Non-Integrated Hot-Reservoir Variable Conductance Heat Pipes

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Presented By

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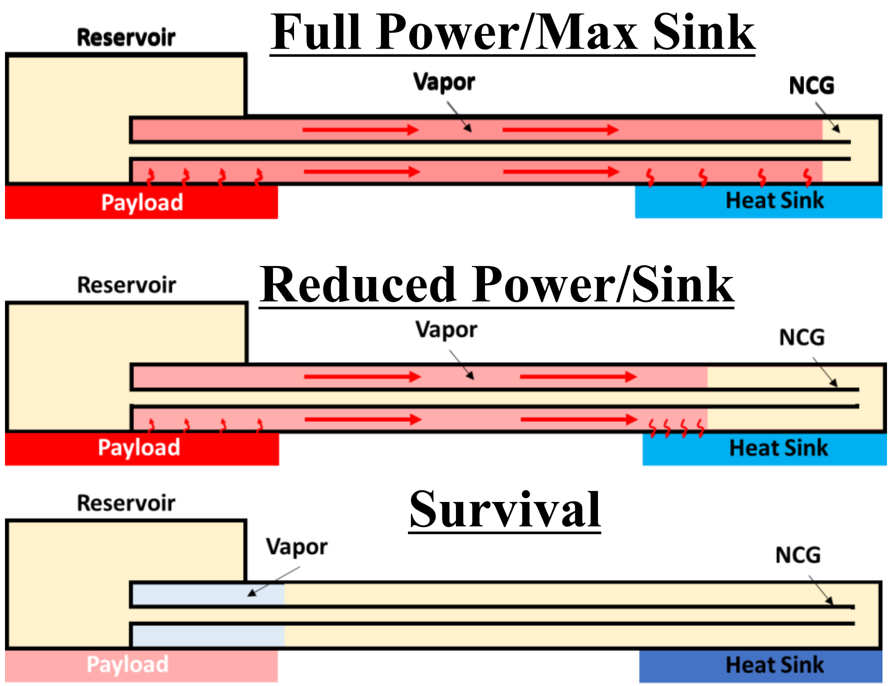
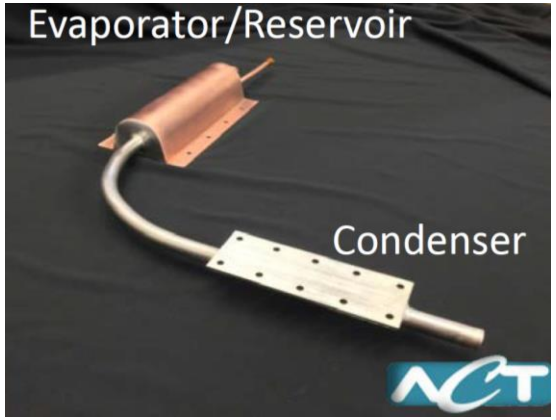
Background and Motivation

- Warm-reservoir VCHPs provide tighter thermal control and larger turndown ratio than a conventional cold-reservoir VCHP
  - Ideal for applications with highly variable thermal environments such as lunar night survival
- Two key challenges for warm-reservoir VCHPs on the lunar surface
  - Mitigating the negative effects of working fluid migrating to the NCG reservoir
  - Reliable startup and operation in both microgravity and gravity aided environments
- ACT designed a fabricated two <u>Non-Integrated</u> <u>Warm-Reservoir</u> VCHPs with <u>Hybrid Wicks</u> for lunar surface applications
  - EDU for NASA's VIPER Thermal Management System
  - Flight hardware for Astrobotic's Lunar Lander Peregrine I



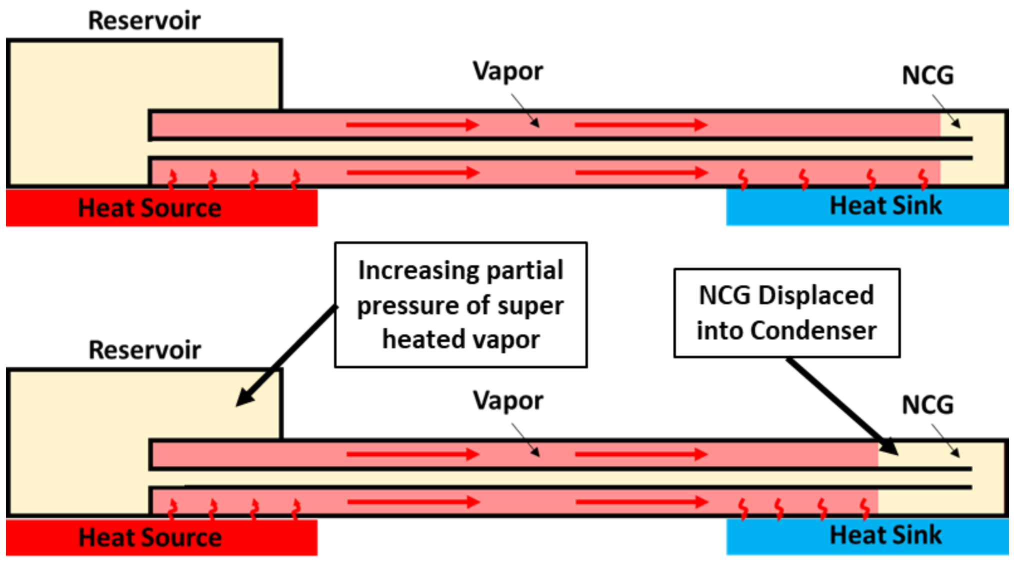


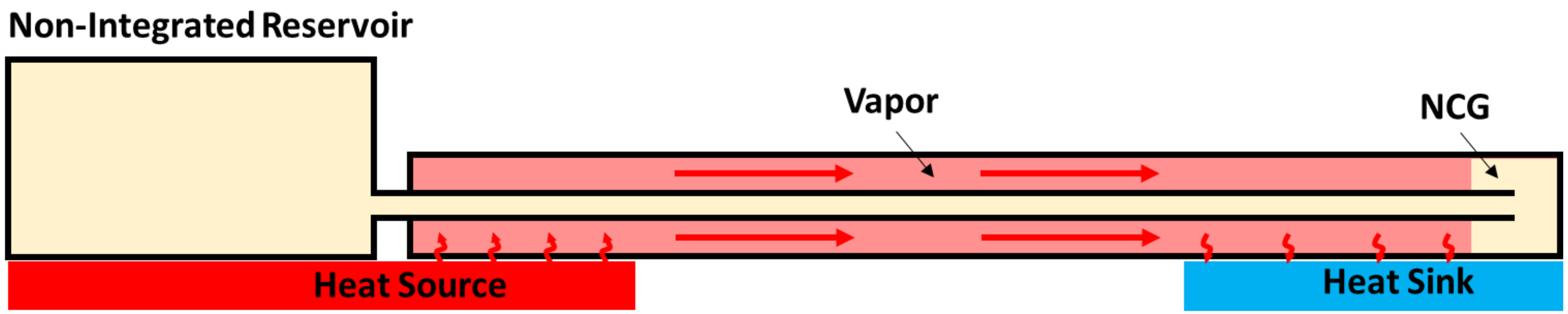
VCHP Tested onboard ISS

Non-Integrated Warm Reservoir

- Humidity in the reservoir displaces NCG increasing overall thermal resistance
  - Diffusion during long periods of non-operation
  - Disturbances can cause working fluid to move to the reservoir

