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Design and Comparision of Mixed mode Solar Dryer with and without using Phase Change Material

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Abstract--- **Drying is carried on for preservation of food items since ages. Industries normally use its 60% of energy Supply to dry Food items. Solar dryers can be a good replacement. This paper represents mixed mode type of dryer for theoretical and experimental evaluation of removing of moisture from raw Banana using phase change material (paraffin wax) as thermal storage system. Mix mode dryer include FPC which contains PCM chamber in it. Phase change material has been used to achieve performance of dryer even during off shine hours. Experiment was performed on the dryer and data was collected for no load condition, loaded condition, using PCM wax as well as without using PCM material. The phase change material used here is 7 Kg paraffin wax. Drying rate was seen 0.8 g/h without using PCM while with PCM it was 1.5 g/h, even during evening time when sun radiation was absent. Heat utilization Factor was seen average 0.8 in presences of PCM, while it was seen average 0.5 without using PCM.**

Keywords---**Phase change material, Paraffin wax, Mix mode, Radiation**

I. INTRODUCTION

Sun emits around 3.85 x 1026 J/s of energy. Among that energy most of the energy is lost in space. After that around 1.74 x 1017J/s of energy strike to earth. Earth gets still a large amount of energy even though this energy is in dilute form, that is we need to collect it and store it efficiently. Food is dehydrated and converted into powder for preservation by using sun's radiation. In general there are several variety different kinds of solar dryers: Direct radiation solar dryers and indirect radiation solar dryers are the most widely used. Drying is considered as one of the most commonly used method of preservation. Preservation simply means to maintain the quality of the food for long period of time.

Dehydration or drying of food refers to getting rid of the unwanted moisture content present in that food item. Drying is carried out to increase the shelf life of the food, also by converting food into powder can make the transportation process much easy. It is very important to learn different methods of storing solar radiations in form of energy. As sun is not available during night time. Many ways solar energy can be utilized like by storing energy in phase changing material, by using in solar cells etc. Sometimes solar energy is used in rocks in form of sensible stored energy. In PCM materials solar energy is stored in form of phase changing energy.

Basically thermal energy storage system is of two type one of them is sensible heat storage system and latent heat storage system. Sensible heat storage in which materials like rock, sand is used which can hold the thermal radiation for more period of time.

Latent heat storage device consists of device in which material like water, paraffin wax is used to store thermal radiation.

II. PHASE CHANGE MATERIALS

A. *What is PCM?*

PCMs are the material which absorbs and releases energy by melting and solidifying respectively. The PCMs absorbs and releases energy in form of latent heat of a substance. PCMs are seen to be more effective and better then sensible heat storage material. They are more convenient to use.

B. *Types of PCM*

There are total three types of PCM that is Organic, inorganic and Eutectic. Organic contains paraffin and non-paraffin type. Inorganic contents salt hydrides and metallic.

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III. SELECTION OF PHASE CHANGE MATERIAL

Paraffin wax was best option because of the following reasons.

- Melting point temperature range of - 360C to 890C
- Specific heat: 2.75 kJ/kg/K
- Latent heat: 255 kJ/kg (approx.100 times more)
- Density: 845 kg/cum (solid); 789 kg/cum (liquid)

As per our requirement the paraffin wax is expected to have a melting point of the range of 60–700C . it was available in CSMCRI institute itself.

Hence Paraffin wax material of melting point of 65 ºC was used in performing the research.

A. Abbreviations and Acronyms

PCM: Phase change material
FPC: Flat plate collector
TES: Thermal Energy Storage
SHS: Sensible heat storage

