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Comparative Studies on Nano-Enhanced PCM (Ne-PCM) for Solar Energy Storage Applications

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Abstract

Widely used applications using Nano-enhanced Phase Change Materials (Ne-PCM) are the focused area of research in the trending modern technologies. Because of two main factors, researchers are compelled to study about Ne-PCMs. One important factor is the usage and storage of non-renewable energy sources. As it is a globally accepted fact that traditional energy sources, i.e., fossil fuels, and natural gases are the main cause of global warming and concerning the time they are extinguishing soon, this fact has led to the idea of using renewable energy sources, especially solar energy. But solar energy is intermittent and unpredictable so this energy must be stored in the form of latent heat or sensible heat using PCMs. In the flow of the study, it is observed that PCMs are lacking few thermophysical properties to achieve the desired results, for example, these materials have low conductivity. This fact gave rise to the idea of enhancing the properties of these phase-change materials. There are many methods to improve the material's thermos-physical properties. Few to tell about encapsulation of the material, insertion of nanoparticles to the material, usage of fins, etc. An appropriate method can be selected based on the application and material properties. The present paper studies one of the methods of insertion of nanoparticles to enhance the properties of phase change materials. It will focus on the properties of PCMs, the usage of nanoparticles to enhance PCM's properties, and how they can be used to store solar energy in various methods. Present paper focuses on the study of Organic, inorganic and eutectic phase change materials and its property enhancement using various metallic and non-metallic nanoparticles to store the energy.

Keywords: *Nanoparticles, PCM, Solar Energy, Synthesis of PCM*

1.0 Introduction

Phase Change Materials (PCM) are emerging widely as researchers become more sentient about the storage of energy[1]. The supply and demand gap between energy usage is increasing worldwide as non-renewable energy sources are depleting fast[2,3]. On the contrary renewable energy sources are available in ample and as we all know these are environmentally friendly. But the disadvantage of these sustainable or renewable energy sources is that renewable energy sources are intermittent[4,5]. Hence it is obligatory to store this energy and use it when it is not available. Phase change materials serve the same purpose of storing renewable energies such as solar energy, etc[6]. These PCMs have great thermos-physical properties such as higher specific heat, reliable density, and better heat transfer efficiency. The disadvantage of the PCMs is that these materials have low conductivity. There are many methods to increase the conductivity, such as using heat pipes, extended fins, nano-encapsulated PCMs, or mixing particles with the base material. In this paper, we will be focusing on the method of mixing nanoparticles.

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2.0 Phase Change Materials (PCMs)

As discussed, energy can be stored in the form of sensible heat or latent heat in the PCMs. The gap between energy supply and demand will be achieved by these phase-change materials[7–9]. The classification of these materials is as shown in the Figure 1. Based on the application temperature range, the material can be selected. Using latent heat of PCMs for storing solar thermal energy is an optimistic method. Common PCMs that are more popular are a series of paraffin wax (Organic), and hydrate salts (Inorganic), a few oils whose melting points and viscosity are suitable for the application Have focused on the advantages and disadvantages very clearly. The main advantage of using PCM is that it can store and deliver energy at a fixed temperature. The PCMs are classified according to their chemical nature, phase transition, shape stabilization encapsulation, and finally temperature. The latent heat Thermal Energy Storage (TES) system stands out as an efficient method for storing thermal energy, leveraging Phase Change Materials (PCMs). Crucial parameters such as melting points and latent heat define the effectiveness of PCMs within the TES system[9].

Following are the advantages of PCM: - [10,11]

1. These materials provide higher energy storage capacity in smaller storage volumes.
2. At a fixed temperature charging and discharging can be achieved.
3. They are readily available at a low cost.

At the same time, they have a few disadvantages also which can be enlisted as: -

1. Though the cost of materials is low, the setup cost might be more initially.
2. Sometimes charging and discharging process gets limitations for the long-term process.
3. It is observed that the conductivity of the PCMs is low.

So, as discussed in the introduction section there are different methods to improve the conductivity of the PCM. This paper's focus will be on Nano-enhanced PCMs. If the application is fixed it is easy to select the PCM based on the classification given in Figure 1.

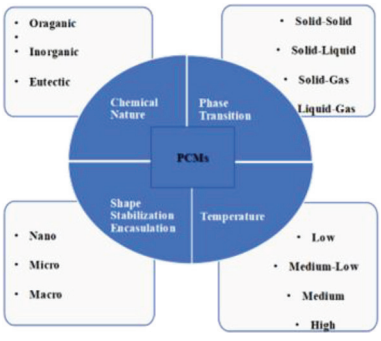


Figure 1. Classification of PCMs.

