

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

Project Review Slides

May 18, 2011

Department Of Energy

Research and Development

Concept and Component Feasibility Studies

Project Number DE-EE0003589

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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. Venkatesetty
Dr. J.E.Garay
 - University of California, Riverside (UCR),

Status/ Timeline

- Kick-off date: October 2010
- Phase I - Prove technology is feasible

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 ($>300\text{ }^{\circ}\text{C}$) 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

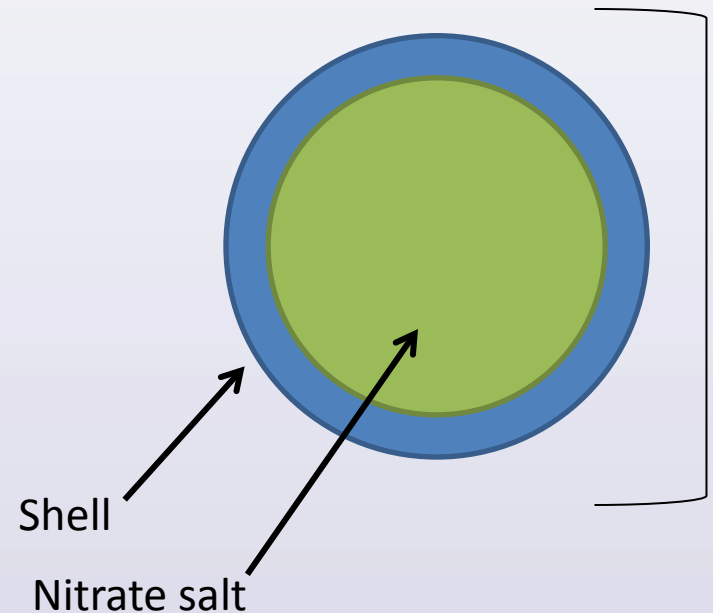
Phase 1, Year 1, Technology Feasibility

Project Tasks

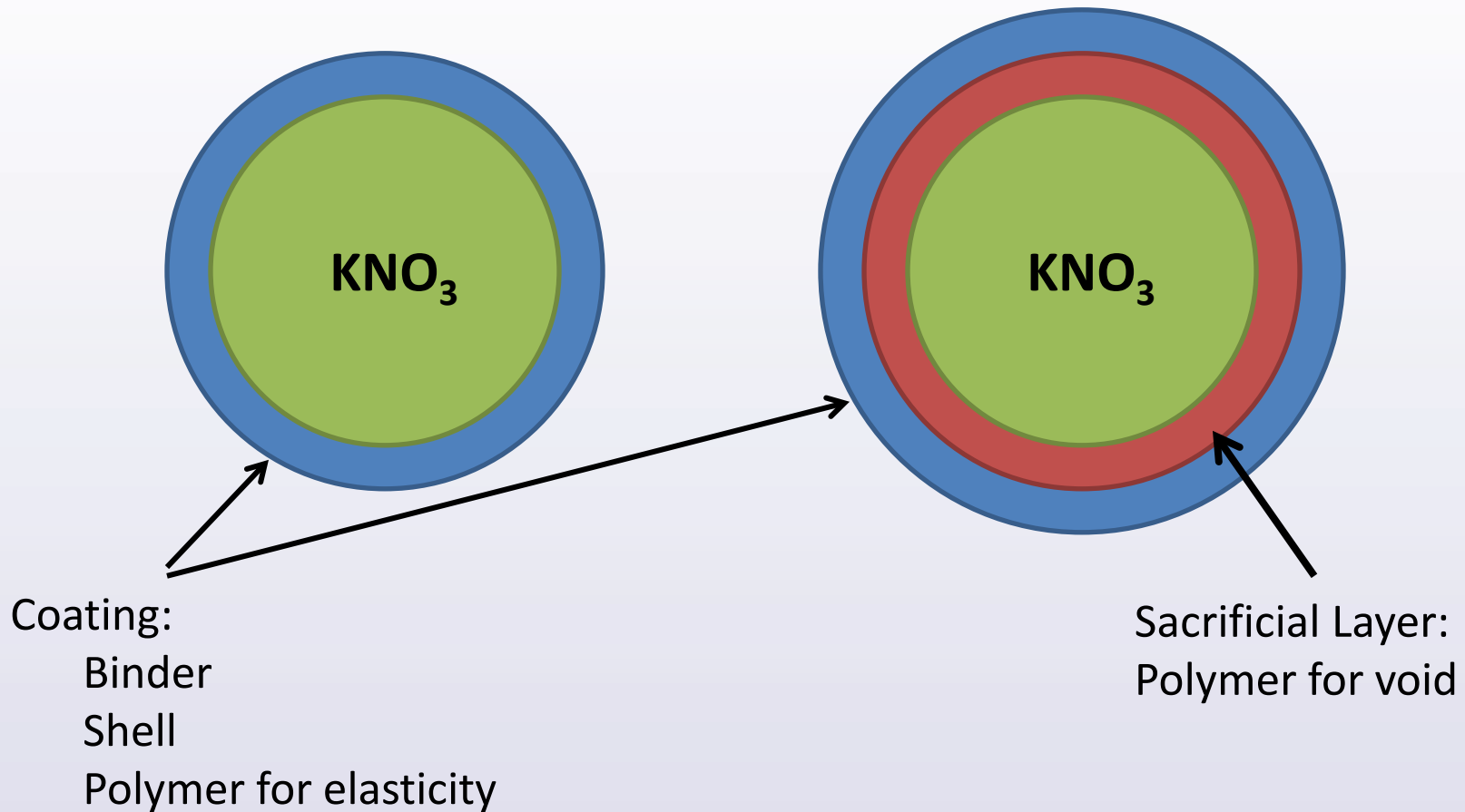
- Identify candidate shell materials for encapsulating a commonly used inorganic PCM
- Develop encapsulation technique to demonstrate shell can accommodate change in volume of PCM inside the shell.
 - Conduct laboratory scale experiments for encapsulation using two methods.
- Demonstrate materials are 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 450-550°C
 - >5000 heating/cooling cycles

