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Evaluation of Solar Dryer/Air Heater Performance and the Accuracy of the Result

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Abstract

This paper investigates the feasibility of using Lauric acid as a phase change material (PCM) to store excess solar energy and release it when the energy availability is inadequate or not available for solar drying process. With the increased emphasis on the efficiency of solar heating and drying facilities, the performance of ancillary equipment is becoming increasingly important. The air heater is a source of lost thermal efficiency in two ways -- air leakage into dryer side and poor heat recovery. Moreover, air in leak makes it difficult to determine the exiting hot air temperature and the performance of the air heater. In the present study, attention was given on the heat transfer characteristics of the PCM during the charge and discharge periods. The effects of inlet hot air temperature and inlet air velocities on the charge time were determined, while during the discharge period only the effect of inlet ambient air velocity was considered. This study also addresses the issue of properly evaluating the air heater performance and the accuracy of the final result. The appendix discusses the procedures used to determine the individual measurements and the uncertainty of these measurements.

Keywords: Solar Energy.;Air Heaters; Uncertainity Analysis; Efficiency of solar air heates; Phase change meaterial storage

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1.0 Introduction

Simulation models play an important role in the drying methods and their improvement. It is difficult to define the moisture transfer in food products in mathematical terms (Bruin and Luyben, 1980). Some researchers have stated that food products usually dry in decreasing rate period and that the moisture transfer in solids can be explained by Fick's diffusion law (Mulet et al., 1987). Thin-layer drying models can be divided into three categories, namely theoretical, semitheoretical and experimental. Theoretical models explain the drying character and their applicable to every working condition but some assumptions relating to product geometry, mass diffusivity and conductivity can lead to some problems (Fortes and Okos, 1981). In semi-theoretical models, Fick's second law is taken as basis and the models are generated upon the results of the conducted experiments (Parry, 1985). Although the models appear some results related to the drying character, they can be validated only within the predetermined experimental study range (Planinic et al., 2005). On the other hand, the experimental models are generated as taking into consideration only the experimental results. Therefore they cannot explain the character of drying process since the experiments are realized within the predetermined range (Ozdemir and Devres, 1999). In the literature it has been presented some models and studies to expose the effects of the dried product features and the dryer environment conditions such as air temperature, moisture, and flow rate on the drying process. Karathanos and Belessiotis (1999) applied thin-layer model for drying the agricultural products consisting high-sugar such as currant, sultana, fig, and plum. They used Page equation for modeling the drying of fresh fruits. Midilli and Kucuk (2003) applied both thin-layer forced and natural solar drying processes in order to explain the drying behaviour and to develop the mathematical modelling of shelled and unshelled pistachios. Lahsasni et al. (2004) presented the thin-layer convective solar drying and the mathematical modelling of prickly pear peel. Midilli–Kucuk drying model gave the best results and showed good agreement with the experimental data obtained by Doymaz (2006), who examined the thin-layer drying behaviour of black grapes in a laboratory dryer. The Page model was found to be the most suitable for describing drying curves of black grapes.Yazdani et al. (2006) determined the sorption isotherms of pistachio by experiment and then fitted by six models. The comparison between the experimental points and predicted sorption isotherms showed that the Smith model seemed to be the most suitable for describing the sorption isotherms of pistachio. Drying experiments were carried out with pears for different operating conditions by Guine (2008). His major purpose was validating a diffusion based model previously developed to represent the drying behaviour of pears in a continuous convective drier, which includes the timely variation of the fruit chemical, physical and thermal properties. Ruiz Celma et al. (2009) proposed a mathematical model for the thin-layer infrared drying process of wet grape residues by using a non-linear regression analysis (Marquart's method) and a multiple-regression analysis. Swasdisevi et al. (2009) developed a mathematical model for predicting the moisture content and temperature of a banana slice undergoing combined vacuum and far-infrared radiation.

