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ASSESSMENT OF THERMAL CONDUCTIVITY OF PHASE CHANGE MATERIALS BY INCORPORATING METAL AND METAL OXIDES NANOPARTICLES

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Abstract

Because of the exceptional thermal characteristics, phase change materials (PCMs) are served in a variety of solar collector designs to increase the amount of useable heat obtained by collectors while minimising waste heat. Furthermore, the addition of nanoparticles to PCMs to form nanocomposite (NC) PCMs with enhanced thermal characteristics has opened the door to new possibilities for the use of nanoparticle dispersed phase change materials (NPCMs) in solar collectors. This review of the literature focuses on the effect of incorporating various types of nanoparticles into PCMs on the heat transfer behaviour and thermal conductivity (TC) of materials. Based on the findings of the previous investigations, it can be concluded that, despite the fact that silver nanoparticles are vulnerable to oxide formation, silver nanoparticles are an efficient alternative for raising the TC of PCM. Moreover, metal oxide nanoparticles outperforms than other metal-based nanoparticles in terms of raising the thermal conductivity of PCMs when compared from without any additions.

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1. Introduction

The need for energy is increasing on a daily basis around the world as a result of increase in inhabitants, rising living standards, and industrialization, among other factors [1]. Traditional energy resources and renewable energy resources are two different types of energy sources that might be used to supply energy [2]. Because of their availability benefits in domestic power generation, solar and wind energy are being evaluated as viable power-generating alternatives in the future.

There is a worldwide effort to find new and sustainable sources of energy. Develop energy storage systems, which are just as vital as discovering new sources of energy, is one of the solutions being considered. Current technical challenges include finding a way to store energy in an acceptable form [3]. Energy storage not only helps to lessen the imbalance between source and requirement, but it also helps to enhance the yield and robustness of energy systems, as well as playing a significant part in energy conservation and renewable energy production.

Thermal energy storage may be allocated in two classes: sensible heat storage and latent heat storage, which are distinguished by heat storage medium used. In sensible heat storage, the heat is preserved or discharged in conjunction to a change in the temperature of the storage medium. Phase change materials (PCMs) on the other hand, have a high heat storage density and are capable of preserving a significant quantity of heat throughout the change of phase process with just a modest difference in PCM volume and temperature [4].

As illustrated in Figure 1.1, PCMs may be divided into three classes: inorganic PCMs, organic PCMs, and eutectic PCMs. There are three main types of Eutectic PCM: inorganic-organic, organic-organic, and inorganic-organic combinations of chemical molecules. Their capacity to melt and freeze without phase segregation and create a single common crystal throughout the crystallisation process is their most essential quality of eutectic PCMs. Inorganic PCMs composed of inorganic elements such as salt hydrates and metallic elements. Organic PCMs, which contains organic compounds such as paraffin wax and certain types of fatty acids. In addition to their high latent heat, these PCMs have the capability of conserving a huge quantity of energy at steady fusion condition, an acceptable phase change temperature, and are cost-efficient and readily available.

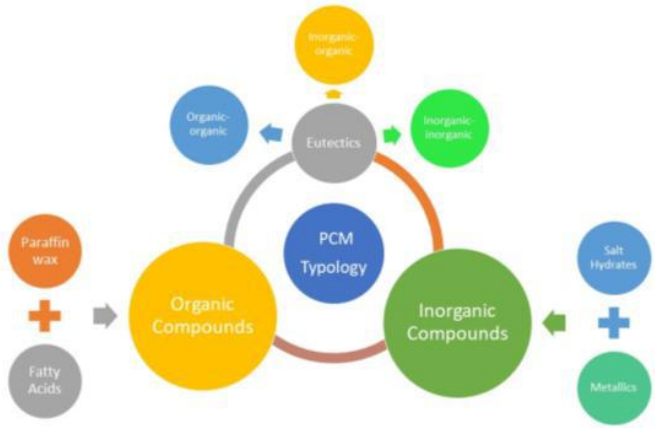

Figure 1.1. Types of PCMs.

