

Experimental Analysis of Graphite Dispersed Salt Hydrates based Phase Change Materials to Determine Enhancement in their Thermophysical Properties

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ABSTRACT

Demand for energy is on a tremendous rise and the need to depend on renewable energy resources is inevitable. But there are several limitations with them, particularly the problem of intermittency. So, the requirement for energy storage is indispensable. Thermal Energy Storage (TES) is one of the most economical and practical system to achieve a solution for this problem. It also has enormous potential to utilize the waste heat rejected in many manufacturing processes and reduce the overall power requirement for heating operations. Salt hydrates are excellent candidates for these kind of applications. But they suffer from the drawbacks of low thermal conductivities and supercooling. This paper presents the effectiveness of dispersion of Graphite into these salts in improving their thermophysical properties. The improvement in thermal conductivity ensures smooth heat transfer to and from the energy storage system and solving the phenomenon of supercooling ensures recyclability of the system as well as efficient withdrawal of stored energy from the Phase Change Material (PCM).

KEY WORDS: Phase Change Material, Thermal Energy Storage, Supercooling, Thermal conductivity.

1. INTRODUCTION

Thermal energy storage is being researched worldwide as it is an eco-friendly technology. The energy storage is essential to bring a balance between the availability (supply) and requirement of thermal energy from renewable energy sources. A thermal energy storage system can store the intermittent energy when it is available, to be used when it is needed. The limitation of intermittency is the main reason for lower adoption of solar thermal energy technology worldwide. The solar energy availability is unpredictable during various time periods in the day as well as under different weather conditions. Thus, the solar energy has to be captured and stored during the day time and in the summer months to be used during the night time and the winter months. The challenge here is to ensure that this is accomplished with little thermal energy loss and high extraction efficiency. If a TES system is installed and charged using waste heat, which otherwise is discharged into the environment, is retained and later used in place of primary energy, then there will be reduction in the overall energy consumption.

Thermal Energy Storage Systems: The three main types of thermal energy storage systems are sensible heat, latent heat and thermo-chemical. All TES systems work on the same principle. The energy-in-excess is stored in the system to be used when the need arises. The thermal energy storage systems are differentiated on the basis of the scale (storage capacity) and the method of storage used. Figure.1, provided by Dincer and Rosen describes the modes of operation of thermal energy storage systems: charging, storing, and discharging.

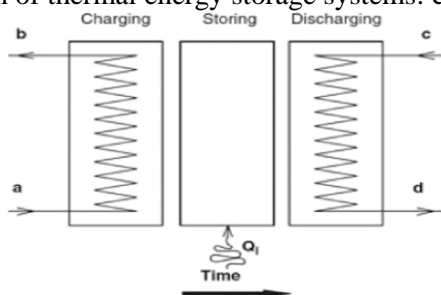


Figure. 1. Basic principle of thermal energy storage systems

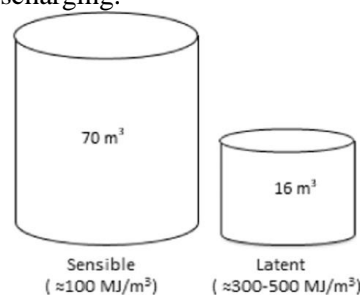


Figure. 2. Comparison between Sensible and Latent heat storage systems

Sensible heat storage works by raising the temperature of a material in solid or liquid form, such as water, oils, molten salts, rocks, metals, concrete and others. The magnitude of heat energy stored is a function of the medium's heat capacity and the degree of temperature increase. The larger the difference between the high temperature and low temperature system, the higher is the heat stored by the material.

Latent Heat Thermal Storage (LHTS) systems make use of Phase Change Materials (PCMs). Among the various forms of phase change processes, the solid-liquid transition is efficient due to its lower volumetric expansion compared to the liquid - gas transition and higher latent heat compared to the solid - solid transition. During phase change, medium stores energy without any temperature rise. Due to this reason, PCMs can store higher magnitudes of heat compared to sensible storage media, for the same operating temperatures.

Latent Heat Thermal Energy Storage: An ideal TES system should have good heat transfer between the Heat Transfer Fluid (HTF) and storage media, and also have fast charging and discharging capability. Though PCMs can

store high magnitudes of heat, most of them have low thermal conductivity which results in slow charging and discharging rates. The solution for this problem is the improvement of their effective thermal conductivity which can be achieved by:

- Addition of high thermal conductivity materials to the pure PCM
- Encapsulation of the PCM and improving convective heat transfer by getting these PCM capsules submerged in a liquid.

Several methods are being employed by researchers to improve the heat transfer features of PCMs which include using extended surfaces, employing multiple PCMs, metallic structures usage, foams impregnated with PCM, dispersion of highly conductive particles and encapsulation of PCM. The methods are summarized in Figure.3.

