Design Consideration of Smart Solar Dryer for Precision Drying

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ABSTRACT

A sensor based solar dryer was designed to control the drying environment for precision drying of agricultural produce. The system entirely used solar energy utilizing both thermal and electrical effect. Paraffin wax was used for storage of thermal energy whereas solar battery was used to store the electrical energy. Hot air blower was also provided to supply heat when there is less or no solar radiation. Temperature sensors were provided to control the environment of drying chamber. The exhaust fan started operating depending on the set temperature and thus control the drying environment. Load cells were provided below each tray to measure the dry weight. The drying chamber was made of mild steel with glass wool insulation. The capacity of the designed dryer was 10-15 kg with 6 trays. The designed dryer has target temperature of 55-60°C.

KEYWORDS

Evacuated tube, solar dryer, phase change material, load cells, sensors

INTRODUCTION

Drying is one of the most common post-harvest unit operations for preservation of agricultural products. It helps to prevent the microbial activity caused due to high moisture content and thus, extends the shelf-life of the product (Jairaj *et al*, 2009). The most common, easy, cheap and traditional method of drying is open sun drying. Open sun drying is carried out at ambient conditions using direct solar radiation. However, it is associated with uncontrolled whether conditions, poor drying quality and large drying time (Sansaniwal *et al*, 2017). A solar dryer can overcome the limitations of sun drying. On the other hand, solar energy is abundantly available in the country with 5.5kWh/m^2/day (Musale *et al*, 2016). Considering the various advantages associated with solar energy and the facts of depleting the conventional energy pool, solar drying would be the best choice that could provide sustainable method of food preservation (Aravindh and Sreekumar, 2015).

Both thermal and electrical power can be harnessed simultaneously from solar energy. Solar photovoltaic has less efficiency than thermal collector in thermal generation. Moreover, thermal and electrical collector are designed for its specific application. Hence, a hybrid system using both electrical and thermal would be more beneficial than singly using thermal generation from solar PV panels. This will be helpful in those areas where availability of grid power is less. Therefore, solar drying provides a viable solution for problems of energy crisis associated with drying and dehydration of agricultural produce. Also, utilizing solar energy in agricultural processing would be a turnover in energy saving as well as in reducing the impact on the environment. Moreover, the government is focusing more on renewable energy sources as the conventional sources has been depleting.

Flat plate type solar collector are commonly used thermal collector used for drying of agricultural produce. This type of dryer has less efficiency than vacuum tube collector due to higher reflection losses. Therefore, use of vacuum tube collector would help in improving the efficiency of drying. On the other hand, use of phase change materials (PCM) for thermal storage medium could help to achieve constant and moderate temperature which is ideal for drying most agricultural produce (Mohanraj and Chandrasekar 2008 and Shalaby *et al* 2014). This helps in reducing the energy requirement as well as maintain a moderate temperature.

Wise selection of temperature for drying is necessary as agricultural crops are sensitive. However, most of the agricultural products are recommended to dry between 40-60°C for safe drying (Kant *et al*, 2016). On the other hand, control of drying chamber in solar drying for precision drying has not been reported. Use of sensor to control the temperature of the drying environment would not only able to maintain the quality of the product but also would increase the efficiency of the system. In most of the dryer, frequent checking of product condition during the process is necessary to avoid over drying. This can be overcome by providing sensor such as load cell in each tray and indicate the final desire weight. Such control environment of drying chamber using sensors for precision drying has not been reported specially for solar dryers. Keeping the above views, a work has been carried out to design sensor based smart solar dryer for precision drying of agricultural crops.