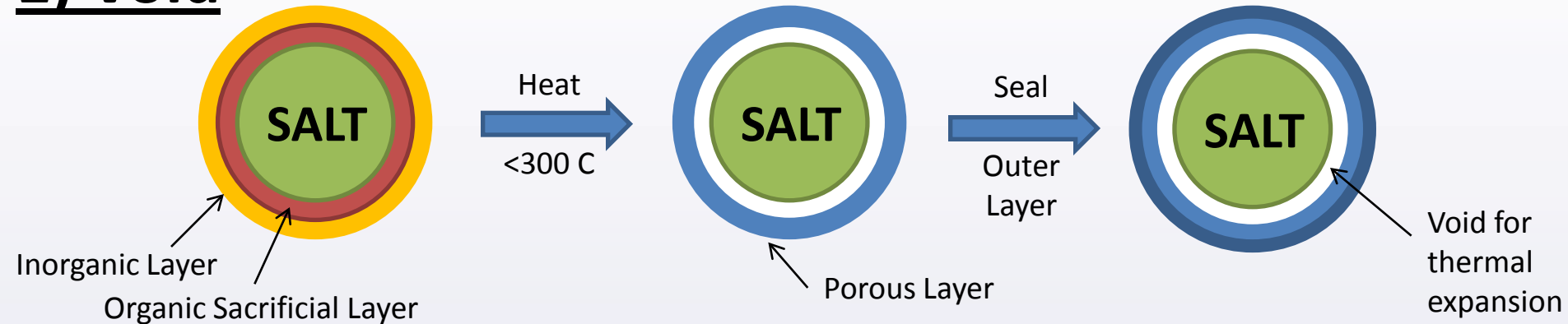


Tested Concepts

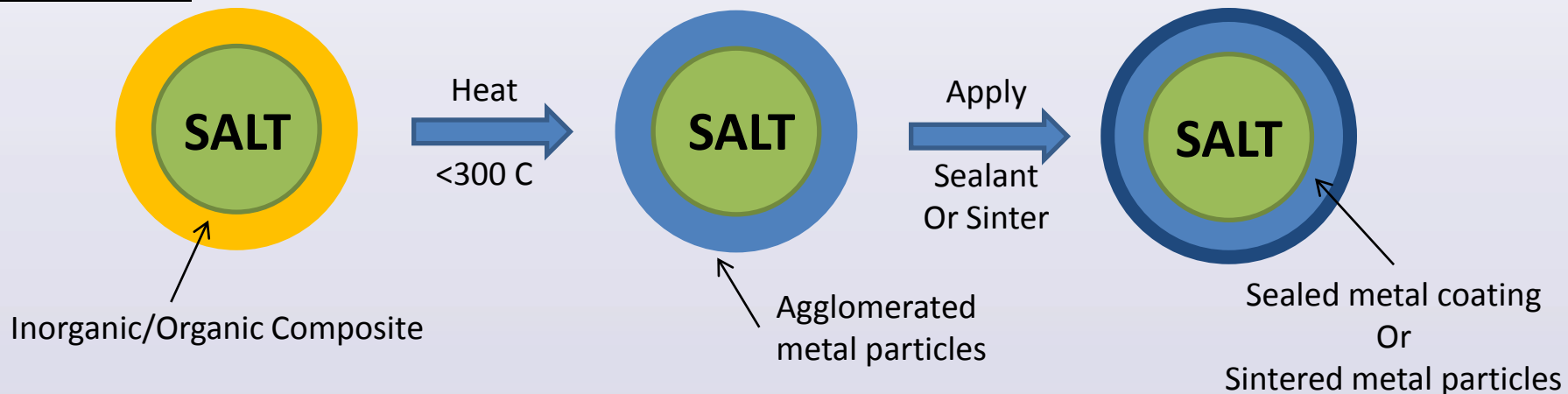


Two Proposed Encapsulation Methods

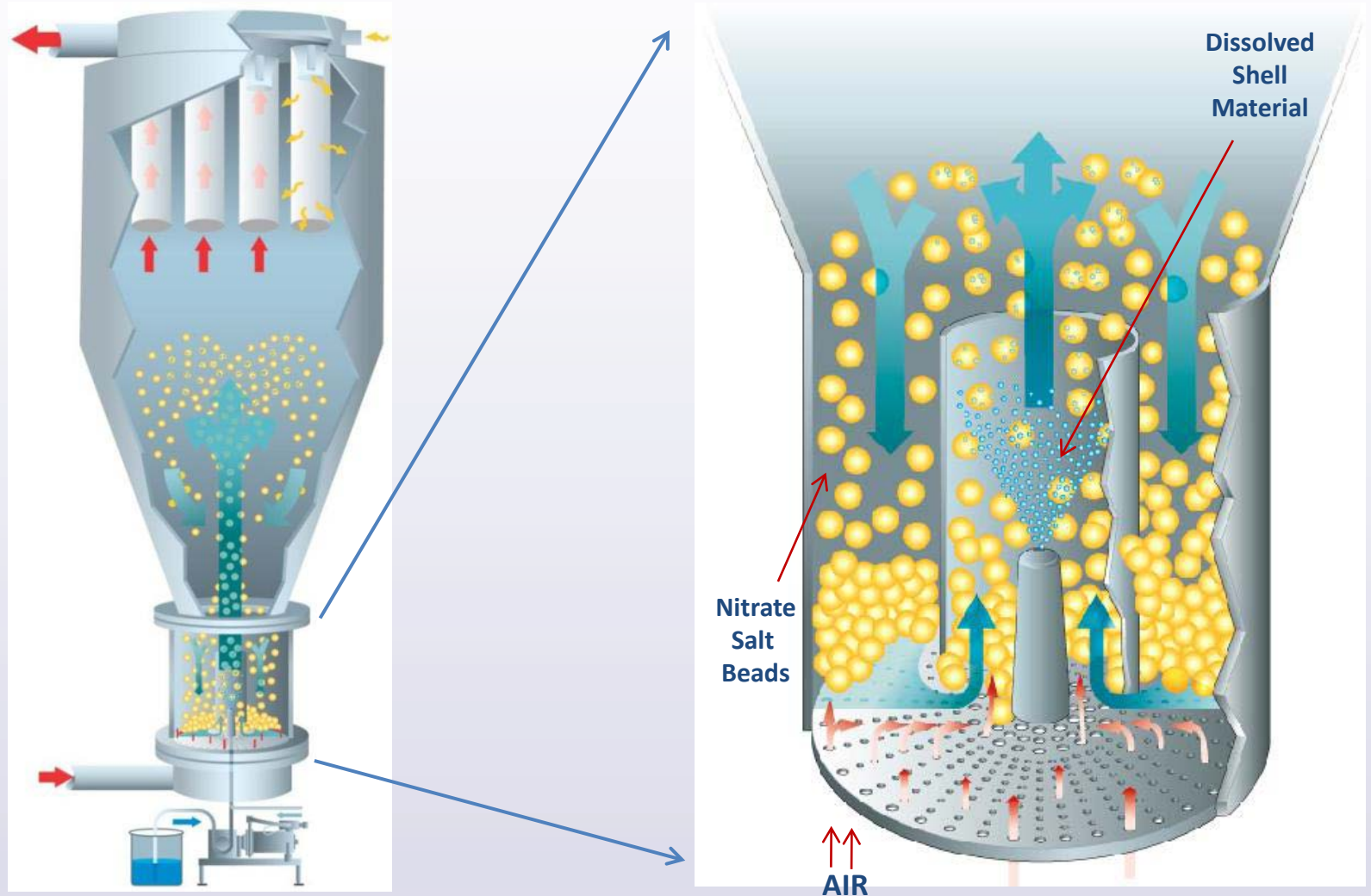
1) Void



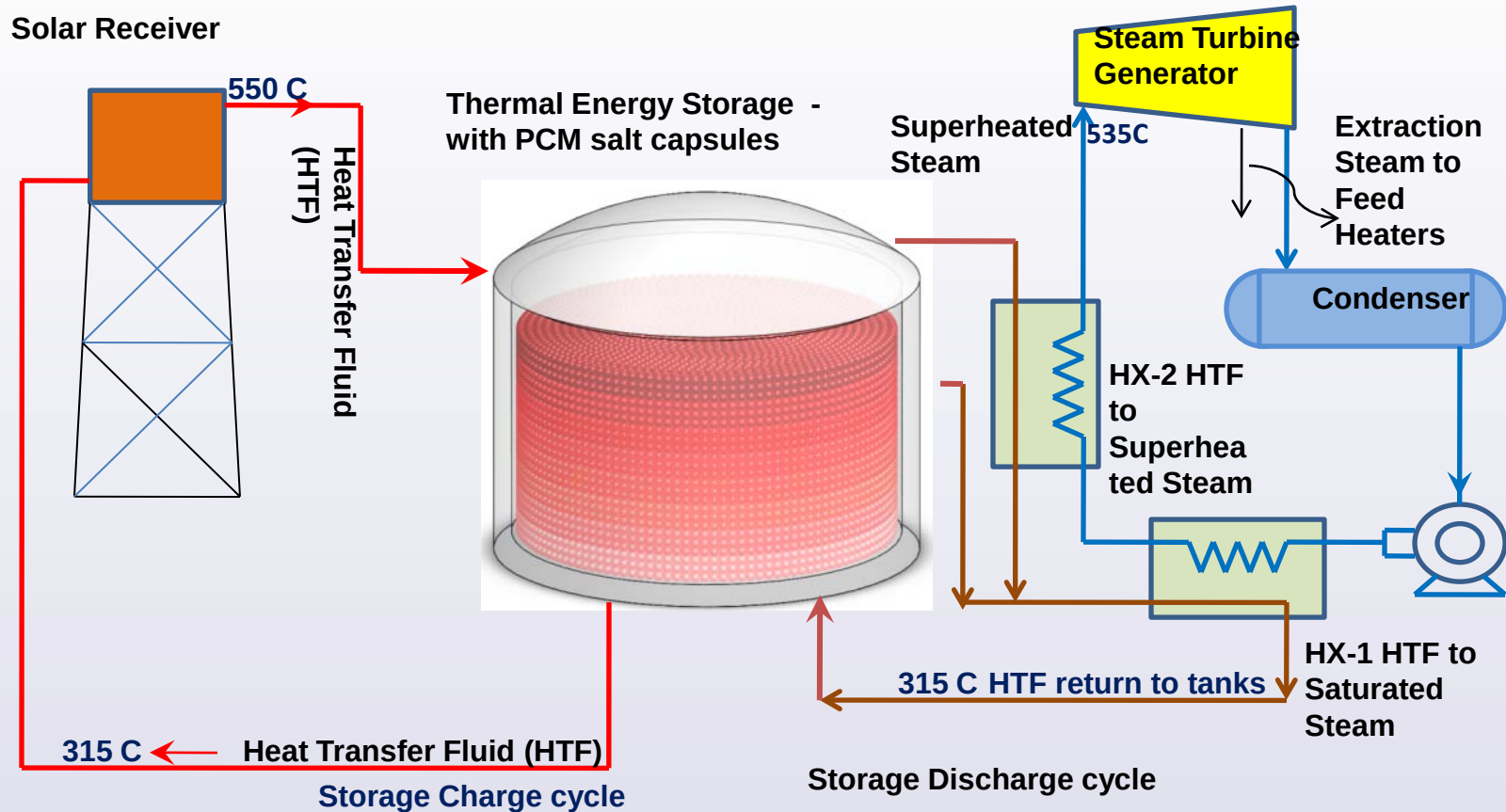
1) Elastic



Encapsulation Process: Fluid Bed Coating



Solar Power Tower with Encapsulated PCM Thermal Storage



A Thermal Energy Storage System Configuration

Matrix of Technical Risks, Mitigation & Probability of Success

