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Review On Heat Transfer Enhancement Techniques in Thermal Energy Storage Systems

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Abstract
Heat transfer enhancements of both experimental and analytical studies have been reported in view of their industrial and domestic significances. This review is confined to the enhancement of heat transfer in solidification processes and latent heat thermal storage system due to low heat thermal conductivity of the PCM. The review covers different methods of heat transfer enhancement techniques, encapsulation of phase change materials in Thermal Energy Storage System and solar system.
Key Words: Thermal Energy storage systems, PCM, Heat Transfer Enhancement. Solar System.

I. Introduction

Thermal energy storage systems have an enormous potential to make the function of thermal energy equipment more effective and to facilitate large-scale energy substitutions. Thermal energy storage is defined as the temporary holding of thermal energy in the form of hot or cold substances for later utilization. They are highly valuable from an economic perspective. It is an advanced energy technology that has recently attracted increasing interest for thermal applications such as space and water heating, cooling and air-conditioning. It appears to be the most appropriate method for reducing the mismatch between the supply and demand of energy. Therefore it is an attractive technology for meeting society's needs and more efficient way of energy uses.

II. Thermal Energy Storage Systems

Thermal Energy Storage (TES) systems play an important role in the effective functioning of diverse systems, such as solar systems, heating and cooling systems, power systems, and industrial waste heat recovery systems. Energy can be stored and retrieved as sensible heat, latent heat and also in thermo-chemical reactions or a combination of any of these. In the case of Sensible Heat Storage (SHS) system, thermal energy is stored by raising the temperature of a solid or liquid. The SHS system utilizes the heat capacity and the change in the temperature of the material during the process of charging and discharging. The amount of stored thermal energy depends on the specific heat of the medium, the temperature change and the amount of storage material. Latent Heat Storage (LHS) system is based on heat absorption or release, when heat supply is given to the system. When materials reach certain level of temperature the additional heat energy is absorbed and stored in the system without any change in the temperature, then the stored energy in the materials undergoes a phase change from solid to liquid or liquid to gas or vice-versa. It is known as latent heat storage system.

In the Thermo-Chemical Energy Storage systems, the energy is absorbed and released while breaking or reforming molecular bonds in a completely reversible chemical reaction. In this case, the storage of heat depends on the amount of chemical material and endothermic heat of reaction.

III. Heat Transfer Enhancement Methods

Enhancement techniques are supporting tools for thermal energy storage systems. The compact enhanced design yields good results in thermal systems. The rapid growth of world literature on this subject indicates that enhancement is now a major speciality area in thermal energy (heat transfer) Research and Development. Hence the industrial and domestic utilization of enhancement techniques increases day by day.

Heat transfer enhancement techniques are required for many latent heat thermal energy storage systems; various methods are proposed to enhance the heat transfer in a latent heat thermal energy storage system, such as Metallic fillers, metal matrix structures, and finned tubes were used to improve the thermal conductivity of the phase change materials as shown in figure 3.1.Enhancements followed with other techniques are also listed below. (i)Active methods of agitators, vibrators, scrapers and slurries. (ii)Microencapsulated PCM. (iii) PCM containing dispersed high conductivity particles, Lessing rings. (iv) PCM mixed with graphite composite material. (v) Extended surfaces such as fins and honeycombs.

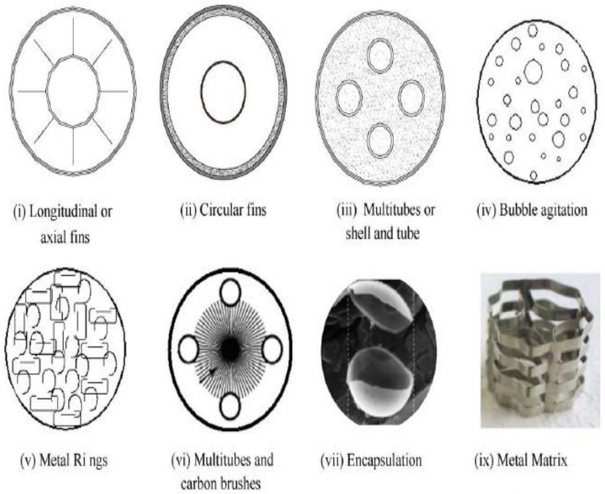

Fig.3.1 Different kinds of Heat Transfer Enhancement fins

Many researchers have studied heat transfer analysis during solidification with the use of internal fins. The use of finned tubes with different configurations has been proposed by various researchers as follows. [1] Experimentally studied different heat transfer enhancement methods for the melting of paraffin, by constructing a model that consists of vertically arranged fins between two isothermal planes, which not only provides additional conduction paths, but also promotes natural convection with the molten PCM.[2] concluded from the experimental results that the enhancement technique were implemented through the numbers of copper tube in the fabricated storage tank, the smaller diameter of copper tubes could effectively enhance the heat from the HTF to the PCM as well as from the PCM to the HTF during charging and discharging processes.

