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Design and Experimentation of Collector based Solar Dryer with Recirculation for Spices

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Abstract
Sun drying system is very common method of preserving agricultural product. Solar energy is used for heating of air and to dry food substance. In open sun drying food is unprotected from rain, wind-borne dirt and dust, infestation by insects, rodents and other animal. This process is practically attractive and environmentally sound. Shell life of agricultural product is improve by drying. This paper present design and construction of active solar dryer with recirculation technique. It consists of solar collector, drying chamber with netted trays and recirculation arrangement. Air is allowed through inlet and it is heated up in collector. Then it is circulated in drying chamber where it is utilize for drying. The design based on geographical location Wardha and meteorological data were obtained for proper design specification. Locally available materials were used for construction such as polyurethane glass, mild steel metal sheet, plywood sheet and insulating material.
Keywords: Collector, Geographical, Meteorological, polyurethane.

I. Introduction

Drying is a very simple and excellent way of preserving food. Drying was probably first ever food preserving method used by man, even before cooking. It involve the removal of moisture from products so that products can be safely stored for longer period of time. Dried food, vegetables and spices are vital source of food and nutrition in human diet like protein, carbohydrate, high density liquid, vitamins and minerals for good health. Traditional drying which is frequently done on ground in the open air, is the most widespread method use for drying.The crop is damage by uncontrolled drying. There is high risk of spoilage due to adverse climate condition like rain, wind, moist and dust. It totally dependent on good weather and leads to slow drying rate, decomposition, contamination and poor quality of dried product.Solar drying is better alternative solution to all drawbacks of natural drying and artificial mechanical drying.(R. Vidya Sagar Raju, Nov- Dec 2013) The solar drying can be seen as one of the solution to the world food and energy crises. With drying most agricultural produce can be preserved. It takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. In compared to natural sun drying, solar dryer generates higher temperature, lower relative humidity lower product moisture content and reduce spoilage during process due to control drying.

Solar drying is very useful for(Oguntola J. AMAMU, Jan-Jun 2010)

- Agricultural crop drying.
- Food processing industries for dehydration of fruit and vegetable.
- Fish and meat drying.
- Dairy industries for production of milk powder.
- Seasoning of wood and timber.
- Textile industries for drying of textile material.

II. Classification of drying systems

All drying system are primarily classified according to operating temperature range or according to heating source. To classify various type of solar dryer it is necessary to simplify complex construction and various mode of operation to the basic principle. Solar dryer can be classified on the base of following criteria:(Warner Weise)

- Mode of air movement
- Exposure to insulation
- Direction of air flow
- Arrangement of the dryer
- Status of solar contribution

Solar dryer can be classified primarily according to their heating mode and the manner in which solar heat is utilized. In broad term it can be classified in two major group: (Akarslan)

- Active solar energy-drying system
- Passive solar energy-drying system

It can be further classified in to sub classes which varies mainly in design arrangement of system, component and mode of utilization of solar heat. (Ekechukwu and Norton, 1999)

III. Psychometric in Drying

In drying phenomenon psychometric is so important as it refers to properties of air-vapors mixture that controls the rate of drying. When an adequate supply of heat is provided for drying, the temperature and rate at which the liquid vaporization occurs will depend on the vapor concentration in the surrounding atmosphere.

The properties of air around the product plays a major role in removal of moisture. The capacity of air to remove moisture depends upon initial temperature and humidity. Higher temperature and lower humidity of air removes the greater percentage of moisture. Absolute humidity is moisture content of air, mass of water per unite mass of air. Relative humidity is ratio of moisture content of air at specific temperature to moisture content of air if it is saturated at that temperature. The changes in condition of air when it is heated using the solar energy and then passed through a bed of moist product are shown in figure. The heating of air from temperature T_a to T_b is represented by the line AB(Figure 1). During heating the absolute humidity remains constant at ω_a whereas the relative humidity falls from ϕ_a to ϕ_b. As air moves through the material to be dried, it absorbs moisture. Under adiabatic drying, sensible heat in the air is converted to latent heat and the change in the condition of air is represented along a line of constant enthalpy, BC. Both absolute humidity and relative humidity increase from ω_b and ω_c and from ϕ_b to ϕ_c respectively, but air temperature decreases to T_c. The absorption of moisture by the air would be the difference between the absolute humidity at C and B. (ω_c -ω_a). If unheated air is passed through the bed, the drying process would be represented by the line AD. Assuming that the air at D to be at the same relative humidity ϕ_c, as the heated air at C, then the absorbed moisture would be (ω_d - ω_a), considerably less than that absorbed by the heated air (ω_c - ω_a).

