Water-Based Phase Change Material Heat Exchanger Development

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Overview

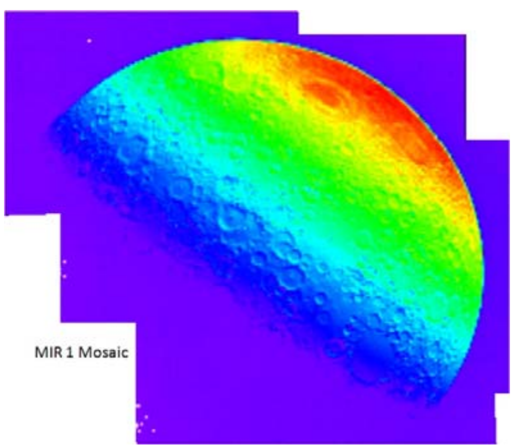
- Why use Phase Change Material Heat Exchanger's (PCM HX's)?
- Prior PCM HX Development and Testing
- Copper HX Coupon Design and Testing
- Microgravity Flight Experiment
- Future Water-Based PCM HX Designs

WHY PCM'S?

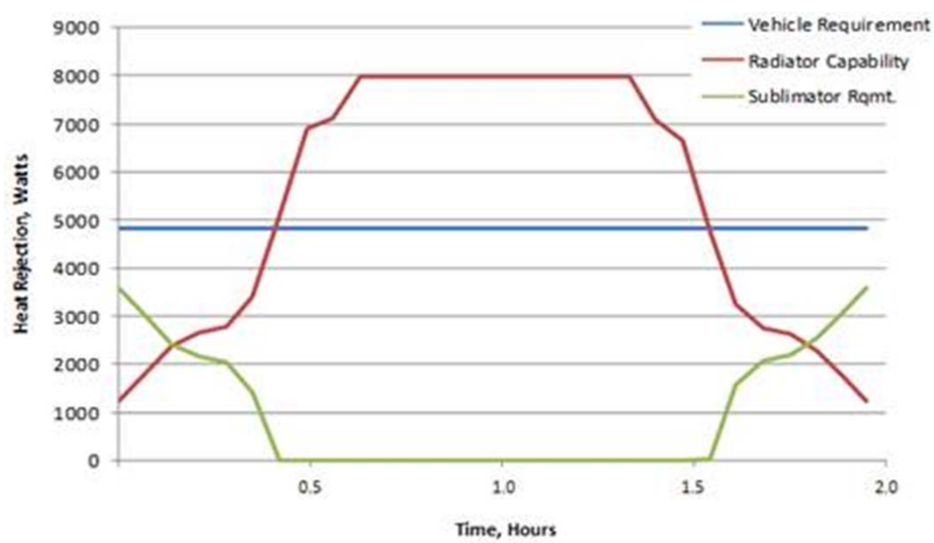
Why Use PCM HX's

- In cyclical heat load environments, a Supplemental Heat Rejection Device (SHReD) is required
  - Typically, accomplished through evaporators, sublimators, or Phase Change Material Heat Exchangers (PCM HX)
  - PCM's act a thermal battery and do not use a consumable
- Wax PCM is baseline for the Orion Spacecraft, but water is being investigated
  - Water has significantly higher latent heat of fusion than wax (333 kJ/kg vs. 163 kJ/kg)
  - Significant mass and volume savings possible

