MULTIPHASE TRANSPORT PHENOMENA IN COMPOSITE PHASE CHANGE MATERIALS FOR THERMAL ENERGY STORAGE

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ABSTRACT

Thermal energy is at the heart of the whole energy chain providing a main linkage between the primary and secondary energy sources. Thermal energy storage (TES) has a pivotal role to play in the energy chain and hence in future clean energy systems. However, a competitive TES technology requires a number of scientific and technological challenges to be addressed including materials, components and devices, and integration of the devices within energy networks and associated dynamic optimization. This requires fundamental understanding of the underlying physics particularly flow and heat transfer of a multiphase system across a very large spatial length scale from atomic/molecular scale to system scale. This talk will first briefly outline the background and challenges of energy storage. Discussion will then be on TES covering TES materials, TES devices (TES heat exchangers) and system integration, with a specific focus on flow and heat transfer across large lengthscales. TES can be sensible heat, latent heat or thermochemical based. This talk shall use the latent heat storage materials, often called phase change materials (PCM), as an example, particularly inorganic salts based PCMs for medium and high temperature applications. Two key challenges for such materials are chemical incompatibility and low thermal conductivity. The use of composite materials provides an avenue to meeting the challenges. Such composite materials use a structural supporting material and a thermal conductivity enhancement material. A right combination of the salt, the structural supporting material and the thermal conductivity enhancement material could give a hierarchical structure that is able to encapsulate the molten salt and give a substantial enhancement in the thermal conductivity. Our recent progress in these aspects will also be covered in the talk.

INTRODUCTION AND OBJECTIVES

Thermal energy storage (TES) refers to a collection of technologies that store energy in the forms of heat, cold or their combination, which accounts for a significant portion of global non-pumped hydro storage installations. TES can be sensible, latent or thermochemical heat based. Figure 1 shows a schematic diagram illustrating energy density and suitable temperature range of these technologies and their development stages.

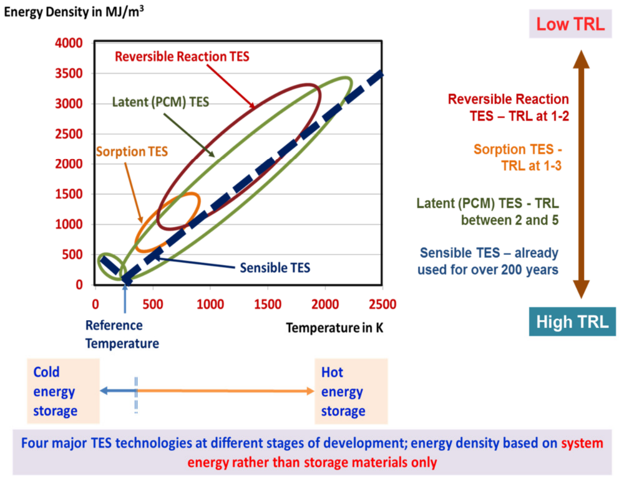


Figure 1 Four major TES technologies at different development stages

The work to be presented here concerns TES using latent heat storage materials, often called phase change materials (PCMs). PCMs can be liquid-solid, solid-solid, gas-solid and gas-liquid. This work will focus on solid-liquid PCMs, particularly inorganic salts based PCMs.

CHALLENEGS AND METHODOLOGY

Two key challenges for the use of such materials are chemical incompatibility and low thermal conductivity. The use of composite materials provides an avenue to meeting the challenges. Such composite materials use a structural supporting material and a thermal conductivity enhancement material. Figure 2 illustrates the structure and the formulation of the composite PCMs. One can see the hierarchical structure of the composite PCMs. Such a structure, combined with liquid-solid phase change, gives very complex flow and heat transfer behavior during repeated charge (heating) and discharge (cooling) processes. This presentation will report our recent progress in the fundamental understanding of the multiphase and multiscale transport phenomena. Figure 3 illustrates the methodology for gaining fundamental understanding of the multiphase and multiscale transport phenomena.

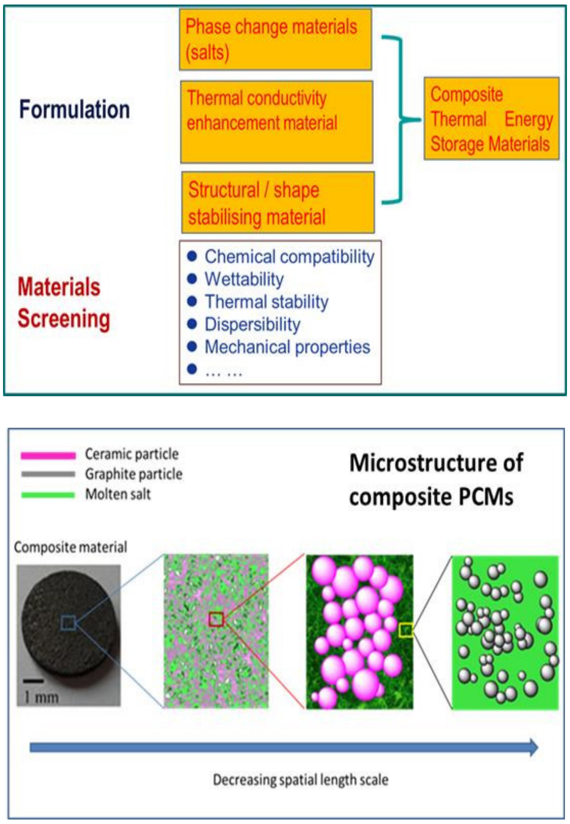
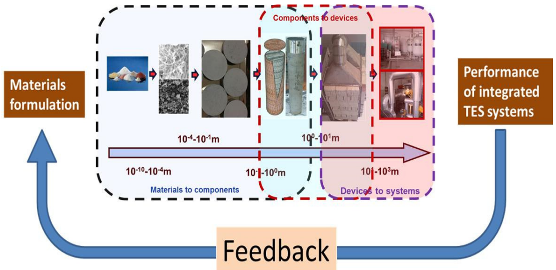


