Hybrid Variable Conductance Heat Pipe and HiK™ Plates – Advanced Passive Thermal Experiment

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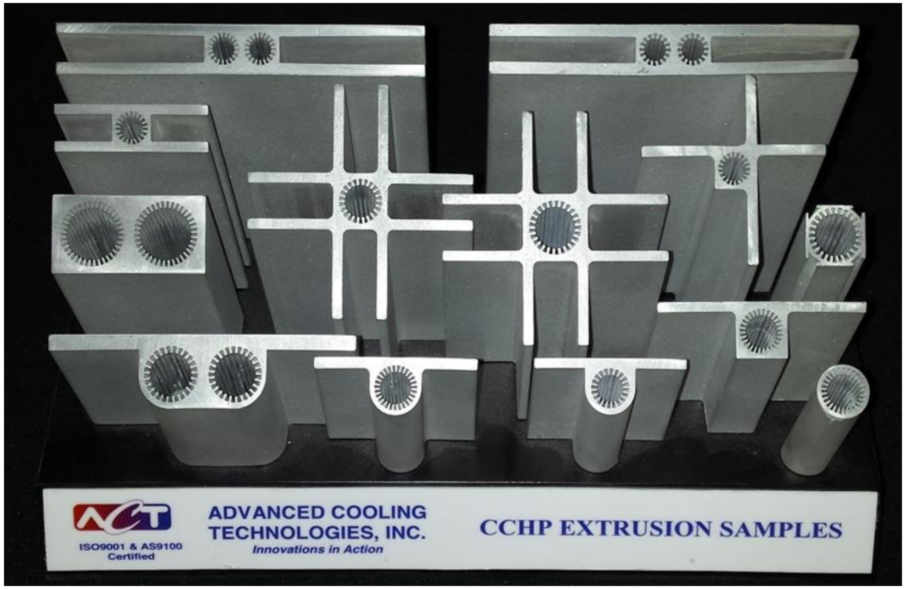
Presentation Outline

- Background
- Hybrid Heat Pipes – Concept
- Hybrid Heat Pipes Applications
- International Space Station (ISS) Experiment
- Thermal Control Analysis and Results
- Vertical Startup with a Liquid Column During Ground Testing

Background – Axial Grooved CCHPs

- **Axial Grooved CCHPs**
  - Standard for spacecraft HPs
    - ➢ Very high permeability.
    - ➢ Allows for very long heat pipes (up to ≈3.5 m).
  - Only suitable for zero-g / gravity-aided operation
    - ➢ Low capillary pumping capability.
    - ➢ 0.1” against earth gravity.
  - Drawbacks:
    - ➢ Low heat flux limitation in the evaporator (~10-15 W/cm^2)
    - ➢ No pumping capability against gravity on planetary surfaces



ACT’s solution – Hybrid wick CCHP

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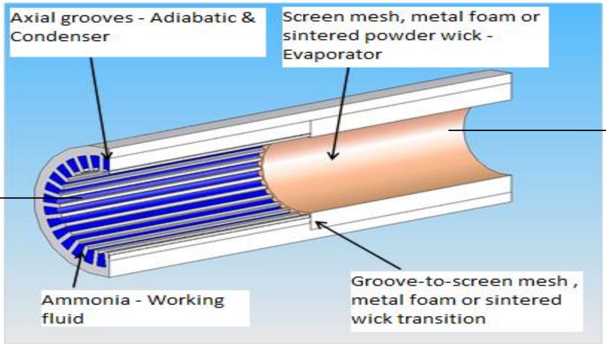
Hybrid Heat Pipes* - Concept

- **Heat pipe with a hybrid wick that contains screen mesh, metal foam or sintered evaporator wicks for the evaporator region.**
  - Can sustain high heat fluxes.
  - Operate against gravity for Lunar landers/rovers
- **The axial grooves in the adiabatic and condenser sections**
  - Can transfer large amounts of power over long distances due to their high wick permeability and associated low liquid pressure drop.

<u>Adiabatic and Condenser sections</u>:
Large pore size responsible for the:
- **High permeability.**
- **Low pumping capability.**
- **Relatively low heat flux limitation.**



<u>Evaporator section</u>:
Small pore size responsible for the:
- **Low permeability.**
- **High pumping capability.**
- **Relatively high heat flux limitation.**
- **Eliminate start-up problems.**

<u>Patent pending</u>

Hybrid Heat Pipes Applications

- 1) High heat flux applications in space.
  - Thermal transport requirements for future missions continue to increase, approaching several kilowatts. At the same time the heat acquisition areas have trended downward, thereby increasing the incident heat flux.
    - A hybrid wick heat pipe will allow such devices to operate at higher heat fluxes as compared to ***axial groove design*****.**
  - Future spacecraft and instruments developed for NASA's Science Mission Directorate will include highly integrated electronics, such as for CubeSat/SmallSat.
    - Can involve high power electronics with heat fluxes approach ~ 50 W/cm^2.
    - High heat flux limitation for future high power electronics such as laser diodes.
  - High heat flux (~ 50 W/cm^2) is a severe limitation for:
    - Standard grooved CCHPs.
    - Loop heat pipes (LHPs).

Hybrid Heat Pipes Applications

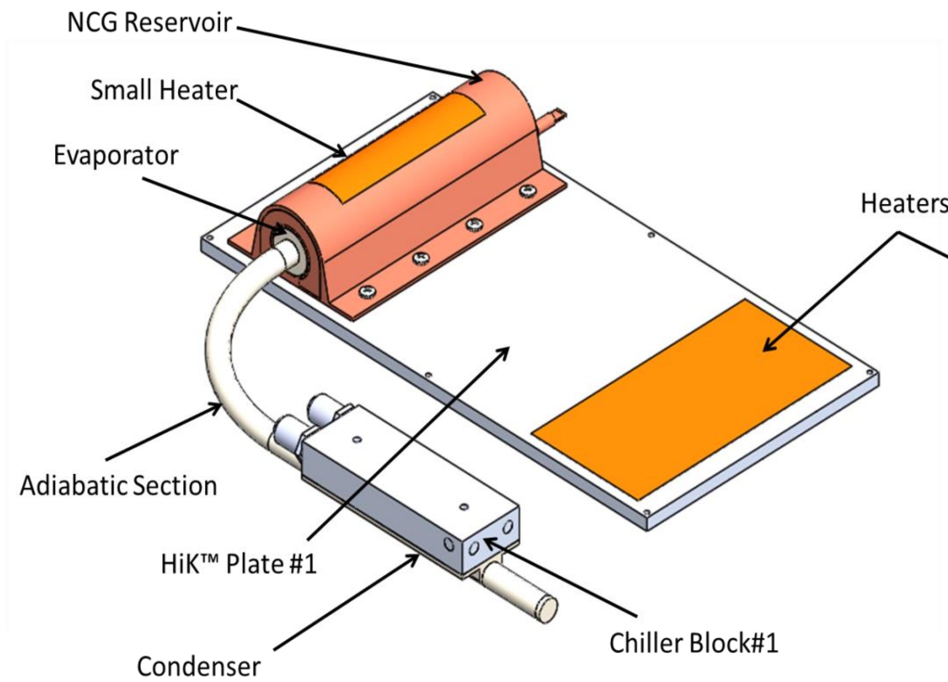
- 2) Adverse evaporator elevations for landers and rovers.
  - Future Martian and lunar surface missions using the next generation of the polar rovers and equatorial landers are among the immediate NASA applications.
- 3) Vertical start-up with a liquid column during ground testing.
  - Vertical start-up with a liquid column is mitigated experimentally with a hybrid wick.

