Development of Flight Demonstration Hot Reservoir Variable Conductance Heat Pipes for Microgravity Testing and Future Lunar Landers and Surface Systems

Advanced Cooling Technologies, Inc
Kuan-Lin Lee, Calin Tarau, Ramy Abdelmaksoud, William Anderson

Case Western Reserve University
Chirag Kharangate and Yasuhiro Kamotani

Presented By
Ramy Abdelmaksoud

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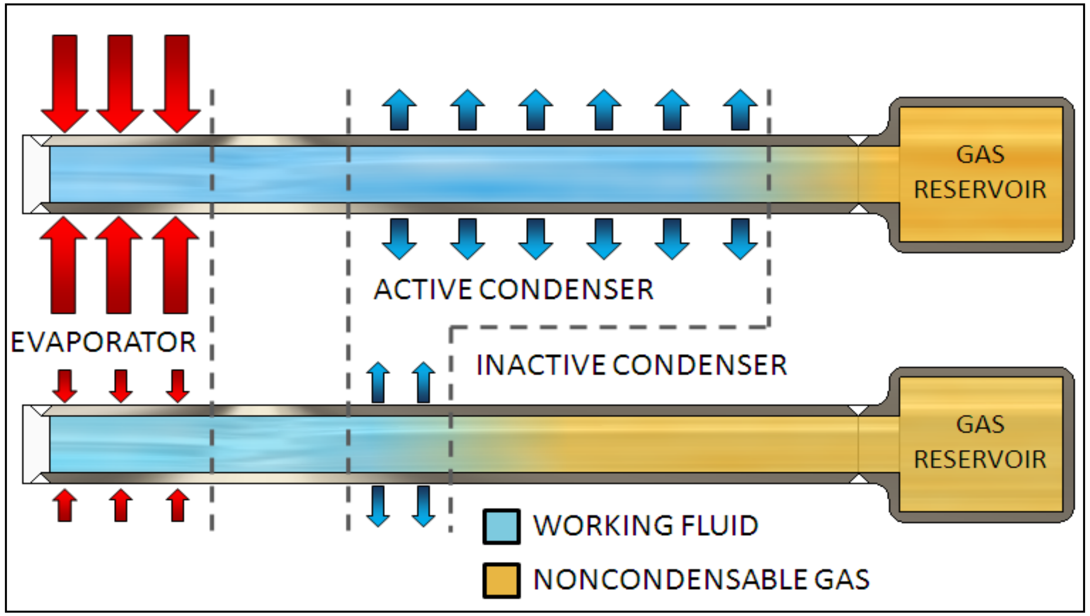
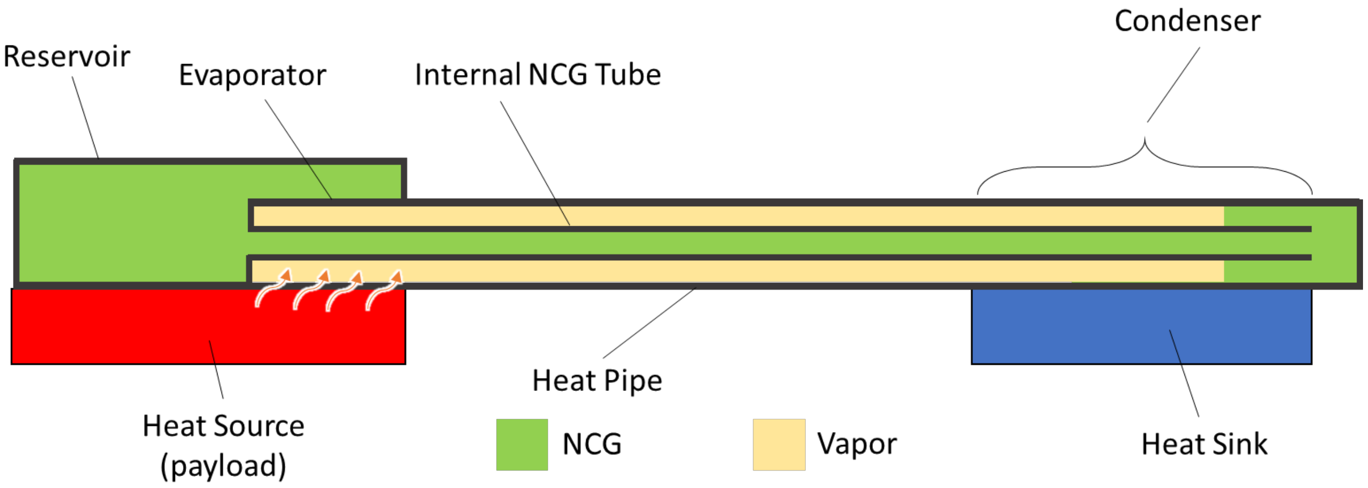
Introduction

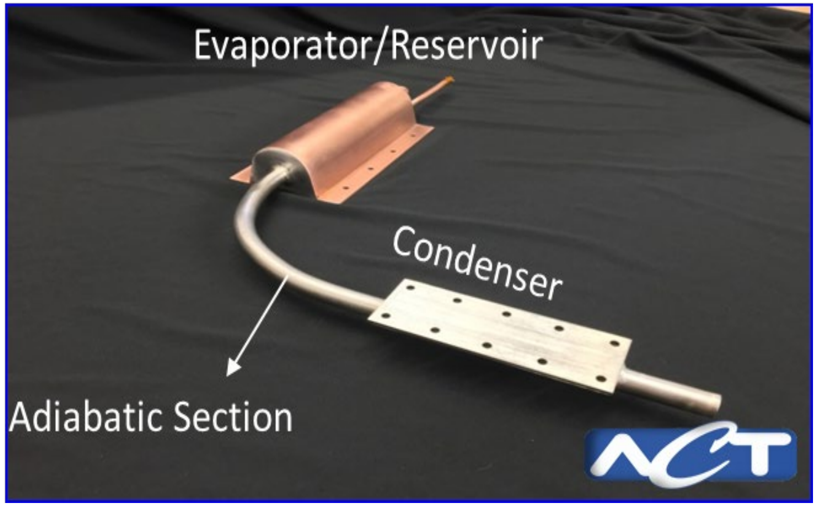
- Future planetary landers and rovers need a variable thermal link between heat sources and sink with large turn-down ratio
  - During the lunar day, higher high transfer rate will allow the shrinkage of the radiators.
  - During the lunar night, at very low sink temperature (100K), the thermal link must be as ineffective as possible to maintain payload temperature with minimum survival power
- Standard VCHPs with a cold-biased reservoir are most often used for temperature control in spacecraft applications
  - Reservoir temperature can be actively controlled by electrical heaters
  - Roughly need 1-2 W of electricity power to heat the reservoir for lunar night survival
    - Every 1 Watt of heat corresponds to ~5kg of battery mass through 14 days lunar shadow



Hot Reservoir VCHP and Fluid Management Challenges

- Reservoir is located near the evaporator and its temperature will follow heat source temperature
- Reservoir can be integrated or non-integrated
- Can offer much tighter thermal control than regular VCHP
- Eliminate electric power required to keep reservoir warm during the 14-day lunar night
- ISS test showed that fluid management of HR-VCHP is a challenge
  - Prevent working fluid liquid entering reservoir during missions
  - Need to remove excessive working fluid from reservoir (purging) more effectively