B. Units

Name of quantity	Symbol	Unit
Air vent dimension	A_v	m^2
Ambient temperature of air	T_a	^0C
Amount of energy stored in PCM material	Q_p	kJ
Amount of water removed from banana	M_r	Kg
Assumed drying time	t_d	H
Backup time or the period of time on which drying process is carried on even after sunshine	t_b	H
Bone dry weight of banana which is used for drying	m_b	Kg
Collector area required for solar dryer	$\mathbf{A_c}$	m^2
Collector temperature	T_c	^0C
Collector outlet Temperature	T_{co}	^0C
Dryer outlet temperature	T_{do}	^0C
Energy required per hour for drying process	Q_t	kJ/h
Final moisture content	W_d	%
Final temperature of banana	T_b	^0C
Initial moisture content of banana	W_t	%
Latent heat of PCM is 176 kJ/kg	L_p	kJ/kg
Latent heat of water vapor present in banana	L	kJ/kg
Latent heat of water vapor present in the banana	Q_L	kJ
Mass Flow rate of air required for drying	m_a	kg/h
Mass of banana to be dried	m	Kg
Mass of PCM required for drying	m_p	Kg
Mass of product which should be kept inside the dryer for drying purpose	M_x	Kg
Mass of water removed per hour	M_{rt}	kg/h
Porosity of banana	E	-
Sensible heat required to raise the temperature of moisture which is present inside the banana	Q_w	kJ
Sensible heat required to raise the temperature of only banana	Q_b	kJ
Solar radiation W/m^2	I	W/m^2
Specific heat capacity of banana	C_b	kJ/kg^0C
Specific heat capacity of water	C_w	kJ/kg^0C
Specific heat of ambient air	C_a	kJ/kg
thickness of banana slice in meter	h_b	M
Total energy required in drying process	Q	kJ
Total quantity of water in raw banana	M_{tw}	Kg
Tray area required for drying banana	A_x	m^2
Velocity of wind	v_w	m/s
Volume of product which should be kept inside the dryer for drying purpose	V_x	m^3
Volume of the PCM required for drying	V_p	m^3
Volumetric flow rate of air	V_a	m^3/h
Greek symbols		
Density of ambient air	ρ_a	kg/m^3
Density of banana	ρ	kg/m^3
Density of the solid paraffin wax	ρ_s	kg/m^3
Efficiency of water absorbing capacity of banana	η_b	-
Loading bed void fraction	ε_f	-
Collector efficiency	η_c	-

C. Design Consideration

For design purpose of the solar dryer with phase change material as a storage medium following criteria are to be considered

1. Total Energy needed to evaporate moisture content from the sample
2. Total Collector area required
3. Mass of air needed for drying purpose
4. Energy stored by Phase change material

Three main components of the dryer can be identified: an air heater (collector), in which solar radiation is falling and its surface is heated.

Table 1 Different assumption and condition made in design consideration

Quantities	Conditions or assumptions
Location	Bhavnagar CSMCRI (21.7590° N, 72.1443° E)
Capacity	5 kg
No. Of tray	1
Before drying moisture content of raw banana(W_t)	72%
After drying moisture content of raw banana(W_d)	15%
Ambient Temperature (T_a)	30^0C average
Ambient relative humidity (X)	40%
Drying temperature(T_d)	40-60^0C
Storage backup time	4 hours approx..
Solar insolation (I)	290 W/m^2
Collector efficiency (η_c)	70%
Density of ambient air (ρ_a)	1.225 kg/m^3
Density of liquid paraffin(ρ_l)	800 kg/m^3
Density of solid paraffin(ρ_s)	900 kg/m^3
Density of Banana(ρ)	950 kg/m^3
Specific heat of PCM in liquid form (C_{lp})	2.14 kJ/kg-K[20]
Specific heat of PCM in solid form (C_{sp})	2.9 kJ/kg-K approx.[20]
Thermal conductivity of PCM in liquid phase(K_l)	0.4 W/m-K[20]
Thermal conductivity of PCM in solid phase (K_s)	0.6 W/m-K[20]
Heat stored in paraffin wax (Q_p)	Joule
Drying time (T_d)	Not definite in hours

D. Design Procedure

Total quantity of water in raw banana (Mtw) in kg

$$M_{tw} = m \times \frac{Wt}{100} \quad (1)$$

Bone dry weight of banana which is used for drying (m_b) in kg

$$m_b = m \times [1 - \frac{Wt}{100}] \quad (2)$$

Amount of water removed from banana (M_r) in kg

$$Mr = \frac{Wt - Wd}{100 - Wd} \times m \quad (3)$$

Rate of amount of water Evaporated , Mrt in kg/h

$$\boldsymbol{M_{rt}} = \frac{M_r}{T_d} \quad (4)$$

Total energy required in drying process (Q) in kJ

$$\boldsymbol{Q = Q_b + Q_w + Q_L} \quad (5)$$

E. Design of PCM chamber

Amount of energy stored in PCM material (Qp)kJ

$$Q_p = Q_t \times t_b \quad (6)$$

Mass of PCM required for drying (mp) kg

$$\boldsymbol{m_p = \frac{Q_p}{L_p}} \quad (7)$$

Volume of the PCM required for drying (Vp) m^3

$$\boldsymbol{V_p = \frac{m_p}{\rho_s}} \quad (8)$$

Amount of heat stored in paraffin wax(Q_p)