Nomenclature

m	mass of substance (kg)
Cp	Specific Heat of substance (kJ.kg^{-1}.K^{-1})
Q	Heat Stored or absorbed (kJ.kg^{-1})
T	Temperature (K)

1.1. Use of Latent Heat Storage System for Solar Drying

Most parts of the India receive mean daily solar radiation in the range of 5–7 kwh m_2, and have more than 275 sunny days in a year. Hence, solar drying has a high potential of diffusion in the country, and offers a viable option in the domestic sector. The major disadvantage of solar dryer is the dependency on local weather conditions, with interrupted insolation that decreases the quality of the dried product. Solar radiation intensity can change quite significantly during one-hour time on partially cloudy day and these changes can have significant impact on the air temperatures at the outlet of the air collectors (pavel et al., 2012). The performance of the integral type natural circulation solar-energy dryer was found to be affected largely by seasonal weather variations (ekechukwu and norton, 1998). Case hardening, shrinkage and over burning of the dried products are the main problems in drying due to the peak temperature rise at noon. Solar driers incorporated with a thermal storage system take care of the problems of interrupted insolation and peak temperature rise during noon. Many thermal energy storage systems have been suggested, and these include sensible heat storage, chemical energy storage and latent heat storage. The thermal performance of the air heater with sensible storage materials is considerably higher than that without storage (aboul-enein et al., 2000). Amongst the various energy storage techniques of interest, latent heat storage is particularly attractive, because of its ability to provide high energy storage density and its ability to store energy at a constant temperature, corresponding to the phase transition temperature of the energy storage substance.

Latent heat storage (lhs) is the heat absorption or release when a storage material undergoes a change of phase from solid to liquid or liquid to gas or vice versa at more or less constant temperature. the storage capacity of the lhs system with a phase change material (pcm) medium is given by

$$Q = \int_{T_i}^{T_m} mC_p dT + ma_m \Delta h_m + \int_{T_m}^{T_f} mC_p dT$$

$$Q = m[C_{SP}(T_m - T_i) + a_m \Delta h_m + C_{lP}(T_f - T_m)]$$

Suitable phase change materials that may be used for latent heat thermal energy storage applications are reviewed (abhat, 1983). The most important pcms include fatty acids, paraffin waxes, glauber's salt, calcium chloride hexahydrate, sodium thiosulfate pentahydrate and sodium carbonate decahydrate (zalba et al.,2003).

2.0 Experimental Setup

The experiment was accomplished in Renewable Energy Lab, Department of Mechanical Engineering, Institute of Technology, Banaras Hindu University, Varanasi, India during June 2013. The experiment was carried out using a solar drying system equipped with latent heat storage[LHS] vessel designed for drying Potato and Carrot using hot air by forced convection. The latitude, longitude and altitude of Varanasi are, respectively, 25.20°N and 83.00°E, 80.71 m above the sea level.

The block diagram of solar dryer[Figure 1] have three main components:

Fig. 1 Block diagram of solar air heater and dryer assembly

A flat-plate collector was used to catch and convert solar radiation to heat and transfer the heat to a moving air. The air heater is connected to a separate drying chamber where the sample is kept. A fan was used to blow the heated air through the heat storage out to a drying chamber, which was used to dry potato and carrot chips. Here, the heat from moisture evaporation is provided by convective heat transfer between the hot air and the wet sample. The drying is basically by the difference in moisture concentration between the drying air and the air in the vicinity of crop surface. Along with the drying, PCM[Lauric Acid] kept in latent heat storage vessel of drying chamber also heats up and stores latent heat in it. This procedure is followed during the sunshine period, but during the off shine period the drying takes place by the PCM stored energy which is released during the phase transform liquid to solid.