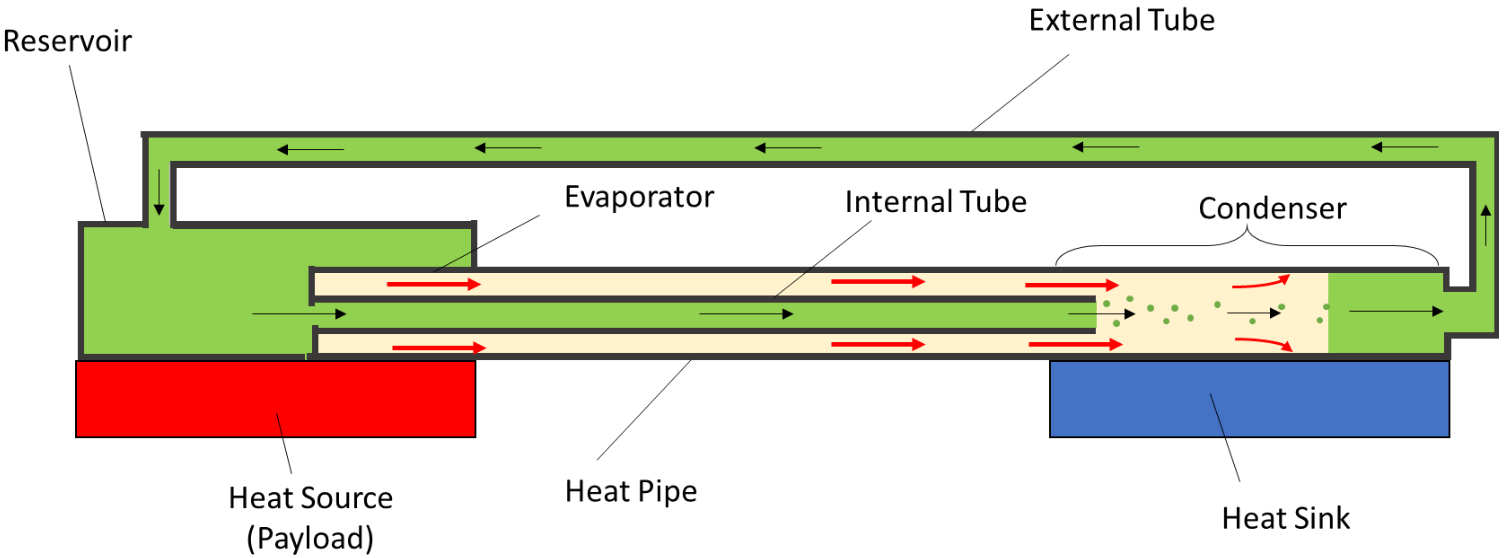


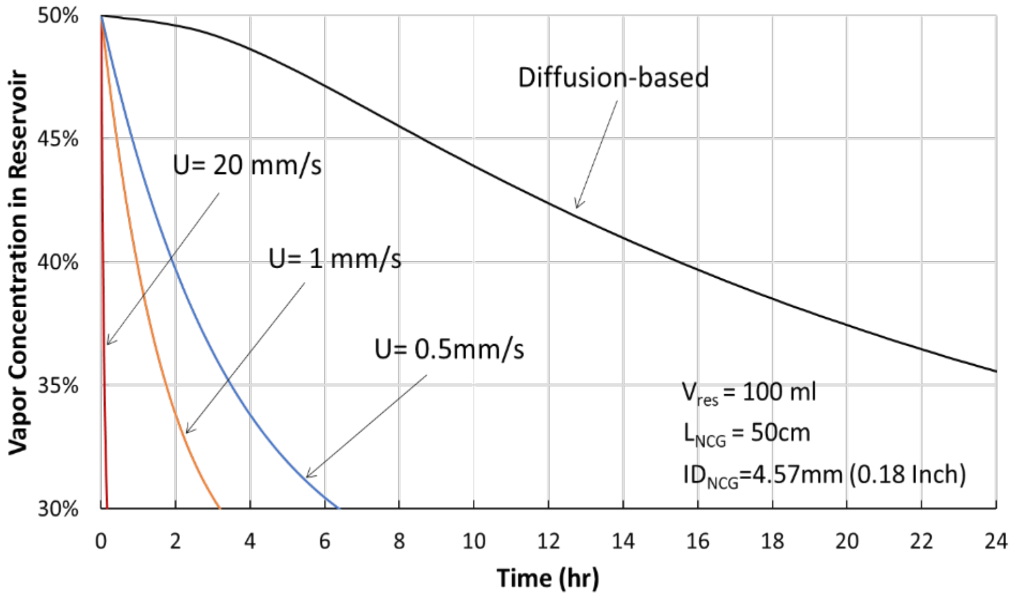


W. G. Anderson et al., "Variable Conductance Heat Pipes for Variable Thermal Links," 42nd International Conference on Environmental Systems (ICES 2012), San Diego, CA, July 15-19, 2012.

Hot Reservoir VCHP Loop Concept

- A loop is created by connecting the condenser and the reservoir with an external tube
- Some momentum of vapor in the heat pipe section can be transferred to the NCG to generate a secondary flow – Momentum induced flow
- Momentum induced flow will be able to remove excessive moisture in the reservoir effectively
- The concept was successfully demonstrated both numerically and experimentally in Phases I & II Programs



