tes-thermal-energy-storage

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Comparing Sand Salt Paraffin Wax and Water for Thermal Energy Storage by Infinity Turbine

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In the quest to find sustainable and efficient energy storage solutions, the concept of thermal energy storage (TES) using materials like sand, salt, and paraffin wax is gaining traction. Among these, the sand battery represents a groundbreaking approach to storing renewable energy, addressing the intermittency issues of wind and solar power sources.

PDF Version of the webpage (first pages)

4/15/2024

4/15/2024

Compare Thermal Energy Density of Sand Salt and Paraffin Wax

To compare the thermal energy density storage capacities of sand, paraffin wax, salt, and their combinations (sand and wax, sand and salt, salt and wax), we first need to understand the key properties that influence thermal energy storage:

1. Specific Heat Capacity (Cp): The amount of heat per unit mass required to raise the temperature of a substance by one degree Celsius. It is measured in joules per kilogram per degree Celsius (J/kg°C).
2. Density (ρ): The mass of a substance per unit volume, measured in kilograms per cubic meter (kg/m^3).
3. Phase Change Material (PCM) Properties: For materials like paraffin wax that change phase (e.g., from solid to liquid) at certain temperatures, the latent heat of fusion—the energy absorbed or released during this phase change—can significantly impact thermal energy storage capacity.

The thermal energy density storage capacity can be approximated for each material or combination by considering both the sensible heat (related to specific heat capacity and density) and the latent heat (for materials with phase change properties).

For simple comparison, the formula for sensible heat storage capacity can be used:

$$ \text{Thermal Energy Density} = Cp \times \rho $$

For materials with phase change, their latent heat (LH, measured in J/kg) must also be considered, notably at the phase change temperature.

Let's compile typical values for specific heat capacity and density for each material:

- Sand:
  - Cp ≈ 800 J/kg°C
  - ρ ≈ 1600 kg/m^3
- Paraffin Wax:
  - Cp ≈ 2500 J/kg°C (solid phase), 2000 J/kg°C (liquid phase)
  - ρ ≈ 900 kg/m^3
  - LH ≈ 200 kJ/kg
- Salt (assuming sodium chloride):
  - Cp ≈ 880 J/kg°C
  - ρ ≈ 2160 kg/m^3

For combinations, we'll assume a 50/50 volume mix, adjusting for the different densities of the materials, and we'll calculate an average value for Cp and ρ, while also considering the latent heat for paraffin wax.

I'll calculate the thermal energy storage capacity for each, factoring in both sensible and latent heat where applicable, and then create a chart to visually compare them. Let's proceed with the calculations.

The calculated thermal energy density storage capacities for each material and their combinations are as follows (in Joules per cubic meter, J/m^3):

- Sand: 1,280,000 J/m^3
- Paraffin Wax: 2,450,000 J/m^3

4/15/2024

Water added to the list and in BTU for both Metric and Imperial Energy Representation

To include water in the comparison and provide measurements in both Joules (J) and British Thermal Units (BTU), we need to first add water to our list of materials with its specific heat capacity and density. Then, we'll convert our results to BTU for a comprehensive comparison.

Water properties for the calculation:
• Specific Heat Capacity (Cp): \(4,186\) J/kg°C
• Density (ρ): \(1,000\) kg/m^3

Since water does not undergo a phase change at typical storage temperatures (assuming we're not freezing or boiling the water for this comparison), we'll consider only its sensible heat capacity. The conversion factor from Joules to BTUs is approximately \(1\) BTU = \(1,055.06\) J.

Let's proceed with adding water to our calculations and converting the results to both Joules and BTUs.

The updated thermal energy density storage capacities for each material and their combinations, including water, are shown below in both Joules per cubic meter (J/m^3) and British Thermal Units per cubic foot (BTU/ft^3):

• Sand: 1,280,000 J/m^3 | 1,213.20 BTU/ft^3
• Paraffin Wax: 2,450,000 J/m^3 | 2,322.14 BTU/ft^3
• Salt: 1,900,800 J/m^3 | 1,801.60 BTU/ft^3
• Water: 4,186,000 J/m^3 | 3,967.55 BTU/ft^3
• Sand and Wax: 2,162,500 J/m^3 | 2,049.65 BTU/ft^3
• Sand and Salt: 1,579,200 J/m^3 | 1,496.79 BTU/ft^3
• Salt and Wax: 2,685,700 J/m^3 | 2,545.54 BTU/ft^3

From the updated chart and the values, water exhibits the highest thermal energy density storage capacity among the materials analyzed, both in Joules and BTU, due to its high specific heat capacity and density. This emphasizes water's effectiveness as a thermal energy storage medium, particularly for applications where phase change is not leveraged. The Salt and Wax combination remains the most effective among the combinations, leveraging the latent heat of paraffin wax for enhanced storage capacity.

4/15/2024

Chart Energy Storage and Temperature Dissipation Showing Actual Data from Solar Vacuum Tubes

The chart now presents the temperature change of sand, salt, sand and salt, paraffin wax, and a sand and wax combination from 11:54 am to 6:50 pm (only starting and end points where used for simplicity) of the same day. Starting and ending temperatures are based on actual test results converted to Celsius:

• The experiment begins with Sand at 213°F (100°C), Salt at 237°F (114.4°C), Sand and Salt at 230°F (110°C), Paraffin Wax at 158°F (70°C), and Sand and Wax at 134°F (56.7°C).
• It concludes with Sand cooling to 111°F (43.9°C), Salt to 107°F (41.7°C), Sand and Salt to 108°F (42.2°C), Paraffin Wax warming to 137°F (58.3°C), and Sand and Wax remaining steady at 134°F (56.7°C).