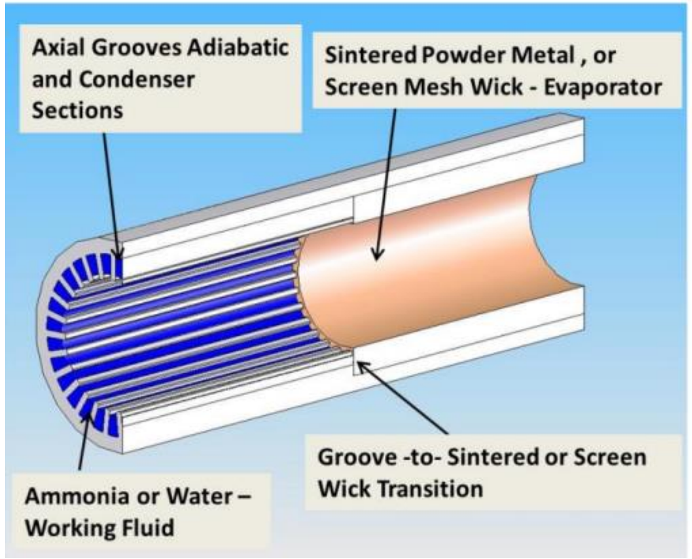
- Independent heating of the reservoir can be used to purge the reservoir of working fluid
  - A non-integrated reservoir allows the reservoir to be heated separately from the evaporator
  - Prior to operation, independent low-power heating can be applied to the reservoir to purge working fluid and restore ideal operation

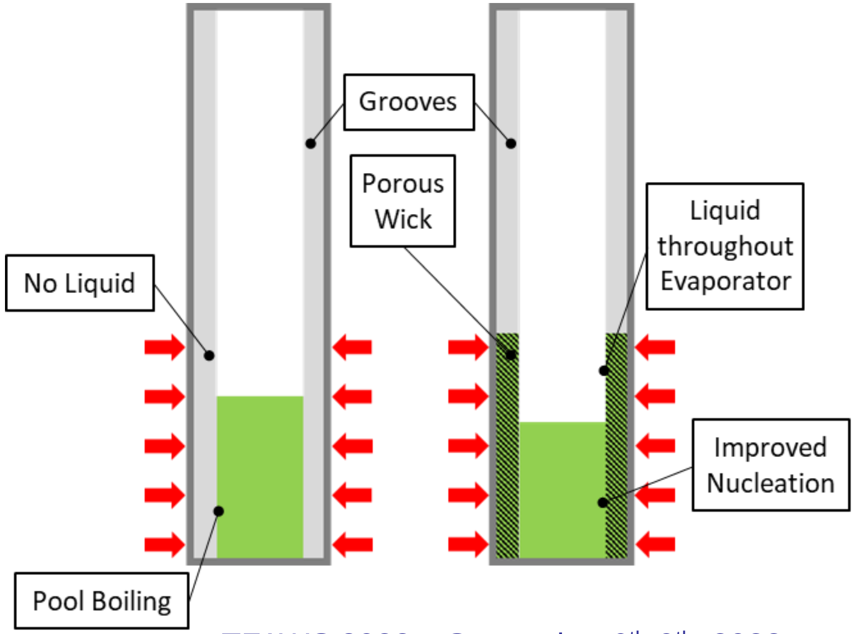




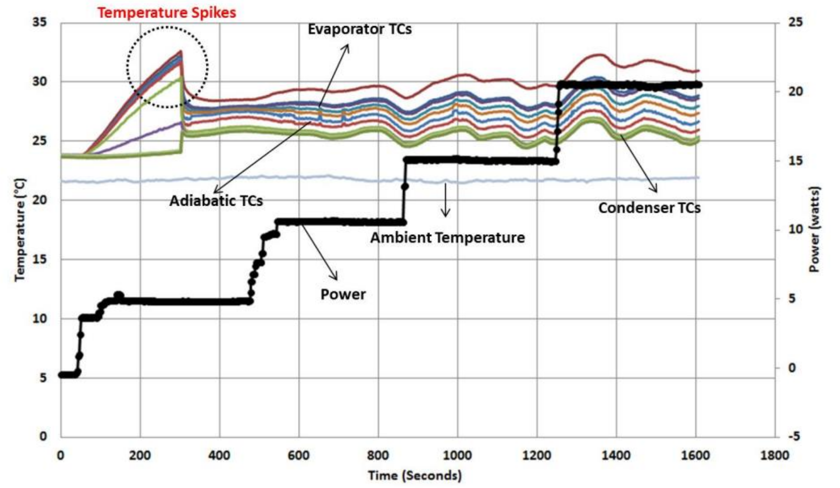
Hybrid Wick

- Grooved heat pipes are commonly used in microgravity
  - High permeability allows for large powers carried over long distances
- On the lunar (or planetary surface) gravity-aided orientation is preferred
  - Liquid pooling in the evaporator can lead to temperature spikes during startup
- A hybrid wick combines a porous wick in the evaporator with grooves in the adiabatic/condenser
  - Improved nucleation in the pool
  - Improved liquid distribution in the evaporator