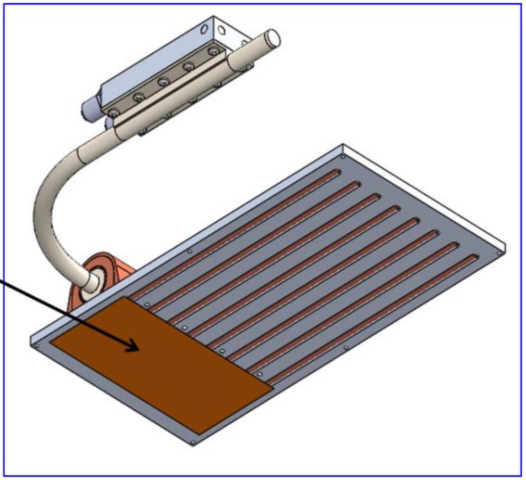
- NASA Marshall and NASA Johnson are working on an ISS flight experiment with components supplied by ACT.
- The following hardware has never been tested in micro-g:
  - Hybrid Wicks (VCHP)
    - Higher heat fluxes (e.g., lasers)
    - Operation against gravity for Lunar landers and rovers
  - VCHP with warm reservoir
    - Eliminates electricity required to heat a standard cold reservoir
    - Minimizing electrical use required for Lunar landers/rovers, some deep space missions
  - HiK™ plates
    - Higher effective thermal conductivity than encapsulated pyrolytic graphite
    - Up to 2500 W/m.K for a 1 m long plate
    - Lower cost and lead time, no reduction in thermal conductivity with thermal cycling
    - Can bend around corners

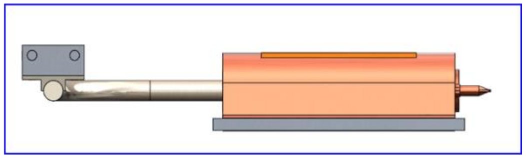
Objectives for ISS Experiment

- Demonstrate VCHP operation and its thermal control capability.
  - Show the gas front dynamics as a function of thermal contexts
- Demonstrate VCHP shutdown at the shutdown temperature.
  - Show that heat leaks are minimized
- Demonstrate the efficiency of the hybrid wick heat pipe in micro-gravity.
- Demonstrate startup and capability to address working fluid location anomalies (e.g. in the reservoir) of the VCHP.
- Demonstrate turndown ratio for the VCHP
- Demonstrate the operation and flight worthiness of the HiK™ plate.
- Demonstrate the ability of the HiK™ plate to survive multiple freeze/thaw cycles.
- Demonstrate the ability of the HiK™ plate to start-up from a frozen state

