Development and Demonstration of an Innovative Thermal Energy Storage System for Baseload Power Generation

CSP Program Award Review Meeting Presentation

Presented by: Dr. Yogi Goswami
Clean Energy Research Center
University of South Florida

Date: May 18, 2011

DE-EE0003590

Institution/Partners, Research Team

Institution

Clean Energy Research Center, University of South Florida

Industrial Partner

SunBorne Energy

Faculty Researchers

Yogi Goswami (PI) ; Co-Director, CERC; Professor, USF
Elias Stefanakos (Co-PI); Co-Director, CERC; Professor, USF
Muhammad Rahman (Co-PI); Affiliate Faculty, CERC; Professor, USF

Research Scientists/ Postdocs

Chand Jotshi, Burton Krakow, Sarada Kuravi, Manoj Ram

Staff/Engineer

Charles Garretson, Engineer, CERC

Graduate Students

Jamie Trahan, Swetha Pendyala, Rupa Nath, Antonio Archibold

Overview

Goal

- Develop suitable encapsulation methods for existing low-cost phase change materials (PCMs) to provide a cost effective and reliable solution for thermal energy storage (TES) to be integrated in solar thermal power plants

Objectives

- Develop an encapsulated PCM for TES in the temperature range of 300 ^{0}C – 450 ^{0}C with a cyclic performance capability of at least 1000 cycles.
- Design a one tank storage system using spherical (or other shapes) PCM capsules immersed in a heat transfer fluid with an integrated heat exchanger for charge/discharge testing.
- Design, build and test a prototype TES system for integration with a State funded 100 kW CSP prototype plant to be built at USF.

Approach, Challenges

PCM storage can provide a cost effective solution to CSP TES, provided PCM can be encapsulated at low cost

Our Research Approach

- Prepare cost effective macro-capsules by:
  - Using low-cost PCMs like salts, eutectics, metal alloys, polymers
  - Form porous pellets of the PCMs by low cost industrial methods
  - Encapsulate the formed porous pellets in high temperature material
- Enhance convective heat transfer by submerging the PCM capsules in a liquid.

Major Challenges

- Forming porous macro-pellets of the PCM material at optimum size and optimum pore volume.
- Encapsulating the macro-pellets of PCM in a higher melting temperature material, at low cost.

Relevance

Impact on CSP program

- The proposed concept has the capability to reduce the TES costs considerably and make LCOE costs of CSP plants competitive with fossil fuels
- Specific cost of thermal storage can be reduced by around 40%-70% compared to the conventional two tank sensible thermal energy storage

Phase I Objective (December 2010 to November 2011)

- Select economical salt mixtures for use with various CSP power plant cycles
- Identify economical methods to fabricate porous pellets
- Research encapsulation methods that can successfully encapsulate the PCMs in a high melting temperature material at low cost

Successful completion of the project will achieve the DOE Goal of TES Cost <$20 / kWh_{th}

Project Approach – Phase I

Task 1.0 Preparation of PCM pellets and coating

1.1 Fabrication of Porous PCM Pellets

- Selection of cost-effective high temperature PCMs
- Formation of macro porous pellets, with porosity to account for volumetric expansion

Milestones Achieved

- We have identified low cost PCMs in the operating temperature range required and are characterizing them for choosing the best economical and high energy storage material.
- Three different commercial methods that can produce porous PCM pellets are identified and pellets are fabricated.

