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Designing and Construction of Low-Cost Hybrid Photovoltaic-Thermal (PVT) Solar Dryer

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Abstract

A low-cost hybrid Photovoltaic-Thermal (PVT) solar dryer was designed and developed at Poornima University Jaipur to test its performance for crop drying. The hybrid Photovoltaic-Thermal (PVT) solar dryer is a designed for multi-crop solar drying. The dryer reduces the moisture content of green chillies from 90% to 10% in 10 hours with an average efficiency of 27%. The drying rate of hybrid dryer was estimated to be around 30 g/hr. The economic cost of hybrid dryer is around Rs 1200/- which is very much affordable for the poor farmers. The dryer developed can be used to substitute electrical/mechanical dryers in semi urban and rural areas of India for drying various agricultural crops.

Keywords: Drying Efficiency; Drying Rate; Moisture Content; Solar Dryer; Hybrid Dryer

INTRODUCTION

The use of solar energy is continuously progressive because of an efficient and cost-free source on the earth. Globally, solar energy contributes to all the necessary heating and cooling tasks such as; cooking, crop drying, water heating, space heating, timber seasoning, power generation, refrigeration, air conditioning, etc. The qualities of this free fuel from the sun are, pollution free fuel, available in good amount at almost locations on the earth, abandon source of energy, reduced greenhouse gas emissions, recovery of despoiled land, less requirement for transmission lines within the power grid, progress in the quality of water resources, etc. Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. These losses related to contamination by dirt, dust and infestation by insects, rodents and animals. Therefore, the introduction of solar dryers in developing countries can reduce crop losses and improve the quality of the dried product significantly when compared to the traditional methods of drying such as sun or shade drying. The most common method of dehydration is by open air sun drying but this often results in food contamination and nutritional deterioration. Food dehydration technology employs direct and/or indirect mixed mode systems with natural or forced distribution of heated air. A hybrid solar-electrical dryer was built, composed of a solar chamber and of a drying chamber. The walls of the solar collector were built with galvanized steel plates, painted in black, thermally insulated with wool glass and covered with galvanized steel plates painted in gray [1]. A portion of the incident solar radiation passes through the glass cover and reaches the absorber in the solar chamber. Ambient temperature air inlets and is heated by convection, raising its temperature while it flows towards the drying chamber. If necessary, the auxiliary heating system heats the air in the entrance of the drying chamber. The drying air passes through the drying trays, removing humidity from the products, and leaves the dryer trough the elbow shaped chimney. The artificial movement of the air is promoted by an exhauster placed inside the chimney. The first stage happens at the surface of the drying material at constant drying rate and is similar to the vaporization of water into the ambient. The second of the second stage determined by the properties of the material being dried.

The solar chamber is covered with glass. The products can be introduced and removed trough two doors, located on the back of the dryer. A thermostat was installed in the chimney to control the airflow temperature in the device outlet. The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time, normally regarded as the ``safe storage period". Drying is a dual process of, Heat transfer to the product from the heating source and Mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air.

1. CLASSIFICATION OF DRYING SYSTEM: -

All drying systems can be classified primarily according to their operating temperature ranges into two main groups of high temperature dryers and low temperature dryers. However, dryers are more commonly classified broadly according to their heating sources into fossil fuel dryers and solar-energy dryers. Strictly, all practically-realized designs of high temperature dryers are fossil fuel powered, while the low temperature dryers are either fossil fuel or solar-energy based systems.

1.1 High Temperature Dryers: -

High temperature dryers are necessary when very fast drying is desired. They are usually employed when the products require a short exposure to the drying air. Their operating temperatures are such that, if the drying air remains in contact with the product until equilibrium moisture content is reached, serious over drying will occur.

1.2. Low temperature Dryers: -

In low temperature drying systems, the moisture content of the product is usually brought in equilibrium with the drying air by constant ventilation. Thus, they do tolerate intermittent or variable heat input. Low temperature drying enables crops to be dried in bulk and is most suited also for long term storage systems. Thus, they are usually known as bulk or storage dryers.