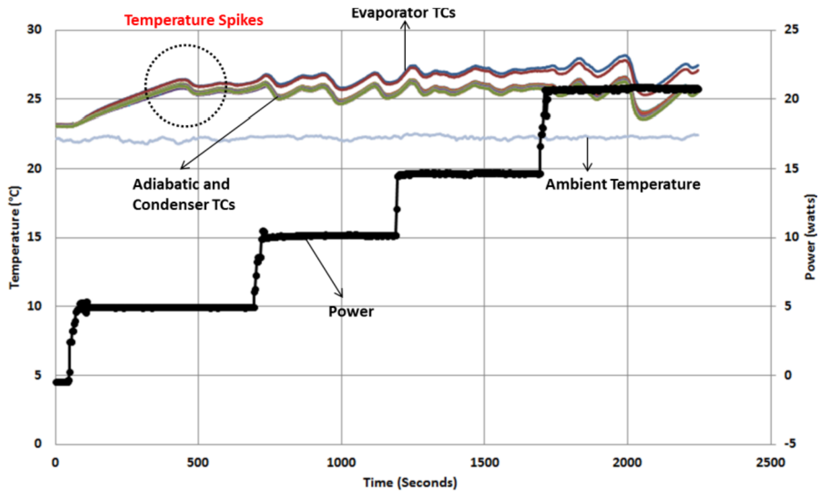




Startup of Grooved Heat Pipe



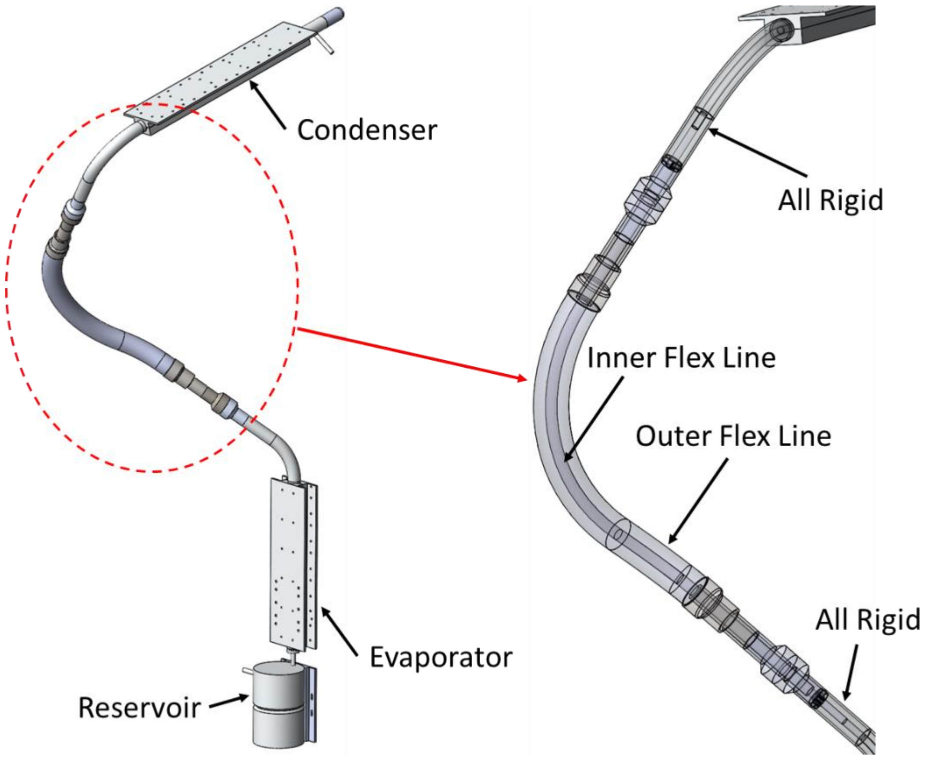
Startup of Hybrid Wick Heat Pipe

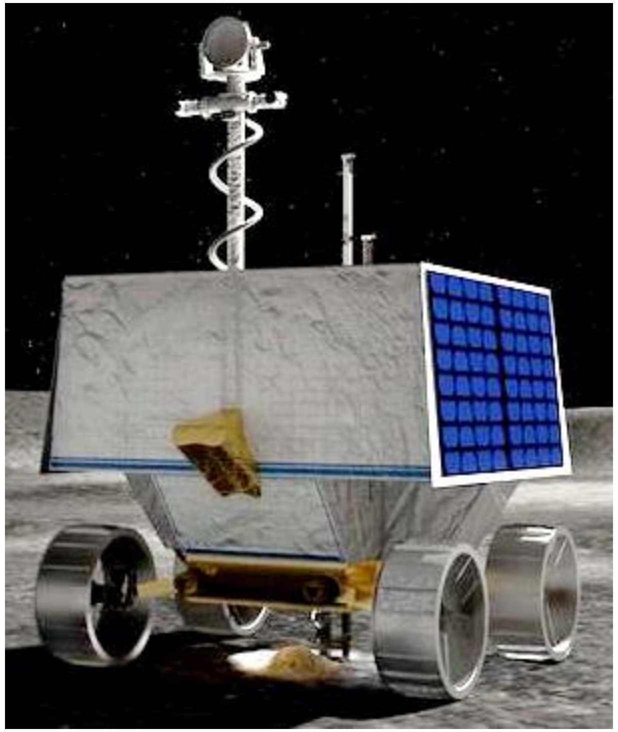


Abaneh, M. et al. "Hybrid Heat Pipes for Lunar and Martian Surface and High Heat Flux Space Applications," ICES-2016-51

VIPER VCHP

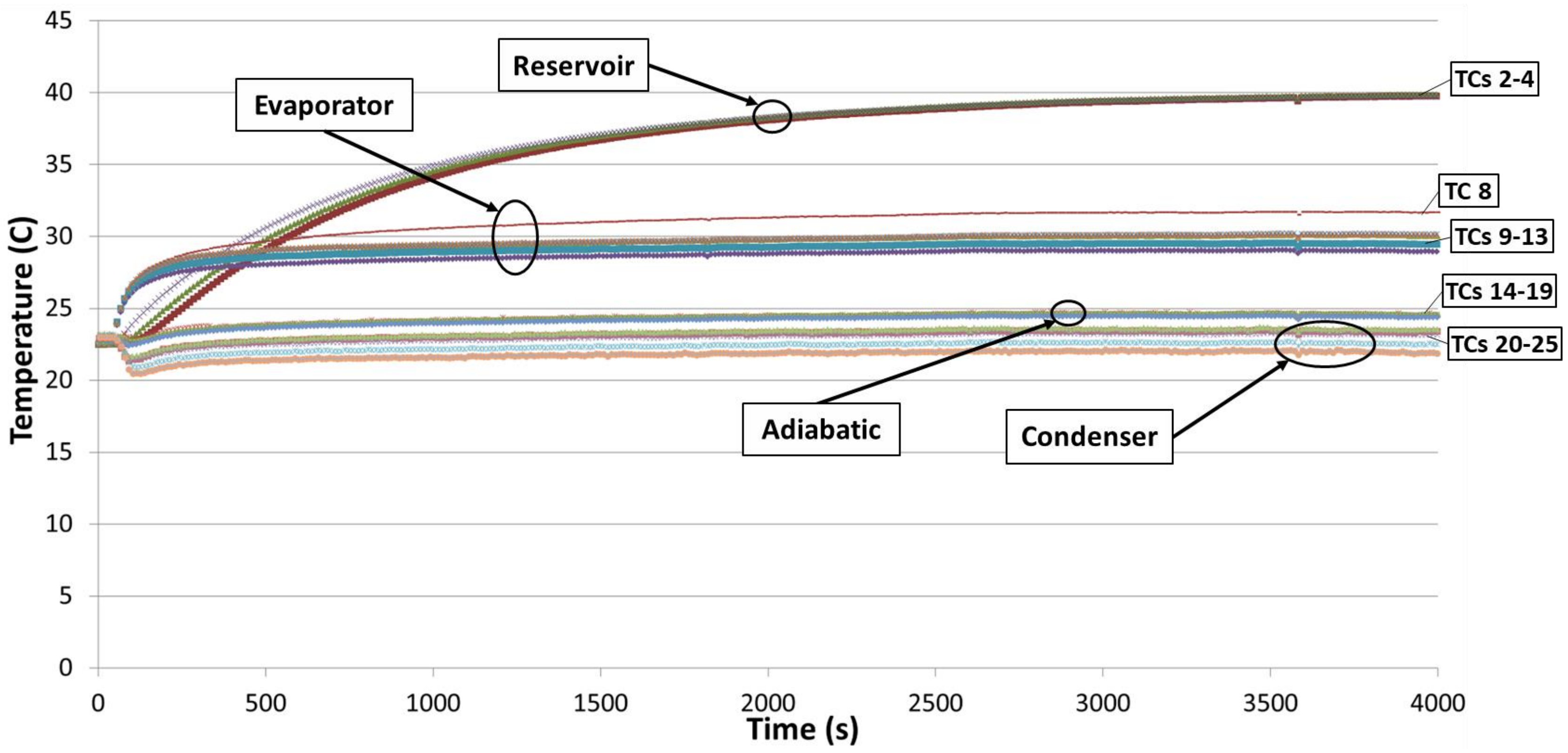
- NASA's VIPER set to explore lunar south pole for 100-day mission
- ACT designed/fabricated a warm-reservoir VCHP for Engineering Demonstration Unit
  - Carry heat from Warm Electronics Box to Radiator Panels
- Aluminum-Ammonia Non-Integrated Warm-Reservoir VCHP
  - Sized for 147W
  - Total length = 1.47 m
  - Screen wick in evaporator
  - Bi-metallic adiabatic section
  - Flexible adiabatic section