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

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

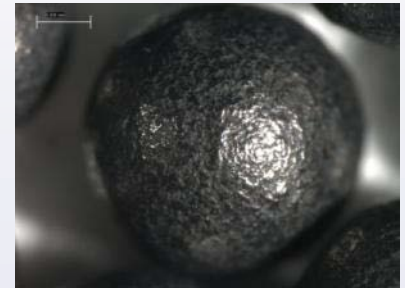
Fluid bed coating composition

Several combinations of shell thickness, binder percent, polymer thickness tested

Heat Treatment

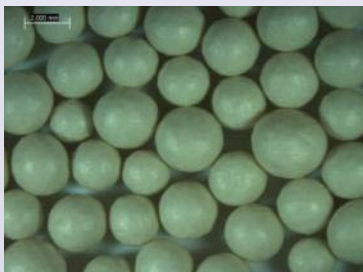
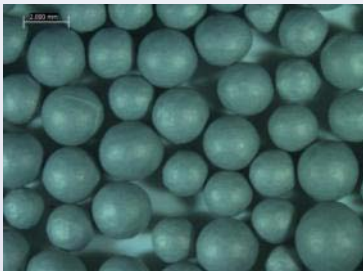
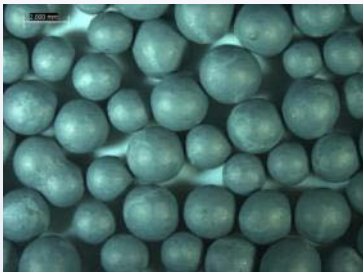
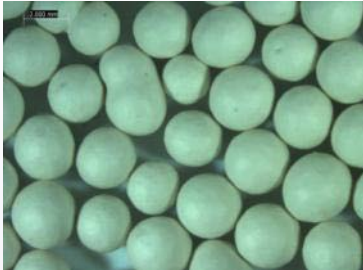
Various heat rates and temperature in presence of air, N₂

