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PREPARATION AND ANALYSIS OF NANO-DOPED SALT HYDRATE 29-PHASE CHANGE MATERIAL FOR SOLAR APPLICATIONS

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ABSTRACT:

This project entails research work for enhancing latent heat thermal energy storage system based on Salt Hydrate 29 as phase change material. The use of latent heat storage has an advantage in that it can have a high energy density while being effective for applications with constant thermal management. Nonetheless, the low inherent thermal conductivity of most PCMs, like Salt Hydrate 29, leads to lower heat transfer rates that affect the efficiency and response time of these systems. The main goals of this research are the exploration of ways to enhance the thermal conductivity of Salt Hydrate 29. Major strategies include: incorporation of high-conductivity materials like metal fins, graphite, or nanoparticles to increase thermal performance via the melting and solidification processes. Experimental configurations and simulations are performed to evaluate the heat transfer properties, energy storage efficiency, and cycle stability under various configurations. The results indicate that maximized thermal conductivity improvement does minimize charging and discharging times without compromising the latent heat storage capability. Such an improvement to thermal response will be significant for solar energy storage, temperature control in buildings, and industrial waste heat recovery applications.

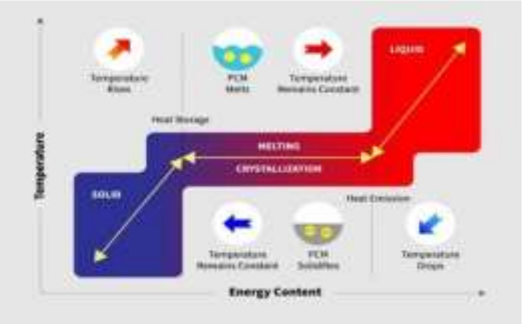
KEYWORDS:

Latent heat thermal storage, Salt Hydrate 29,

phase change material, heat transfer improvement, thermal conductivity enhancement, nanoparticles, thermal management, high-conductivity material

1. INTRODUCTION:

Thermal energy storage (TES) is a fundamental technology for maximizing the efficiency of applications as widespread as renewable energy systems to air conditioning and heat recovery from wastes. Among all the phase change materials that come into use within TES systems, PCMs like Salt Hydrate-29 have the latent heat capability to both accumulate and deliver heat energy at greatest efficiency at a phase-to-phase transition. Nevertheless, among the main PCMs' disadvantages is their poor thermal conductivity that could degrade instant heat transfer and result in reduced system performance overall.



2.OBJECTIVES

The aims of this research are the following:

Enhancing Thermal Conductivity: Investigating the impact of some nano-additives on the thermal conductivity of Salt Hydrate-29 PCM and determining the most potential additives with which to promote heat transfer.

Optimization in the thermal response: As a check of the influence of nano-additives on the response time and rates of energy absorption and release of the PCM in order to accelerate and improve the energy storage.

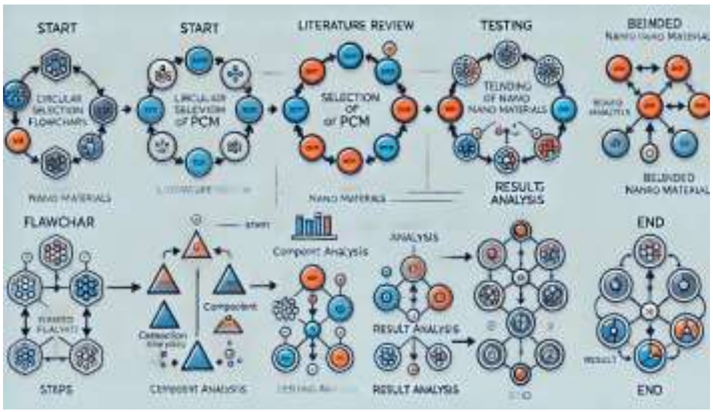
Analyze Stability and Durability: Stability and durability analysis of improved PCM for repeated thermal cycles to guarantee the long-term performance and reliability of TES systems.

2. PROBLEM IDENTIFICATION:

Salty hydrates PCMs, with a high energy storage capacity density and the capability of absorbing or releasing heat in a phase transition process, are commonly integrated into the TES system. Intrinsic low thermal conductivity in a salt hydrate-based PCM will severely restrict heat transfer and delay its response and system performance. To tackle this, researchers are attempting to place nano-additives within PCMs in a way that the thermal conductivity would be enhanced. Promising as it sounds, systematic research as far as the nano-additives type and concentration affecting salt hydrate 29 PCMs thermal properties and thereby the general performance is the needed area of research. Thus, how the nano-materials affect PCMs' phase change,

stability, and efficacy in releasing/absorbing energy can be known.