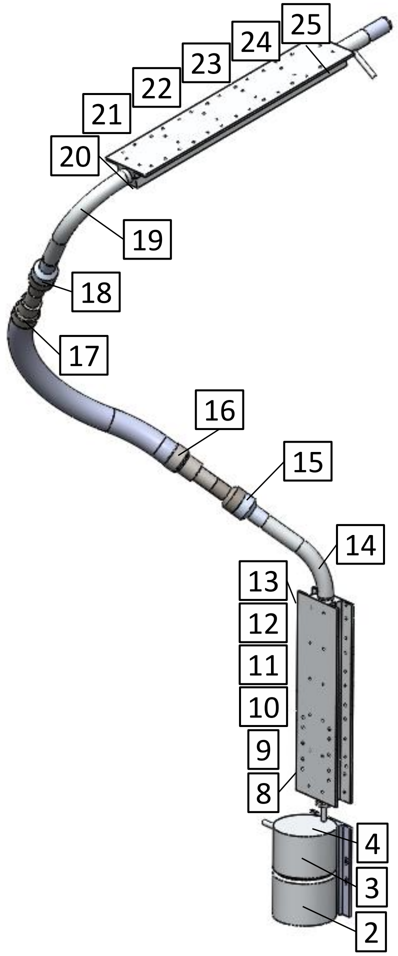




Artist's concept of NASA's VIPER

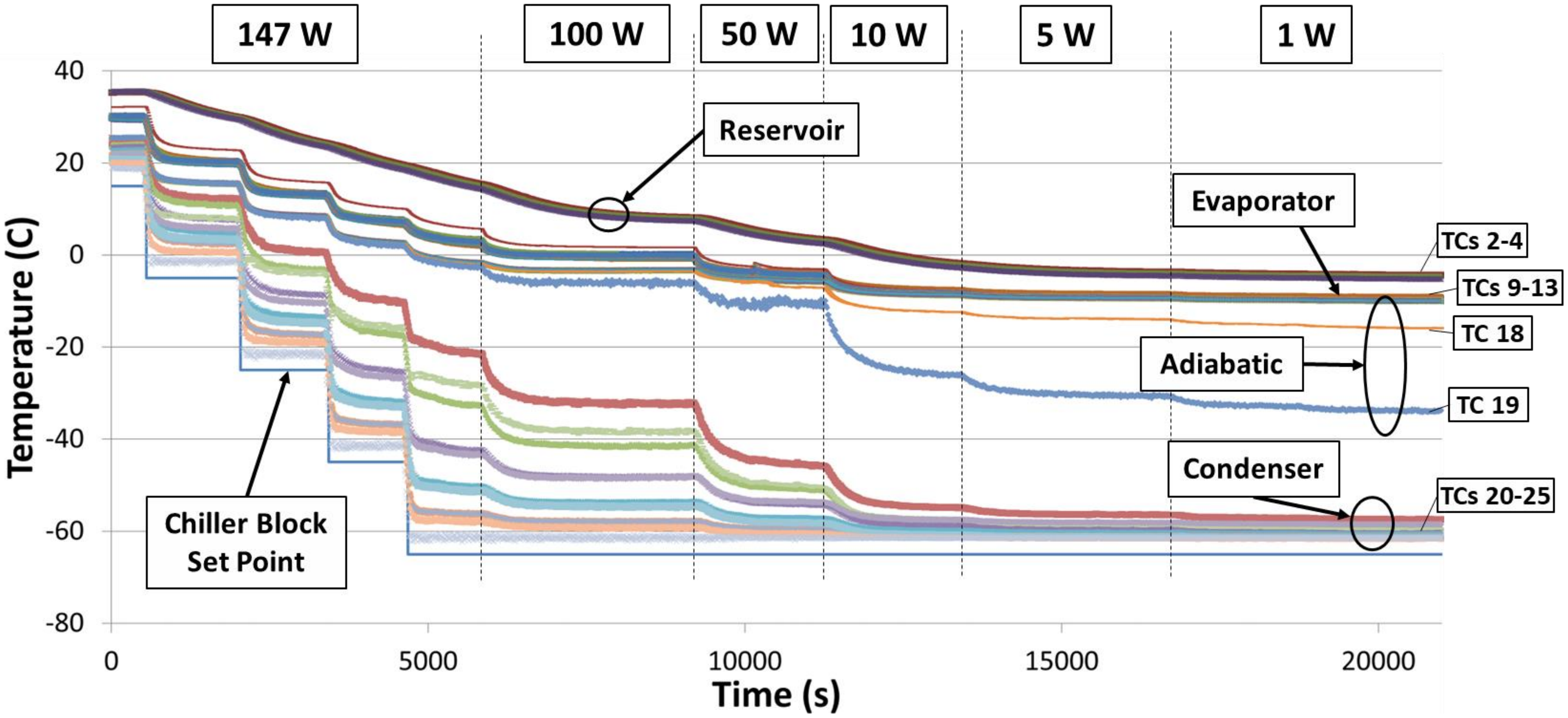
VIPER VCHP: Startup

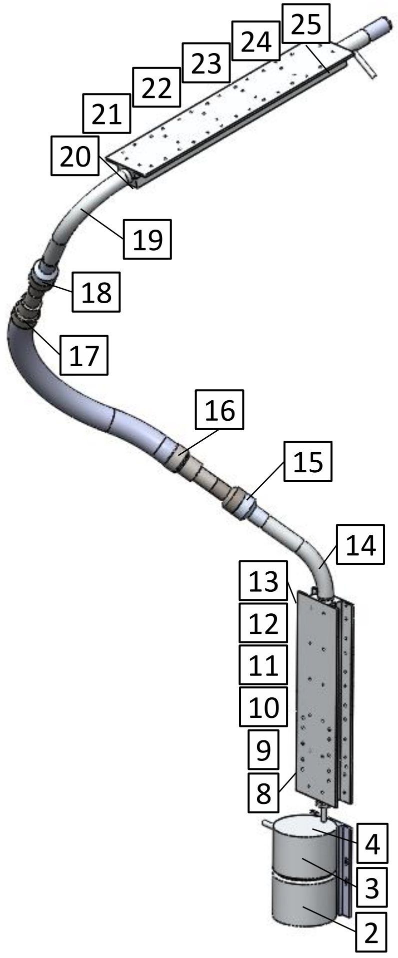




- 147 W applied to evaporator
- Screen wick in the evaporator successfully prevents temperature spikes during startup

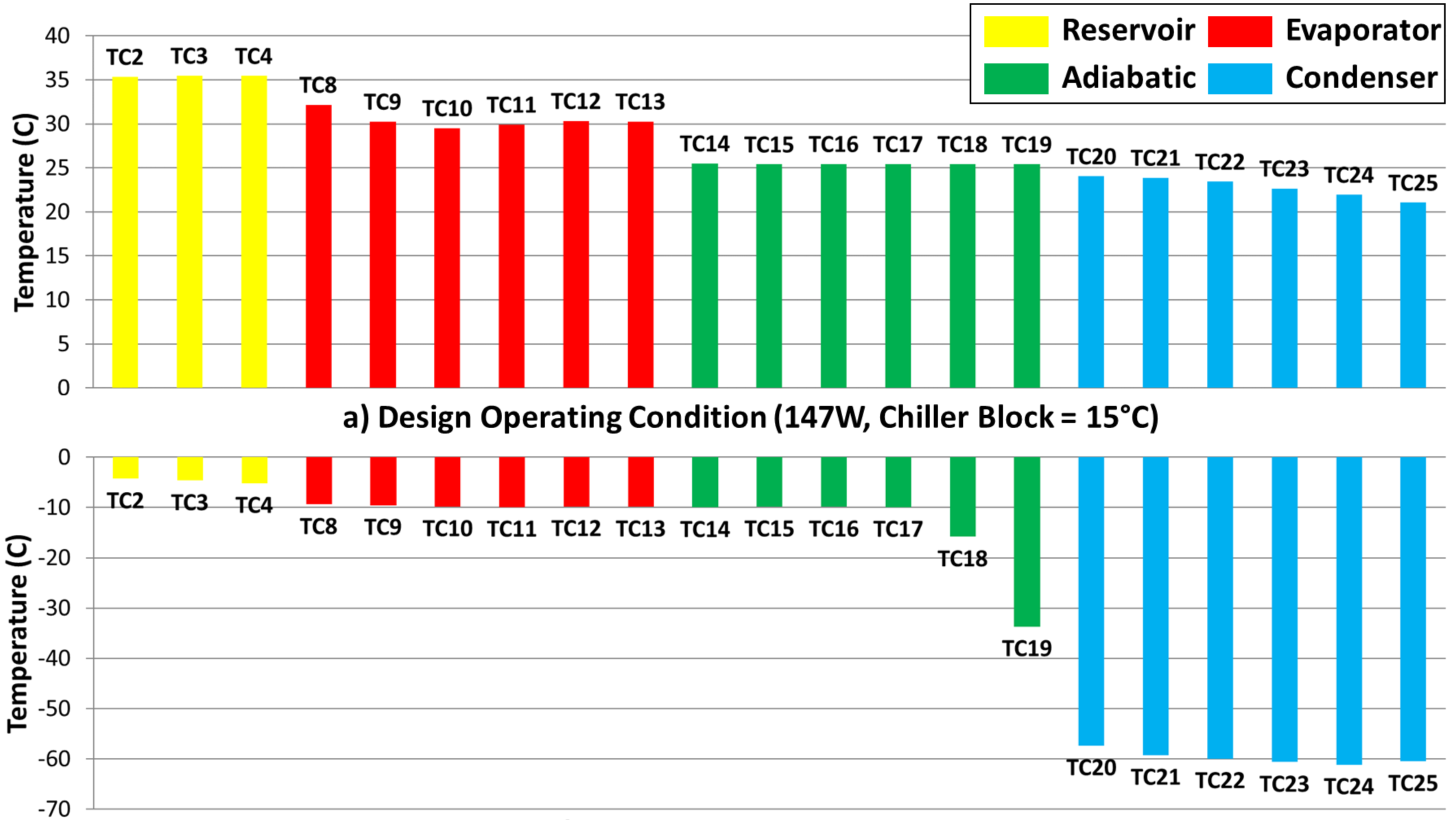
VIPER VCHP: Thermal Control Demonstration