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

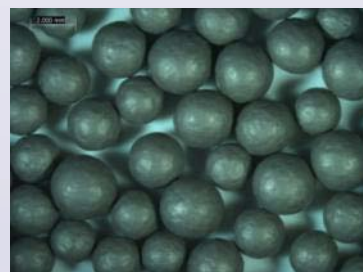
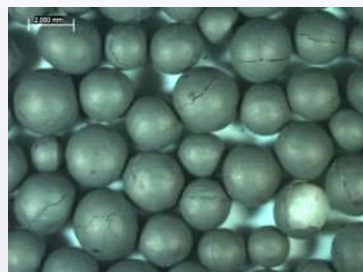


Initial Results

25 C



300 C



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

Composite shell with
polymer
Better performance
(no sacrificial polymer)

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

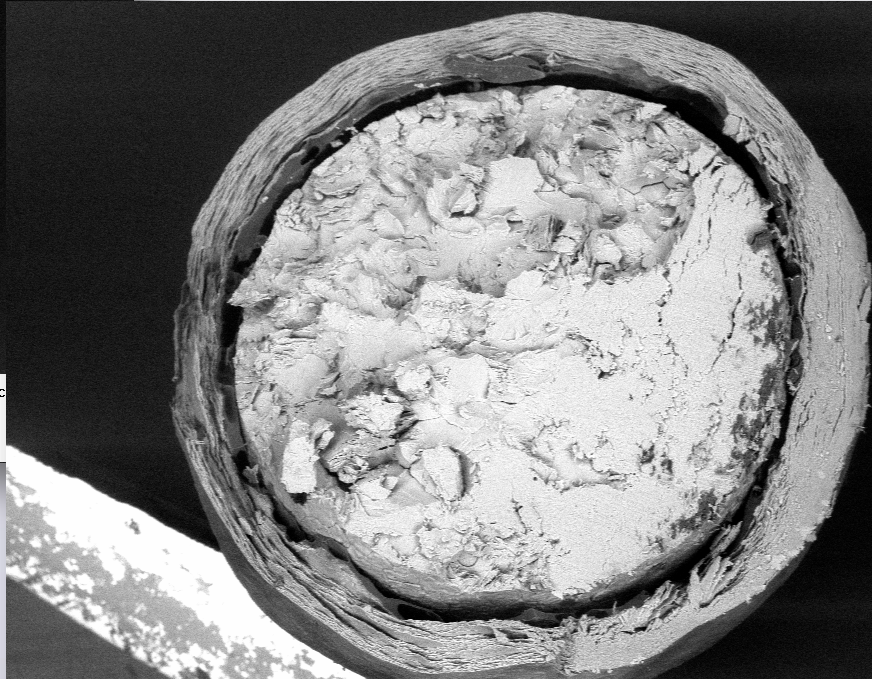
Optimized Composite shell with
polymer & sacrificial layer
Notice void

Sacrificial Layer



EHT = 20.00 kV Signal A = QBSD Mag = 100 X WD = 7.5 mm Peltier Temp = 20.0 °C
Chamber = 100 Pa Date : 6 May 2011 Time : 13:28:15
User Name = JOXLEY File Name = 15994 p50 xsec before_058.tif

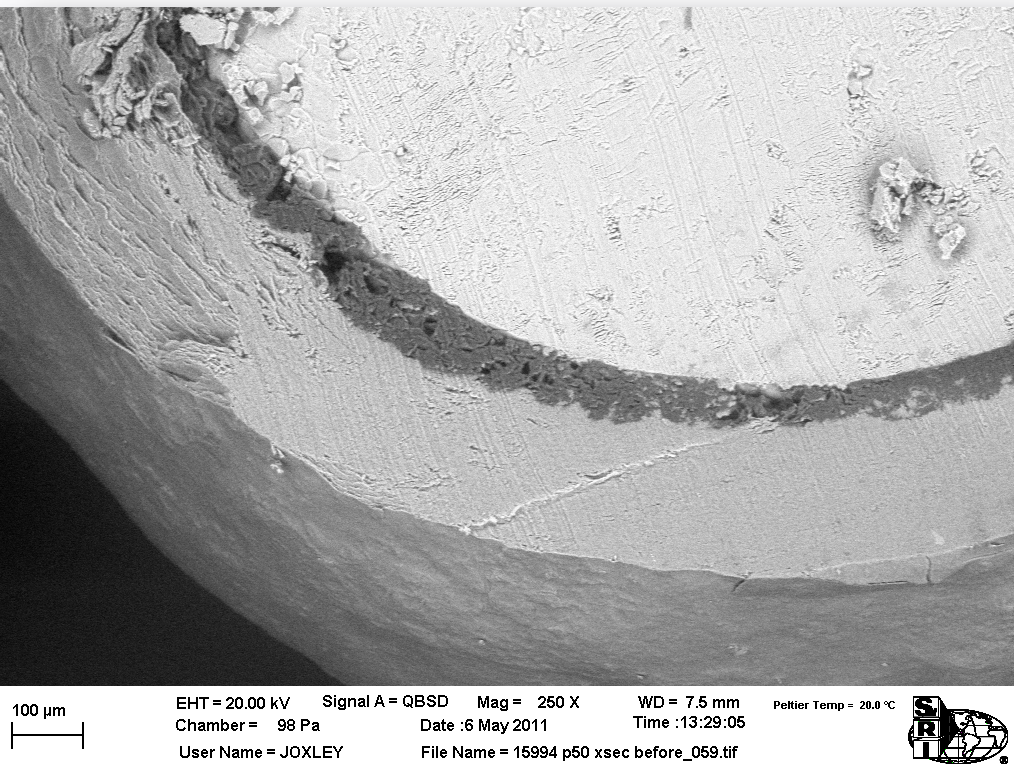
250 C
48 hrs.



