Design and Thermal Vacuum Testing of a Propylene Miniature Loop Heat Pipe (MLHP)

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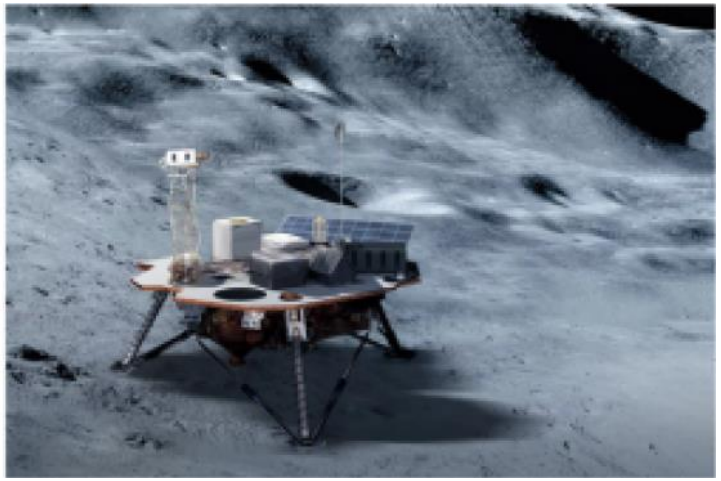
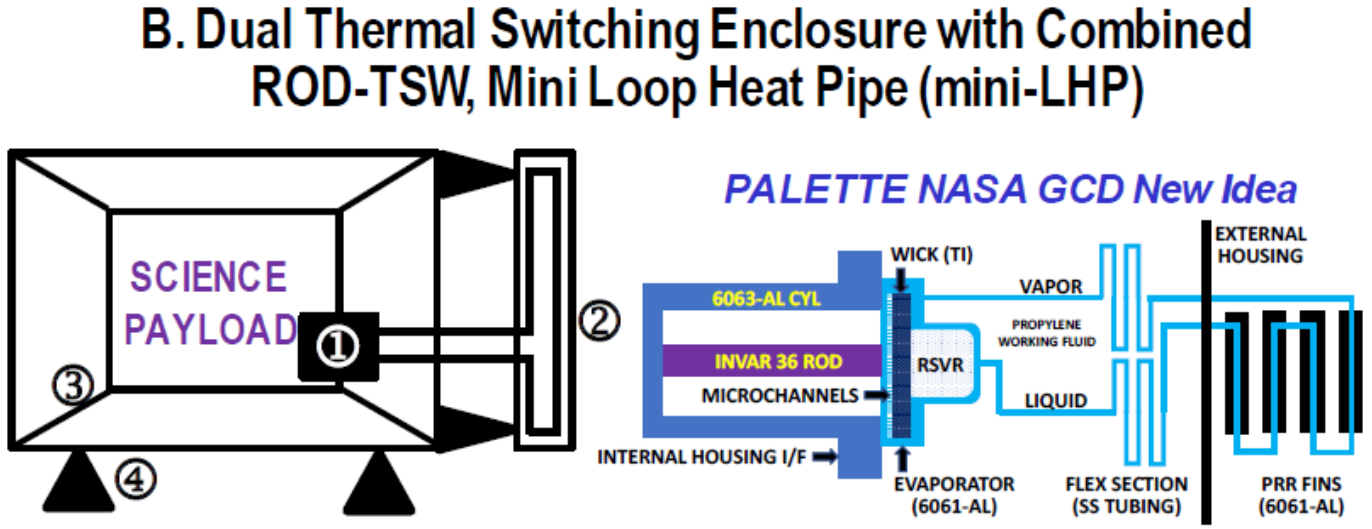
Background