1.3. Classification of Solar-Energy Drying Systems: -

Solar-energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized. In broad terms, they can be classified into two major groups [2]: -

- Active solar-energy drying systems (most types of which are often termed hybrid solar dryers)
- Passive solar-energy drying systems (conventionally termed natural-circulation solar drying systems).

Three distinct sub-classes of either the active or passive solar drying systems can be identified (which vary mainly in the design arrangement of system components and the mode of utilization of the solar heat) are [4]: -

- Integral-type solar dryers
- Distributed-type solar dryer
- Mixed-mode solar dryers

1.2.1. Integral-Type Solar Dryers: -

In integral-type natural-circulation solar-energy dryers (often termed direct solar dryers), the crop is placed in a drying chamber with transparent walls that allow the insolation necessary for the drying process to be transmitted. Thus, solar radiation impinges directly on the product. The heat extracts the moisture from the crop and concomitantly lowers the relative humidity of the resident air, thereby increasing its moisture carrying capability [8].

It is easiest method product drying but it has following disadvantage:-
(1) It depends on climate conditions and requires a large surface and longtime of exposure to the sun.
(2) Final product condition is on observations of unskilled human being.
(3) Final condition of dried product will never control scientifically.
(4) Product may loss quantity wise on attack of birds, animals and rodents.
(5) Product may expose to all kinds of weather changes.
(6) Drying rate is very low for direct solar drying.
(7) The direct exposure to sunlight can greatly reduce the level of nutrients such as vitamins in the dried product.

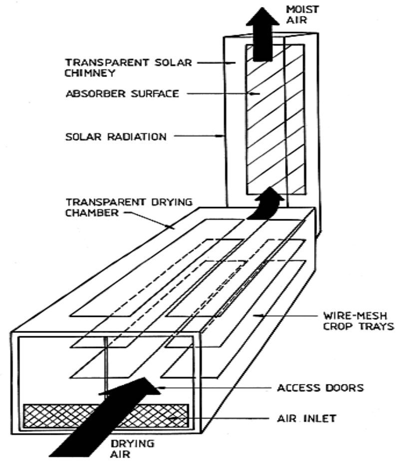

Figure 1:- Integral-Type Solar Dryer

1.2.2. Distributed-Type Solar Dryers:-

These are often termed indirect passive solar dryers. Here, the crop is located in trays or shelves inside an opaque drying chamber and heated by circulating air, warmed during its flow through a low pressure drop thermosyphonic solar collector. Because solar radiation is not incident directly on the crop, caramelization and localised heat damage do not occur. These dryers are also recommended generally for some perishables and fruits for which their vitamin content are reduced considerably by direct exposure to sunlight and for colour retention in some highly pigmented commodities that are also very adversely affected by direct exposure to the sun. Distributed solar dryers have higher operating temperatures than direct dryers or sun drying and can produce higher quality products.

Advantages and Disadvantages of Indirect Solar Drying:

(1) Drying rate is high as compare to direct solar drying.

(2) Final condition of product after drying can be controlled scientifically.

(3) Losses in product are avoided on the circumstances of natural phenomena.

(4) Floor surface area 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) Preserve the nutrient content in product as avoiding direct exposure to solar radiations.

(7) Main disadvantage of indirect solar drying is the high initial cost.

