ISSN: 2633-4828 Vol. 4 No.3, December, 2022

International Journal of Applied Engineering & Technology

STUDY ABOUT NANOFLUIDS IN SOLAR ABSORPTION AND THERMAL ENERGY STORAGE SYSTEMS

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ABSTACT

The use of nanofluids in thermal energy storage (TES) and solar absorption devices are reviewed in detail in this work. Solar technologies have drawn a lot of interest due to their ability to lessen environment effects and decrease reliance on fossil fuels, which are in line with the growing demand for sustainable energy alternatives. Their widespread acceptance is hampered, therefore, by issues including their intermittent nature and low efficiency. One promising way to tackle these issues is through the integration of nanofluids, which are essentially colloidal suspensions of nanoparticles in base fluids. This review highlights how important nanofluids are to improving solar absorption and thermal energy storage's sustainability, dependability and efficiency.

Keywords: Phase Change materials, Thermal Energy Storage Systems, Nano-fluids, Thermal conductivity.

INTRODUCTION

Nanofluids are indeed composite materials where solid nanoparticles are dispersed within a liquid medium. These nanoparticles are typically on the scale of nanometers, hence the name. One of the fascinating properties of nanofluids is their enhanced thermal conductivity compared to the base fluid alone.

By incorporating nanoparticles with higher thermal conductivity than the surrounding liquid, nanofluids can exhibit significantly improved thermal properties. This enhancement in thermal conductivity has attracted attention for various applications, including heat transfer fluids in thermal management systems, cooling applications, and even in enhancing the efficiency of energy conversion systems like solar cells.

The increased thermal conductivity of nanofluids opens up possibilities for more efficient heat transfer processes, which can be crucial in various engineering and industrial applications. Various researches on nanofluids in solar absorption and thermal energy storage systems has gained significant attention in recent years due to the potential for improving the efficiency and effectiveness of these systems. Below are some key aspects.

(i) **Enhanced heat transfer**: Nanofluids offer improved heat transfer properties compared to conventional heat transfer fluids. By dispersing nanoparticles, within the working fluid of solar collectors, such as parabolic troughs or flat plate collectors, the heat transfer efficiency can be increased, leading to better energy capture from sunlight.

(ii) **Increased Absorption**: Certain nanoparticles have properties that can enhance the absorption of solar radiation. For instance, plasmonic nanoparticles, such as gold or silver nanoparticles, can concentrate electromagnetic fields, thereby increasing the absorption of sunlight. Incorporating such nanoparticles into the heat transfer fluid can enhance the overall efficiency of solar absorption systems.

(iii) **Broad Spectrum absorption**: Certain nanoparticles have the ability to absorb sunlight across a broad spectrum of wavelengths, including visible and infrared radiation. By incorporating such nanoparticles into nanofluids, solar collectors can capture a wider range of solar energy, maximizing energy conversion.

(iv) **Reduced Reflection**: Nanofluids can help minimize reflection losses by reducing the amount of incident sunlight that bounces off the surface of solar collectors. This is particularly beneficial in improving the performance of concentrated solar power systems, where mirrors or lenses focus sunlight onto a receiver.

(v) **Temperature Control**: Nanofluids can aid in temperature control within solar collectors by absorbing excess heat and distributing it throughout the system. This helps prevent overheating and thermal damage to the components, ensuring stable operation and prolonging the lifespan of the system.

(vi) **Thermal Energy Storage**: Nanofluids are also investigated for their potential in thermal energy storage systems, which are crucial for enabling continuous power generation in solar energy systems, especially during periods without sunlight. Nanofluids can be used as the heat transfer medium in TES systems, offering advantages such as high thermal conductivity and enhanced heat transfer rates during charging and discharging cycles.

(vii) **Phase Change Materials**: Nanofluids can be combined with phase change materials to create advanced composite materials for thermal energy storage. By dispersing nanoparticles within the phase change materials the thermal conductivity of the material can be improved, leading to faster heat transfer rates and better overall performance of the thermal energy storage system.

(viii) **Stability and Longevity**: One challenge in utilizing nanofluids in solar absorption and thermal energy storage systems is maintaining their stability and preventing nanoparticle agglomeration or sedimentation over time. Researchers are actively investigating methods to enhance the stability of nanofluids to ensure their long-term performance in practical applications.

Thermal Energy Storage Systems: An overview

Thermal Energy Storage systems (TESS) are that store thermal energy for later use, providing flexibility and efficiency in various applications. These systems essentially store heat or cold generated during off-peak hours or when excess renewable energy is available, and then release it when needed thus optimizing energy use and reducing overall costs. There are several types of thermal energy storage systems.

(i) **Sensible heat storage:** This type of storage involves heating or cooling a material to store energy. Common materials used include water, molten salts, rocks etc. When the stored energy is needed, the material is passed through a heat exchanger to transfer the stored heat or cold to a working fluid, such as air or water, which then can be used for heating, cooling or power generation.

