Analysis of Solar Dryer using Tono Therm M-65 Phase Change Material

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Abstract: This paper presents the construction and performance evaluation of a solar dryer. The objective of this work is to study the performance analysis of solar dryer system with and without Tono Therm m-65 PCM. In this heated air from a separate solar collector is passed through a food tray, and the drying cabinet absorbs solar energy directly through glass roof. an indirect type natural and forced convection solar dryer integrated with PCM has been developed and tested its performance for drying food products under the meteorological conditions of Solapur, India. The performance analysis of a solar dryer system with and without PCM is done for drying grapes. The inclusion of PCM increases the drying time after sunset by 3 hours per day. The forced convection with PCM is more efficient, more suitable for reducing drying time, increasing drying rate, and produces high quality dried grapes. The results obtained that temperatures inside dryer and solar collector were much higher than outside air temperature during most hours of the daylight.

Keywords: ***Indirect type solar dryer, Tono Therm m-65, Phase change material, Night drying, Grapes***

1 Introduction

The food crises in most developed countries are due in part to the inability to preserve food surpluses. Most of the farmers in world are facing problem with reducing the moisture content from crops to prevent spoilage during storage [1]. The situation is worst for farmers in rural areas where there is no access to electricity. Due to poor preservation most of the harvested crops are susceptible to deterioration [9]. To preserve food products for longer periods drying is one of the most efficient methods. Due to drying the bacterial growth in the products is reduces, drying helps for preserving the products for a long time. There are different solar drying methods, direct type, indirect type, and mixed mode type solar drying. Solar energy is one such renewable source of energy available and is encouraged to be used in every country for its sustainability. There are several researchers working on energy conservation and energy efficiency. As per the present market condition, there are few solar dryers which can be used after the sunset. The solar energy can be stored with the help of energy storing material [8] and this stored energy can be use after the sunset.

2 Literature review

Amedorme S. K. et. al. [2] designed and constructed indirect forced convention solar crop dyer for drying 2 kg moringa leaves having initial moisture of 80 % from which 1.556 kg of water is removed with 0.62 m2 of solar collection area and solar intensity of 320 W/m2. Ogheneruona D. E. et. al. [3] designed and fabricated direct type solar dryer to dry 100 kg tapioca which is having initial moisture of 79% in 20 hours. They had taken 7.56 m2 area of solar collector with solar radiation 13 MJ/m2/day. Bolaji B. O. et. al. [4][12] have designed, constructed and tested the solar wind ventilated cabinet dryer. They observed that drying with the solar cabinet dryer showed better results than open air-drying. Gaeta A. A. [5] had designed and analyzed a cylindrical section solar drying system for drying 70 kg of bean with collector area of 1.21 m2, 750 W/m² and 2.43 kg/hr flow rate of air. He got a maximum value of thermal efficiency 25.64 %.

B. Iyer, S. Nalbalwar and R. Pawade (Eds.)
ICCASP/ICMMD-2016. Advances in Intelligent Systems Research.
Vol. 137, Pp. 35-40.

Mohanraj M. and Chandrasekar P. [6] designed; fabricated and investigated an indirect forced convection solar dryer integrated with heat storage material for drying chilli from 72.8% to the final moisture content 9.2 %. They concluded, forced convectionwith inclusion of heat storage material is more suitable for producing high quality dried chilli and increases drying time by 4 hours/day. Forson et al. [7] designed a mixed mode natural convection solar dryer for drying 160 kg cassava and other crops. 100 kg of water is required to be removed in 30–36 hours from initial moisture of 67% with minimum of 42.4 m2 of solar collector area and solar intensity of 340.4 W/m2. Joshua F. [10] design, construction and testing of a simple solar maize dryer. Test results gave temperature above 45oC in the drying chamber, and the moisture content of 50 kg of maize reduced to about 12.5 % in three days of 9 hours each day of drying. Cengiz Y. and Cakmak G [11].

3 Experimental work

The experimental setup consists of different components such as, solar flat plate collector, phase change material storage tank, drying chamber, trays, blower, reflectors, insulation, etc. The solar dryer consists of solar collector of area 0.5 m2 (1m×0.5m). The absorber plate is placed directly behind transparent glass with a layer of air separating. The air to be heated passes between the glass and absorber plate. To pass air into flat plate collector, gap between glass and absorber maintained at 70 mm [19]. The drying chamber with dimensions 0.5 m × 0.5m × 0.375 m and is made up of 4 mm Bakelite sheet. The solar collector was tilted to an angle 30o with respect to ground surface and system is faced to south direction.

