Performance Enhancement of Mixed Mode Solar Dryer by Using Thermal Energy Storage Material

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Abstract- *The purpose of the present work is to carry out an experimental investigation of an indirect solar dryer with PCM as thermal energy storage material. The integrated solar dryer with paraffin wax as PCM was designed and tested under prevailing weather conditions of Karad city* ($17^0$18'34.1"N, 74^o11'10''E*),India. The dryer was fabricated using low cost and locally available materials. In this experimental work, fresh potato chips of 0.5kg with initial moisture content of 84% were dried by considering four different cases and observed drying rate, period of drying and mass of water removed. For open solar drying; time required, mass removed and drying rate are 5.33hrs, 0.412kg and 77.25grams/hr respectively. For natural convection these values are 2.5hrs, 2.75hrs, 0.204 kg, 0.202kg at top and bottom trays resp. with overall drying rate is 168.488grams/hrs and reduced moisture content at top and bottom is 11.11%(wet basis) and 13.043%(wet basis).For forced convection these values are 1.5hrs,276.10grams/hrs and 0.415kg.For both natural and forced with PCM these values are 3.5hrs,2.67hrs,118grams/hr and 154.2grams/hr respectively This design is simple; it can easily be replicated elsewhere in the world. The products can be dried in one day and has capability to dry products at commercial scale while retaining the color, flavour and nutrients.*

Keywords- Solar energy; Mixed mode solar dryer; PCM; Design; Drying mechanism

I. INTRODUCTION

A. Indirect mixed mode solar dryer

A new design has been devised for drying potato chips efficiently in both sunshine as well as the cloudy situation by instant storage of solar energy. This dryer not only transfer energy efficiently and stores it for continuous usage. In solar dryer the potato chips are placed in a drying chamber. Due to the green house effect air gets heated in solar air heaters and then blown through the drying chamber. At the top of drying chamber vents are provide through which moisture is removed. There are several researchers working on energy conservation and energy efficiency, therefore designing and developing a new solar dryer system is necessary to use the solar dryer after the sunset, so the solar energy can be stored with the help of energy storing material. In this present work experimentation were carried out to dry sliced potato chips of 1to 2mm thickness spread over the drying trays. The different parameters which affecting the thermal performance of an indirect mixed mode solar dryer such as time required for drying, moisture, drying rate and temperature were presented with and without PCM for both natural and forced convection. Also carried comparative experimental analysis on the basis of time required for both open and closed drying. Bolaji et al. [1] they have designed, constructed and tested the solar wind ventilated cabinet dryer in Nigeria on latitude 7.5^{o}N. They observed that drying with the solar cabinet dryer showed better results than open air-drying. During the period of testing, they got an average air velocity through the solar dryer was 1.62 m/s. They found maximum drying air temperatures was 64 0C inside the dryer. Mohanraj [4] he designed, fabricated and investigated an indirect forced convection solar dryer integrated with heat storage material was for drying chili. They dried chili from initial moisture content of 72.8 % to the final moisture content about 9.2 % and 9.7 % in the bottom and the top trays respectively.

II. METHODOLOGY

In this section methodology for design, experimental set up and drying mechanism were explained.

A. Methodology for Design

a) Climatic data collection

The latitude angle and longitude angle of Karad is $17^0$18'34.1"N and 74^o11'10''E respectively with an average solar radiations of 680 W/m2

b) Design Considerations for Solar Dryer

The following some considerations are very important in the solar dryer design,

i) Temperature - The minimum temperature for drying food is 30°C (assumed) and the maximum temperature is 65°C, therefore 45°C and above is considered average and normal for drying samples and some other.

ii) Drying time - Drying times range from 0.25 sec (drying of tissue paper) to five months (for hardwood)

iii) Air gap - It is suggested that for hot climate passive solar dryers, a gap of 5 cm (0.05m) should be created as air vent (inlet) and air passage.

iv) Flat plate collector - The metal sheet thickness of 0.8–1.2 mm, the outer cover is glass for the collector. The efficiency of the flat plat collector is 30%.

v) Area of solar flat plate collector is $0.3m^2$ and width is 0.5 m

vi) Dryer Trays - Net of aluminium was used as dryer screen or trays to pass air circulation within the drying chamber. The design of the dry chamber making use of wooden wall sides and a glass top (tilted).