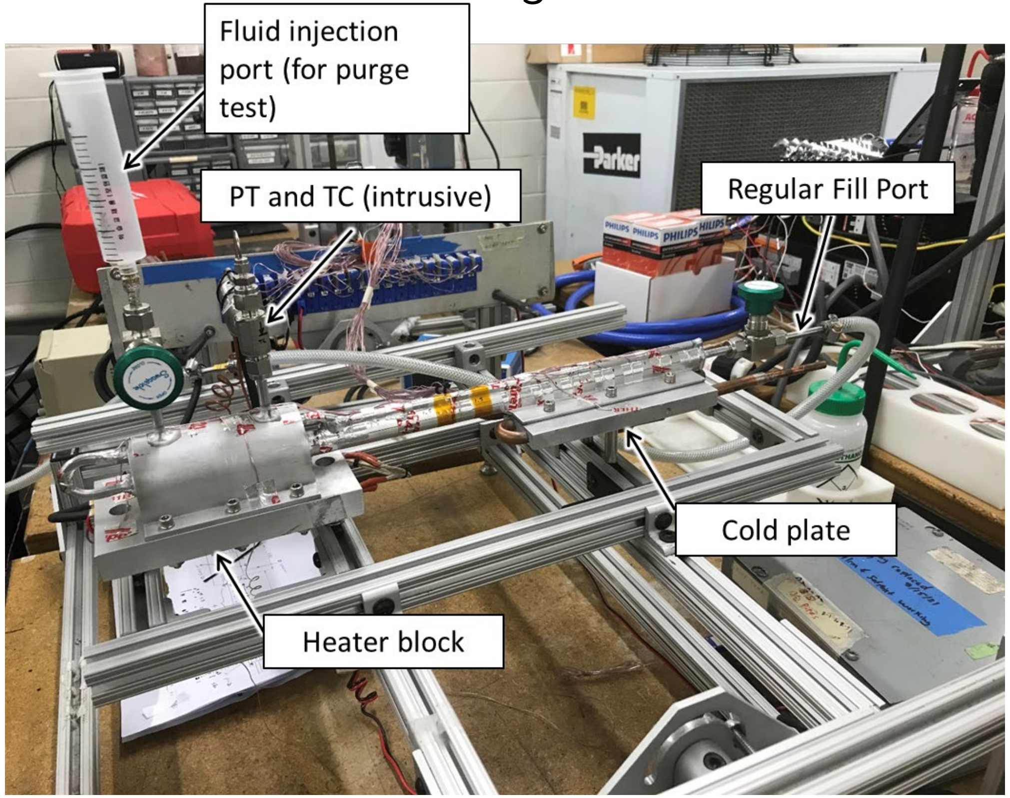


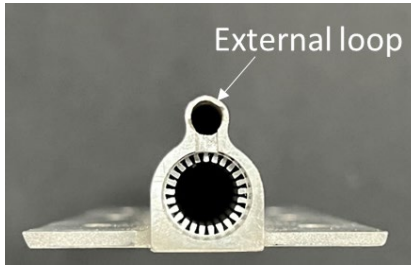
Objective

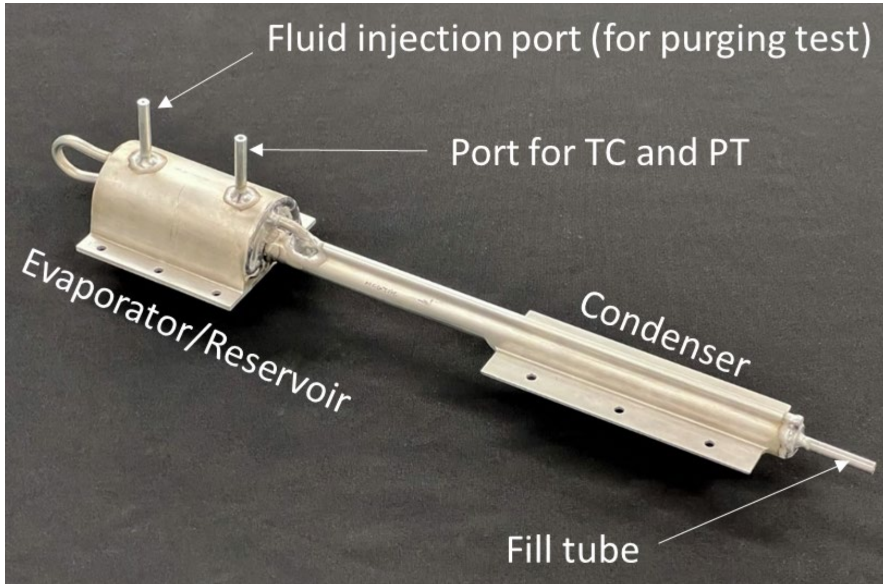
- Develop two proto-flight VCHPs for potential ISS testing and planetary landers
  - International Space Station (ISS) Testing VCHP – Copper-water
  - Commercial Lunar Payload Services (CLPS) Lander VCHP – Aluminum-ammonia (or Propylene)

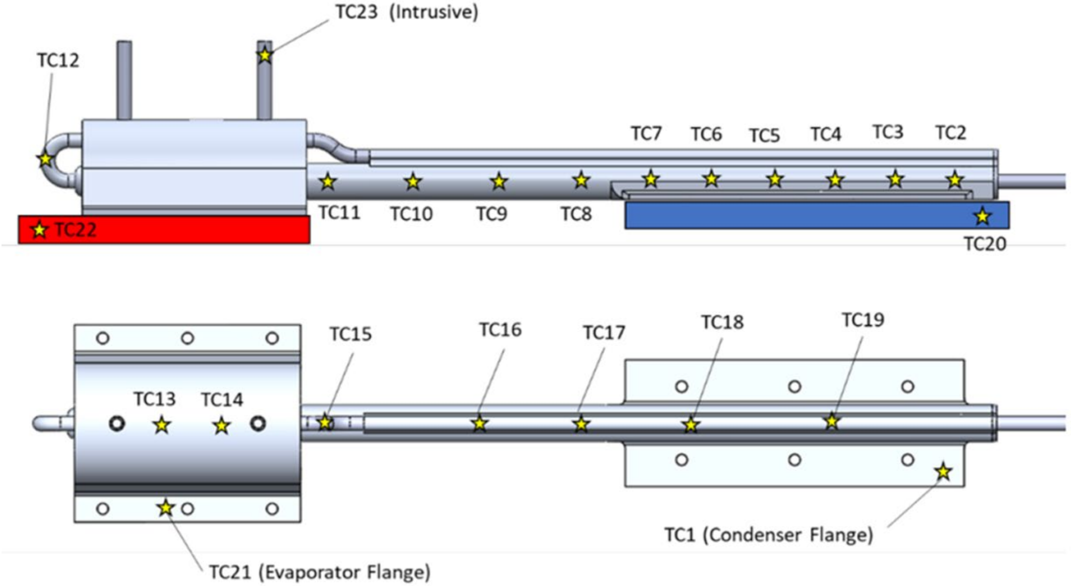
Overview on a Previous Prototype

- Both reservoir and external tube were integrated with the main heat pipe body
- Envelope material: Aluminum
- Thermal control performance and reliability of the prototype were tested using acetone and toluene as working fluid



