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Novel approaches and recent developments on potential applications of phase change materials in solar energy

A.K. Pandey[a,*], M.S. Hossain[a], V.V. Tyagi[c], Nasrudin Abd Rahim[a,b], Jeyraj A./L. Selvaraj[a], Ahmet Sari[d]

[a] UM Power Energy Dedicated Advanced Centre (UMPEDAC), Wisma R & D, Level 4, Jalan Pantai Murni, University of Malaya, Kuala Lumpur 59990, Malaysia
[b] Renewable Energy Research Group, King Abdulaziz University, Jeddah 21589, Saudi Arabia
[c] Department of Energy Management, Shri Mata Vaishno Devi University, Katra 182320, J & K, India
[d] Karadeniz Technical University, Department of Metallurgical and Material Engineering, 61080 Trabzon, Turkey

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ABSTRACT

Phase change materials (PCMs) can be applied to several different solar energy systems for the extended heat energy storage which is quite useful as the solar energy is intermittent in nature and is unavailable during the night period. Application of PCMs in solar energy systems allows the solar energy to be used at any time even in the absence of the natural solar radiation. Thus, the use of PCMs in the solar energy systems can bridge the demand and supply gap of the normal electrical energy. This paper deals with the recent advances in PCMs application in different solar energy systems and presents almost all of the emerging areas where the applications of PCM in solar energy systems are urgently required. The novel and most recent developments of PCMs in solar thermal energy systems, such as, solar thermal power plants, solar air heater, solar water heater and solar cooker have been duly covered. Furthermore, the application of PCMs in heating and cooling of buildings have been presented as well as the investigation of the PCM application in the solar photovoltaic systems for the performance enhancement of PCMs. Intrinsically important, from the study it has been found that PCMs have been in use in almost all of the solar energy systems even though their uses are still limited and commercially not available due to several economic and environmental constraints. Thus, the paper attempts to present recent and novel approaches by the authors around the world on PCMs applications in the solar energy in well documented forms. Based on the findings, future recommendations have also been given to provide the idea and pragmatic concepts for the researcher to work on the areas of research for further improvements in the systems.

1. Introduction

The demand for energy is increasing day by day around the world due to increased population, life style, industrialization etc. Energy demand can be fulfilled by two different sources viz. fossil fuels which has limited stock in the nature and renewable energy which is abundant and can be renewed at a significant rate. Fossil fuels have limitations in terms of availability and negative environmental impact. On the other hand, renewable sources, such as, solar energy, bio energy, wind energy, geothermal energy, etc., are renewable in nature, freely available and having positive environmental impact. But, renewable energies have certain limitations too, especially, solar energy which is only available in the day time and intermittent in nature. Therefore, solar energy requires an efficient energy storage option to store it in the day time to be used in the absence of solar radiation. Due to unavailability of solar radiation in the night time and intermittency in nature the success of usage of the solar energy largely depends on the energy storage method. The energy in different forms can be stored in different ways, such as, electrical, mechanical and thermal energy. The most popular energy storage option in the solar photovoltaic (PV) cells is through batteries where the commonly available battery for the solar photovoltaic cells is the lead-acid type [1]. The mechanical energy can be stored using pumped hydropower storage (PHPS), flywheels and compressed air energy storage (CAES). Out of these mechanical energy storage methods, PHPS and CAES can be used for large scale utilities, however, flywheel energy can be used for intermediate storage. This energy storage can be used in the absence of the main power supply from the grid [1]. The thermal energy can be stored in different forms, such as, sensible heat, latent heat and thermochemical or a combination of these. Sensible heat energy storage is a kind of a TES which is due to the temperature change in the material during the charging and discharging processes. The specific heat is the measure of the amount of

* Corresponding author.
E-mail addresses: adarsh.889@gmail.com, adarsh@um.edu.my (A.K. Pandey).

