



Heat transfer enhancement of phase change materials for thermal energy storage applications: A critical review



Nasiru I. Ibrahim^a, Fahad A. Al-Sulaiman^{a,b,*}, Saidur Rahman^{a,c}, Bekir S. Yilbas^b, Ahmet Z. Sahin^b

^a Center of Research Excellence in Renewable Energy (CoRERE), Research Institute, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran 31261, Saudi Arabia

^b Mechanical Engineering Department, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran 31261, Saudi Arabia

^c Faculty of Science and Technology, Sunway University, No. 5, Jalan Universiti, Bandar Sunway, 47500 Petaling Jaya, Malaysia

ARTICLE INFO

Keywords:

Heat transfer enhancement
Thermal conductivity
Phase change material
Latent heat thermal energy storage

ABSTRACT

This paper presents a state-of-the-art review on various techniques of heat transfer enhancement in latent heat thermal energy storage (LHTES) systems. Heat transfer enhancement in LHTES systems can be achieved through either geometric configuration and/or thermal conductivity enhancement. The use of extended surfaces such as fins or heat pipes is a common technique for heat transfer enhancement in LHTES systems and therefore, reviewed in details in this paper. Next, we studied the thermal conductivity enhancement techniques, which include the use of porous materials, nanoparticles with high thermal conductivity, and low-density materials. Finally, studies involving combined techniques for heat transfer enhancement are reviewed in the paper. The paper discusses research gaps in the methods of heat transfer enhancement for LHTES systems and proposed some recommendations.

1. Introduction

Thermal energy storage is inevitable for effective use of renewable energy sources due to their intermittent nature, particularly solar energy, which is the most prospective energy source. Thermal energy storage plays a vital role in bridging the gap between energy supply and its demand, which in turn, improves the performance and reliability of the energy systems [1]. Thermal energy storage can be classified as sensible heat storage (SHS), latent heat thermal energy storage (LHTES) and thermochemical storage. In sensible heat storage (SHS), the thermal energy is stored by rising the temperature of the storage material without undergoing phase transformation and therefore, the amount of energy stored is a function of the specific heat of the material, the temperature change, and the amount of storage material. On the other hand, LHTES involves phase transformation of the storage material from one state to another such as solid-liquid, solid-solid or liquid-gas and vice-versa when heated to the transformation temperature. A liquid-gas transition requires large volume of material conduit while a solid-solid transition involves low energy storage density per unit volume of material. Therefore, the solid-liquid transition as applied to latent heat storage applications is more efficient compared with the other transformations and hence, is the most widely

used [2,3]. The third method of energy storage is the thermochemical storage, which involves a reversible physio-chemical phenomena to store the thermal energy chemically and recovers the energy upon supplying heat [4].

For a specific requirement of thermal energy, sensible heat storage requires a larger vessel as compared with latent heat and thermochemical storages. Thermochemical storage on the other hand, is associated with high energy storage density but still at pre-matured stage in terms of research and development. Among the three thermal energy storage methods, latent heat energy storage is the most promising and attractive due to its compactness and ability to store energy at nearly constant temperature corresponding to the phase-transition temperature of the material [1]. The material used in latent heat energy storage is called phase change material (PCM). Variety of PCMs exists and include organic, inorganic, and eutectics, all available in a wide range of melting/freezing points. Details on the classifications of the PCMs are available in the literature [1,5–10] and are summarized in Fig. 1.

The choice of any material for latent heat storage lies on the target application as the materials exhibits different characteristic properties. However, certain desirable properties of PCMs that include thermodynamic, kinetic, physical, and chemical properties as well as economic

* Corresponding author at: Mechanical Engineering Department, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran 31261, Saudi Arabia.
E-mail address: fahadas@kfupm.edu.sa (F.A. Al-Sulaiman).

Nomenclature		Greek Symbols	
a_m	fraction melted	λ	latent heat of fusion (J/kg)
C_p	specific heat (J/kg-K)	ρ	density (kg/m ³)
H	height (m)		
Δh_m	heat of fusion per unit mass (J/kg)		
k	thermal conductivity (W/m °C)		
L	length (m)		
m	mass (kg)		
Q	quantity of heat stored (J)		
r	radius (m)		
S	distance between heat pipes, location of shoreline (m)		
t	time (s), thickness (m)		
T	temperature (°C or K)		
		Subscripts	
		f	fin, final
		i	inner, initial
		l	liquid
		m	middle, melting
		o	outer
		s	solid
		w	wall

