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Review

Influence of nanomaterials on properties of latent heat solar thermal energy storage materials – A review

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ABSTRACT

Thermal energy storage system plays a critical role in developing an efficient solar energy device. As far as solar thermal devices are concerned, there is always a mismatch between supply and demand due to intermittent and unpredictable nature of solar radiation. A well designed thermal energy storage system is capable to alleviate this demerit by providing a constant energy delivery to the load. Many research works is being carried out to determine the suitability of thermal energy storage system to integrate with solar thermal gadgets. This review paper summarizes the numerous investigations on latent heat thermal energy storage using phase change materials (PCM) and its classification, properties, selection criteria, potential research areas and studies involved to analyze the thermal–physical properties of PCM.

Contents

1. Introduction

The world is hurtling towards two major crises: serious energy shortages and accelerating climate change. Together, they threaten to destroy the achievements of human civilization. Solutions to both the crises are interlinked; the diversification of the fuel base and adoption of emerging clean and green alternative for energy production. Many scientists are involved in search of new and renewable sources of energy and have proved that solar energy has the maximum potential to solve the problem of energy crisis. The use of solar energy for thermal applications such as water heating, space heating, cooking, and drying sometimes becomes unreliable as the solar energy is variable and unpredictable; hence there exists a mismatch between the availability and utilization time. Therefore it necessitates an effective thermal energy storage system to store the energy whenever it is available, which can be utilized during non-solar hours. Thermal energy storage system will reduce the imbalance between the demand and the supply of energy, thereby improving the performance of the system and reduce the cost incurred due to loss of energy [1–3].

Thermal energy can be stored as a change in internal energy of a material as sensible heat, latent heat and thermo-chemical or combination of all these. Thermal energy storage system requires some

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Nomenclature

a_m	fraction melted	Q	quantity of heat stored (J)
a_r	fraction reacted	T_f	final temperature (°C)
C_p	specific heat (kJ/kg K)	T_i	initial temperature (°C)
C_{sp}	average specific heat between T_i and T_m (kJ/kg K)	T_m	melting temperature (°C)
C_{lp}	average specific heat between T_m and T_f (kJ/kg K)	Δh_m	heat of fusion per unit mass (kJ/kg)
dt	change in time	Δh_r	endothermic heat of reaction
m	mass of heat storage medium (kg)		

distinctive features such as high heat storage efficiency, large storage capacity per unit mass and volume, very small heat losses, should be non-corrosive and long life with less expensive [4–8]. This paper gives review on classification, studies of thermo-physical properties, thermal stability and thermal reliability of phase change materials. Apart from that the effect of encapsulation, shape stabilization and influence of nanomaterials on the properties of phase change materials are also discussed which will be an aid to the scientific community.

2. Classification of thermal energy storage

Thermal energy can be stored as either sensible heat or latent heat or as chemical storage based on the specific heat capacity, latent heat and chemical reactions of the material [9]. Basic classification of thermal energy storage is given in Fig. 1.

2.1. Sensible Heat

In sensible heat storage, thermal energy is stored based on the specific heat capacity of the material. Here the temperature of the material varies and does not undergo any phase transformation during charging or discharging cycles [4,9,11,12]. The amount of energy stored is given by Eq. (1). The amount of heat stored depends upon the amount of the storage material, specific heat of the medium and difference between the change in temperature at initial and final stage. Some examples of the solid and liquid sensible heat storage medium are given in Table 1.

$$Q = \int_{T_i}^{T_f} mC_p dt = mC_p(T_f - T_i) \quad (1)$$

2.2. Chemical reactions

Thermal energy can also be stored using the reversible chemical reactions. It is more advantageous compared to sensible and latent heat storage techniques, such as high energy density, ambient temperature storage and possibility of heat pumping and long distance transport. Technical compatibility of this method is yet to be proven. There are three modes of storage using chemical reactions: reversible reactions, thermo-chemical pipeline energy transport and chemical heat pump storage. Thermal energy is stored and retrieved by breaking and reforming of molecular bonds through reversible chemical reactions [4,9,11,12]. Thermal storage is relied on the amount of storage material, endothermic heat of reaction and the extent of conversion given by the Eq. (2)

$$Q = a_r m \Delta h_r \quad (2)$$

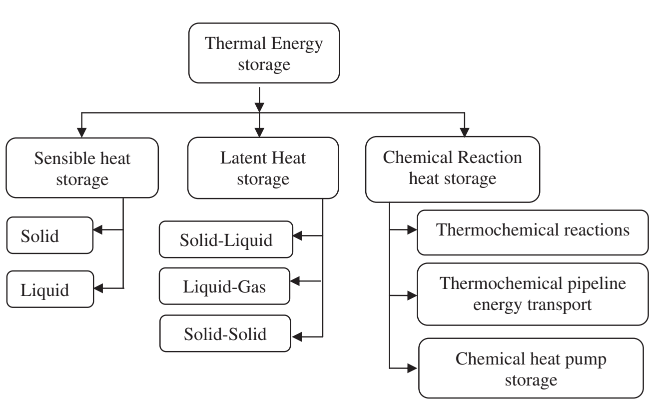

Fig. 1. Classification of thermal energy storage.

2.3. Latent heat storage

In latent heat storage system, the process of storing and retrieving the thermal energy is based on the latent heat of fusion, where storage medium undergoes a phase transformation. The heat stored during the phase change process of the material is called latent heat. As the source temperature increases the chemical bonds of the PCM material breaks up which leads to the transformation from one phase to other [9,11–14]. Here the temperature is almost constant with less temperature swing.

Energy stored in latent heat storage medium is given by Eq. (3)

$$Q = \int_{T_i}^{T_m} mC_p dt + ma_m\Delta h_m + \int_{T_m}^{T_f} mC_p dt = m[C_{sp}(T_m - T_i) + a_m\Delta h_m + C_{lp}(T_f - T_m)] \quad (3)$$

Phase transformation of the material can be solid–solid, solid–liquid, or liquid–gas. Transformation of crystalline nature from one to other will be observed in solid–solid latent heat storage material whereas phase change of the material will be used to store thermal energy in other two methods of the latent heat storage materials. Solid–solid has an advantage of small change

Table 1
Examples of sensible heat storage materials.

Materials	Operating temperature (°C)	Heat capacity (J/kg K)	Density (kg/m^3)
Water	0–100	4.190	1000
Therminol	−9 to 343	2.100	750
Engine oil	Upto 160	1.880	888
Lithium	180–1300	4.190	510
Sodium	100–760	1.300	960
Ethanol	Upto 78	2.400	790
Butanol	Upto 118	2.400	809
Octane	Upto 126	2.400	704
Aluminium	Upto 660	0.896	2707
Brick	1000	0.840	1698
Concrete	1000	1.130	2240
Cast iron	Upto 1100	0.837	7900
Copper	Upto 1000	0.383	8954
Sodium carbonate	Upto 850	1.090	2510
Limestone	Upto 825	0.900	2500
Magnesium oxide	Upto 2800	0.960	3570