Hybrid VCHP for ISS Experiment



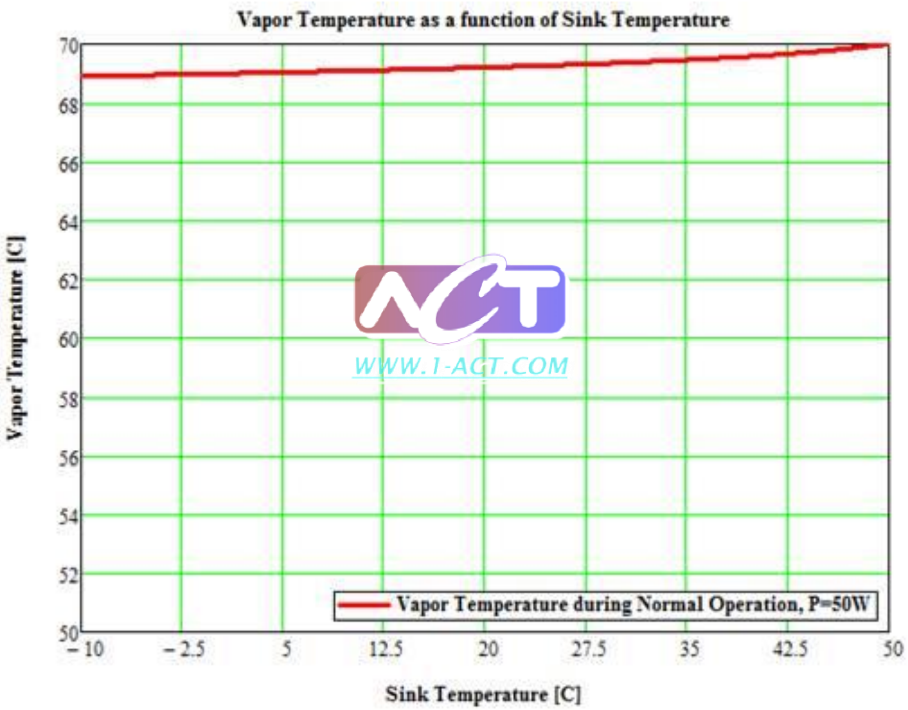


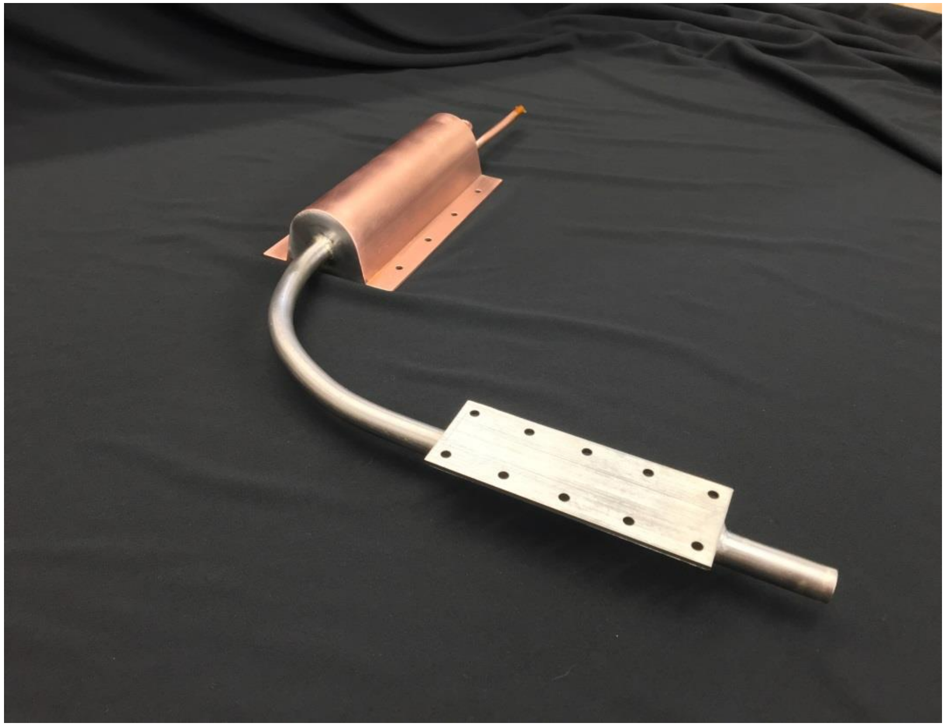


- 3 heaters (will operate one heater at a time)
  - A 50W heater located remotely on the HiK™ plate (to demonstrate operation of both systems)
  - A 50W heater located directly below the evaporator (to demonstrate operation of VCHP without HiK™ plate – if needed)
  - A 20W at maximum from a small heater located on the NCG reservoir.
  - The actual applied power is ~ 100 W (assuming the power losses is ~ 30 W)
- 40 TC's
- A chiller block attached to the VCHP condenser to offer sink temperature that will be sweeping between -10 to 50 ^{0}C.

Thermal Control Analysis

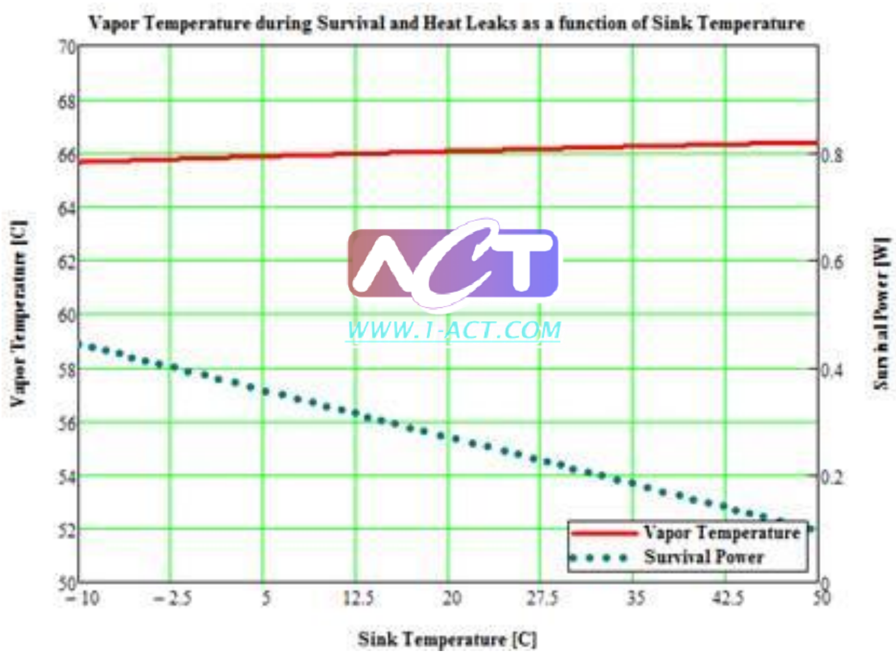
- As sink temperature changes within the limits, vapor temperature will change within a very narrow interval while 50W are rejected.
- Maximum Vapor Temperature is 70 ^{0}C, the VCHP rejects 50W into the hottest Sink (50 ^{0}C); this is the only scenario when the condenser is fully active.





Thermal Control Analysis

- **As sink temperature changes within the limits and only power for survival is applied, vapor temperature will take the values shown below**
  - NCG fills both condenser and the adiabatic (front is at the exit of the evaporator)
    - Heat leaks (survival power) can be easily calculated from this scenario.
      - Survival Power between 450mW (Cold Sink) and 100mW (Hot Sink)



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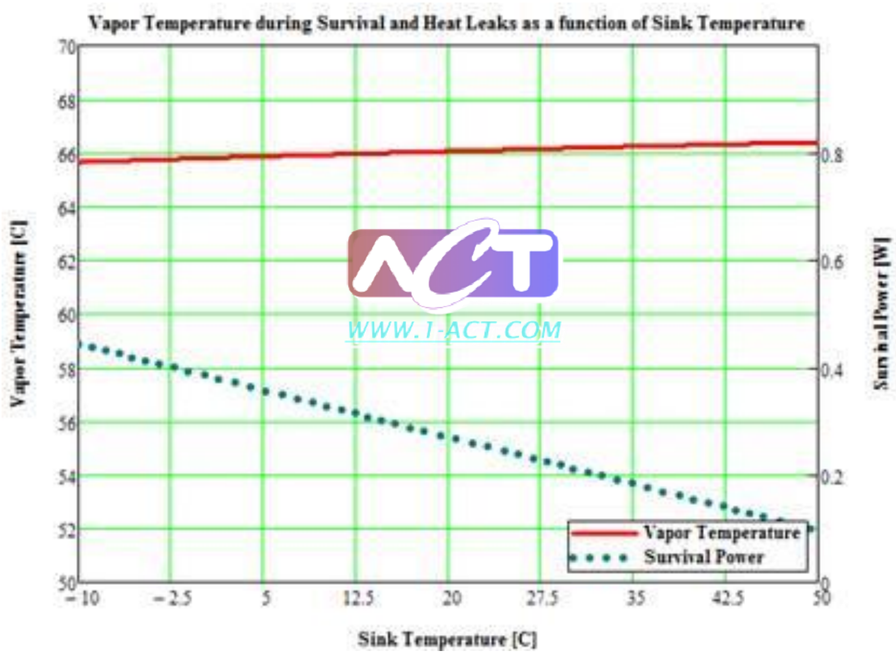
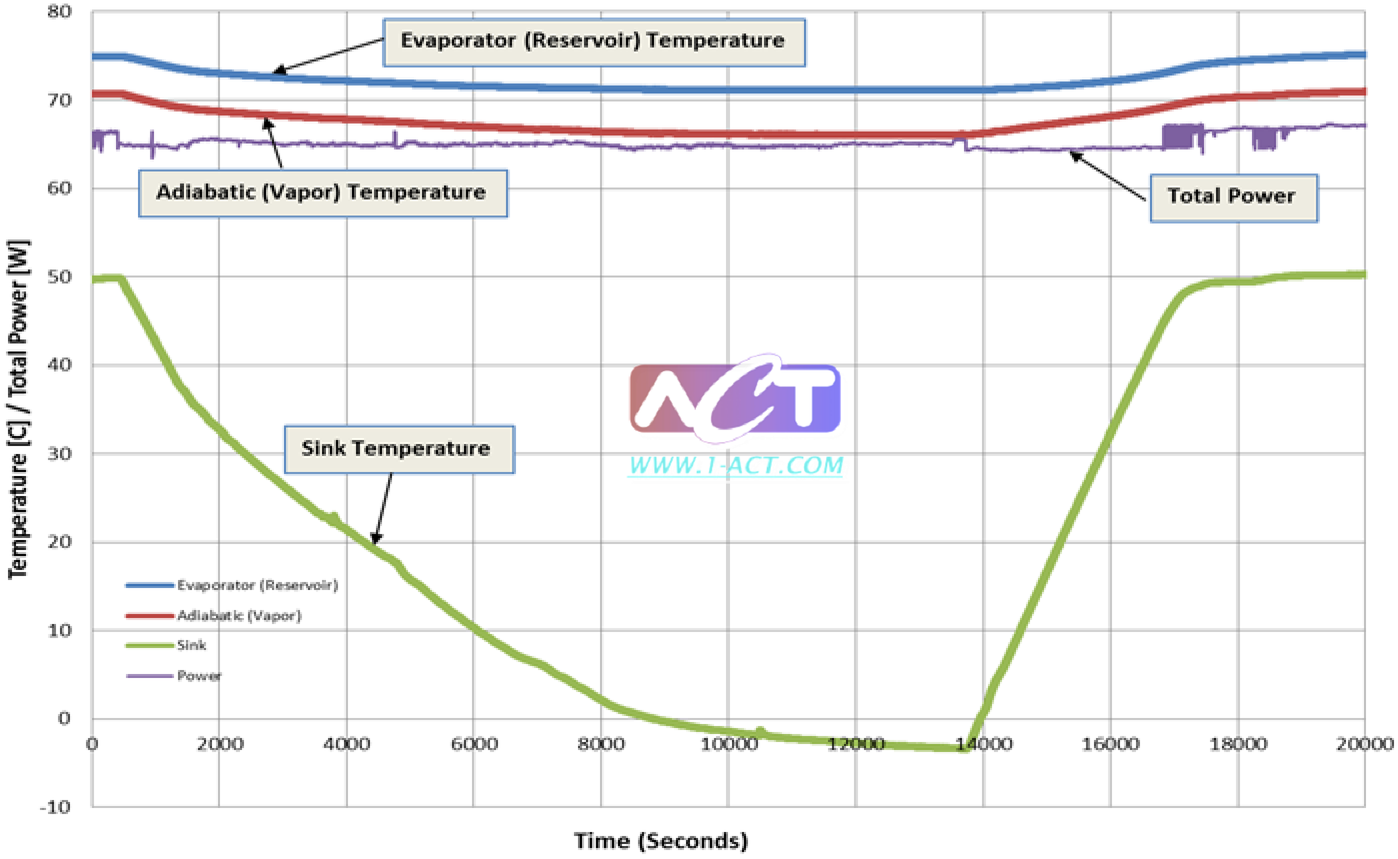