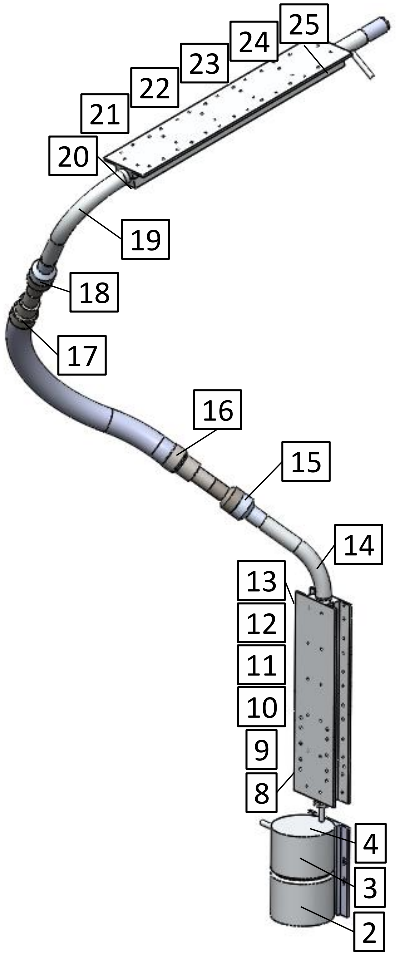
- At 147W and chiller block set point reduced from +15°C → -65°C
  - Evaporator temperature: 30°C → 2.8°C
- Chiller block setpoint -65° and power reduced from 147W → 1W
  - Evaporator temperature: 2.8°C → -9.8°C

VIPER VCHP: Turndown Ratio



a) Design Operating Condition (147W, Chiller Block = 15°C)

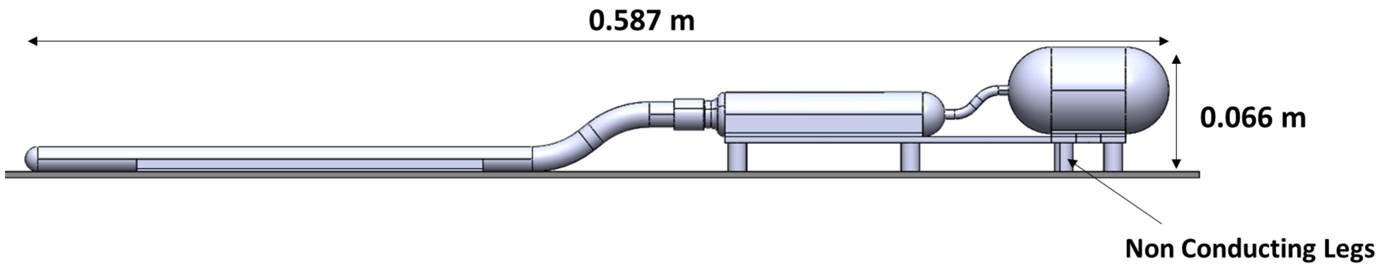
b) Low Temperature/Low Power Condition (1W, Chiller Block = -65°C)

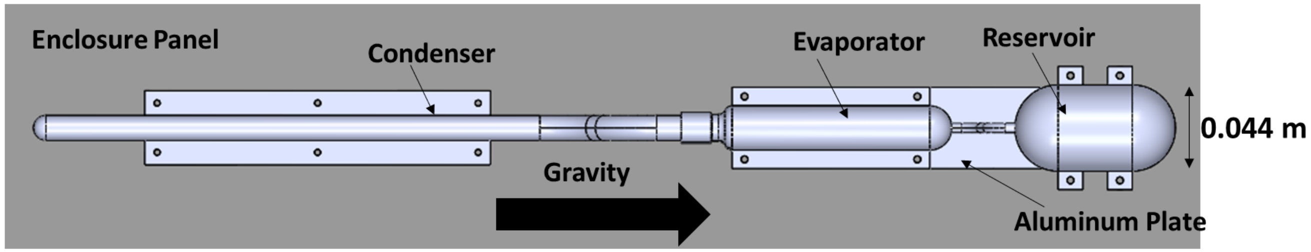


- Maximum Conductance: 9.8 W/K
- Minimum Conductance: 0.018 W/K
- Turndown Ratio: 544:1

Astrobotic VCHP

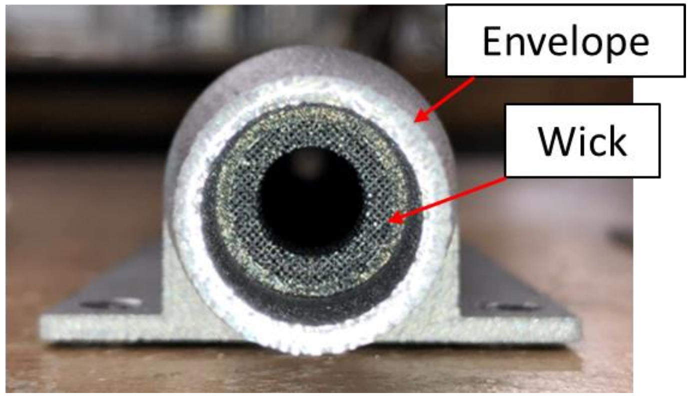
- ACT designed/fabricated a warm-reservoir VCHP as flight-hardware Astrobotic's Lunar Lander Peregrine I
  - Will operate as a stand alone Technology Demonstration Unit
  - Will operate in microgravity and on the lunar surface
- Aluminum-Ammonia Non-Integrated Warm-Reservoir VCHP
  - 3D printed evaporator
  - 3D printed wick interfaces with grooved extrusion