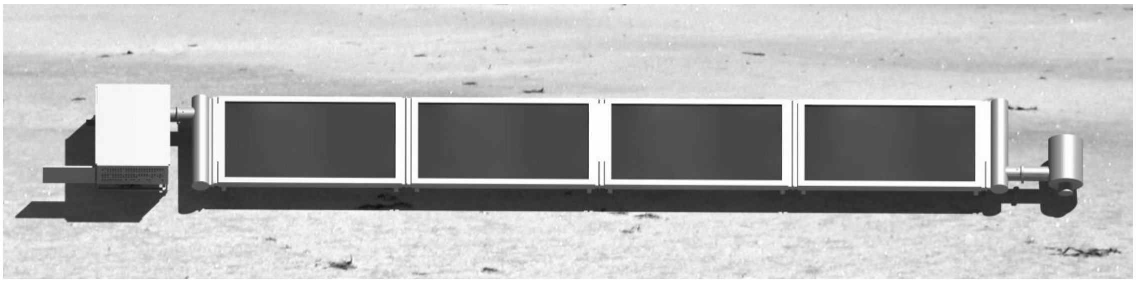

Fig. 2: Schematic Diagram

2.1 Sample Drying

The Potato and Carrot purchased from a local market were cut manually into slices of diameter 15 mm and thickness 3 mm and 5 mm. The samples were spread evenly in a single layer on eight similar stainless steel wire mesh trays, three kept inside the drying chamber of forced convection solar dryer and another one over wooden blocks in open air sun. Solar drying experiments were carried out simultaneously under both drying conditions on a clear sunny day. The temperatures of the drying air were measured by calibrated chromel-alumel thermocouples. The sample weight loss was measured at regular intervals of time, using a precision Goldtech Brand electronic weighing machine maximum capacity 20 kg and minimum 0.40 gm. Moisture content (dry basis) was calculated from weight loss data and dry solid weight of the samples. The dryer contributed to reduction in drying time in comparison with open sun drying.

3.0 Uncertainity Analysis

An estimation of uncertainity has been carried out separately for both days. Data of a particular measurement for a number of days have been taken and an estimate of individual uncertainties of the sample values has been calculated. An estimate of internal uncertainities (U_i) has then been found by:

$$U_i = \sqrt{\frac{\Sigma \sigma_i^2}{N^2}}$$

where σ_i are the standard deviations of each sample and N is the total number of samples.

Uncertainty in collector efficiency = 0.0859
Uncertainty in dryer efficiency = 0.0507

5.0 Results and Discussions

The experimentation was carried out and data were obtained on the experimental setup shown in Fig.2. On the basis of the experimental data, the results have been reported. Figs. 3 and 4 show the variation of solar radiation intensity on 6 and 7 June 2013 under local climatic conditions of Varanasi, India.