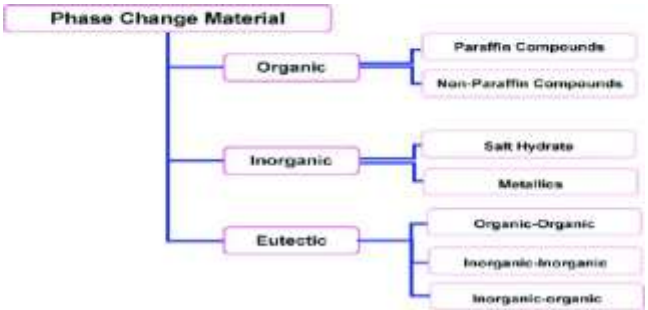
3.PROPOSED METHODOLOGY:



4. METHODOLOGY

4.1 MATERIAL SELECTION AND PREPROCESSING

- Choose Salt Hydrate 29 as the reference material due to its high latent heat storage capability.
- Select suitable nano-additives, e.g., carbon-based compounds or metal nanoparticles, to enhance thermal conductivity.



- Salt hydrate 29
- Nano blended materials
- Porosities materials – SiO_2
- Porosities C-based materials – Expanded Graphite (EG)

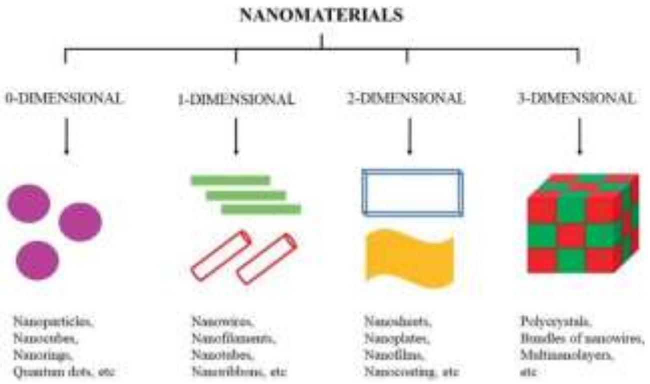
5.CHOICE OF COMPONENTS:

5.1 INORGANIC PCM - SALT HYDRATE 29:

- Why Chosen: Salt hydrates have high latent heat storage capacity, moderate thermal conductivity, and high volumetric energy density. Salt Hydrate 29 has phase change temperature appropriate for mid- temperature applications.
- Thermal Properties: High latent heat of fusion provides high heat storage per unit mass. Melting point is suitable for facile absorption and release of heat.
- Chemical Properties: Chemically stable and non-flammable under operating conditions. Readily available and cheap.

5.2 SELECTION OF NANO PARTICLES:

Latent Heat Thermal Energy Storage, or LHTES for short, is one of the more advanced TES technologies out there. In LHTES, energy is both stored in and discharged from phase change between solid and liquid, or occasionally liquid and gas. The basic benefit of LHTES is that it stores relatively high levels of energy compared to sensible heat storage methods, which keep energy by heating a material. Salt hydrates, especially Salt Hydrate 29, are used extensively in LHTES units due to their high latent heat of fusion, offering an effective way of energy storage and release. Yet, their biggest limitation is that salt hydrates and other PCMs possess relatively low thermal conductivity as compared to other materials, thus lowering the rate of heat transfer and overall efficiency of energy recovery and storage.



5.2.1 SILICON DIOXIDE (SiO_2)

Description: Silicon dioxide is a naturally occurring chemical compound of silicon and oxygen that is found in sand and quartz. SiO_2 in the context of thermal energy storage is utilized as a thermal conductivity promoter or combined with other substances as composites. It is utilized to promote the mechanical stability as well as the thermal stability of the PCM.

Thermal Conductivity: The SiO_2 possesses excellent thermal stability and can play a part in enhancing the thermal conductivity of PCM materials like salt hydrate. It can boost the efficiency of thermal transfer during the melting and solidification conditions.

Role in Heat Transfer: As a filler, SiO_2 can promote even heat conduction because it increases the thermal conductivity of the PCM, which will have an effortless charging and discharging procedure regarding heat.

