DIODE HEAT PIPES FOR LONG-LIVED VENUS LANDERS. M. Dechristopher[1], C. Tarau[1], W. G. Anderson[1] [1]Advanced Cooling Technologies, Inc.,1046 New Holland Ave. Lancaster, PA 17601 U.S.A. 717-295-6066, Calin Tarau@1-act.com

Introduction: Cooling during normal operation of the Long-lived Venus Lander can be provided by a Stirling Duplex System [1] that uses a radioisotope Stirling power converter to energize Stirling coolers. High temperature heat from roughly 10 General Purpose Heat Source (GPHS) modules must be delivered to the Stirling convertor with minimal temperature drop ΔT. In addition, the cooling system must be shut off during transit to Venus without overheating the GPHS modules. This high temperature (~1150ºC) heat is managed by a passive High Temperature Thermal Management System (HTTMS) [2]. During normal operation, waste heat is produced at both the cold end of the main Stirling converter and the hot end of the highest rank Stirling cooler. Rejecting this waste heat to the environment, also with a minimal temperature drop, is critical to maintaining a high efficiency for the cooling system. A passive Intermediate Temperature (~520ºC) Thermal Management System (ITTMS) that will reject this waste heat is under development and consists of two major components:

1. **Heat Transport System** – alkali metal *Diode Heat Pipes* **(DHPs)**.
2. **Heat Rejection System** – alkali metal *Radiator Heat Pipes* (**RHPs**).

In terms of functionality, the ITTMS will collect (function 1) and reject (function 2) this heat. These two functions and the two componenets of the ITTMS are related as follows:

Function 1 (Collecting Heat): Three categories of heat are collected from three sources:

- *Waste heat* from the *cold end* of the Stirling convertor and from the *hot end* of the highest rank Stirling cooler at ~ 520°C. This heat is available only when the Stirling convertor is operating, and will be transported by a set of alkali metal gas charged *Diode Heat Pipes* – **DHPs,** which are the focus of this paper.
- *Bypass heat* from the *VCHP radiators* of the HTTMS (at ~ 800-900°C). This heat is available when Stirling convertor is not operating and Pu238-based GPHS modules are used.
- *Excess heat* from the *VCHP radiators* of the HTTMS (at ~ 800-900°C), if alternative isotopes are used. This decaying excess heat must be continuously removed. This heat is added to the bypass heat at all the times, regardless of whether the Stirling convertor is operating or not. Both excess and bypass heat are initially transported by the HTTMS through its VCHPs.

***Function 2 (Rejecting Heat)*:** The entire amount of heat is rejected into the environment (earth, space, or Venus) by a set *of Radiator Heat Pipes* – **RHPs**. However, the RHPs are outside the scope of this paper.

During transit, the cooling system is inactive and no waste heat is generated. As such, the HTTMS will reject high temperature heat that bypasses the Stirling converter's heater head. This operation heats the condensers of the Heat Transport System (or the DHPs) of the ITTMS, which reverses the direction of the heat flow. Since this heat is at a higher temperature than 520ºC, reversing the heat flow is not desirable as this may overheat the cold end of the Stirling converter and hot end of the highest rank cooler. A gas charged alkali metal Diode Heat Pipe (DHP) is under development for this purpose and its proof of concept experimental results are the focus of this paper.

Background: Diode heat pipes are designed to allow the heat to flow only from the evaporator to condenser, while preventing flow in the reverse direction. In Figure 1, a *gas charged* Diode Heat Pipe is presented in principle. A Diode Heat Pipe can also be *with trapped liquid;* however, they are not suitable for the current application.

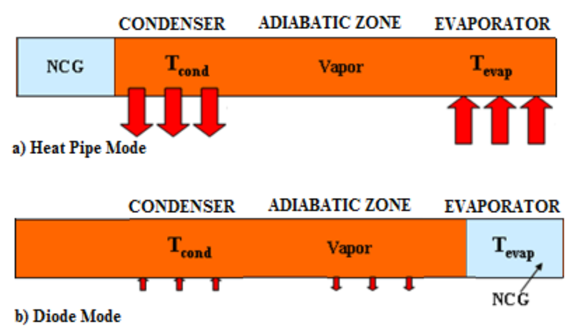

Figure 1. Gas charged Diode Heat Pipe (DHP) schematic of principle a) Normal operation (Heat Pipe Mode), T_{evap}> T_{cond} while the NCG is kept in reservoir b) Non-conducting state (Diode Mode) when T_{evap} < T_{cond} and the NCG is swept to the evaporator blocking it.

