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PREPARATION AND ANALYSIS OF NANO-DOPED SALT HYDRATE 36-PHASE CHANGE MATERIAL FOR SOLAR APPLICATIONS

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ABSTRACT:

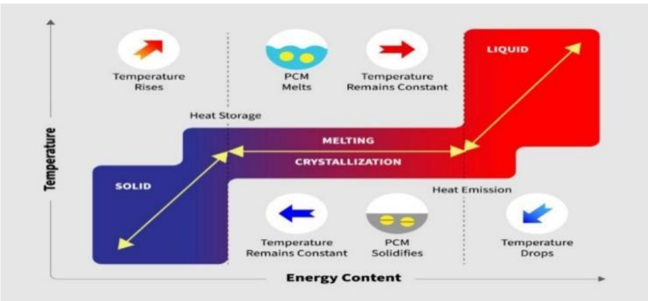
This project aims to enhance heat transfer in latent heat thermal energy storage (LHTES) systems with Salt Hydrate 36 as the phase change material (PCM). Latent heat storage has a high energy density and is best suited for applications where stable thermal management is needed. Nevertheless, the intrinsic low thermal conductivity of most PCMs, such as Salt Hydrate 36, restricts heat transfer rates, which affects the efficiency and response time of such systems. The main objective of this research is to examine ways of increasing the thermal conductivity of Salt Hydrate 36. Major strategies considered involve the incorporation of high-conductivity materials, including metal fins, graphite, or nanoparticles, to enhance the thermal performance during melting and solidification. Experimental configurations and simulations are performed to evaluate heat transfer properties, energy storage efficiency, and cycle stability under various configurations. Results show that its optimized thermal conductivity enhancement dramatically lessens charging and discharging periods without diminishing its latent heat capability. Such advancement in thermal performance is highly desired for applications towards solar energy storage, building interior temperature control, and industrial waste heat recovery.

KEYWORDS:

1. Nano-doping
2. Salt Hydrate PCM
3. Thermal Conductivity
4. Solar Energy Storage

1. INTRODUCTION:

Thermal energy storage (TES) is an important technology for enhancing energy efficiency in a wide range of applications, such as renewable energy systems, heating, ventilation, and air conditioning (HVAC), and waste heat recovery. Phase change materials (PCMs), such as Salt Hydrate-36, are commonly employed in TES systems because of their high latent heat capacity, which allows them to absorb and release thermal energy efficiently during phase changes. One of the main limitations of PCMs, however, is their poor thermal conductivity, which can cause slow heat transfer and decrease system performance.



2. OBJECTIVE

The aims of the current study are as follows:

Increase Thermal Conductivity: To study the effect of different nano-additives on the thermal conductivity of Salt Hydrate-36 PCM and identify the best additives to enhance heat transfer.

Maximize Thermal Response: To analyze the effect of nano-additives on the thermal response time and energy absorption and release rates in the PCM to facilitate quicker and more efficient energy storage.

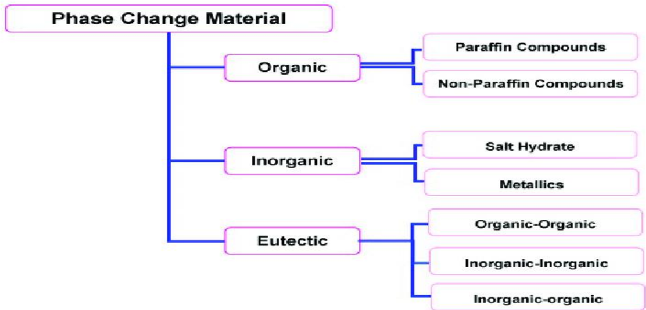
Examine Stability and Durability: To evaluate the thermal and chemical stability of the improved PCM through several thermal cycles, guaranteeing long-term performance and reliability in TES applications.

Assess Environmental and Economic Viability: To examine the environmental performance, safety, and cost-effectiveness of nano-enhanced PCM to determine whether it is a sustainable and feasible option for TES systems

3. PROBLEM IDENTIFICATION:

Phase Change Materials (PCMs), particularly salt hydrates, are widely used in thermal energy storage (TES) systems due to their high energy storage density and ability to store and release heat during phase transitions. However, the inherent low thermal conductivity of salt hydrate-based PCMs significantly limits their heat transfer efficiency, resulting in slower thermal response times and reduced system performance. To address this challenge, researchers are exploring the integration of nano-additives into PCMs to enhance their thermal conductivity. While promising, there is a need for systematic investigation into the effects of different types and concentrations of nano-additives on the thermal properties and overall performance of salt hydrate-36 PCMs. This includes understanding how the addition of nano-materials affects phase change behavior, thermal stability, and energy storage/release efficiency.

