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Development of Phase Change Materials/ Nanoparticles for Thermal Energy Storage: Review

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Abstract: Phase change materials/ nanoparticles and nanocomposites maybe used for many fields of energy storage applications due to their thermal, electrical, mechanical and optical properties. The recent review on phase change materials/ nanoparticles and nanocomposites for thermal energy storage has been investigated. The classification of nanofluids, classification of the heat storage methods and applications of nanofluids/ composites in thermal energy storage were discussed. The previous studies showed that the phase change materials/ nanoparticles and nanocomposites have good characteristics make it may be used for different energy storage fields.

Keywords-phase change material, energy storage, nanocomposites, nanofluid.

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1.INTRODUCTION

Technological innovation, industrial development improves standards of living of mankind and it is directly proportional to energy consumption. The energy from the sun is the main source of energy on the earth. The different forms of energy available are geothermal energy, hydro energy, tidal energy, solar energy, wind energy, oil, coal, natural gases and other fossil fuels. Unfortunately, the majority of the energy requirement of globe is met by fossil fuels such as coal, natural gases, and oils. Though these conventional fuels are predo– minant sources to generate usable energy but their limited capacity, harmful by-products (CO_2, CO, NOx, SOx, particulate matters, ash, ODP, GHE, chemicals), geographical distribution are the main concerns and gives rise to many social, economic and environmental issues. Hence energy becomes an important aspect of technology which should be carefully studied and utilized. The more attention should be provided on all possible existing and new renewable energy technologies to avoid an ill effect of conventional sources [1]. After industrial revolution with the increase in energy demand, availability of the fossil fuels is decreasing gradually. Because of sharp increase in prices of fossil fuels and their harmful effects to environment, renewable energy sources, especially solar energy, is getting more attention compared to past years. Solar energy is the most popular one among renewable energy sources. It provides the required energy by the sun entire year around the world by conversion of solar radiation to useful heat or electricity. In order to obtain better performance with solar thermal systems, many studies have been conducted both experimentally and numerically. Some studies suggest that changing working fluid could improve the efficiency [2]. Global energy crisis caused by the rapid world population and industrial growth as well as the rapid development of the society, increases day by day and may become a humanitarian crisis. The consumption of conventional fossil fuels is aggravated rapidly, while their availability is continuously decreasing. Nowadays, renewable energy generated from natural resources, such as solar, wind, and geothermal energies, is a good alternative to the conventional fossil fuels. Solar energy is the most important renewable source of energy to produce electricity and heat. Many solar based thermal systems are used for generating electricity, water desalination, buildings air-conditioning, and water heating from solar radiation. Enhancing heat transfer process in solar energy systems (SESs) is one of the most important issues to achieve a better performance of these systems with compact designs. This may be achieved by using working fluids with enhanced thermo-physical properties. One of the effective methods is to replace the working fluid with nanofluids as a novel strategy to improve heat transfer characteristics of the fluid. Nanofluids are formed by suspending of nano-sized particles (smaller than 100 nm) in a base fluid. Recently, many researchers have become interested in the use of nanofluids in water heaters, solar collectors, solar cooling systems, solar stills, absorption refrigeration systems, solar cells, and a combination of different solar devices due to their superior properties over the conventional fluids. The benefits of using nanofluids in SESs are summarized as follows [3]:

1. The nanoparticles have a very small particle size with a very large surface area, which result in a significant increase in the heat capacity of the nanofluid as well as the absorption of the solar energy.
2. The optical characteristics of nanofluids are better than that of the base fluid (higher absorption and extinction coefficients). They show high absorption and low emittance in both solar spectrum range and in infrared spectrum range, respectively.
3. The thermal conductivity of the nanofluids is significantly high compared to the base fluid due to the presence of nanoparticles.
4. The good stability of nanofluids under wide range of temperature gradients combined with high absorption coefficient make nanofluids as an excellent absorbing medium.