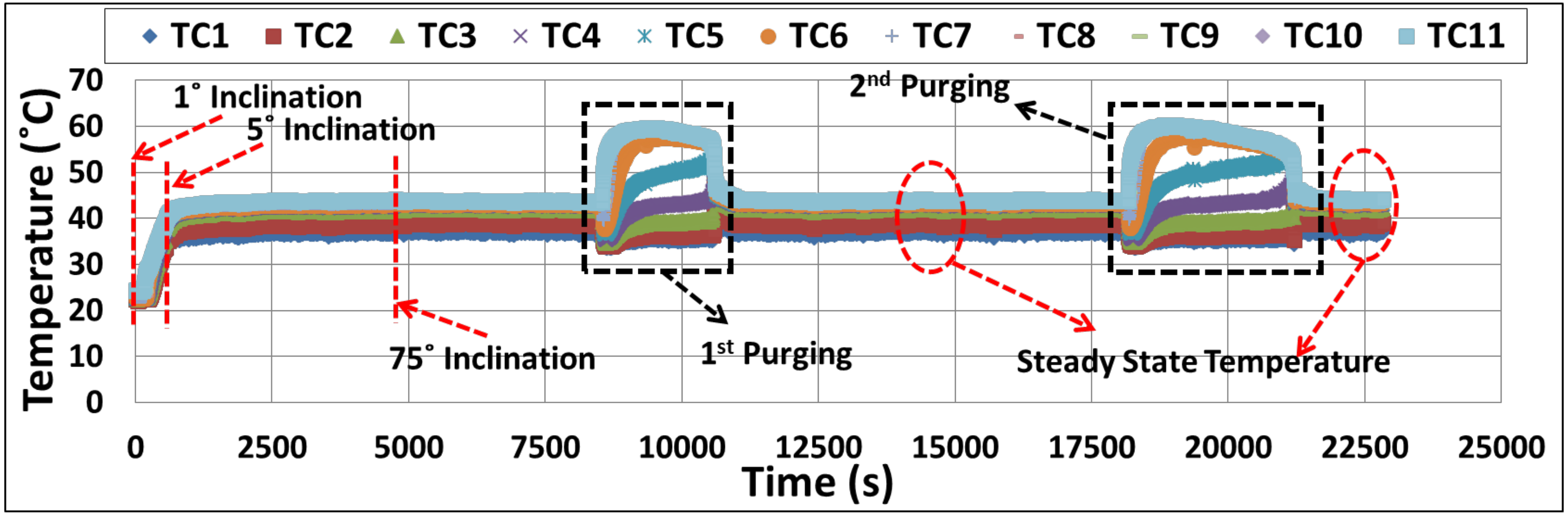


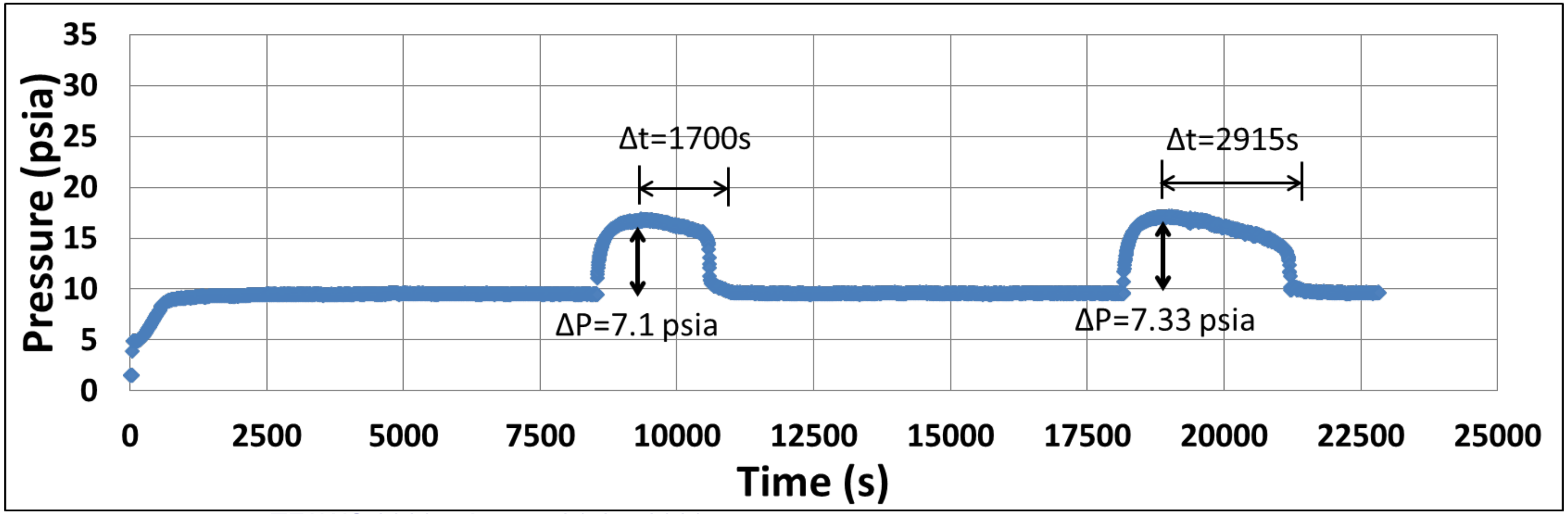




Successful VCHP Purge Test of the Previous Prototype

- Acetone: 5cc
- Q=75 W
- 0.5cc of acetone was injected for each purging
- VCHP was able to purge in gravity-aided orientation (75° inclined)





Validation of the Purging Model (Comparison of Pressure Variation During Purging)

- Acetone: 5cc
- Q=75 W
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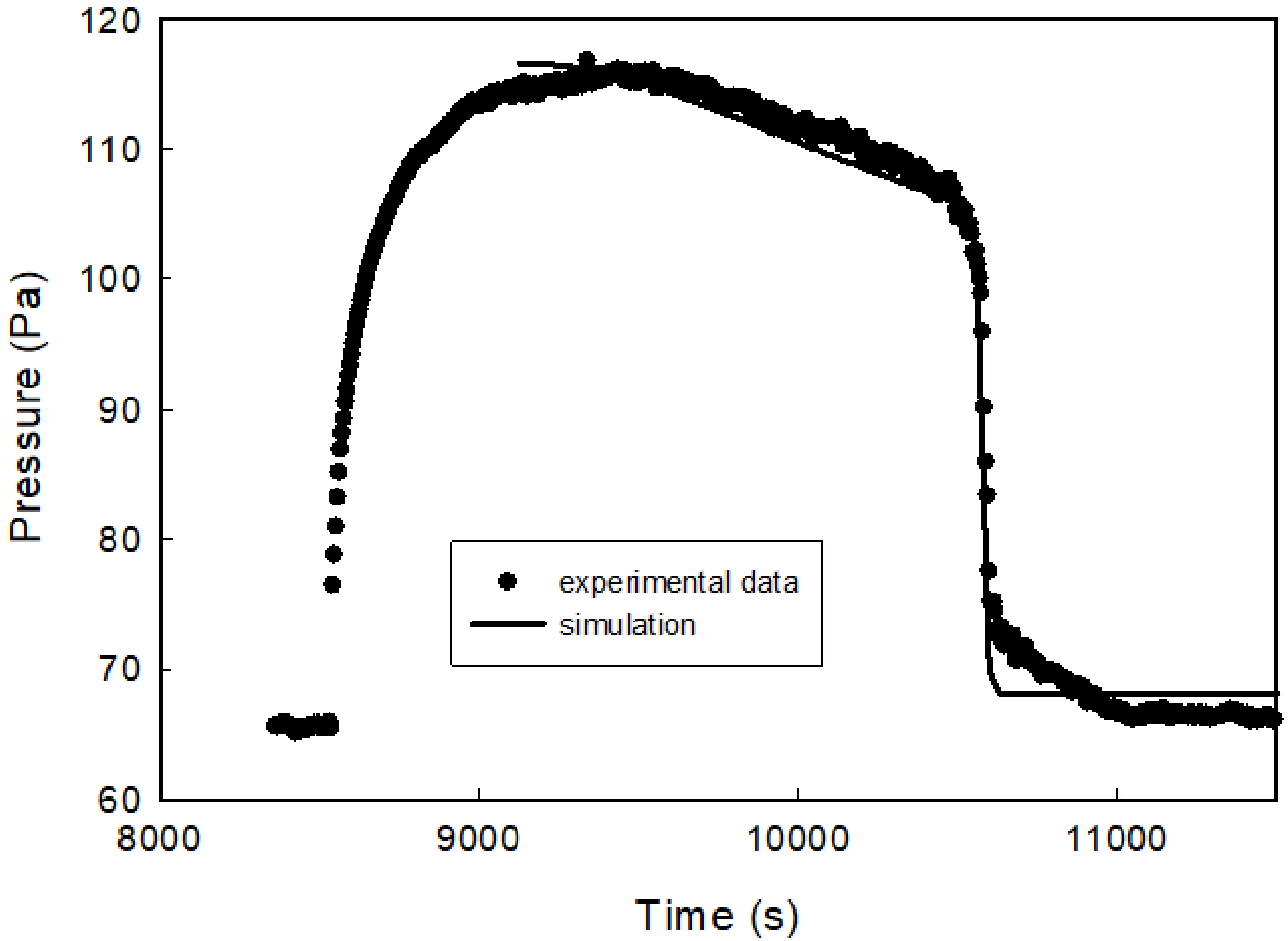
- VCHP was able to purge in gravity-aided orientation (75° inclined)



Vapor density, saturation pressure, and kinetic energy values of acetone, toluene, propylene, ammonia, and water at different operating temperatures based on 75 W heat input and heat pipe ID 10.16 mm.