[3] Presented a theoretical model for predicting the transient behaviour of a shell and tube storage test, in which annular fins were externally fixed in the inner tube with the PCM on the shell side, and the HTF flowing inside the tube. The numerical results have validated with the experimental data for various parameters, like the shell radius, the mass flow rate, and the inlet temperature of the HTF. [4] Studied the phase change process occurring in a cylindrical annulus in two ways such as (i) rectangular, uniformly spaced longitudinal fins, spanning the annulus (ii) annular fins are attached to the outer surface of the inner tube.

There are several methods to enhance the heat transfer in a latent heat thermal energy storage system. The use of finned tubes with different configurations has been proposed by various researchers. [5] Used finned tubes in thermal storage systems and studied the improvement in solidification rate in molten salt dispersed with high conductivity particles. [6] Studies two thermal conductivity enhancement techniques. The first technique focused on placing an encapsulated PCM of various shapes in a liquid metal medium. The second technique involved a metal and PCM composite to enhance the system.

[7] Developed Latent heat storage systems using organic materials, and experiments were carried out to enhancing the thermal response of paraffin wax by incorporation of aluminium.[8] presented the theoretical and experimental work for a thermal storage unit that consist of a cylindrical vertical tube with internal longitudinal fins, and it has been concluded that this configuration which forms a v-shaped enclosure for the phase change material gives the maximum benefit to the fin arrangement and extended his study to make an experimental analysis with numerical modeling of inward solidification on a finned vertical tube for a latent heat storage unit. The solidification time in a finned tube was reduced approximately by the number of fins in the tube. The researchers proved that heat can be enhanced through Lessing ring.

[9] Reviewed a heat storage system with phase change materials. He found out that the most influential parameter is the distance between the fins and explained time-based variations of the temperature distributions and heat flux in thermal energy storage system.[10] Developed a numerical simulation method and studied the enhanced heat transfer rate for water and air, in which numerical solutions were obtained for constant properties. Another method used is to embed the PCM in a metal matrix structure. The PCM is embedded inside a graphite matrix to increase the thermal heat conductivity in the PCM without much reduction in energy storage.

[11] Performed experiment with fin tubes in thermal storage systems. The system was based on the pure conduction mechanism of heat transfer. The enthalpy formulation approach and the control volume method were used. The number of fins, fin length, fin thickness, degree of super heat and the aspect ratio of the annular spacing were found to be influencing factors for the solidification process. The results conforms the importance of the fins in delaying the undesirable effects of natural convection during the phase change processes.[12] Evaluated the influence of carbon fibers on thermal conductivity enhancement of an inorganic PCM. Fibers of different length were randomly distributed and thermal conductivity measurements of the obtained composite were carried out by hot-wires method. It has been observed that the homogeneity grade of the composite (PCM+fiber) plays a fundamental role in the enhancement of heat diffusion.

[13] Focused on heat transfer enhancement in double pipe energy storage system. Enhancement is achieved by the use of metal screens/spheres placed inside the phase change material. He conducted the experiments, as a function of the pipe diameter and number of spheres inserted in the phase change material. He presented the results in terms of Nusselt number and Fourier number. [14] Enhancement techniques implemented using fins and honeycombs to increase the heat – transfer in the storage system. The analytical results are compared with the numerical results. The results show that the analytical model gives a satisfactory estimation for the fin temperature.

IV. Encapsulation of Phase Change Materials

There are many advantages in using an encapsulated PCM, which increases the heat transfer area, reduces the PCM reactivity towards the outside environment, and control the changes in the storage material volumes. The phase change materials are encapsulated in specified design containers with metal or plastic materials as shown in Figure.4.1

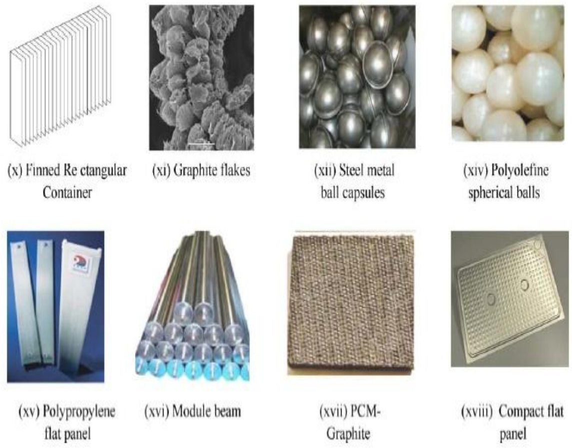

Fig.4.1 Heat Transfer Enhancement Encapsulation

[15] Developed a computer model for the estimation of the temperature profiles of solid and fluid. The length of the packed bed contains encapsulated AL-Si PCM shots. Air was used as the heat transfer fluid (HTF) in their study.[16] Developed an ID porous medium model to determine the thermal characteristics of ice-water cool storage in packed capsules for air conditioning, in which the water as PCM and alcohol as coolant for various porosities.[17] Analyses numerical investigation on packed bed thermal models for sensible and latent heat storage systems. The models was compared in relation to the influencing factors of particle size, void fraction, particle material, flow rate variations, working fluid inlet temperature and wall thermal losses. [18] Compared Sodium acetate try hydrate has more efficient than paraffin wax in which the storage tank contains number of encapsulated PCM balls in which solar energy is absorbed and stored as latent heat. Large quantity of solar energy can be stored in a day time and same heat can be retrieved for later use. It concluded Sodium acetate try hydrate has more efficient than paraffin wax and extended [19] with thermal cooling on PCB.