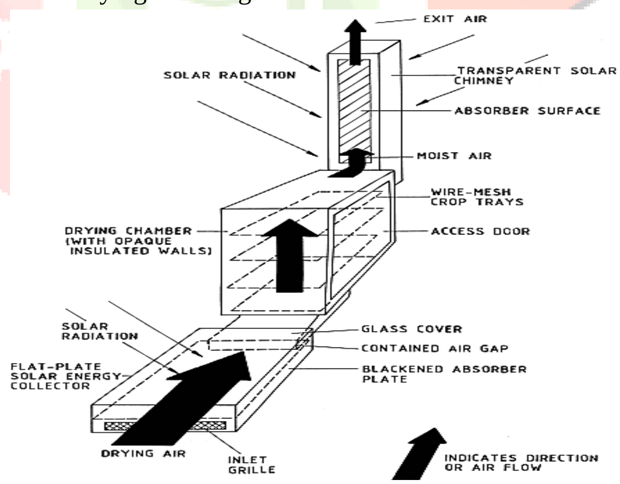

Figure 2:- Distributed-Type Solar Dryer

1.2.3. Mixed-Mode Solar Dryers:-

These dryers combine the features of the integral (direct) type and the distributed (indirect) type natural-circulation solar-energy dryers. Here the combined action of solar radiation incident directly on the product to be dried and pre-heated in a solar air heater furnishes the necessary heat required for the drying process. The unit consists of a solar air heater, a cabinet for the rice bed and a chimney which provides a tall column of warm air to increase buoyancy. The air heater's absorber consists of a thick layer of burnt rice husks covered by a clear plastic sheet on an inclined bamboo framework. The drying chamber is a shallow wooden box with a base made of bamboo mat with a fairly open structure to allow for an easy flow of the drying air [2]. It is covered with a nylon netting to prevent the rice grains from falling through. A clear plastic sheet covering the rice bed allows the direct heating of the rice (by direct absorption of solar radiation) while protecting it against rain [3]. The chimney consists of a bamboo framework clad with dark plastic sheet (which absorbs solar radiation, thus keeping the chimney inside warm).

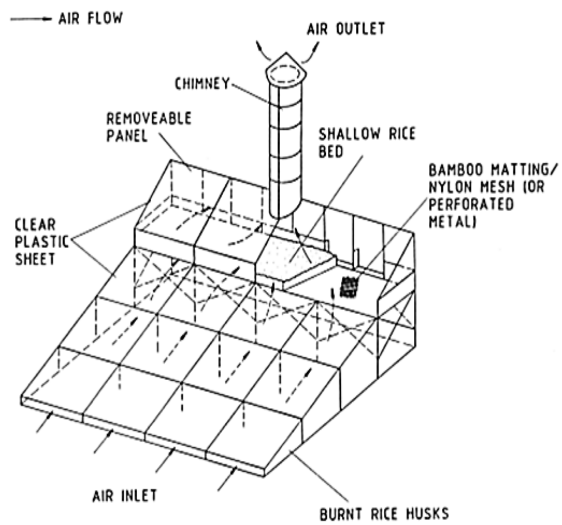

Figure 3:- Mixed-Mode Solar Dryers

2. Working Principles: -

The main principle of this low-cost solar cabinet dryer is based on greenhouse effect where the solar heat is trapped inside the drying chamber and thus increases the temperature level. It is a mixed-mode solar cabinet dryer [6]. Here both direct and the indirect solar energy collected in the chamber heats up the food products. The direct solar energy collected in the chamber converted in to heat energy heats up the food. Design, Construction and Calibration of Low-Cost Solar Cabinet Dryer 353 product and thus removes moisture from the food product [7]. The indirect heat energy collected in the solar collector heats up the fresh air entering from atmosphere through air inlet and is passed through the bottom of the drying chamber and it collects the moisture from the food product and exhausted through air outlet. It is fully based on natural phenomenon. No mechanical and the electrical energy are applied. Here fresh air having atmospheric temperature enters the dryer at the bottom end of the solar collector and leaves at the upper most portion of the drying chamber through exhaust air outlet. The essence of keeping solar energy absorbing portion at an inclination of 21^0 is because, most of the research found that at this angle absorption of solar radiation is maximum.

3. Component: -

3.1. Drying chamber:

Drying chamber is made of dried wooden flank (12mm thick). The chamber is combination of two geometrical parts i.e. one cubical shape and other triangular prism shape at the head portion of the chamber. Inside drying chamber is coated with noncorrosive GI-sheet. It contains an exhaust outlet portion at the top of triangular shape and it is joined with solar collector at the bottom of the drying chamber which allows pre-heated air coming from solar collector to pass through food products. The position of the trays are made in such a way that the gap between each tray is 1/2 or 1/3 to that of the gap between lower most trays and the bottom of the chamber. The essence of making this particular gap is to provide equal drying facility to the entire food product inside the drying chamber and thus increases the rate drying. The upper most part of the drying chamber is covered with transparent glass sheet (6mm thick) or transparent plastic paper in an inclination of 21^{0} from the top of triangular portion making cubical top as its base.