MATERIALS AND METHODS

Design of the dryer

The designed solar dryer was powered entirely by solar energy using both thermal and electrical modules. The ther-

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mal energy was collected through evacuated tube thermal collector whereas electrical energy was obtained through solar photovoltaic panels. Thermal storage was provided through paraffin wax (as phase change materials, PCM) and electrical energy was stored at solar battery. A hot air blower which is powered by electrical energy derived from solar battery was also provided to supply heat when there is less or no radiation. The speed control of the exhaust fan was made in order to control the temperature of the drying chamber. Load cells were provided below each tray to indicate the weight of dry matter and thus prevent overheating. The dryer consisted of drying chamber with sensors and microcontroller arrangement, air heating unit, air handling and distribution unit, thermal storage and power supply. The factors taken for the design of the dryer were moisture content to be removed, total solar energy received in the region and permissible temperature for drying agricultural produce. The designed capacity of the dryer is 10-15 kg.

Determination of design values

Firstly, the amount of moisture to be removed was calculated. Depending on the mass of the moisture, the quantity of heat required to obtain the desire level of drying was estimated. The total quantity of heat required was determined by the mass of the product to be dried and amount of heat required to vaporize the moisture from the product.

Drying load estimation

a) The amount of moisture to be removed from the product, m_w (kg) was determined using the following equation (Tonui *et al* 2014 and Ogheneruona and Yusuf 2011).

$$m_w = m_p \frac{(m_i - m_f)}{(100 - m_f)} \qquad (1)$$

b) The quantity of heat required to remove the moisture content was determined using equation (2).

$Q = m_p C_p \triangle T_p + m_w h_{fg}$ (2)

C_p= Specific heat of product (Sahay and Singh (2004))

C_w= specific heat of water (4.18 kJ/kgK)

C_d= specific heat of dry matter (1.463-1.881 kJ/kgK)

$\triangle T_p$= change in temperature before and after heating (^oC), t_a-t_p

Therefore, C_p=2kJ/kgK

h_{fg}=the latent heat of evaporation in kJ/kg.

The amount of heat required is the function of temperature and moisture content of crop. The latent heat of vaporization was determined by, (Ogheneruona and Yusuf (2011) , Dasin *et al* (2015))

$h_{fg} = 4.186(597 - 0.56(t_{pr}+273))$ (3)

where, t_{pr} is the product temperature [^oC]

Design of drying chamber

The designed drying chamber accommodates six perforated trays in such a way that it provides thin layer drying and at uniform manner. The design factors of drying chamber included its size, number of trays, space between two trays and materials for insulation. The drying chamber was made of mild steel with glass wool insulation of 2.5 cm to prevent

heat loss from the chamber. A hole is provided at the bottom side for the hot air entrance through evacuated tube collector. Parameters like initial moisture content, final moisture content, initial mass of the product, average ambient temperature, solar radiation etc. were considered while designing (Table 1). Materials of construction for the drying chamber were selected based on the technical and economic considerations.

Table 1: Design parameters considered for solar dryer

Sl. no.	Parameters	Standard values/ assumptions/ Determined values
1.	Initial moisture content of the product (m_i)	85-86% w.b.
2	Final moisture content of ginger (m_f)	10-13% w.b.
3.	Initial mass of the product to be dried (m_p)	10-15 kg, capacity of the designed dryer
5.	Initial temperature of product (t_p)	25^oC
6.	Specific heat of air (C_{pa})	1.005 kJ/kg K
7	Average Ambient temperature (T_a)	24^oC (considering winter season)
8	Density of air (ρ_a)	1.225 kg/m^3

Designing and Selection of Solar thermal collector

Vacuum tube type solar thermal collector was selected as it has less reflection losses and more advantageous than flat plate type thermal collector. Number of tubes are selected based on the temperature required inside the drying chamber, average inclined radiation and manufacturer's values such as optical efficiency, first and second order heat loss coefficient. The thermal output of the system is characterized in terms of the GIR and (T_m-T_a) (IS:16648, 2017).

$$\frac{Q}{Unit\ Area} = GIR \times \eta_0 - a_1(T_m - T_a) - a_2(T_m - T_a)^2 \qquad (4)$$

Where,

Q = Rate of energy, Watt

A_P=Aperture area, m^2

GIR= Global inclined radiation, W/m^2

a_1= Temperature dependence first order heat loss coefficient, W/m^{2}K

a_2= Temperature dependence second order heat loss coefficient, W/m^{2}K^2

T_m= Mean temperature of the system, ^oC

T_a= Ambient temperature, ^oC

η_o= Optical efficiency

Air handling and distribution unit

The dryer was operated with forced convection process. The important part of air handling units included of fan that blew hot air to the drying chamber. An exhaust fan was provided at the top side of the dryer.