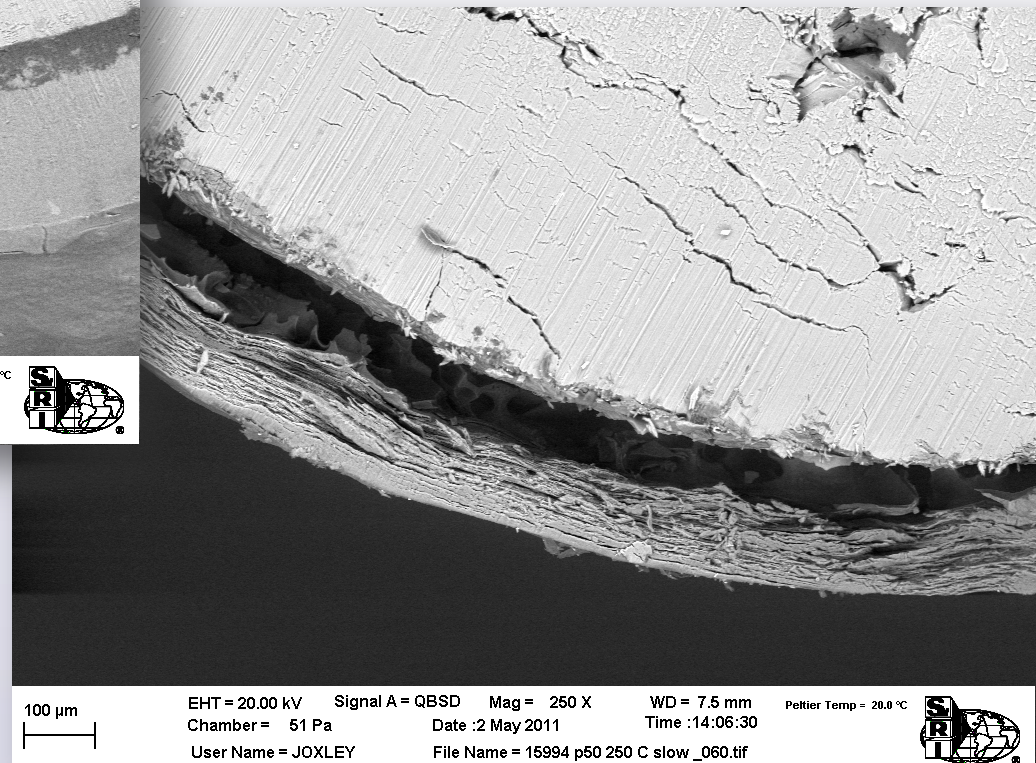
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Chamber = 52 Pa Date : 2 May 2011 Time : 14:00:35
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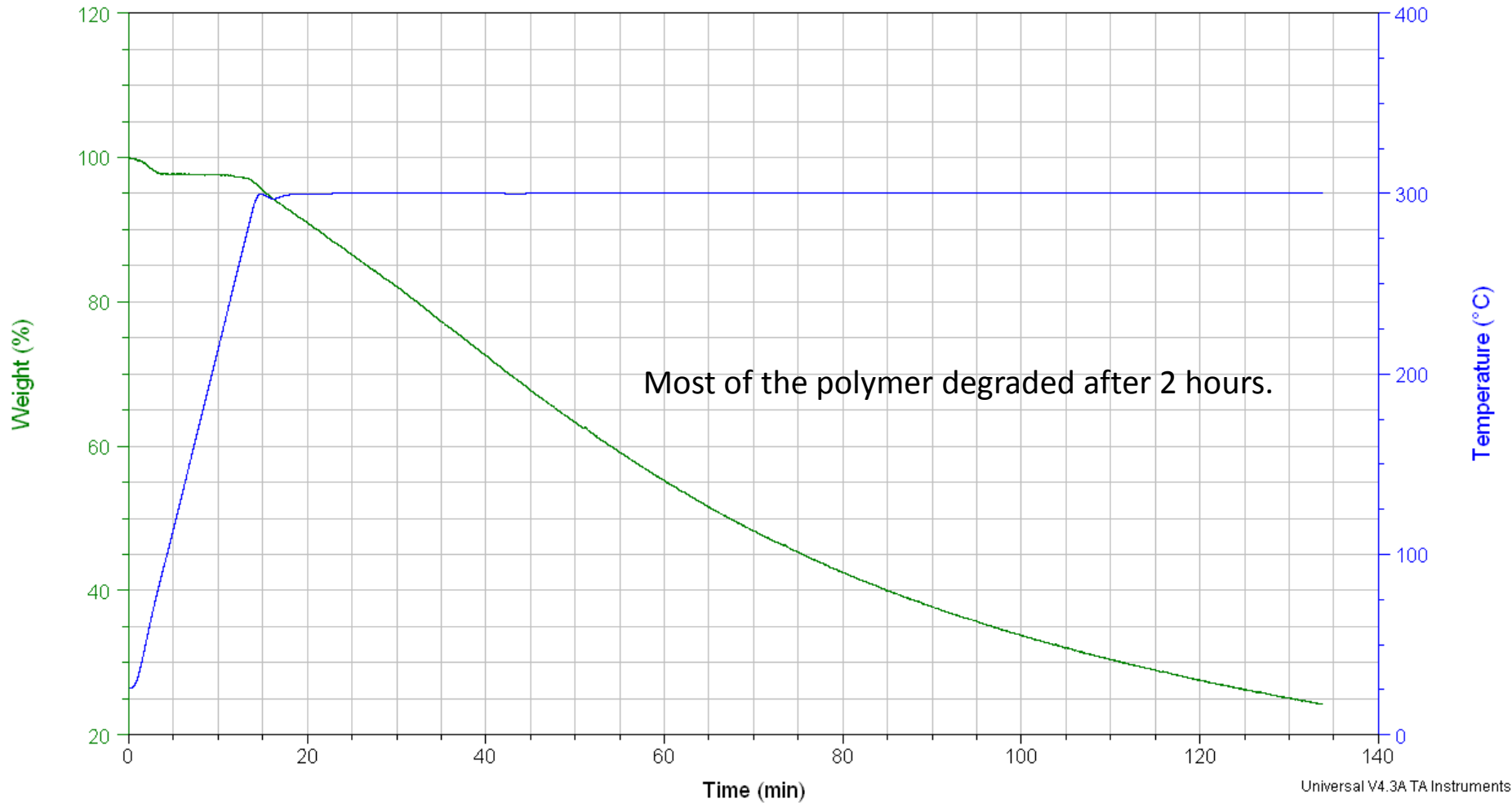
Sacrificial Layer Removed