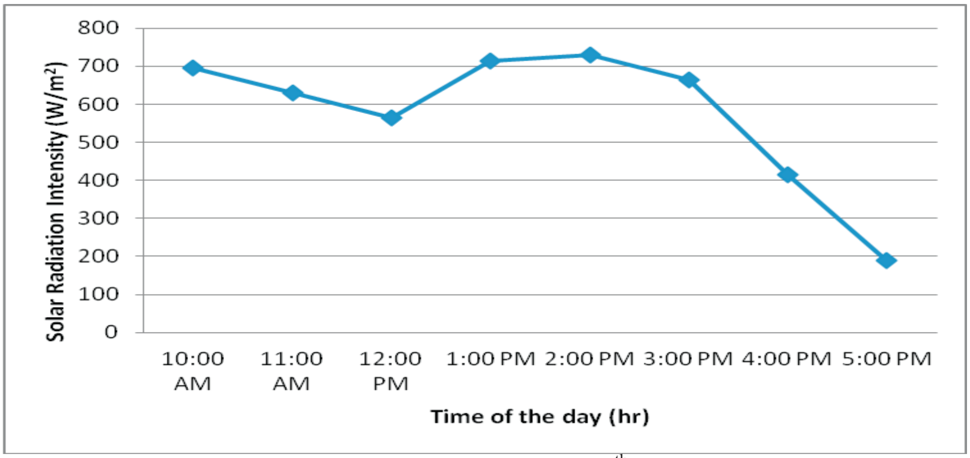

Fig. 3: Variation solar Intensity on 6th June 2013

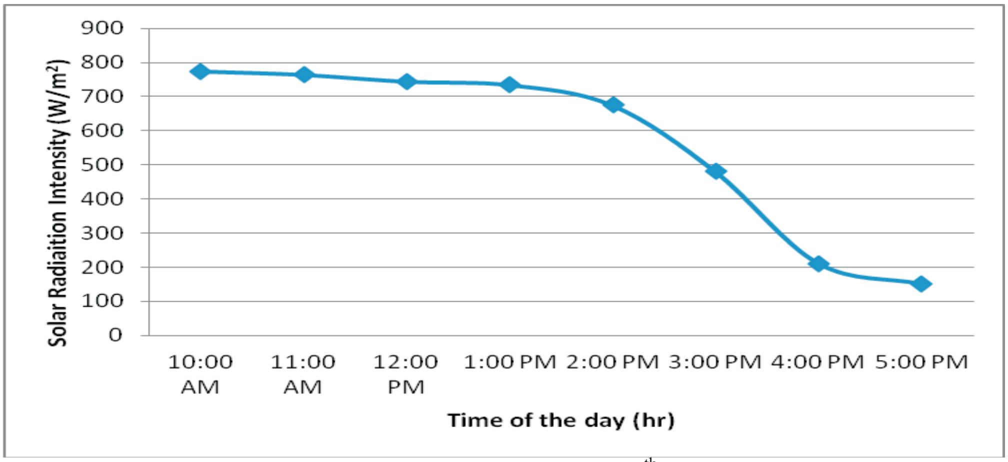

Fig.4: Variation of solar intensity on 8th June 2013

Fig.5 and 6 show the variation of ambient temperature, inlet temperature and outlet temperature of air on 6 June and 8 June 2013 respectively. It is clear from the figures that the temperature variation is directly proportional to the intensity variations. Also there is considerable difference in hot air and ambient temperature due to collector capacity of heating the ambient air.

