Performance Analysis of Evacuated Tube Solar Dryer with Desiccant Dehumidifier and PCM as Thermal Storage Material.

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Abstract - In the present experimental study the performance analysis of evacuated tube solar dryer with desiccant as dehumidifier and PCM as thermal energy storage is studied. In the setup forced convection is used. The spinach leaves of 5 kg are used as drying material. The performance is tested for 8 hours and satisfactory results are obtained.

***Key Words*: Evacuated tube, desiccant, PCM(Phase Change Material), Forced convection, Spinach leaves**

1. INTRODUCTION

Drying process is most common form of food preservation method, it increases the food shelf life. Different types of energy sources are used for drying, such as fossil fuel, natural gas, solar, etc. There are some disadvantages of using conventional energy sources like depletion of fossil fuels, rising fuel cost, and environmental damages caused due to the fossil fuels, the uses of solar energy for drying increases.

Traditional methods of food drying is to spread the foodstuffs to place in the sun in the open air. This method, called open sun drying also called as natural sun drying, is effective for small amounts of food. It has disadvantages like the area needed for sun drying expands with food quantity and since the food is placed in the open air, it is easily contaminated by birds, insects, etc. ; also weather uncertainty like rain, long timespan required for drying and large amount of labour cost for handling the products[1].

To overcome the problems of open sun drying and alternative solutions for traditional drying process different types of closed solar dryers has been developed. The closed dryers are mainly classified as direct mode solar dryers, indirect mode solar dryers and mixed mode solar dryers.

We developed the indirect forced convection type dryer. The indirect mode solar dryer does not fully expose the crop to solar radiation. The indirect mode forced convection solar dryer essentially consists of an air heater, drying chamber and a blower to duct the heated air into the drying chamber[2]. The incident solar radiation is absorbed by a solar collector where solar energy converted into heat energy. The air for drying flows over this absorber and absorbs the heat energy, so its heated. The heated air is then passes over food products in the drying chamber. Heated air transfer the heat to the crop located within drying chamber. Drying chamber is an opaque structure. By using blower or fan to force the air in solar collector high and controllable temperatures can be achieved in this type of solar dryer.

During the drying process, heat energy is required to evaporate moisture from the foodstuff and airflow is sued for carrying away the evaporated moisture. In drying mechanism two basic processes are present; the migration of moisture from the interior of an food to the surface, and the evaporation of moisture from the surface of food material to the surrounding air.

The drying mechanism is mainly depend upon temperature and humidity of air. If initial humidity is lower, then moisture absorption capacity is higher. We can reduce initial humidity of air by using air dehumidifiers. Desiccant drying involves forcing air through a packed bed of solar-regenerated desiccant to absorb moisture[3].

Flat-plate collectors usually lose more heat to the environment than evacuated tubes, as an increasing function of temperature. They are inappropriate for high temperature applications such as process steam production. Flat plate collectors are used for temperature range from 30-80°C, while evacuated tube collectors are used for temperature above 100°C[4].

The use of nonconventional energy sources are increases now a days due to some disadvantages of conventional energy sources. Solar energy is one of the most prominent nonconventional energy source. But the amount of solar energy received from sun is not constant at all time.so, there is discrepancy between the energy supply and demand in solar heating applications. To overcome this problem the thermal energy storage device are used. This thermal energy storage material are store energy at pick time and use this energy during off-sunshine hours[5]. By using PCM (Phase change material) as thermal energy storage we can reduces the time gap between energy demand and energy supply. There are some essential physical properties of PCM that should be identified in order to use it. These properties are high specific heat, high heat of fusion, high density, high thermal conductivity, stable composition, chemically inert and nontoxic[5].

India has different types of agricultural products. Preservation of this agricultural products is essential. For this purpose different types are dryers are developed. We developed an evacuated tube solar dryer with desiccant as dehumidifier and PCM as thermal energy storage material. We use 5 kg use spinach leaves as drying material.

2. Materials and methods

2.1 Measuring instruments

A digital anemometer is used to measure the velocity of air. Here we select optimum velocity before starting project. This optimum velocity is kept constant during experiment. For temperature measurement chromel-alumel thermocouple with digital temperature indicator are used. Electronic weighing scale is used for weight measurement.