Preliminary Thermal Control Testing for the Hybrid VCHP in Reflux Mode



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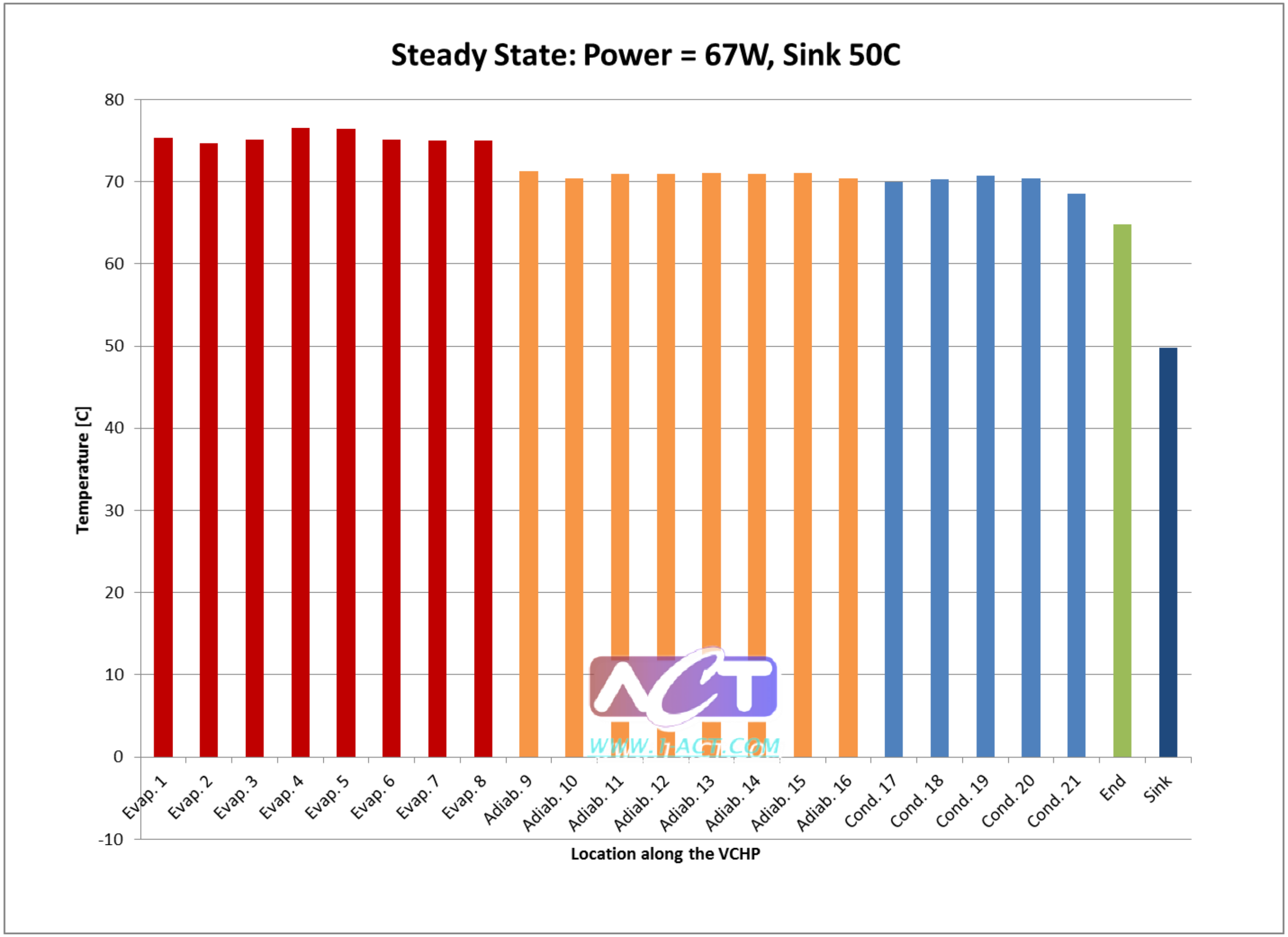