$$Q_p = \int_{T_{ip}}^{T_{fp}} m_o\, C_{pp} dT + m_p a_p \Delta h_p + \int_{T_{mp}}^{T_{fp}} m_p C_{pp} d \quad (9)$$

F. Energy Analysis of Dryer

It is very necessary to analysis the energy producing system so that we can use the total amount of available energy. For this purpose and to reduce pollution created study of energy analysis is very essential.

Here considering the total amount of energy used to dry banana to be Q.

$$\boldsymbol{Q = I + Q_p} \quad (10)$$

Also Q can be written as [6]

$$\boldsymbol{Q = AF\left(I\zeta - U(T_c - T_a)\right)} \quad (11)$$

$$U = U_t + U_b + U_e + U_x \quad (12)$$

G. Exergy Analysis of Dryer

The maximum amount of work which can be done by the process without any wastage in drying time is called exergy. The mistakes at source level and design stage can be modified by exergy analyses.

Exergy means simply the available amount of energy or heat availability of system.

Exergy in flow in drying chamber (E_{xin})

$$E_{xin} = m_a C_a \left[(T_{co} - T_a) - \left(T_a \log \frac{T_{co}}{T_a} \right) \right] \quad (13)$$

Exergy out flow of drying chamber (E_{xout})

$$E_{xout} = m_a C_a \left[(T_{Do} - T_a) - \left(T_a \log \frac{T_{Do}}{T_a} \right) \right] \quad (14)$$

Efficiency of drying process(Exergy) (η_{Ex})

$$\eta_{Ex} = \frac{E_{xout}}{E_{xin}} \quad (15)$$

IV. EVALUATION OF PERFORMANCE OF SOLAR DRYER.

The Evaluation of solar dryer is made by keeping many parameters in consideration. Some quantity like dryer's efficiency, moisture removal rate etc. It is not possible to take record of whole sample as the heat loss takes place so two slices of weight 2.65 g were taken for weighting purpose.

Moisture content

$$W_t(w.b.)\% = \frac{m - m_b}{m} \times 100 \quad (16)$$

Rate of drying of banana

$$Drying\ rate\ (D_r) = \frac{\Delta W}{\Delta t} \quad (17)$$

Drying efficiency

$$\eta_{di} = \frac{m_{rtL_w}}{0.86\ x\ I\ x\ A_c} \times 100 \quad (18)$$

Heat utilization factor

$$HUF = \frac{T_{co} - T_{do}}{T_{co} - T_a} \quad (19)$$

V. EXPERIMENT PERFORMANCE AND OBSERVATION

The raw banana was cut into slice each of 20 mm thickness approximately. For drying process 100 g of banana was taken, hence the initial mass of product was 100 g. paraffine was chamber is kept inside collector chmaber.

Finding initial moisture content in sample: To find out the initial moisture content present in the banana oven drying was done. 20 g of fresh raw banana slices were washed and dried. This sample was kept in electric air oven at 110°C for 24 h. After that it was taken out and the weight was measured by electronic balance of capacity 220g and least count 0.001g. Hence the initial moisture content of raw banana was considered as 72 to 79 % w.b. Reading was taken for 24 hours in case of PCM wax while it was compared with the 9-hour day time reading of data without using wax. The data which were recorded in test are Temperatures of collector inlet air, Collector Outlet air, Collector plate, PCM, drying chamber, product or source of drying, collector glass, dryer glass.

