Development of Cryogenic Methane Constant Conductance Heat Pipe

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Cryogenic heat pipes have been of great interest for thermal management of space applications involving cooling and thermal control of optical surfaces, infrared scanning systems, large superconducting magnets, etc. However, the development of cryogenic heat pipes is more challenging than ambient temperature or liquid metal heat pipes, due to the relatively low surface tension of candidate working fluids and their high-pressure values that present the safety challenges during the storage. In this study, the design, fabrication, and demonstration of a constant conductance heat pipe (CCHP) that uses methane as the working fluid is conducted to carry a design power of 15 Watts in the operational cryogenic temperature range of 100 – 140 K. Funded by NASA Goddard Space Flight Center (GSFC), Advanced Cooling Technologies Inc (ACT) has developed a methane CCHP using axial grooved structures for efficient capillary pumping of otherwise low surface tension methane working fluid. The thermal performance testing demonstrated that the cryogenic heat pipe can carry about 3 times the required power, i.e., 45 Watts, for up to 0.762 cm (0.3”) of inclination against gravity, about three times the space qualification of 0.254 cm (0.1”). Steady isothermal heat pipe operations were observed with less than 5 Kelvin temperature drop for a 1.42 meter (56”) length heat pipe.

Keywords: Cryogenic heat pipe; methane; thermal management; grooves

Various space applications and instruments require efficient thermal management at low (cryogenic) temperature levels. Therefore, the development of cryogenic heat pipes is of great interest. Existing studies[1,2] have identified the lack of appropriate wick structure designs to efficiently pump low surface tension fluids such as methane, nitrogen, argon, etc. as the most critical aspect of cryogenic heat pipe development. In this NASA GSFC-funded work, ACT developed a cryogenic constant conductance heat pipe using *axial* groove structures and methane as a working fluid.

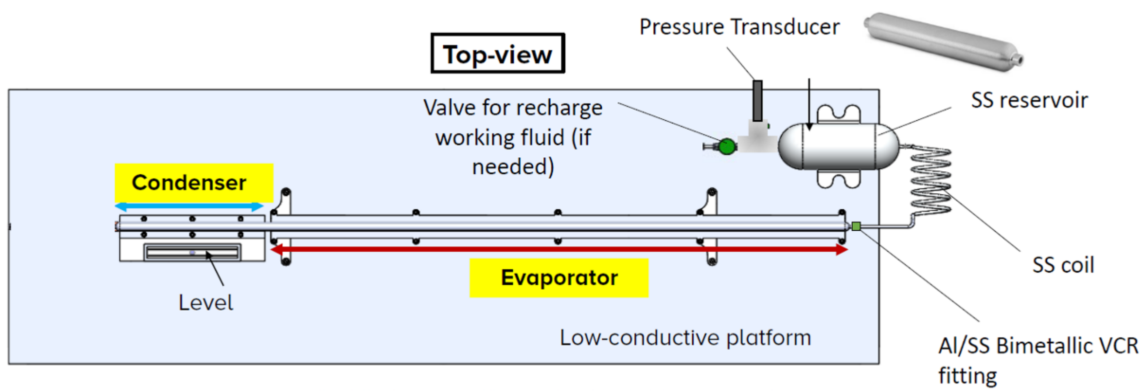

Figure 1. Schematic representation of methane CCHP design and associated components.

Figure 1 shows the design of the Methane CCHP and associated components. The design requirements identified for the development of methane CCHP are as follows:

1. Operating temperature: 100 – 140 K
2. Minimum power carrying capacity: 15 Watts.
3. Steady state operations at space orientation i.e., 0.254 cm inclination against gravity during

ground testing.

4. Heat pipe dimensions: 1.1 meters (44”) evaporator and 0.3 meters (12”) condenser with no adiabatic section.
5. Storage temperature of about 333 K
6. Factor of safety of 4 or higher

