Renewable and Sustainable Energy Reviews 82 (2018) 2730–2742

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Review on thermal conductivity enhancement, thermal properties and applications of phase change materials in thermal energy storage

Yaxue Lin, Yuting Jia, Guruprasad Alva, Guiyin Fang*

School of Physics, Nanjing University, Nanjing 210093, China

ARTICLE INFO

Keywords:
Thermal energy storage
Phase change materials (PCMs)
Thermal conductivity enhancement
Thermal properties
PCMs applications

ABSTRACT

In recent years, energy conservation and environmental protection have become most important issues for humanity. Phase change materials (PCMs) for thermal energy storage can solve the issues of energy and environment to a certain extent, as PCMs can increase the efficiency and sustainability of energy. PCMs possess large latent heat, and they store and release energy at a constant temperature during the phase change process. Thereby PCMs have gained a wide range of applications in various fields, such as buildings, solar energy systems, power systems and military industry. However, low thermal conductivity of PCMs leads to low heat transfer rate, thus, numerous studies have been carried out to improve thermal conductivity of PCMs. The main purpose of this paper is to review the methods for enhancing thermal conductivity of PCMs, which include adding additives with high thermal conductivity and encapsulating phase change materials. It is found that addition of thermal conductivity enhancement fillers is a more effective method to improve thermal conductivity of PCMs, where carbon-based material additives possess a more promising application prospect. Finally, the applications of PCMs in solar energy system, buildings, cooling system, textiles and heat recovery system are also analyzed.

1. Introduction

There are many forms of energy in nature. Among these forms, thermal energy is extensively distributed in solar radiation, geothermal energy, etc. Thermal energy is regarded as a low–grade type of energy and treated as waste in industrial production in general [1]. On the other hand, solar radiation continues to supply abundant solar energy during day time. However, large quantity of energy is often wasted. If large amount of thermal energy can be stored and released when it is supplied and demanded, fossil fuels consumption will be reduced, which plays an important role in overcoming the troubles of energy crisis and environmental pollution. Hence, thermal energy storage has been gaining great attention and undergoing rapid development.

There are three types of thermal energy storage: latent heat, sensible heat and reversible thermochemical reaction [2]. Among different types of thermal energy storage, latent heat storage type plays a vital role. Particularly, phase change materials (PCMs) absorb or release heat from the environment by changes in phase or structure, so as to realize the storage and release of thermal energy. Some studies [3–5] have pointed out that the advantages of PCMs are high heat storage density, huge latent heat storage capacity, low cost, excellent chemical stability, etc. PCMs have a wide range applications due to continuous research, such as industrial waste heat recovery, comfort applications in buildings, electric peak–shaving, solar energy systems, etc. [6–8]. In addition, PCMs have a prominent feature that the temperature nearly remains constant during phase change process, which can be used in temperature control system [9].

There are many kinds of PCMs and they can be classified according to different criteria. According to the state of substances before and after phase change, PCMs can be divided into solid–solid PCMs, solid–liquid PCMs, solid–gas PCMs and liquid–gas PCMs. At present, the most commonly used is solid–liquid PCMs, because of their high latent heat capacity and low volume change during phase change process as compared with the others [3,9]. Temperature of solid–liquid PCMs rises until the temperature reaches phase change temperature, then PCMs absorb massive heat as latent heat storage while phase change occurs from solid to liquid [10]. On the basis of their chemical nature, they are classified into organic PCMs, inorganic PCMs and eutectic PCMs. Organic PCMs can be further divided into paraffin and non–paraffin [11], where non-paraffin contains fatty acid, polybasic alcohol etc. Non-corrosive, non-toxic, congruent melting, chemical stability, almost no supercooling and so on are the advantages of the organic PCMs [5,11,12]. Inorganic PCMs, which commonly refer to water, hydrated salt, molten salt and metal or alloy [13], possess the merits of high latent heat per unit mass, non-flammable and low cost with the same volume as compared with organic PCMs. Eutectics are two or more

* Corresponding author.
E-mail address: gyfang@nju.edu.cn (G. Fang).

http://dx.doi.org/10.1016/j.rser.2017.10.002
Received 29 May 2017; Received in revised form 5 September 2017; Accepted 2 October 2017
Available online 09 October 2017
1364-0321/