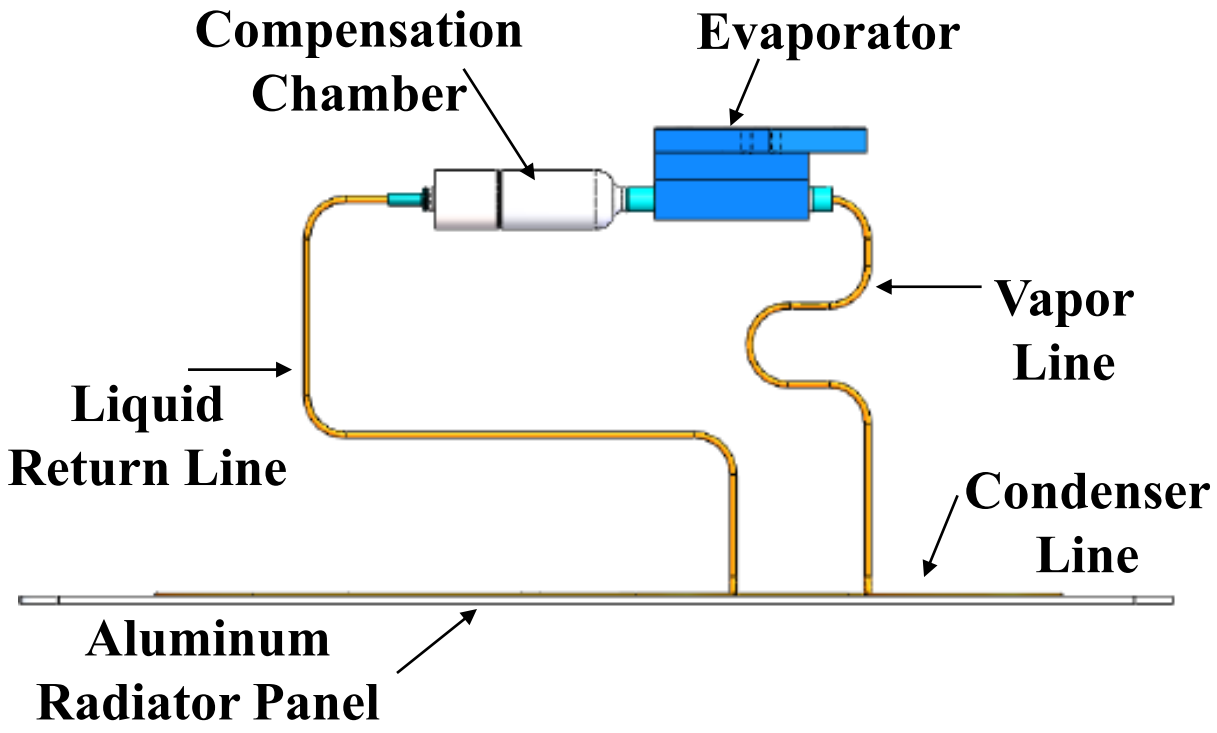


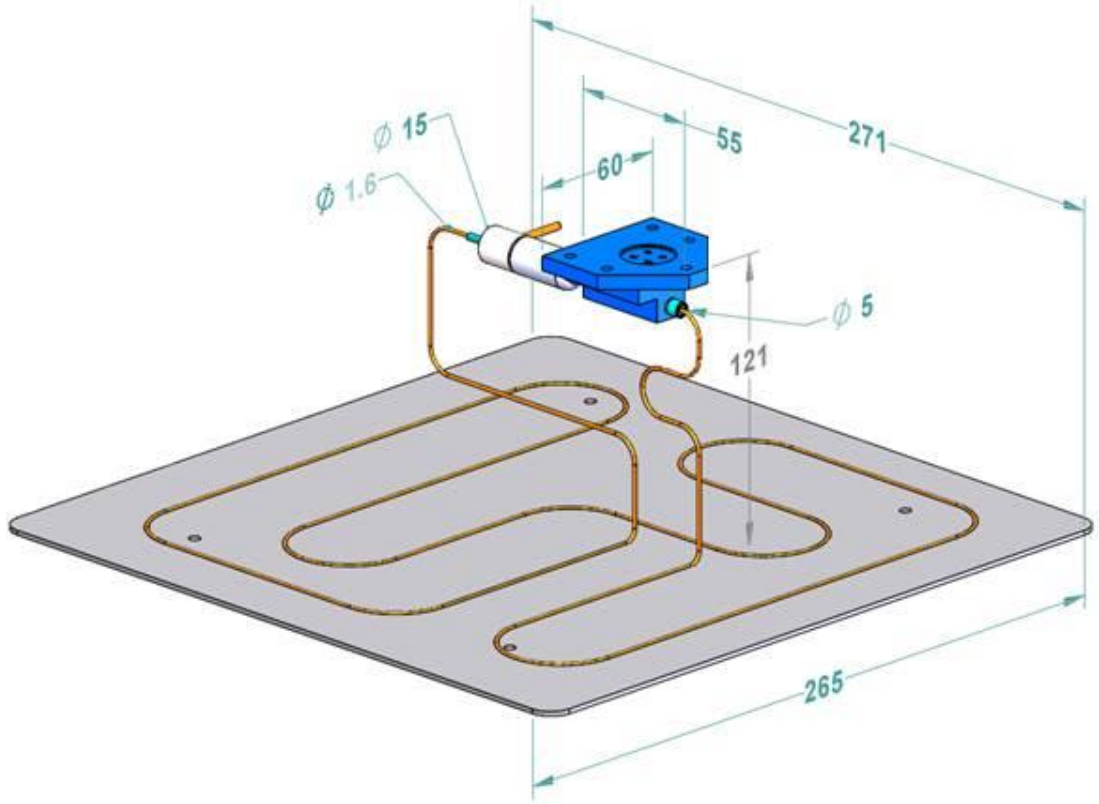
- The Planetary and Lunar Environment Thermal Toolbox Elements (PALETTE) project is to develop passive thermal management tools necessary for future instrument/system operation in extreme environments
- A dual enclosure system with high strength, low k tension cable (TC) supports and a variable conductance thermal link (VCTL) composed of a reverse-operation DTE thermal switch (ROD-TSW) in series with a miniaturized loop heat pipe (mini-LHP)