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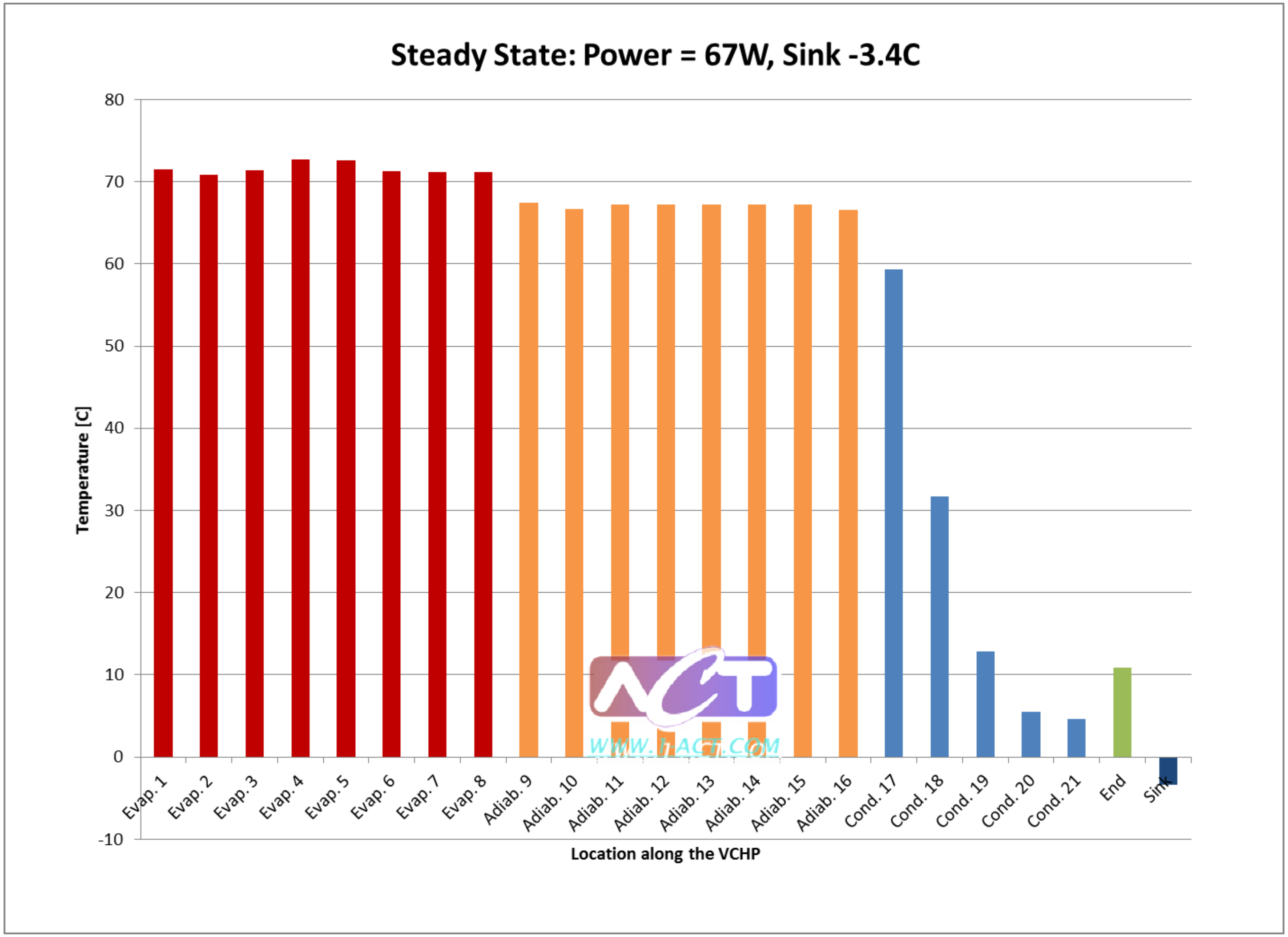
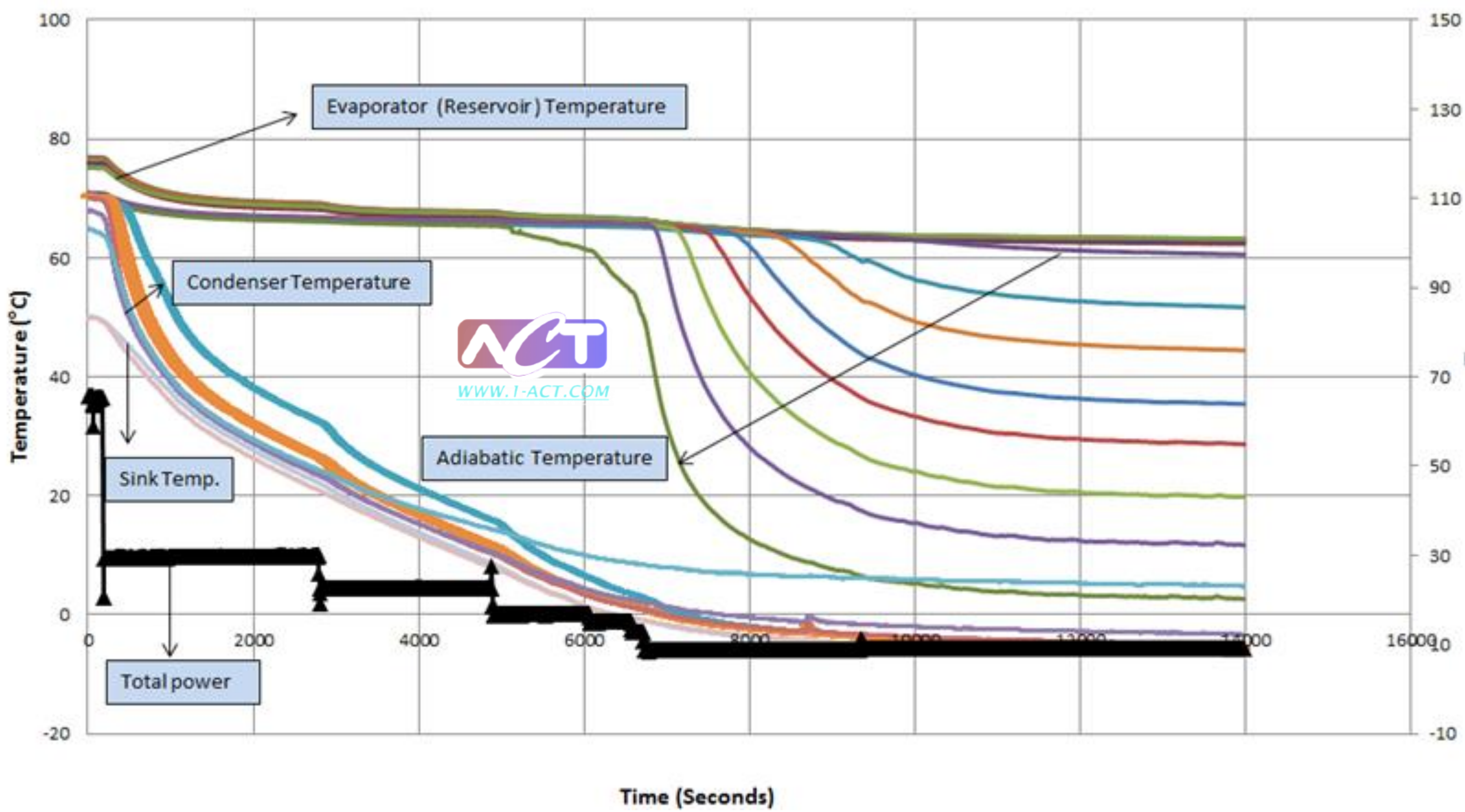
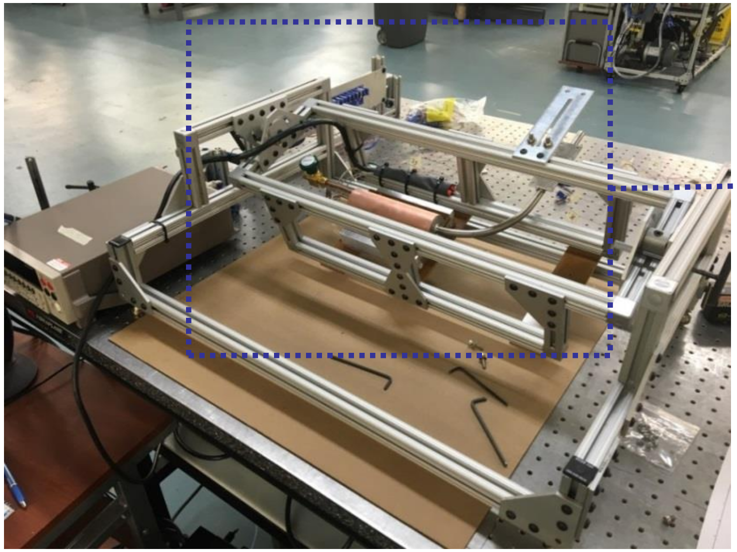
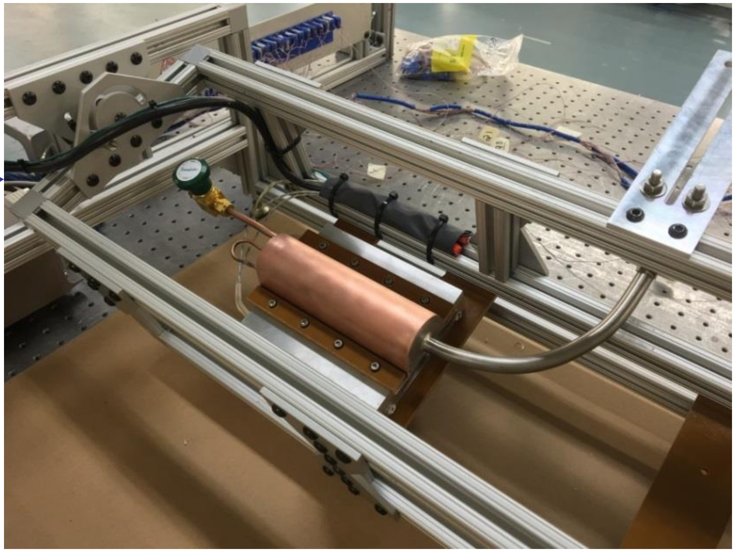