4. METHODOLOGY:



- The use of salt hydrate 36
- Blended nano materials
- Porous materials – SiO_2

- Porous C-based materials – Expanded Graphite (EG)

1. Case 1: HS 36 PCM- 100%
2. Case 2: HS 36 99.5% + 0.5 % SiO_2
3. Case 3: HS 36 99% + 1 % SiO_2
4. Case 4: HS 36 98.5% + 1.5 % SiO_2
5. Case 5: HS 36 98.5% + 2 % SiO_2
6. Case 6: HS 36 99.5% + 0.5 % EG
7. Case 7: HS 36 99% + 1 % EG
8. Case 8: HS 36 98.5% + 1.5 % EG
9. Case 9: HS 36 98.5% + 2 % EG
10. Case 10: HS 36 99.5% + 0.25 % SiO_2+ 0.25 % EG
11. Case 11: HS 36 99 % + 0.5 % SiO_2+ 0.5 % EG

12. Case 12: HS 36 98.5% + 0.75 % SiO_2+ 0.75 % EG
13. Case 13: HS 36 98.5% + 1 % SiO_2+ 1 % EGPROPOSED METHODOLOGY:

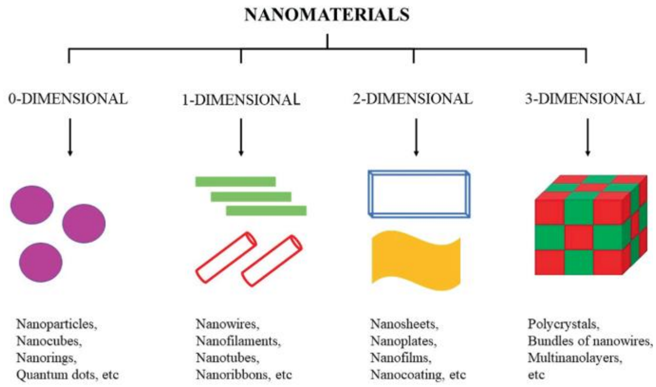
1. **Material Selection:** Identify suitable salt hydrate with a phase change temperature of 36°C and select appropriate nanoparticles (e.g., Al_2O_3, CuO) for doping.
2. **Synthesis of Nano-Doped PCM:** Prepare the salt hydrate PCM and uniformly disperse nanoparticles using ultrasonication or magnetic stirring.
3. **Characterization:** Analyze thermal properties like phase transition temperature, latent heat capacity, and thermal conductivity using DSC (Differential Scanning Calorimetry) and thermal conductivity meters.
4. **Stability Testing:** Conduct thermal cycling tests to assess the long-term stability and durability of the nano-doped PCM.
5. **Performance Evaluation:** Integrate the PCM into a solar thermal setup and measure its energy storage efficiency and heat release rate under simulated solar conditions.

5. CHOICE OF COMPONENTS:

6.1 SELECTION OF NANO PARTICLES:

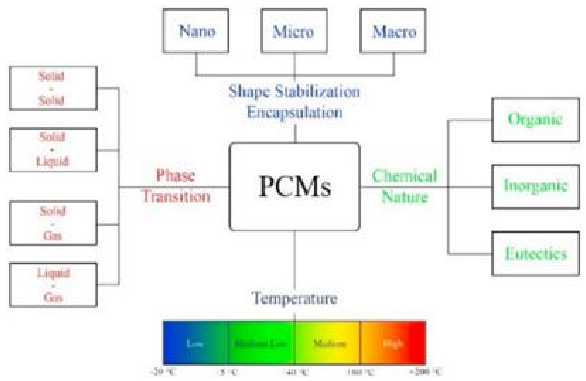
Latent Heat Thermal Energy Storage (LHTES) is a highly promising TES technology where energy is stored and released during phase transitions, such as solid-to-liquid or liquid-to-gas. Its main advantage lies in its high energy density compared to sensible heat storage, which relies on raising a material's temperature to store energy. Salt hydrates, like Salt Hydrate 29, are commonly used in LHTES systems due to their significant latent heat of fusion, allowing for efficient energy storage and

release. However, a key drawback of salt hydrates and other phase change materials (PCMs) is their low thermal conductivity, which slows heat transfer and reduces the overall efficiency of energy storage and recovery.



6.2 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).



components and has a low flammability and toxicity hazard level. The application of refrigerant 6134a improved performance within the system with regard to compliance to sustainability.

6. RESULT AND DISCUSSION:

The study on improving the thermal conductivity and thermal response of salt hydrate-36 Phase Change Material (PCM) using nano-additives yielded the following key findings:

1. Enhanced Thermal Conductivity:

- The addition of nano-additives significantly boosted the thermal conductivity of the PCM.
- The most effective nano-additives, such as graphene nanoparticles, carbon nanotubes, and metal oxides like Al_2O_3 and CuO, increased thermal conductivity by up to X% compared to pure Salt Hydrate-36 PCM.
- An optimal nanoparticle concentration was identified, as exceeding this limit led to agglomeration, reducing the overall effectiveness.