Fabricated Porous Pellets of PCMs

Project Approach – Phase I

Task 1.0 Preparation of PCM pellets and coating

1.2 Encapsulation of PCM Pellets

- Encapsulating the PCM in a high melting temperature material
- Optimization of coating process for required shell thickness

Milestones Achieved

- We have tried three different low cost encapsulation techniques and developed a high temperature encapsulating mechanism

Encapsulated PCM Pellets using Method 1

Encapsulated PCM Pellets using Method 2

Project Approach – Phase I

Task 2.0 Characterization of PCM pellets

- Characterize important properties for optimization

Milestones Achieved

- Characterization of latent heat of the PCMs under consideration
- Additional equipment for characterizing other properties being procured


Hitachi-SEM


DSC


Simultaneous DSC/TGA


Dilatometer

Characterization Equipment

CERC Clean Energy Research Center

USF UNIVERSITY OF SOUTH FLORIDA

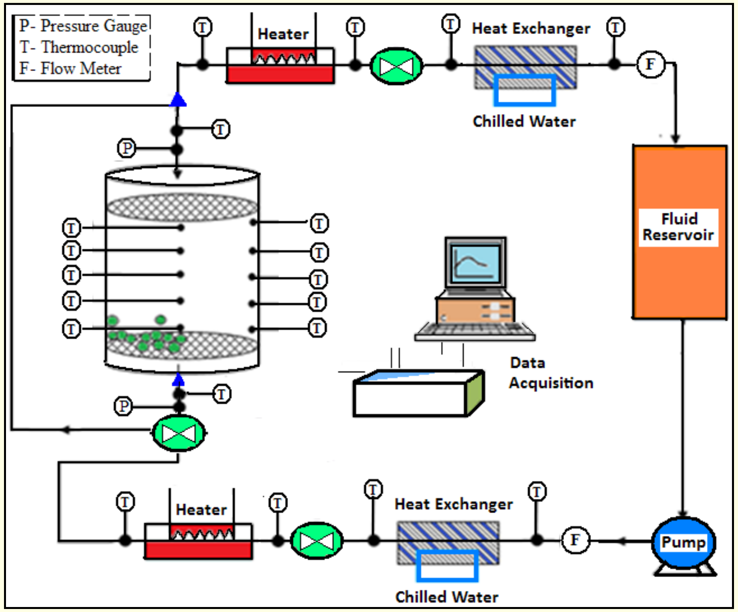
Project Approach – Phase I

Task 3.0 Testing of PCM pellets

- Analyze the thermal performance of the formed pellets under charging and discharging cycles

Milestones Achieved

- The test setup has been designed. Construction will follow.

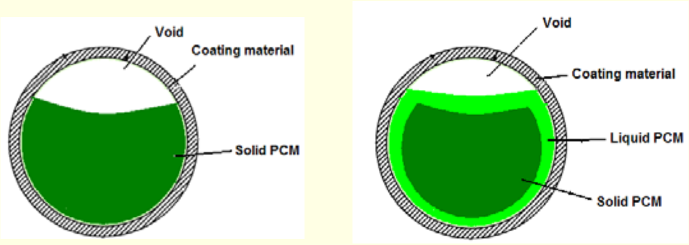


Test setup - Schematic

Project Approach – Phase I

Task 4.0 Numerical analysis of a PCM pellet

- To simulate heat transfer in a PCM capsule subjected to cyclic boundary conditions.
- To simulate the heat storage performance of a capsule.
- Volumetric expansion/contraction in the presence of void space is being simulated in this task.