Fig.1. Experimental Set-up

4. Results and Discussion

The performance analysis of this system carried out by testing this experimental set-up under different atmospheric conditions (temperature), different air flow rate, and compared these results, this is very necessary for the purpose of evaluation of system parameters. The experiments were carried out with and without phase change materials.

4.1 Results of natural convection drying with PCM (Case-I)

Natural convection drying with PCM (Case –I) – In this case the drying is done by without any external agency, i.e. only the naturally flowed air is used. The natural air is having a less velocity and flow rate is varying time to time. In this case PCM is used to store the solar energy; this stored energy can be utilized after the sunset or during no sunshine (clouds).
Initial temperature of food sample 28oC and initial weight 2000 gm., weight of dried sample obtained 550 gm; the moisture removed 72.50% from food sample in 30 hours at a drying rate of 48.33 gm/hr.

Table 1 Observations of Natural Convection with PCMs

Time	T_a (°C)	I_c(LUX)	T_{in} (°C)	T_{out} (°C)	T_t(°C)	T_m (°C)	T_b (°C)
First day							
10 am	38	100400	38	38	30	30	30
11 am	39	101200	40	43	33	32	32
12 noon	40	102300	42	45	34	33	33
1 pm	41	103000	43	47	35	34	34
2 pm	40	102600	45	49	36	35	35
3 pm	39	102000	42	46	37	36	36
4 pm	36	101200	40	43	38	37	37
Drying with PCM							
Time	**T_a(°C)**	**T_{PCM}(°C)**	**T_{in} (°C)**	**T_{out}(°C)**	**T_t(°C)**	**T_m (°C)**	**T_b (°C)**
5 pm	36	78	48	53	39	38	38
6 pm	35	76	47	51	40	39	39
7 pm	35	73	45	49	41	41	41
8 pm	34	71	43	46	42	42	42
Second day							
10 am	38	100200	38	38	38	38	38
11 am	40	101400	40	42	39	39	40
12 noon	41	102600	42	45	40	40	41
1 pm	41	102900	43	47	41	41	42
2 pm	40	102400	44	48	41	41	42
3 pm	39	101800	45	49	40	40	40
4 pm	38	101000	43	46	41	40	40
Drying with PCM							
Time	**T_a(°C)**	**T_{PCM}(°C)**	**T_{in} (°C)**	**T_{out}(°C)**	**T_t(°C)**	**T_m (°C)**	**T_b (°C)**
5 pm	36	79	50	55	42	41	41
6 pm	35	76	49	53	43	42	42
7 pm	35	74	47	50	43	43	43
8 pm	34	72	43	45	44	44	44
Third day							
10 am	37	100100	37	37	37	37	37
11 am	39	101300	40	43	38	38	38
12 noon	40	102000	42	45	39	39	39
1 pm	41	102700	44	48	39	40	40
2 pm	39	101800	45	49	40	41	41
3 pm	38	101200	43	47	41	40	40
4 pm	37	99800	43	46	42	41	41
Drying with PCM							
Time	**T_a(°C)**	**T_{PCM}(°C)**	**T_{in} (°C)**	**T_{out}(°C)**	**T_t(°C)**	**T_m (°C)**	**T_b (°C)**
5 pm	36	79	49	5	43	42	42
6 pm	35	77	48	53	44	43	43
7 pm	35	76	46	50	44	44	44
8 pm	34	72	43	45	45	45	45

4.2 Results of forced convection drying with PCM (Case-II)

Forced convection dryingwith PCM (Case –II) – In this case the drying is done by using external agency, that is, air blower and energy storing material as PCM for backup purpose.

Table 2 Observations of Forced Convection with PCMs

Time	T_a(°C)	I_c(LUX)	T_{in} (°C)	T_{out}(°C)	T_t(°C)	T_m (°C)	T_b (°C)
First day							
10 am	38	100500	38	38	29	29	29
11 am	39	101200	40	43	32	32	32
12 noon	39	102400	43	47	34	33	34
1 pm	40	102900	48	53	35	34	35
2 pm	40	102600	50	55	38	37	37
3 pm	39	101900	51	56	40	39	39
4 pm	37	101000	49	48	42	40	40
Drying with PCM							
Time	**T_a(°C)**	**T_{PCM}(°C)**	**T_{in} (°C)**	**T_{out}(°C)**	**T_t(°C)**	**T_m (°C)**	**T_b (°C)**
5 pm	36	79	47	51	43	42	43
6 pm	35	76	46	50	44	43	43
7 pm	34	72	43	46	43	41	42
8 pm	34	69	40	42	41	41	41
Second day							
10 am	38	100700	38	38	38	38	38
11 am	39	101800	40	42	40	40	40
12 noon	39	102700	43	45	42	41	42
1 pm	40	103200	44	48	44	43	44
2 pm	38	102800	45	50	45	45	45
3 pm	36	102200	46	50	46	46	46
4 pm	35	101100	44	49	47	46	47
Drying with PCM							
Time	**T_a (°C)**	**T_{PCM} (°C)**	**T_{in} (°C)**	**T_{out} (°C)**	**T_t(°C)**	**T_m (°C)**	**T_b (°C)**
5 pm	35	79	47	51	48	48	48
6 pm	34	76	46	50	46	46	46
7 pm	34	73	43	46	43	44	43