(ii) **Latent heat storage:** In latent heat storage, energy is stored by changing the phase of a material ,usually from solid to liquid or liquid to gas, at a constant temperature. PCMs like paraffin wax, hydrated salts, or certain organic compounds are commonly used. During the phase change process, a large amount of energy is absorbed or released without a significant change in temperature, making it an efficient way to store thermal energy.

(iii) **Thermochemical Storage:** Thermochemical storage system store energy by utilizing reversible chemical reactions. Energy is absorbed or released during the reaction, and the stored energy can be released by reversing the reaction. This method is less common but can offer high energy densities and long term storage capabilities.

Thermal energy storage systems find applications in various sectors including:

(i) **Building HVAC Systems:** TES systems can store excess heat or cold generated by HVAC systems during off-peak hours and use it to regulate building temperature during peak demand periods, reducing energy costs.

(ii) **Concentrated Solar Power (CSP) Plants:** CSP plants use mirrors to concentrate solar energy onto a receiver to produce high temperature heat. TES systems allow these plants to store excess heat and generate power even when the solar energy is not available.

(iii) Industrial Processes: Many industrial processes require heat at specific temperatures. TES systems can provide a reliable and efficient source of thermal energy to meet these process requirements.

(iv) District Heating and Cooling: TES systems can be integrated into district heating and cooling networks to store excess heat or cold and distribute it to multiple buildings as needed.

Overall thermal energy storage systems play a crucial role in increasing energy efficiency, integrating renewable energy sources, reducing greenhouse gas emissions in various sectors.

Review on Nanoparticles in Phase Change Materials

Nanoparticles are increasingly being integrated into phase change materials to enhance their thermal properties, addressing some of the inherent imitations of traditional PCMs. These advancements are significant for applications in thermal energy storage where efficient energy management is critical. Poor heat conductivity in typical PCMS is a major drawback that can restrict the rate of energy storage and recovery. The thermal conductivity of PCMs is greatly increased by the addition of nanoparticles. Faster heat transfer during the phase transition process is made possible by this improvement. Additionally, PCM stability is aided by nanoparticles. In numerous applications, the potential for PCMs to leak when they melt is a challenge. During phase transitions, the PCM matrix can be stabilized by the employment of nanoparticles, which will stop leaks and preserve the material's integrity. Latent heat storage capacity of PCMs can be increased by the addition of nanoparticles resulting in more thermal energy storage or release, during phase transition without change in temperature. Afolabi L.Owolabi et.al [1] conducted experimentation to determine how Fe-nanofluid affects solar water heater performance when combined with a thermal energy storage device. The results revealed that the system's working duration in night mode was increased by five hours , annual cost savings by 28.5% and the addition of Fe – nanofluid results a 9.5% reduction in the embodied energy emission rate, collector size and weight. Hongyun Zhang et;.al [2] suggested direct absorption solar collector uses a ternary mixed molten salt (44% $Ca(NO_3)_2$,12% $NaNO_3$ and 44% KNO_3) as the heat storage core and works with grapheme oxide(GO) nanosheets and titanium nitride (TiN) nanoparticles mixed with heat transfer oil as working fluids. The test results revealed that collector has a maximum thermal energy spacity of over 526.96 J and an energy retention rate of up to 51.7% and a solar thermal efficiency of up to 56.5%. Bashria A.A Yousef et.al [3] discovered that silica and alumina nanopaaticles are the most effective option for increasing the specific heat capacity of the storage medium and has a stability up to 400-450 ^oC. An average improvement in heat capacity and thermal conductivity can be achieved by using one percent weight concentration up to 120 and 60% respectively. Z.A Alrowail et.al [4] investigated mono CuO and hybrid CuO+Cu/water nanofluids as the working fluid to examine an evacuated tube solar collector's performance. According to the thermal conductivity investigation, there has been a 21% increase in hybrid nanofluid. The solar collector was evaluated at three different flow rates 0.0125 L/s,0.015 L/s and 0.0175 L/s. A mixed nanofluid can lower the collection area by as much as 38%.It was discovered that the heat removal factor was 0.894.The thermal-optical efficiency of the hybrid CuO 2.5 g + Cu 1.5g nanofluid is 14.9% higher than that of water and mono CuO, respectively. Vednath P.Kalbande et.al [5] prepared Soybean oil based nanofluid containing Al_2O_3 nanoparticles at a volume concentration of 1% for thermal energy storage. It was proved that nanofluid of soybean oil and Al_2O_3 enhanced the performance of solar collector and thermal storage and absorber temperature reached to 153 ^{o}C and 178 ^{o}C . Aimen Zeinya et.al [6] evaluated the performance of three different categories of nanofluids-gold, copper, carbon black and their hybrids in terms of photo thermal conversion efficiency, specific absorption rate and material cost.The results showed that combining distinct nanofluids with different ansorbance peaks did not improve the photothermal conversion efficiency.Also identified that carbon black nanofluids are more practical even if gold nanofluids have a higher specific absorption rate due to the higher cost. Vednath P.Kalbande et.al [7] emphasized how popular hybrid nanofluids, which combine oil and nanoparticles, as efficient heat transfer fluids for solar energy-based thermal energy storage and heat transmission systems. Principal results demonstrated the enhanced heat transfer properties of alumina nanoparticles and multi-walled carbon nanotubes when dissolved in different base fluids. Furthermore phase change materials that are ideal for effectively storing thermal energy include erythritol and nitrate salt. Baha El Far et.al [8] created molten salt nanofluids by adding spherical SiO_2 nanoparticles to a binary combination of $NaNO_3$ and KNO_3 at 1 wt%.The findings demonstrated a 15% increase in heat capacity and a 41-429% increase in viscosity.