5. Use of nanofluids avoids the sedimentation, clogging, fouling of pipes and pumps due to its extremely small size compared with micro or millimeter sized particles, which is a useful property in many solar applications.
6. Nanofluids reduce the required heat transfer area of the thermal devices and as a result reduce the total cost of the SESs.
7. Nanofluids, in general, have high density and high convective heat transfer coefficient (HTC) with a low specific heat of nanoparticles which result in increasing the efficiency of the thermal devices.

The growing world energy demand is increasing the burning of fossil fuels and, consequently, the carbon dioxide emissions. In order to limit these emissions, it is necessary to make better use of the produced thermal energy by increasing the energy efficiency of industrial processes (heat recovery) and buildings and the use of renewable sources such as solar energy. Economic storage of thermal energy (thermal energy storage - TES) is a key technological issue for solar thermal power plants and industrial waste heat recovery. The overall objectives of heat storage integration are to increase the solar contribution, to improve efficiency, and to reduce the levelized energy cost (LEC). TES systems can be used at high temperature ($T > 400°C$) or at lower temperature (ranging from 100°C to about 300°C) for heat and solar cooling. Low-temperature storage systems are based almost entirely on sensible heat storage using liquid water, but for temperatures exceeding 100°C (concentrated solar power plants), non-pressurized liquid water and the use of pressure vessels make this technology unattractive. Among the various methods of energy storage, latent heat thermal energy storage (LHTES) systems using phase change materials (PCMs) have been gaining importance in such fields as solar energy systems, district heating and cooling systems, energy efficiency buildings, cool storage systems for central air-conditioning systems, and waste heat recovery systems. This is mainly due to their high energy storage density and their ability to provide heat at a constant temperature. Since the latent heat of fusion between the liquid and solid phases of PCMs is high compared to sensible heat, storage systems utilizing PCMs can be reduced in size with respect to systems based on sensible heat. Therefore,several studies on PCM used as thermal energy storage material have been published. The materials needed for phase-change thermal energy storage must have a large latent heat and high thermal conductivity. They should have a melting temperature lying in the practical range of operation, offer chemical stability and they should be low cost, nontoxic, and noncorrosive. PCMs studied during the last 40 years are mainly paraffin waxes, fatty acids, metal alloys, salts (fluorides and chlorides, hydroxides, nitrates, carbonates). There are many LHTES systems used in practical applications. They can be composed of PCM elements with similar shapes such as PCM spheres, PCM cylinders, PCM flat plates or even PCM capsules with irregular shapes [4]. Despite their poor thermal conductivity (k), various advantages, including light weight, low cost, and easy processability, make polymers the material of choice for several heat-intensive applications such as electronic chip encapsulation, cell phone casing, and LED (light emitting diode) housing. These existing applications, along with emerging technologies such as flexible electronics, for which the requirements on flexibility and light weight cannot be met by most conventional thermal management materials (metals and ceramics), put greater technological incentives on developing thermally conductive polymers. Blending with high-k fillers such as metal or ceramic particles, carbon nanotubes (CNTs), or graphene flakes is the most commonly used method to enhance polymers' thermal conductivity [5]. The influence of nanoparticles, macroparticles and biomaterials on some characteristics of polymer or polymeric blend were investigated by many studies which included the optical properties [6-30], AC or DC electrical properties [31-46], for biomedical and environmental applications[47-64], and heat transfer enhancement using phase change materials [65-111].

2.CLASSIFICATION OF NANOFLUIDs

Nanofluids can be normally classified into two categories metallic nanofluids and non-metallic nanofluids. Metallic nanofluids often refer to those containing metallic nanoparticles such as (Cu, Al, Zn, Ni, Si, Fe, Ti, Au and Ag), while nanofluids containing non-metallic nanoparticles such as aluminium oxide (Al_2O_3), copper oxide (CuO) and silicon carbide (SiC, ZnO,TiO_2) are often considered as non-metallic nanofluids, semiconductors (TiO_2), Carbon Nanotubes (SWCNT, DWCNT and MWCNT) and composites materials such as nanoparticles core polymer shell composites. In addition, new materials and structure are attractive for use in nanofluids where the particle liquid interface is doped with various molecules [62].

