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Thermal Energy Storage

Storage Techniques, Advanced Materials, Thermophysical Properties and Applications

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Preface

Thermal energy storage becomes increasingly vital as renewable energy sources are currently catching up and speedy diminishing of fossil fuels. It is one of the major dawns in the field of thermal energy management. The usage of thermal energy in the form of sensible or latent heat is an effective method to store and utilization of energy. Thermal energy based on phase change materials can alleviate the energy crisis due to high energy output and high energy density. So, the emphasis of this book is to cover various outlooks regarding thermal energy storage: The different thermal energy storage techniques along with traditional materials that store thermal energy are canvassed in detail. A concise discussion regarding current status, leading groups, journals and the countries related to advance energy storage materials has also been discussed. But the poor performance of these materials is the main concern, which limits its applications. Thus, various advanced materials for efficient energy storage are proposed in literature, which are also discussed broadly for the first time in this book regarding comprehensive understanding for efficient thermal energy storage. The thermophysical properties of advanced materials and the role of these materials for thermal energy storage in different applications as buildings, solar energy, seawater desalination, cooling devices as well as photovoltaic thermal systems are also mentioned. The results suggest that advanced energy storage materials have a massive impact on heat transfer along energy storage capacity compared to conventional energy storage materials. Finally, emerging future research of advanced energy storage materials is also highlighted in this book, which will help in generating new insides for thermal energy storage development.

Keywords: Energy storage materials · PCM · Heat transfer · Thermophysical properties · Applications

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Contents

Nomenclature

Abbreviations

a	Length of nanoparticle (m)
b	Diameter of nanoparticle (m^2)
C	Carbon atom
d	Mean diameter (m)
d_c	Diameters of core material
d_p	Diameters of micro/nano capsule
h	Convective heat transfer (W/m^2K)
h	Phase change enthalpy (KJ/kg)
k	Thermal conductivity (W/mK)
k_c	Thermal conductivity of core material
k_p	Thermal conductivity of micro/nano capsule
k_s	Thermal conductivity of shell material
m	Mass (kg)
T	Temperature (K)
V	Volume (m^3)
BN	Boron nitride
CO_2	Carbon dioxide
CNFs	Carbon nanofibers
CSP	Concentrated solar power
EC	Electrical conductivity
ENEA	Italian National Agency for New Technologies (Energy and Sustainable Economic Development)
G-NF	Graphene nanofibers
GA	Gum Arabic
GNP	Graphene NPs
GO	Graphene oxide
GJ	Gega Joule
H	Hydrogen
HT	Heat transfer

$H_{M,Micro\,PCM}$	Heat of fusion of microencapsulated PCM
$H_{M,PCM}$	Heat of fusion of PCM only
MWCNTs	Multi-wall carbon nanotube
MIT	Massachusetts Institute of Technology
MJ	Mega Joule
NPs	Nanoparticles
NFs	Nanofibers
Ni	Nickel
PA	Palmitic acid
PCM	Phase Change Material
PEG	Polyethylene glycol
PEG/Ti3C2Tx	Polyethylene glycol/MXene
PW	Paraffin Wax
PV/T	Photovoltaic/thermal
Q	Heat stored in material (KJ)
R	Encapsulation ratio
SEM	Scanning Electron Microscope
SWCNTs	Single-wall carbon nanotube
TC	Thermal conductivity
TES	Thermal energy storage
TEM	Transmission Electron Microscopy
UV-Vis-NIR	Ultraviolet-Visible-Near infrared region
W	Watt

Symbols

C_p	Specific heat (KJ/kgK)
ρ	Density ($\frac{\mathrm{kg}}{\mathrm{m}^3}$)

Chapter 1
Introduction

1.1 Summary

The chapter contains the background of thermal energy storage, which is one of the major factors for minimizing dependency on fossil fuels. If thermal energy is not stored, it will simply waste into the environment. The energy storage materials are employed as thermal energy storage system that has optimum thermal properties. The research in the last few decades exhibited that these materials have better advantages due to superior properties, which are discussed in this book.

