

Importance of Phase Change Materials in Heat Transfer Fluids for Solar Heat Absorption

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Abstract

Solar heat absorption involves capturing and storing solar energy for later use. Phase change materials play a crucial role in enhancing the efficiency of heat transfer fluids in solar thermal systems and are integral to the optimization of heat transfer fluids in solar thermal systems. Their ability to store and release thermal energy efficiently, regulate temperatures, and enhance overall system performance makes them a valuable component in the transition towards sustainable and renewable energy sources. This article summarizes that, the use of phase change materials in solar heat transfer fluids is an important way for improving the thermal performance, energy efficiency, and lifespan of a solar thermal system. The paper also discusses about the role of phase change material in heat transfer fluid, the various types of PCMs and the effect of adding various nano particles with PCMs.

Keywords: Phase change materials, microencapsulated phase change materials, nanofluid, thermal conductivity

INTRODUCTION

The growing depletion of natural resources brings an alarming situation to the global energy sector. For the past several decades fossil fuels shoulders the major share of energy demands. Global energy demand is raising daily at an accelerated rate. The increasing use of fossil fuels ends up in the huge emission of greenhouse gases during power generation which ultimately is responsible for global warming and climatic changes. This scenario shifts the global community and researchers to focus on renewable energy sectors like solar, wind, biogas and geothermal energy. Because solar energy is abundant and environmentally friendly, it plays a significant part. It is estimated that in one hour the earth's atmosphere receives sunlight to power the electricity needs of each human being on earth for an year .Also the steady and limitless supply of sunlight will last at least for another 5 billion years. But the main huddle lies in the area of effective storage and utilization of solar energy. Many researches are being carried out to utilize phase change materials for solar energy entrapment and subsequently for power generation. This paper discusses about the importance of phase change materials in heat transfer fluids for solar heat absorption.

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PHASE CHANGE MATERIAL: A BRIEF NOTE

Substances that undergo a phase transition from solid to liquid or vice versa are known as phase change materials (PCMs), and they have the ability to store and release huge amounts of thermal energy. Because they may enhance the efficiency of thermal energy storage systems, phase change materials have garnered interest. When a substance transforms from a solid to a liquid, energy per unit mass is stored, and when a substance freezes at a set temperature, it is released. The energy that the

material absorbs raises the vibrational energy levels of the atoms or molecules that make up the substance. The molecular bonds loosens while melting and subsequently the material changes from solid to liquid. While during solidification the material transfers energy and the molecules lose energy and changes to solid state.

OVERVIEW OF PHASE CHANGE MATERIALS IN HEAT TRANSFER FLUIDS

In heat transfer fluids, phase change materials can be used as additives to enhance their thermal properties. By adding phase change materials to a heat transfer fluid, the fluid's heat capacity can be increased, which in turn allows it to absorb more heat energy and reduce the temperature fluctuations. The size of the heat exchangers can be reduced by employing phase change materials as it can store heat during the period of excess production and release it during low production hours. There are various benefits to using phase change compounds in heat transfer fluids for solar thermal applications. Firstly, phase change materials have high energy storage densities, which means that a smaller volume of material can store a large amount of thermal energy. This will result in smaller and more compact thermal energy storage systems. In addition, phase change materials have a high latent heat of fusion, which enables them to absorb or release significant thermal energy during the phase transition. Thermal energy storage and transfer may become more effective as a result [9].

Types of Phase Change Materials Used in Heat Transfer Fluids

The various types of phase change materials that can be used in heat transfer fluids are as detailed below.

- a. *Organic Phase Change materials:* These are usually made from paraffin waxes, fatty acids or esters. Examples include paraffin, beeswax and stearic acid. Organic phase change materials are abundant, often inexpensive, and have a high energy density. However they can be flammable and have a limited temperature range.
- b. *Inorganic Phase Change Materials:* These are made from salt hydrates, metals or metal alloys. Examples include hydrated salts such as sodium sulfate decahydrate and calcium chloride hexahydrate, and metals such as aluminum and copper. Inorganic phase change materials are generally non-flammable, have a high melting point and are stable over a wide range of temperature. However, they are typically more expensive than organic phase change materials and have a lower energy density.
- c. *Eutectic Phase Change Materials:* These are a combination of two or more substances that melt and solidify at a lower temperature than either of the individual substance. Examples include calcium chloride and sodium hydroxide or sodium acetate and potassium acetate. Eutectic phase change materials have a high energy density and can be tailored to meet specific temperature requirements. But compared to other kinds of phase transition materials, they can be more costly and challenging to find [10].

A system's specifications, including the required temperature range, heat capacity, and cost, will determine which phase change material is best for the given application. Some systems may even use a combination of different phase change materials to achieve the desired performance (Figure 1).