Hence, effective utilization of thermal energy storage system needs enhanced thermal conductivity of storage medium [5], nanoparticles additive dispersed in the PCM [6], and enhanced thermal conductive materials [7]. In order to raise the thermal conductivity and heat transfer behaviour of PCM, dispersed nanoparticles may be categorized into organics, inorganics, and hybrid nanoparticles as illustrated in Figure 1.2. Nanoparticles made of organic materials, such as graphite and other carbon-based materials including multi-walled carbon nanotubes (MWCNTs) and carbon nanofibers (CNFs), are considered under the organic nanoparticles. However, inorganic nanoparticles include metal and metal oxide nanoparticles such as titanium oxide, iron oxide, and aluminium oxide. On the other hand, Hybrid nanomaterials includes the combination of organic-organic, inorganic-inorganic and organic-inorganic materials.

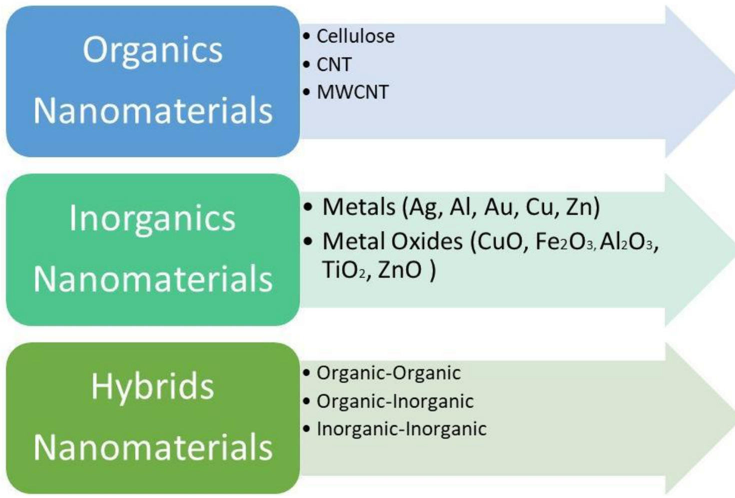

Figure 1.2. Categories of nanomaterials.

On the basis of experimental and theoretical findings, this study provides a complete assessment of the heat transfer behaviour along with thermal conductivity improvements of PCMs loaded with nanoparticles. The primary focus of this assessment is to get a good comprehension of role of nanomaterial additions (metallic and metal oxides) in the thermal performance of PCM.

2. Production of Nanoparticles Embedded PCMs (NPCMs)

Nanoparticle embedded phase change material (NPCM) is a liquid-solid combination that should have a homogenous and equilibrium suspension. The two most common procedures for synthesizing NPCM are the one-step method and the two-step method, respectively. The generation of Nano Particles (NPs) and dispersed in the base PCM are accomplished in single step using the one-step approach. Whereas, it is necessary to obtain or manufacture the nanoparticles in advance of dispersing them in the base PCM in two-step method. Procedures that fall within the two-step approach for the synthesis of NPCM.

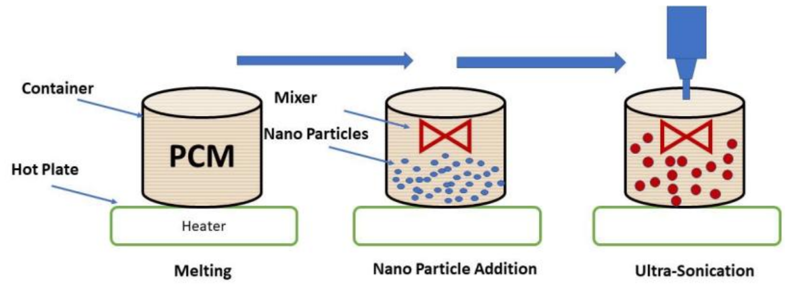

Figure 2.1. Diagrammatic representation of synthesis of NPCM by ultra-sonication process.