3.2. Drying Trays:

The trays can be made of two different materials i.e. non-corrosive wire mesh (net) made of stainless steel and the bamboo nets. Bamboo net is preferable for low cost solar cabinet dryer. The capacity of the dryer depends on the area of the tray and its strength.

3.3. Solar Collector:

Solar collector is a cubical shape having breadth equal to the breadth of the bottom of the drying chamber. Solar collector is so connected with drying chamber that it does not allow air to enter from any other side except air inlet portion. The solar collector is connected with the chamber in an inclination of 21^0 from bottom of the chamber and to the ground level base [8]. It is designed with an air inlet at the nadir point of the end portion of the solar collector. The bottom portion of the solar collector is fitted with non-corrosive GI sheet and dark black paint is painted on it. Upper portion of the collector is covered with transparent glass sheet or transparent plastic paper.

3.4. Material Used:

Locally available wooden flank, Transparent glass or Transparent thin plastic sheet, Stainless steel net or bamboo net, GI-sheet (tin for black body and steel for chamber), Temperature sensor, Black paint, non-corrosive alpines, Adhesive glue and taps, Door clips.

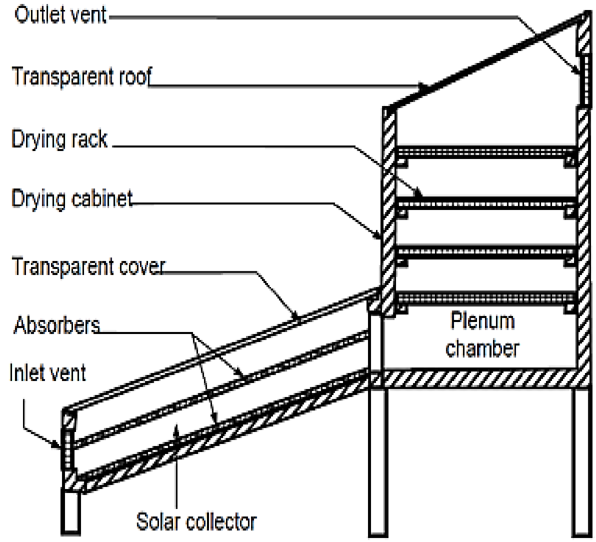

Figure 4:- Solar dryer

LITERATURE REVIEW

Designed and fabricated direct natural convection solar dryer to dry tapioca in rural areas. A minimum of 7.56 m^2 solar collector area is required to dry a batch of 100 kg *tapioca* in 20 hours (two days drying period). The initial and final moisture content considered were 79 % and 10 % wet basis, respectively. The average ambient conditions are 32ºC air temperatures and 74 % relative humidity with daily global solar radiation incident on horizontal surface of 13 MJ/m^2/day. The weather conditions considered are of Warri (lat. 5°30', long. 5°41'), Nigeria. A prototype of dryer was fabricated with minimum collector area of 1.08 m^2 [1]. Debbarma, M., Rawat, P., & Sudhakar, K. (2013), The performance of an indirect forced convection solar drier integrated with heat storage material was designed, fabricated and investigated for chili drying. The drier with heat storage material enables to maintain consistent air temperature inside the drier. The inclusion of heat storage material also increases the drying time by about 4 h per day. The chili was dried from initial moisture content 72.8% to the final moisture content about 9.2% and 9.7% (wet basis) in the bottom and top trays respectively. They concluded that, forced convection solar drier is more suitable for producing high quality dried chilli for small holders. Thermal efficiency of the solar drier was estimated to be about 21% with specific moisture extraction rate of about 0.87 kg/kW h [2]. Built a simple and inexpensive mixed mode solar dry locally source materials. The temperature rise inside the drying cabinet was up to 24 ºC (74%) for a hours immediately after 12.00h(noon). The drying rate, collector efficiency and percentage of moist removed (dry basis) for drying yam chips were 0.62 kgh-1, 57.5 and 85.4% respectively. The dryer sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it superior quality of the dried product [3]. Designed, constructed and tested the solar wind ventilated cabinet dryer in Nigeria on latitude 7.5 ^{0}N. Comparatively, drying with the solar cabinet dryer showed better results than open air-drying. During the period of test, the average air velocity through the solar dryer was 1.62 m/s and the average daylight efficiency of the system was 46.7%. The maximum drying air temperatures was found to be 64 ºC inside the dryer. The average drying air temperature in the drying cabinet was higher than the ambient temperature in the range of 5 ºC in the early hours of the day to 31 ^{0}C at midday.80% and 55% weight losses were obtained in the drying of pepper and yam chips, respectively, in the dryer [4]. Designed and developed solar drying system for maize with V-groove collector of 2.04 m² area, drying chamber and blower. The thermal energy and heat losses from solar collector were calculated for each three tilt angles (30º,45º, 60º). The results obtained during the test period denoted that the maximum gained energy occurred at 11 o'clock hour and then gradually declined since the maximum solar radiation occurred at this time. Other many important results found are The theoretical thermal energy, the experimentally actual heats gain increase by increasing radiation intensity, the maximum values occurred at the 11 am and then gradually declined. The energy gained obtained at the angle tilt 45º is higher than the corresponding values obtained at 60º, 30º tilt [5]. Designed and developed A Mixed mode type forced convection solar tunnel drier to dry hot red and green chillies under the tropical weather conditions of Bangladesh. Moisture content of red chilli was reduced from 2.85to 0.05 kg/kg(db) in 20 h in solar tunnel drier and it took 32 h to reduce the moisture content to 0.09 and 0.40 kg/kg (db) in improved and conventional sun drying methods, respectively [6].

