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DIODE HEAT PIPES FOR LONG-LIVED VENUS LANDERS

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ABSTRACT

Cooling during normal operation of the Long-lived Venus Lander can be provided with a radioisotope Stirling power converter that energizes Stirling coolers. High temperature heat from roughly 10 General Purpose Heat Source (GPHS) modules must be delivered to the Stirling convertor with minimal ΔT. In addition, the cooling system must be shut off during transit to Venus without overheating the GPHS modules. This heat is managed by a High Temperature Thermal Management System (HTTMS). 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. It is critical for this waste heat to be rejected into the environment also with a minimal ΔT to maintain 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. During transit, the cooling system rests and no waste heat is generated. In turn, the HTTMS will reject high temperature heat bypassing the Stirling converter's heater head and heating the ITTMS. Diode heat pipes are required so that heat will not be transmitted in the reverse direction, from the radiator heat pipes to 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. Two proof of concept potassium DHPs that differ in the size of their reservoir connecting tube were tested at 525ºC transporting a power of 500W. The pipes worked in both Heat Pipe Mode and Diode Mode intermittently as the power was applied at the evaporator and condenser, demonstrating the concept. The DHP with a larger diameter reservoir connecting tube showed faster transients during the returning from the Diode Mode to the Heat Pipe Mode.

Keywords: cooling system, long-lived Venus lander, Stirling convertor, gas charged alkali metal Diode Heat Pipe

Acronyms

BOM	Beginning of Mission
DHP	Diode Heat Pipe
GPHS	General Purpose Heat Source
HPVL	High Power Venus Lander
HTTMS	High Temperature Thermal Management System
ITTMS	Intermediate Temperature Thermal Management System
LN	Liquid Nitrogen
NCG	Non Condensable Gas
RHP	Radiator Heat Pipe
TC	Thermocouple
VCHP	Variable Conductance Heat Pipe

I. INTRODUCTION

The difficult operating environment on the Venus surface, 460°C and 9.3 MPa pressure, presents significant thermal design and implementation challenges for any mission. None of the previous missions operated more than two hours on the Venus surface. For a greater science return, missions with longer operating duration on the Venus surface are needed. 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 the 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 able to provide the following features:

1. Allows the Stirling convertor to shut off during transit to Venus without overheating the GPHS modules.
2. Pre-cool the system before the entry of the Venus atmosphere.
3. Work at nominal temperature on Venus surface.
4. Briefly shut-off on Venus surface to allow scientific measurements.
5. Reject the excess heat during the entire mission when short-lived energy sources are used.

This high temperature (~1150ºC) heat from the GPHSs is managed by a passive High Temperature Thermal Management System (HTTMS)[2] that is capable of working within the above mentioned features. 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 cooling system. A passive Intermediate Temperature (~520ºC) Thermal Management System (ITTMS) that will reject this waste heat is under development and consists of the following 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 waste heat. These two main components and two functions of the ITTMS are strongly related and their description is given below. Note that only the first component of the ITTMS, the alkali metal Diode Heat Pipe **(DHP),** is the object of this paper.

II.CONCEPT

As already mentioned, the Intermediate Temperature Thermal Management System (ITTMS) works with the High Temperature Thermal Management through all its features.

Figure 5 shows one of the five identical segments of the entire thermal management system where both the ITTMS and the HTTMS with all the inputs, outputs and thermal interactions are shown. The HTTMS consists of Variable Conductance Heat Pipes (VCHPs) that collect and transport the heat from the GPHS modules to the Stirling converter and also provide backup cooling for the GPHS modules[3,4,5]. As seen, a VCHP evaporator is attached to the GPHS stack, the first condenser is attached to the Stirling converter's heater head and the second condenser is attached to the backup cooling radiator. During normal operation, heat is transmitted from the GPHSs to the first condenser attached to the heater head. When the Stirling is shut off, the heat is transmitted to the second condenser, and then radiated to the Diode Heat Pipes.

A segment of the ITTMS consists of a Diode Heat Pipe (DHP) and a Radiator Heat Pipe (RHP) that are physically and thermally connected. A Diode Heat Pipe is designed so that heat is readily transmitted in the forward direction, but blocked in the reverse direction. Two groups of DHPs are used within the entire ITTMS, one for removing the Stirling converter's waste heat and the other for removing the highest rank Stirling cooler's waste heat. The only difference between the two DHP groups is the location of the evaporator. The condensers are identical and they are attached to the inner side of the shell. Any segment of the ITTMS has just one DHP of either category. Three out of the five segments have DHPs of the first category while the other two have DHPs of the second category. The DHPs are entirely (evaporator, adiabatic zone and condensers) inside the shell. To minimize the thermal resistance of the waste heat path, the condensing vapor comes in direct contact with the shell's material. The Radiator Heat Pipes are located entirely on the outside of the shell, and also have the working fluid in direct contact with the shell. As described below, the ITTMS is used for collecting and rejecting the waste heat from the Venus Lander.