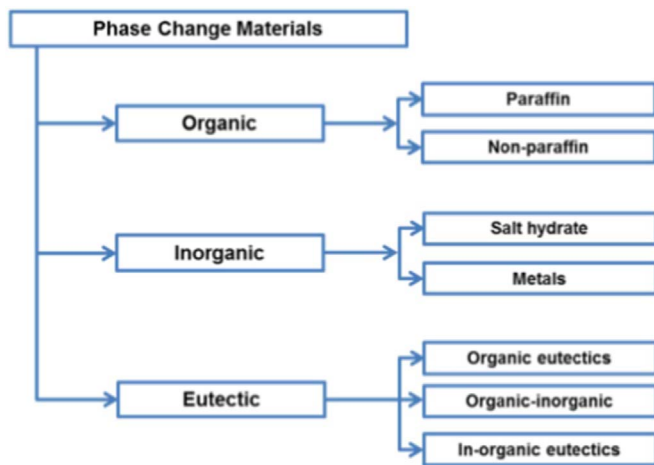


Fig. 1. General classification of phase change materials [11].

viability and availability must be taken into account for proper selection of the right materials [12]. The main desirable properties of PCMs as obtained from the literature [1,3,7,9,10,13] are summarized in Table 1.

There is no single PCM that possesses all the desirable properties highlighted above and as such, the PCMs exhibit some undesirable properties and behaviors that hinder their performance in LHTES systems. Among the undesirable characteristics of the PCMs is the low thermal conductivity, which affects the rate of phase change process and leads to poor performance of the storage system. This applies to almost all classes of pure PCMs except the metallic-type. The effect of low thermal conductivity can be manifested during the charging (energy absorption; melting) and discharging (energy retrieval; solidification) processes [14]. Another problem of PCMs as applied to LHTES is the corrosive behavior while in contact with the storage container or transport conduits. Salt hydrates and fatty acids based-PCMs exhibit greater potential to corrosion problem. Other problems of PCMs include thermal instability at high temperatures, supercooling and phase segregation especially in hydrated salts PCMs.

Many studies have been carried out to address the above listed

Table 1
Desirable properties of PCM.

Thermal properties	Physical properties	Kinetic properties	Chemical properties	Economics
<ul style="list-style-type: none"> High latent heat of transition High thermal conductivity Suitable melting/freezing temperature 	<ul style="list-style-type: none"> Small volume change Low vapor pressure High density. 	<ul style="list-style-type: none"> Sufficient crystallization rate No supercooling 	<ul style="list-style-type: none"> Long-term chemical stability No toxicity Non flammable Non corrosive 	<ul style="list-style-type: none"> Abundant Cost effective Available Commercially viable

problems for better energy storage practices. Jegadheeswaran and Pohekar [14] reported a review on heat transfer enhancement of LHTES systems. Liu et al. [15] presented a review on heat transfer characteristics and enhancement of PCMs and focused mainly on encapsulated PCMs. A large number of researchers have conducted significant work including theoretical and experimental studies on heat transfer enhancement in LHTES. However, based on the literature survey and to the best of the authors' knowledge, there is limited number of review articles focusing on heat transfer enhancement of LHTES, dealing with the problem of poor thermal performance due to low thermal conductivity. With ever increasing research interest on LHTES heat transfer enhancement, the present review covers recent progress on the use of heat pipes and combined heat transfer enhancement methods that are not considered in the previous review works [14,15]. The paper presents a state-of-the-art review on heat transfer enhancement in LHTES systems, covering the techniques summarized in Fig. 2.

2. Heat transfer characteristics and modeling of LHTES systems

Melting and solidification processes of PCM occur in different transformation stages due to heat transfer between the PCM and the heat source or heat transfer fluid (HTF). Understanding the heat transfer characteristics and modeling approaches of the phase transformation process is important for the design, evaluation and optimization of LHTES systems.

2.1. Heat transfer characteristics of PCMs

In addition to fixed boundaries of PCM domain, phase change process of the PCM involves moving boundary between phases and is generally known as Stefan problem. Melting and solidification are the two thermal processes for latent heat storage. Melting occurs when a solid PCM receives and absorbs heat energy and this represents the actual storage. Retrieval of the latent heat energy from the PCM is accomplished through solidification (freezing) of the liquid [16]. The PCM phase transition proceeds from a solid to a mushy state and then to a liquid state during the melting process and vice versa during solidification process. The heat transfer mechanisms associated with

Download English Version:

<https://daneshyari.com/en/article/5483104>

Download Persian Version:

<https://daneshyari.com/article/5483104>

[Daneshyari.com](https://daneshyari.com)