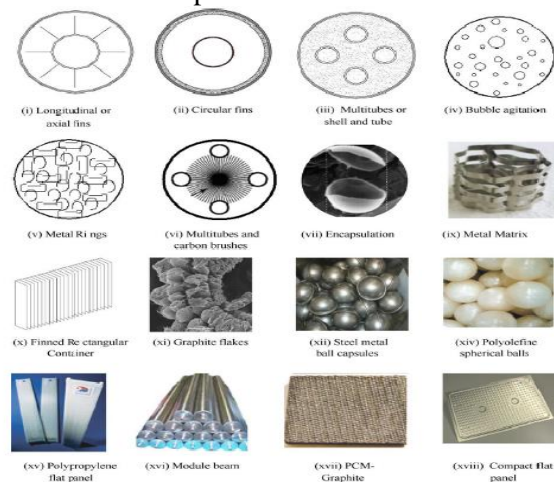


Figure. 3. Heat transfer enhancement techniques employed for various PCMs

Solution for Phenomenon of Supercooling: The biggest limitation with salt hydrates as PCMs is their tendency to supercool considerably. This behaviour has not always received sufficient attention from researchers in the field. The reason for the high degree of super cooling is that either the nucleation rate (of crystals from the melt) or the growth rate of these crystals (or both) is very slow. Therefore as the melt is cooled, it does not solidify at the thermodynamic melting point. Thus, the advantage of the material for heat storage is reduced. Supercooling can often be mitigated through addition of nucleating materials. Usually nucleating agents (additives) are discovered by trial and error.

In homogeneous nucleation, the nucleation rate of crystals from the melt is increased without adding any foreign materials, usually using ultrasonic waves. In heterogeneous nucleation, the walls of the container or impurity present in the melt act as a catalyst for nucleation by providing a substrate from which the nuclei can form.

In order for an impurity to be an effective nucleating agent, it should satisfy the following criteria:

- Have a melting point higher than the highest temperature reached by the energy storage material in the storage cycle
- Be insoluble in water at all temperatures
- Not form solid solutions with the salt hydrate
- Have a crystal structure similar to the salt hydrate
- Have variations in the unit cell dimensions to be less than 10% from those of the salt hydrates
- Not chemically react with the hydrate

2. RESEARCH MATERIALS AND METHOD

Heat transfer to and from a storage unit strongly depends on the thermal conductivities of solid and liquid PCM. The higher the conductivities, the more efficient the heat transfer for a given design. The crystallization rate of a salt hydrate can be low and can become the limiting factor in the heat storage rate and restitution.

This research focuses on determining the enhancement in the thermophysical properties of the salt hydrates chosen, namely Magnesium nitrate hexahydrate ($\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$) and Magnesium chloride hexahydrate ($\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$) on addition of 10% by mass of Graphite powder into them. The approach of addition of 10% of Graphite powder is based on the results of the research by Sari et al. (2007) related to Paraffin/EG (Expanded Graphite) composite. The thermophysical properties of these dispersions were measured using Differential Scanning Calorimetry (DSC). The DSC analysis was carried out at Sophisticated Analytical Instrument Facility (SAIF), IIT-Madras.

During the testing, only the unknown crucible was used, while the reference side was capped to suppress its heat loss. The results were tabulated and the thermal conductivities were calculated using Fourier law of conduction and the specific heats were also found out. The DSC curves for the two mixtures used in this study are shown in Figure.4 and Figure.5.

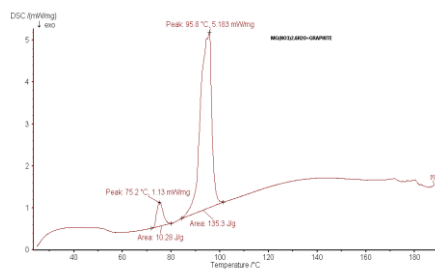


Figure 4. DSC curve obtained for the mixture of Mg(NO₃)₂.6H₂O and Graphite

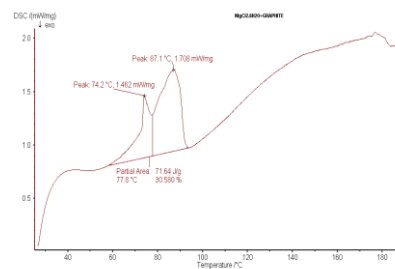


Figure 5. DSC curve obtained for the mixture of MgCl₂.6H₂O and Graphite

The results indicate an increase of about 260 % in the thermal conductivity of Mg (NO₃)₂.6H₂O in the solid state (at 37 degree Celsius) and 68 % in the liquid state (at 100 degree Celsius). The thermal conductivity for MgCl₂.6H₂O has increased by about 71 % in the solid state (at 80 degree Celsius) and about 39 % in the liquid state (at 120 degree Celsius). The specific heat values have also either increased or remained almost the same for the salts. The mixture Mg(NO₃)₂.6H₂O/Graphite is found to have a latent heat of 145.58 kJ/kg (melting point = 95.8 degree Celsius) and the mixture of MgCl₂.6H₂O/Graphite is found to have a latent heat of 71.64 kJ/kg (melting point = 87.1 degree Celsius). There may be some differences in the theoretical and experimental values of the thermo-physical properties of the mixtures due to:

- Variation in the degree of purity of sample
- Moisture inclusion as the salts chosen are hygroscopic in nature

The tables given below show the variation of thermal conductivity and specific heat of the mixtures with temperature.