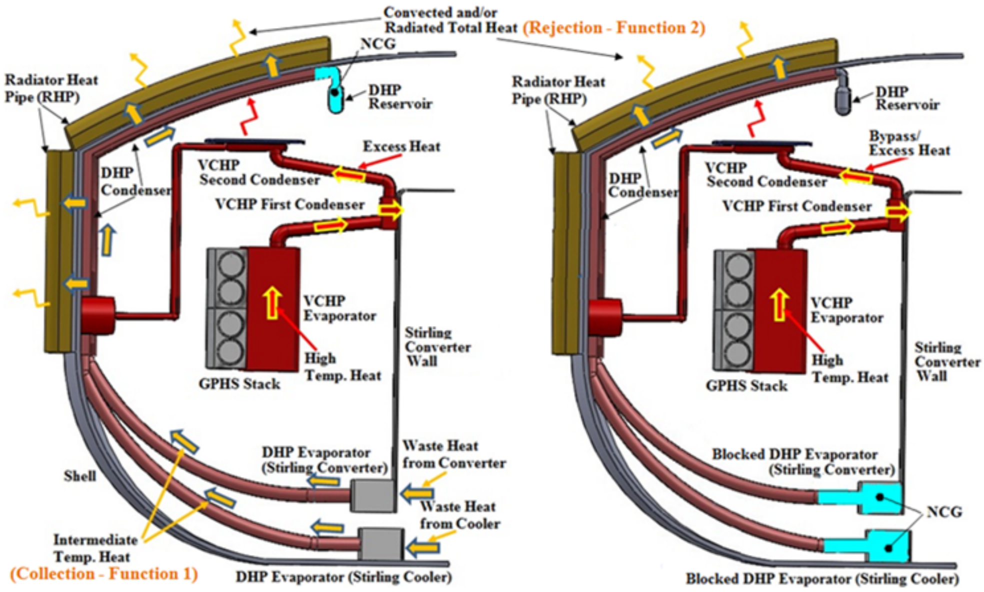
Function 1 - Collecting Heat

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 it will be transported by a set of alkali metal gas charged *Diode Heat Pipes* (DHPs).
- *Bypass heat* from the *VCHP radiators* of the HTTMS (~ 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 (~ 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 that Stirling convertor is operating or not. Both excess and bypass heat are transported by the HTTMS through its VCHPs.

Function 2 - Rejecting Heat

The entire amount of heat that is collected in *Function 1* is further transferred and rejected to the ambient (space/Venus atmosphere) by the Radiator Heat Pipes (RHPs). As seen, the RHPs form the ultimate heat rejection device. Although they will reject heat by both radiation in space and convection on Venus, they are referred as Radiator Heat Pipes (RHPs) for simplicity. As seen in Fig. 1 each DHP condenser rejects heat to two RHPs, a vertical one and a horizontal one. Unlike the vertical RHP, the horizontal RHP will also receive excess and/or bypass heat from the VCHP Radiator. The reason for splitting the RHP into a vertical one and a horizontal one is that the cylindrical portion of the pressure vessel may be heated during transit, when excess and/or bypass heat is rejected at a relatively high temperature (500-700ºC). This heating is not desired since the VCHP reservoir is attached to the inner side of the shell and an excessively warm reservoir would determine an increase in temperature of the Stirling converter's heater head.



a) b)

Fig. 1. Segment of the Intermediate Temperature Thermal Management System (ITTMS). a) Waste heat is generated (Stirling is working) and the Diode Heat Pipe is working. b) Waste heat is not generated (Stirling is not working) and the Diode Heat Pipe is not working. This prevents heating of the Stirling cold end from the excess/bypass heat.

A. The role of the Diode Heat Pipe

During transit, the cooling system is inactive and no waste heat is generated. When the Stirling systems are shut off, the HTTMS must rejects the high temperature heat that bypasses the Stirling converter's heater head. This heat is rejected to the Radiator Heat Pipes (RHPs) that in turn will further reject it into the environment. However, during this process, heating the condensers of the heat collecting part of the ITTMS, the Diode Heat Pipes (DHPs), is unavoidable and the direction of heat flow reverses. Since this heat is at a higher temperature than 520ºC, reversing the heat flow is not desirable as this may overheat both the cold end of the Stirling converter and the hot end of the highest rank cooler. The role of the Diode Heat Pipe within the Thermal Management System of the Long-lived Venus Lander is to allow the radiator to work higher than 500°C during transit when no waste heat is generated. This is also beneficial for the case when alternative isotopes are used (ex. polonium) and the excess heat is significant at the Beginning of Mission (BOM) when higher heat rejection temperatures will allow reasonable size for the heat pipe radiator. This gas charged alkali metal Diode Heat Pipe (DHP) is the focus of this paper.