DESIGN AND CONSTRUCTION

1. **Drying Chamber: -**

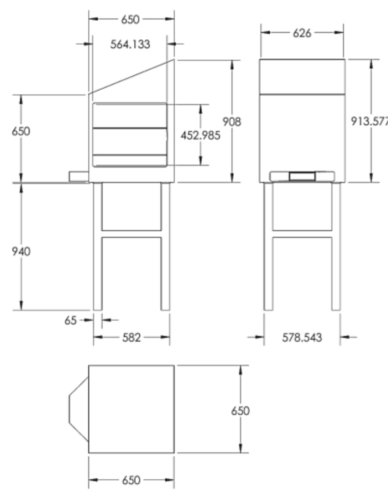

Figure 5:- Dimension of Drying Cabinet

2. **Solar Panel :-**

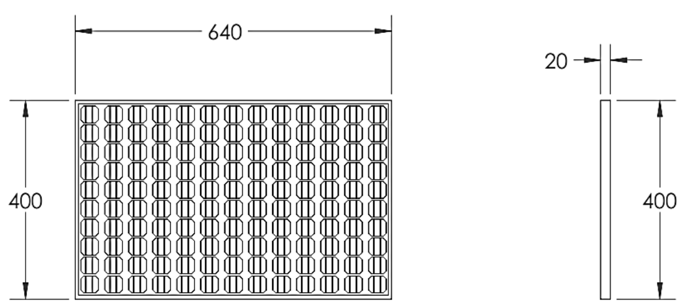

Figure 6:- Dimension Solar Panel

3. Solar Collector:-

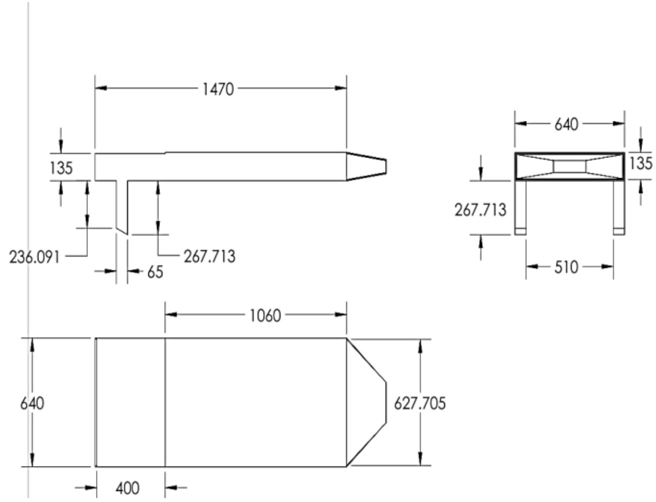

Figure 7:- Dimension of Solar Collector

4. Detailed Design:-

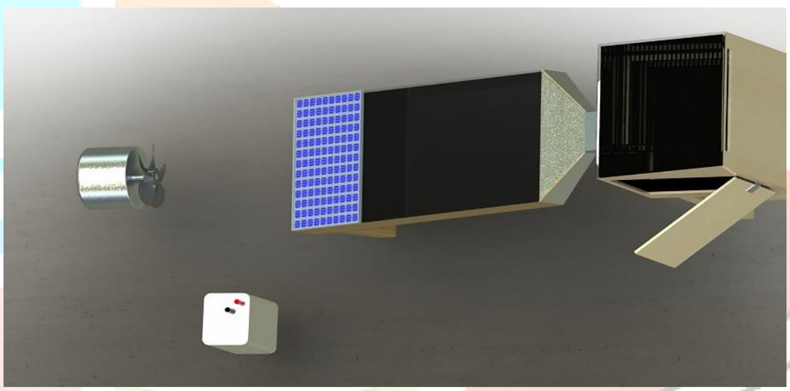

Figure 8:- Design of Project

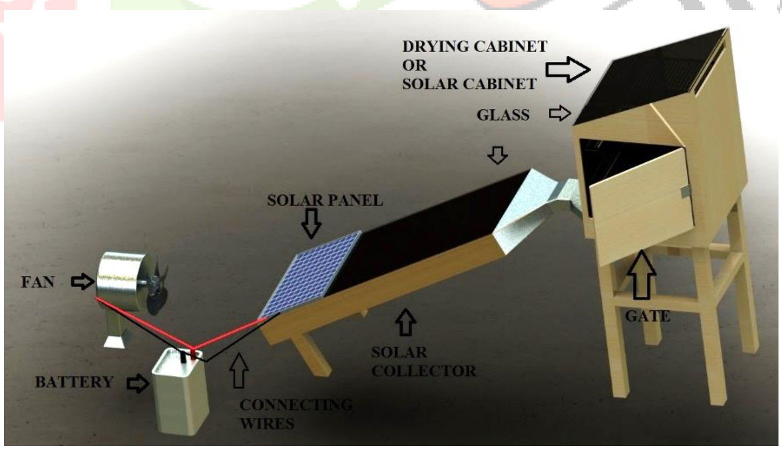

Figure 9:- Component and its design

Figure 10:- Final and Completed Project image

CONLUSION

Hybrid Solar dryer is the best alternative technology to avoid disadvantages of conventional drying methods. Hybrid Solar dryer is designed for a particular crop and atmospheric conditions of location. Forced circulation solar drying shows better result with reduced drying time than open air solar drying and natural circulation solar drying. The use of hybrid PV/T solar dryer considerably reduced the drying time [12]. This project has been able to establish that, the need for a dryer that can function effectively and efficiently with minimal maintenance, yet is inexpensive to construct, is both possible and achievable. The overall cost and choice of materials would promote mass production and hence, it can be a substitute to the expensive conventional dryers thereby making it assessable and affordable by local farmers. In all the cases the use of solar dryer leads to considerable reduction of drying time in comparison to sun drying and the quality of the product dried in the solar drier was of quality dried products as compared to sun dried products and they are appropriate for production of quality dried fruits, vegetables, spices, herbs and medicinal plants, and fish. Solar dryers are simple in construction and can be constructed using locally available materials by the local craftsman [11]. They may vary in construction depending upon their loading capacity. The solar drier can be operated by a photovoltaic module independent of electrical grid.

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