3.0 Nano-Enhanced PCM (Ne-PCM)[12]

Dispersion of high conductivity particles in the PCMs for better conductivity is called nano-enhanced PCMs. There are a few materials such as alumina, graphene, titanium dioxide, copper is examples of nano-particles. But all the materials cannot be compatible with all the PCMs. High-density metals cannot be used with organic materials as the particles might settle down the container and along with that, they might increase the overall weight of the setup. Studied, for example, alumina gives good results when combined with paraffin wax pared to nickel or copper[13]. Few combinations of Ne-PCM combinations are listed in Table 1. Hence it is very important to use high conductivity with low-density material as nanoparticles. Later, after synthesizing nanoparticles and PCM, the composite materials are tested for different thermophysical properties using different characterization techniques. The different techniques to study properties are as below. Nanoparticles strengthen the convective heat transfer and the conductivity of liquids. Nanofluids are the colloidal mixture of a base liquid, nanoparticle fluid suspension, and nanoparticles. Thermophysical properties of Ne-PCM can be tested using the following techniques.

3.1 SEM (Scanning Electron Microscopy)

This technique measures the purity and homogeneity of the nanoparticle. The advantage of the SEM method lies in the fact that it gives a detailed 3D topographical image. Another advantage can be stated that the microscope is easy to use[14]. But at the same time disadvantage of this method is that it is bulky and its initial cost is more. This technique provides collective information about the topography of the surface, its electrical behaviour, crystalline structure, etc.

3.2 EDX (Energy Dispersive X-ray)

This is a very highly sensitive method to analyze the elements present in the material. The analysis depends on the interaction of the sample and the X-ray beam. A detector will convert the X-ray beam energy to a voltage signal.

3.3 XRD (X-Ray Diffractometer)

It is a very important technique to measure the structural characterization of crystalline materials. This technique is based on the principle of diffraction of the X-ray from the crystalline material. It gives important information about the sample such as purity of the material, phase, morphology, and crystal size.

3.4 DSC (Differential Scanning Calorimetry)

This is the technique with which thermal properties can be studied. The parameters that can be measured include melting point, crystallization behavior, mass change, temperature stability, phase transition, decomposition, reduction, or oxidation, etc.

3.5 FTIR (Fourier-Transform Infrared Spectroscopy)

FTIR is an important technique that is used to get the infrared spectrum of emission, photoconductivity, and absorption of all the three phases of material *viz*. solid, liquid and gas. It is used to detect different functional

Table 1. Outline of PCM-Nanoparticles combination and their conclusions[5]

PCM	Nanoparticle	Conclusion
Paraffin wax	Al_2O_3	6 wt. % MWCNT addition to paraffin wax shows the best results. The peak temperature obtained was 70.55°C.
Paraffin wax	MWCNT	Composite improved the efficiency of the system. The addition of 1% Cu to the paraffin wax increased outlet temperature by 2K.
Copper made porous media (95%, 98 % porosity	1% Cu	1%, 2% nanoparticle addition improved the performance but 4% addition deteriorated.
Paraffin RT82	1%, 2%, 3% Al_2O_3	The addition of nanoparticles at an early stage is not effective but otherwise melting time is saved between.
Paraffin Wax	combined with Lauric acid	Productivity increased from 6650 mL/m^3 per day compared to 2800mL/m^3 per day due to the usage of nanoparticles. Efficiency also increased to 63.8% at 0.3 rpm.
Paraffin wax	CuO	CuO and silver affected the heat transfer rate. It was 18% to 14% higher than normal PCM but aluminium oxide and MWCNT has not much change in heat transfer rate.
Myristic acid	CuO	PCM showed high chemical stability and thermal stability, which reduced phase change time considerably.
n-hexadecane $C_{16}H_{34}$ (99%)	Silver	When nanoparticle is added to PCM conventional PCM started behaving as a Newtonian fluid having low viscosity.
Bio-based pure PCM, i.e., coconut oil	CuO	At the beginning of the process, nano-PCM and pure PCM behave the same but later Ne-PCM increases the rate of melting and other thermal properties.
Paraffin RT82	Aluminum oxide	It concluded that the addition of nano-particles does not affect much in enhancing properties.
99% lauric acid	MWCNT	It is found that thermal properties were enhanced in porous media and nanofluid composite.
40% ethylene glycol	MWCNT	Higher nanoparticle concentration and Reynold's number give a better phase change process.
PCM	Graphene	Enhanced performance of PV is observed. The power produced found using PCM/AMF is 4.14% more.
Paraffin wax	Nano-graphite	Stirring speed increased charging energy and discharging energy time and efficiency. The heat transfer mechanism has In these two applications various experiments have been done so far to improve the efficiency using PCMs and Ne-PCMs been enhanced by forced convection.

groups. This process uses the mathematical process of Fourier transform. Different combinations of PCMs and nanoparticles are studied by scholars and those are enlisted in Table 1.

4.0 Solar Applications of Ne-PCMS[9]

Wherever modern technology uses solar energy, this technology is applicable and research is going on in all areas. Right from space technology to building technology (Temperature control of the space) and domestic appliances such as solar cookers and solar water heaters PCMs can be used. Following solar application can use the technique of Ne-PCM to store the energy.

4.1 Solar Desalination

Jilte *et al.*,[6] have focused on solar energy applications where PCMs are used. Especially Anand et al reviewed the experimental and theoretical aspects of solar desalination using the Ne-PCM concept. It has been observed that the performance of the setup has been increased up to 120% for the active method and 700% for the passive method as compared to the solar stills without PCM. It is also observed that the efficiency of this system is more during the daytime than at night time.

