A review of phase change material based thermal energy accumulators in small-scale solar thermal dryers

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Institute of Chemical Engineering

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Introduction

The efforts in science and technology are directed towards more effective utilization of renewable energy sources. The objectives are higher yields of product per device and less ecological risk combined with less initial material used for the total amount of devices.

In solar air drying, thermal energy storage is one of the useful methods to overcome the weakness of the solar intermittent and instable energy characteristics. The heat storage diminished the fluctuation in the inlet temperature and supplied heat flow near constant temperature. The constant temperature regulation helps to prevent degradation of product quality.

The thermal storage can be performed by storing the sensible heat or the latent heat of the storage material. The latent heat is stored when the storage material changes its phase at the working temperature. The advantage of the latent heat storage in respect to sensible one is that much smaller mass and volume of the storage material is needed to store a certain amount of energy.

The aim of the present review is to reveal the current level of development of heat storage with phase change material (PCM) in solar air dryers, which is an area of intensive research. The particular task is on the base of the collected and compared solutions and data on latent heat storage, with a focus on paraffin as PCM, to evaluate the perspectives for energy and cost efficient of latent heat storage for solar dryers of small capacity (for households and small producers).

System types

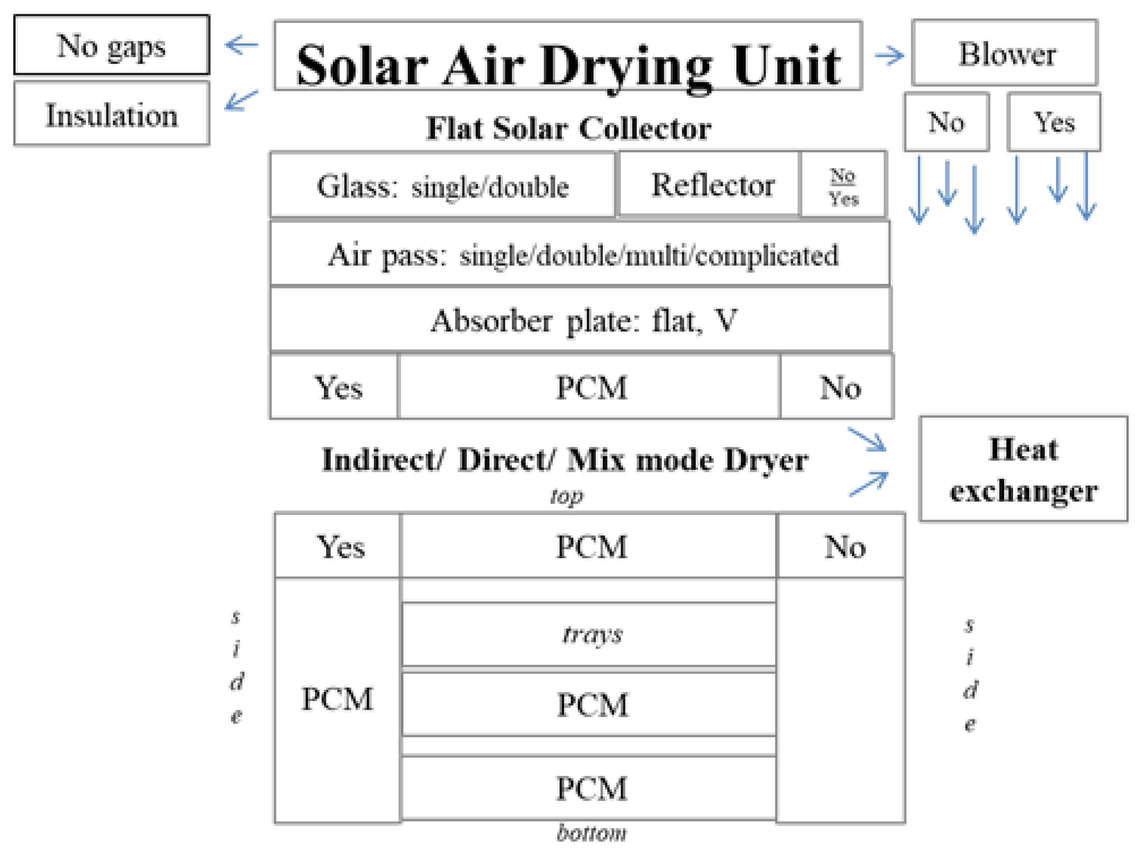

Fig. 1 Solar air drying unit and possible location of PCM

Types of solar drying systems [9], (Fig.1)

By working principle:

-direct,

-indirect,

-mixed mode

By mode of operation:

-passive (natural convection)

-active (forced convection)

By type of construction:

-cabinet (box-type)

-greenhouse

Types of thermal energy storage (TES) with PCM in solar dryers

-separate unit (Fig.2),

-inbuilt (Fig.3)

