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Study on Performance of Solar Dryer with Thermal Storage and Desiccant

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Abstract: This paper presents experimentation on model developed to compare the performance of solar drying with and without dehumidification system. Basic components of system consist of flat plate solar collector, drying chamber, desiccant bed and blower to maintain forced air circulation inside the system.
Humidity of fresh air supplied to collector reduced by passing it through two stationary desiccant beds, which work alternately for adsorption and regeneration. Exhaust heat used for regeneration thereby overall efficiency of system increased. Drying rate obtained from solar drying with desiccant bed, solar drying without desiccant bed and open sun drying are 0.1094 Kg/hour, 0.09375 Kg/hour, and 0.0775 Kg/hour respectively.
It concluded that by use of desiccant bed increases drying rate that takes near about three hours less to reach same moisture content compared with solar drying without desiccant bed.
From results obtained it further found that desiccant bed based solar dryer gives higher drying chamber efficiency than without desiccant bed system due to increased moisture pick-up capacity.
Also, in built latent heat thermal storage was able to provide 7 to 8 ^{0}C higher temperature than surrounding after sunset for about 2 hours.
Keywords: Solar dryer; desiccant bed; drying chamber; thermal storage material; collector efficiency.

I. INTRODUCTION

For fulfilment of need of food to every individual reduction in wastage of food takes same importance as going for higher crop productivity.

One of method to reduce wastage of food is sun drying which is being use from several years. Drying involves removal of moisture from the product by heating by supplying heated mass of air around it to carry moisture along it. Process of solar drying depends on various parameters such as solar radiation, ambient temperature, air velocity, relative humidity, and initial moisture content, type of crop, and mass of food product exposed to drying per unit area [1]. There is limit on maximum drying temperature for various products and varies from products to products [2].

Maximum temperature attained inside dryer under static air condition as compared to forced air condition [3]. Forced convection drying system has higher drying capabilities as compared to natural convection system as mass transport is dominant in forced convection and takes lesser drying time [4].

Mass flow rate of air, collector inclination affects the performance of collector, also moisture removal rate and drying air humidity increases with increase in depth of drying bed [5]. Drying air with lesser humidity took less time to dry the product and humidity can reduced by use of solar based dehumidification system [6]. Moisture absorbing capacity of desiccant material is higher at lower temperature and reduces with operating temperature [7].

Solar drying based on forced circulation with desiccant material gives optimum performance. Further performance of desiccant based solar drying system improved by 20% by use of reflective mirrors [8]. Solar dryer integrated with desiccant thermal energy storage makes solar drying more effective in terms of drying time and specific energy consumption, near about 45% reduction in drying time obtained with desiccant based system. [9].

About 153% heat gain obtained through desiccant wheel based solar drying system with optimum wheel rotation of 15 revolutions per hour [10].

Nomenclature,

A_c	Area of collector	m^2
C_p	Specific heat	J/kg ^{0}C
I	Solar radiation intensity	W/ m^2
m_i	Initial mass of product	kg
m_f	Final mass of product	kg
m_{drv}	Moisture content on dry basis	kg/kg
m_{wet}	Moisture content on wet basis	kg/kg
m_a	Mass flow rate of air	kg/sec
T_{ic}	Inlet temperature of collector	^{0}C
T_{oc}	Outlet temperature of collector	^{0}C
T_{id}	Inlet temperature of collector	^{0}C
T_{od}	Outlet temperature of collector	^{0}C
η_c	Collector efficiency	-
η_d	Drying chamber efficiency	-

Abundant solar radiations available during daytime and this can be store by use of thermal storage media. Sand, brick, stones, steel balls, water are commonly used sensible heat storage media [11]. Phase change materials (PCM) are commonly used latent heat storage media and are more effective due to high-energy storage density [12].

Energy stored in PCM material given by,

$$Q = \int_{T_i}^{T_m} m \times C_p \times dT + m a_m \Delta h_m + \int_{T_m}^{T_f} m \times C_p \times dT$$

Effective arrangement to store PCM for solar drying application is packed bed arrangement, which helps to maintain 40-45 ^{0}C temperature for about 6 hours after sunset [13]. Airflow has effect on collector performance; airflow rate between 0.0894 Kg/sec to 0.1204 Kg/sec gives higher temperature rise inside dryer [14]

II. EXPERIMENTATION

Experimental set-up consists of two desiccant bed of similar size to which fresh air supplied from blower. Piping and valve arrangement provided to keep both beds working simultaneously for absorption and regeneration. Dried air from desiccant bed supplied to flat plate air collector where it gets heated and supplied to drying chamber. This heated air inside drying chamber evaporates the moisture from chilies kept on drying trays and leaves the drying chamber. Air leaving the drying chamber again re-use for regeneration of desiccant bed and then air exhaust is open to atmosphere.