[20] Performed a transient phase change thermal storage system. The control volume finite difference approach was used to solve the equations. The SIMPLE scheme was used to solve the pressure and velocity fields of the HTF. The influencing factors such as radial temperature distribution, phase change interface position and heat accumulation have been discussed. [21] Dealt with the experimental evaluation of the thermal performance of a packed bed latent heat thermal energy storage unit, integrated with solar flat plate collector, in which the TES unit contained paraffin as phase change material is filled in spherical capsules.[22] Described the preparation of a form-stable phase change material and polyethylene paraffin compound. It consists of paraffin as a dispersed phase change material and a high density polyethylene (HDPE) as a supporting material to promote the heat storage.

[23] Investigated the solidification of an n-hexadecane inside a spherical enclosure. The performance of solidification process estimated for three different constant surface temperatures and three different initial superheats of n-hexadecane. He observed that the solidification phase propagates uniformly inwards towards the centre of the sphere. [24] Studied four different capsules (sphere, cylinder, plate and tube) for investigating the effects of geometrical configurations. The effects of the capsule diameter and shell thickness and the void fraction on the performance of the heat storage system were also investigated. The experiment was conducted by using a commercial plate heat exchanger as the heat storage tank. It was found that the spherical capsule showed the best heat release performance among the four types of investigation capsules.

V. Thermal Energy Storage Based on the Solar System

Thermal energy storage comprises a number of technologies that store thermal energy in reservoirs for later use. They can be employed to balance the energy demand between the day time and the night time.Solar energy is a major renewable energy resource, of an intermittent nature, and its effective utilization is a part of efficient and effective energy storage systems. If no energy storage is used in solar energy systems, the major part of the energy demand will be met by the back-up or auxiliary energy, and therefore the annual solar load fraction will be very low.

[25] Presented thermal performance of a multi-layer phase change material storage unit. Electrical heat sources embedded inside the PCM are used for heat storage and HTF is employed for heat recovery. Parametric studies performed to assess the effect of various design and operating conditions, which lead to correlations for the total energy stored and the average output of heat load. [26] Presented a two-dimensional model for the phase change materials. The energy equation is written in the enthalpy form, and the heat flow problems are coupled by an energy balance on the fluid element. The results show the effect of the variation depends on the ratio of radius of inner tube to outer tube and discussed about Biot number, Stefan number,NTU and effectiveness.

[27]Sharma et al (1999) conducted experimental test on commercial-grade stearic acid, aetamide and paraffin wax. During the analysis latent heat of fusion, melting temperature and specific heat of PCM have been discussed. He concluded that acetamide and paraffin wax were found to be more stable phase change materials than stearic acid and extended his study with erythritol as PCM of latent heat storage material. He created a prototype solar cooker based on an evacuated tube solar collector with phase change material. Solar energy is stored in the PCM storage unit during sunshine hours and is utilized for cooking in late evening/night time. Cooking experiments and PCM storage processes were carried out simultaneously. It was observed that noon cooking did not affect the evening cooking, and evening cooking using PCM heat storage was found to be faster than noon cooking.

[28] Developed a model of open-loop passive solar water-heating system combined with sodium thiosulfate pentahydrate-phase change material. It was observed that the water temperature at the midpoint of the storage tank decreased regularly by day until the phase-change temperature of PCM. Heat storage performances of the same solar water-heating system combined with the other salt hydrates-PCM such as zinc nitratehexahydrate, disodium hydrogen phosphate dodecadydrate, calcium chloride hexahydrate and sodium sulfate decahydrate (Glauber's salt) were examined theoretically by using meteorological data and thermo physical properties of PCM with some assumptions, finally he proved that the PCM solar water header had a higher thermal efficiency than the conventional solar water-heating system.[29] concentrated Experimental Study of Heat Transfer Enhancement in Latent Heat Thermal Storage System during Charging and Discharging Processes. Hybrid thermal energy storage system used for phase change materials, for managing simultaneously the storage of heat from solar and electric energy. This is developed and validated with experimental data. Simulations carried out for a period of 4 consecutive winter months indicate that, with such a system, the electricity consumption for space heating is reduced about 32%. Also more than 90% of the electric energy is consumed during off-peak hours. For electricity markets where time-of-use schemes are in effect, the return on the investment in such a thermal storage system is very attractive.

VI. Conclusion

The review of this paper carried out different methods of heat transfer enhancement techniques in thermal energy storage system. The paper mainly focused on PCM based thermal energy storage system, which is more attractive and useful to the energy conservative system and covered current research papers in particular field.

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