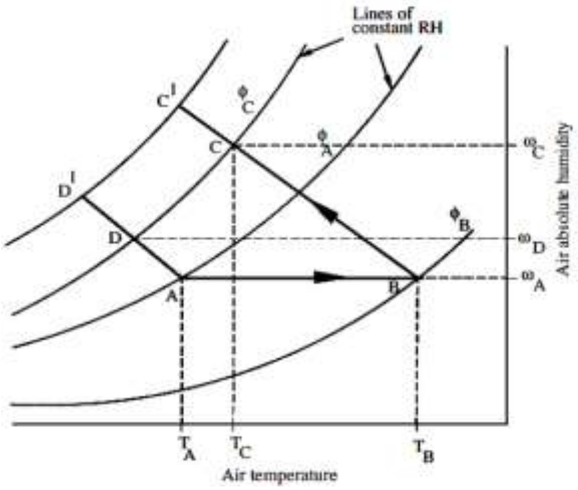


Figure 1: Psychometric chart for water vapour

IV. Design Approach

In the process of drying, heat is necessary to evaporate moisture from the material and a flow of air helps in carrying away the evaporated moisture. There are two basic mechanisms involved in the drying process: the migration of moisture from the interior of an individual material to the surface, and the evaporation of moisture from the surface to the surrounding air.

The drying of a product is a complex heat and mass transfer process which depends on external variables such as temperature, humidity and velocity of the air stream and internal variables which depend on parameters like surface characteristics (rough or smooth surface), chemical composition (sugars, starches, etc.), physical structure(porosity, density, etc.), and size and shape of products. The rate of moisture movement from the product inside to the air outside differs from one product to another and depends very much on whether the material is hygroscopic or non-hygroscopic. Non-hygroscopic materials can be dried to zero moisture level while the hygroscopic materials like most of the food products will always have residual moisture content. This moisture, in hygroscopic material, may be bound moisture which remained in the material due to closed capillaries or due to surface forces and unbound moisture which remained in the material due to the surface tension of water. For dryer we are using close loop system. Air from the atmosphere in pass in the collector box where collector plate is cover with glass. Collector is painted with black colour so that it can absorb more heat. In dryer box number of tray are place. In this dryer air movement in dryer box is maintain with the help of D C fan.Dryer box is provided with ventilation outlet and recirculation pipe. Recirculation is provided to remove that unbounded moisture with recirculation valve. There is provision to remove moisture from air during recirculation.

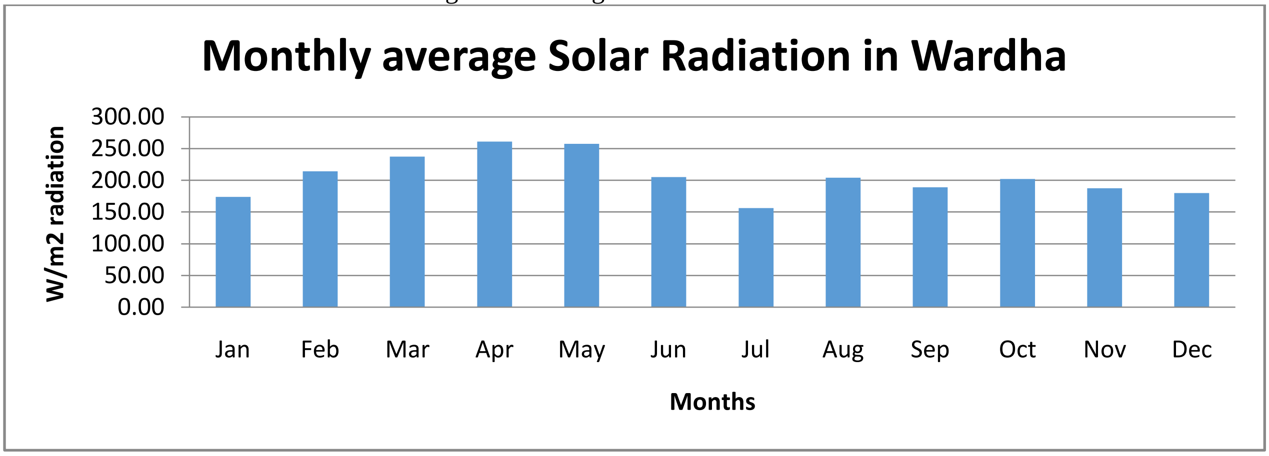
V. Design Consideration

1. Temperature - The minimum temperature for drying food is 30°C and the maximum temperature is 60°C, therefore. 45°C and above is considered average and normal for drying vegetables, fruits, roots and tuber crop chips, crop seeds and some other crops.
2. Design - The design is made for the optimum temperature for the dryer T_0 of 60°C and the air inlet temperature or the ambient temperature T_1= 30°C.
3. Air gap - It is suggested that for hot climate passive solar dryers, a gap of 5 cm should be created as air vent (inlet) and air passage.
4. Glass collector - It is suggested that the glass covering should be 8-12 mm thickness. In this work, 10 mm thick transparent glass is use. Also suggested that the metal sheet thickness should be of 0.8 – 3.0 m thickness; here a Galvanized steel of 1.0mm thickness was used. The glass

used as cover for the collector was $1800 \times 900 mm^2$.