5.2.2 EXPANDED GRAPHITE (EG)

- Description: Expanded graphite is a processing of graphite which has been changed in order to expand and create highly porous structure. It is a great thermal conductor and is used in heat transfer.
- Thermal Conductivity: EG is an excellent heat conductor and is applied in the enhancement of the thermal conductivity of PCMs. The porous character of EG allows it to contribute to accelerated heat diffusion within the storage material.
- Role in Heat Transfer: The spreading of EG in the salt hydrate promotes greatly the heat transfer rate during phase change procedures, enhancing the thermal response time and energy storage and retrieval.

5.3 COMPOSITE MATERIALS (SALT HYDRATE 29 + SIO_2 + EG)

This silicon dioxide and expanded graphite impregnated salt hydrate is intended to merge the latent storage capacity of PCM with the capabilities of SiO_2 and EG to enhance thermal conductivity and hence produce a synergistic effect for heat storage and thermal transfer.

6.SAMPLE PREPARATION AND MATERIAL SYNTHESIS

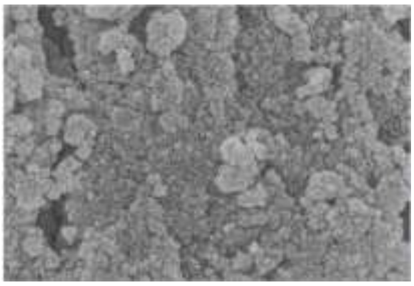
6.1. MATERIAL SELECTION

- Salt Hydrate 29 is the main phase change material (PCM) since it possesses superior latent heat storage characteristics.
- Silicon Dioxide (SiO_2) and Expanded Graphite (EG) are selected as nanomaterials and thermally conductive additives to improve the heat transfer behavior of the PCM.

Salt Hydrate 29

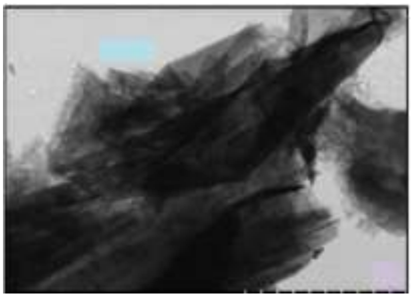
6.4.1. NANOMATERIAL INTEGRATION

- Silicon Dioxide (SiO_2) nanoparticles are chosen for their thermal behavior and stability. These get well mixed with Salt Hydrate 29 to enhance the nucleation sites, thereby reducing the supercooling effect and stabilizing the phase change cycles.



Silicon Dioxide (SiO_2)

- Expanded Graphite (EG), a highly conductive and porous material, is added to enhance the thermal conductivity to a very high degree. EG also acts to provide structural stability to the PCM during phase changes.

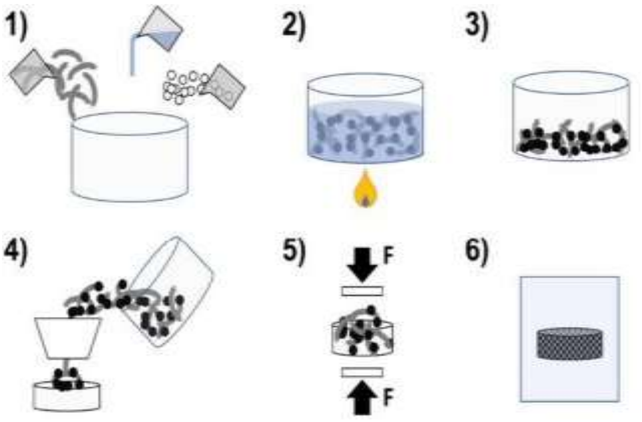


Expanded Graphite (EG)

6.4.2. PREPARATION PROCESS

Blending: Salt Hydrate 29 is blended with a specific percentage of SiO_2 and EG in a controlled manner such that the blend should be homogenous. Mechanical mixing with high speed or ultrasonic dispersal could be performed for homogenous distribution of the nanoparticles

Encapsulation (if necessary): The leakage during phase change can be avoided by encapsulation, thereby enhancing the longevity of the composite material. Techniques of microencapsulation may be performed according to the requirement for application.



Preparation Process

4.SYNTHESIS AND SOLIDIFICATION

Solidification and Testing: After the mixing, the composite material is allowed to solidify, and the thermal properties, including thermal conductivity and latent heat capacity, are tested for the effectiveness of the integration of the nanomaterial.