vii) The drying sample is taken potato because in India production of potato chips are more as compared to other drying food and mass of food sample for drying is taken as 0.5kg

c) Design calculations

Mass of water to be evaporate from product,

$$M_w = M_p \times \frac{Mi - Mf}{100 - Mi} \quad \text{.......... (1)}$$

Energy required for evaporating water from product

$$E_p = M_w \times L_v \quad \text{.......... (2)}$$

Energy gain by air from radiation

$$E_a = m_a C_{pa} \Delta T \quad \text{.......... (3)}$$

Drying time required

$$E_p = E_a \times t \quad \text{.......... (4)}$$

Determination of drying rate

$$\frac{dM}{dt} = \frac{Mi - Mf}{t} \quad \text{.......... (5)}$$

Determination of moisture removal

Wet basis

$$M_{wb} = \frac{Mw}{Mw + Md} \quad \text{.......... (6)}$$

Dry basis

$$M_{db} = \frac{Mw}{Md} \quad \text{.......... (7)}$$

Determination of Heat Losses from Solar Air Collector

The energy balance on the absorber is obtained by equating the total heat gained to the total heat lost by the absorber of collector.

The amount of solar radiation received by the absorber of solar collector is:

$$Q_i = I_c (\tau\alpha) \cdot A_c \quad \text{.......... (8)}$$

The rate of heat loss by solar collector is:

$$Q_L = U_L A_c (T_c - T_a) \quad \text{.......... (9)}$$

Thus, the rate of useful energy extracted by the collector (Q_u),

$$Q_u = Q_i - Q_L = I\tau\alpha \cdot A_c - U_L A_c (T_c - T_a) \quad \text{.......... (10)}$$

The calculation of heat removal factor by using useful heat gain is:

At $T_i = T_a$

$$Q_u = F_R A_c I \tau\alpha \quad \text{.......... (11)}$$

Thermal energy gained by PCM

$$Q_{gain} = (mc_p \Delta T)_s + (m \Delta H) + (mc_p \Delta T)_l \quad \text{.......... (12)}$$

Determination of the Base Insulator Thickness for the Collector

$$F_R m_a c_{pa} (T_{out} - T_{in}) = \frac{KAc(Tout - Ta)}{tb} \quad \text{.......... (13)}$$

d) Experimental setup

Fig. 1 shows the experimental set-up. The solar dryer consists of flat plate solar collector (air heater) of area 0.3 m^2 (0.6×0.5) connected with drying chamber. The solar collector has 0.6 mm thick galvanized sheet as absorber plate coated with matte black paint to absorb solar radiation. The absorber plate is placed directly behind the transparent cover (glass) with a layer of air separating it from the cover. The air to be heated passes between the transparent cover (glass) and the absorber plate. To increase the temperature of the air by the greenhouse effect, a glass cover of 5 mm thickness was placed. The gap between the glass and the absorber surface was maintained at 50 mm for air circulation. The drying chamber is made up of a bakelite sheet of 4 mm thickness with width, depth and cross sectional height of (0.5×0.4×0.35) m respectively. The solar air heater was tilted to an angle about 27.18^o with respect to horizontal. The system is faced to south direction because to absorb maximum solar radiations.

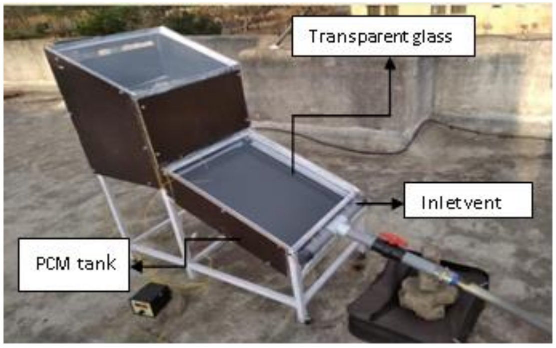

Fig. 1Experimental set up

e) Selection of TESM

The selection of PCM itself was a very critical condition because to select the PCM some important parameters are necessary, such as melting temperature, latent heat, heat storing capacity, etc. Commonly used Paraffin wax is used as PCM, which melts at 58 to 60 °C. It's having 210 kJ/kg latent heat and 7kg mass. It is white solid at room temperature.

Fig. 2 Paraffin wax

f) Experimental Procedure

Experiments were conducted during March-April 2018. Potato chips were taken as samples for drying with initial weight of 0.5kg measured by an electronic balance (accuracy:±0.01 g) and then kept in the hot air oven (accuracy:±0.5 °C) maintaining temperature of 125 °C till it attained a constant weight. Initial moisture level was then calculated and found 84% (wet basis). Experiments were performed by using four drying methods; natural convection solar drying, forced convection without thermal storage system and natural, forced convection with TESM. Fresh potatoes were sliced into 1-2 mm chips and then distributed 0.25 kg in each top and bottom tray for every set of experiments. Experiment was continued till the desired level of moisture achieved (11%). After drying the product is packed in airtight jars or plastic containers

g) Visual Depiction of Drying Mechanism

The drying mechanism of potato chips is explained with drying rate as given below;

