Utilization of Solar Energy for Drying Applications

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ABSTRACT
In many countries of the world, the use of solar thermal systems in the agricultural area to conserve vegetables, fruits, coffee and other crops has shown to be practical, economical and the responsible approach environmentally. Solar energy is freely available during day time, while it's not available in the night, which is the major drawback for such type of the systems. Developing efficient and inexpensive energy storage devices using through phase change materials (PCMs) in solar dryers, which can play an important role in energy conservation to fill the gap in between energy supply/demand and important as developing new sources of energy. Also the PCMs storage integrated with a solar dryer for drying of fruits and vegetable and other food products is found to be promising low cost option for preservations. Therefore, in this paper, an attempt has been taken to summarize the investigation of the solar drying system incorporating with PCMs for drying agricultural food products and also the development of the PCMs for these applications at NCEL, RGIPT, Rae Bareli, U.P., India.

Keywords: Solar Energy, Solar Drying, Phase Change Materials, Energy Storage

I INTRODUCTION

Drying using the sun under the open sky for preserving food and agricultural crops has been practiced since ancient times. However, this process has many disadvantages: spoilt products due to rain, wind, moisture and dust; loss of produce due to birds and animals; deterioration in the harvested crops due to decomposition, insect attacks and fungi, etc. Further, the process is labour intensive, time consuming and requires a large area for spreading the produce out to dry [1]. Artificial mechanical drying, a relatively recent development, is energy intensive and expensive, and ultimately increases the product cost. Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs [2]. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment. Solar drying can be used for the complete drying process or as a supplement to artificial drying systems, in the latter case reducing the fuel energy required [3]. Solar dryer technology can be used in small-scale food processing industries to produce hygienic, good quality food products [4]. At the same time, this can be used to promote renewable energy sources as an income-generating option. Further, this solar technology is ideally suited for women since they can place a load in the dryer and then get on with their other numerous tasks [5].

The justification for solar dryers is that they may be more effective than sun drying, but have lower operating costs than mechanized dryers. A number of designs are proven technically and while none are yet in widespread use, scientists still have optimism about their potential. However, available dryers still have some disadvantages such as low efficiency, short time of use within year round, dependence of inside temperature on temporary solar radiation. In order to overcome these troubles, there are some trends being investigated such as adding in phase change materials (PCMs) to keep stable temperature inside and prolong working time of the systems. Energy storage through PCMs not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy.

The aim of this study is to identify and develop the low cost PCMs for drying application and also to find out their thermal properties employing the DSC method. For this purpose, the binary mixtures based on commercial grade fatty acids *i.e.* lauric acid (LA), myristic acid (MA), palmitic acid (PA), stearic acid (SA) and acetamide developed with different weight percentages (10/90, 20/80, 30/70, 40/60, 50/50, 60/40, 70/30, 80/20 and 90/10) and their thermal properties measured through the DSC method. Several slat hydrates i.e. Zinc Nitrate Hexa-Hydrate, Calcium Nitrate Tetra-Hydrate, Sodium Thio-Sulfate, Penta-Hydrate and Sodium Acetate Tri-hydrate are also found as potential candidate, abundant and cost-effective materials for latent heat storage applications from points of view of melting temperature and high latent heat of fusion [6]. The developed PCMs in the present work can use for the other thermal applications and would be easily available in the commercial market in India or as well as in other countries.

II MATERIALS AND METHOD

Commercial grade materials (purity > 98%) such as MA, PA, Acetamide, Zinc Nitrate Hexa-hydrate, Calcium nitrate tetra-hydrate, Sodium thio-sulfate penta-hydrate and Sodium acetate tri-hydrate supplied from the Burgoyne Pvt. Ltd. company used as promising PCMs for this research work and used without purification. To develop the binary mixtures, a series of binary mixtures, i.e., MA-AC, PA-AC and SA-AC prepared with different weight percentages (10/90, 20/80, 30/70, 40/60, 50/50, 60/40, 70/30, 80/20 and 90/10 wt. %). Twenty seven samples (100 g each) formed by mixing in melted state, kept at room temperature for one hour. A semi analytical digital balance (accuracy ±0.0001 g) also used to measure the weight of the samples (g).