2.2 Setup for experimentation

Evacuated tube solar dryer with desiccant as dehumidifier and PCM as thermal energy storage consist main parts as desiccant dehumidifier, blower, evacuated tube collector, collector with PCM and drying chamber. The schematic diagram of experimental setup is as shown in Fig.1. Desiccant bed consist of three bed to kept desiccant material. Desiccant material can produce hot and dry air that is useful in drying process. By using desiccant bed we increase the moisture absorption capacity of air. We going to use silica gel as desiccant bed. When air passed through desiccant bed, silica absorbs the moisture from air and air will become dry. Blower is used to force the air in the evacuated tube collector. Here we used 10 numbers of evacuated tubes. The angle of inclination of evacuated tube with ground is taken as 30°. The outer diameter of tube is 58 mm and inner diameter of 47 mm. Length of evacuated tube is 1800mm. Evacuated tube is made up of two tubes, vacuum is present in between them. Due to vacuum convective heat losses are absent. The collector with PCM is used to store thermal energy, here we use wax as PCM material. The drying chamber consists of three number of trays for placing agricultural products. Drying chamber is made up of galvanised iron sheet.

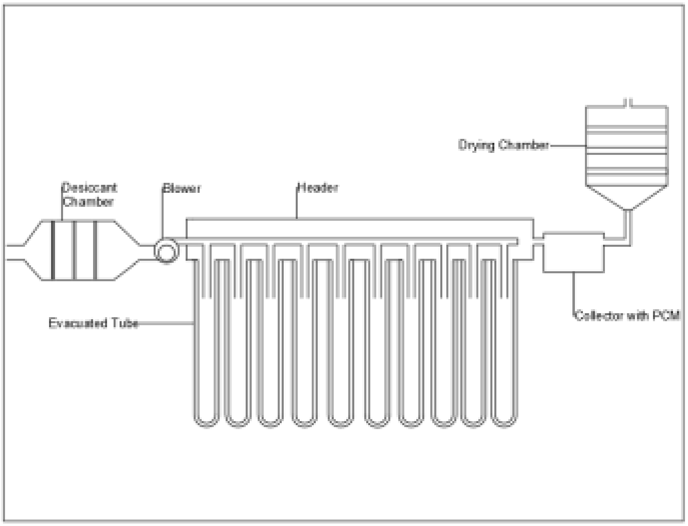

Fig -1: Schematic sketch of experimental setup

2.3 Experimental procedure

The stems of spinach leaves are removed and this spinach leaves are chopped in to medium size, then this leaves spread uniformly on the drying trays. Air comes in desiccant chamber where it loses its moisture and become dry. So moisture absorption capacity of air increase. Then blower forces this air into the evacuated tube, where it absorbs the heat energy from collector, then this air passed through PCM collector towards the drying chamber. In drying chamber air losses its heat to the spinach leaves and absorbs the moisture from leaves. The dry bulb temperature and wet bulb temperature at different locations of setup are measured from that relative humidity are also calculated. We measure the temperatures at hourly basis. The setup is started at 8 am in the morning and first reading is taken at 9 am and last reading is taken at 5 pm. We performed this experiment with solar dryer without desiccant, solar dryer with desiccant. After that we compare temperature and relative humidity at different locations.

3. Results and discussions

3.1 Solar dryer without desiccant

In this case we performed experiment without desiccant chamber. Fig.2 shows the temperatures at various locations of dryer at different times of the day. Setup is started at 8 am in the morning. First reading was taken at 9 am, at that time ambient temperature was 30°C, collector outlet temperature was 43°C, drying chamber inlet temperature was 40°C. As the time lapse temperature increases. Maximum collector outlet temperature was 70°C and maximum drying chamber inlet temperature was 67°C at 1 pm. After that again temperature is reducing.