Summary of the Technical requirements

1. Operating Temperature Range **-30 to +20°C**
2. Transport Capability: **from 1 W to 20 W**
3. Working Fluid: **Propylene**
4. Evaporator Body: **Aluminum or Stainless Steel (Al preferred)**
5. Evaporator Wick OD: **Less than (or equal to) 0.3 inches**
6. Evaporator Wick Pore Size: **Less than (or equal to) 3 microns**
7. Transport Line OD: **1/16 - 3/32 inch**
8. Reservoir Volume: **Minimize (compact as possible)**
9. The mini-LHP is held rigidly at the evaporator and radiator

MiniLHP Design and Overall Dimensions





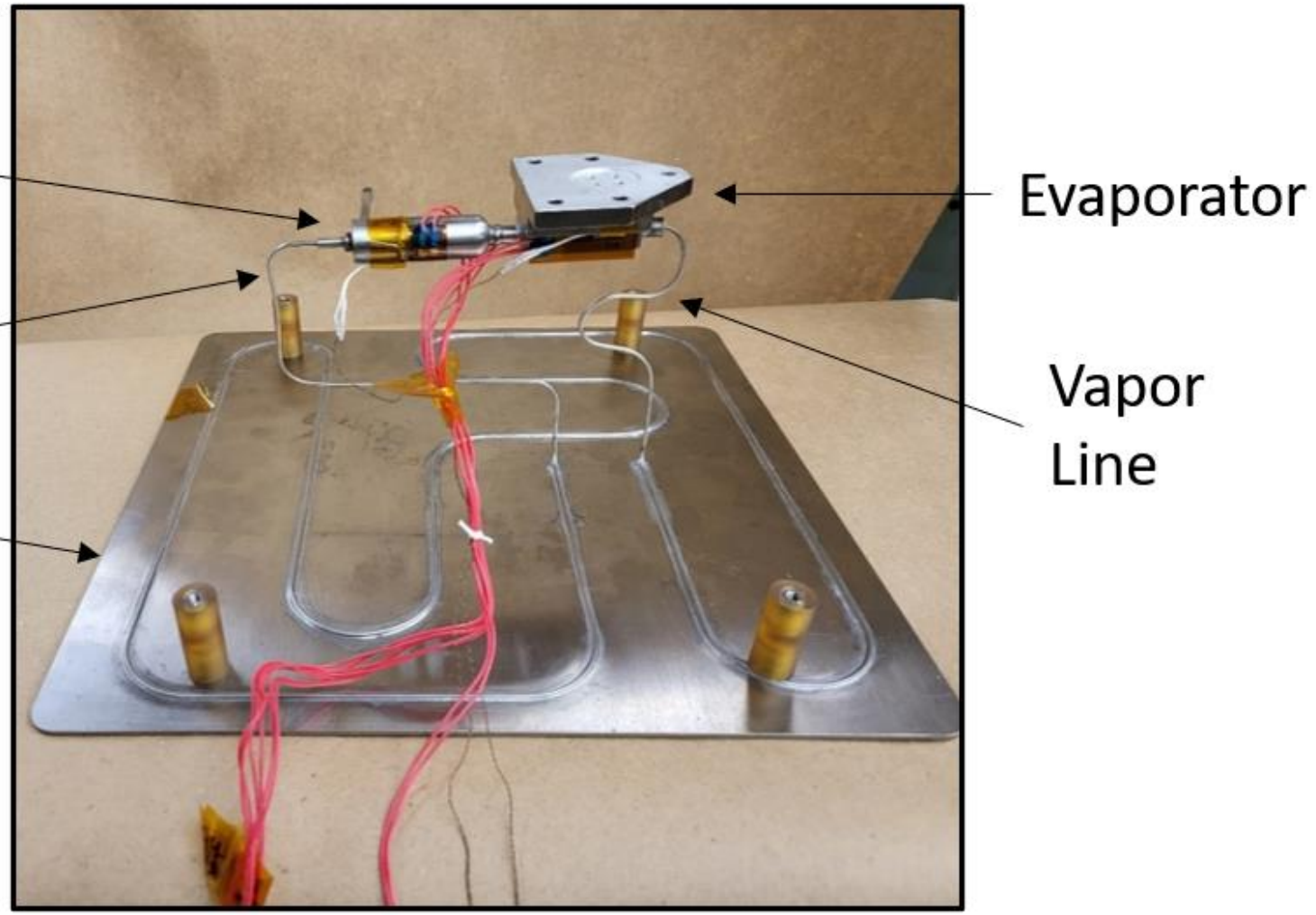
Significant Parameter of the Mini-LHP

Working Fluid	Propylene	**Liquid Line Length**	226 mm