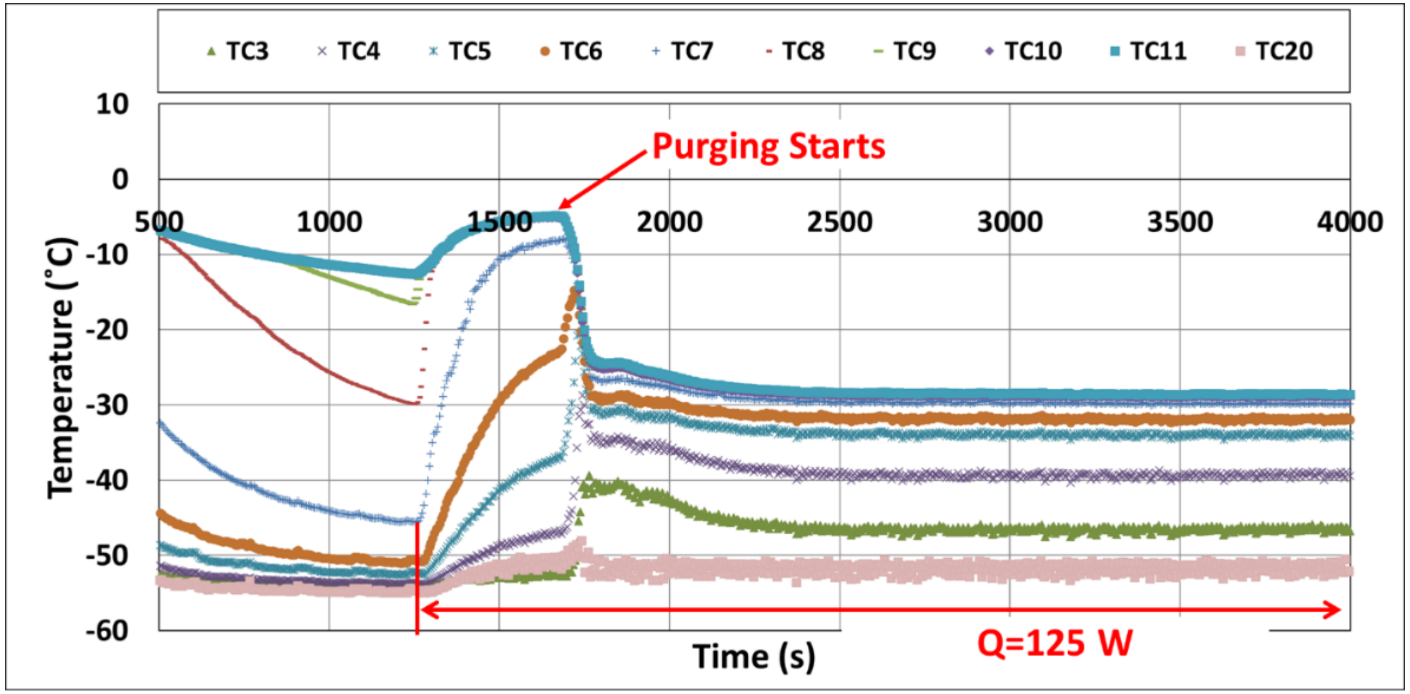
	Acetone			Toluene			Water		
T (°C)	ρ_v (kg/m³)	P (bar)	K.E. (Pa)	ρ_v (kg/m³)	P (bar)	K.E. (Pa)	ρ_v (kg/m³)	P (bar)	K.E. (Pa)
-50	0.01	0.003	115.01	0.0007	0.0001	2547	-	-	-
0	0.24	0.093	5.67	0.036	0.009	63.46	0.0048	0.006	14.2
40	1.31	0.566	1.21	0.28	0.079	9.32	0.051	0.074	1.44

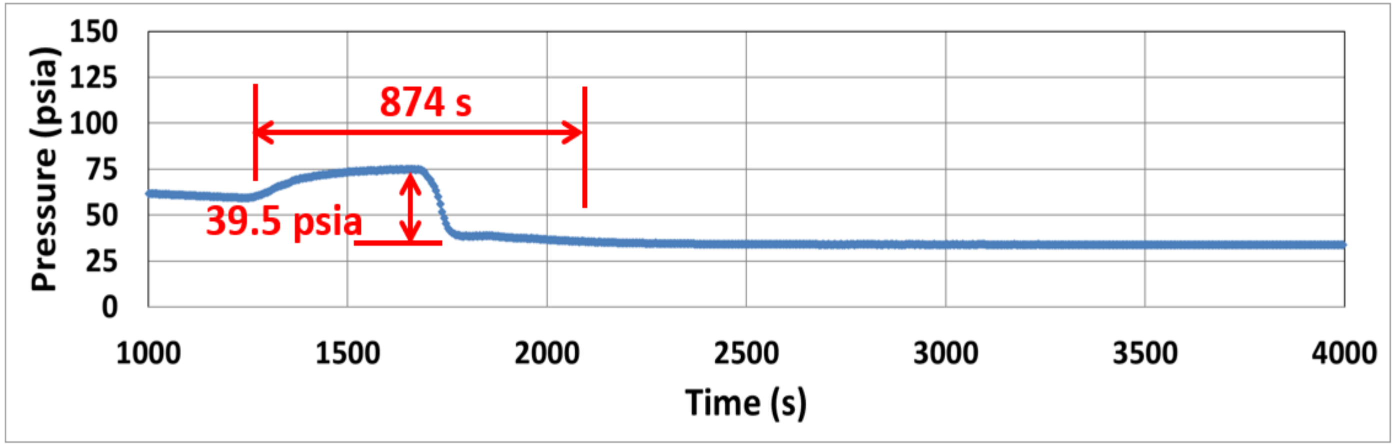
	Propylene			Ammonia		
T (°C)	ρ_v (kg/m³)	P (bar)	K.E. (Pa)	ρ_v (kg/m³)	P (bar)	K.E. (Pa)
-50	2.13	0.91	1.026	0.38	0.41	0.56
0	12.35	5.86	0.243	3.45	4.29	0.078
40	35.71	16.52	0.13	12.03	15.55	0.029

$$K.E. = \frac{Q^2}{2h_{fg}^2 \rho_v A^2}$$

Successful Propylene Purging Testing at Low Temperature

- **Procedure:**
  - Charged VCHP with the designed amount of propylene. The NCG charged was ~ 7% of the designed value.
  - Let the VCHP sit in ambient conditions overnight, letting diffusion create a uniform distribution of vapor/NCG mixture.
  - Applied cooling to the HR-VCHP (e.g., a sink temperature of -50˚C) for more than 20 mins to reduce system pressure.
  - Heat was applied to the evaporator (125 W) at t=1250 seconds while maintaining the same cooling condition at the condenser.
  - Overserved purging at 1600 seconds