Problem: Water expands ~10% when frozen



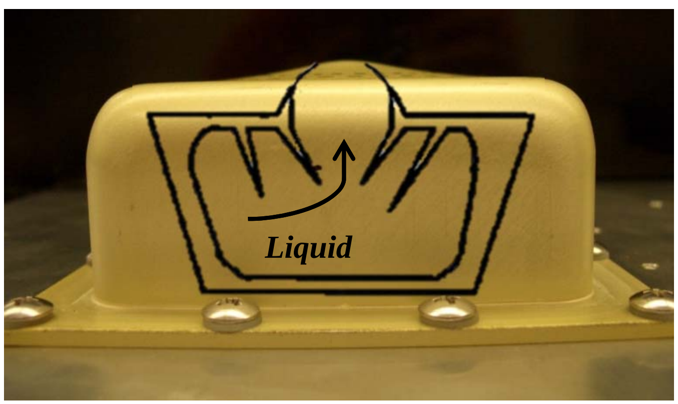
LCROSS IR Image of Lunar Surface

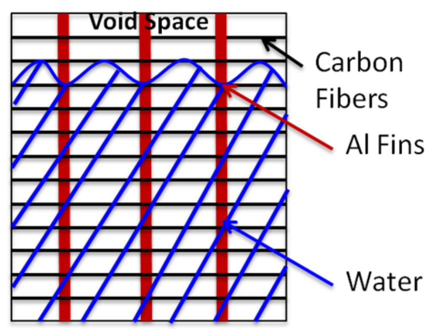


PRIOR PCM HX DEVELOPMENT AND TESTING

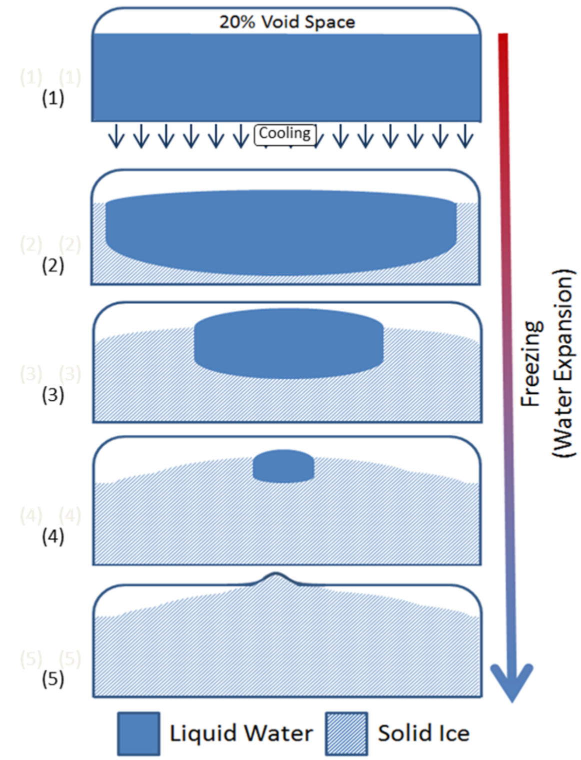
PCM Testing History

- RIP/SHRIMP's testing focused on utilizing aluminum fins/carbon fibers to control void space location
  - RIP: 450 kJ (1.35 kg)
  - SHRIMP: 45 kJ (0.135 kg)
- Total of 13 RIP/SHRIMP's tested – all failing
  - Tested in various orientations
- Ultimately, knowing void space location is not sufficient
  - Even with 20% void space, test articles still failed
  - Void space will not necessarily be known in microgravity





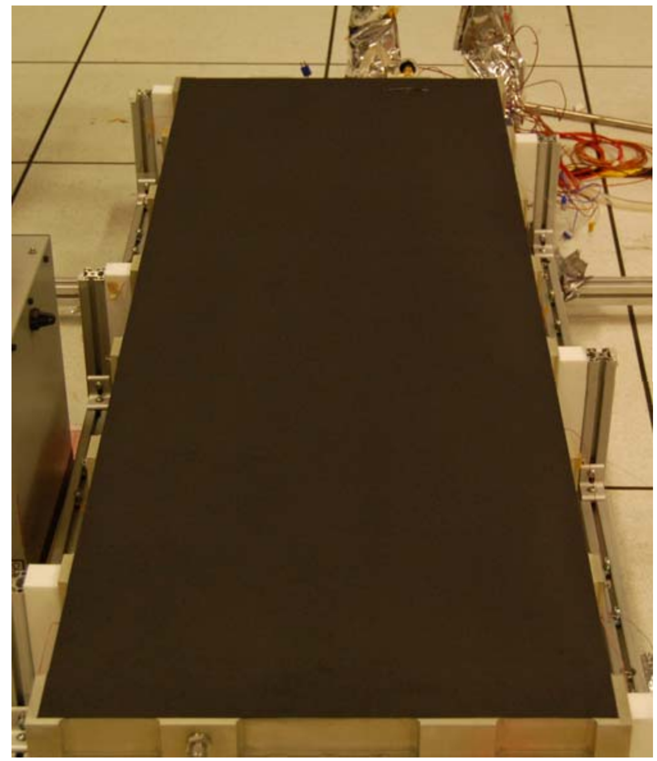
Ice Spike Formation Comparison in SHRIMP