3.CLASSIFICATION OF HEAT STORAGE METHODS

It is well known that every energy system is composed of a primary energy source (e.g. solar energy or biogas), a transformer (e.g. solar collector or CHP unit) to transform primary energy into useful form of energy, and a final energy user-appliance (e.g. a heating system, a hot water supply system or some industrial process). However in some systems, especially with renewables, so-called spatiotemporal disagreements between the energy supply and energy consumption may arise. Therefore, the primary intent of the heat storage is to minimize or totally prevent these disagreements by means of shifting the supply of thermal energy in time. Obviously, a thermal flask is an example of the simplest and most widely used conventional heat storage device in the world. The heat storage system usually consists of: storage tank, which is usually heat-insulated, working substance, which is also known as the storage material, facilities for charging and discharging. In general, for charging and discharging some special heat exchangers are used, and some auxiliary facilities, for instance: pumps, sensors, controllers etc., to transfer heat from, e.g. solar collectors, to the storage substance, and control the charging and discharging process [63].

In general, two criteria define the technology and material applied to store heat: (i) the heat storage period, and (ii) needed temperature level. Regarding the heat storage period, the storage technology can be used for:

- seasonal or long-term heat storage, when storage period is about several months,
- medium-term heat storage, when storage period is about a week,
- and short-term heat storage, when storage period is up to 24 hours.

Concerning needed temperature level, the heat storage technology can be exploited for :

- High-temperature (HT) heat storage, when the temperature of the stored heat is above 200 °C. In this case, the stored heat has the greatest energy potential and can be used as a backup heat source to support power generation in the concentrating solar thermal power plants and even some industrialprocesses, e.g. plastic molding, rubber and polymer vulcanization, industrial pasteurization andsterilization etc.
- Middle-temperature heat storage, when the temperature of the stored heat is above 40 °C. Suchtemperature level of the stored heat is particularly suitable for district heating and domestic hot waterpreparation.
- And for cooling applications, when the temperature of the stored heat is below 20 °C, to support airconditioning systems, refrigerators, transplants in medicine etc.

According to the system design the heat storage systems are classified as :

- Direct, where the storage substance and the heat transfer fluid (HTF) are the same fluid pumpedthrough the solar absorber and heated up on its way to the heat storage reservoir;
- Indirect, where the storage substance is located in a separate storage reservoir and another fluidtransfers the solar heat from solar absorber to the storage substance by means of a heat exchanger;
- And the hybrid concept, which is a combination of direct and indirect system designs to increaseflexibility and performance of the renewable energy system [64].

4.APPLICATIONS OF NANOFLUIDS/ COMPOSITES IN TES

Nanoparticles have one dimension that measures in 100nanometers or less and the properties of the bulk materialchanges with changes in the nanoscale particles. Theverse changes in the physio-chemical properties are partlydue to the kinetic movement of the nanoparticles at thesurface layer. They exhibit greater surface area per weight than larger particles which causes them to be more reactiveand have a continuous random motion. The dispersion of thenanoparticles in polymers, metals, ceramics and fluids hasfurther opened pathways for more engineering of flexiblecomposites that exhibit advantageous thermophysical properties. These new hybrid nanofluids/composites areapplied in many technological applications ranging frombiomedical and transportation to energy etc.The application of nanoparticles dispersed into basefluids for TES is still a new research area. The amount ofnanoparticles needing to be dispersed into base fluids to suitcertain applications for specific TES is still under study andinvestigation. To date, carbon nanotubes are the most widelyused additives as their thermophysical properties have beenestablished and the advantages have been proven comparedto other nanoparticles.TES is a combination of different technologies that storethermal energy in a reservoir for later use. They can be usedto balance energy demand at peak and off peak periods.Among the several diverse technologies in TES are theheating and cooling applications especially with respect tobuildings [64].

5.CONCLUSION

In this review, the phase change materials/ nanoparticles and nanocomposites used for thermal energy storage applications. The nanocomposites have thermal, optical, mechanical and electrical properties were depended on the additive concentration. The system of (polymer/ nanoparticles) nanofluidmay be considered as promising materials for thermal energy storage with easy processability and low cost.

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