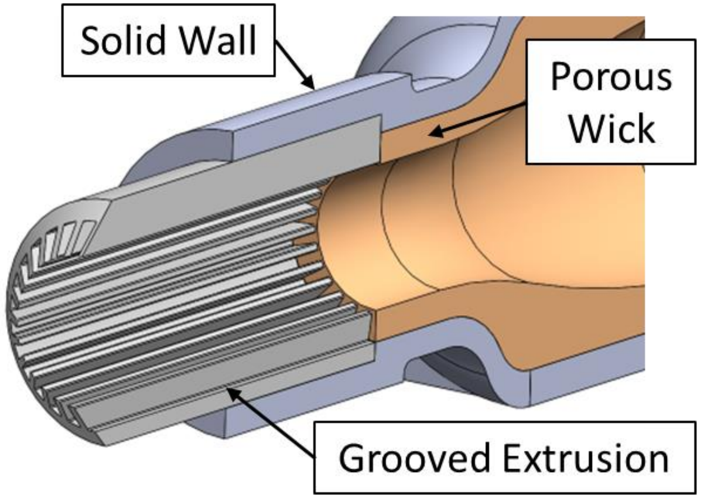


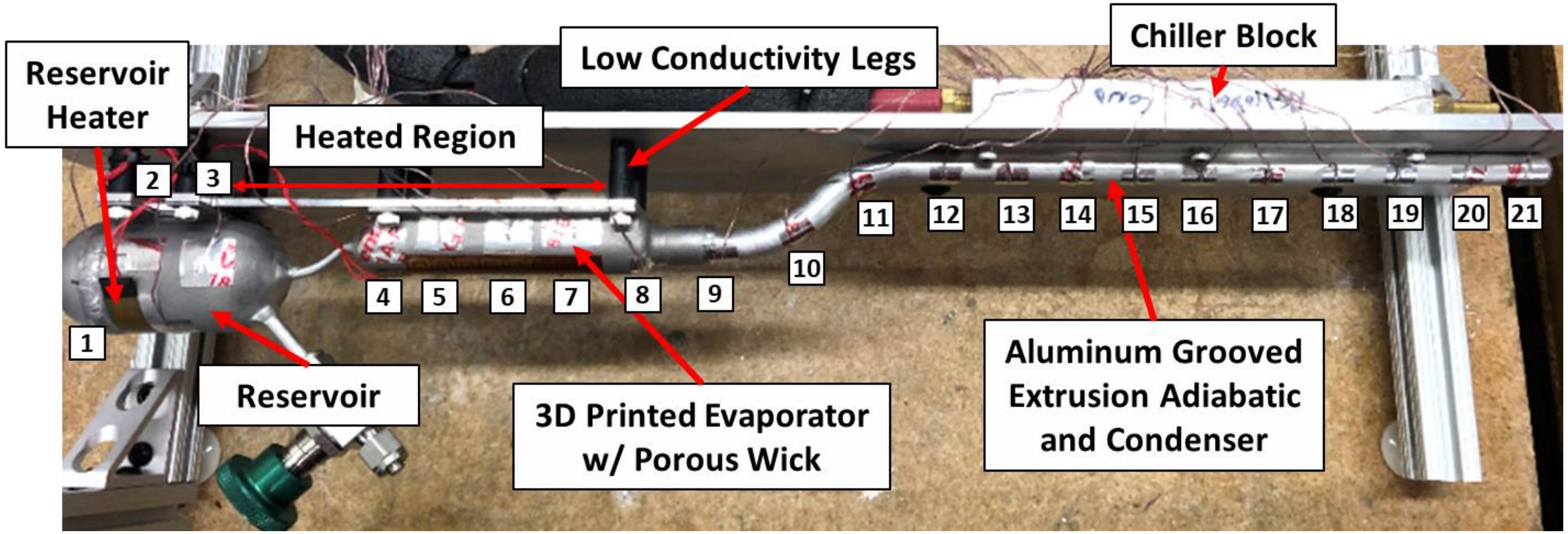


Astrobotic's Peregrine Lunar Lander in Mid-Latitude Configuration

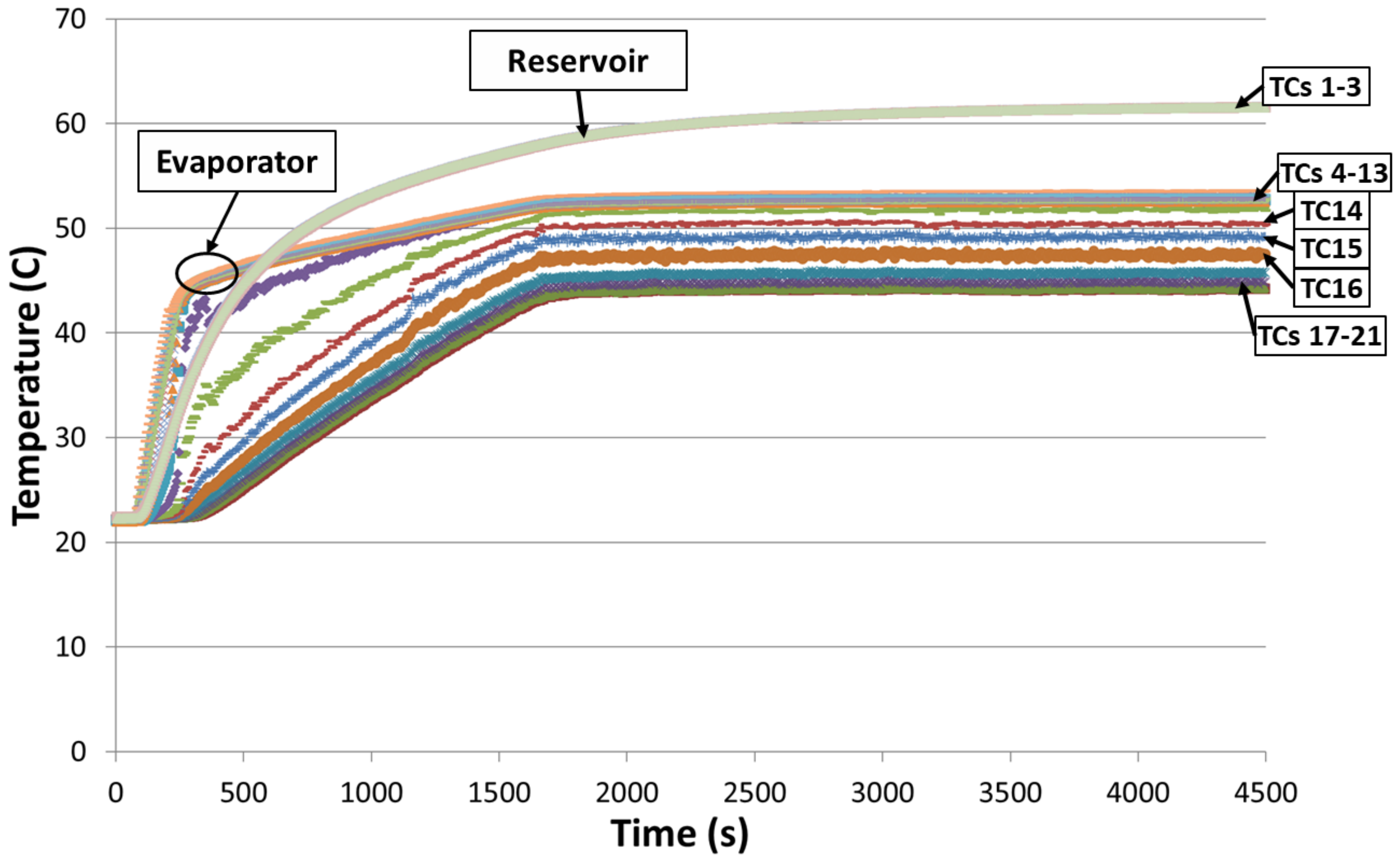
Astrobotic VCHP: Fabrication

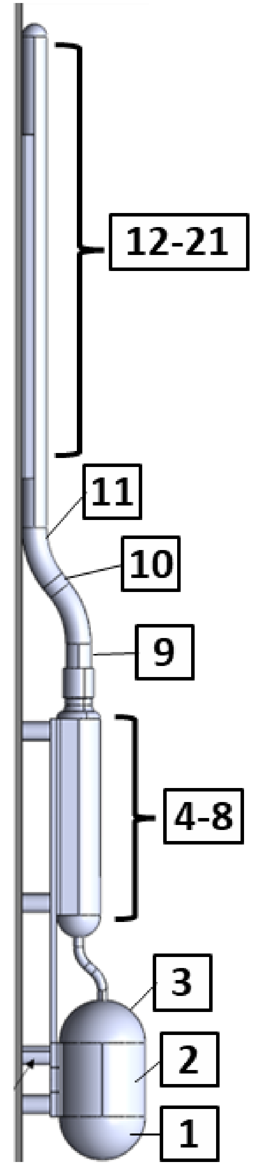