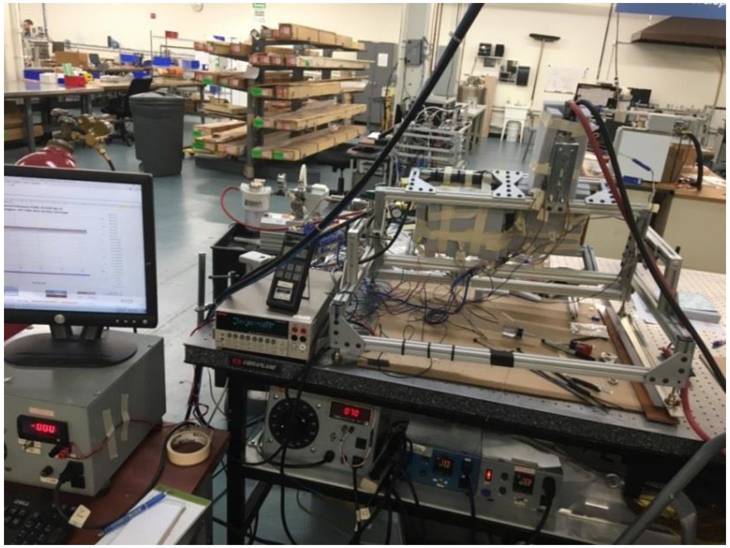
Survival Testing Results for the Hybrid VCHP