Schematic image showing pcm chamber and Image of unit while doing experiment is as below

Fig.1. Experimental set up

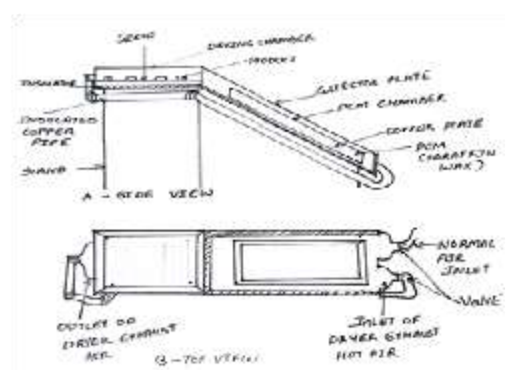

Fig.2. Location of PCM chamber

VI. RESULT AND DISSCUSSION

It is analyzed that within 1-hour banana chips were dried from 72% to 50%. The initial decrease in moisture content is only due to PCM material. The initial decrease in moisture is very rapid and the quality of chips also enhanced as it is not dried by direct radiation of solar which contains UV rays. Almost 16 hours are taken to reduce the **moisture content** up to 15%.

Heat utilization without using PCM was found maximum at 13.30 around 0.75; and with using paraffin was 17.30 around **0.95**. **Drying rate** was also very constant (1.5 g/h) in case were PCM material was used compare to the rate were PCM was not used.

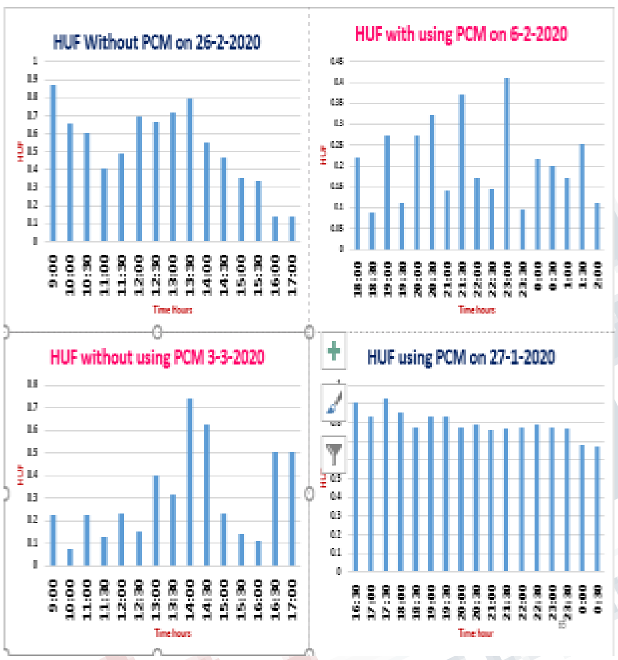

Fig.3. Comparision of HUF

The **rate of drying** of banana chips was derived by first calculating the moisture content of sample. Every hour mass of sample was measured and then how much moisture was removed was calculated. The following figure contains the graph of average drying rate. Drying rate varies from first 3 hours on high rate of 2.2 g/h. After that from 3 to 16 hour the rate becomes almost constant with rate of 0.02 g/h. This simply proofs that initially the moisture removal rate is very high compare to later on time. So it is better to use latent heat of paraffin wax for initial drying.

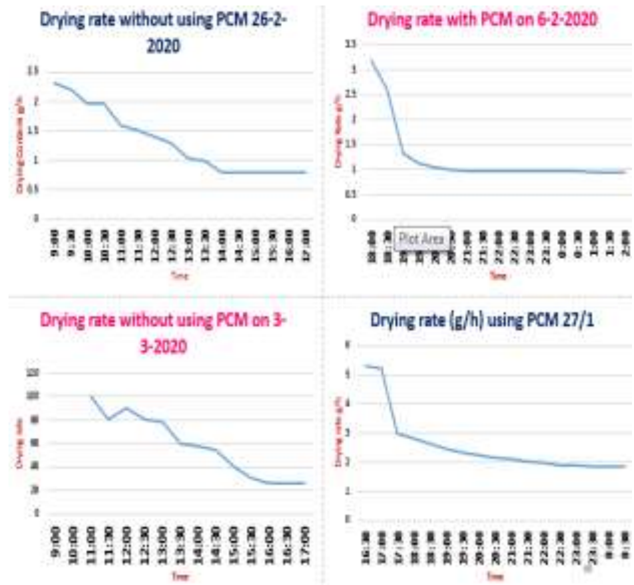

Fig.4. Comparison of drying rate in different cases

The average **efficiency** of the solar dryer is shown in the figure. The efficiency varied from 26 to 15 %. The average efficiency was calculated as 20%.