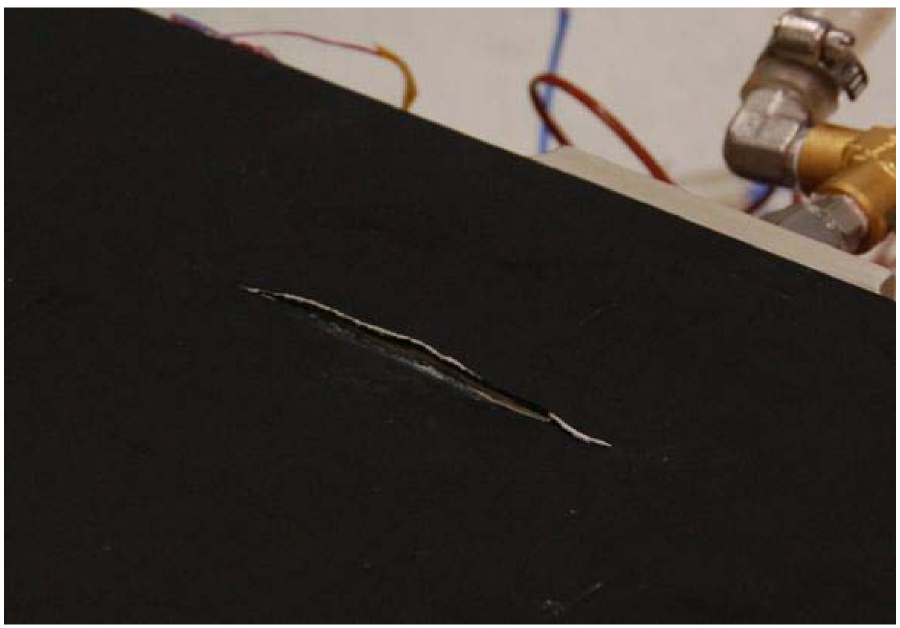


Ice Spike Formation in SHRIMP

PCM Testing History

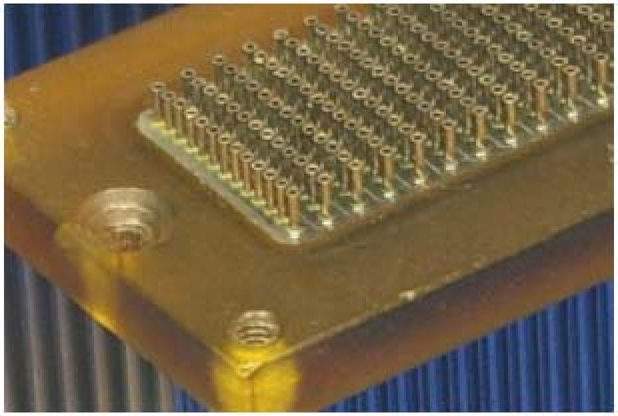
- Integrated Replicative Ice PCM (IRIP)
  - Full Scale 12.6 kW PCM for use on the Lunar Electric Rover
  - Consisted of aluminum brazed fins and 38 kg of water with 20% void space
  - 5-day vacuum test with thermal cycling
  - Resulted in failure (2” tear) on day 4

