DESIGN AND TEST CONSIDERATIONS FOR COPPER-WATER HEAT PIPES IN SPACE APPLICATIONS

Richard Jones
Clayton Hose
Ryan Spangler
Advanced Cooling Technologies, Inc.

ABSTRACT

Copper-water heat pipes have been used terrestrially for decades and the materials of construction (copper and water) are widely accepted as compatible and capable of performing for typical operational lifetimes (10-15 years). Unlike terrestrial applications, spaceflight imposes tough thermal design limitations such as size, weight, shape, and accessibility. These restrictions make many traditional thermal management solutions unsuitable. However, heat pipes allow for passive cooling solutions with minimal weight and custom sizes and shapes. Specifically, copper-water heat pipes are capable of transporting far higher heat fluxes (up to approximately 50W/cm^2) than the more traditional space heat pipe: the axially-grooved aluminum-ammonia CCHP (5-15 W/cm^2). This allows thermal management of more power in a smaller package reducing the footprint of the heat pipe and reducing weight. One drawback is water expands when it freezes. If contained in a vessel, the water can pool and stress the containing vessel to the point of breaking upon freezing. This is especially true with repeated cycles. Fortunately, a heat pipe contains a wick, which can be designed to retain the entire volume of working fluid and prevent the formation of a puddle or slug of working fluid. A copper-water heat pipe must be properly designed if it is to be subjected to sub-zero degree Celsius temperatures in order to survive the stressful freeze situation.

ACT has developed and refined the design, manufacturing, and part filtering processes required to yield a spaceflight-worthy copper-water heat pipe product. Space Copper-Water Heat Pipes (SCWHP) are constructed to a much higher level of scrutiny than traditional copper-water heat pipes for terrestrial applications. Additionally, copper-water heat pipes allow for flexibility that is not available with other solutions. Pipes can be mounted to heat input areas externally via soldered on evaporator blocks or they can be directly imbedded in other structural elements to provide constant and distributed heat transfer. Regardless of the application, special attention must be paid to both fluid inventory and wick construction, among other critical items, to assure tolerance to the maximum number of freeze-thaw cycles required for a particular mission. While test data has shown limitations to the maximum number of freeze-thaw cycles a SCWHP can survive, ACT has shown success in a variety of qualification programs with over 1000 freeze-thaw cycles. Each freeze-thaw cycle can add a small amount of cumulative damage to a heat pipe, similar to cyclic stresses in a structural element. Properly design heat pipes can reduce this cumulative damage to a level well below the critical limit across the span of a mission. These successes and developments on SCWHPs provide satellite and spacecraft design

engineers a tool for their toolbox that enables higher heat fluxes, more targeted thermal management, and a broadened scope of what is possible in space.

With its experience in qualifying SCWHP, ACT has also learned a great deal about the dynamic response of a heat pipe as the working fluid freezes. One critical lesson learned simply put: "Test-Like-You-Fly". One advantage of operating heat pipes in space is the lack of or reduced gravity. Without gravity, the heat pipe wick does not need to overcome the gravitation pressure head and typically results in better heat pipe performance. However, ground-based tests may not show how the heat pipe will truly operate in space. The most evident discrepancy would be thermal resistance/conductance if the heat pipe is tested in a gravity aided or against gravity orientation. The heat pipe's maximum transport capability also affected by the orientation with respect to gravity, as a gravity adverse test orientation would cause an earlier dryout (lack of liquid return to the evaporator) relative to a horizontal or gravity aided orientation. Testing the heat pipes in a horizontal or slightly adverse incline (~0.1") is the preferred option but may not be feasible for non-planar heat pipes (3-dimensional bends). Another aspect of space heat pipe testing that can be overlooked are secondary conduction paths and source/sink mass. While not as critical for steady state testing, dynamic tests, such as freeze-thaw/temperature cycling, may not show accurate dynamic responses if the source mass, sink mass, and secondary paths are not accounted for in testing. Secondary paths and system masses should be simulated for dynamic testing as without it you are not truly testing like you fly and testing could show anomalous responses that would not actually occur in space. Alternatively, a dedicated secondary path, such as a solid copper rod running next to the heat pipe, would eliminate the need to simulate the secondary path and would act as a redundant heat transfer path should the heat pipe freeze or in the unlikely event of a failure.