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Review of latent heat thermal energy storage for improved material stability and effective load management

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ABSTRACT

Thermal energy storage is important to counter balance demand and supply of energy and maintain balance in the system and boost the use of intermittent renewable energy source. Phase change material-based thermal energy storage has massive potential to substitute large-scale energy demand and assist both economic and environmental benefits. This paper reviews functional principle, thermophysical properties and other material characteristics of different phase change materials for thermal energy storage system. Long-term stability of phase change material and its interaction with storage container have been discussed. Various heat transfer and thermal conductivity enhancement technique to enhance latent thermal energy storage system have been discussed. The paper also examines the schematics of some of the proposed & tested systems and describes the results of prototype setup for thermal load management and application in water heating system and buildings. The paper also summarizes energy and exergy analysis of some thermal energy storage systems.

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1. Introduction

With growing population and enhanced lifestyle energy demand and thereby energy generation has been increased globally during last few decades from 7069 TWh in 1980 to 22933 TWh in 2016, of which conventional resources contribute more than 70% [1–3]. But limited reserves of fossil fuel and environmental issues like acid rain, global warming, and emission of greenhouse gases have focused our interest for energy generation from renewable resources. However, many renewable sources like wind and solar energy are sporadic, unpredictable and inconsistent in supply. One of the possibilities is to develop systems which can store energy effectively and whenever it is required it will serve the purpose [4,5]. Energy storage system includes different technical methods to maintain balance in power supply and its use. The different energy storage system includes mechanical, electrochemical, chemical, electrical and thermal [6,7]. Table 1 illustrates an overview of different energy storage systems. Among all methods for thermal application thermal energy storage (TES) is one of the direct means of energy storage as it avoids the need to convert energy from one form to another and thus cut down conversion losses [8,9].

In TES, excess energy from solar collector or waste heat from various process applications is stored in a storage medium as internal energy for later applications. TES systems have massive potential to substitute large-scale energy demand and make thermal energy equipment more effective. Basically, TES is categorized into three different categories (i) sensible (or specific heat) storage (ii) latent heat storage (iii) thermochemical heat storage [5,6,8,9]. In sensible TES energy is stored in a medium when heat is added or removed from it. It is simple, cheap and easy to control method of TES. The storage capacity of sensible TES is between 10 and 50 kWh/t with efficiency between 50 and 90% depending upon the material. In latent TES system, massive energy is stored when the phase change material (PCM) undergoes a phase transition. PCM has multiple time storage capacity compared to sensible heat materials ranging from 50 to 150 kWh/t with efficiency between 75 and 90%. In thermo chemical storage, energy is stored or released in a material by a reversible chemical reaction. Thermochemical storage system has high energy storage capacity ranging from 12 to 250 kWh/t with efficiency between 50 and 90% and can store thermal energy in chemical bond for a long duration with low heat losses. TES have been investigated by many researchers in last few decades and lot of work on experimental and numerical analysis can be found in this area especially latent thermal energy storage. Many review papers can also be found in the literature, but there are very limited number of review articles focusing on different aspects of latent thermal energy storage. This paper reviews functional principle, thermophysical properties and other material features of many PCM for thermal storage system. Long-term stability, heat transfer, and thermal conductivity enhancement technique to enhance latent thermal energy storage system have been discussed. The paper also examines thermal load management and application of water heating system and buildings with PCMs.

2. Latent heat storage system

Unlike sensible TES material, in PCM energy is stored or removed when there is a phase transition in the material (solid-

Table 1
Overview of different energy storage system.

Storage method	Functional Principle	Performance	Storage Duration	Ref
Mechanical energy storage				
Compressed air energy storage	Energy is used to compress air during off-peak hours and is stored in large underground reservoirs	Complex, costly, fast response, large storage capacity	Medium	[10,11]
Pumped hydro system	Water is pumped from lower reservoirs to upper reservoirs during off-peak hours	Simple, inexpensive, fast response, large storage capacity	Long	[12,13]
Flywheel	Rotational energy is stored in large rotational cylinder for intermediate storage	Simple, costly, intermediate storage, small storage capacity	Short	[14–16]
Electrochemical energy storage				
Batteries storage	Chemical energy is stored in active material when a source of electrical energy is connected to the terminal	Simple, costly, fast response, convenient, small storage capacity	Medium	[17–19]
Chemical energy storage				
Chemical energy storage	Energy is stored in bonds of atoms and molecules due to chemical reactions	Complex, inexpensive, long storage duration, large storage capacity	Long	[20,21]
Electrical energy storage				
Superconducting magnetic energy storage (SMES)	Superconducting coil and a cryogenically cooled refrigeration system stores the energy in magnetic field	Complex, costly, indefinite storage duration, small storage capacity	Long	[22]
Electric double layer capacitor (EDLC)	Large power densities and high efficiencies charge stored in capacitor layer	Complex, costly, Can be charged in seconds with no danger of overcharge, small storage capacity	Medium	[23]
Thermal energy storage				
Sensible storage	Energy storage and release with change in storage medium temperature	Simple, inexpensive, low energy density	Medium	[24]
Latent storage	Energy storage and release with storage material phase change at certain temperature	Complex, costly, high energy density	Medium	[24]
Thermochemical storage	Energy storage and release based on reversible chemical reaction.	Complex, costly, high energy density	Long	[24]