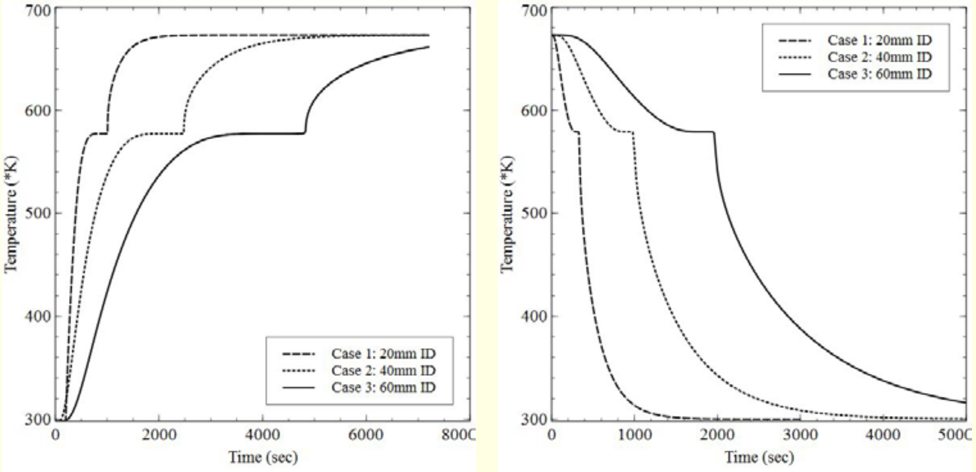


PCM (Solidified) PCM (Melting)

Solidification and melting in TES pellet are being simulated in this task

Milestones Achieved

- A numerical model to estimate the melting and solidification times of a single thermal energy storage (TES) capsule under different geometrical, heat transfer and material conditions has been developed.



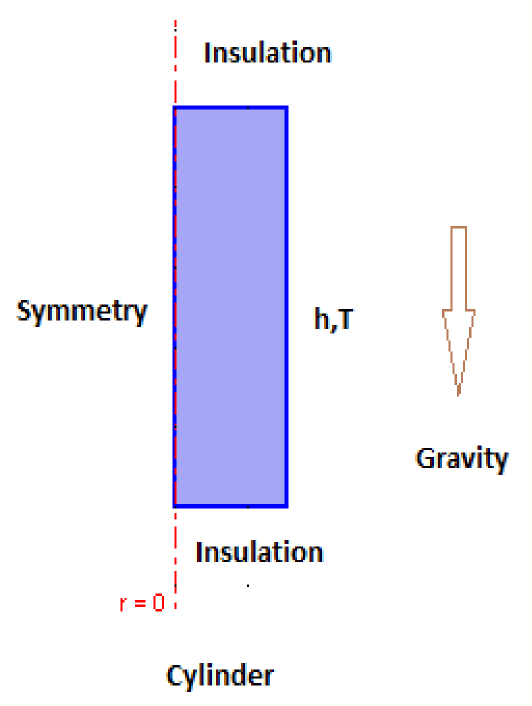
Melting and solidification profile for different PCM sphere diameters (T_{melt} = 579 K)

Project Approach – Phase I

Task 4.0 Numerical analysis of encapsulated PCM

Milestones Achieved (Cont'd)

- A numerical model has been developed that includes solid-liquid phase change and natural convection inside the molten/liquid PCM.
- The numerical model has been validated with published results from prior literature.
- The phase change behavior under different boundary conditions is currently being simulated.