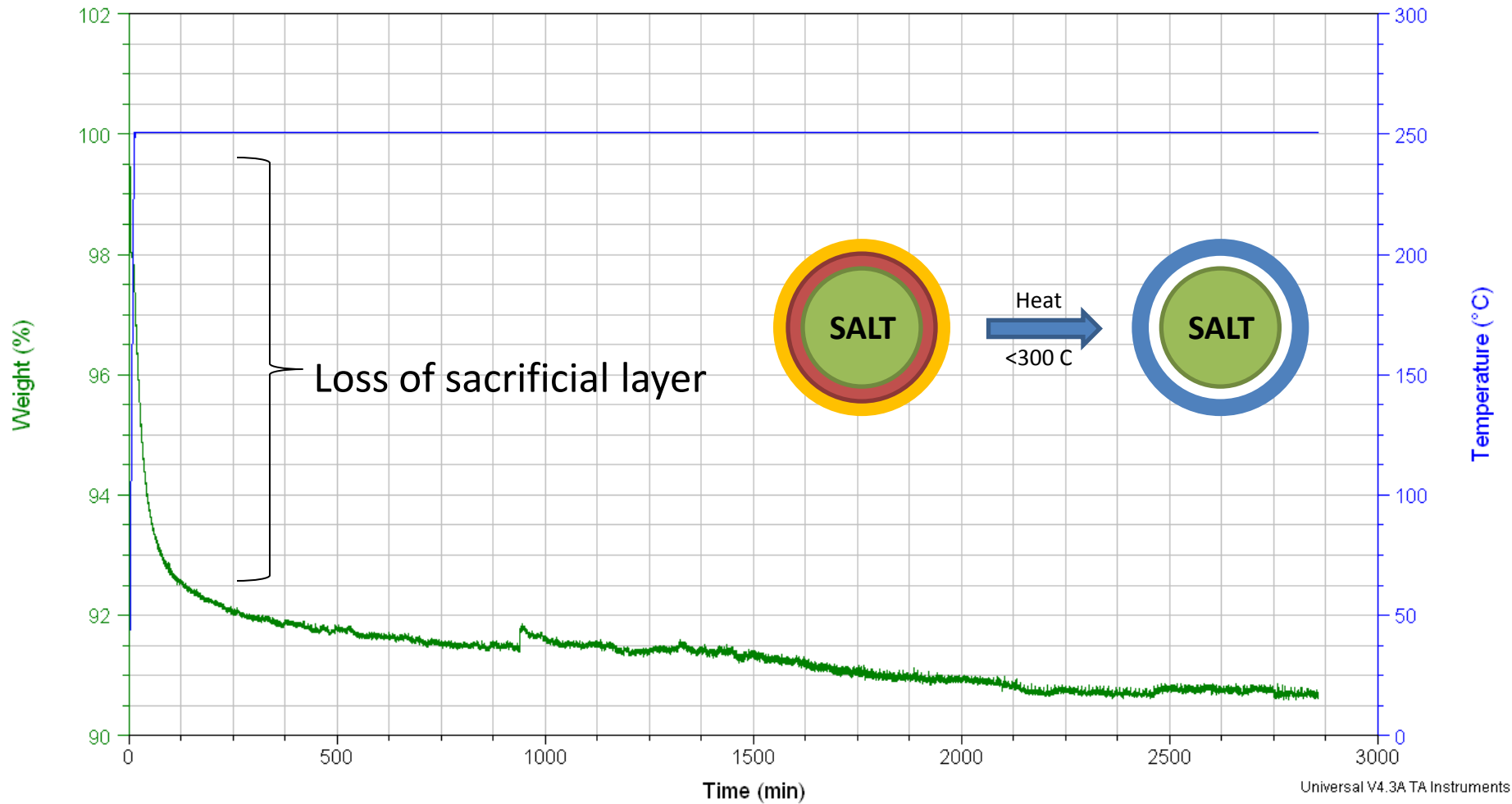
250 C
48 hrs.



Sacrificial Layer Stability

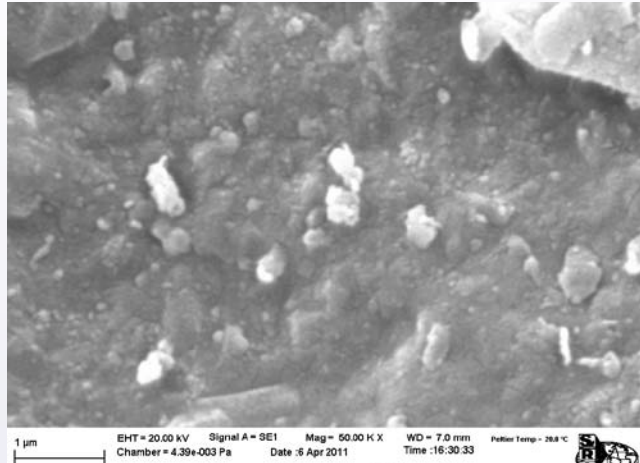


Removal of Sacrificial Layer

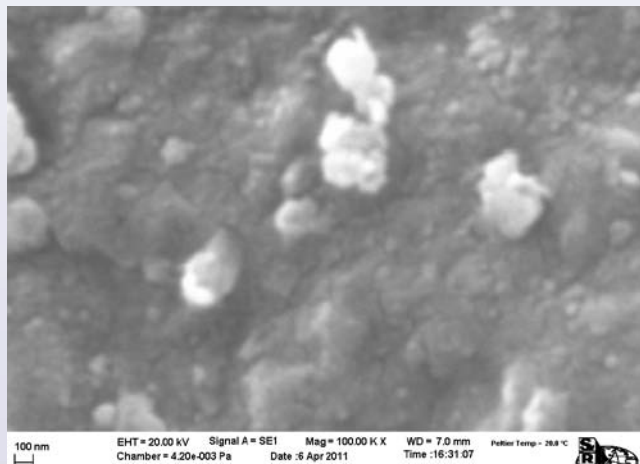
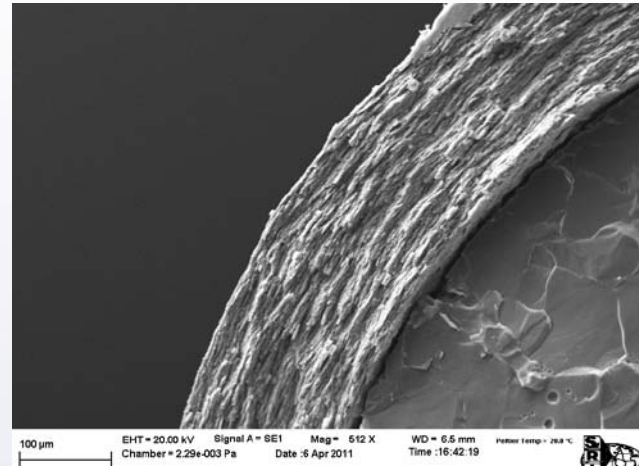


