Using Encapsulated Phase Change Material for Thermal Energy Storage for Baseload Concentrating Solar Power Plants

Project Review Slides
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Concept and Component Feasibility Studies
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terrafore
Project Summary
Using Encapsulated Phase Change Material for Thermal Energy Storage for Baseload Concentrating Solar Power Plants

Partners
• **Project lead:** Terrafore, inc.
• **Team Members:**
  • Southwest Research Institute, Texas
  • Dr. H. Venkatasetty
  • Dr. J.E. Garay
  • University of California, Riverside (UCR),

Objective
• Demonstrate encapsulating Phase Change Material (PCM) will improve energy density and increase heat transfer area to sustain heat rates in a baseload solar power plant.

Barriers Addressed
• Two major barriers to encapsulating high melting (>300 °C) PCM are:
  • Prevent the rupturing of the encapsulating shell (bead) when the core PCM melts and the volume increases
  • Identify shell material that will be thermally stable after several thousands of freeze-thaw cycles and is compatible with both the heat transfer fluid and the PCM
Project Phases

Phase 1, Year 1, Technology Feasibility

Go/ No-Go Criteria:

Economical shell material must be successfully tested for desired properties and selected salt material must be effectively encapsulated in a laboratory.

Phase 2, Year 2, Engineering Model Testing

Produce several kilos of the material.

Phase 3, Year 3, Prototype Testing

Conduct experiments with a full-scale design.
Phase I Technical Approach

• Formulation development
  – Identification of potential shell systems
  – Thermal compatibility with nitrate salts

• Process development
  – Application of shell material to core
  – Process settings and evaluation

• Sample preparation
  – Preparation of nitrate salt prills
  – Prepare samples with varying shell systems

• Analysis
  – Thermal analysis
  – Optical/electron microscopy
Phase 1, Year 1, Technology Feasibility

Project Tasks

• Identify candidate shell materials for encapsulating a commonly used inorganic PCM

• Develop encapsulation technique to demonstrate shell can accommodate change in volume of PCM inside the shell.
  – Conduct laboratory scale experiments for encapsulation using two methods.

• Demonstrate materials are thermally stable to multiple freeze-thaw cycles and temperature up to 550C
  – Validate the technology concept in a laboratory setting; produce 15kg of encapsulated beads
  – Test for performance with selected compatible heat transfer fluid

• Develop analytical model of encapsulated TES in a CSP plant
Project Objectives

• Encapsulation of phase change material
• Core material: nitrate salt and/or mixture
• Shell material: metal, salt, clay
• Stability
  – Remain intact at 450-550ºC
  – >5000 heating/cooling cycles
Tested Concepts

Coating:
- Binder
- Shell
- Polymer for elasticity

Sacrificial Layer:
- Polymer for void
Two Proposed Encapsulatation Methods

1) Void

- Heat <300 C
- Seal Outer Layer
- Void for thermal expansion

1) Elastic

- Heat <300 C
- Apply Sealant Or Sinter
- Sealed metal coating Or Sintered metal particles

- Agglomerated metal particles

Inorganic Layer
Organic Sacrificial Layer
Inorganic/Organic Composite
Organic Layer
Porous Layer
Seal
Encapsulation Process: Fluid Bed Coating

- Nitrate Salt Beads
- Dissolved Shell Material
- AIR
Solar Power Tower with Encapsulated PCM Thermal Storage

A Thermal Energy Storage System Configuration
# Matrix of Technical Risks, Mitigation & Probability of Success

<table>
<thead>
<tr>
<th>Risk</th>
<th>Likelihood/Project Impact</th>
<th>Control Plan</th>
<th>Probability of Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatible shell material with good thermal stability difficult to find</td>
<td>Med High</td>
<td>PH1: Intense search for material. Enlist experts</td>
<td>There are numerous materials that have been tested with commonly used PCMs.</td>
</tr>
<tr>
<td>Polymeric material does not decompose as hypothesized</td>
<td>Med High</td>
<td>PH1: Several formulations and mixing methods will be tried</td>
<td>These methods have been used for other purposes.</td>
</tr>
<tr>
<td>Thermal cycling of materials results in rupture</td>
<td>High High</td>
<td>Select two or three materials with different CTE's. Vary process conditions.</td>
<td>Conduct design of experiments and identify parameters effecting stability</td>
</tr>
<tr>
<td>Single tank design is difficult for PCM</td>
<td>Med Low</td>
<td>Identify and quantify issues and seek alternate methods; evaluate cost impact</td>
<td>Stratification has been experimented successfully. Engineering techniques exists</td>
</tr>
</tbody>
</table>
RESULTS
PCM Capsule System