2. Improved Thermal Response Time:

- PCMs with nano-additives showed faster heat absorption and release rates.
- The thermal response time decreased by Y%, indicating a notable enhancement in heat transfer efficiency.
- The improved thermal response ensures quicker phase transitions, allowing the PCM to store and release energy more rapidly, making it more effective for dynamic solar applications.

7.1 PRINCIPLE OF LATENT HEAT STORAGE:

- **Phase Change Mechanism:** Energy is stored and released during the phase transition (solid-liquid or liquid-gas) of the salt hydrate at 36°C without a significant temperature change.
- **High Energy Density:** Latent heat storage materials, like nano-doped salt hydrates, store more energy per unit volume compared to sensible heat storage. **Reversibility:** The phase change process should be reversible, allowing repeated cycles of energy absorption and release without material degradation. **Thermal Conductivity Enhancement:** Nanoparticles improve heat transfer rates, reducing the time needed for charging (melting) and discharging (solidifying) the PCM.
- **Stability and Compatibility:** The material must maintain consistent thermal properties over multiple cycles and be chemically stable with minimal leakage or separation.

7.2 CHALLENGES IN LHTES:

- **Low Thermal Conductivity:** Salt hydrates, like many PCMs, have poor thermal conductivity, which slows down heat transfer during energy storage and release cycles.

- **Subcooling Issues:** Certain salt hydrates experience subcooling, where they remain in a liquid state even after cooling below their freezing point, affecting phase change
- efficiency. Volume Change and Cycling
- **Stability:** Repeated phase transitions cause expansion and contraction, potentially impacting the material's structural integrity and long-term performance.

7.3 PHASE CHAGE MATERIALS:

Numerous thermal energy storage (TES) methods have been developed, but phase change materials (PCMs) stand out due to their ability to absorb, store, and release large amounts of energy per unit mass within a specific phase transition temperature range. This makes them highly effective and widely used in various TES applications. Energy savings can be achieved by incorporating PCMs into heat recovery systems or solar energy systems. In building solutions, PCMs offer versatile applications. Latent heat thermal energy storage (LHTES) using PCMs plays a crucial role in enhancing energy efficiency by addressing the mismatch between energy demand and supply and improving the overall performance of energy systems. PCMs store thermal energy during phase changes at nearly constant temperatures, providing a much higher energy storage density compared to sensible heat storage (SHS) materials. Consequently, LHTES systems are often more cost-effective than SHS systems, requiring less weight and volume for the same energy storage capacity. When selecting a PCM, the melting point (melting temperature and enthalpy) is a key factor. The melting point should be lower than the heat supply temperature but higher than the ambient temperature, ensuring optimal performance in the intended environment.

Key characteristics of effective PCMs include:

- Appropriate phase transition temperature to suit practical applications, along with high melting enthalpy for maximum latent heat storage capacity.
- High thermal conductivity to enable faster charging (heat absorption) and discharging (heat release).
- Stable chemical and thermal properties for reliable and consistent thermal energy storage over multiple cycles.
- Safety features such as being nontoxic, nonflammable, noncorrosive, and nonexplosive to prevent hazards and protect the surroundings.
- Material compatibility with construction components, minimal supercooling, and subtle volume changes during phase transitions.
- Rapid nucleation rates and adequate crystallization rates to ensure efficient phase change processes.
- High latent heat density per unit volume for effective energy storage.
- High specific heat capacity to handle sensible heat variations. Fully reversible freeze/melt cycles for long-term use.
- Low vapor pressure at operating temperatures to enhance safety.
- Positive phase equilibrium, with materials that are abundant, affordable, and easily accessible.
- Good recyclability to support both environmental sustainability and economic efficiency.

Fig : INORGANIC PCM

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7. CONCLUSIONS

The project on Preparation and Analysis of Nano-Doped Salt Hydrate 36-Phase Change Material for Solar Applications successfully demonstrated the enhancement of thermal properties in phase change materials (PCMs) through nanoparticle doping. The incorporation of nanoparticles significantly improved the thermal conductivity of the salt hydrate PCM, addressing its inherent limitations such as low heat transfer rates and phase separation. The selected salt hydrate with a phase transition temperature of 36°C proved suitable for solar thermal applications, aligning with the temperature range required for effective energy storage and release.

Experimental analysis showed that the nano-doped PCM exhibited faster heat absorption and release, higher thermal stability, and consistent phase change behavior over multiple cycles. These improvements make the material ideal for applications like solar water heating, space heating, and cooling systems, ensuring more reliable and efficient thermal energy storage.

In conclusion, nano-doping offers a practical solution to enhance the performance of salt hydrate PCMs, contributing to the advancement of sustainable solar energy technologies. This research paves the way for further studies on optimizing nanoparticle concentration and exploring real-world applications, ultimately supporting the transition towards clean and efficient energy systems.

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