1) Installation of potato chips in solar dryer

Fig.3 drying of potato chips

2) Constant rate period

Fig.4 Drying of Potato chips with constant drying rate

3) 1st Falling rate period

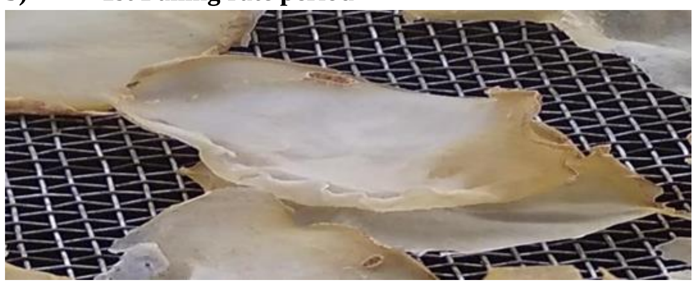

Fig.5 1st falling rate

4) 2nd Falling rate period

Fig.6 2nd falling rate

III. RESULTS AND DISCUSSION

This Chapter covers the detail result and discussion of the experimentation conducted during this dissertation work. The various system affected parameters are analyzed through the graphical representation. Each system parameter is discussed based on the analysis of results obtained from the experimentation.

A) Mass reduction of potato chips was explained by following three cases;

Case 1: By using open drying method potato chips of 0.5kg was reduced to 0.412kg in 5.33hrs with drying rate of 77.25grams/hr.

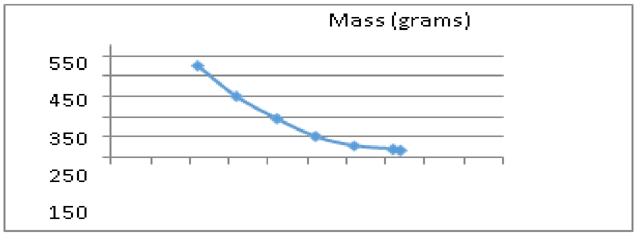

Fig.7 Mass reduction with time

Case 2: By natural convection indirect solar dryer 0.5kg of potato chips at top and bottom tray were reduced to 0.202kg in 2.5 and 2.75hrs respectively with overall drying rate of 168.488grams/hrs.

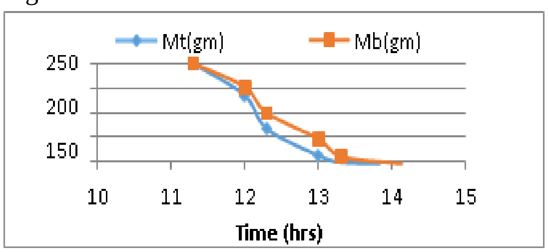

Fig.8 Mass reduction with time

Case 3: By using forced convection solar drying method potato chips of 0.5kg was reduced to 0.415kg in 1.5hrs with drying rate of 276.10grams/hr.

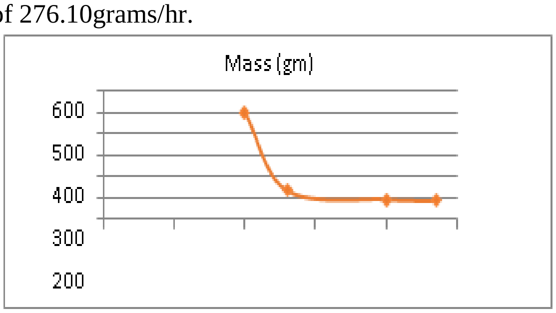

Fig.9 Mass reduction with time

B) By using paraffin wax the drying time of solar dryer during off sunshine period was increased by 1-2hrs and temperature increased by 40c-60c as compared to ambient temperature.

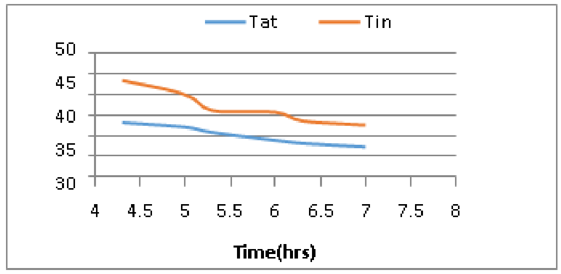

Fig.10 Temperature difference with time

IV.CONCLUSIONS

Designing the solar dryer, the design considerations, design calculations, selecting the materials these are the very important parameters. From the above results it is cleared that open drying method takes more time as compared to indirect mixed mode solar dryer. The temperature difference between ambient and solar dryer inlet is 40c-60c during off sunshine period

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