Figure 1a shows the pipe under normal operation (Heat Pipe Mode) when the evaporator temperature (T_{evap}) is higher than the condenser temperature (T_{cond}). In this case, the NCG is kept beyond the condenser in a reservoir. If by some reason the condenser temperature becomes higher than the evaporator temperature, T_{cond} > T_{evap}, (see Figure 1b), then the NCG is swept to the evaporator and blocks it, not allowing the vapor to condense in the evaporator. However, as seen in Figure 1b, a small amount of heat is allowed to be transferred from the condenser to the adiabatic zone or the evaporator. The small amount of generated vapor is necessary to continuously sweep and maintain the NCG in the evaporator.

Experimental Results: Two proof-of-concept potassium DHPs with different gas reservoir tube size were designed and fabricated. Figure 2 shows the Diode Heat Pipe that has a smaller reservoir tube (5 mm inner diameter).

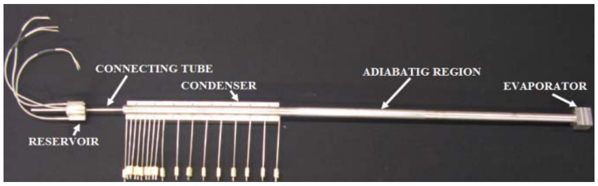

Figure 2. First Diode Heat Pipe before for testing

Promising initial testing results were obtained for the DHP shown in Figure 2. This DHP was tested for a nominal temperature of 525ºC while transporting 500W in a "space" orientation meaning that the condenser was elevated above the condenser with ~3mm (1/8") . The pipe worked in both Heat Pipe Mode and Diode Mode intermittently as the power was applied at the evaporator and at the condenser, which demonstrated the concept.

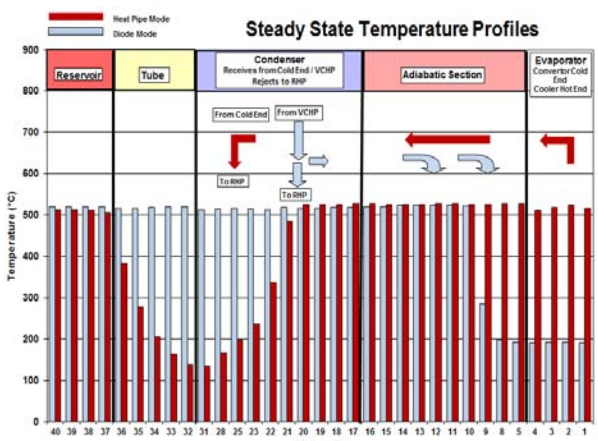

Figure 3. Steady state temperature profiles along the Diode Heat Pipe corresponding to the Heat Pipe Mode and Diode Mode

Figure 3 shows two steady state temperature profiles that correspond to the initial Heat Pipe Mode, where heat was applied to the evaporator and rejected by the condenser, and to the Diode Mode, where heat was both applied to and rejected by the condenser. To a lesser extent, some heat is also rejected at the adiabatic zone. As seen in Figure 3, the Diode Mode shows a separation front between Non-Condensable Gas (on the low temperature side) and potassium vapor (on the high temperature side) just before the evaporator. This separation proves that the diode effect is indeed enforced by the relocated Non-Condensable Gas that now blocks the evaporator. Note that, slow transients were observed and we believe that the cause is the small size (5 mm) of the reservoir to condenser connecting tube. The second DHP that has a larger reservoir to condenser connecting tube (16 mm innder diameter) will also be tested and all the results will be presented in the final paper.

References: [1] Dyson, R.W., Schmitz, P.G., Penswickz, L.B., and Bruderx, G.A., (2009) IECEC. [2] Tarau C., Anderson W.G. and Peters C. J., (2011) *Journal of the British Interplanetary Society*, Vol. 63 .336-344.