B. Background – Diode Heat Pipe

Diode heat pipes are designed to allow the heat to flow from the evaporator to condenser, while preventing flow in the reverse direction. In Fig. 2, a *gas charged* Diode Heat Pipe is presented in principle. The alternate diode heat pipe, with a liquid trap, is not suitable for the current application. Figure 2a shows the pipe under normal operation 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 the condenser temperature becomes higher than the evaporator temperature, $T_{cond} > T_{evap}$, (see Fig. 2b), the NCG is swept to the evaporator and prevents vapor from condensing in the evaporator. However, as seen in Fig. 2b, a small amount of heat is allowed to be transferred from the condenser to the adiabatic zone or the evaporator, which is necessary to continuously sweep and maintain the NCG in the evaporator.

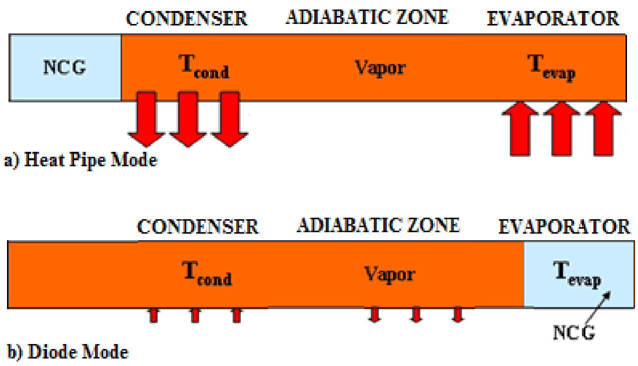


Fig. 2. Gas charged Diode Heat Pipe (DHP) schematic of principle. a) Normal operation (Heat Pipe Mode), $T_{evap} > T_{cond}$ while the NCG is kept in reservoir. b) Non-conducting state (Diode Mode) when $T_{evap} < T_{cond}$ and the NCG is swept to the evaporator blocking it.

III. DIODE HEAT PIPE DESIGN AND TEST SETUP

This section of the paper will provide the diode heat pipe design, overall configuration and dimensions of the pipes, and information regarding the test setup including the selection of the working fluid, , sensor (thermocouple) placement as well as testing strategy.

A. Working Fluid Selection

Based on a heat pipe with 1” (2.54 cm) diameter and 47” (119.4 cm) length, performance calculations were completed for the following three potential alkali metal working fluids: sodium, potassium and NaK. The power limitations considered for these calculations are:

- Sonic Limit
- Viscous Limit
- Capillary Limit
- Flooding Limit
- Entrainment Limit.

As previously noted, the DHP must be able to work in both space and the gravity environment of Venus. On Venus, the entire thermal management system of the Lander is gravity aided. It is expected that the dominant power limitation in these conditions to be flooding or entrainment. Moreover, the ITTMS may be required to work in space as well, for pre-cooling. In this case, the capillary limit is expected to be dominant. In other words, the heat pipes shall be sized for the most limiting case in either environment. Figure 3 shows the overall power limitations for all three fluids. It is clearly shown that potassium is the most capable working fluid in the temperature domain of interest (490-520ºC). For an ITTMS working temperature of 520ºC, potassium may be capable of transporting ~1000W, with power capped by the capillary limit. In conclusion, since the RHPs (Radiator Heat Pipes) will work in a slightly lower temperature range (where sodium and NaK have poorer performance), potassium will be the working fluid for the entire ITTMS, which includes both the DHPs and the RHPs. However, as mentioned, the focus in this paper is the DHP.

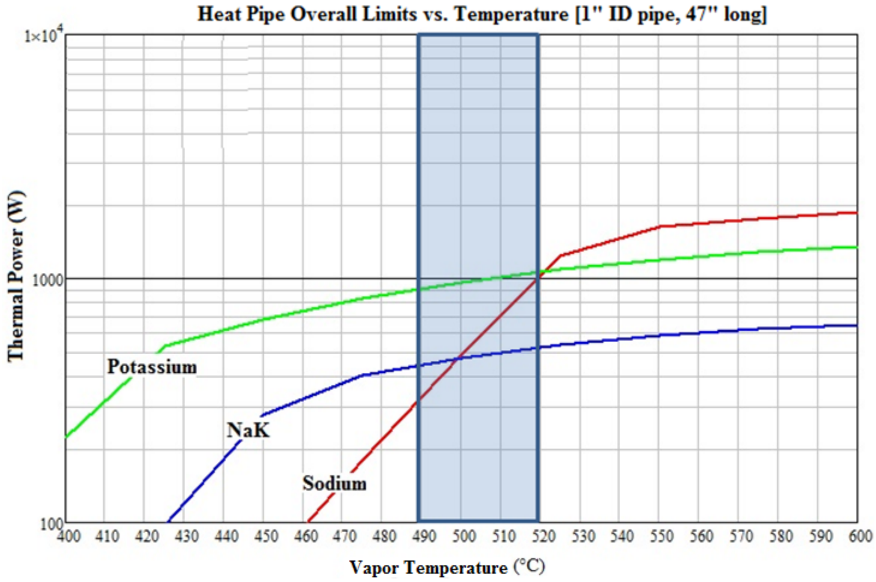


Fig. 3. Overall thermal power limitations for sodium, potassium and NaK

B. Test Setup

Two proof-of-concept potassium Diode Heat Pipes (DHPs) were designed, fabricated and tested. The difference between the two pipes was the size of the reservoir connecting tube. A schematic of the assembly is shown in Fig. 4 and the geometry of the DHPs is shown in Table 1. As seen, the DHP consists of five regions plus a fill tube (the fill tube and reservoir dimensions are not shown in the table). Both DHPs were tested to verify the operation in Heat Pipe Mode, Diode Mode, and the transient conditions between these two modes. In fact, these transients are the main reason for testing a second DHP with a different (larger) diameter of the reservoir connecting tube.