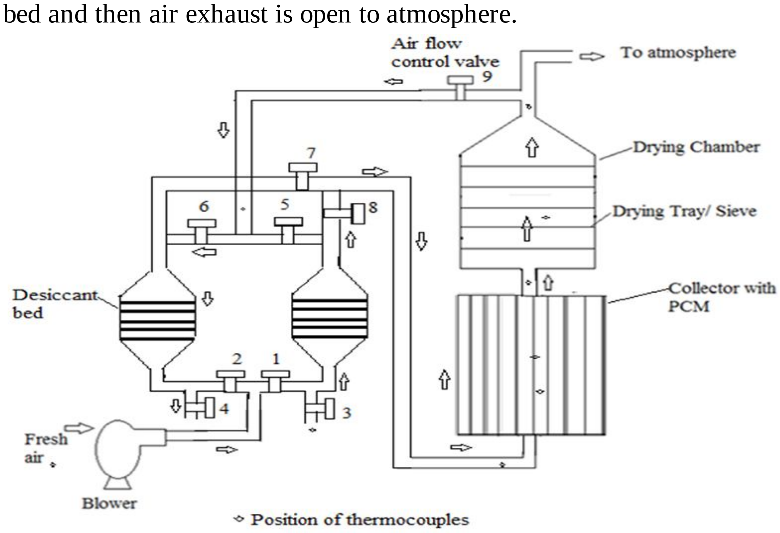

Figure 1. Schematic of experimental set-up

Main purpose of this to compare the performance of solar drying system with and without dehumidification system over open sun drying, to compare this performance following tests are performed

A. Solar drying system with desiccant bed
B. Solar drying system without desiccant bed
C. Open sun drying

To compare the performance of these three tests first sample of 3 Kg of red chilies taken for individual test. For first test solar drying with desiccant bed 3 Kg of Red chilies loaded inside drying chamber. Experimentation is started at 10:00 AM at Nagpur (Latitude21.14580 N and longitude 79.08820 E).
Initial readings of temperature noted and blower switched on. Air supplied to collector through desiccant bed B1 for first hour then for next hour fresh air passed through bed B2 by manually operating various valves, at the same time desiccant bed B1 supplied with exhaust air for regeneration purpose.
Same procedure continued till desired moisture content in product id obtain and readings of temperature, relative humidity and solar radiations taken hourly basis.
Second test solar drying without desiccant bed performed by directly supplying air from blower to collector and exhaust made open to atmosphere. Same 3 Kg of red chilies loaded on drying trays and readings are noted till desired moisture content is achieved.
Third test is open sun drying for which 3 Kg of red chilies kept on open space under direct solar radiations and allowed to dry till final moisture content is achieved.

Parameters required to evaluate performance of solar drying system

1) *Moisture content on dry basis [8],*

$$m_{dry} = \frac{(m_i - m_f)}{m_f}$$

2) *Moisture content on wet basis [8],*

$$m_{wet} = \frac{(m_i - m_f)}{m_i}$$

3) *Average Drying rate:* It is the ratio of amount of product dried to the total time required to attain required moisture content.

$$\text{Avg. drying rate} = \frac{\text{Amount of product dried}}{\text{Total time required for drying process}}$$

4) *Collector efficiency [6]:* Collector efficiency defined as ratio heat gain by air flowing through collector to total incident radiation. Collector efficiency calculated by following formula,

$$\eta_c = \frac{m_a \times C_p \times (T_{oc} - T_{ic})}{A_c \times I}$$

5) *Drying Chamber Efficiency [6]:* Drying chamber efficiency given by equation,

$$\eta_d = \frac{M_w \times h_{fg}}{m_a \times C_p \times (T_{id} - T_{od})}$$

III. RESULT AND DISCUSSION

Maximum solar radiations available nearly about at 1:00 PM followed by rise in ambient temperature maximum temperature found near about 2:00 PM where relative humidity is also low compared to morning and evening hours. From graph, it seen that time between 1:00 PM to 3:00 PM more favorable condition available for drying.

