 15 kg green chili from 70% to 75% dry basis in two days under ambient conditions during summer and winter months. A prototype of the solar tunnel dryer was constructed and commissioned at the factory site. The performance of solar tunnel dryer for drying green chili was evaluated through no-load and full-load conditions tests in the summer and winter months. The air temperature inside the solar tunnel dryer was higher than outside by 18–21°C. No constant rate drying period was observed. the moisture reduced continuously with cumulative drying hours.

XI. Nomenclature

wb: Wet basis
db: Dry basis
x: Mass of selected product taken for drying, kg
m_1: Initial moisture content of selected product in % (wb)
m_2: Final moisture content of selected product in % (wb)
T_1: Ambient air temperature (∘C)
T_2: Temperature inside the solar tunnel dryer (∘C)
T_3: Temperature inside the chimney of dryer (∘C)
Cp: Specific heat of water (kJ kg∘−1C−1)
t: Total drying time (h)
C_d: Specific heat of product (kJ kg−1 ∘C−1)
Ca: Specific heat of air (kJ kg−1 ∘C−1)
λ: Latent heat of vaporization of water (kJ kg−1)
ρ_i: Density of inlet air (kg m−3)
ρ_e: Density of exit air (kg m−3)
ρ_o: Density of air at 0∘C (kg m−3)
G: Gravity constant (m s−2)
T_0: Temperature of air at 0∘C (∘K)
M: Mass of initial water content (kg)
M_1: Initial moisture content in % (db)
M_2: Final moisture content in % (db)
M_d: Mass of bone dry product (kg)
M_w: Mass of water to be removed (kg)
Q: Total energy required for drying of selected product (kJ)
Ac: Collector area of solar tunnel dryer required (m2)
η: Overall thermal efficiency of solar tunnel dryer, %
I: Global solar radiation for Udaipur region (kJ h−1 m−2)
a: Area of hemicylindrical shape of solar tunnel dryer (m2)
r: Radius of dryer (m)
L: Length of dryer (m)
A: Drying area of solar tunnel dryer (m2)
Da: Actual draft (kg m−1 s−2)
Dp: Produced draft (kg m−1 s−2)
a_c: Area of chimney (m2)
d_c: Diameter of chimney (m)
Q_c: Rate of air flow in chimney (m3s−1)
Qa: Rate of air required (m3 s−1)
V: Velocity of exit air (m s−1)
q: Mass of exit air (kg)
$a1$: Area of transparent cover (m2)
a_p: Area of north wall to be protected (m2)
w: Arc width of north wall (m)
p: Perimeter of solar tunnel dryer (m)
d_l: Diametrical length of north wall(m)
hp: Height of protector (m)
P_{vt}: Private
Ltd: Limited
kW: Kilowatt
∘C: Degree centigrade
k: Drying rate (kg h−1)

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