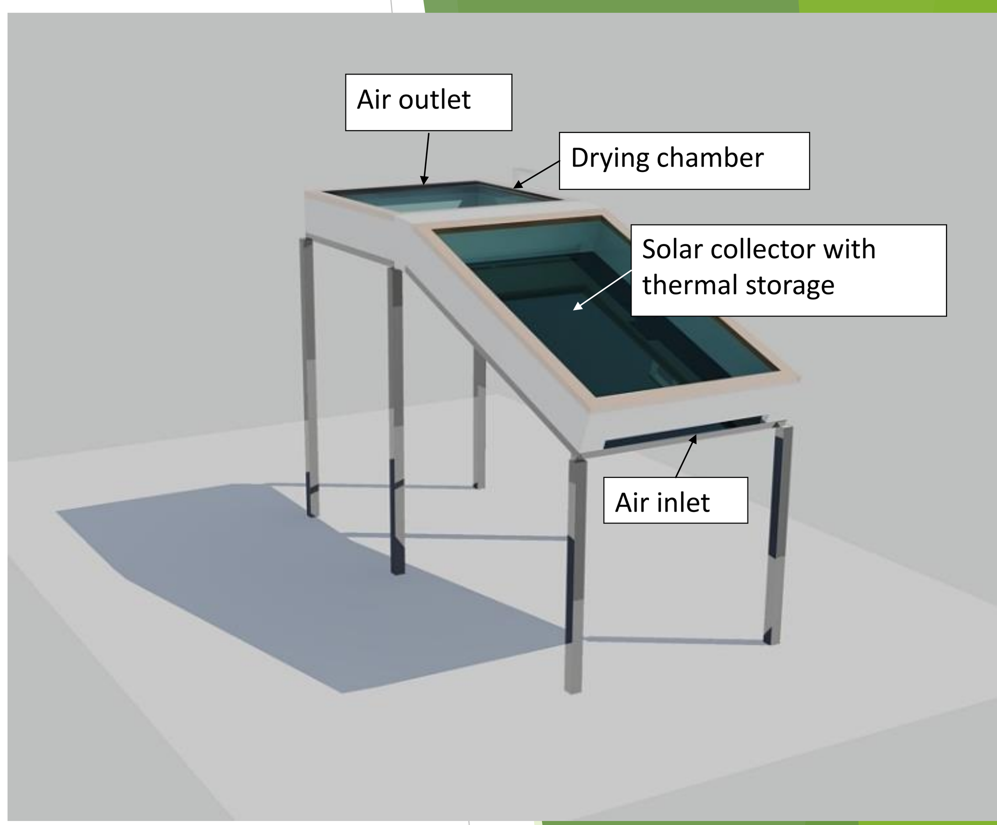

Fig. 3. Inbuilt TES unit in a solar dryer system.

PCM types

Reference	material	status	material type	phase change temperature	thermal conductivity	density	heat of fusion/ solidification	specific heat
				°C	W/mK	kg/m^3	J/kg	J/kgK
[1]	paraffin wax [solid]	average	PCM	55-60	0.4	850	200 000-220 000	2940
[1]	paraffin wax [liquid]	good	PCM	55-60	0.21	775	200 000-220 000	3890
[1]	pebble stone	very good	PBTES	-	-	1920	-	835
[2]	mixture fatty acids OM 55 Anon [solid]	good	PCM	55	0.135	840	210 000	2300
[2]	mixture fatty acids OM 55 Anon [liquid]	good	PCM	55	-	-	210 000	730
[2]	paraffin wax (PW), Type-II [solid]	average	PCM	61	0.4	861	213 000	1800
[2]	paraffin wax (PW), Type-II [liquid]	average-	PCM	61	-	-	213 000	2380
[3]	paraffin wax [solid]	good	PCM	54	0,21	876	190 000	2100
[3]	paraffin wax [liquid]	good-	PCM	54	0.21	795	190 000	-
[4]	paraffin wax [solid]	very very good	PCM	56.6	0.11	969	383 870	2100
[4]	paraffin wax [liquid]	very very good	PCM	56.6	0.11	933	383 870	1160
[4]	wood resin	bad	PCM	42.1	-	932.9	23 610	-
[5]	paraffin wax E53 [solid]	average	PCM	56.4	0.33	funct.of temp.	194 320	funct.of temp.
[5]	paraffin wax E53 [liquid]	average	PCM	57.01	0.33	funct.of temp.	194 110	funct.of temp.
our project	paraffin wax [solid]	good	PCM	57	0.21	910	255 000	2730
our project	paraffin wax [liquid]	good	PCM	57	0.21	765	255 000	2730
[6]	RT44HC	good	PCM	43.28	0.22	800	218110	2000
[7]	Erythritol	good	PCM	118	0.73	1450	340000	2700
[8]	Palmitic Acid [solid]	good	PCM	62.9	0.29	850	149000	-

The PCM can fill part of the volume of the unit; or can be encapsulated in containers with different form, size and material, arranged or dumped in a packed bed.