The variation of **exergy efficiency** with time is represented in following figure. The exergy efficiency ranges from 100 to 28.59. The average exergy efficiency was calculated to be 68%.

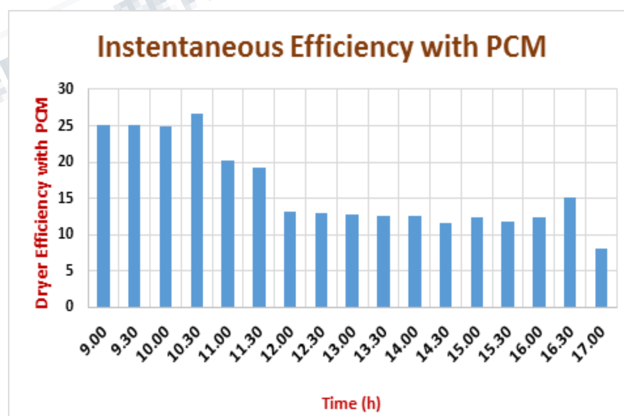

Fig.5. Instantaneous Efficiency

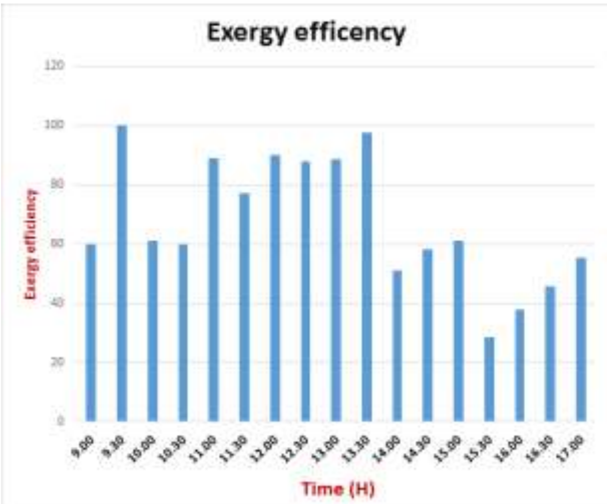

Fig.6. Instantaneous Exergy efficiency

It can be observed that the **Dryer mass** is reduced in each case even if PCM is used or not used comparing to the open sun shine. But compare to without using PCM, using PCM will be more beneficial. Of course solar radiation was very bit of different in each day but it is tired to select similar radiative days.

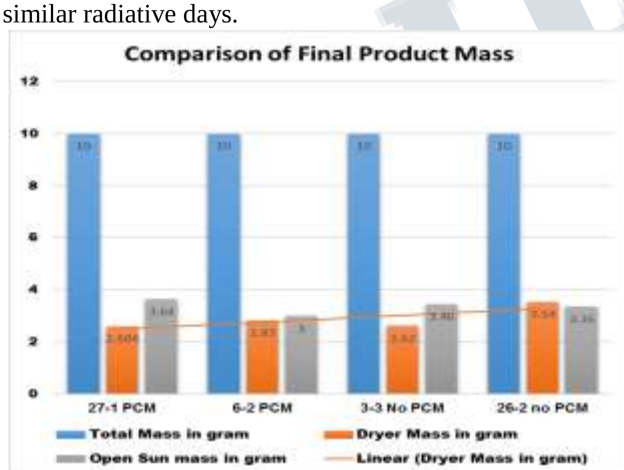

Fig. 7. Comparison of dried product mass

VII. CONCLUSION

Banana Chips were dried within 16 hrs. from the moisture content of 72% to 15 % when PCM was used.

The Heat utilization factor varied in the range of 0.12 to 0.91. The average heat utilization factor average was calculated 0.34 without using PCM and it was 0.53 using PCM.

For drying process, the exergy efficiency varied in range of 28.5% to 100 % and the average exergy efficiency was calculated 67.61%.

Fig. 8. Comparison of raw banana after drying Process

VIII. ACKNOWLEDGMENT

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