Table 1. DHP geometry

<table>
<tr><th>Section Name</th><th>Length (cm)</th><th>Outer Diameter (cm)</th><th>Wall Thickness (cm)</th><th>Number of screen Wraps</th></tr>
<tr><td>Evaporator</td><td>4.4</td><td rowspan="3">2.5</td><td rowspan="5">0.05</td><td rowspan="3">3</td></tr>
<tr><td>Adiabatic</td><td>81.2</td></tr>
<tr><td>Condenser</td><td>40.6</td></tr>
<tr><td>Reservoir Tube (DHP 1)</td><td>10.2</td><td>0.635</td><td>1</td></tr>
<tr><td>Reservoir Tube (DHP 2)</td><td>10.2</td><td>1.9</td><td>1</td></tr>
</table>

To test the operation, the DHPs were installed in a test fixture used to control the temperature and power loading of the heat pipe. Additionally, the fixture allowed the investigation of the sensitivity of the design to a variety of boundary conditions. Heat was applied to the evaporator of the DHP via electrically resistive cartridge heaters. The cartridge heaters supplied heat through a stainless steel interface block. The length of the heater block is 1.75 inches (4.4 cm) and contacts the DHP around the full circumference of the pipe outside diameter. The condenser of the DHP was cooled using liquid nitrogen (LN). The LN passed through two passages in a stainless steel interface block. The block was interfaced with the DHP along the full 16 inch (40.6 cm) condenser and half (180 degrees) of the DHP circumference. The condenser block was mechanically attached to the DHP via 8 stainless steel clamps. The evaporator thermocouple locations are shown in Fig. 5, while the two modes of operation, Heat Pipe Mode and Diode Mode are shown in Fig 6.

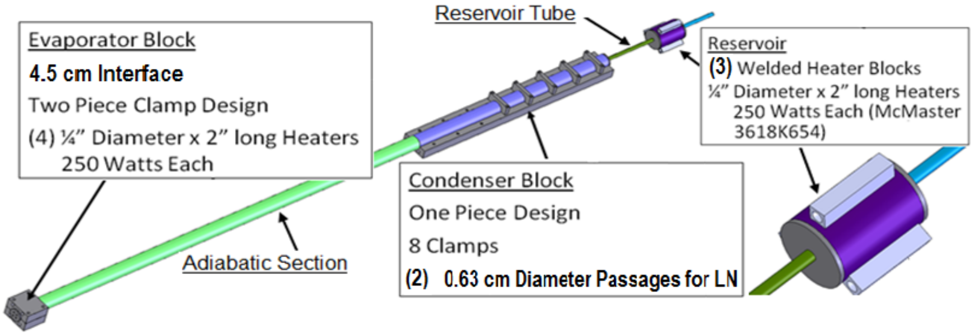


Fig. 4. DHP with test fixture interface blocks

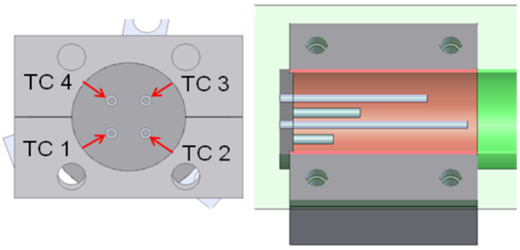


Fig. 5. Evaporator thermocouple schematic

The temperature of the reservoir was controlled using 3 electrically resistive heater cartridges (250 Watts each). The heaters applied power to the reservoir via three stainless steel heater blocks welded to the reservoir body. Each DHP under test was instrumented sufficiently to determine the location of the NCG front in both Heat Pipe Mode and Diode Mode. The temperature was measured using K type thermocouples (TCs). The evaporator had four intrusive TCs that passed through the evaporator end cap. They measured the vapor temperature in the evaporator at equidistant axial locations as shown in Fig 5. The DHP adiabatic section was instrumented with 10 TCs spot welded at equidistant locations. The DHP condenser was instrumented with 10 probe type TCs (intrusive) also at equidistant locations. The DHP reservoir was instrumented with 4 spot welded TCs (not shown in Fig. 4).

Fig. 6 below shows DHP 1, which is the DHP with a thinner reservoir connecting tube. The higher density of thermocouples that can be observed at the end of the condenser was originally created to detect the front location with a good resolution. However, as mentioned above, only 10 equidistant TCs were used for the temperature profile representations that are shown in the next section of the paper.