Thermal storage unit

Paraffin wax as phase change material was used to store thermal energy during sunshine hours and utilized it during night hours. Considering 70% of heat energy required for drying is to be supplied during the day time and remaining 30% energy is to be stored in the thermal storage system for used in non-sunshine hours, the amount of paraffin required for storing the energy can be calculated using the following formula:

$$Amount\ of\ PCM = \frac{Amount\ of\ energy\ required\ to\ be\ stored}{Latent\ heat\ of\ storage}$$

Sensor node

Temperature sensors (NTC-negative temperature coefficient) was provided at the exit of hot air. It has keys, LED display, relay, and operates on DC 12V power supply. The controller module has an inbuilt embedded micro-controller, thus not much programming knowledge is required. The heater of the hot air blower was kept ON when the temperature obtained from the evacuated tube collector was less than the set values. Depending on the set/ programmed conditions of the drying environment, speed of the exhaust fan are controlled after being actuated by the signal received from sensors. Load cells are provided below each tray to measure the mass of dry weight. The change in weight during the drying process is being displayed in the Organic Light Emitting Diode (OLED). The controls are made through microcontroller, programmed through Arduino (Arduino Mega 2560) integrated development environment (IDE) software.

The schematic and designed prototype solar dryer is shown in Figure 1 and Figure 2, respectively
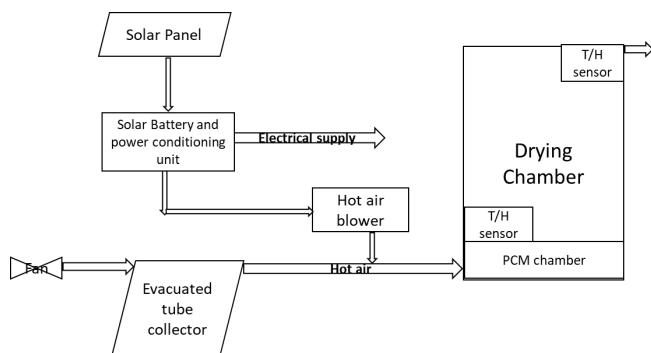

Fig. 1: Schematic diagram of the developed solar dryer

Performance evaluation of the dryer

The dryer was evaluated for following characteristics

System Efficiency

The system efficiency can be defined as the ratio of energy required to evaporate the water and sensible heat require to raise the temperature of the product to the useful energy gained from solar collector (Tonui *et al*, 2014).

$$\eta_{dryer} = \frac{m_p C_p \triangle T_p + m_w h_{fg}}{Q_a}$$

Where, Q_a = total energy received from the evacuated tube solar thermal collector.

Specific moisture extraction rate (SMER

SMER is one of the important performance indicators of a drying system which is defined as the amount of water evaporated per unit energy consumption in kg/kWh as given by (Prakash and Kumar (2017)).

$$SMER = \frac{Mass\ of\ water\ removed,\ kg}{Total\ energy\ consumption,\ kwh}$$

The reciprocal of SMER gives the Specific energy consumption (SEC).