III MEASUREMENT TECHNIQUES OF LATENT HEAT OF FUSION AND MELTING TEMPERATURE

The latent heat of fusion and melting temperatures is the main interest of TES systems, which is generally measured by DSC. In this research work, thermal properties of the samples measured by using a DSC 4000 Perkin Elmer model instrument at 2oCmin−1 under a constant stream of nitrogen at a flow rate of 20 ml −1minThe largest deviation in enthalpy measurements was ±2% and the largest deviation in temperature measurements was ±0.1°C. A semi analytical digital balance (accuracy ±0.00001 g) also used to measure the weight of the samples (mg) for the DSC test. Thermal properties i.e. melting temperature (Tm), and latent heat of fusion (λm) of identified and developed PCMs measured by DSC for drying applications are given in Table 1.

Table 1
Thermo-physical properties of identified and developed PCMs

S. No.	*T_m	^ λ_m	Laboratory Code/Name
1	40.72	165.93	Zinc Nitrate Hexa-hydrate
2	45.67	145.15	Calcium nitrate tetra-hydrate
3	46.13	190.21	Lauric acid
4	51.66	206.34	Sodium thio-sulfate penta-hydrate
5	56.65	197.34	Myristic acid
6	57.73	180.79	Stearic acid
7	59.91	135.68	Paraffin Wax
8	62.04	211.43	Sodium acetate tri-hydrate
9	64.89	206.31	palmitic acid
10	81.24	214.59	Acetamide
11	48.08	160.13	MA-AC (60/40 wt.%)
12	48.99	170.13	MA-AC (70/30 wt.%)
13	46.04	188.39	MA-AC (80/20 wt.%)
14	50.69	195.93	MA-AC (90/10 wt.%)
15	55.82	144.01	PA-AC (50/50 wt.%)
16	55.72	143.98	PA-AC (60/40 wt.%)
17	59.42	187.03	PA-AC (70/30 wt.%)
18	59.61	190.34	PA-AC (80/20 wt.%)
19	58.00	184.79	PA-AC (90/10 wt.%)

*Tm : Melting temperature (°C)
^ λm : Latent heat of fusion (kJ/kg)

IV RESULT AND DISCUSSION

Authors identified technical grade fatty acids, i.e., MA (T_m =56.83°C, λ_m =168.27 kJ/kg), PA (T_m =64.25°C, λ_m =206.11 kJ/kg) and AC (T_m =81.24°C, λ_m =214.59 kJ/kg) for this study as these materials having high latent heat of fusion and also easily available with low price in the Indian market.

Pure acids characterized by a single peak in DSC graph, which are also sharp and well-defined. Binary mixtures samples prepared in the laboratory for MA-AC and PA-AC composition to find out their melting temperature and latent heat of fusion through DSC analysis technique with a scan rate of 2oCmin−1 and dat a obtained from the DSC curves were also given in Table 2.

Table 2
Thermal properties of the MA-AC and PA-AC developed materials

S. No.	A	B	MA-AC		PA-AC	
	Wt%		Tm (°C)	λm (kJ/kg)	Tm (°C)	λm (kJ/kg)
1	10	90	N.A.		69.03	69.43
2	20	80	N.A.		55.39	51.72
3	30	70	48.29	60.39	55.03	118.53
4	40	60	48.11	96.26	55.48	83.07
5	50	50	47.70	114.53	55.82	144.01

6	60	40	48.08	160.13	55.72	143.98
7	70	30	48.99	170.13	59.42	187.03
8	80	20	46.04	188.39	59.61	190.34
9	90	10	50.69	195.93	58.00	184.79

N.A. data not available due to the various peaks in D.S.C. figures

Overall nine samples were prepared at different mass fraction of MA-AC which was characterized by DSC measurement were not compatible with each other for proper mixing that is why in the DSC results showed two separate peaks were found [7, 8]. AC binary mixture follows a regular trend within the range of 46°C-48°C still the concentration of MA increase in the mixture from 30 wt.% to 80 wt.%. It was also found that melting temperature was nearly maintained at 48°C for the concentration range of 30 wt.% to 70 wt.%. The binary mixture samples (60/40, 70/30, 80/20 and 90/10 wt.%) showed melting temperature in the range of 46°C-51°C and their latent heat of fusion also high and due to this factor, these binary mixture can be recommended for the drying applications. Figure 1 shows the DSC curves for these four samples MA-AC (60/40, 70/30, 80/20 and 90/10 wt.%) for the 0th cycle. From the figure it's clear that the developed PCMs have a single peak in DSC curve, which are also sharp and well-defined.