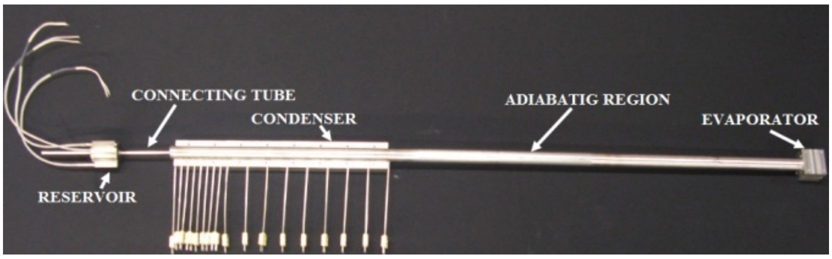


Fig. 6. First Diode Heat Pipe (DHP 1) before testing

C. Testing Strategy and Objectives

The objectives and the strategy of the proof of concept testing are described below:

- Demonstrate heat pipe operation (without NCG blockage of condenser) in Heat Pipe Mode under nominal conditions listed in Table 2
- Demonstrate diode heat pipe operation with NCG blockage of evaporator in Diode Mode under nominal conditions listed in Table 2.
- Demonstrate the transition from one mode to the other.

D. Operating Modes

A brief description of the operating modes is presented below:

Table 2. Temperature targets for relevant DHP components

Temperature	Heat Pipe Mode (ºC)	Diode Mode (ºC)
Evaporator	525ºC	205ºC
Condenser	525ºC	525ºC
Reservoir	525ºC	525ºC

1. During the *Heat Pipe Mode* testing, the heat load (500W) is applied to the evaporator and rejected by the condenser as shown in the upper view of Fig. 7. Electrically resistive heater cartridges are used. During this test the NCG is swept to and maintained in the reservoir by the incoming potassium vapor from the evaporator. A proportional controller is used to vary the liquid nitrogen (LN) flow through the condenser in order to maintain the vapor temperature at the desired value (520-525°C). The reservoir temperature is also maintained at the desired temperature (525-530°C) using electrically resistive heaters and an additional proportional controller. The DHP is oriented with a slight adverse elevation (top of the evaporator 0.1” (0.25cm) above the top of the condenser) to simulate zero-gravity conditions. During this test, the infrared heater is off.

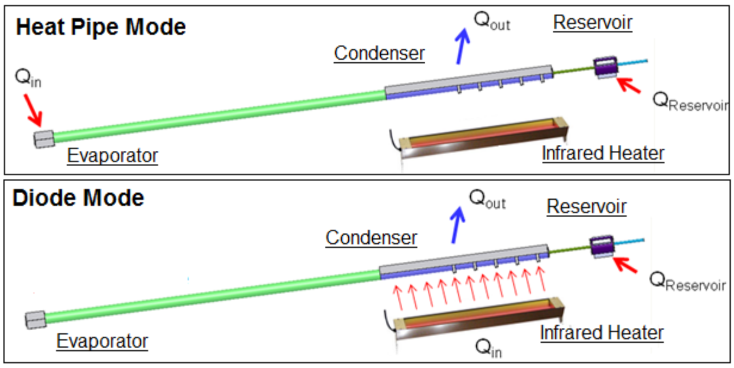


Fig. 7. Operation of the Diode Heat Pipe in Heat Pipe Mode (upper) and in Diode Mode (lower)

2. During the *Diode Mode* testing, power is applied to the condenser by the infrared heater and rejected also via the condenser as shown in the lower view of Fig. 7. The NCG is swept to the evaporator and part of the adiabatic section and it is maintained by the heat leaks. Power is also applied to the reservoir to maintain the desired temperature. No power is supplied to the evaporator. Again, a proportional controller is used to vary the LN flow through the condenser in order to maintain the desired vapor temperature (525-540°C). The reservoir temperature is also controlled and the DHP maintains the same orientation as in the Heat Pipe Mode. The assembly is fully insulated except for the view region between the infrared heater and the condenser. The expected result of the test was that the NCG is swept to the evaporator blocking it. As a consequence, the evaporator, not being heated, will drop in temperature. Also, as a proof of proper NCG charge, the front between vapor and NCG will be located somewhere within the adiabatic region close to the evaporator.
3. *Transient* states are also monitoredl. The transition between the steady states of the two operating modes is important. The influence of the reservoir tube on the transient times is observed and it is expected that the transient times are shorter as the reservoir tube is larger in diameter.

E. Test Sequences

Both Diode Heat Pipes were tested in the following succession of sequences:

- Sequence 1 - Heat Pipe Mode ***steady state***
  - Power applied at the evaporator and cooling at the condenser.
- Sequence 2 - Diode Mode ***transient*** **(**transition from Heat Pipe Mode to Diode Mode)
  - Power applied to the condenser (radiation) and cooling at the condenser. During this sequence, the NCG is swept to the evaporator.
- Sequence 3 - Diode Mode ***steady state***
  - Power applied to the condenser (radiation) and cooling at the condenser, it is in fact the end of Sequence 2.
- Sequence 4 - Heat Pipe Mode ***transient*** (transition from Diode Mode back top Heat Pipe Mode)
  - Power applied at the evaporator and cooling at the condenser. During this sequence, the NCG travels back to the condenser and reservoir.
- Sequence 5 - Heat Pipe Mode ***steady state*** (identical to Sequence 1)
  - Power applied at the evaporator and cooling at the condenser, it is in fact the end of Sequence 4.