1.2 Overview

The utilization of energy is escalating now-a-days with the enhancement in industrialization, better living standard and population. The energy consumption may be managed by fossil fuels and renewable energy. It is very clear that CO_2 is a major contributor towards climate change of the world and the big share of that CO_2 is evolved by fossil fuels burnt by power generation and transport sector. These two mentioned sectors release around 90% of CO_2 into the atmosphere [1].

The progressive development of CO_2 in atmosphere becomes the cause of temperature rise in the world and it melts polar ice caps. It turns causes the depletion of ozone layer, which also raises world temperature. So, it will not commercially favorable to use fossils fuel as energy resources in the future. In Europe, North America and Middle East; researchers started to think about renewable energy technology to avoid and control the problem of global warming caused by CO_2 emissions [2].

Nowadays, people want that they live in an ideal environment like's they want to live in cold climate in summers and hot climatic conditions in winters in their residential as well as working areas by using these so many invented technologies.

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This is also a factor that is increasing world demand. As world energy demand is increased hugely so dependency on conventional or non-renewable energy resources is also increased and potential of these resources decreasing rapidly.

The whole world is shifted to renewable resources of energy for their energy production. Solar energy is the most suitable and reasonable choice out of all renewable energy resources. According to IEA, 30% of electricity needs will be supplied through renewable energy by 2035. All new power generation systems will comprise around 60% clean sustainable energy technology by 2025 [3]. Nowadays, world is concentrating on renewable energy resources due to rapidly consumption of fossil fuels resources. There are many renewable energy resources accessible in world, among these resources; solar energy is the most eminent and clean energy resources, but these resources are still way to go.

In 2018, the world population increased by 1.13% yearly, which is a countable change, so the need for energy consumption by human being is also increasing [4]. Besides these, people of the world are entered such an age where everything became machinery [5]. With technology development tasks or works which once was done by human being are replaced by machine and equipment due to such increment of population, and introduction of so many machineries in our domestic industrial or any sector of life world energy consumption is also increasing drastically.

Enormous studies have been done to fill the energy supply for the efficient system [6, 7]. The storage of energy can be done by means of electrical, mechanical as well as thermal. The thermal energy storage may be in the form of sensible, latent, thermochemical or a combination of these. The temperature changes in materials during charging and discharging result in the storage of sensible heat. The latent heat storage deals with phase change behavior of materials. The latent heat is a superior way for thermal energy storage and results illustrated that latent heat showed storage density 5–10 higher than sensible heat [1, 8, 9]. The various methods for energy storage are sensible, latent and chemical in thermal energy storage systems as shown in Fig. 1.1.

The latent heat storage materials are recognized as phase change materials (PCM). The energy storage materials as PCMs study were initially investigated by Telkes and Raymond in 1940 [12] after PCMs were used for thermal energy storage, which released sensible and latent heat during 1973–1974 energy crisis [13]. The resources of fossil fuels are limited currently and green-house emissions make key issues for efficient energy utilization. The storage materials for thermal energy storage (TES) give an optimum solution to improve the performance of domestic as well as industrial applications [9, 10, 14–16]. The key benefits of using PCM for storing thermal energy are:

- Relatively constant temperature during charging and discharging.
- Storage capacity of maximum thermal energy related to the sensible energy storage in water.
- The backup generation unit of burner cycle; therefore, reducing harmful gases [17].