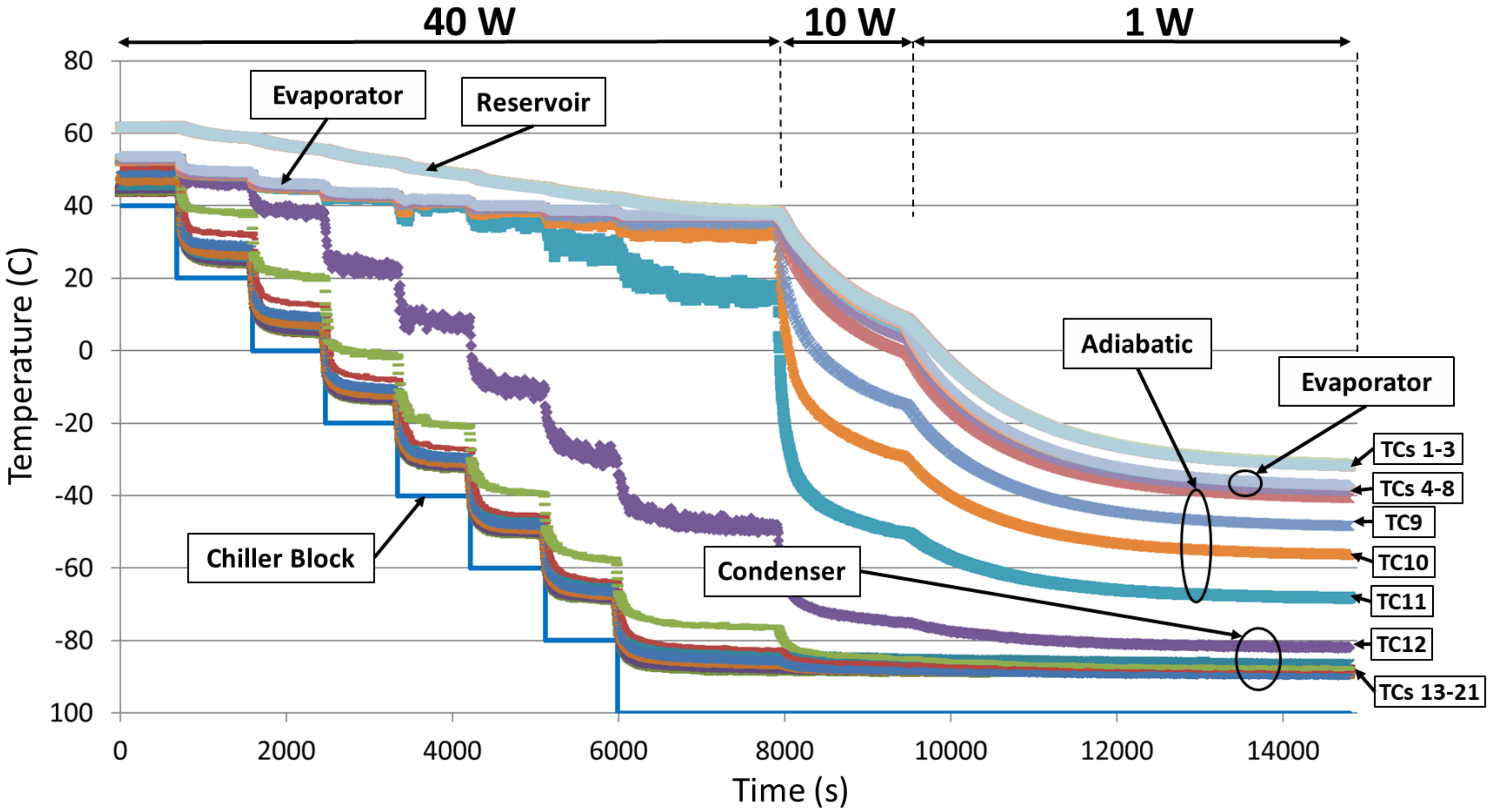


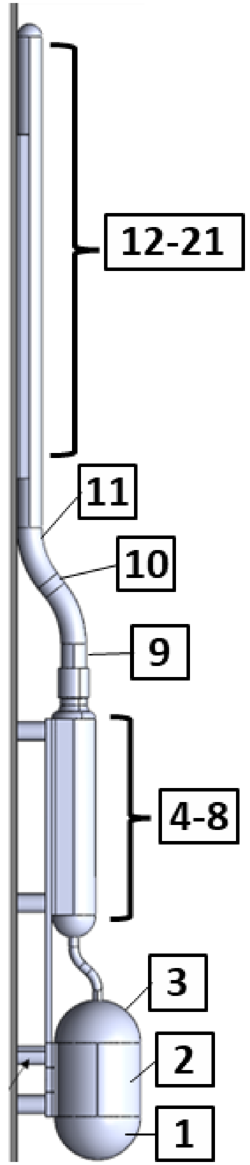
Astrobotic VCHP: Startup





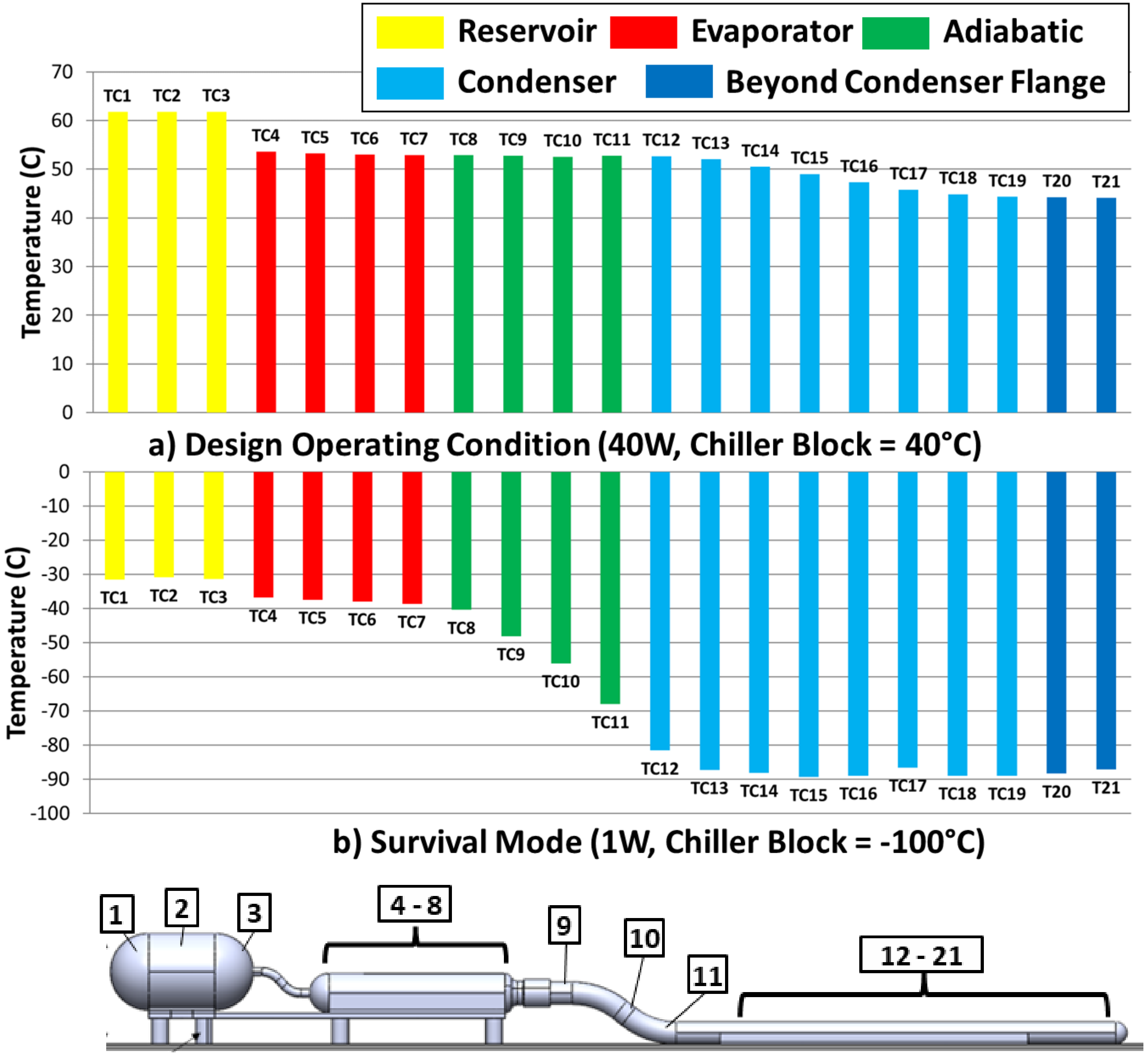
- 40 W applied to evaporator
- 3D Printed wick in the evaporator successfully prevents temperature spikes during startup