The experimental results presented in the next section of the paper are explained based on the above described sequences.

IV. EXPERIMENTAL RESULTS

Both DHPs were tested following the same strategy and procedure. Because of similarity of the experimental results, only the results obtained for DHP 2 are presented in this paper. However, the difference in transient times of DHP 1 and DHP 2 are briefly discussed at the end of the paper.

A. Initial Testing – Setup Calibration

The initial test consisted of calibration of the testing setup. Heat losses to the ambient were evaluated for a working temperature of 525ºC in order to properly quantify the power transported by the tested pipe. The reservoir was also heated separately to maintain the same temperature as the evaporator, 525ºC. The heat losses were found to be approximately 160W for each DHP.

B. Experimental Results (DHP 2)

The second Diode Heat Pipe (DHP 2) was fabricated and tested to observe the influence of the reservoir tube diameter on the NCG motion from the reservoir/condenser to the evaporator and back to the reservoir/condenser. Figure 8 shows the steady state temperature distributions along the DHP 2 for Sequences 1 and 3, Heat Pipe (red) and Diode (blue) Modes, for a vapor temperature of 525ºC. Total power (electric) was 660W since the heat losses were measured as ~ 160W and the targeted power to be transported by the pipe was ~500W.

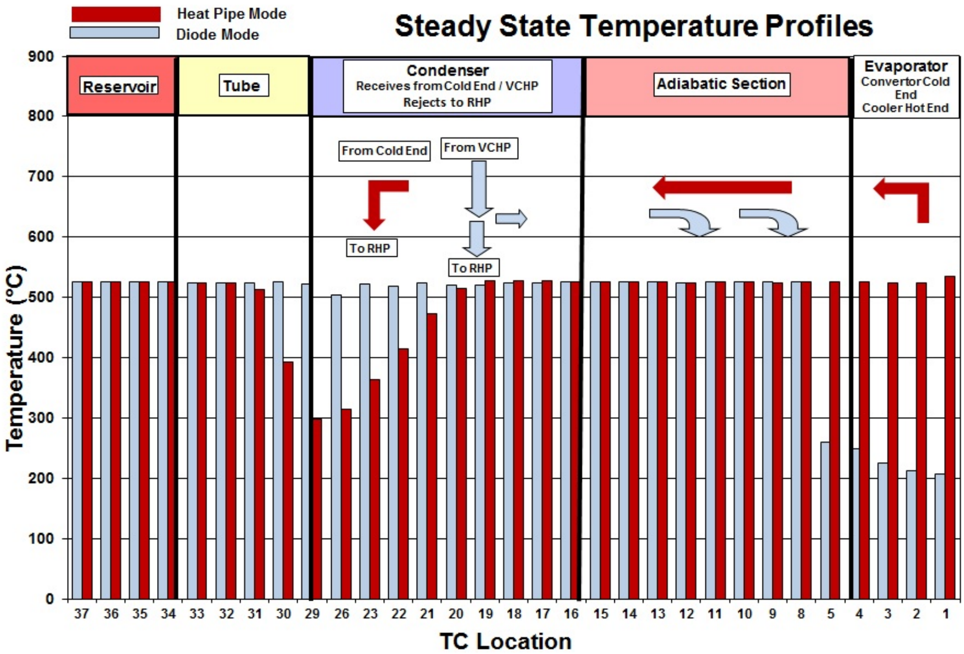


Fig. 8. Temperature profiles along the DHP 2: Sequences 1 (steady state of the Heat Pipe Mode - red) and 3 (steady state of the Diode Mode - blue)

During the Diode Mode, the power was applied at the condenser by radiation while the evaporator was not heated. Cooling of the condenser was active at all the times, including the Diode Mode. Similar to the DHP 1 experiment, during the Heat Pipe Mode, the heat flow was from the evaporator to the condenser. When the condenser was heated (by radiation), the heat flow was divided. The bulk of the heat was further rejected by the condenser into the chiller block while a small portion of the heat flowed in reverse toward the evaporator and was rejected as losses within the adiabatic section. As already stated, this heat flowing in reverse is always necessary in a gas charged Diode Heat Pipe to maintain the NCG in the evaporator. It can be observed in Sequence 1 (looking at the low temperature portion in the condenser) that the amount of NCG was slightly oversized, however, less than in the DHP 1's case which is not shown here. A drawback of both pipes was the small diameter (0.25") of the fill tube. This rather reduced dimension contributed significantly to clogging of the pipe with potassium. In these conditions, a dynamic adjustment of the NCG amount was not possible leading to inaccurate NCG charging in both pipes. Also, since the reservoir tube was not heated, its temperature was significantly lower than the nominal value of 525ºC. Temperature distribution corresponding to Sequence 3, the steady state of the Diode Mode, shows that the NCG front is indeed within the adiabatic zone, however, significantly far from the evaporator (~ 15 cm). It confirms the fact that the NCG charge is oversized.