Shell Porosity – Example Formulation 1

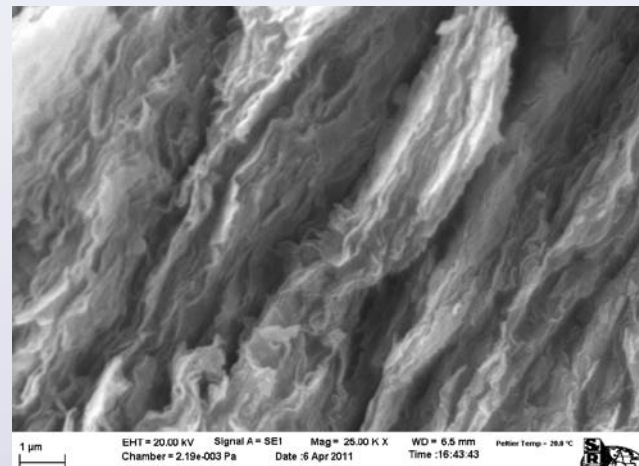
Surface w/o sacr. 50K X



Cross Section w/o sacr. 512X



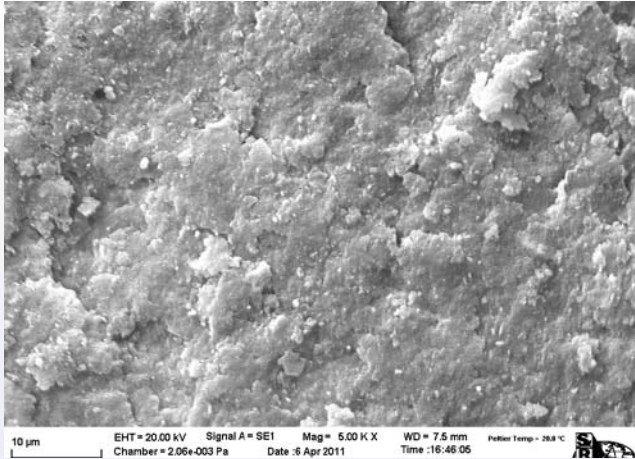
Surface w/o sacr. 100K X



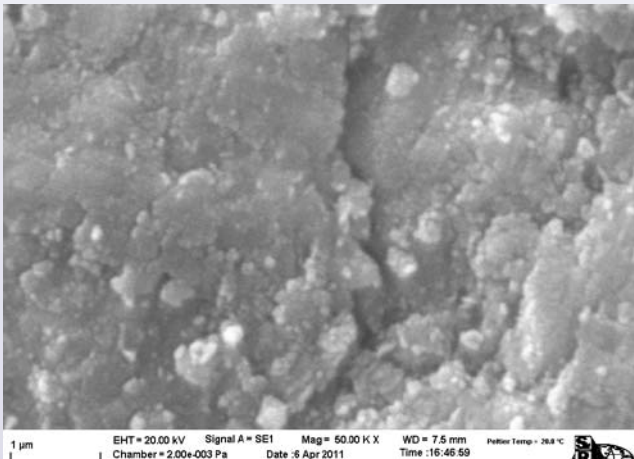
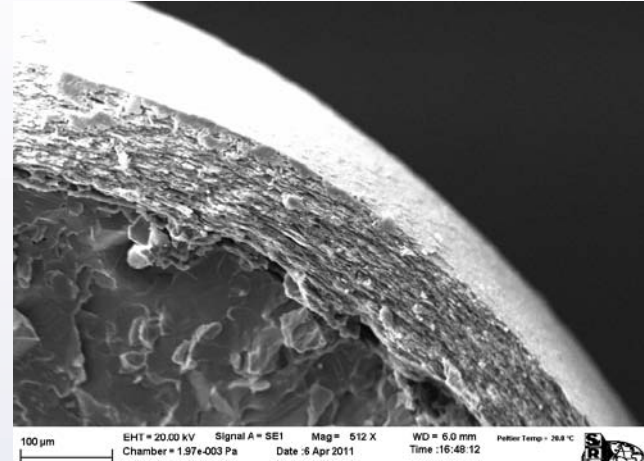
Cross Section w/o sacr. 25K X

