Phase Change Material Composite Heat Sinks for Space Batteries

Eric Darcy (edarcy@ems.jsc.nasa.gov), NASA-Johnson Space Center, Houston, TX, USA
Foad Derisavi-Fard (Friwo-derisavi@t-online.de), Friemann & Wolf, Duisburg, Germany
Timothy R. Knowles (Knowles@esli.com), Energy Science Laboratories, Inc., San Diego, CA, USA

Introduction

A phase change material (PCM) heat sink with a specific latent heat exceeding 150 J/g is required to allow a 350 Ah, 32V battery to safely discharge adiabatically for the Crew Return Vehicle of the International Space Station. The purpose of the battery is power the vehicle avionics from ISS separation until separation of the De-orbit Propulsion Stage of the vehicle (a period of up to 7 hours).

Design Problem

Energy, power, volume and thermal constraints dictate that this Li/MnO_2 battery module be capable of adiabatically absorbing all 7000 kJ generated internally during discharge, with a maximum allowable ΔT of 50 ºC. Additionally, with a mass limit of 95.4 kg on the battery module, we determined that the needed battery thermal capacitance can only be achieved by adding a heat sink with > 3,300 kJ of latent heat and > 150 kJ/kg. Even though the specific latent heat of some suitable waxes exceed 250 kJ/kg in pure form, best prior PCM heat sink designs achieved ~ 75 kJ/kg. This is because traditional solutions involved loading the wax with conductive fillers or foams and using strong containers. Three design problems must be overcome when designing high specific latent heat PCM wax heat sinks. One, the thermal conductivity is so poor that it limits the heat fluxes can be accommodated. Two, they must be sealed from the vacuum of space to prevent sublimation. Three, the volumetric expansion of phase change (~15% for paraffin waxes) requires sealing an allocation of void space in the container with the PCM. Aggregation of these voids into a big bubble during phase change can cause severe structural stresses on the sealed container during melting.

Design Solution

All three problems are addressed by packaging the PCM wax in a carbon fibercore matrix having 90% porosity. The matrix uses 8 µm diameter fibers cut to a 2.5 mm length which are glued orthogonal to an aluminum foil as shown in Figure 1. The resulting matrix is designed to trap the wax with very strong capillary forces such that when the wax is melted, it will not drip from the matrix. Thus, the voids necessary to accommodate the volume change are present as a distribution of fine pores throughout the composite.

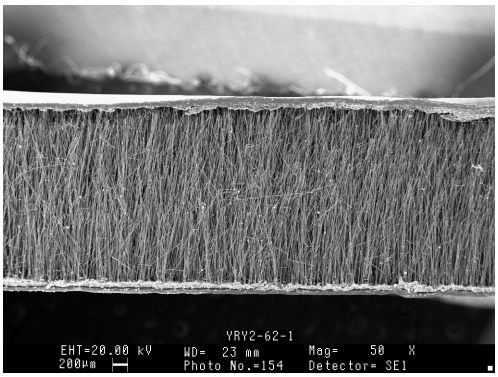

Figure 1. Close-up of carbon fibercore.

Results and Discussion

Using this carbon fibercore technology, we assembled a battery base with over 3600 kJ of latent heat weighing an additional 20 kg over the previous non-PCM base design. It contained >14 kg of n-docosane ($C_{22}H_{46}$) wax which melts at 42-44 °C with a latent heat of 248 kJ/kg. Overall, the added capacitance to this battery achieved over 180 kJ/kg once all the carbon fibercore and extra base structure are added. Also, the heat capacity of the composite heat sink base was increased from that of aluminum (0.215 cal/g/°C) to ~ 0.47 cal/g/°C with the added wax. The carbon fibercore improves the thermal conductivity of the wax by a factor of 50. As shown in figure 2, the temperature difference across the 73-mm thickness of the heat sink base remained below 5 °C at 300 W heat rate.

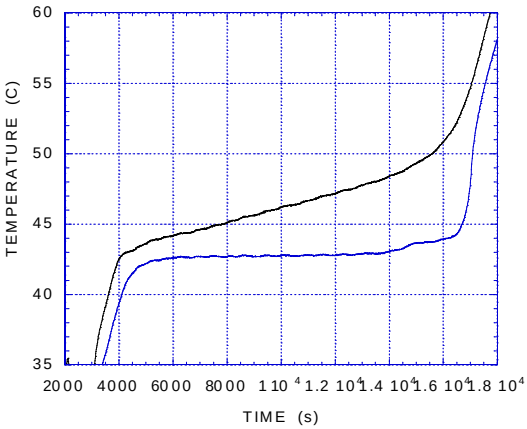

Figure 2. The top and bottom surfaces of the PCM composite heat sink with 300 W applied to the top.