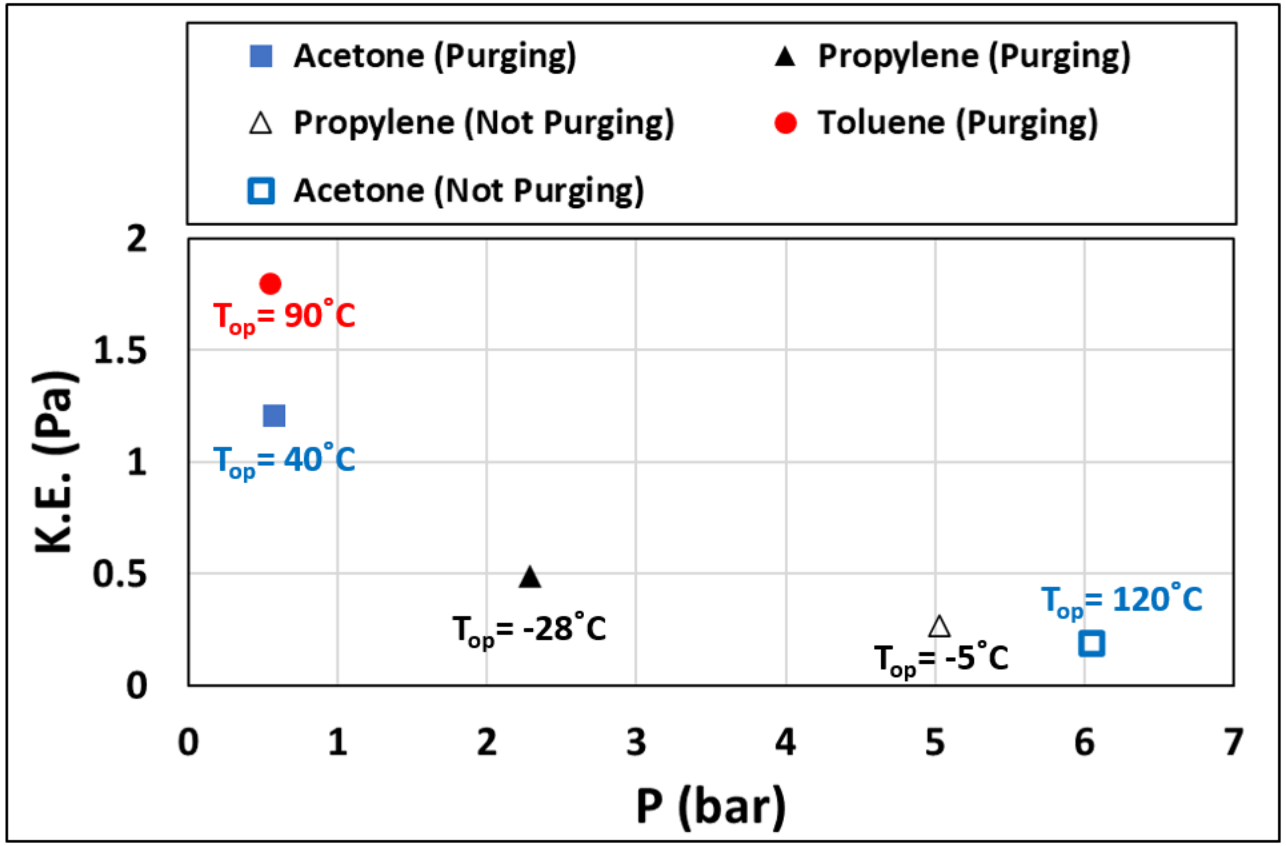


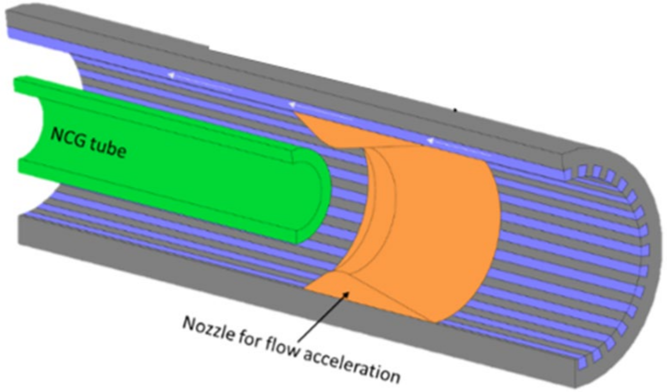
Comparison of Successful and Unsuccessful Purging Tests

- As K.E. is lower than a certain value, the VCHP CANNOT purge (or start up) appropriately.

- This limit value is related to hydraulic resistance that consists of:
  - Friction loss
  - Minor loss
  - Hydrostatic pressure

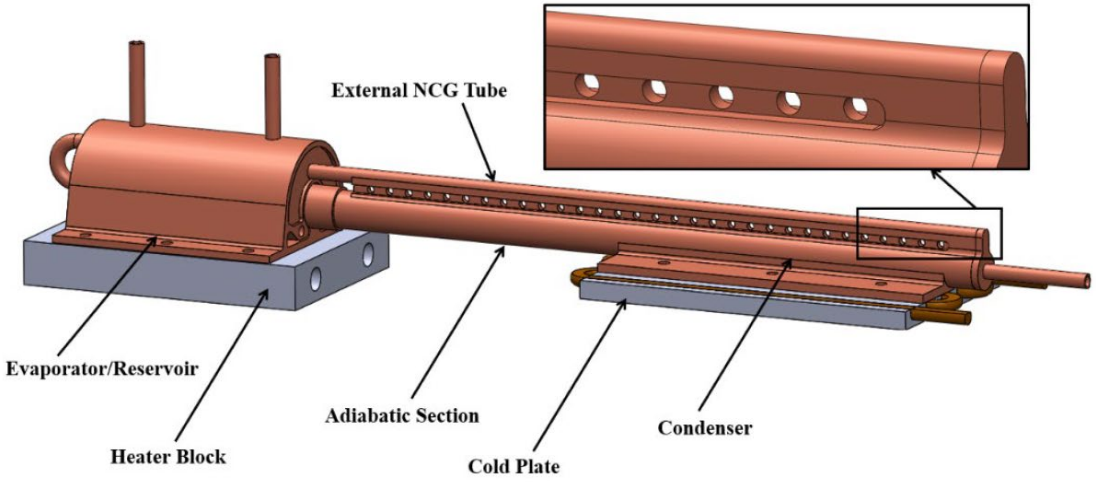
- This limit value must be minimized by optimizing external and internal NCG tubes and reservoirs.

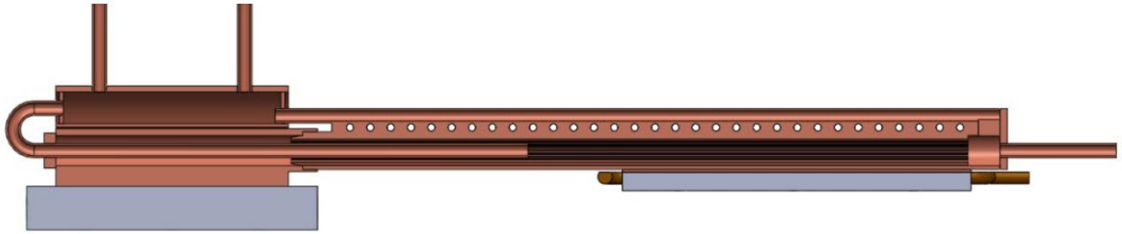


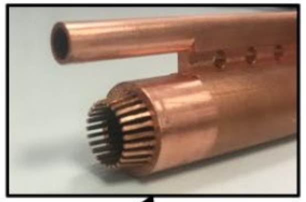


Development of the Protoflight 1 (for Potential ISS Testing)

- Power < 100W
- Working fluid : water
- Envelope material: all copper (due to cost and long lead time)
- Hybrid wick (screen in the evaporator and grooves in the rest of the heat pipe).







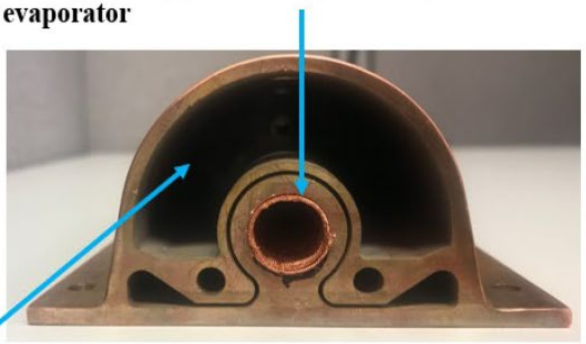
The external NCG tube and adiabatic section with extruded grooves to be inserted into the evaporator part

Axial grooves at the condenser end. A ring will be placed to seal the grooves and an end cap will be brazed.

4 Wraps of copper screen (Mesh 100) inside the evaporator

Reservoir end cap 1 (welded to the reservoir body)