Initial temperature of food sample 26oC and initial weight 2000 gm., weight of dried sample obtained 530 gm; the moisture removed 73.50% from food sample in 21 hours at a drying rate of 77.4 gm/hr.

Natural convection drying without PCM (Case –III) – In this case the drying is done by without any external agency, i.e. only the naturally flowed air is used. The natural air is having a less velocity and flow rate is varying time to time. In this case PCM is not used and drying is done up to sunset only.

Forced convection drying without PCM (Case –IV) – In this case the drying is done by using external agency, that is the air blower up to sunset only because of not used PCM to store solar energy.

The results of case III in this, initial temperature of food sample 26oC and initial weight 2000 gm., weight of dried sample obtained 550 gm; the moisture removed 72.50% from food sample in 45 hours at a drying rate of 32.22 gm/hr.

The results of case IV in this, initial temperature of food sample 26oC and initial weight 2000 gm., weight of dried sample obtained 540 gm; the moisture removed 73.50% from food sample in 32 hours at a drying rate of 45.63 gm/hr.

The variation of drying time and drying rate with different cases are calculated and plot graph case Vs drying time, and case Vs drying rate is shown in Fig. 2 and Fig. 3 respectively.

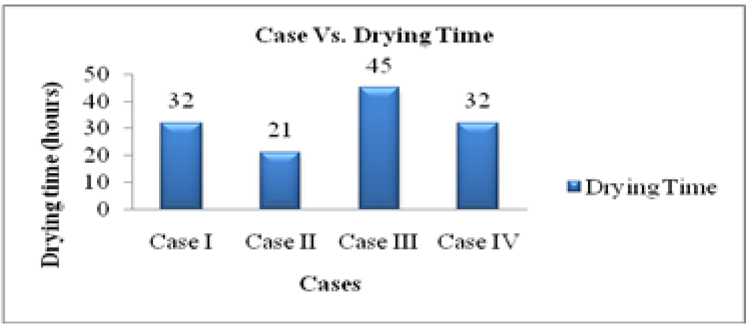

Fig. 2. Case Vs Drying Time

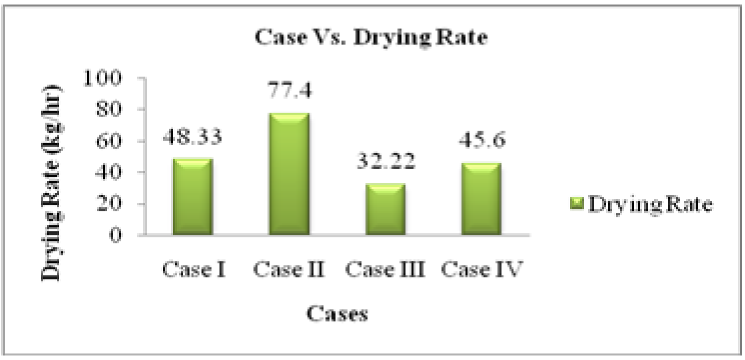

Fig. 3. Case Vs Drying Rate

5 Conclusions

The dryer with PCM enables to maintain consistent air temperature inside solar dryer. This dryer system is analyzed in four different conditions like natural convection, natural convection with PCM, forced convection, and forced convection with PCM. The performance of the system is directly based on the atmospheric condition, the intensity of solar radiation, and airflow rate. Thermal efficiency of system was found maximum in forced convection with PCM comparatively in all other three cases. The reduction in drying occurs by increasing air flow rate. The inclusion of PCM increases the drying time by 3 hours per day. The forced convection solar dryer with PCM is more suitable for maintaining high quality dried samples. Although this dryer was used to dry grapes, it can be used to dry other crops like spinach, potato, onion and chilli etc. The capital cost involved in the construction is much lower to that of a mechanical dryer.

Nomenclature

T_a: Ambient Temperature	I_c: Solar Intensity
T_{in}: Inlet air Temperature	T_{out}: Outlet air Temperature
T_t: Temperature of top tray	T_m: Temperature of middle tray
T_b: Temperature of bottom tray	T_{PCM}: Temperature of PCM

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