Testing for the VCHP with TECs







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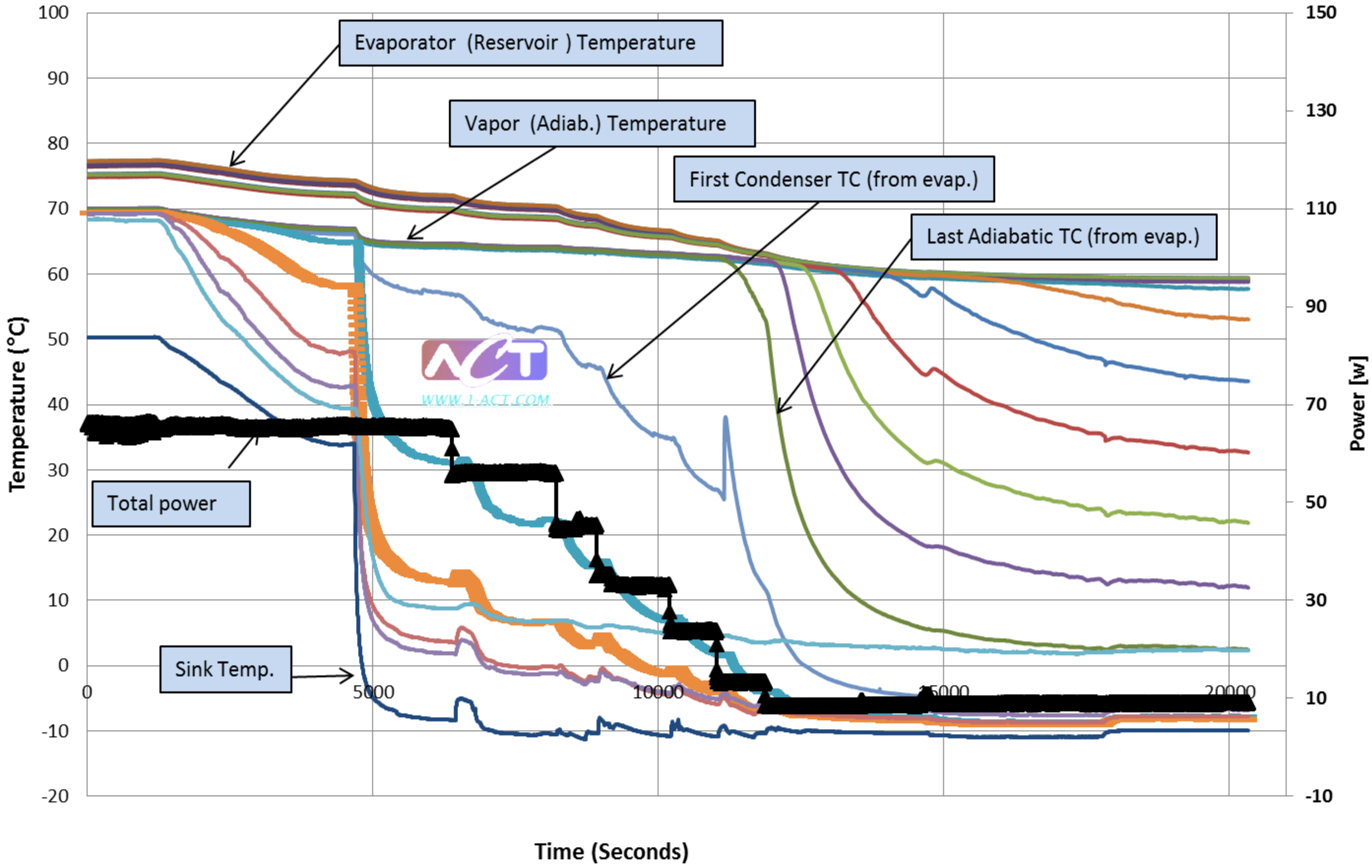
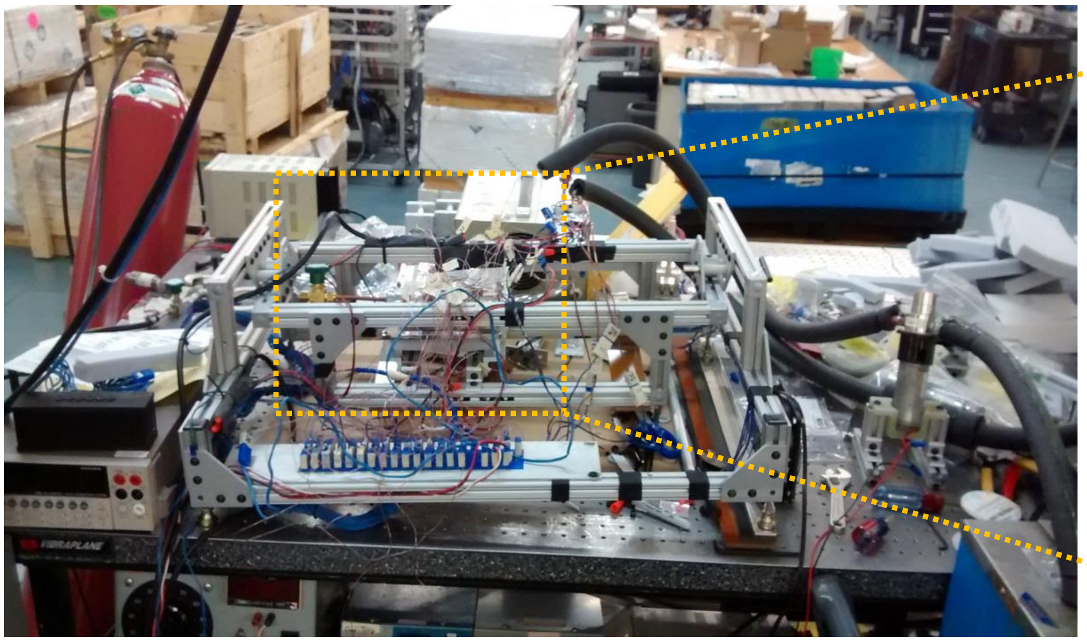
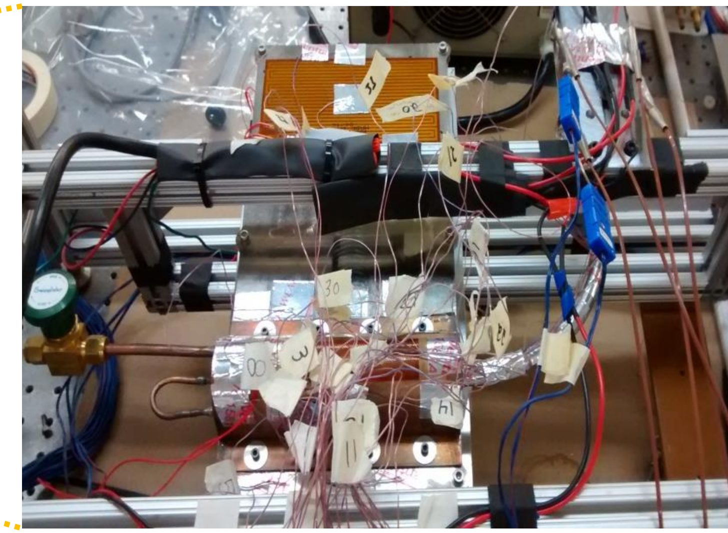
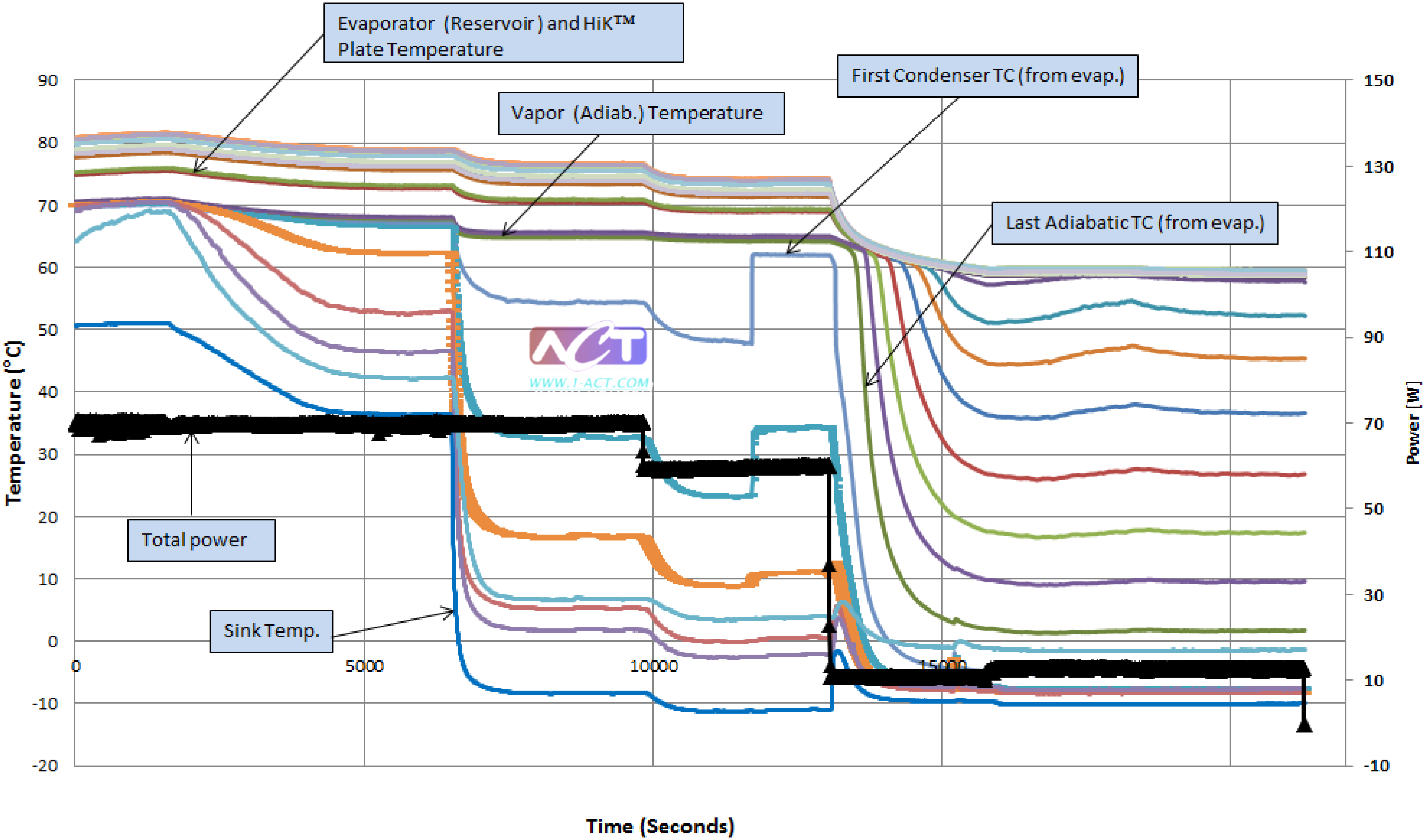