Reservoir end cap 2 to be welded in this region

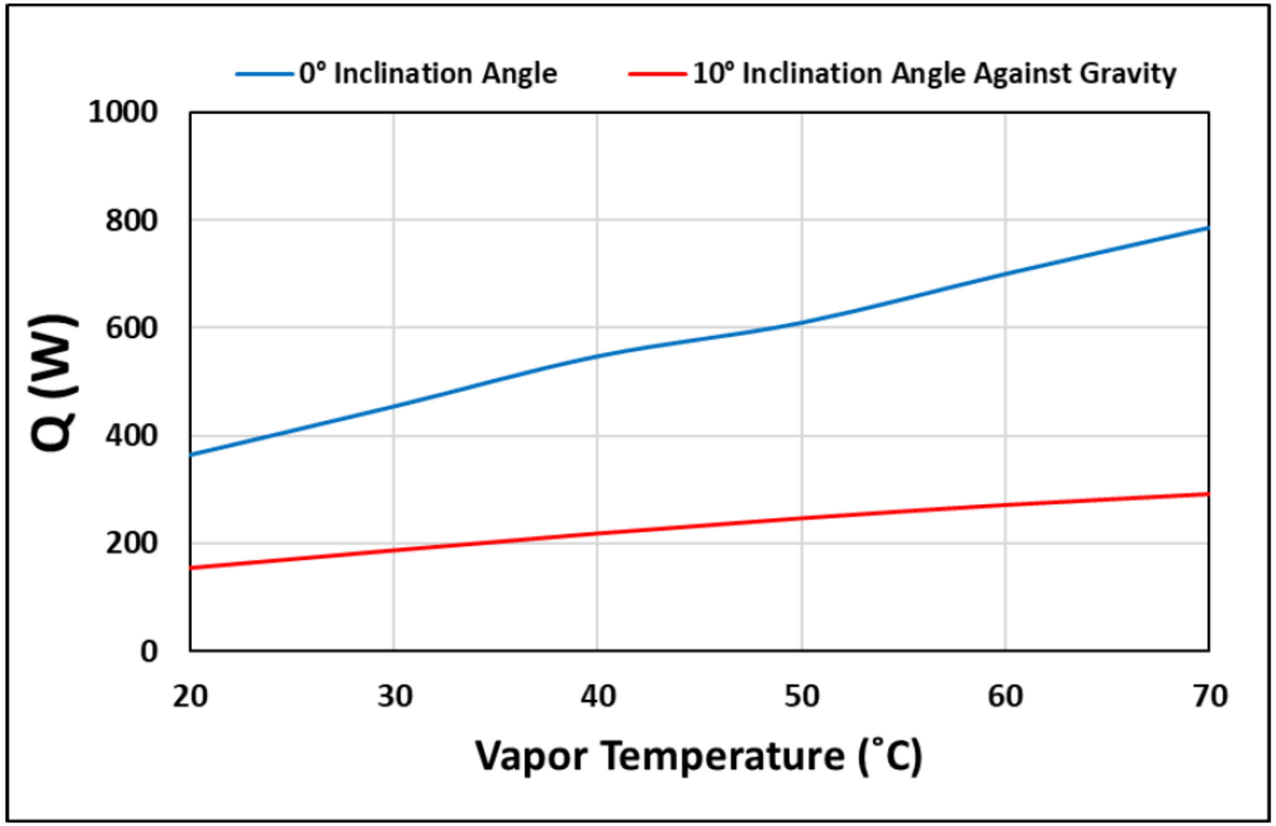


The back end of the reservoir/evaporator

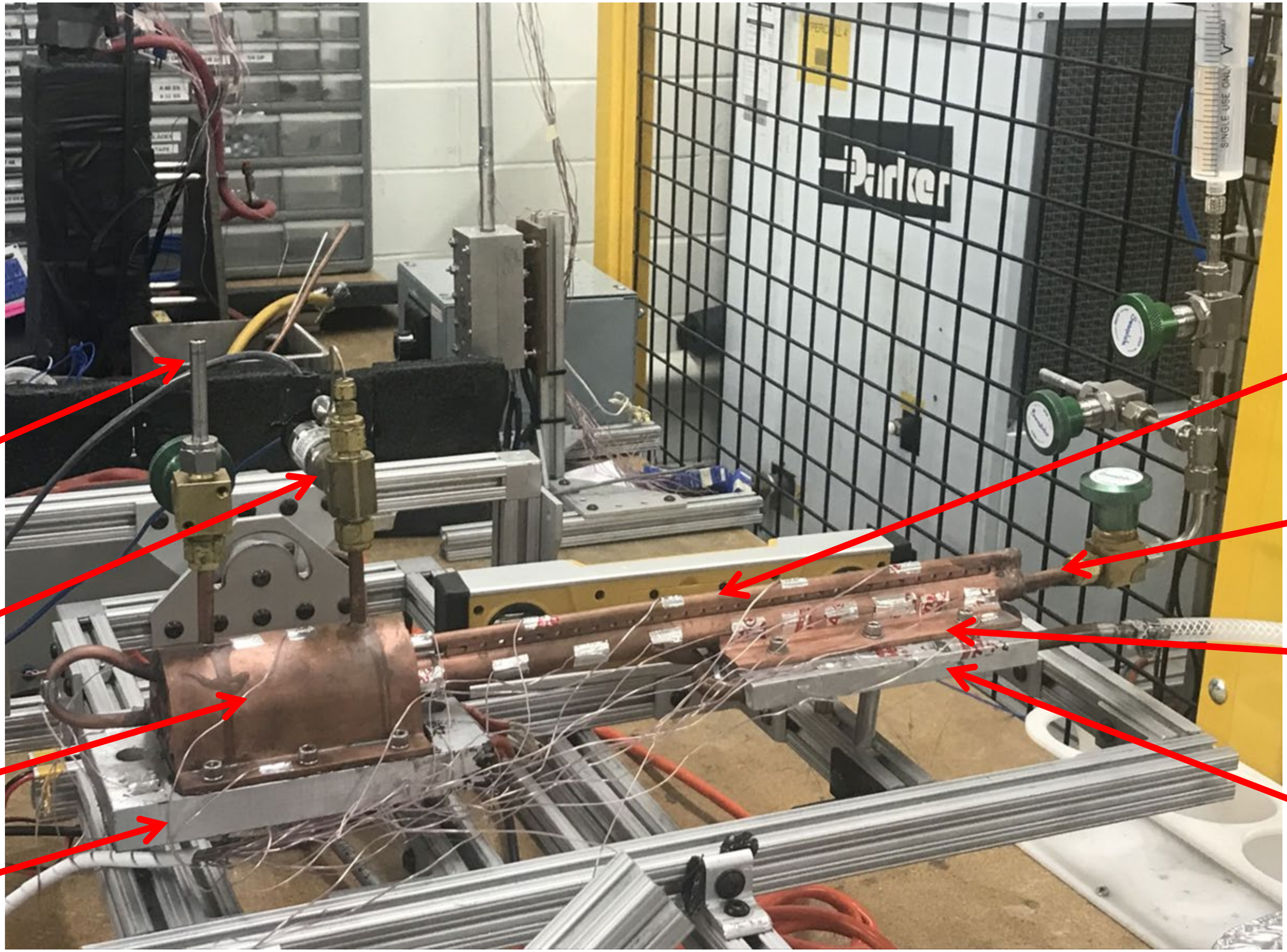
The front end of the reservoir/evaporator where it will be welded with the heat pipe

Design Requirements and Heat Transfer Capability of Protoflight 1

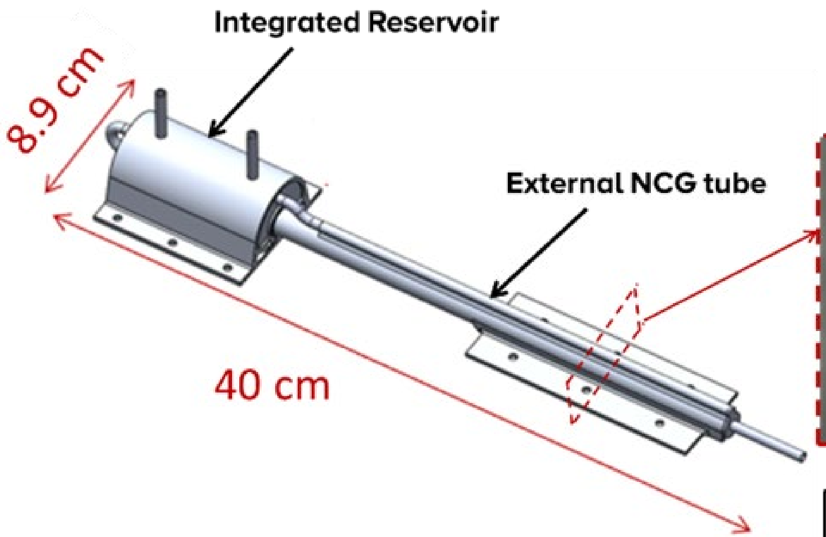
Nominal Power (W)	100
Maximum Operating Temperature (˚C)	70
Minimum Operating Temperature (˚C)	20
Nominal Operating Temperature (˚C)	50
Maximum Sink Temperature (˚C)	20
Minimum Sink Temperature (˚C)	0
Payload Survival Temperature (˚C)	-10