Figure 2 Structure (lower) and formulation (upper) of composite PCMs



A mutlscale & multiphase problem across *tens orders of magnitude*

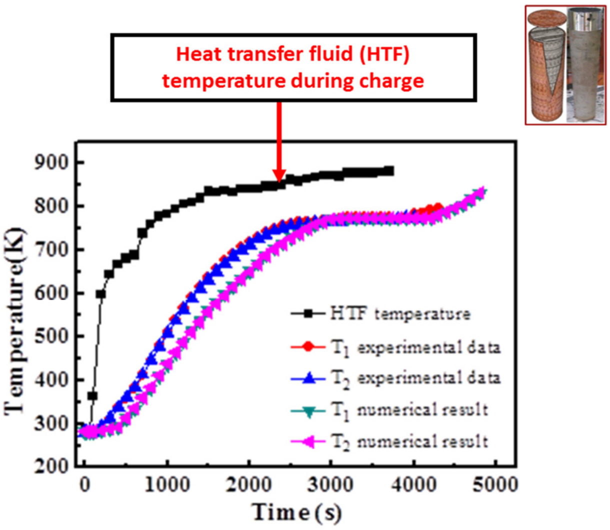
Figure 3 Methodology for the understanding the multiscale and multiphase transport phenomena of TES using composite PCMs

MULTIPHASE AND MULTISCALE MODELLING STUDY AND EXPERIMENTAL VALIDATION

The work to be presented will mainly include the following:

a) Molecular modelling based composite PCM formulation and experimental validation;
b) Modelling and experimental validation of thermal conductivity of composite PCM containing aggregated nanoparticles;
c) Particle scale modelling and experimental validation of thermal conductivity of composite PCM modules;
d) Particle migration within composite PCM structure during repeated heating and cooling cycles;
e) CFD modelling and experimental validation of composite PCM components.

As an example, Figures 4 and 5 respectively show the charge and discharge results of the CFD modelling of a composite PCM component, together with experimental validation. One can see very good agreement has been achieved.



Heat storage process

Figure 4 Modelling and experimental validation of the charge process of composite PCM based TES components

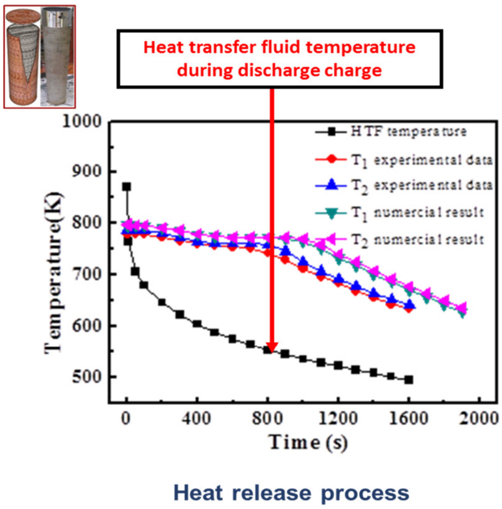


Figure 5 Modelling and experimental validation of the discharge charge process of composite PCM based TES components

Figure 6 shows a set of SEM images of a composite PCM module containing 5% graphite flake at different cycles. One can see that repeated heating and cooling of the material can lead to forces within the materials microstructure that can break heat transfer enhancing materials.

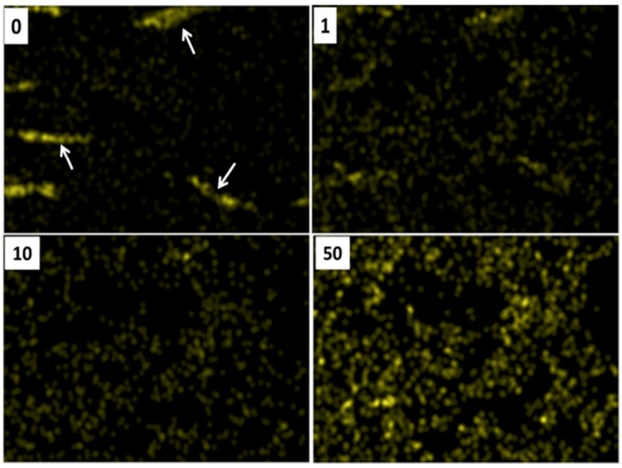


Figure 5 SEM pictures of composite PCM containing 5% graphite flakes at 0, 1, 10 and 50 cycles