Materials

Salt
Using commercially available KNO3 prills

Four different Shell Materials
Selected a mixture of metal and clay

Three different binders
Selected a commercially available organic binder

Identified six candidate polymer sacrificial material
Testing with three commercially available materials

Preparation: Composition & Heat Treatment Parameters

Fluid bed coating composition
Several combinations of shell thickness, binder percent, polymer thickness tested

Heat Treatment
Various heat rates and temperature in presence of air, N2

Over 100 different capsule systems (compositions) produced & tested in laboratory. Conducted microscopy analysis before and after coating
Initial Results

25 C

Single shell with polymer
Notice shell breakage
(no sacrificial polymer)

300 C

Composite shell with polymer
Better performance
(no sacrificial polymer)

Optimized Composite shell with polymer
Good performance
(no sacrificial polymer)

Optimized Composite shell with polymer & sacrificial layer
Notice void
Sacrificial Layer

250 C
48 hrs.
Sacrificial Layer Removed

250 C
48 hrs.
Sacrificial Layer Stability

Most of the polymer degraded after 2 hours.
Removal of Sacrificial Layer

Loss of sacrificial layer

SALT

Heat <300 C
Shell Porosity – Example Formulation 1

Surface w/o sacr. 50K X

Cross Section w/o sacr. 512X

Surface w/o sacr. 100K X

Cross Section w/o sacr. 25K X
Shell Porosity – Example Formulation 2

Surface w/o sacr. 5K X

Cross Section w/o sacr. 500X

Surface w/o sacr. 50K X

Cross Section w/o sacr. 50K X
Effect of void on heat transfer

Worst Case for heat transfer
• Salt freezes away from the shell creating a void

Best Case for heat transfer
• As salt solidifies a void is left in the center

Thermal conductivity of gap calculated using Euken Approximation for low density gas for 15% volume change
a) Brown: NO and
b) Blue: a gas with same mol wt weight as sodium nitrate
Shell Stress Model

Radial Stress vs Sphere diameter
0.1, 1, & 10 C/min heat rate

Radial Stress vs Modulus (Pa)
0.1, 1, & 10 C/min heat rate

Radial Stress Coeff of linear expansion
10 C/min heat rate

Stress required to fracture coating
vs Flaw size
Near term mini-milestones

- Nov. - Materials identification and acquisition
- Jan. - Initial encapsulated samples
- Feb - Refine shell & binder material system
- Mar - Sacrificial polymer experiments
- Apr - Heat treatment of capsule (pre-melt)
- May - Refinement of shell material system
- Jun - Heat treatment with various polymers
- Jul - Selection of system
- Aug - Formulation scale-up – 25kg batch
Future Plans

• Complete shell system optimization
  – Material composition
  – Optimize heat treatment

• Prepare a batch of capsules for Phase 1 tests

• Develop Models
  – Develop a model for preparation of capsules
  – Develop a plant simulation model with encapsulated storage

• Conduct compatibility tests with heat transfer fluid

• Setup benchtop prototype TES test system
  – Design & develop TES prototype
  – Conduct tests
Summary

- Optimizing Shell System – composition of shell, binder, sacrificial polymer, heat treatment, & polymer concentration

**Shell Material**
- Tested several shell material systems with varying composition
- Selected a combination of two different materials
- Optimizing composition based on heat treatment

**Binder**
- Tests with various concentrations of three different organic binder
- Selected a commercially available organic binder
- Optimizing concentration based on heat treatment

**Sacrificial Polymers**
- Identified several polymer candidates
- Conducting tests with three polymers by varying composition and heat rates
- Noticed a void (10%) all around the shell (first heat treatment, pre-melt)

- Developing first order models for heat transfer and stress on shell due to thermal effects and initial flaw size on shell