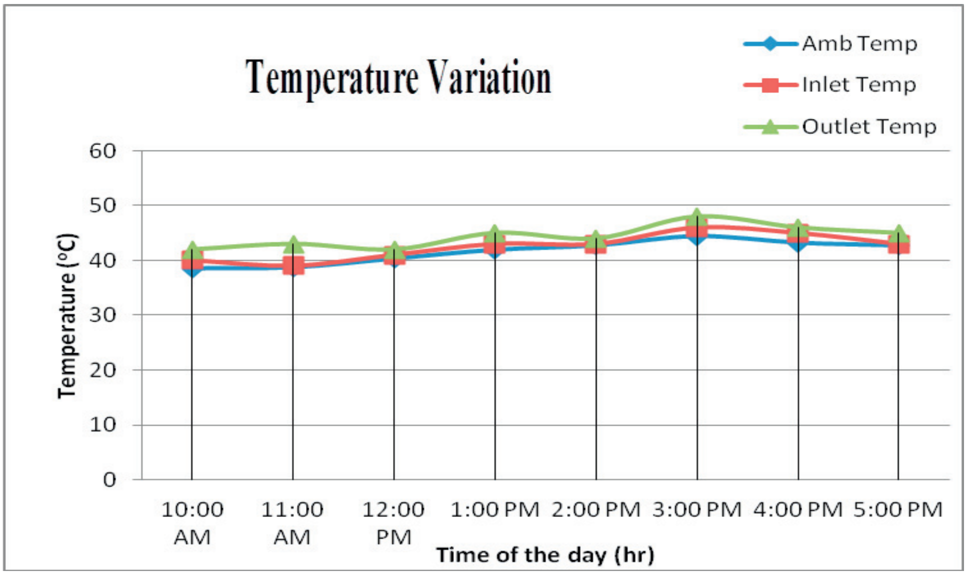

Fig.5: Ambient, Inlet and Outlet Temperature variation 6th June 2013

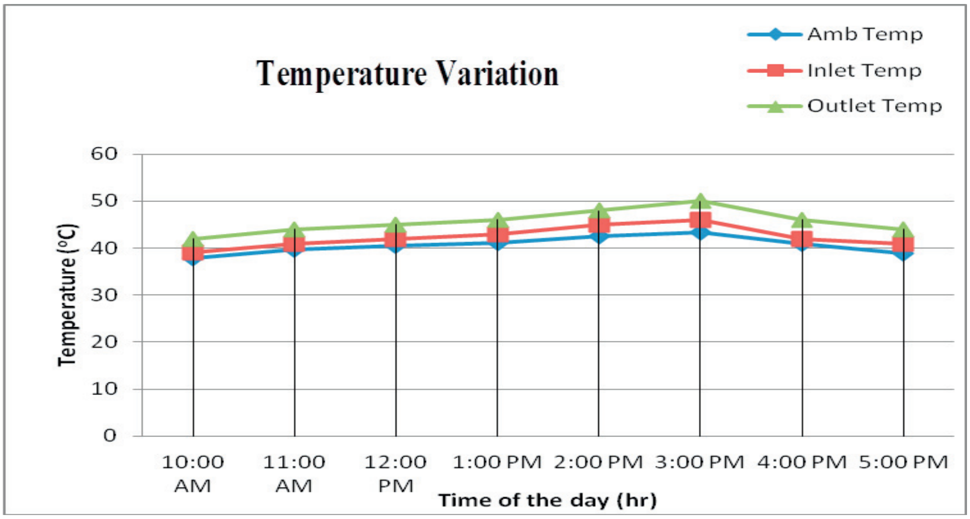

Fig.6: Ambient, Inlet and Outlet Temperature variation on 8th June 2013

Figure 7 and 8 show the collector and dryer efficiency on June 6, 2013. On first day, the collector efficiency varies from 9.3% to 52%, whereas the average collector efficiency is 24.07% which is illustrated in Fig. 8. The dryer efficiency varies from 9.8% to 26%, whereas the average dryer efficiency is 17.53% which is illustrated in Fig.9.On second day, the collector efficiency varies from 26.5% to 57.1%, whereas the average collector efficiency is 33.4% which is illustrated in Fig.9. The dryer efficiency varies from 17.7% to 42.8%, whereas the average dryer efficiency is 24.75% which is illustrated in Fig. 10. It is clear from the both the figures that the trend of efficiency variation for both collector and dryer is similar and vary with the intensity, which indicates the experimental setup design is error free. Similar results have been obtained on June 8, 2013 as depicted in Figs. below.