RESULTS AND DISCUSSION

The proposed designed of the solar dryer has capacity of 10-15 kg. The schematic diagram of the developed solar dryer included dryer with PCM chamber, evacuated tube thermal collector, fan, Solar Photovoltaic panel, solar battery with power conditioning unit, hot air blower etc. (Figure 1). The dryer is entirely operated by solar energy including both thermal and electrical storage. The thermal energy is obtained from Evacuated tube thermal collector whereas photovoltaic panels provided the electrical energy required for fans and sensors. A hot air blower is also provided to be used when there is less or no radiation. The hot air reached the drying chamber through PCM box. Temperature sensor is provided at the exhaust. Depending on the set desire temperature at the exhaust side, the fan speed actuated through microcontroller through temperature sensor. Thus the temperature inside the chamber is being controlled. Load cells are provided below each tray to indicate the mass of dried product. Hence, the dried product can be removed in time and thus preventing overheating of the product.

The drying chamber was made of mild steel with glass wool insulation of 2.5 cm. The dryer has capacity of 10 to 15 kg with 6 trays. The targeted temperature to be attained inside the drying chamber was kept as 55-65°C. The proposed dimensions of the designed dryer are (77 x 65 x 96) cm at front and (77 x 65 x 121) cm at back side. The slope provided at back side would enable easy flow of the exhaust air.

CONCLUSIONS

A solar dryer was designed to control the drying environment using sensors for precision drying keeping in view of huge potential of solar energy, its availability and environmentally friendly. The designed dryer is solely operated with solar power utilizing both thermal and electrical energy. Used of sensor for controlling drying chamber enable to achieve precision drying. Application of solar energy could provide sustainable approach of agricultural processing. This proposed design low capacity solar dryer will be economical to use by the farmers to maintain the quality of the dry product. Also, it can be scale up for entrepreneur and industrial applications.
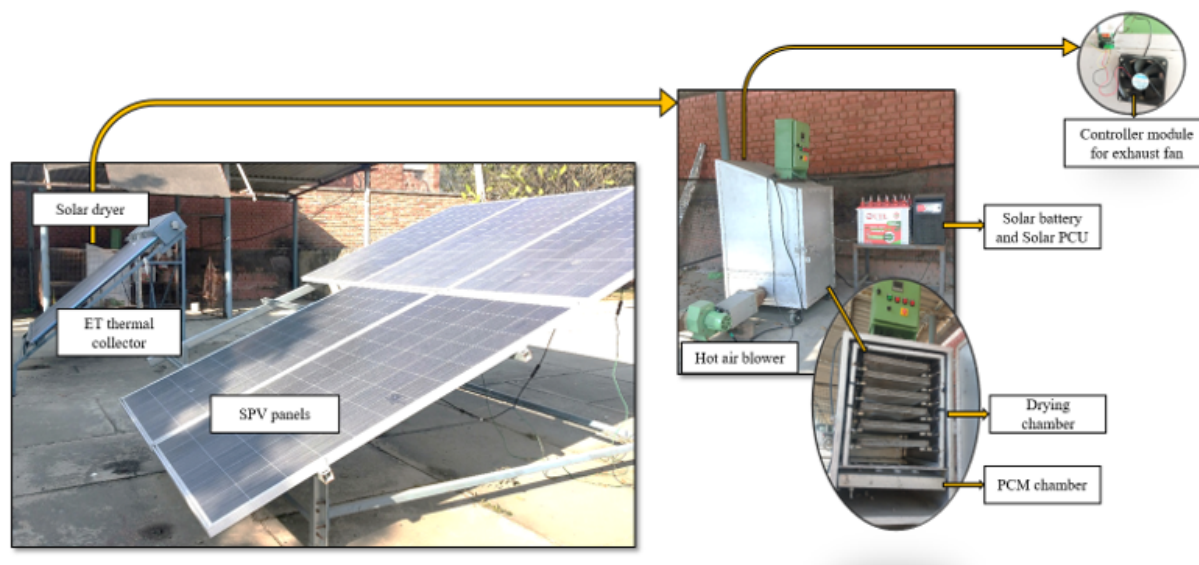
Fig. 2: Developedsystem of the solar dryer

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