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Using encapsulated phase change salts for concentrated solar power plant

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Abstract

Storing thermal energy as latent heat of fusion in phase change material (PCM), such as inorganic salt mixtures, can improve the energy density by as much as 50% while reducing the cost by over 40%. However, to discharge stored energy from PCMs, which has low thermal conductivity, requires a large heat transfer area which drives up the cost. Fortunately, salts encapsulated into small capsules can provide high specific surface area thus alleviating this problem. However, a technical barrier with encapsulating salts is that when it is produced, a void must be created inside the shell to allow for expansion of salt when it is heated above its melting point to 550°C. Terrafore's method to economically create this void consists of using a sacrificial polymer which is coated as the middle layer between the salt prill and the shell material. The polymer is selected such that it decomposes much below the melting point of salt to gas leaving a void in the capsule. Salts with different melting points are encapsulated using the same recipe and contained in a packed bed consisting of salts with progressively higher melting points from bottom to top of the tank. This container serves as a cascaded energy storage medium to store heat transferred from the sensible heat energy collected in solar collectors. Mathematical models indicate that over 90% of salt in the capsules undergo phase change improving energy density by over 50% from a sensible-only thermal storage. Another advantage of this method is that it requires only a single tank as opposed to the two-tanks used in a sensible heat storage, thereby reducing the cost from a nominal $27 per kWht to $16 per kWht and coming close to the SunShot goal for thermal storage of $15 per kWht.

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Keywords: Molten salt, encapsulation, phase change material, cascaded thermal storage, concentrated solar power, capsules

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1. Background

Thermal energy storage (TES) is essential to any concentrating solar power plant (CSP). as it is required for generating power smoothly and predictably, especially on days when there is no or intermittent sunshine and when the cost and demand for electricity is high. Currently, CSP plants use sensible energy storage in molten salt to store thermal energy which requires large volume of salt, two large tanks and cost over \$30 per kWht [1],[2].To economically produce electricity from CSP, SunShot set the goal at \$15 per kWht for TES for a high temperature CSP.

Storing thermal energy in phase change material (PCM) such as inorganic salt mixtures, as latent heat of fusion can increase the energy density for storage by as much as 50% and can reduce the cost by over 40%.. However, a major issue that has prevented the commercial use of PCM-TES for CSP is that it is difficult to discharge the latent heat stored in the PCM melt at specified heat rates. This is because when heat is extracted, the PCM-melt which has low thermal conductivity solidifies onto the heat exchanger surface decreasing the heat transfer, and requiring large heat transfer area and hence a higher cost. Thus, to obtain consistently high heat rates, either heat transfer area and /or heat transfer coefficient must be increased. Several methods were unsuccessfully investigated to improve heat transfer coefficient [3].

Encapsulating PCM material inside small capsules increases the specific surface area and using heat transfer fluid in direct contact with the capsules, increases the heat transfer coefficient. However, a technical barrier with encapsulating salts is that a void must be created inside the shell when it is produced. This void is necessary to accommodate the volume increase when melting and heating occur. Under contract with Department of Energy, Terrafore Inc., is researching innovative methods to economically create this void and encapsulate the salt in shell material that can withstand high temperature thermal cycles and will last for more than thirty-year life of a solar plant.

The project's objective is to produce 5mm to 15 mm size capsules containing inorganic salt mixture for storing thermal energy as a combination of latent heat from solid to liquid and as sensible heat. The shell used to encapsulate the salt must be compatible with a molten salt heat transfer fluid heated to temperatures up to 600°C and must be robust to withstand over 10,000 thermal cycles between 300°C and 600°C. The breakage rate, if any, must be less than 0.1% per year.

Phase-1of the project completed in January 2012, successfully developed a recipe to encapsulate a nitrate salt melting at 370°C in 5mm capsules in a suitable shell material that withstood temperatures to 500°C. Phase 2, currently in progress, is optimizing this recipe and will demonstrate that the capsules can withstand over 10,000 thermal cycles between 300°C and 550°C. Designed experiments and statistical analyses are used to estimate the breakage rate, which must be <0.1% per year and the cost to manufacture these capsules must be less than \$5 per kWht. Next step will be to make these capsules on a pilot scale, preferably at a commercial facility, and demonstrate the encapsulated PCM-TES concept on a small scale TES system.

2. Technical details

2.1. Sacrificial polymer encapsulation method and results

Figure 1 shows a schematic of the concept for creating a void in the capsule. The process consists of first applying a layer of sacrificial polymer on a salt prill of selected diameter and another coating containing a mixture of binder and inorganic shell material. A fluid-bed coater is used to coat these layers on the prill. The

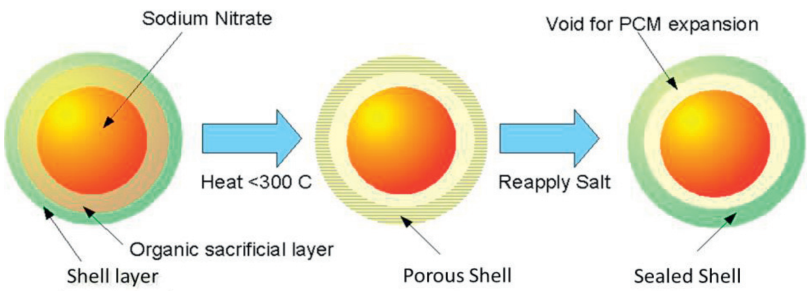

Figure 1 A polymer layer between shell and prill is decomposed to gas to create a void in the capsule