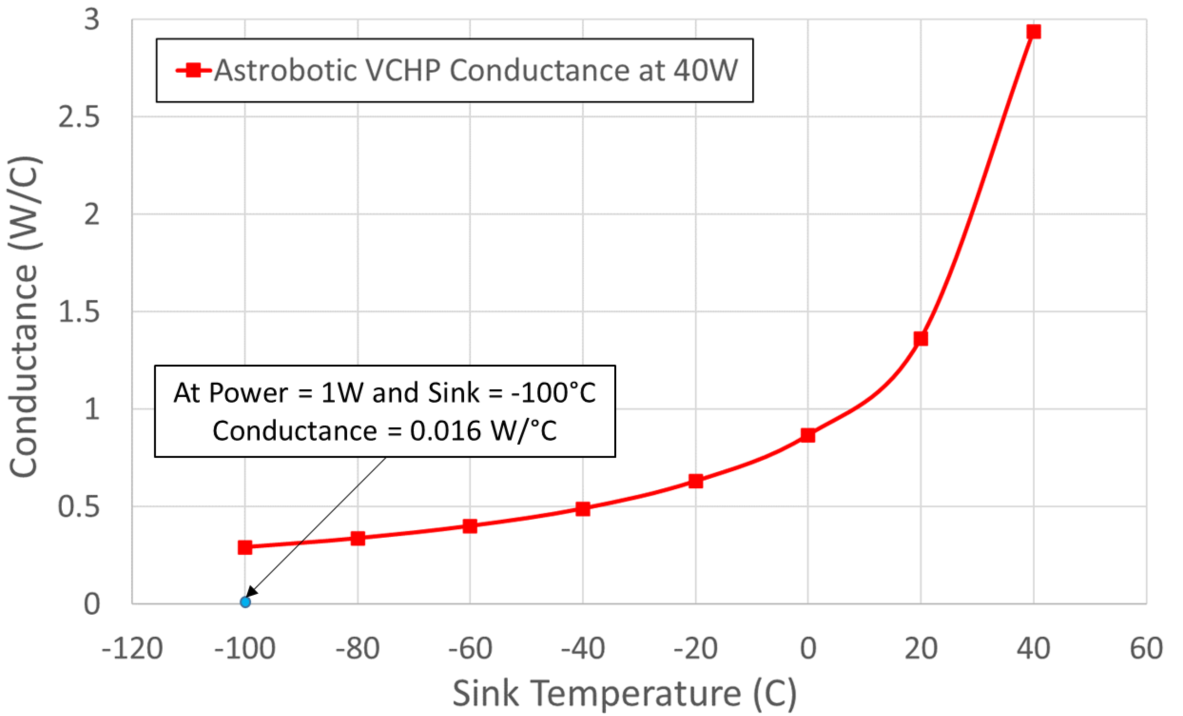




- At 40W and chiller block set point reduced from +40°C → -100°C
  - Evaporator temperature: 53.6°C → 37.3°C
- Chiller block setpoint -100° and power reduced from 40W → 1W
  - Evaporator temperature: 37.3°C → -37.0°C

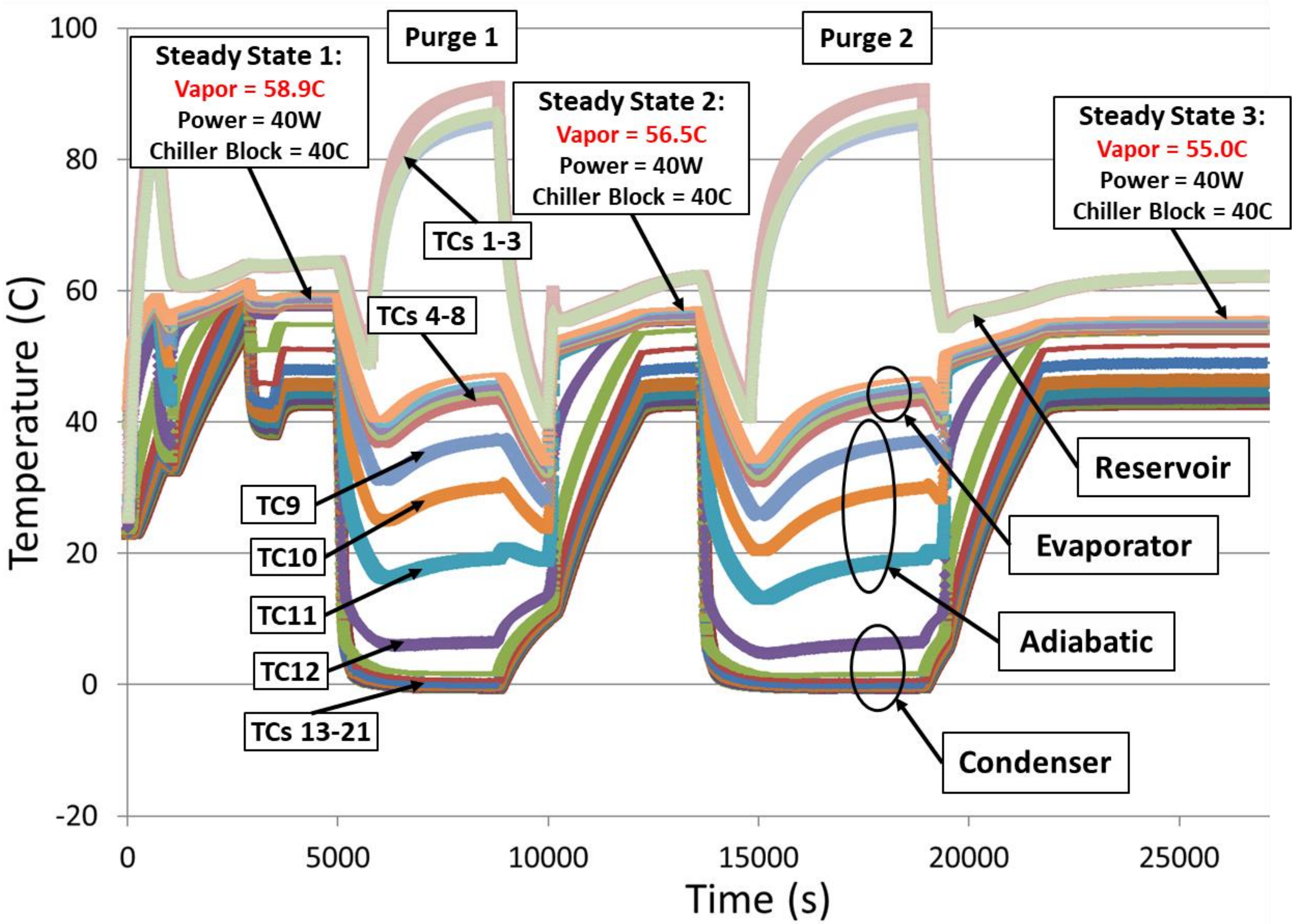
Astrobotic VCHP: Turndown Ratio





- Maximum Conductance: 2.93 W/K
- Minimum Conductance: 0.0158 W/K
- Turndown Ratio: 185:1

Astrobotic VCHP: Reservoir Purge Demonstration



- Initial Steady State:
  - Vapor = 58.9°C
  - 40W to Evaporator
  - Chiller Block Setpoint = 40°C
- Purge Test:
  - Apply 12W to Reservoir
  - Chiller Block Setpoint = 0°C
- After First Purge Test:
  - Vapor = 56.5°C
- After Second Purge Test:
  - Vapor = 55.0°C

Summary and Conclusions

- Non-integrated Warm-Reservoir VCHPs with hybrid wicks provide many advantages for applications such as operation on the lunar surface
- Non-integrated Warm-Reservoirs allow for improved fluid management of warm-reservoir VCHPs
  - Independent heating of the reservoir can be used to purge working fluid
- Hybrid wicks prevent temperature spikes during startup in gravity aided environments
- ACT designed and fabricated two non-integrated warm-reservoir VCHPs
  - EDU for NASA’s VIPER
  - Flight hardware for Astrobotic’s Peregrine Lunar Lander
- Both VCHPs demonstrated strong thermal control and high turndown ratios
  - VIPER: 544:1
  - Astrobotic: 185:1
- Independent heating of the reservoir to purge working fluid was successfully demonstrated for the Astrobotic VCHP