5. Dimension - It is recommended that a constant exchange of air and a roomy dryingchamber should be attained in solar food dryer design, thus the design of the drying chamber was made as spacious as possible of average dimension of 920 × 770 × 460 mm with air passage (air vent) out of the cabinet of 75×50mm2.
6. Dryer Trays - Net metal sheet is selected as the dryer trays to aid air circulation within the drying chamber. Two trays are made with edges. The tray dimension is 670×400 mm of mm with frame.
7. Efficiency - This is defined as the ratio of the useful output of a device to the input of thedevice.

Figure 2: Average Solar Radiation



Source: SRRA Center Wardha.

VI. Design Calculation

1.Angle of Tilt (β) of Solar Collector-It states that the angle of tilt (β) of the solar collector should be,

$\beta = 10° + \text{Lat } \phi$

Here Lat ϕ is the latitude of the collector location, the latitude of Wardha where the dryer is designed is latitude 20.45°N. Hence, the suitable value of β use for

$\beta = 10° + 20.45° = 30.45°$

2. Isolation on the Collector Surface Area - A research obtained the value of insolation for Wardha i.e. average daily radiation H on horizontal surface(

Figure **2**)

$H = 205.7 \text{ W}/m^2$

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

R = 1.0035

Thus, isolation on the collector surface is obtained as,

$I = HR = 205.7 * 1.0035 = 206.07 \text{ W}/m^2$

3. Determination of Collector Area and Dimension - The mass flow rate of air Ma was determined by taking the average air speed Va =0.15m/s.The air gap height was taken as 5cm = 0.05m and the width of the collection assumed to be 81.2cm = 0.812m.Thus, volumetric flow rate of air

V_a = V * inlet area

$V_a = 0.15 * 0.05 * 0.812 = 6.09 * 10^{-3} m^3/s$

Thus mass flow rate,

$M_a = V_a * \delta_a$

M_a = Mass flow rate of air.

δ_a = Density of air, 1.225 kg/m^2.

V_a = Volumetric flow of air.

$M_a = 6.09 * 10^{-3} * 1.225 = 7.46 * 10^{-3}$ Kg/s

Now,

$Q = m_a * c_p * \Delta T$

$= 7.46 * 10^{-3} * 1000 * 30$

Q = 223.8 W.

Hence Efficiency is,

$\eta = Q / I * A_c$

$A_c = \frac{0.00746 * 1000 * 30}{206.07 * 0.50} = 2.17\ m^2$

Thus, the length of the solar collector was taken approximately as 1804mm.

4. Determination of Heat Losses from the Solar Collector - Total energy transmitted and absorbed is given by

Heat Transmitted = Heat Use.

$I_c\ A_c T_c = Q_u + Q_l + Q_s$

Q_s = Energy stored negligible.

$Q_u = m_a c_p\ \Delta T$

$Q_l = U_l A_c\ \ \Delta T$

$Q_l = I_c\ A_c T_c - Q_u$

Hence,

$U_l = \frac{I_c\ A_c\ T_c - m_a c_p \Delta T}{A_c\ \Delta T}$

$U_l = \frac{206.07 * 2.17 * 0.75 - 7.46 * 10^{-3} * 1000 * 30}{2.17 * 30}$

$U_l = 1.87 \text{ W}/m^2$

Total loss = 2.17 * 1.87 = 4.1 W

VII. Conclusion

Solar radiation can be effectively and efficiently utilized for drying of agricultural produce spices in our environment if proper design is carried out. This was demonstrated and the solar dryer designed and constructed exhibited sufficient ability to dry agricultural produce most especially spices items to an appreciably reduced moisture level. Chilly is dried very efficiently with following rise of temperature.

1. Cut Chilly (8 to 12 mm)

- This sample of chilly dried with-in 14 to 18 hour.
- During drying it did not change its colour.
- Its chlorophyll content are maintain with its taste.
- Its weight reduced to 57gm from 330gms.

2. Chilly with vertical cut.

- This sample of chilly dried with-in 16 to 20 hour.
- In this sample 10% chilly changed its colour.
- It becomes red due to carotenite.

3. Chilly (complete)

- It took 20 to 26 hour.
- If it is dried for long time, it become red and yellow due to carotenite and anthosynin.

All samples are provided with 20% - 25% recirculation, If it is more than 30-35% then chilly changes its colour to black. It is also tested for other spices like turmeric, ginger, garlic.