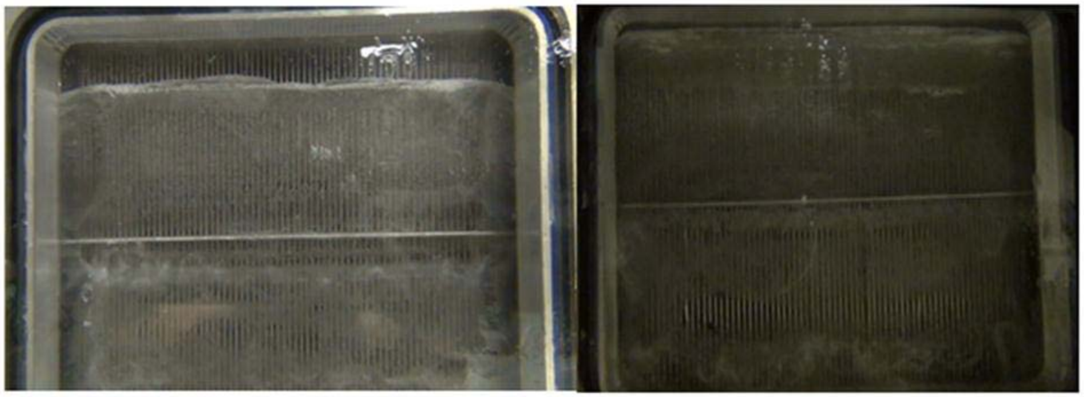




Mezzo Technologies PCM

- Microtube HX
  – HX utilizing ~5,000 tubes positioned in a 4"x4" area
  – Originally used as a wax PCM for Lockheed
  – 19 total cycles in various orientations (favorable, unfavorable, neutral) with no visible signs of failure
- Noticed volume of ice was greater when frozen in "unfavorable" orientation





Favorable Adverse

COPPER HX COUPON DESIGN & TESTING

Copper Test Articles

- Fabricated to:
  - Understand freeze front propagation and ice spike formation
  - Understand outside-in, inside-out, and uniform freezing
- 2 Outcomes:
  - Ice spike always occur where freezing occurs last
    - o Void space (or deformable media) must be present at this location
  - Ice spike distribution should be considered in HX design

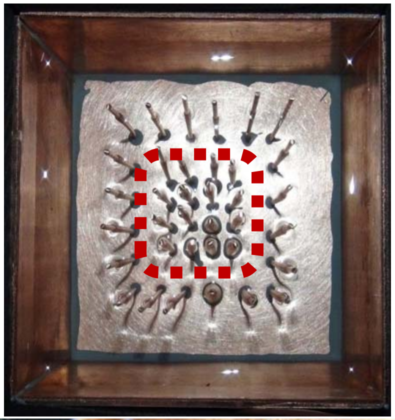
Copper Gen 1 *Copper Gen 2.0* *Copper Gen 2.1* *Copper Gen 2.2*