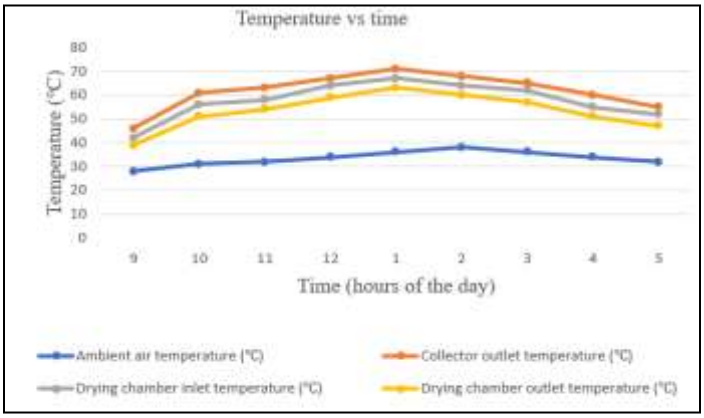

Fig-2: Variation of temperature at different location with time

Fig.3 shows the variation of ambient relative humidity, collector outlet relative humidity, drying chamber inlet relative humidity and drying chamber outlet relative humidity with time. The maximum ambient air relative humidity observed at 9 am which was 60.6% and minimum was 33.2%. The maximum collector outlet air relative humidity was 31.7% and minimum was 6.7%. The maximum drying chamber inlet air temperature relative humidity was 36.1% and minimum was 7.2%.

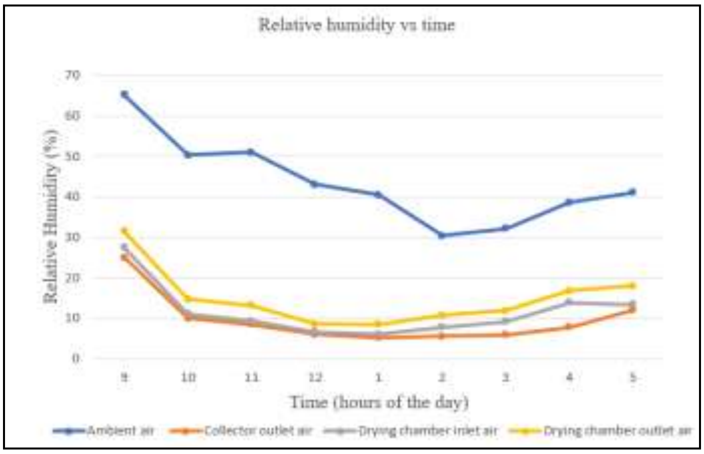

Fig-3: Variation of relative humidity at different location with time

3.2 Solar dryer with desiccant

In this case we performed experiment with desiccant chamber. Fig.4 shows the temperature at different locations in solar dryer at different times of the day. Setup is started at 8 am in the morning. At 9 am first reading was taken, at that time ambient air temperature was 29°C, outlet temperature of desiccant bed was 38°C, collector outlet temperature was 49°C and drying chamber inlet temperature was 43°C. The maximum collector outlet temperature was 73°C at 1 pm. The last reading was taken at 5 pm, at that time ambient air temperature was 32°C, outlet temperature of desiccant bed was 38°C, collector outlet temperature was 54°C and drying chamber inlet temperature was 49°C. As the air passes through the desiccant bed its temperature increases by 3-9°C.

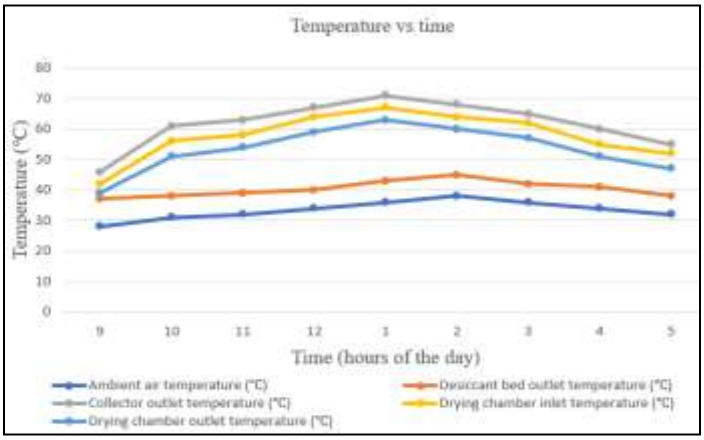

Fig-4: Variation of temperature at different location with time

Fig.5 shows the variation of ambient relative humidity, desiccant bed outlet relative humidity, collector outlet relative humidity, drying chamber inlet relative humidity and drying chamber outlet relative humidity with time. The maximum ambient air relative humidity observed at 9 am which was 59.8% and minimum was 30.4%. The maximum desiccant bed outlet relative humidity was30.4% and minimum was 18.6%. The maximum collector outlet air relative humidity was 22.3% and minimum was 5.3%. The maximum drying chamber inlet air temperature relative humidity was 25.3% and minimum was 6%. After passing through the desiccant bed relative humidity of air decreases.