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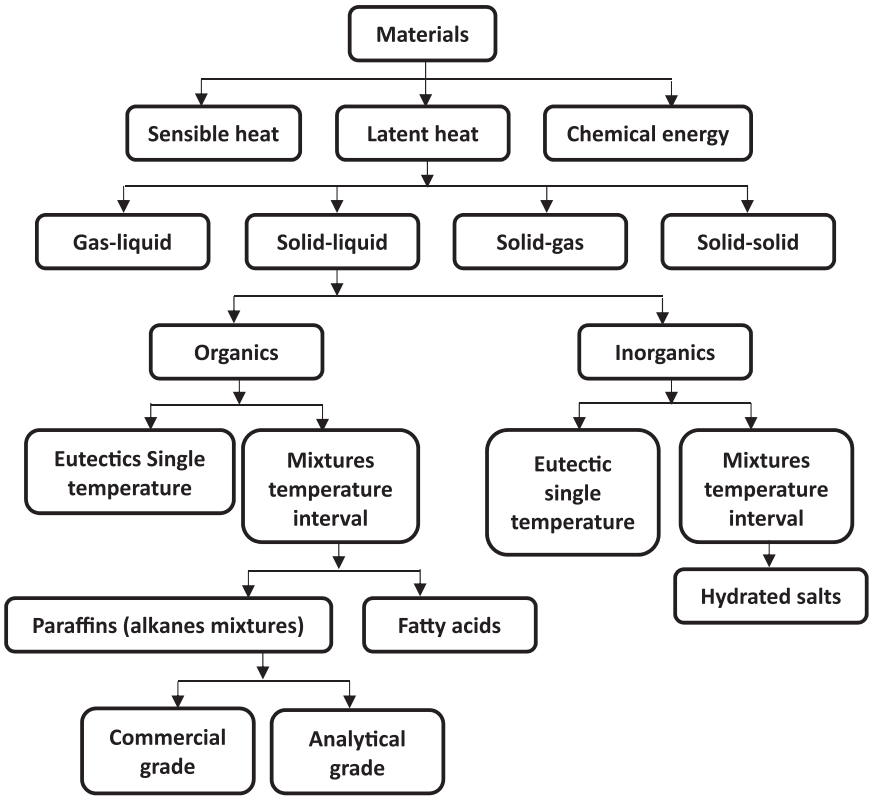

Fig. 1. Energy storage materials and their groupings [17,18].

heat stored depending on the amount of material and the change in temperature [2]. However, the latent heat storage deals with the change of phase from solid to liquid and liquid to gas or vice versa. One of the methods of latent heat energy storage is by using PCMs where the material can store energy at a particular temperature by changing its phase. Enormous amount of work on PCMs is being carried out around the world to fill the demand and supply gap with means of usage of the solar energy in efficiently effective methods and systems [3,4]. PCM study was initiated in 1940 by Telkes and Raymond and significantly due to the energy crisis in the late 1970s and early 1980s, the researches on PCMs have gained much interest, especially, in the solar energy applications, such as, solar heating [5,6]. During this period many studies had been carried out by the researchers in the form of books and research papers [7–9].

Recently few authors [10–13] had presented the review on PCM based applications in the solar energy systems. Wang et al. [12] presented the review on the solar water heater (SWH) with PCMs covering the technical and economic aspects. Technical opportunities include PCM characterization for a better use in the SWHs, development of a novel SWH which can be integrated with the PCMs, a long term performance analysis and standardization of the SWHs for marketing. It is of interest to note that the economic opportunities include cost benefit analysis in different locations around the world and also to provide subsidies, especially, in countries where solar radiation is abundant. Application of PCMs for the thermal management of photovoltaic (PV) systems was studied by Browne et al. [10] in which the study covered the use of PCMs for thermal regulation in the PV, building integrated PV (BIPV) and concentrated PV (CPV). They found that the use of PCM enhanced the performance of the PV systems but still more areas had to be explored in terms of discharge and solidification of PCMs. Kenisarin and Mahkamov [11] presented the status of research in PCMs applied in the solar active and passive space heating systems, solar cooking and greenhouses. They found that none of the solar energy products with PCMs were commercially available at that time.

After going through the literature, it is found that none of the literature gives the consolidated review on the application of PCMs in all of the solar energy systems. Therefore, in this paper an attempt has been made to present the recent developments and advances in the applications of PCMs in the solar energy systems. The manuscript has been divided into eight different sections to present an overview and current updates on PCM applications in the solar energy. The first section deals with the introduction of the applications of PCMs in the solar energy and the initial studies carried out by the researchers. The second section deals with an overview and classifications of PCMs to give an idea on PCM concept and the range of availability of PCMs to be used in the solar energy systems. The third section deals with the thorough review on the application of PCMs in the solar thermal systems, such as, solar thermal power plant, solar air heater, solar water heater and solar cookers. The fourth section presents the application of PCMs in heating and cooling of buildings. The application of PCMs in photovoltaic (PV) panels is presented in the fifth section. The use of nanotechnology in PCM for performance enhancement is dealt with in the sixth section. The seventh section gives the recent trends of publications in PCM application in the solar energy systems. Based on the studies presented in different sections as mentioned above, the conclusions and recommendations for the future study are given in section eight.

2. Phase Change Materials (PCMs): an overview

Phase change materials are specifically applied as a TES medium which has been explored mostly in the recent 20 years, yet at the same time the data is quantitatively colossal and hard to discover. Phase change materials have three unique states, namely, solidifying, melting and gasses states where melting and solidifying are the fundamental characteristics. During these processes, the materials have the capacity to store and discharge substantial measure of energy. Taking into account of these characteristics, PCMs are used for storing thermal energy in many real life applications [1].

The usefulness of the TES is given by Abhat in 1983 [3] in which the