Wick Material	Stainless steel	**Liquid Line ID**	1 mm
Wick Pore Radius	1.2 μm	**Condenser Length**	1665 mm
Wick Permeability	1.4×10^{-14} m^2	**Condenser ID**	1 mm
Evaporator Material/OD	Aluminum/6.4 mm	**Volume of Reservoir (compensation chamber)**	6.75 cc
Wick Heated Length	40 mm	**Dimensions of Cold Plate**	200 mm× 265 mm
Vapor Line Length	117 mm	**Radiator Material/dimensions**	200 mm× 265 mm
Vapor Line ID	1 mm	**Secondary wick screen mesh**	200×1150
Total MLHP Mass	544.3g		

Operating Conditions

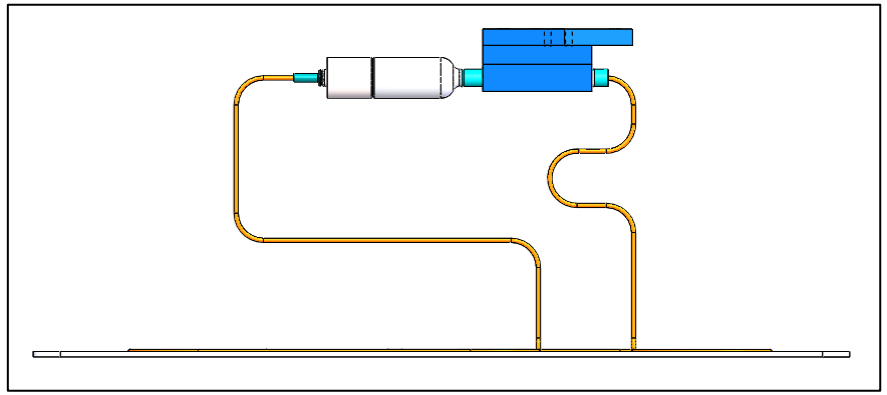
- Hot case
  - Temperature: 20 ° C (293.15 K)
  - Heat load: 1W, 5W, 10W, and 20W
- Cold case
  - Temperature: -30 ° C (243.15 K)
  - Heat load: 1W, 5W, 10W, and 20W