Review on Phase Change Materials as Thermal Energy Storage System

Phase change materials (PCMs) have considerable potentials for a wide range of applications and provides a promising alternative for thermal energy storage. The below are a summary of their main features.

a. **High Energy Density:** When phase transitions, usually between solid and liquid phases, occur, PCMs absorb and release significant amounts of thermal energy. Their efficient nature for small storage systems originates from their high energy density.

b. **Temperature Regulation:** PCMs are advantageous for applications needing accurate temperature management, like building climate control and electronics cooling, because they keep a practically constant temperature during phase transition.

c. **Versatility:** PCMs can be customized to meet the unique temperature needs of a variety of applications since they come in a broad range of materials with varying melting and freezing points.

d. **Longevity and Stability:** PCMs capacity to withstand multiple heat cycles is essential to their practical application. PCM compositions and encapsulation processes have advanced, improving PCM longevity and dependability.

e. **Environmental Sustainability:** A large number of PCMs are made of non-toxic, environmentally friendly materials, which is in line with the increased focus on sustainability technology. Their environmental benefits are further amplified by incorporation of renewable energy sources for PCM charging.

f. **Limitations and Challenges:** Although PCMs have many benefits, they also have drawbacks. For example, their low thermal conductivity might have an impact on the rate at which heat is transferred, particularly in large scale applications. Careful consideration is also needed when choosing PCM materials that are compatible with the current infrastructure and suitable for a given temperature range.

g. **Cost Considerations:** The price of PCMs, including the materials and encapsulation, continues to be a major determinant of how widely they are adopted. Ongoing research and technology developments, however ,are bringing costs down and making PCM-based systems more cost effective.

h. **Integration with existing systems:** Careful planning and engineering are needed to assure optimal performance and compatibility with existing components when integrating PCM-based thermal energy storage system into existing infrastructure, such as buildings or industrial operations.

Jundika C.Kurnia et.al [9] statistically evaluated numerous PCM thermal energy storage device topologies including U-tube, U-tube with in-line fins, U-tube with staggered fins, and a unique festoon design. The new festoon design outperform U-tubes with fins in terms of heat transfer efficiency, according to the research. Staggered fin U-tubes are proven to outperform in-line fin U-tubes in terms of performance. Also it is noted that using numerous PCMs may improve heat transfer efficiency within TES. M.Samykano [10] noted that PCM distributed in foam and porous materials have superior heat transfer and storage capacities. The thermal conductivity found 2 to 500 times higher. Furthermore, because of their long-term stability, low or nonexistent supercooling, low or nonexistent corrosion, and recyclability, organic PCMs have been employed extensively. Also it is noted that for long term thermal exchange/heat transfer applications, the highly stable thermally enhanced PCMs are employed. Malik Muhammad Umaira et.al [11] identifies that organic phase change materials have limited practical applicability in thermal energy storage due to their propensity to leak out during the phase transition process. One useful tactic for stopping leaks and increasing the organic phase transition material’s capability for energy storage is shape stabilization. The development of phase change materials with solid-solid phase transition or encasing the organic phase change materials in a shell by microencapsulation and integrating into the matrix of the supporting materials are two ways to achieve shape stability. Karunesh Kant et.al [12] examined the performance of five distinct fatty acids – capric, lauric, myristic, palmitic and stearic in aluminum containers. Among the five capric requires the least amount of time to melt and solidify under the same boundary conditions. Overall, the potential benefits of PCMs in addressing energy storage and thermal management challenges are substantial, suggesting that continued research and innovation in this field could lead to significant advancements in sustainable energy utilization and thermal regulation systems.

CONCLUSION

In brief, the study of nanofluids in solar absorption and thermal energy storage systems hold great promise for improving the efficiency, reliability, and sustainability of solar energy technologies. Continued research and development efforts are essential to further optimize nanofluid formulations, system designs, and integration strategies, ultimately driving the widespread adoption of these innovative solutions in the renewable energy sector. Also challenges remain, particularly concerning the selection of appropriate PCMs tailored to specific temperature ranges and applications, as well as the scalability and cost-effectiveness of large scale implementations. Furthermore, issues related to PCM encapsulation, thermal conductivity enhancement, and long-term stability require further research and development to optimize PCM based thermal energy storage system.

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