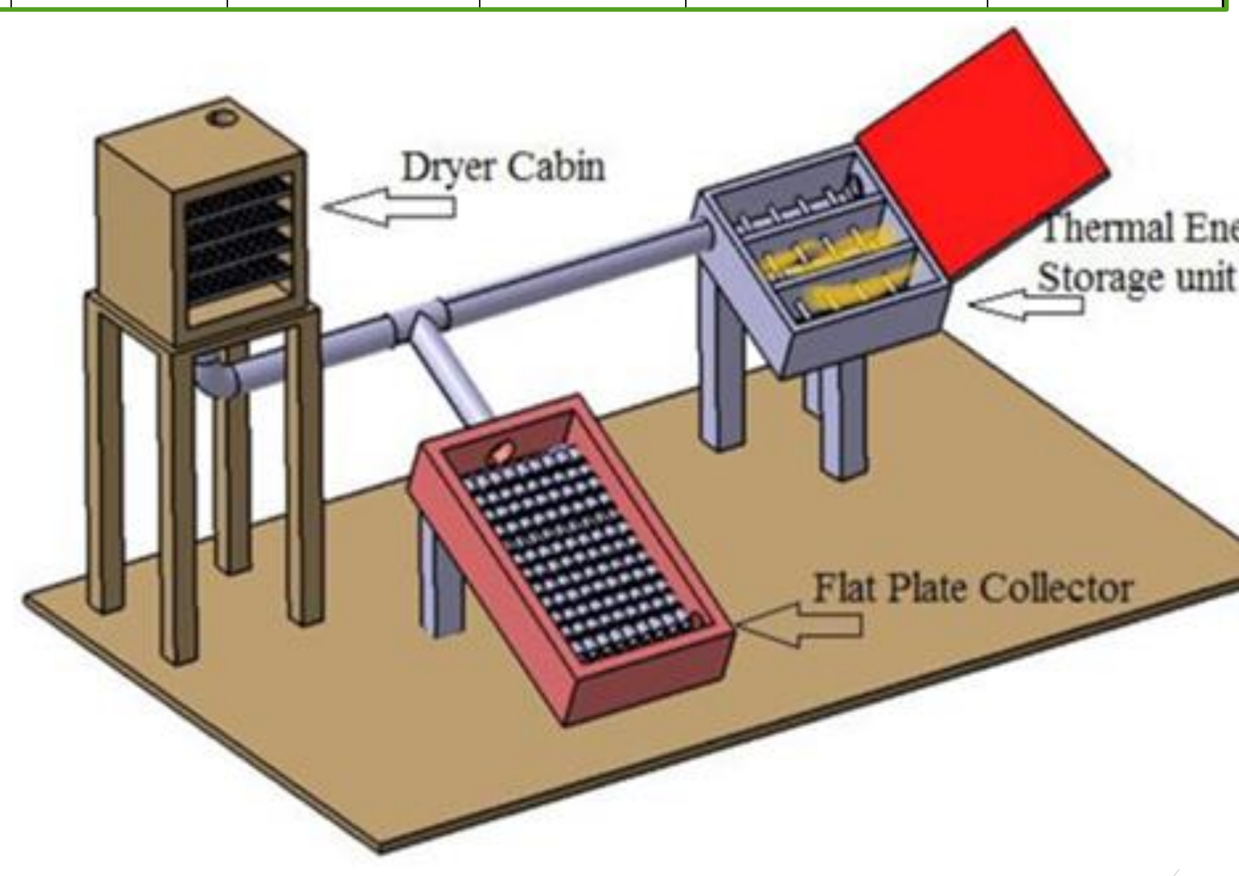

Fig. 2. Separate TES unit in a solar dryer system [10].

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Efficiency evaluation

✓ **Energy analysis (First law of thermodynamics models)**

Energy efficiency (First law efficiency)

$$\eta_I = \frac{E_{out}}{E_{in}} = \frac{E_{in} - E_{loss}}{E_{in}}$$

Efficiency of PCM module $\eta_{PCM} = \frac{Q_{dis}}{Q_{ch}}$

✓ **Exergy analysis (Second law of thermodynamics models)**

Second law efficiency

$$\eta_{II} = \frac{Ex_{out}}{Ex_{in}} = \frac{Ex_{in} - Ex_{loss} - Ex_{des}}{Ex_{in}}$$

Exergy efficiency of heat storage $\eta_{Ex,es} = \frac{Ex_{dich}}{Ex_{ch}}$

Conclusions

The good design of a solar dryer has to ensure continuously stable temperature of the drying air at least 5-6°C above the ambient temperature. This is necessary to avoid the dried object to re-absorb the moisture during night, when the air temperature drops and its humidity increases. The latent heat storage integrated in the system is a good solution for that purpose. The main requirements in the design of the storage unit are:

-Choice of proper PCM according to the drying regime;

-Intensive heat transfer with proper organisation of the air flow (measures for reduction of air convective resistanse and enhancement of thermal conductivity of PCM);

-Minimal heat loss by effective thermal insulation.

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