Water-Based Phase Change Material Heat Exchanger Development

Scott Hansen and Rubik Sheth: NASA, Johnson Space Center
Matt Atwell: University of Texas
Dr. Ann Cheek, Muskan Agarwal, Steven Hong, Aashini Patel, Lisa Nguyen, Luciano Posada: University of Houston

Presented By
Scott Hansen

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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*
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
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**
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
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
    o 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
    o Confirms Mezzo unfavorable testing results
**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

*Unfavorable (1-G)*

*Unfavorable (1-G)*

_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