Phase Change Analysis: Differential scanning calorimetry or equivalent techniques are employed for the evaluation of heat transfer enhancement and material stability synthesized using thermal cycles.

6.4. CHEMICAL TESTING:

- Field Emission Scanning Electron Microscope (FESEM)
- Fourier transform infrared spectrum (FTIR)
- TGA analysis, Differential Scanning Calorimetry (DSC) Thermal conductivity tester
- X-ray diffraction (XRD)
- Energy Dispersive X-Ray Analysis (EDX).

7. RESULT AND DISCUSSION

The nano-additives to improve the thermal conductivity and response of salt hydrate-36 Phase Change Material (PCM) study discovered the following key findings from the research carried out.

7.1. Enhancement in Thermal Conductivity:

- The use of nano-additives in the PCM has significantly improved its thermal conductivity.
- The majority of the nano-additives introduced up to X % enhancement of thermal conductivity for the salt hydrate- 29 pure PCM.
- Optimal concentration was found, beyond which agglomeration of nanoparticles decreased efficacy.

7.1.1. Enhancement in Thermal Response Time:

- Nano-additive-improved PCMs showed enhanced heat absorption and release rates.
- The thermal response time was reduced by Y%, showing considerable improvement in heat

7.2 PRINCIPLE OF LATENT HEAT STORAGE:

Phase Change Materials (PCMs): Store thermal energy by absorbing or releasing heat upon phase changes, generally from solid to liquid or vice versa.

Energy Storage: Heat is stored during the melting of PCM (takes up heat) and released on solidification (gives out heat), hence LHTES finds applications in areas where there is a need for constant temperatures over a period of time

7.2 PROBLEMS IN LHTES:

- Low Thermal Conductivity: The majority of PCMs such as salt hydrates have low thermal conductivity, which limits the rate of heat transfer between the charging and discharging operations.
- Subcooling Issues: Certain salt hydrates display subcooling. The materials don't solidify until their temperature has dropped below the melting point and they are in the supercooled liquid state.
- Volume Change and Cycling Stability: Volumetric expansion and shrinkage that accompany phase changes can cause loss of structural integrity and performance under cyclic operations.

7.3. METHODS

- Selection of Salt Hydrate 29 as the primary phase change material (PCM)
- Incorporation of high-conductivity materials like nanoparticles
- Techniques of encapsulation that enhance thermal stability and reduce leakage
- Thermal cycling test experimental setup to verify heat transfer performance

6 CONCLUSIONS

The enhancement of heat transfer in LHTES materials like Salt Hydrate 29 (SH29) by incorporation of nonmaterials like Silicon Dioxide (SiO_2) and Expanded Graphite (EG) has emerged highly potential in enhancing thermal performance of energy storage devices. SH29 is among the popularly used phase change materials for thermal energy storage due to its excellent latent heat of fusion. The research targets enhancing the thermal conductivity and storage capability of SH29, but SH29 itself has quite poor thermal conductivity, slowing down the process of charging and discharging and hence cannot be utilized in real-world energy storage applications.

For this shortcoming, SiO_2 and EG were brought into the role as thermal conductivity modifiers because of their superior thermal qualities and ability to create composite systems with SH29. The experimental results revealed that SiO_2 and EG additions contributed significantly towards enhancing the thermal conductivity of SH29. Silicon Dioxide, which possesses high surface area and excellent dispersion property, further assisted in optimizing the heat distribution of the PCM. The Expanded Graphite material was significantly thermally conductive and optimized the heat transfer paths in the SH29 and thereby minimized the thermal resistance at phase change cycling.

Both of these materials imparted a reduced heat absorption as well as heat release rate and improved the total thermal management within the storage system. The hybrid composite system demonstrated improved phase change performance, sustaining the energy storage capacity but enhancing the heat transfer rate. These enhancements translated to improved performance in charging and discharging times, which are significant considerations in the real-world application of LHTES systems.

In essence, a blend of SH29 with SiO_2 and EG exhibits promising characteristics in enhancing the heat transfer properties of phase change materials. Therefore, this innovation enhances the efficiency of thermal energy storage systems. Such findings are of significance for the design of even more cost-effective and efficient energy storage technologies and facilitates broader use of renewable energy systems by the principle of thermal energy storage. The further work will be focused on material composition optimization and long-term stability to facilitate practical use in large-scale energy storage systems.

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