Table.1. Thermophysical properties of Mg (NO₃)₂.6H₂O and Graphite mixture

Temperature (deg. C)	Time (min)	DSC Output (W/g)	Thermal Conductivity (W/mK)	Specific Heat (kJ/kg.K)
45.829	2.70914	0.52145	1.264627	2.64907
50.829	3.15081	0.51166	1.002253	2.77801
55.829	3.61511	0.4211	0.691819	2.38258
60.829	4.09495	0.41212	0.583029	2.39780
65.829	4.58522	0.44396	0.551479	2.57491
70.829	5.08071	0.49892	0.552385	2.97316
80.829	6.08091	0.6398	0.581869	3.84110
85.829	6.58197	0.83134	0.694093	4.99702
90.829	7.08299	1.80979	1.39654	10.90435
100.829	8.08564	1.13892	0.763218	6.78979
105.829	8.58519	1.21047	0.761094	7.28170
110.829	9.08684	1.30958	0.775537	7.87634
115.829	9.58709	1.41154	0.789989	8.46416
120.829	10.08769	1.50483	0.798335	9.04252

Table. 2. Thermophysical properties of MgCl₂. 6H₂O and Graphite mixture

Temperature (deg. C)	Time (min)	DSC (W/g)	Thermal Conductivity (W/mK)	Specific Heat (kJ/kg.K)
40.728	2.40199	0.76062	2.766998	3.18685
45.728	2.77128	0.7639	2.047632	3.52876
50.728	3.18015	0.76033	1.613467	3.86673
55.728	3.62207	0.78338	1.375763	4.25610
60.728	4.08773	0.8457	1.266795	4.80375
65.728	4.56877	0.93382	1.21946	5.44100
70.728	5.06017	1.06268	1.230039	6.30977
75.728	5.5585	1.35676	1.410185	8.14707
80.728	6.05991	1.44705	1.364768	8.71443
85.728	6.56228	1.67255	1.443764	10.08548
90.728	7.0651	1.3638	1.085275	8.22208
95.728	7.56676	0.98727	0.728712	5.94435
100.728	8.06934	1.0669	0.734279	6.43853
105.728	8.57231	1.15693	0.745846	6.98115
110.728	9.07431	1.25308	0.759746	7.54104

115.728	9.57517	1.36036	0.778454	8.17359
120.728	10.07606	1.46521	0.793855	8.80708

A prototype of a cascaded Latent Heat TES system was developed using the researched salt hydrates/Graphite mixtures.

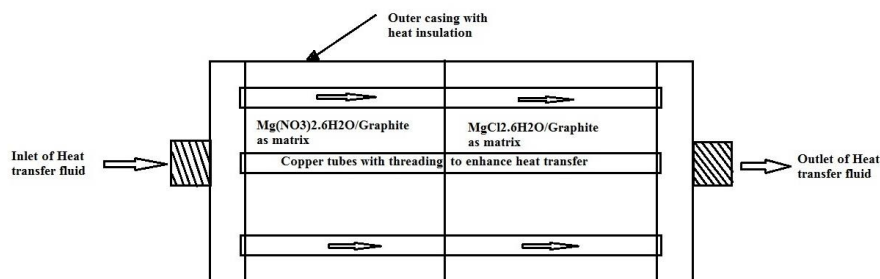


Figure. 6. A diagram of the prototype developed of the cascaded TES system employing the studied mixtures

4. CONCLUSION

The experimental results clearly show that there is an enormous potential to improve the thermo-physical properties of the salt hydrates which are not currently used widely because of their poor thermal conductivities and specific heats. By employing additives like graphite powder, these properties can be improved without the need for more expensive enhancement mechanisms like polymer encapsulation. Provision of such additives can also mitigate the problem of supercooling by providing nucleation sites, thereby increasing the recyclability of the system. Further extensive researches can provide more breakthroughs, so that such materials can be transferred from laboratory to industrial-scale systems. These materials can find wide range of applications in the fields of solar energy harvesting, waste heat recovery, dampening of heat loads in electronics circuits, momentary failure prevention and many more.

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