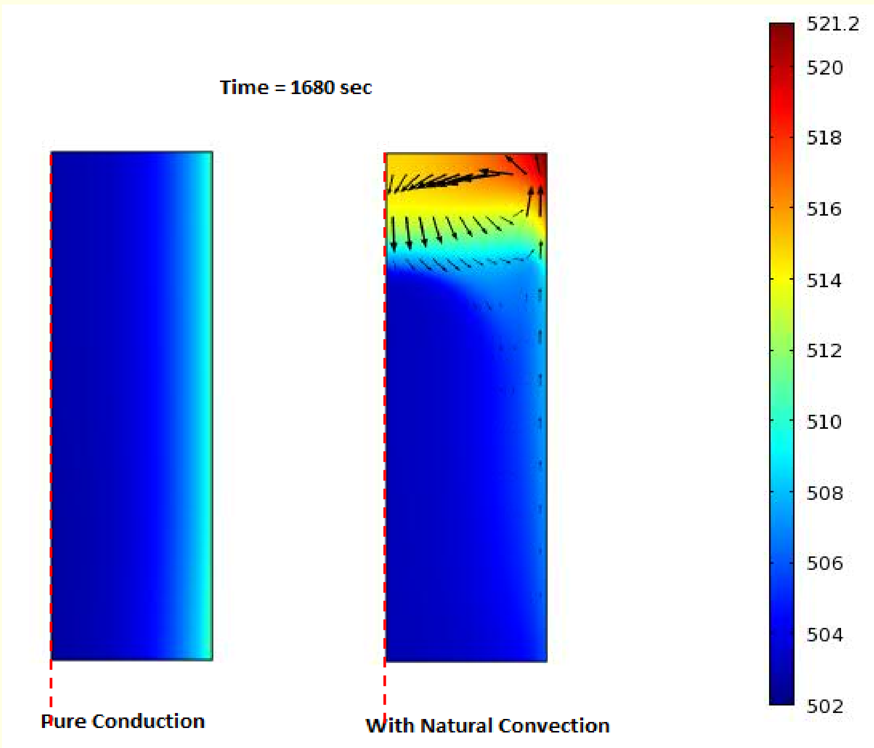
Simulation domain

Project Approach – Phase I

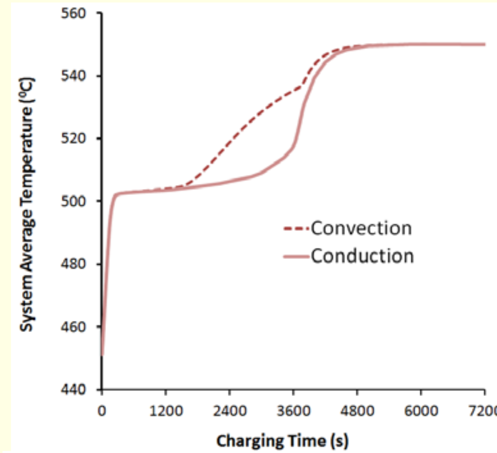
Task 4.0 Numerical analysis of encapsulated PCM

Milestones Achieved (Cont'd)

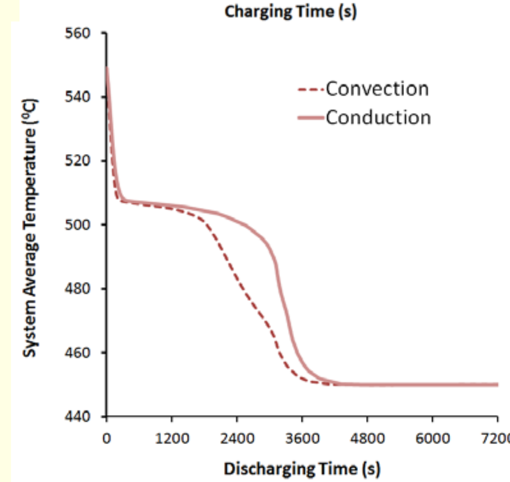
Temperature Profiles during Charging Mode



System Average Temperatures



Charging



Discharging

- Inclusion of natural convection is important to accurately predict transient heat transfer phenomena

Project Approach – Phase I

Task 5.0 Cost Analysis, Project Management and Reporting

- A detailed cost analysis, including breakdown of component, material, and labor costs, using the SAM model economic assumptions will be provided.
- Submission of reports, publications and presentations.

Milestones Achieved

- Quarterly reports submitted
- One conference paper on numerical work has been completed
- A journal paper will be submitted soon

Phase I Go - No Go Criteria: Test the developed encapsulated PCMs for 50 cycles

Future Work

Phase II – Engineering Design

- Detailed numerical modeling of the TES system
- Experimental studies to evaluate the heat transfer performance of a TES system and demonstrate the reliability of PCM pellets for 1000 cycles
- Design a pilot scale TES system for a 100 KW_e solar power plant based on the results

Phase III – Prototype Build, Test and Evaluation

- Fabricate a storage system for a 100 kW_e solar power plant
- Test the TES system under actual conditions in integration with a power plant system to be built at USF
- Use the results to design an optimum configuration of a TES system for baseload power generation

Thank You
Questions ?