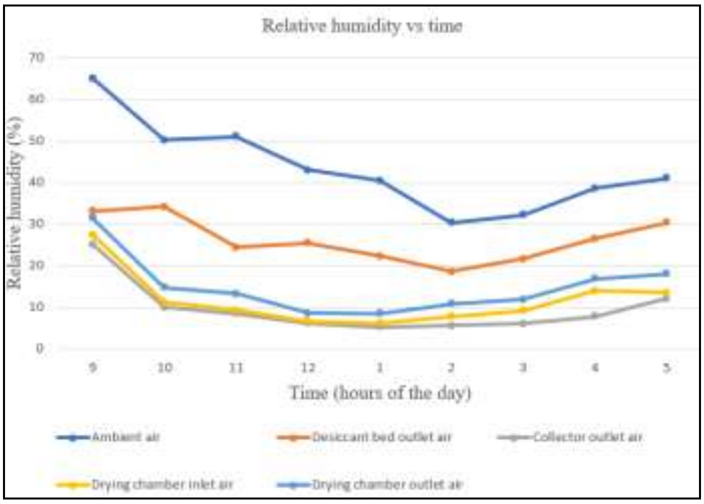

Fig-5: Variation of relative humidity at different location with time

3.3 Solar dryer with PCM

In this case we use PCM as thermal energy storage material. Collector with PCM is kept under the sun for whole day. And we use this after 5 pm for drying purpose when sun is not present. At 5 pm ambient temperature was 34°C and PCM collector outlet temperature was 55°C. As time going PCM outlet temperature reduces. After 8 pm temperature reduces drastically. At 9 pm PCM collector outlet temperature was 33°C.

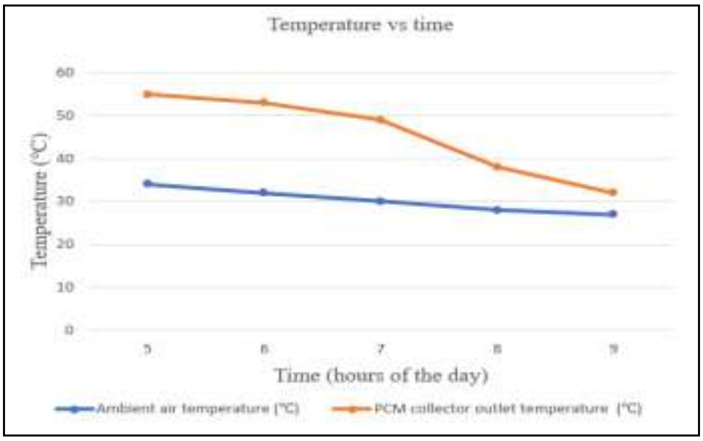

Fig-6: Variation of ambient temperature with PCM collector outlet temperature.

3.4 Analytical results

a. Moisture loss

Moisture loss from product calculated by using formula,

$$ML = M_i - M_f$$
$$ML = 5 - 1.692$$
$$ML = 3.308\ kg$$

Where, ML =Moisture loss.

M_i = Initial mass of sample

M_f = Final mass of sample

b. Drying rate

The drying rate is given by,

$$DR = \frac{dM}{dt}$$

$$DR = \frac{3.308}{8}$$

$$DR = 0.4135 kg/hr$$

Where, DR = Drying rate

dM = Mass loss

dt = Drying time

4. CONCLUSION

In this experiment we study, solar dryer with desiccant and without desiccant. In the case of solar dryer with desiccant the drying chamber inlet temperature is higher than solar dryer without desiccant. Also drying chamber inlet relative humidity is less for solar dryer with desiccant. By using desiccant temperature of air increases and relative humidity decreases, it will increases the moisture absorption capacity of drying chamber inlet air.

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