Phase-change Materials' Significance in Solar Heat-transfer Fluids

Phase change materials play an important role in solar heat transfer fluids because they allow for more efficient and effective heat transfer and storage. Solar thermal systems are used to collect and store solar energy for later use, but the effectiveness of these systems depends on the ability to store the collected energy. In solar thermal systems, phase change materials are often used in the heat transfer fluid that circulates between the solar collector and the storage tank. When the fluid is heated by the sun, the phase change materials absorb the excess heat and undergoes a phase change, which allows it to store the thermal energy. This stored energy can then be released when the fluid cools down, which helps to maintain the temperature of the storage tank and ensures that the energy can be used when

needed. The capacity of phase change materials to store and release significant amounts of thermal

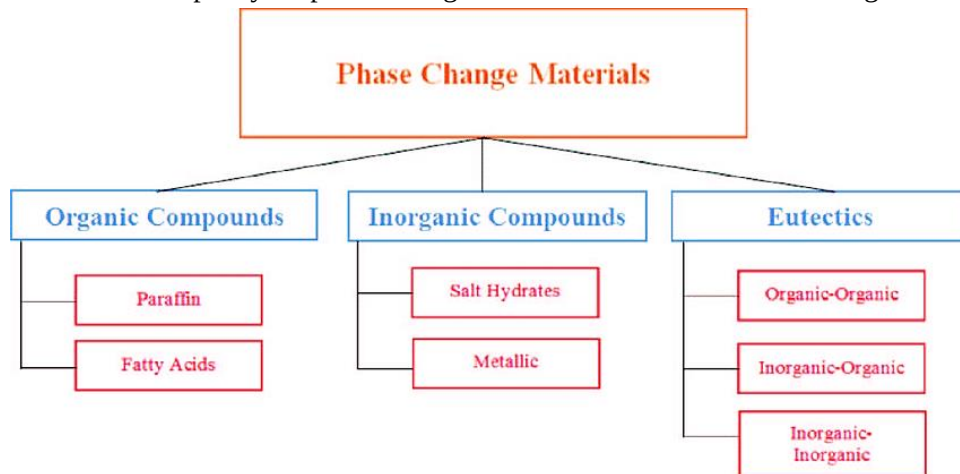


Figure 1. Types of phase change materials.

energy during the phase change process makes them essential components of solar heat transfer fluids. For solar thermal applications, this has a number of benefits, some of which are listed below.

- Enhanced thermal Efficiency:** Through the absorption of excess thermal energy during high solar radiation times and its release during low solar radiation periods, phase change materials can enhance the thermal performance of solar thermal systems. This can lessen the need for supplemental heating or cooling by helping to keep the system's temperature constant.
- Energy effectiveness:** The energy needed to maintain a constant temperature can be decreased in solar thermal systems by the use of phase change materials. Carbon emissions and energy expenses may go down as a result of this.
- Reduced volumes of storage:** Due to their high energy storage densities, phase change materials may store a significant quantity of thermal energy in a smaller amount of material. This may lead to the creation of more compact and smaller thermal energy storage systems, which may be especially useful in applications with limited space.
- Greater system durability:** By lowering the amount of heat stress on the system components, phase change materials can increase the lifespan of solar thermal systems. By doing this, you may lessen the chance that the system may get damaged and require maintenance or repairs.

LITERATURE SURVEY ON PHASE CHANGE MATERIALS IN HEAT TRANSFER FLUIDS

An analysis of six possible heat transfer fluids for use in a high temperature flat slab phase change thermal storage unit is presented by Ming Liu et al [1]. The fluids used in heat transfer are atmospheric air, compressed air operating at 10 bar, supercritical CO₂ operating at 100 bar, steam operating at 10 bar, liquid sodium, and solar salt. For a design thermal storage capacity of 140 MW on average, the comparison is predicated on each heat transfer fluid having the same heat capacity rate under the same thermal energy input. The optimal sensible storage system was contrasted with the PCM storage system that included every heat transfer fluid. Liquid sodium was shown to be the optimal heat transfer fluid throughout the discharge process, providing the grid with the greatest electrical energy delivery rate of 99.4% in comparison to the ideal scenario. A value of 93.6% was attained by solar salt, but 87.9% to 91.3% of the ideal supplied electricity was achieved by the gaseous fluids of atmospheric air, air at 10 pressure, supercritical CO₂ at 100 bar, and steam at 10 bar. [2] AlSi₁₂, a eutectic aluminum-silicon alloy, was identified by Johannes P. Kotze et al [2]. as a promising PCM. The melting point of AlSi₁₂ is 577°C, higher than the operating temperature of conventional heat transfer fluids. It is determined that the best heat transfer fluid for a storage system using metallic PCMs is the eutectic sodium-potassium alloy (NaK). A concept is presented that integrates the thermal energy storage unit and steam generator into

one unit. As NaK is highly reactive with water, the inherently high thermal conductivity of AlSi₁₂ is utilized in order to create a safe concept.