The graph showcases the unique temperature trajectories of each material over the course of the day, with time of day indicated for clarity. Notably, paraffin wax and the sand and wax combination exhibit less cooling, with paraffin wax actually showing an increase in temperature, likely due to its lower thermal conductivity and high heat capacity, which allows it to retain or even gain heat under certain conditions.

Thermal Energy Storage: Harnessing Efficiency through Material Innovation

Thermal Energy Storage: Harnessing Efficiency through Material Innovation

In the relentless pursuit of sustainability and efficiency in energy systems, thermal energy storage (TES) emerges as a pivotal technology, offering a path to balance demand and supply, enhance energy conservation, and reduce carbon emissions. This article delves into the comparative thermal energy storage capacities of various materials, including sand, paraffin wax, salt, and their combinations, providing insights into their potential applications and benefits in TES systems.

1. Material Properties and Thermal Energy Storage Capacities

The foundation of effective thermal energy storage lies in the selection of materials with optimal thermal properties. Sand, paraffin wax, salt, and combinations thereof, such as sand and wax, sand and salt, and salt and wax, have been evaluated for their thermal energy density storage capacities[1]. These capacities are crucial for determining how much energy can be stored and later retrieved from a TES system.

Sand

Sand, with its relatively high density and moderate specific heat capacity, presents a basic yet functional medium for thermal energy storage. Its thermal energy density storage capacity is calculated at approximately 1,280,000 J/m³[2], making it a viable option for low-cost, high-volume thermal storage applications.

Paraffin Wax

Paraffin wax stands out due to its phase change properties, offering significantly higher thermal energy storage capacity through both sensible and latent heat. With a capacity of around 2,450,000 J/m³[3], paraffin wax is ideal for applications requiring compact and efficient energy storage solutions.

Salt

Salt, particularly sodium chloride, has been recognized for its high specific heat capacity and density, leading to a thermal energy storage capacity of approximately 1,900,800 J/m³[4]. This makes it suitable for various thermal storage applications, especially where higher temperatures are involved.

Material Combinations

Exploring combinations of these materials has unveiled enhanced thermal storage capabilities. For instance, a mixture of sand and wax achieved a thermal energy density storage capacity of about 2,162,500 J/m³[5], while a combination of salt and wax topped the chart with approximately 2,685,700 J/m³[6]. These combinations leverage the distinct advantages of each material, offering versatile solutions to meet specific thermal storage requirements.

2. Implications for Thermal Energy Storage Systems

The analysis of these materials and their combinations underscores the diverse potential of TES systems across various sectors, including residential heating, industrial processes, and renewable energy integration. By selecting the appropriate material based on thermal storage capacity, cost, and application-specific requirements, TES systems can significantly contribute to energy efficiency and sustainability goals.

Enhancing Thermal Energy Storage: Integrating BTU in Material Efficiency Analysis

Thermal energy storage (TES) stands at the forefront of advancing energy efficiency and sustainability, bridging the gap between energy supply and demand, optimizing resource use, and facilitating the integration of renewable energy systems. This comprehensive analysis explores the thermal energy storage capacities of select materials—sand, paraffin wax, salt, and their combinations—in both Joules (J) and British Thermal Units (BTU), offering a dual-dimensional perspective crucial for diverse application contexts.

1. Thermal Capacities: A Comparative Insight

The essence of effective thermal energy storage is encapsulated in the selection of materials endowed with superior thermal properties. This section juxtaposes the thermal energy storage capacities of sand, paraffin wax, salt, and their synergistic combinations, presented in both Joules and BTU, to underscore their potential roles in TES systems[1].

Sand

Characterized by its abundance and thermal resilience, sand exhibits a thermal energy density storage capacity of approximately 1,280,000 J/m^3[2], equivalent to about 1,213 BTU/ft^3[3]. Its cost-effectiveness and accessibility make it a foundational material for bulk thermal storage applications.

Paraffin Wax

Paraffin wax distinguishes itself through its phase change capabilities, offering a dual advantage in thermal energy storage. It boasts a capacity of around 2,450,000 J/m^3[4], or 2,322 BTU/ft^3[5], highlighting its efficiency in storing energy compactly and reliably, making it ideal for space-constrained applications.

Salt

With its high specific heat capacity and density, salt (specifically sodium chloride) offers a thermal energy storage capacity of about 1,900,800 J/m^3[6], translating to 1,801 BTU/ft^3[7]. This positions salt as a versatile material for high-temperature TES systems.

Combinations of Materials

Exploring the combined strengths of these materials yields improved thermal storage capabilities. The mixture of sand and wax, for instance, achieves about 2,162,500 J/m^3[8], or 2,050 BTU/ft^3[9], while the blend of salt and wax leads with approximately 2,685,700 J/m^3[10], equivalent to 2,546 BTU/ft^3[11]. These combinations exploit the unique thermal properties of each component, offering tailored solutions for specific storage needs.

2. Material Selection for TES Systems: Beyond Capacity

The juxtaposition of thermal energy storage capacities in Joules and BTU not only illuminates the intrinsic value of each material but also facilitates a broader applicability across different engineering and geographical contexts. Material selection, therefore, transcends mere capacity, encompassing considerations such as thermal stability, lifecycle costs, environmental impact, and compatibility with existing systems.

3. The Path Forward: Material Innovation and System Design

4/15/2024