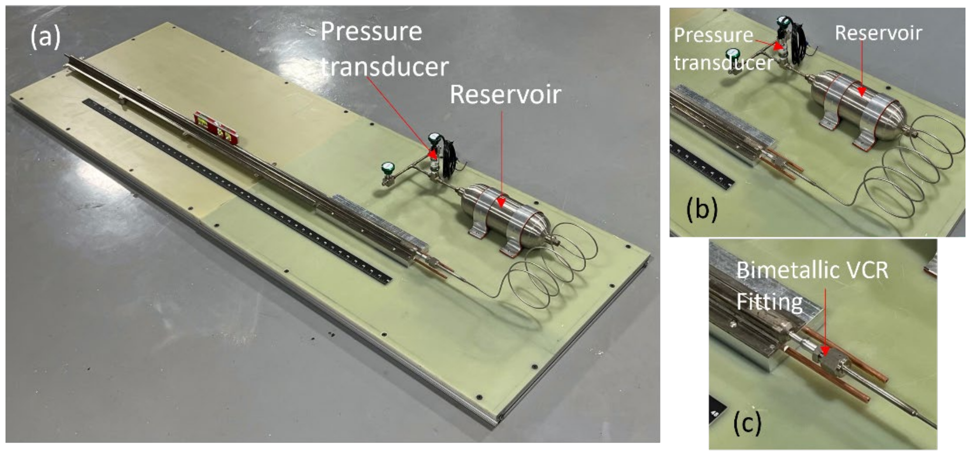

Figure 2. Fabrication and assembly of methane CCHP system.

Figure 1 shows that the aluminum envelope of methane CCHP is connected to a stainless-steel reservoir via a stainless-steel to aluminum bimetallic Vacuum Coupling Radiation (VCR) fitting. Higher operating pressures of methane gas at ambient and storage temperatures require the addition of a reservoir. Additional safety requirements ensured the inclusion of a pressure transducer and fluid recharge valve. Figure 2 shows the as-fabricated methane CCHP with associated components. The heat pipe assembly is positioned on a non-conductive platform to minimize conductive heat losses.

The methane heat pipe testing was carried out in a thermal vacuum chamber with multi-layer insulation sheets significantly reducing the radiation heat leaks into the system. The performance of methane CCHP was measured with transient temperature variation. Two configurations of heat pipe namely ‘up configuration’ and ‘upside down configuration’ are studied as a part of the test.

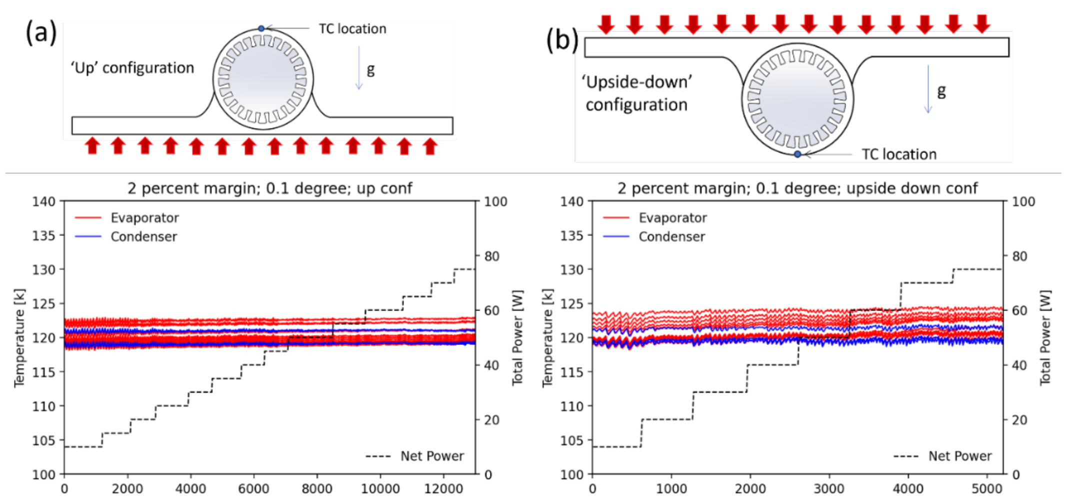

Figure 3. Methane CCHP performance for up and upside-down configurations.

Figure 3 shows that both the configurations of Methane CCHP oriented at about 0.1° i.e., about 0.1” inclination against gravity shows isothermal behavior for a range of powers from 10 Watts to 75 Watts. The maximum temperature drop on the heat pipe is consistently less than 5 K indicating a successful performance demonstration. It is noted that the methane CCHP carried higher power than the design requirement of 15 Watts. Additional tests indicated that the heat pipe dried out at about 40 Watts when operating at 0.4” inclination against gravity in an upside-down configuration. The superior performance of the methane CCHP to carry much higher powers even at higher inclinations against gravity may be partly attributed to the puddle formation due to the drainage of top grooves. The details of the investigation and discussion on the overall performance of the Methane CCHP will be presented in the follow-up full-length paper and future studies.

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