Figure 3: Variation of Temperature with Time

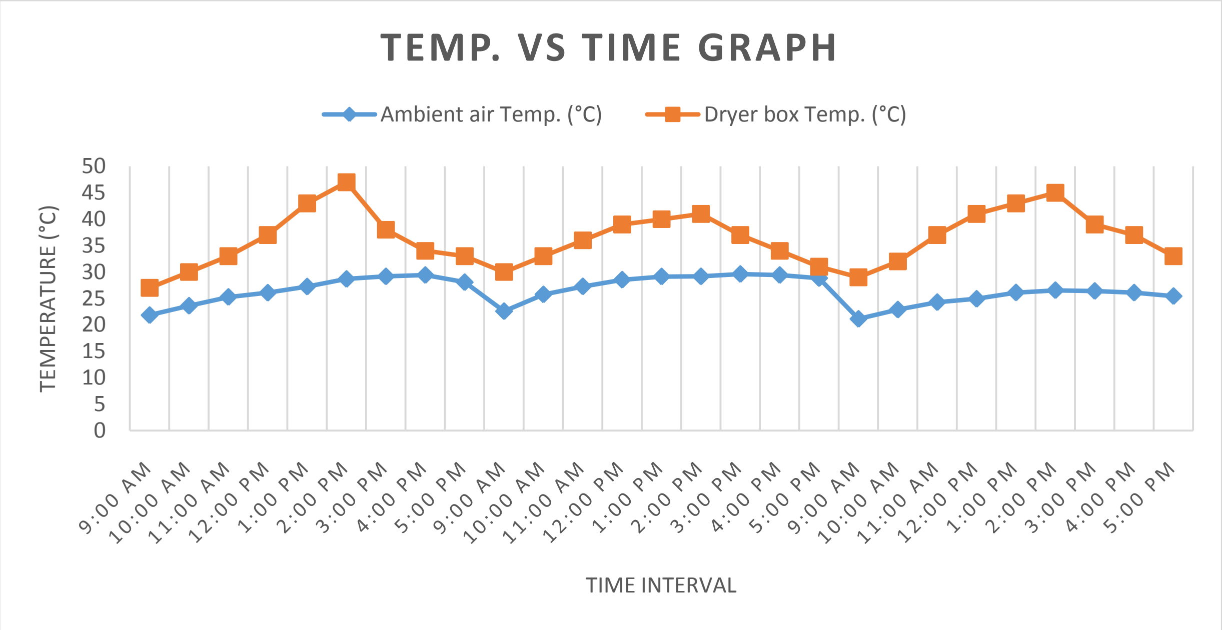
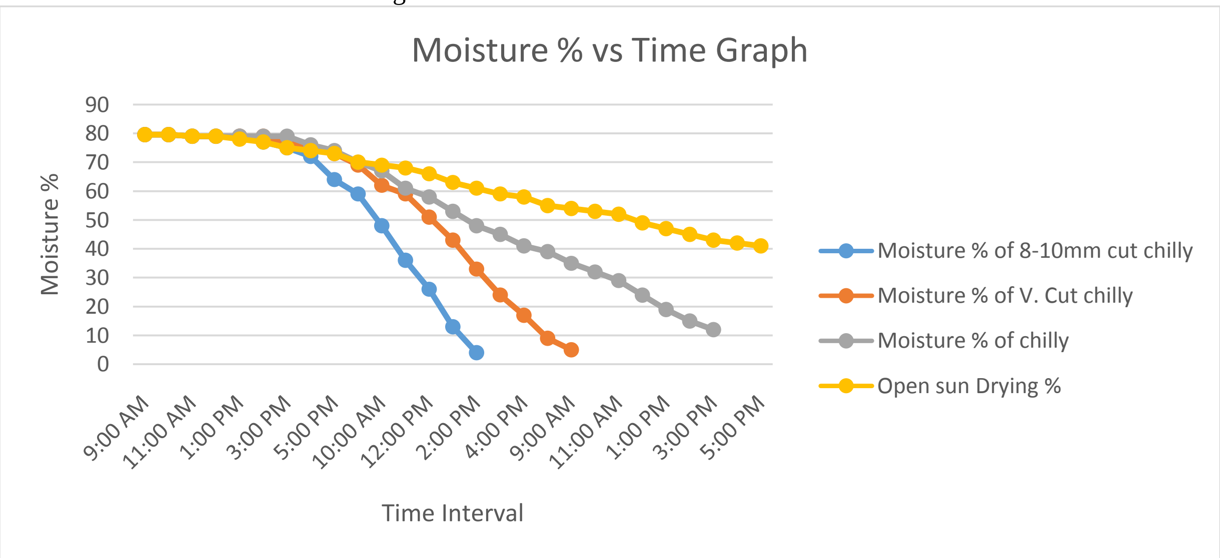


Figure 4: Variation of Moisture with Time



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