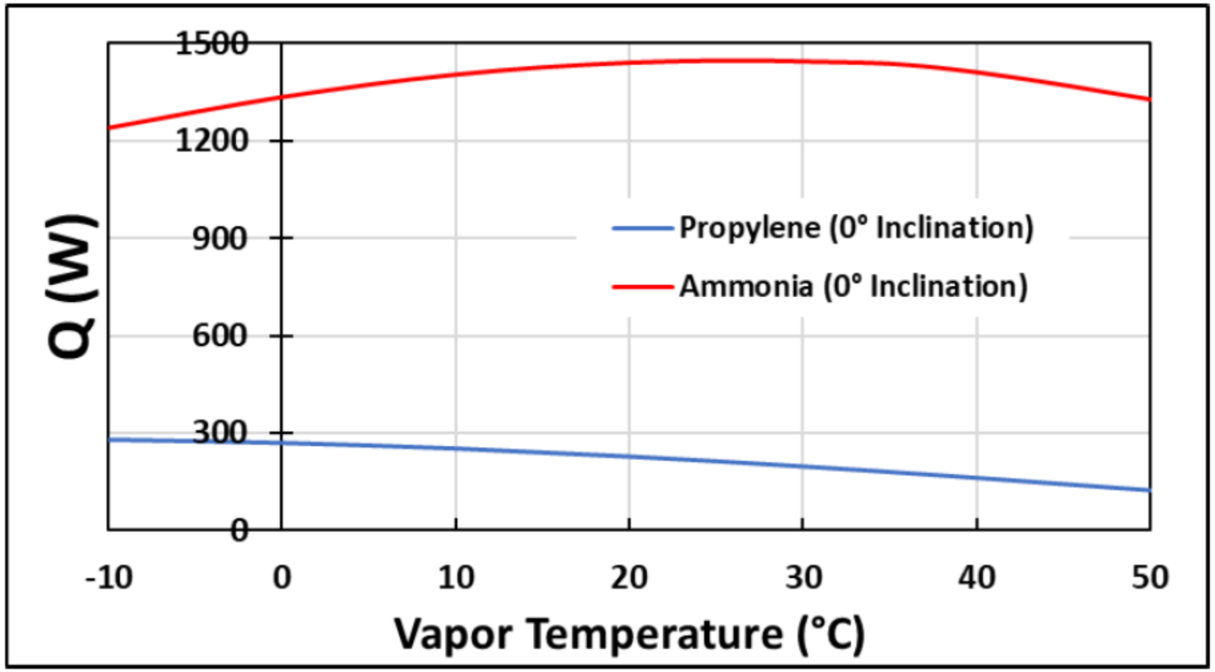
Test Setup of the Protoflight 1



Development of the Protoflight 2 (for Lunar Landers)

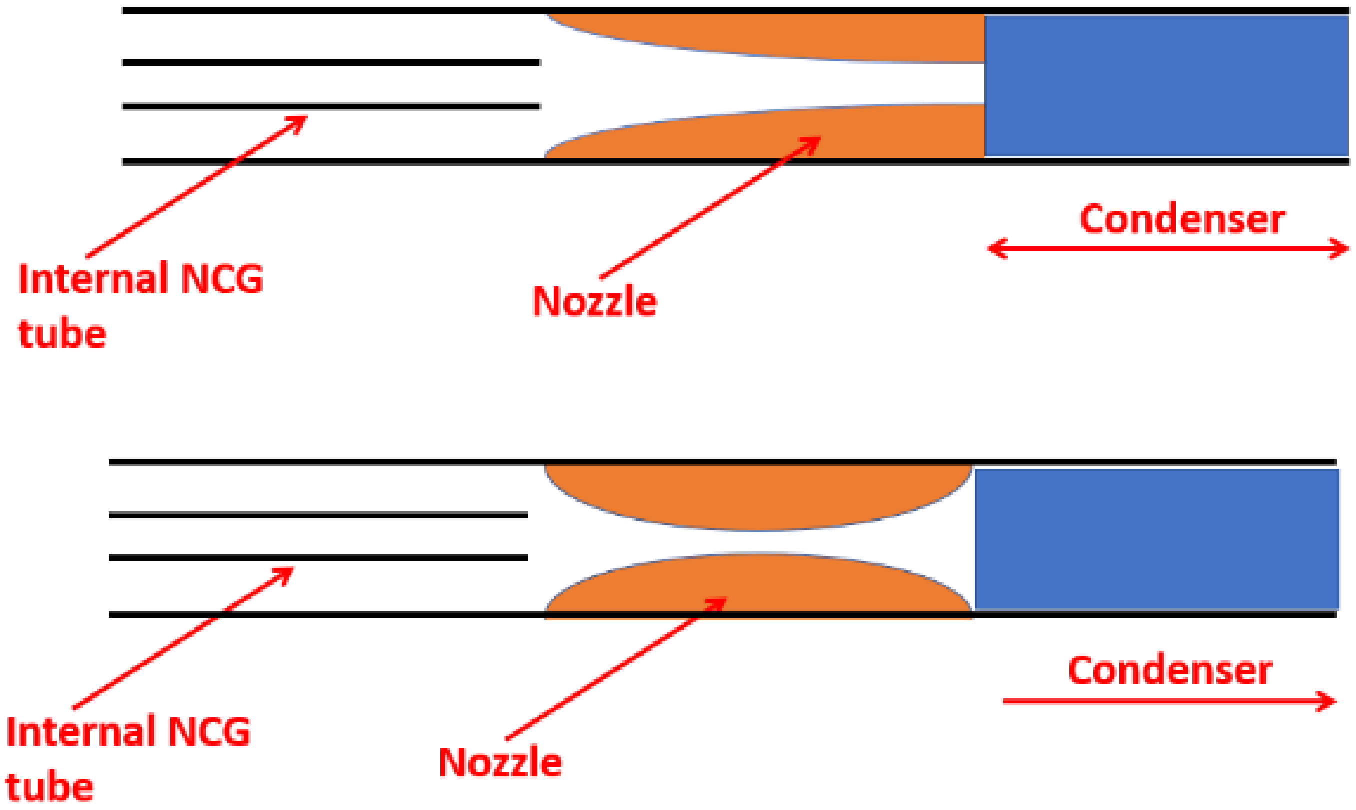


Nominal Power (W)	50
Nominal Operating Temperature (˚C)	20
Maximum Sink Temperature (˚C)	50
Minimum Sink Temperature (˚C)	-130
Payload Survival Temperature (˚C)	-40



Nozzle Design Optimization to Improve the Purging Behavior

- Multiphase modeling is being conducted to optimize the nozzle design to achieve optimal purging behavior for high-saturation pressure working fluids



Two Conceptual Nozzle Designs

Conclusions

- Successful purging (reliability testing) with acetone and toluene as working fluids.
- High saturation pressure working fluids (e.g., ammonia and propylene) have low purging pressure (kinetic energy). Other features (e.g., nozzle) should be added in the adiabatic section to accelerate the flow and mitigate the formation of undesired wakes/vortices.
- Testing of Protoflight I (copper-water VCHP) is ongoing
- Finalize the design of Protoflight I (aluminum-ammonia VCHP) (e.g., adding the Venturi-like nozzle to the design) and send for fabrication.
- Testing of Protoflight II

Acknowledgement

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- Technical Monitors are Dr. Jeff Farmer and Mr. William Johnson (NASA Marshall)
- Technicians who made significant contribution to this project are Phil Texter and Eugene Sweigart.

Thank you for your attention

Any Questions?