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A review on thermal conductivity enhancement of paraffinwax as latent heat energy storage material

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ABSTRACT

Increasing energy demand calls for the implementation of proper thermal energy storage which is one of the most important components of solar energy conversion systems. Phase change material based latent heat energy storage systems have emerged as a promising option to effectively store thermal energy. Generally, paraffin wax is used as the most common phase change material for low to medium temperature storage applications because it has a large latent heat and low cost besides being stable, nontoxic and non-corrosive. The performance of paraffin wax based latent heat energy storage systems (LHESS) is limited by its poor thermal conductivity. In this paper, the previous experimental and theoretical research studies on LHESS using paraffin wax as phase change material with different performance enhancement techniques are reviewed. Further, research works related to dispersing different kind of nanoparticles in paraffin wax for the enhancement of its thermal conductivity are comprehensively reviewed with respect to synthesis, characterization and thermophysical properties of the nanoenhanced phase change material.

Contents

1. Introduction

The increasing gap between the global demand and supply of energy is becoming a major threat as well as a challenge for the engineering community to quench for the unquenchable thirst for energy. Many forums and energy management groups have been formed to emphasize the storage of energy in both industrial and domestic sectors, in any possible form. The utilization of the abundant source—solar thermal energy and hot waste streams available in industries has attracted the scientific community to provide attractive solutions for the problems on energy

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Nomenclature

d_c	Diameter of container
Re	Reynolds's number
Ste	Stephen number
T_h	Hot water temperature
T_c	Cold water temperature
m	Mass flow rate of fluid
ε	Emissivity
K	Thermal conductivity
LH	Latent Heat capacity
mf	Mass fraction

Subscripts

l	Liquid state
s	Solid state

Acronyms

PCM	Phase Change Material
PW	ParaffinWax
NePCM	NanoEnhanced Phase Change Material
LHESS	Latent Heat Energy Storage System
TES	Thermal Energy Storage
CNT	Carbon Nano Tube
CNF	Carbon Nano Fibers
GNF	Graphite Nano Fibers
SWCNT	Single Walled Carbon NanoTube
MWCNT	Multi Walled Carbon NanoTube
NG	NanoGraphite
GO	GrapheneOxide
NM	NanoMagnetite
xGnP	Exfoliated Graphite Nano Platelet
CVD	Chemical Vapor Deposition
ES	Electro Spinning
ATRP	Atom Transfer Radical Polymerization
SEM	Scanning Electron Microscope
FE-SEM	Field Emission Scanning Electron Microscope
TEM	Transmission Electron Microscope
XRD	X-Ray Diffraction
FT-IR	Fourier Transform Infrared Spectroscopy
DLS	Dynamic Light Scattering
DSC	Digital Scanning Calorimeter
TGA	Thermo Gravimetric Analysis

conservation and storage/retrieval. Thermal energy can be stored in the form of sensible heat in which the temperature of the storage material varies with the amount of energy stored. Water or rock can be the best example [1]. Alternatively, thermal energy can be stored as latent heat in which energy is stored when a substance changes from one phase to another by either melting or freezing. The temperature of the substance remains constant during phase change. Of the two, latent heat thermal energy storage technique has proved to be a better engineering option due to its various advantages like large energy storage for a given volume, uniform energy storage/supply, compactness, etc. LHES units employ PCMs which undergo change of phase (solid-to-liquid and vice versa) during the energy transfer process. Wide range of PCMs with their properties, advantages and limitations have been comprehensively reported in [2–4]. Several experiments have been conducted in order to study the characteristics of paraffin Wax during solidification and melting processes [5–14]. The studies show that commercial grade paraffin wax and other pure paraffins have stable properties after 1000–2000 cycles. Paraffin wax did not show regular degradation in its thermal properties after repeated melting/freezing cycles. Paraffin waxes are safe and non-reactive. They are compatible with all metal containers and easily incorporated into heat storage systems. Paraffin wax have been widely used for LHESS applications due to large latent heat and desirable thermal characteristics such as little or no super cooling, varied phase change temperature, low vapor pressure in the melt, good thermal and chemical stability and self nucleating behavior [15–19]. PCMs are used in various engineering applications such as thermal energy storage in building structures and equipment [20], including domestic hot water, heating and cooling systems, electronic products, drying technology, waste heat recovery, refrigeration and cold storage, solar cookers, and solar air collectors [21]. Several attempts have thus been made to enhance the thermal conductivity of paraffin, including incorporating fillers, such as conducting fins [22–27], carbon fibers/graphite [28–30], metal powder/spheres [13,31]; and inserting metal matrix structures [6,32,33]. Over the last decade, enormous research interest has been drawn to the concept of dilute particle suspension containing nanoparticles with higher thermal conductivity than their base fluids such as water and ethylene glycol, dubbed nanofluids, which can result in thermal conductivity enhancement significantly higher than predicted by classical solid–liquid mixture models [34,35]. Recently, the potential of applying the concept of nanofluids was exploited by dispersing nanoparticles in the phase change material for enhancement in the thermal conductivity and hence improvements in the heat transfer efficiency of latent-heat thermal energy storage system. Khodadadi and Hosseinizadeh [36] reported a numerical solution on improvement of thermal storage energy using nanoparticle enhanced phase change material (NePCM). They found that the resulting nanoparticle-enhanced phase change materials exhibit enhanced thermal conductivity in comparison to the base material. In addition, their numerical results showed reduction in the overall solidification time. Ranjbar et al. [37] investigated the influence of utilizing nanoparticle on enhancement of heat transfer in a three-dimensional cavity. They showed that the suspended nanoparticles substantially increase the heat transfer rate. Hosseinizadeh et al. [38] investigated numerically unconstrained melting of nanoparticle enhanced phase change materials inside a spherical container. They used paraffin wax (RT27) and copper particle as base material and nanoparticle respectively that enhanced the thermal conductivity of base material. Their investigations showed that the nanoparticles cause an increase in thermal conductivity of NePCM compared to conventional PCM. Wu et al. [39] developed a new sort of nanofluid phase-change material by suspending a small amount of nanoparticles in melting paraffin. Nanoparticles of Cu, Al, and C/Cu were added to the melting paraffin to enhance the heat transfer rate of paraffin. They concluded that Cu nanoparticles have the best performance for heat transfer. In general, Metals have excellent thermal conductivity; therefore, they can be expected to enhance the thermal conductivity of PCMs significantly. However, metal materials oxidize, and their application to PCMs can degenerate and reduce the thermal conductivity of PCMs in the long run. Although adding metal oxides or minerals to PCMs to enhance thermal conductivity is worth considering, the thermal conductivity of such additives must be higher than that of the PCM if they are to enhance the thermal conductivity of PCMs. Moreover, a poor combination of additives to PCMs can increase interface