Testing for the VCHP with HiK™ Plate and TECs



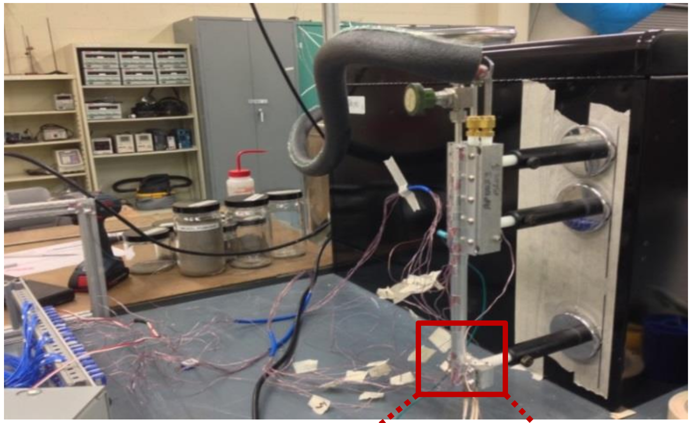


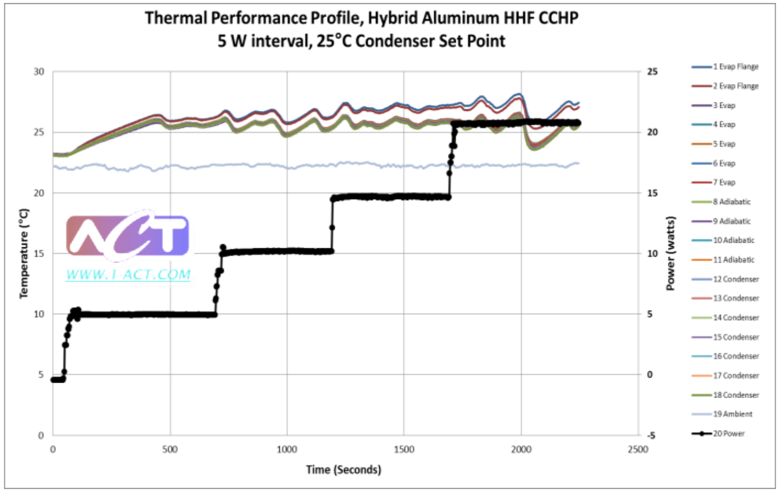
Testing Results for the VCHP HiK™ Plate and TECs

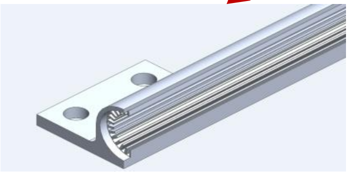


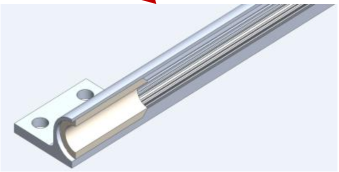
Vertical start-up with a Liquid Column During Ground Testing

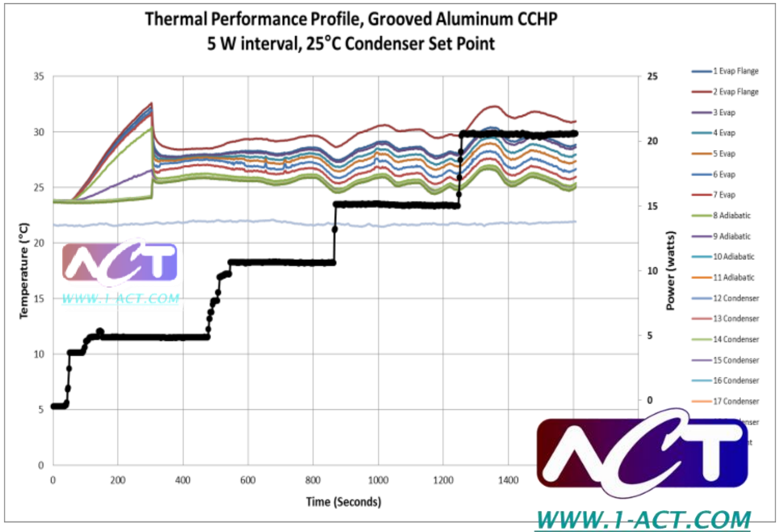
- The sintered and grooved evaporator wick heat pipes were tested to prove that start-up related temperature spikes in vertical gravity aided heat pipes can be eliminated/reduced by using sintered evaporator wicks.











- The experimental results proved that the large number of nucleation sites in sintered wicks facilitates boiling initiation in pool boiling systems and, consequently, the temperature spikes are minimized.

Questions

Hybrid Variable Conductance Heat Pipe and HiK™ Plates – Advanced Passive Thermal Experiment

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