Shell Porosity – Example Formulation 2

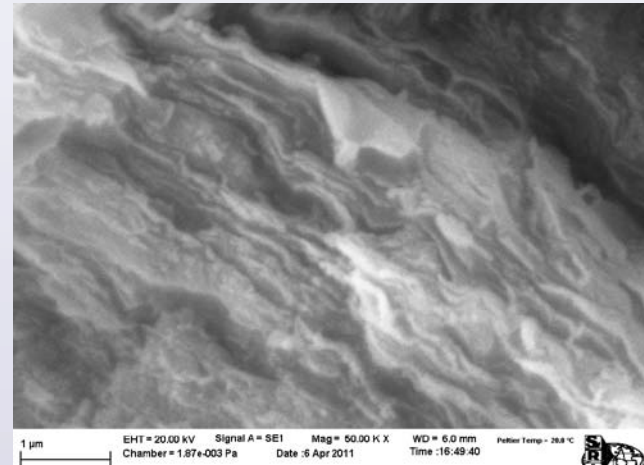
Surface w/o sacr. 5K X



Cross Section w/o sacr. 500X

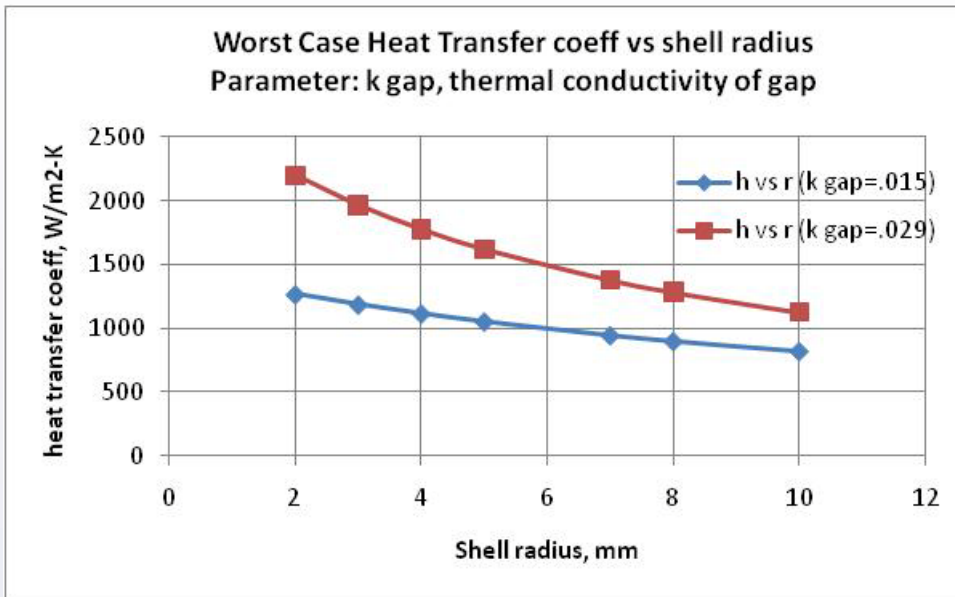


Surface w/o sacr. 50K X



Cross Section w/o sacr 50K X

Effect of void on heat transfer



Worst Case for heat transfer

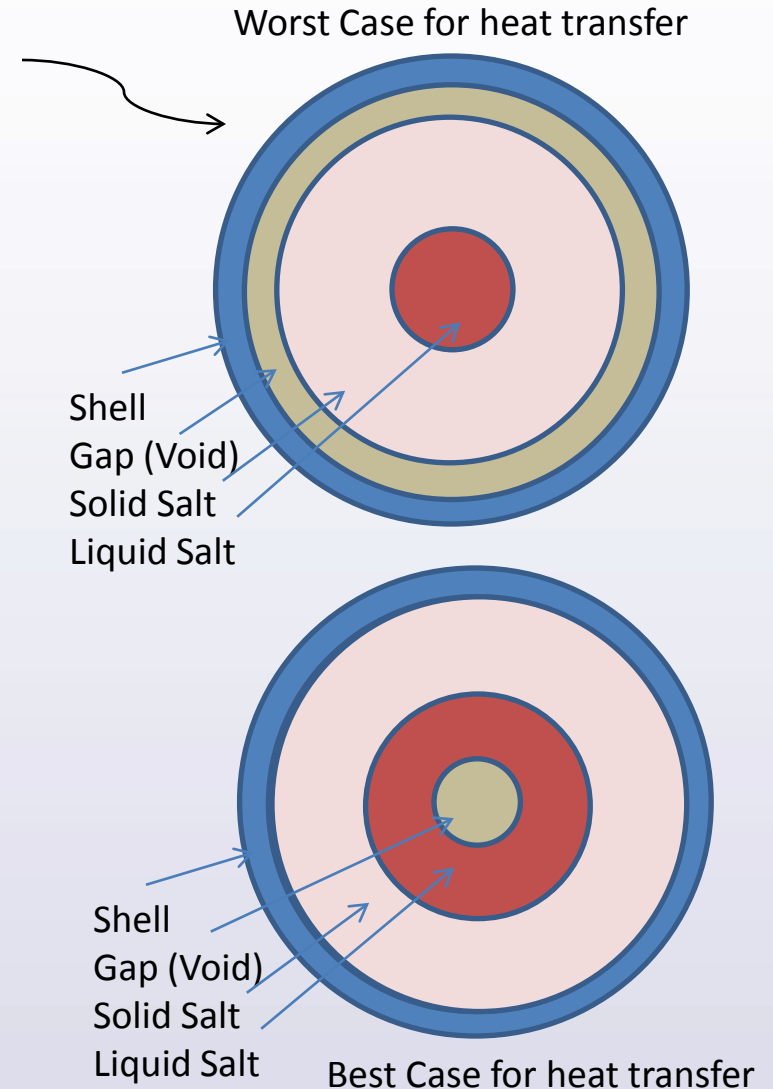
- Salt freezes away from the shell creating a void

Best Case for heat transfer

- As salt solidifies a void is left in the center

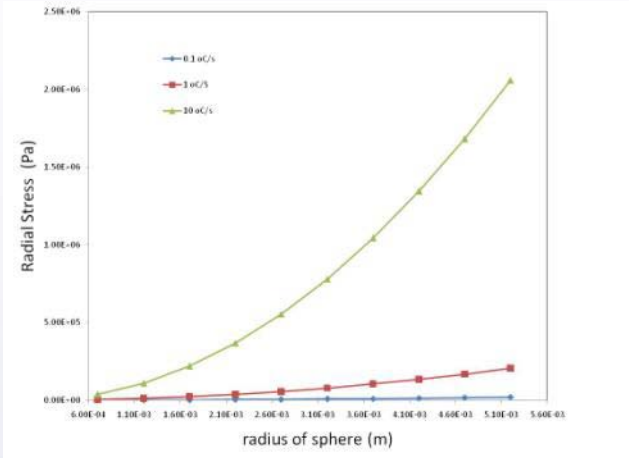
Thermal conductivity of gap calculated using Eucken Approximation for low density gas for 15% volume change

- Brown: NO and
- Blue: a gas with same mol wt weight as sodium nitrate

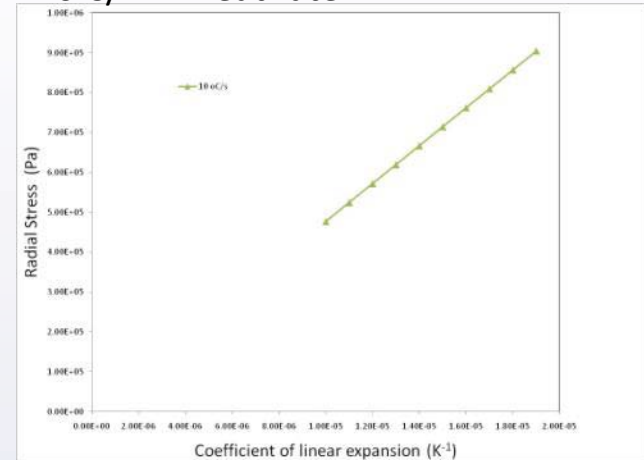


Shell Stress Model

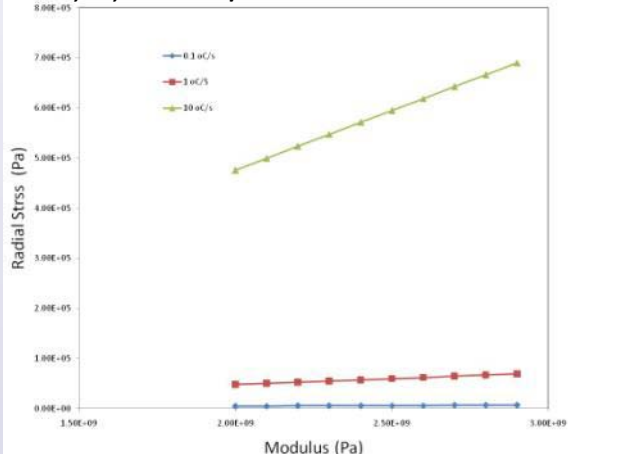
Radial Stress vs Sphere diameter
0.1, 1, & 10 C/min heat rate



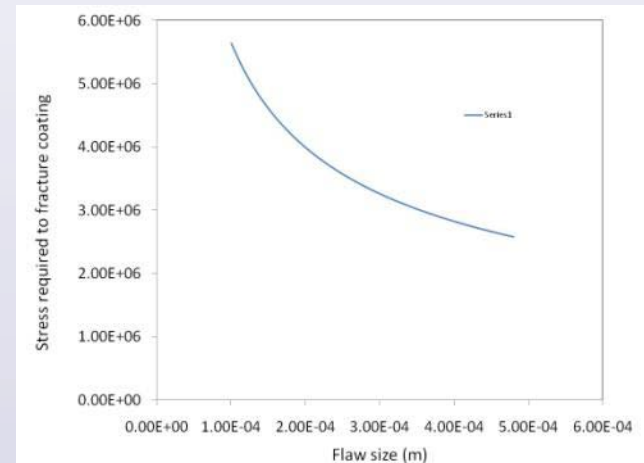
Radial Stress Coeff of linear expansion
10 C/min heat rate



Radial Stress vs Modulus (Pa)
0.1, 1, & 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