However, number of researchers use the mixing and ultrasonication techniques to achieve the best results among other synthesis techniques. Figure 2.1 illustrates the schematic of the synthesis process, in this method prior to adding NPs, the PCM should be heated to a temperature above its melting temperature. The shear mixing technique or the magnetic stirrer can be used to mix this combination. Mixing time can be varied from 15 minutes to 3 hours. The NPCM mixture is ultrasonicated to minimise NP clumping. The ultrasonication process is influenced by two variables: time and frequency of operation. Heat is generated as a result of prolonged ultrasonication, which may alter the morphology of the nanoparticles (NPs). Ezhumalai et al. proposed using an ultrasonic frequency of 40 kHz for ultrasonication. It was possible to vary the duration of ultrasonication from 2 minutes to 4 hours [8].

3. Effect of Nanoparticles Inclusion on Thermal Conductivity of NPCMs

When deploying PCMs as a thermal energy storage material incorporated in a thermal storage system, poor heat transfer rate is regarded to be the most significant issue. Because of the poor heat transfer rate, there is insufficient heat exchange between the PCM and the Heat Transfer Fluids (HTF), resulting in partial melting and solidification of PCM. As a result, it is desirable to raise the thermal conductivity of PCM as well as the heat transfer levels of the PCM system in terms of enhancing the collector efficiency. The addition of nanoparticles to PCM, resulting in NPCMs with improved thermo-physical properties, resulted in new advantages for PCMs in terms of raising their thermal conductivity and heat transfer attributes.

3.1 Effect of metallic nanomaterials on Thermal Conductivity of NPCMs

Aluminum (Al), Copper (Cu), and Silver (Ag) nanoparticles, are among the solid metal nanoparticles which have been added to attain high thermal conductivity.

Al-Shannaq et al. employed electroless plating of silver (Ag) metal onto microcapsule containing the PCM in one of their experiments. As a result of metal coating, the assessed thermal conductivity of the PCM microcapsules improved considerably from 0.189 to 2.41 W/m K, indicating a substantial improvement in the performance [9][10].

3.2 Effect of metal oxides nanomaterials on Thermal Conductivity of NPCMs

The thermal conductivity of metal oxides such as alumina and copper oxides are typically adequate, ranging from 30 to 40 W/m K, and as a result, they are regarded to be good heat conductors. However, Metal oxides have a lower thermal conductivity than pure metals, but they have higher chemical equilibrium and economical to synthesize. Therefore, metal oxides have been utilised in place of pure metals as a cost-effective substitute. Babapoor and Karimi (2015) done an experimental investigation on effects of incorporating several types of metal oxide nanoparticles into paraffin wax. Specifically, three distinct concentrations of all studied nanoparticles (4.0 weight percent, 6.0 weight percent, 8.0 weight percent) were developed for the author's studies. In one study, it was discovered that the utmost increment in TC was achieved by doping Al2O3 nanoparticles, subsequently by improvements of 140 percent, 110 percent, and 110 percent for Fe3O4.

4. Conclusions

This work has demonstrated that, despite the fact that silver nanoparticles are susceptible to oxide formation, silver nanoparticles are an excellent option for increasing TC of PCM. As a result of the employment of Ag NWs as a TC enhancer inside PCMs, the TC of the Ag NWs/PCM composites was shown to be much higher than without any metallic inclusion. Furthermore, as compared to other metal-based nanoparticles, metal oxide nanoparticles are superior additions in terms of enhancing the thermal conductivity of PCMs. Overall, metal nanoparticles, especially Al2O3 when utilised at concentrations ranging from 1-27 weight percent, and Fe3O4 when doped in the PCM at weight fractions ranging from 4.6% to 20%, have been shown to significantly increase the thermal conductivity of the PCM.

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