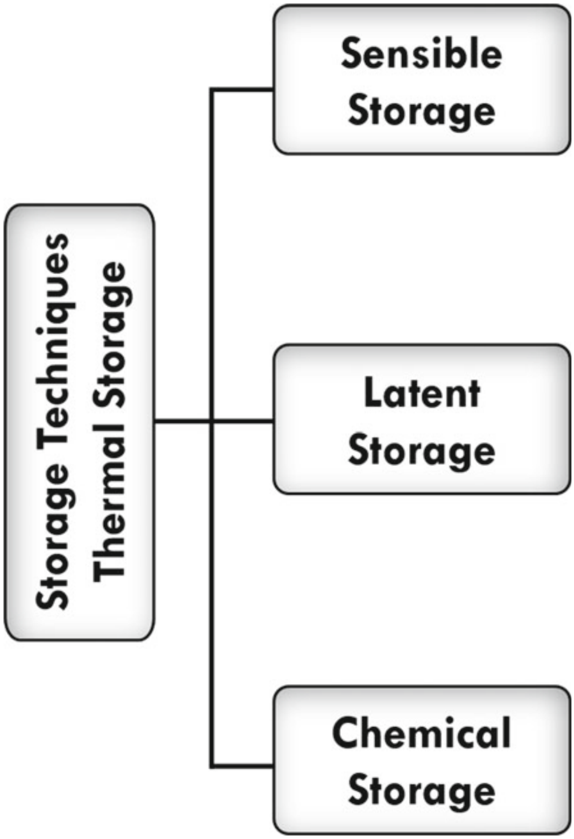

Fig. 1.1 Storage techniques and their classifications in thermal storage [10, 11]

The latent energy storage materials have a high value of heat of fusion to store or release large amount of heat. Different types of materials are under consideration containing organic compounds that included paraffin and fatty acids, inorganic materials as salts and their hydrates. These compounds have better heat of fusion and chemically stable [18] for thermal energy storage. The TES is broadly used in various applications and some of the benefits are [19]:

- The reliability of the system increased as the system works under more stable limits.
- The system generation capacity is enhanced, which is the most beneficial for demand sector.
- The cost for generation is optimized by thermal energy storage.

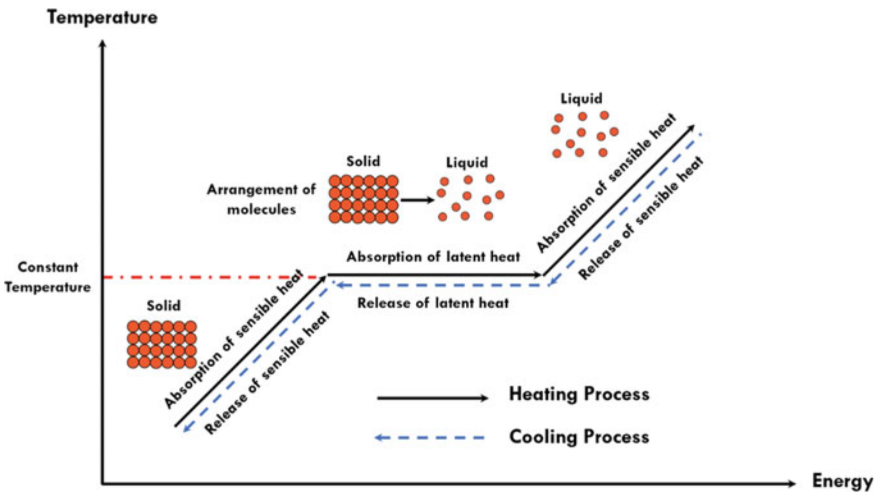

Fig. 1.2 Ideal case of PCM during heating and cooling process [20]

The ideal phase change curve is illustrated in Fig. 1.2 as temperature increases rapidly and reached the point of phase change of that material. At this, energy supplied is used only to convert the change of phase rather than increment of temperature. After the phase change, the temperature of material rises gradually. But the process of HT for conversion of phase change is too slow, which limits its usages.

But due to high HT rates, requirement and low TC of material make it a challenge for many applications. The conventional energy storage materials have a low value of TC and less rate of HT. The available energy storage materials do not meet the current requirements of the applications. The application of phase change material (PCMs) includes the techniques of storing thermal energy. Unfortunately, it is necessary to determine frequent impacts at the research and development phase before the important practical exercise of this technology. Some of the issues are as follows:

- Phase separation leads to inhomogeneous material distribution; hence the modification in the heat storage efficiency occurs; all properties vary in the space, and the storage procedure would be affected.
- Subcooling leads to change in phase at a low temperature than the probable one, i.e. the melting point; that means the production of energy will start at low temperature.
- Low thermal conductivity can cause problems as more time will require to attain desired temperature level in the whole material at the same heat flux, the temperature in the whole material will not be constant, and it will significantly vary from the heat source away.