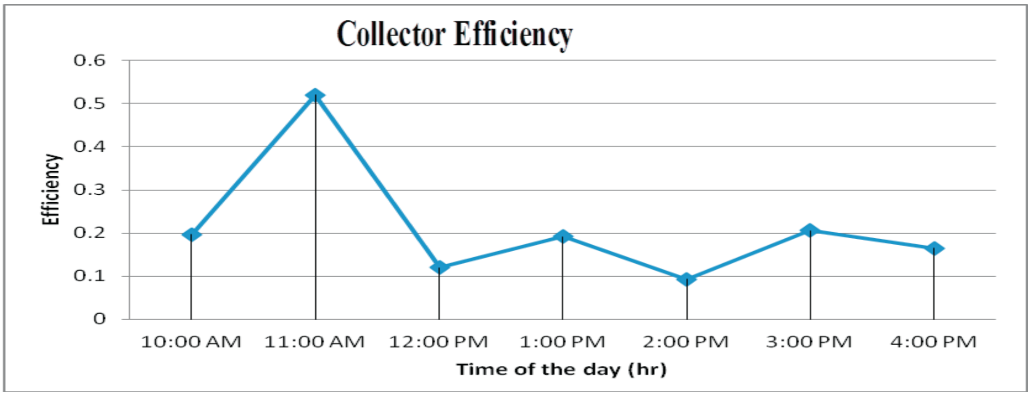

Fig.7: Collector Efficiency on 6th June 2013

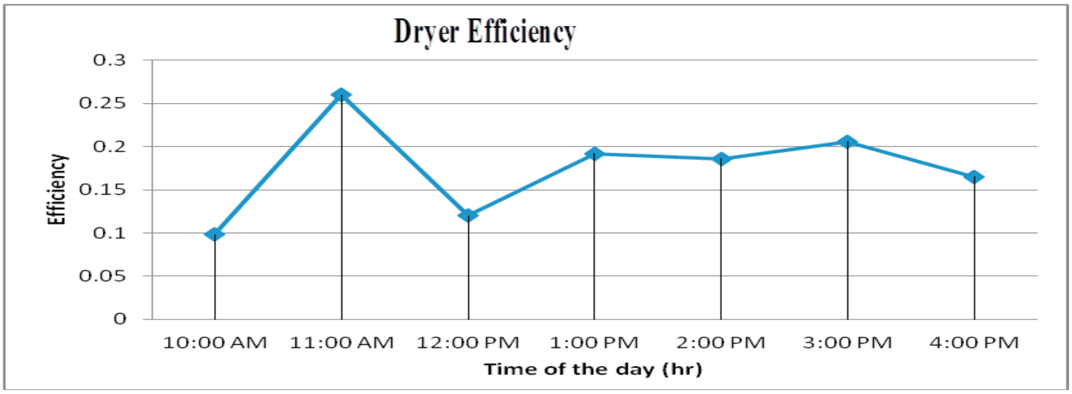

Fig.8.Dryer Efficiency on 6th June 2013

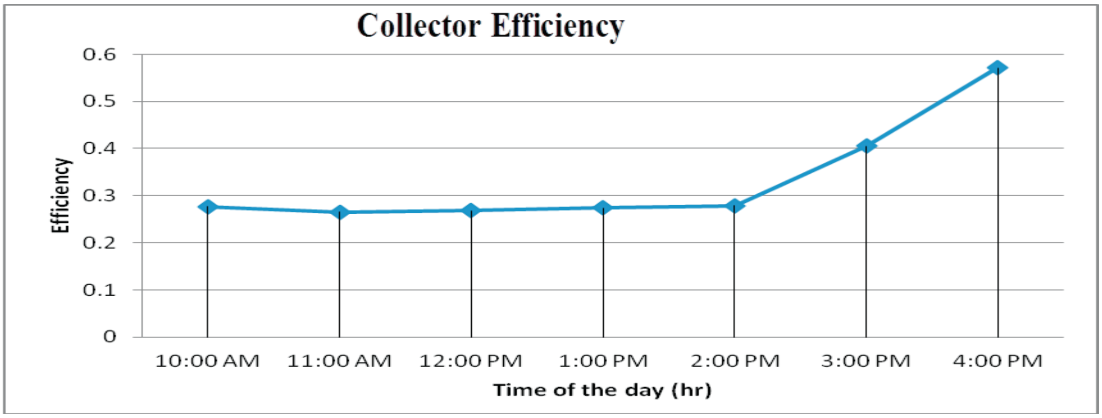

Fig.9: Collector Efficiency on 8th June 2013

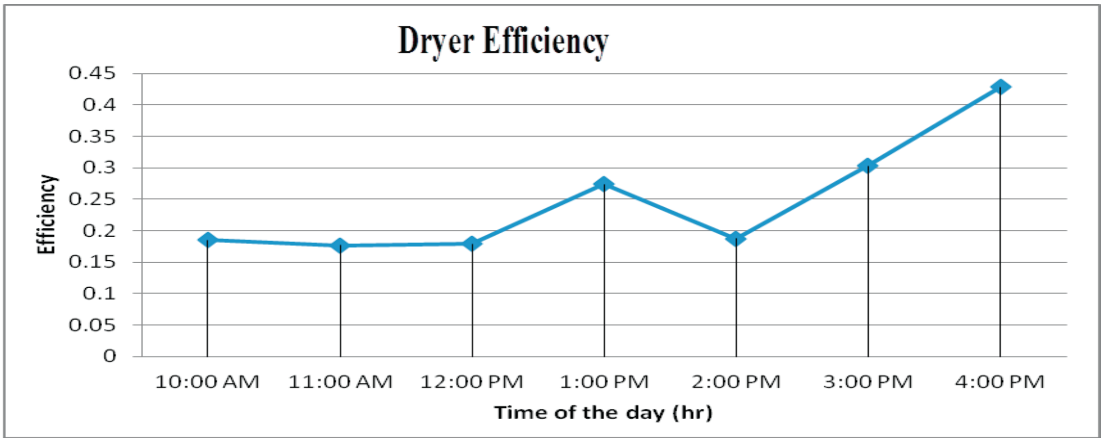

Fig.10: Dryer Efficiency on 8th June 2013

Figs. 11 and 12 show the variation of the moisture content (%) of potato with the time of day on June 6 and difference in moisture removal with thickness of 3 mm and 5 mm of potato chips on June 8, 2013.It is seen from the Fig.13 that the moisture removal is slightly higher in case of low thickness chips. However, this variation will be more when the quantity of drying is less. Figs, 14 shows the variation of the moisture content (%) of carrot with the time of day on June 8, 2013. It is found that there is more variation in % moisture removal in case of carrot for low thickness of carrot chips. The moisture Content was measured on dry basis in both the cases and shown in Figs.15&16 to verify that the curve follow characteristics curve of drying process which is true in this case.

