24-HOUR CONSUMABLE BASED COOLING SYSTEM FOR VENUS LANDERS.
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Introduction: Venus in-situ exploration has been ranked as one of the highest priorities for future inner solar system studies [1]. However, the extremely hostile Venusian environment presents significant challenges in designing of the thermal management system for a Venus lander. The Venus surface temperature can be as high as 460°C and the atmospheric pressure can be around 92 bar (1334 psi), making it extremely difficult to reject the waste heat generated by the electronics inside a lander. To date, the longest survival duration on Venus surface was achieved by the Russian Venera lander 13 (127 minutes), which uses Phase Change Material (PCM) to absorb the payload waste heat, and multi-layer insulation (MLI) to mitigate the incoming heat leaks from the environment [2] [3]. Another attractive concept for Venus lander cooling is by venting two-phase coolant (ammonia) into Venus ambient. However, the limitation is that the ammonia vapor pressure at the payload set point (70°C) is not enough to overcome the high pressure on Venus environment. Therefore, the evaporative cooling of ammonia venting is only applicable to reject the incoming environmental heat leaks, maintaining the lander shell temperature at 121°C.

In order to address this thermal design challenge, Advanced Cooling Technologies, Inc. (ACT) developed an innovative cooling concept that is based on venting of consumable fluids into an environment with higher pressure than the vapor pressure that corresponds to the temperature of payload.

The consumable-based cooling system consists of two pressurized vessels: the primary vessel and the secondary vessel. The primary vessel will contain two-phase working fluid where the vapor will be mixed with a secondary species (i.e. compressed gas such as argon or helium) that serves as pressurizer. The secondary vessel will contain only the compressed gas, initially at a much higher pressure (~ 400 bar). The role of the secondary vessel is to pressurize the primary vessel, so that the total pressure consisting of working fluid vapor pressure at saturation and gas partial pressure is higher than the environmental pressure. Internal heat load of payload will be transferred to the primary vessel through thermal links (heat pipes or other…) to vaporize the working fluid within the vessel. Two valves will be used to control system pressure and temperature. A venting valve will be mounted on the top of the primary vessel to control venting of the consumable fluid mixture. Another valve will be installed between the two pressure vessels to control recharging of the primary vessel with compressed gas.

The system has a bonus heat guarding effect: the consumable fluid mixture (working fluid vapor + compressed gas) leaving the primary vessel will be at payload set point (~70°C). Before being ultimately vented into Venus ambient at 460°C, there is a significant amount of sensible heat capacity which can be used to absorb incoming environmental heat leaks and then vented away. The flow paths (tubing) embedded within the lander structure that will allow the consumable fluid to collect incoming environmental heat leaks and ultimately rejected into the ambient is referred as the “heat guarding system”. In Phase I, a thermodynamic-based model for consumable-based cooling was developed and validated by a pilot-scale experimental system with three different pairs of working fluid/compressed gas. After validation, the mathematical model was employed to predict the required fluid mass to achieve 24 hours survival of Venus lander in relevant operating conditions.

References:

[1] National Academy of Science, “Vision & Voyages Planetary Science Decadal Survey 2013-2022,” National Academies, Press, 2011.

[2] NASA Goddard Space Center, “NSSDC Chronology of Venus Exploration,” 2014 [Online]. Available: https://nssdc.gsfc.nasa.gov/planetary/chronology_venus.html.

[3] J. L. Hall, M. Bullock, D. Senske, J. Cutts and R. Grammier, "Venus Flagship Mission Study: Final Report of the Venus Science & Technology Definition Team," National Aeronautics and Space Administration, 2009.