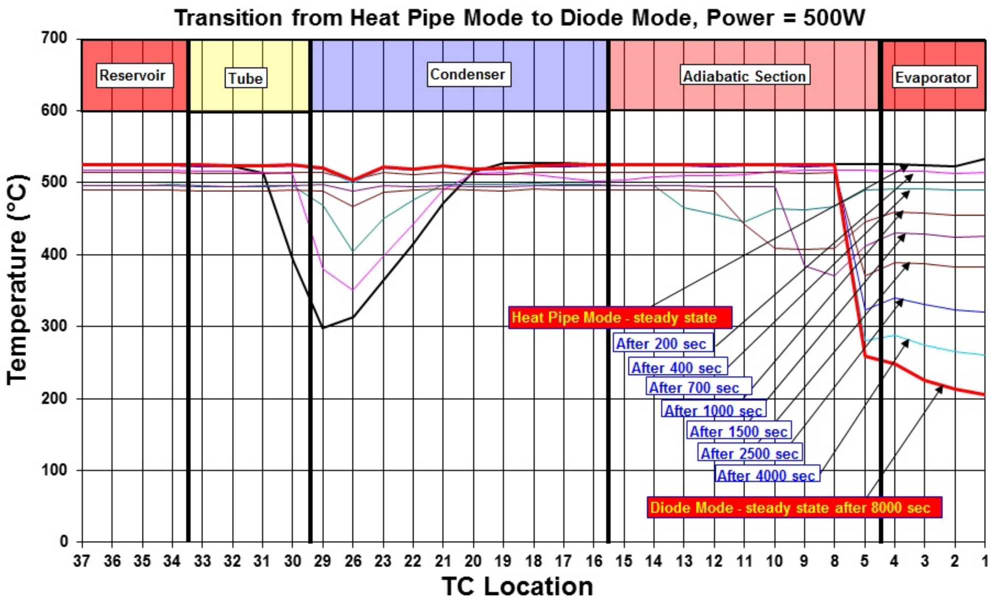


Fig. 9. Temperature profiles along the DHP 2 during the transition from Heat Pipe Mode to the Diode Mode. This is Sequence 2

Figure 9 shows instantaneous temperature profiles (Sequence 2) during the transition of the pipe from Sequence 1 to Sequence 3 (Heat Pipe Mode to Diode Mode). Observe that the NCG "bubble" is swept by the vapor to the evaporator. As the NCG accumulates in the evaporator, a new separation front is formed within the adiabatic section, before the evaporator. During Sequence 3, the evaporator is fully blocked by the NCG and most of the heat is rejected to the chiller block. The time duration of Sequence 2 is ~ 8,000 sec, significantly longer than the time duration of the Sequence 2 for the DHP 1 case that was 4400 sec (see Table 3 below) . The process is slower despite the larger diameter of the reservoir tube and less NCG overcharge. This unexpected result shows significant uncertainaty regarding the initial location of NCG within the reservoir, connecting tube and condenser that influenced the duration of Sequence 2. The steady state reached in Sequence 1 also becomes questionable. Explanations will be sought in future work. However, the duration of Sequence 2 is not critical for this particular Diode Heat Pipe application.

Figure 10 below shows instantaneous temperature profiles (Sequence 4) during the transition of the pipe from Sequence 3 (Diode Mode) back to the steady state of the Heat Pipe Mode (Sequence 5). The NCG "bubble" is now swept back to the reservoir. The duration of the Sequence 4 is ~ 3300 sec. This process (Sequence 4) is significantly faster than Sequence 2, the transition to the Diode Mode. Moreover, Sequence 4 of DHP 2 is also significantly shorter than Sequence 4 of DHP 1 (~10,000 sec.) as shown in Table 3 below. This time, both the smaller amount of NCG and the increased size of the reservoir tube determined a much faster Sequence 4. Pushing the NCG in the reservoir to replace the existing super heated vapor of potassium was less demanding in this case. This increase in the speed of Sequence 4 in the DHP 2 case was expected and the authors believe that both factors, the larger diameter reservoir tube and the smaller amount of NCG were decisive.