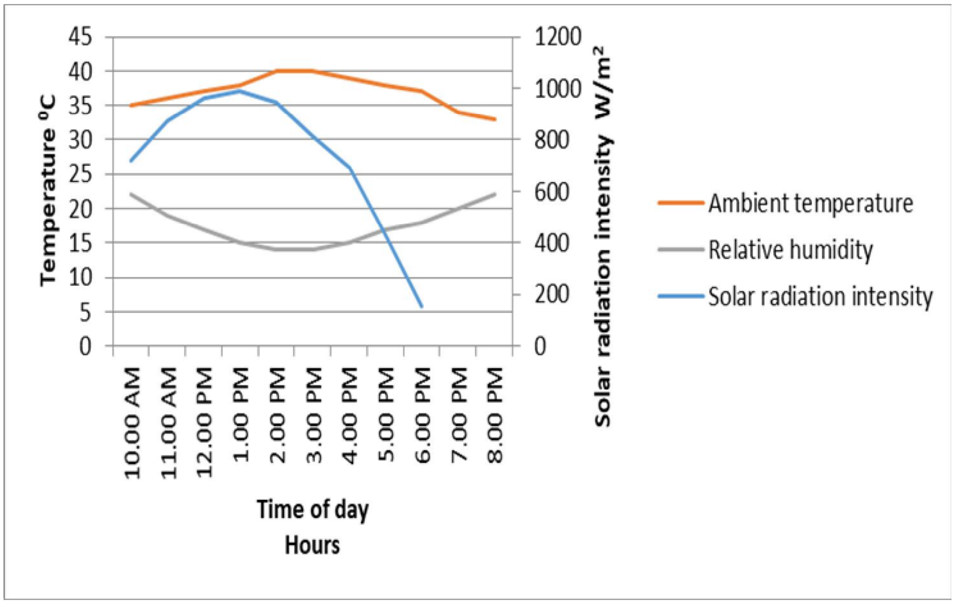

Figure 2. Variation of ambient conditions along day time

Figure 3 shows variation of ambient, collector inlet temperature, collector outlet temperature, dryer inside and exhaust temperature along the day time for Test-I with use of desiccant bed. Due to variation of solar intensity, all temperature varies along daytime. Maximum temperature attained in system about 2:00 PM. It seen from graph collector provides higher temperature than ambient even after sunset due use of phase change material about 2 hours.

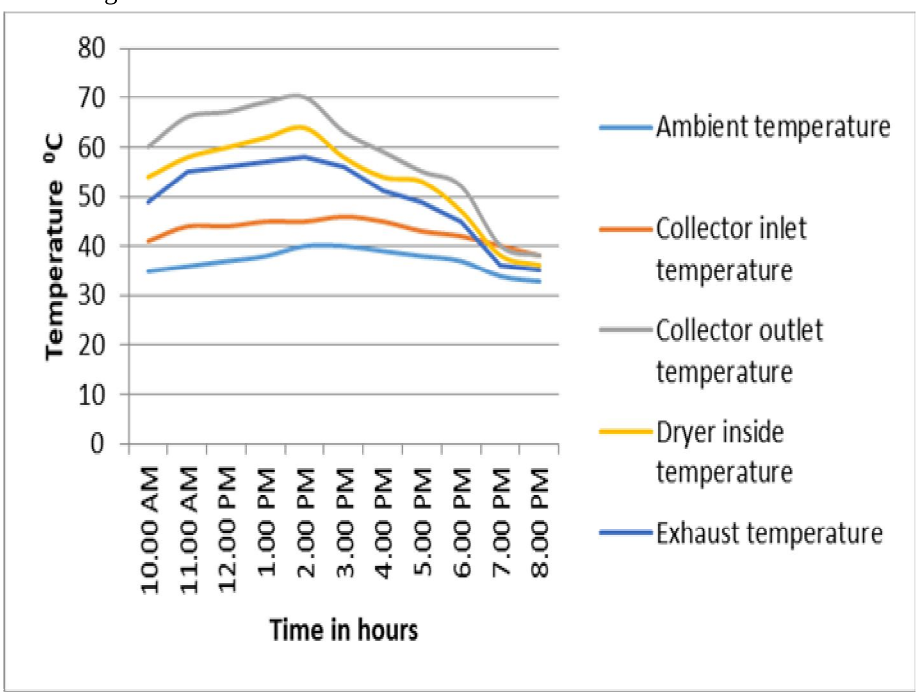

Figure 3. Variation of temperature at various location during Test-I

Figure 4 shows variation of ambient, collector inlet temperature, collector outlet temperature, dryer inside and exhaust temperature along the day time for Test-II without use of desiccant bed. As comparing variation of temperatures with previous Test-I it seen that Test-I provides neat about 2-3 ^{0}C higher temperature than Test-II due to use of desiccant bed.