4.2 Solar Water Heater

Wong *et al.*,[12] reviewed that solar water heaters with PCM give better thermal efficiency than non-PCM solar water heaters. Zhang *et al.*,[10] studied that the efficiency of the system has increased by 39% when paraffin wax is used as PCM to store the energy. Moreover, energy can be used when solar energy is not available. Aiswarya and Das studied the same phenomenon of charging and discharging the solar water heater. They carried out this experiment in China where weather extremities can be observed (Figure 2).

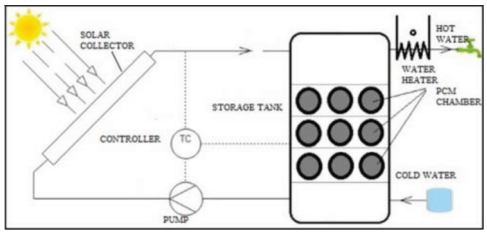


Figure 2. PCM used in solar water heating storage.

4.3 Photovoltaic Cells Using PCM[14]

As electricity has become a vital need of day-to-day life, research must be carried out more in this field. Right from the domestic need to the recent development of electric vehicles electricity is unavoidable. Studied the effect of PCMs and natural convective heat transfer using PCMs on the performance of PV cells for electricity generation. PCMs enhanced the efficiency of the PV cells while generating electricity. Three case methods were concluded by tanks filled with Ne-PCM, nanofluid flows through cooling tubes and cooling tubes inside a reservoir that is filled with PCM having circulating water. They used SiC as a nanoparticle and paraffin wax as PCM. They observed that the current of the PV/T system increased from 3.69A to 4.04A

4.4 Solar Dryer

Concluded that after using Ne-PCM (PCM-paraffin wax Nanoparticle-aluminum oxide 0.5% and 1.5% by weight) in the solar dryer thermal efficiency of the setup increased by 12% used the same composite of alumina and paraffin wax for drying mushrooms. They found that without Ne-PCM mushrooms contained 17.45g water/g dry mushrooms whereas with Ne-PCMs it contained 0.0515g water/g mushrooms.

4.5 Solar Cooker and Solar Air Heater

Various experiments are going on for these two applications using PCM or Ne-PCM. In solar cooker energy is stored during the daytime when an ample amount of sunlight is available in the form of latent heat and then later it can be used during night time when sunlight is not available. Similar is the case with solar water heaters. Increment in efficiency and performance has been observed by when organic PCM and alumina as nanoparticle is used by them (Figure 3-5).

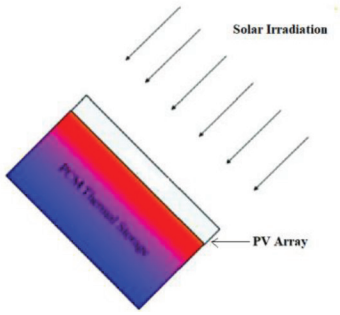


Figure 3. PV cells coupled with PCM.

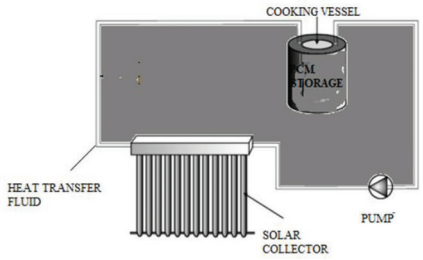


Figure 4. Schematic of Solar cooker with PCM.

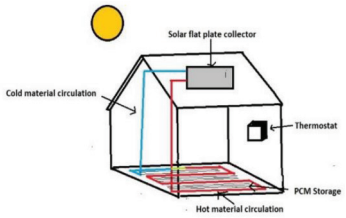


Figure 5. Cooling and Heating of a floor using PCM.

4.6 Building Applications[15]

The integration of PCMs within building applications for energy efficiency, including space heating, space cooling, and water heating, is a subject of considerable study. PCMs offer significant potential for energy savings owing to their capacity to absorb and release thermal energy during phase transitions, such as melting and solidification. Passive incorporation of PCMs involves embedding them directly into building materials or components during construction. This integration enables effective temperature control within the building environment. While active utilization of PCMs involves incorporating them into systems that actively regulate the release and absorption of thermal energy based on specific temperature or environmental conditions, passive integration remains a promising strategy for improving energy efficiency and thermal comfort in buildings. It contributes to sustainable construction practices and aids in reducing environmental impact.

5.0 Conclusion and Future Work

Phase change materials are very helpful in storing nonconventional energy sources, especially solar energy. Its thermos-physical properties are increased by adding nanoparticles. Almost all solar energy applications are found more effective and efficient when PCMs or Ne-PCMs are used. Although they have concluded that efficiency is increased with Ne-PCMs, lots of research is yet to be done on various combinations of nanoparticles and PCMs. For example, maximum research is done on the series of paraffin wax if talking about organic PCMs. Similarly, more investigations must be done on the use of different nanoparticles with different melting points

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