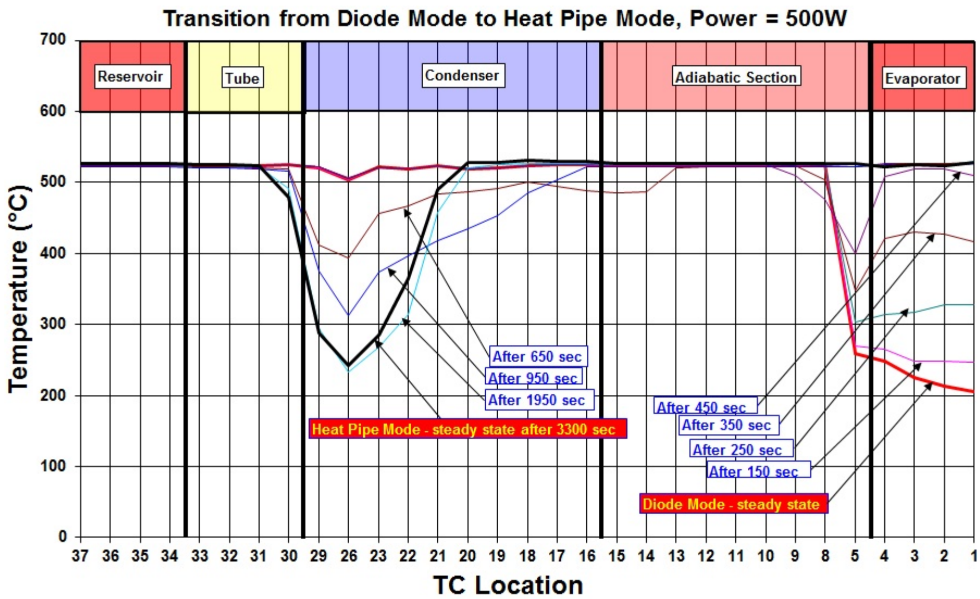


Fig. 10. Temperature profiles along the DHP 2 during the transition from Diode Mode back to the Heat Pipe Mode. This is Sequence 4

Figure 11Fig. shows the transient representation of the entire DHP 2 experiment where the most relevant temperatures are shown. All five sequences are represented and the trend towards steady state can be observed at the end of Sequences 2 and 4.

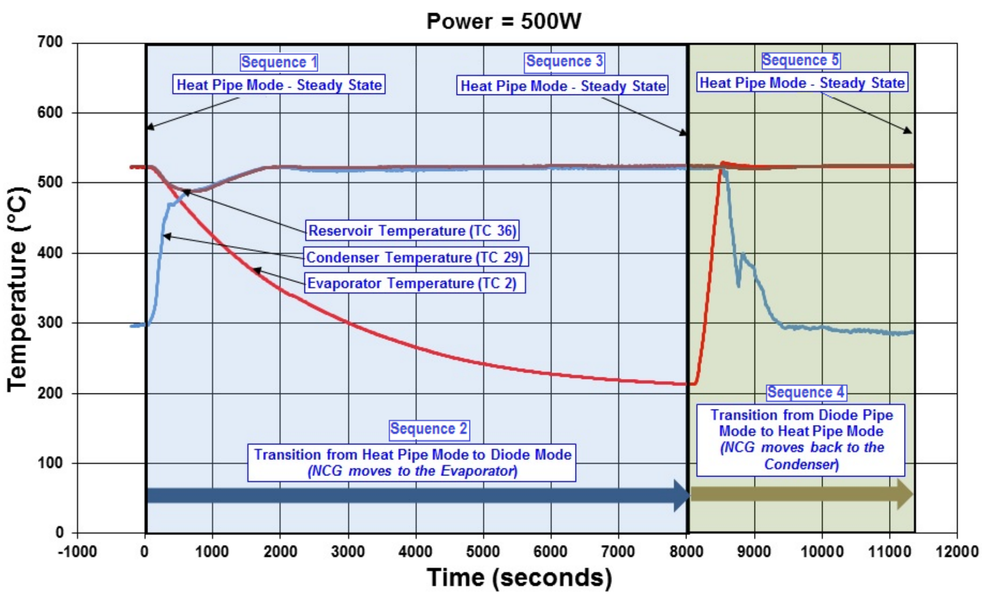


Fig. 11. Temperature profiles along the DHP 2 during the transition from Diode Mode back to the Heat Pipe Mode. This is Sequence 4

Table 3. Temperature targets for relevant DHP components

	DHP 1 (thin reservoir tube and more NCG)	DHP 2 (thick reservoir tube and less NCG)
Sequence 2 (HP Mode to D Mode)	4400s	8000s
Sequence 4 (D Mode to HP Mode)	10000s	3300s

V. CONCLUSION

The Thermal Management System for one of the current designs of the Long-lived Venus Lander requires alkali metal Diode Heat Pipes as main components for waste heat rejection. Two proof of concept pipes were designed, fabricated and successfully tested in Heat Pipe Mode, Diode Mode and transient mode. The working fluid was potassium. Both Diode Heat Pipes demonstrated the concept at the desired temperatures (~525ºC). The duration needed for the pipe to turn from Heat Pipe Mode to Diode Mode seems to increase when both the diameter of the reservoir tube and the amount of NCG decrease. This result was unexpected and both the true NCG location and the steady state reached in Sequence 1 become questionable. A full explanation is under investigation. However, the duration required for the pipe to transition from Diode Mode back to Heat Pipe Mode tends to decrease when the diameter of the reservoir tube is increased. Both Diode Heat Pipes transported 500W in conservative “space” orientation (horizontal position versus gravity aided). Further development would involve the design, fabrication and testing of a full scale Diode Heat Pipe (for the 2.5 kW Venus Lander) and its integration within the Intermediate Temperature Thermal Management System.

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