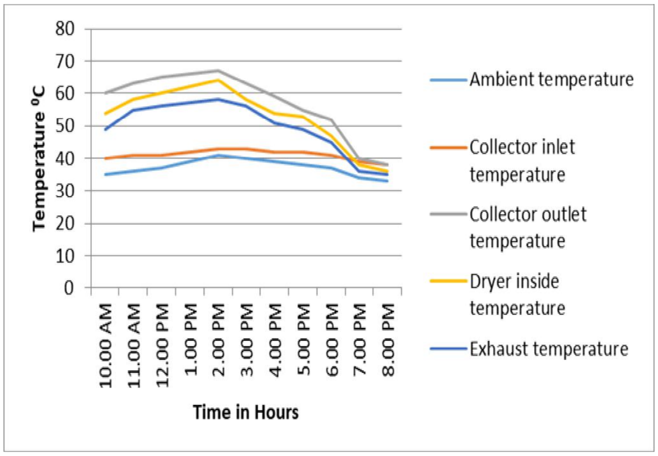

Figure 4. Variation of temperature at various locations during Test –2

Figure 5 shows variation of collector efficiency with time for first day of both tests. Collector efficiency depends on solar radiation it increases with intensity of radiation. Maximum value of efficiency attained is 59.24% at 2:00 PM later it declines as solar radiation intensity reduces in evening hours. Results show collector efficiency of solar drying with desiccant bed gives higher efficiency than solar drying without desiccant bed.

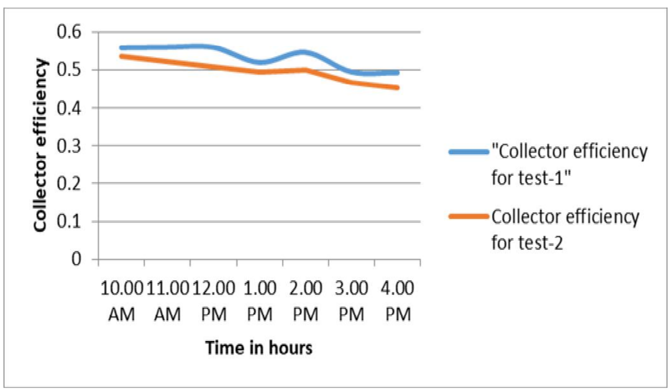

Figure 5. Variation of collector efficiency with time for Test-I

Figure 6 shows variation of drying chamber efficiency along daytime for both the tests, maximum efficiency 16.18% obtained during solar drying with desiccant bed whereas only 12.98% drying chamber efficiency achieved during Test-II.

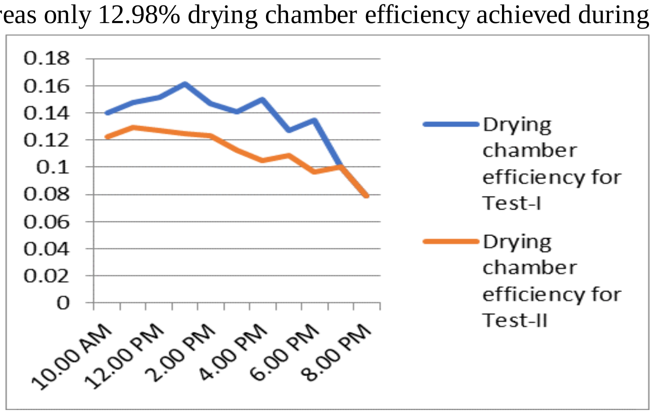

Figure 6. Variation of drying chamber efficiencies for both tests

Table 1. Result summary

Parameters	Solar drying with desiccant bed (Test-I)	Solar drying without desiccant bed (Test-II)	Open sun drying (Test-III)
Initial Weight (Kg)	3	3	3
Final Weight (Kg)	0.660	0.668	0.670
Initial moisture content (wet basis) %	78	77.73	77.66
Final moisture content (wet basis) %	22	22.26	22.33
Drying time (Hours)	29	32	52
Drying rate (Kg/hour)	0.1034	0.09375	0.0557
Blower operating hours	15	18	-

IV. CONCLUSION

Based on above discussed results following conclusion are drawn,

1) Solar drying with desiccant bed and exhaust recirculation (Test-I) gives higher drying rate 0.1034 Kg/hour and it took only 29 hours to dry chilies from initial moisture content of 78% to final moisture content of 22% on wet basis. While Solar drying without desiccant bed (Test-II) took 32 hours to dry chilies from initial moisture content of 77.73% to final moisture content of 22.26% on wet basis and has drying rate 0.09375 Kg/hour which is lower than Test-I. Third test was for open sun drying which took 52 hours to dry chilies from 77.66 % to final moisture content of 22.33% on wet basis. Thus, thus solar drying with desiccant bed gives higher drying rate and takes lesser drying time to attain final moisture content compared with solar drying without desiccant bed and open sun drying.

2) Use of paraffin wax as thermal storage increases drying time after sunset up to two hours and provides 7 ^{0}C to 8 ^{0}C higher temperature than the surrounding.

3) Quality of dried chilies under open sun drying regards with colour and appearance was very poor compared with solar drying system.

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