For the PA-AC binary mixture development, sample (10/90, 20/80, 30/70 and 40/60 wt. %) did not show high latent heat of fusion, that's why these binary samples can not recommend for the applications. The melting temperature of PA-AC samples (50/50, 60/40, 70/30, 80/20 and 90/10 wt.%) were 55.82oC, 55.72oC, 59.42oC, 59.61oC and 58oC, respectively. The latent heat of fusion was 144.01, 143.98, 187.03, 190.34 and 184.79 kJ/kg, which proved that these developed materials had enough latent heat of fusion. From the table 2, it was also found that melting temperature was nearly maintained within at 55-56oC for the concentration range of 20 wt.% to 60 wt.%, while melting temperature was maintained within at 58-59oC for the concentration range of 70 wt.% to 90 wt.%,. Figure 2 shows the DSC curves of binary mixture samples (50/50, 60/40, 70/30, 80/20 and 90/10 wt.%) for the 0th cycle and these binary samples have a single peak, which are sharp and well defined.

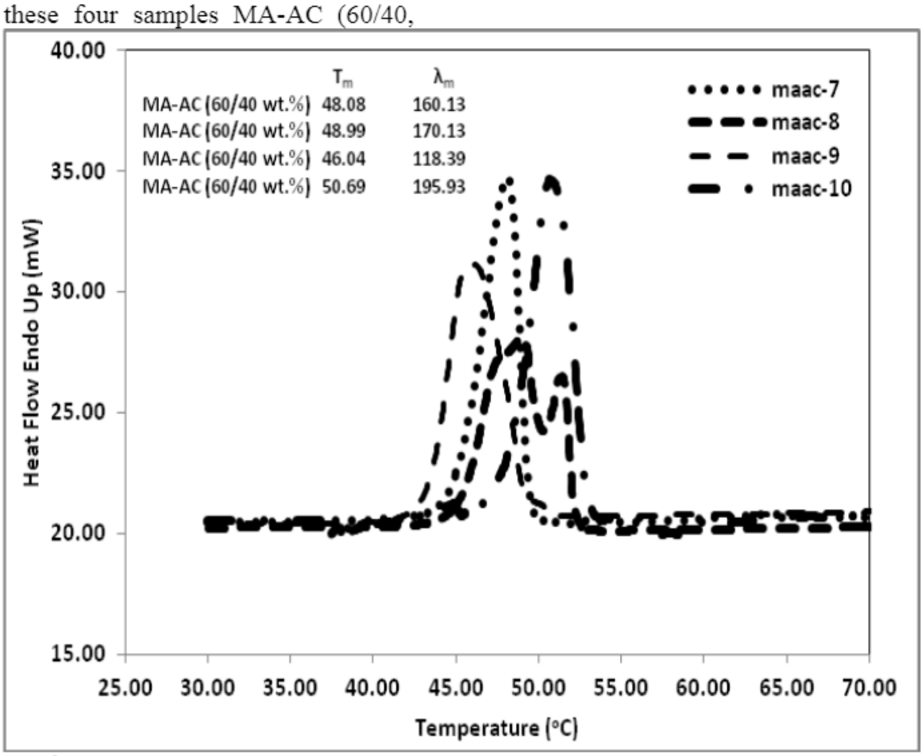

Fig 1: DSC curve with 2°C scanning heating rate for MA-AC (60/40 wt.%), MA-AC (70/30 wt.%), MA-AC (80/20 wt.%) and MA-AC (90/10 wt.%) 0th Cycle.