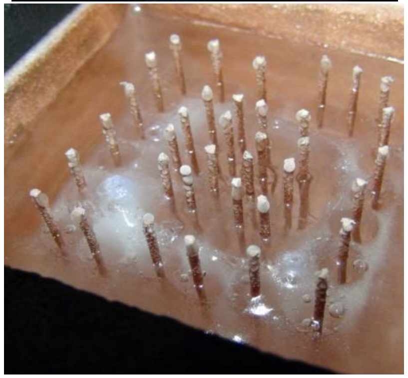
Ice Spike Distribution

Outside-In Freezing

Single ice spike (0.25”) formed at middle of test article

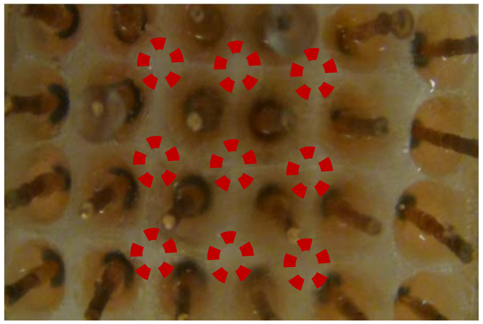
Inside-Out Freezing

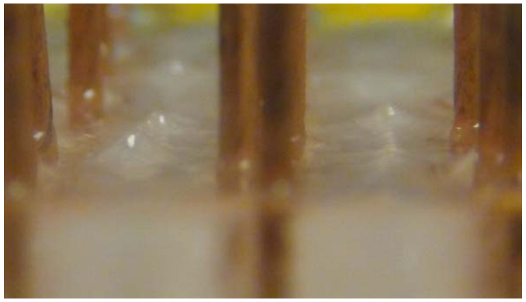




Ice spike ridge (0.18”) formed at middle of test article

Uniform Freezing

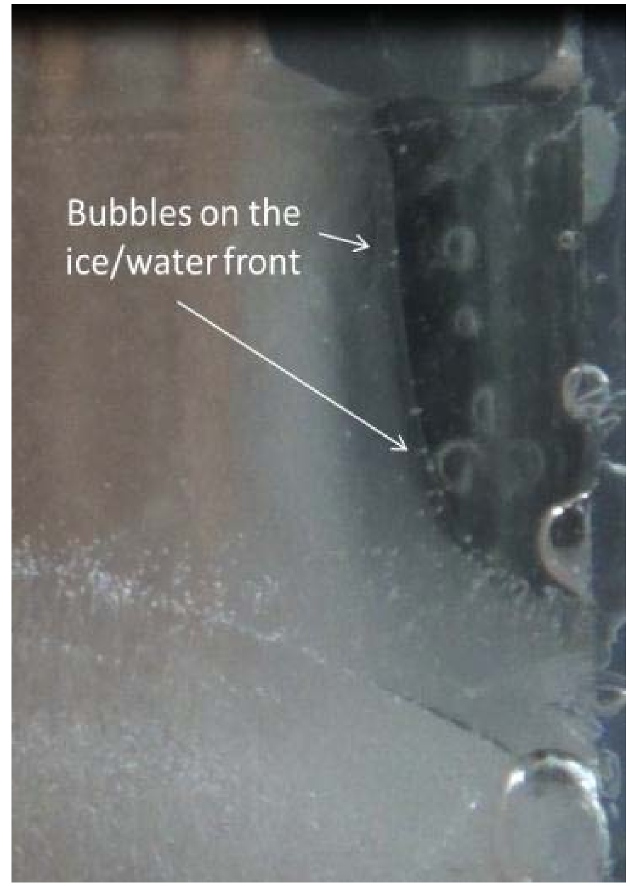




Several small ice spikes formed (<0.12”) at intersections between copper rods

Microgravity Flight Experiment

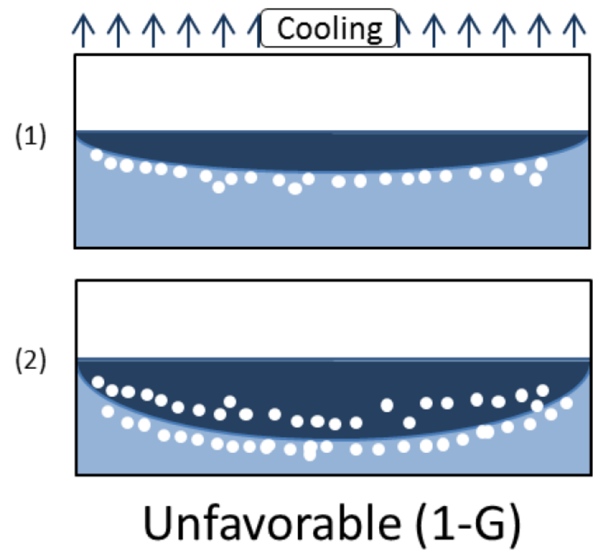
- Microgravity flight experiment developed in conjunction with University of Houston through NASA's MUREP Program
  - Individual water droplet study
  - Three copper coupon test articles
    - Continually frozen in various gravity loads
- Results
  - 1-g: Dissolved gasses escape from freeze front and float to surface
  - 0-g: Dissolved gasses escape from surface and float in place with some becoming entrapped in ice
- Hypothesis
  - Because air is trapped in the ice during zero-g a greater volume of ice will be formed when frozen in microgravity
    - Confirms Mezzo unfavorable testing results



Gas Bubbles forming on the ice/water front

Freeze Rate and Orientation

- Copper test article was frozen in liquid nitrogen to freeze quickly
  - Ice spike was approximately 0.5” in height compared to 0.25” when normally frozen.
- Hypothesis
  - Typically air bubbles are allowed to escape and float to surface
  - In quick freeze, dissolved gasses do not have sufficient time to escape and to surface, but become trapped in the freeze front



Dissolved gas freezing in ice

Ice spike formation in liquid nitrogen

FUTURE WATER-BASED PCM HX DESIGNS

Future Direction

- Currently working with Mezzo Technologies to develop a bladder based HX
- Utilizes a flexible bladder, ice spike distribution, and degassed water
- Two HX designs are currently being constructed
- Testing will be carried out in September 2014
- 1/10 scale will be tested in 2016 in microgravity on ISS