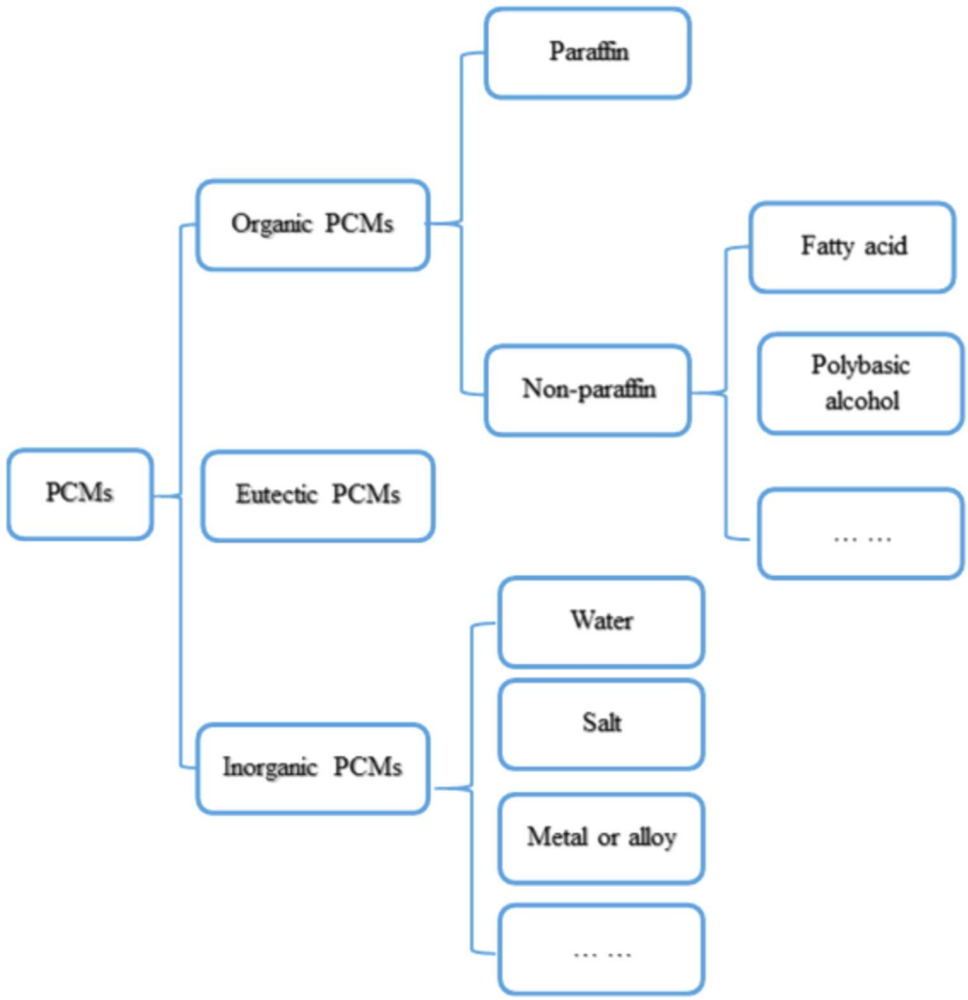

Fig. 1. The classification of PCMs.

soluble ingredients mixed together, which have the feature of simultaneous melting and solidification without material's separation [14]. Fig. 1 shows the classification of PCMs.

Not all PCMs can be used in practical application. The selection of PCMs has the following requirements [9,15–17]: (1) Phase transition temperature is within the range of practical operation. (2) High latent heat storage capacity. (3) High thermal conductivity. (4) Stable chemical and thermal properties. (5) Non–toxic, non–corrosive and harmless to environment. (6) Low cost and easily available. (7) Small volume change. (8) No or little supercooling.

No PCMs can fully meet the above requirements. Always there are few defects, like supercooling, phase separation, low heat transfer rate, leakage in the molten state, instability of performance [8,18,19]. However except metallic-based PCMs, all other kinds of pure PCMs have a common defect of low thermal conductivity. Organic PCMs have the lowest thermal conductivity and thermal conductivity of inorganic PCMs is slightly higher than that of organic PCMs [20]. Hence, improving thermal conductivity is one of the focuses in the field of PCMs. This paper reviews the reported studies in recent years about thermal conductivity enhancement of PCMs by adding fillers with high thermal conductivity and encapsulating PCMs, where the fillers mainly include carbon-based materials and metal-based materials. Fig. 2 shows the approaches of thermal conductivity enhancement. Furthermore, the advantages and disadvantages of each method for improving the thermal conductivity of PCMs are summarized and compared, with the aim of providing the reader with a relatively systematic and detailed awareness of them.

PCMs are applied in various fields, Khan et al. [21] reviewed PCMs used in solar absorption refrigeration systems, Kenisarin and Mahkamov [22] reviewed PCMs employed in residential buildings with passive thermal control. As PCMs can maintain constant temperature and store (or release) massive latent heat during the phase transition process, they are widely employed in the field of solar energy system, buildings, cooling system, textile and heat recovery, and the applications with PCMs in recent years will be summarized in this paper.

2. Thermal conductivity enhancement and thermal properties of phase change materials in thermal energy storage

Thermal conductivity enhancement can increase the rate of charging and discharging heat, thereby improving the efficiency of thermal energy storage systems [23]. The ways of enhancing thermal conductivity are roughly divided into two types: adding substances with high thermal conductivity and encapsulated phase change materials, which will be discussed in the following sections.

2.1. Adding substances with high thermal conductivity

As we know, pure PCMs suffer from deficiency of low thermal conductivity. Therefore, there are numerous researches about adding additives with high thermal conductivity to improve thermal conductivity of PCMs. This review paper focuses on the additives of carbon–based materials and metal-based materials, and their thermal conductivity parameters are listed and compared with each other.