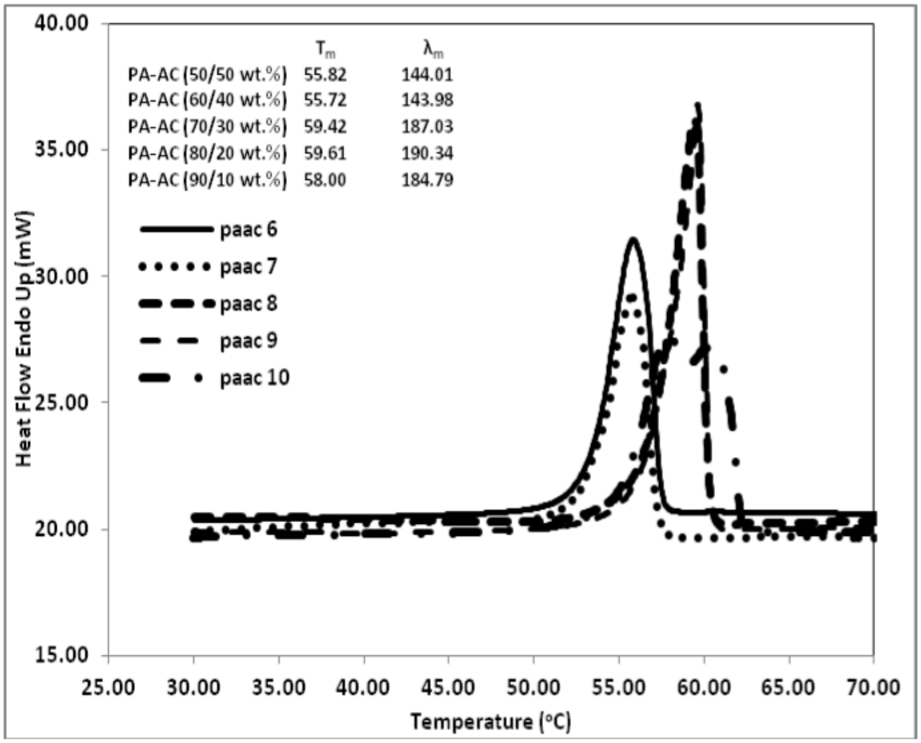

Fig 2: DSC curve with 2°C scanning heating rate for PA-AC (50/50 wt.%), PA-AC (60/40 wt.%), PA-AC (70/30 wt.%), PA-AC (80/20 wt.%) and PA-AC (90/10 wt.%) 0th Cycle.

V CONCLUSION

In this study, binary mixtures were prepared as stable PCMs for solar drying applications. The developed PCMs such as MA-AC and PA-AC with different weight percentages were characterized by using DSC analysis techniques. DSC results showed that only few binary samples were found satisfactory with due to respect of melting temperatures in the desired temperature range for the drying application. These samples also showed high latent heat of fusion (140-220 kJ/kg) with appropriate phase change temperature; this is another reason to recommend these PCMs for the drying applications. It is also recommended that before employing any PCM for applications, its thermal cycle test should be conducted, as the behaviour may change [9]. It was also found that several PCMs are available in local Indian market and having good potential for the drying application.

VI ACKNOWLEDGEMENT

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REFERENCES

[1] Singh P.P, Singh S, Dhaliwal S.S, (2006). Multi-shelf domestic solar dryer. *Energy Converse Manage,* 47 1799–1815.

[2] Anil Kumar and G.N. Tiwari, (2007). Effect of mass on convective heat transfer coefficient during onion flakes drying, *Journal of Food Engineering*, 79, 1337-1350.

[3] Anil Kumar, G. N. Tiwari, Subodh Kumar and Mukesh Pandey, (2006). Role of greenhouse technology in agricultural engineering. *International Journal of Agricultural Research,* 364-372.

[4] Anil Kumar and G. N. Tiwari, (2006). Thermal modeling of a natural convection greenhouse drying system for jaggery: An experimental validation, *Solar Energy*, 80, 1135-1144.

[5] A. Sharma, C.R. Chen, N. V. Lan, (2009). Solar-energy drying systems: A review, *Renewable and Sustainable Energy Reviews*, 13, 1185–1210.

[6] A. Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, (2009). Review on thermal energy storage with phase change materials and applications, *Renewable and Sustainable Energy Reviews*, 13, 318-345.

[7] D. Feldman, M.A. Khan, D. Banu, (1989). Energy storage composite with an organic PCM, *Solar Energy Materials*, 18, 333–341.

[8] D. Feldman, M.M. Shapiro, D. Banu, C.J. Fuks, (1989). Fatty acids and their mixtures as phase-change materials for thermal energy storage. *Solar Energy Materials*, 18, 201–216.

[9] Sharma A, Sharma SD, Buddhi D, (2002). *Energy Conversion and Management,* 43, 1923-1930.