The plant was designed to deliver 100 MW with 15 h of storage. Thermodynamic and heat transfer analysis showed that the concept is viable [3]. Jacob Mingear et.al reported that a mere 0.10 volume fraction of Gallium–indium nanoparticles increase the overall thermal conductivity by nearly 50% and can be optimized to melt at temperatures as low as -46°C [4]. Clara Delgado-Sánchez et.al developed a stable emulsions composed of stearic acid with a melting point of $68\text{--}71^{\circ}\text{C}$ dispersed in silicone oil. They evaluated the thermo-physical properties, viscous and viscoelastic behavior and microstructure of the samples and concluded that stearic acid-in-silicone oil emulsions are an attractive candidate for energy storage applications with a phase change enthalpy in emulsions with the 10 wt% of phase change material of 22.32 J/g. [5] Sandro Nizetic et.al studied the energy applications of Nano enhanced phase change materials and fluids and concluded that the addition of nanoparticles improves specific thermal properties of nano-enhanced materials. The thermal conductivity can be increased by between 20% and 100%, with respect to the base fluid. Other general thermal properties are slightly reduced such as latent heat, while for specific heat capacity the results are variable [6]. P. Chandrasekaran et.al investigated the solidification characteristics of water based nanofluid phase change material. The nanofluid phase change material was prepared by dispersing copper oxide nanoparticles and a nucleating agent in the base phase change material. The experiments were conducted at various bath temperatures and the nanofluid phase change material exhibited a significant reduction in solidification time of about 35% due to enhanced heat transport properties. Further, 50% of total mass solidified during 25% of total solidification time in both phase change material and nanofluid phase change material. Also the presence of nucleating agent eliminated the ramifying problem of subcooling in the phase change material and this will allow the evaporator to operate at a higher temperature in a chiller. Furthermore, it is mentioned that many cool thermal energy storage applications benefit from the nanofluid phase transition material's increased heat transfer rate without subcooling. [7] Kalpana Tumuluri et.al formulated three new heat transfer fluids consisting of combinations of multi-walled carbon nanotubes and microencapsulated phase change materials and tested their thermal properties like thermal conductivity, viscosity and heat transfer coefficient.

The heat transfer results of the microencapsulated phase change material slurry containing octadecane obtained a good result. A maximum thermal conductivity enhancement of 8.1% was obtained for multi-walled carbon nanotubes with diameter of 60–100 nm and length 0.5–40 μm . Heat transfer results indicate that multi-walled carbon nanotubes nanofluid exhibits a convective heat transfer enhancement in the range of 20–25% in turbulent flow conditions. The blend of microencapsulated phase change materials and multi-walled carbon nanotubes was highly viscous and displayed a non-Newtonian shear thinning behavior. Due to its high viscosity, the blend exhibited laminar behavior and lower heat transfer rate, though the maximum local heat transfer coefficient achieved by the blend was comparable to that obtained with microencapsulated phase change materials slurry alone. The pressure drop of the blend was also lower than that of the multi-walled carbon nanotubes nanofluid. [8] The main drawback of Polyalphaolefins (PAOs), according to Fangyu Cao et al [8]., is that they have a low thermal conductivity of approximately 0.14 W/mK, which makes them extensively used for electronics cooling needs. Nonetheless, the fluid thermal characteristics of a PAO can be greatly enhanced by the addition of thermally conductive phase-change material (PCM) particles. Using the emulsion polymerization process, Fangyu Cao et al. experimented with PCM microcapsules and silver-coated PCM microcapsules. The thermal performance of PCM fluids was examined in a microchannel heat sink and contrasted with that of pure PAO. The synthetic PCM fluids were tested using a test loop that was constructed and built. The fluid containing uncoated PCM microcapsules had a 36% greater heat transfer coefficient than the pure PAO. Moreover, PCM fluids containing silver-coated PCM microcapsules had a heat transfer coefficient that was 27% greater than that of pure PAO but lower than that of fluids containing uncoated PCM microcapsules. Despite having a higher viscosity, the uncoated PCM fluid had a 20% lower heat resistance than the pure PAO fluid at the same pumping power.

CONCLUSION

In summary the use of PCMs in solar heat transfer fluids is an important way for improving the thermal performance, energy efficiency, and lifespan of a solar thermal system. PCMs offer several advantages over conventional heat transfer fluids, including higher energy storage density, better thermal stability, and lower risk of leaks or spills. They also allow for smaller and for more efficient storage tanks, which can help to reduce the cost and footprint of solar thermal systems. PCMs will probably play a bigger role in the creation of more effective and affordable solar thermal systems as the market for renewable energy sources expands.

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