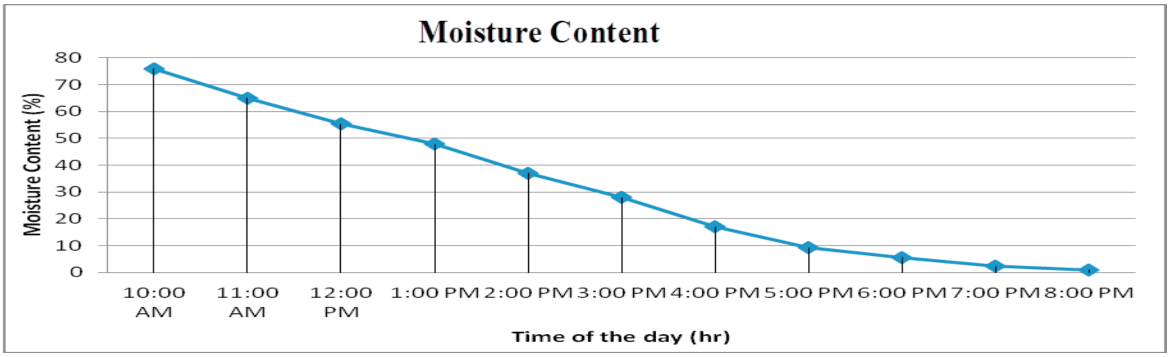

Fig.11: Moisture Content (%) of potato of thickness 3mm on 6th June 2013

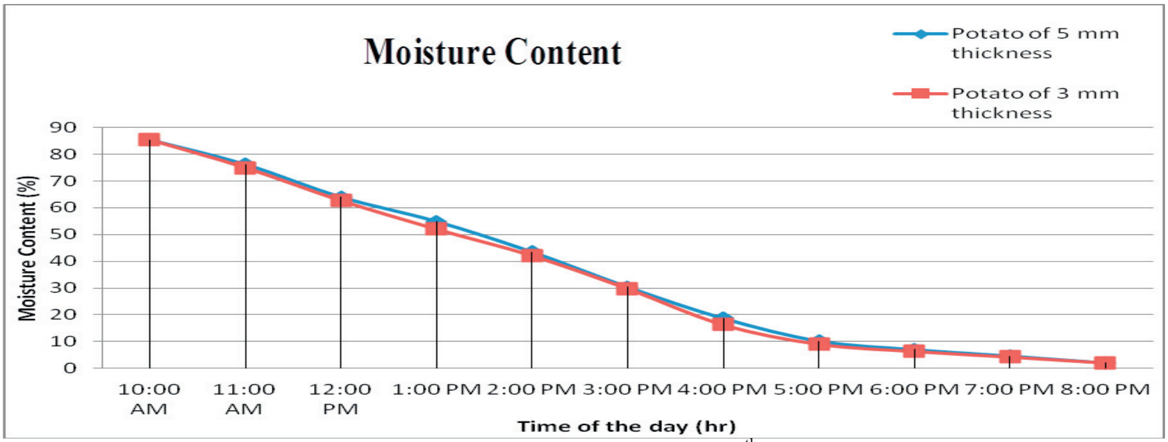

Fig. 12: Moisture Content (%) of potato on 8th June 2013

6.0 Conclusions

A great deal of experimental work over the last few decades has already demonstrated for drying of agricultural food products using solar dryer having solar thermal energy storage in the form of Sensible Heat Storage and Latent heat storage. Heat storage using ‘phase change materials’ is a wise alternative. The main applications for PCMs are when space restrictions limit larger thermal storage units in solar drying systems. Solar energy holds the key to future’s non-exhaustive energy source. Because of discrepancy between the energy supply and demand in solar heating applications, thermal energy storage (TES) device has to be used for the most effective utilization of the energy source. This concept of ‘solar thermal energy storage using PCM in the solar dryer’ reduces the time between energy supply and energy demand, thereby playing a vital role in energy conservation and improves the solar drying energy systems by smoothening the output and thus increasing the reliability for continuous drying of agricultural food products. This system can be considered as a reliable alternative to similar systems with conventional backup for medium scale drying of vegetables and fruits, which require a drying temperature of 50–60°C.

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