Mini-LHP Hardware

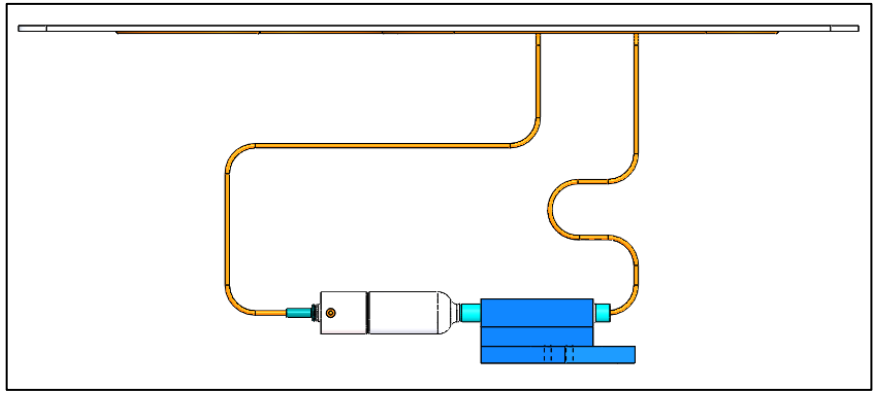


Test Orientations

Vertical Orientation

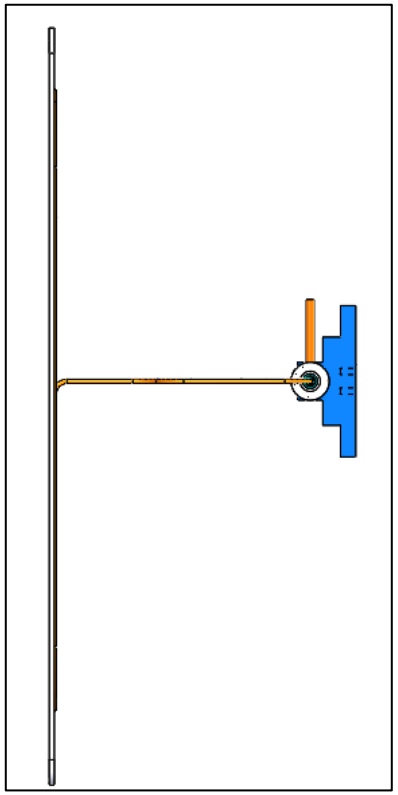


Case 1

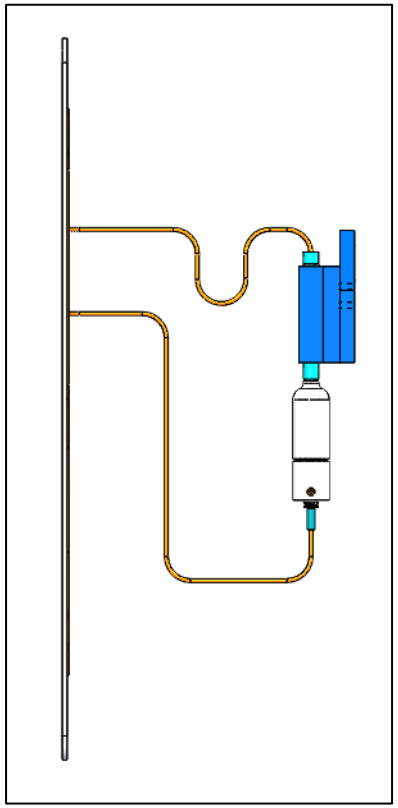


Case 2

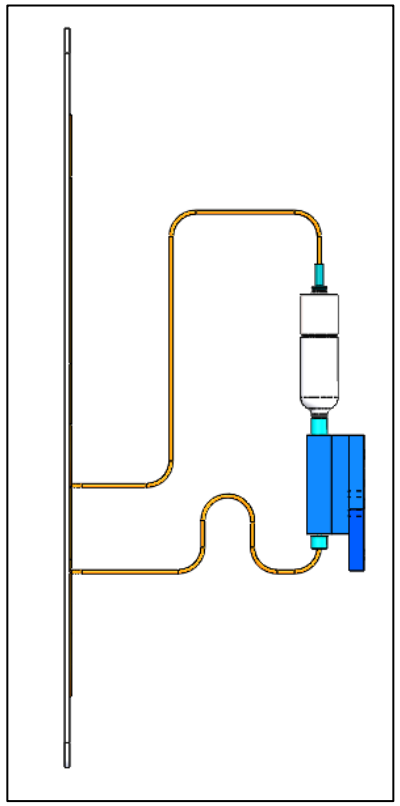
Horizontal Orientation



Case 3



Case 4



Case 5

Instrumentation

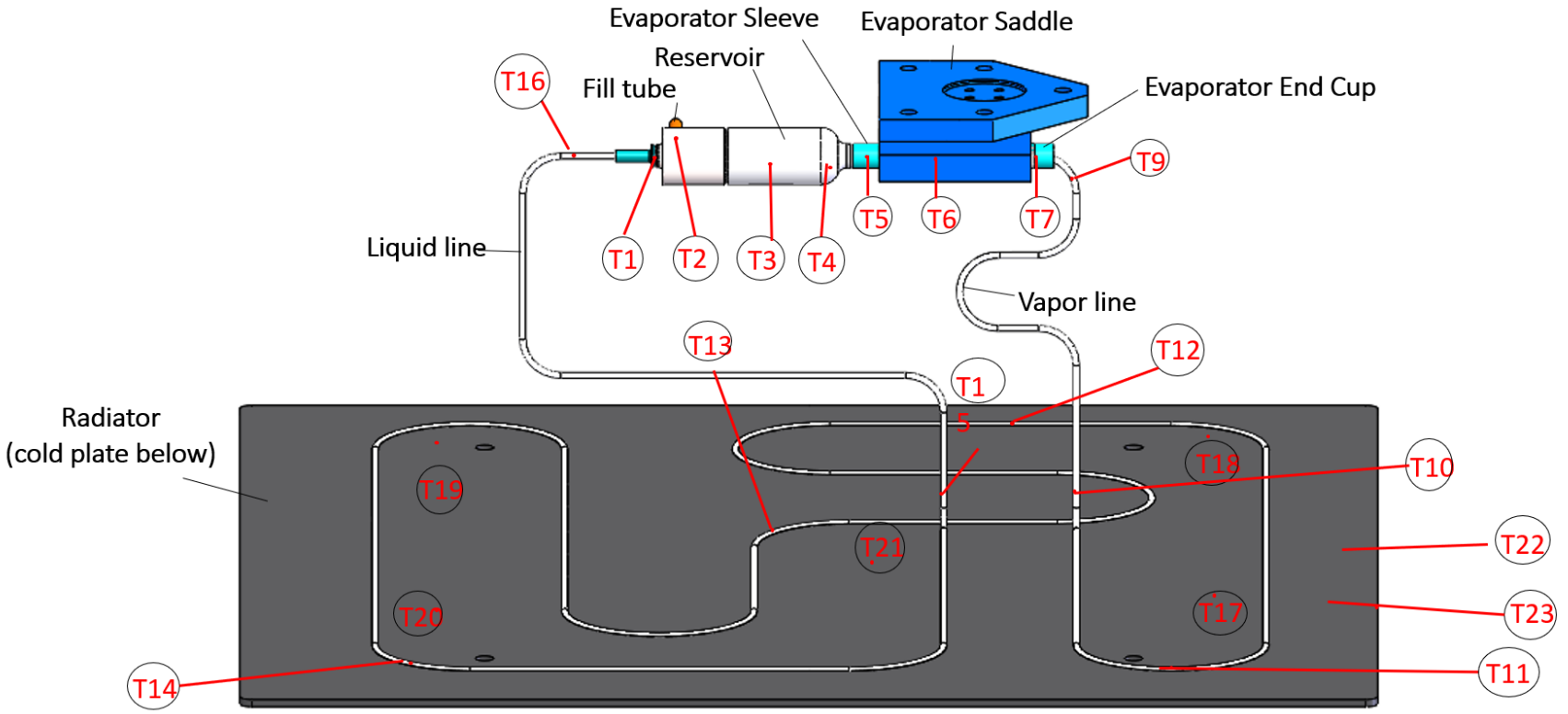
Parameter	Value	
	SI units	*BG units*
Length	**3050mm**	10 ft
Inside Diameter	750 mm	29.5 inches
Volume	1.344 m^3	47.465 ft^3
Minimum pressure at room temperature	10^{-4} Pa	1.5×10^{-8} psi (10^{-6} torr)

Parameter	Value
Number of TC feed through (type T)	40
Number of wire feed through (for power inputs 30Amps)	12
Number of wires 20AWG	32
Number of windows (flange 6.75")	4
Number of tubes for liquid cooling/heating (1/2" tube VCR fittings)	6
Flange for cryocooler 8" flange	1

- Vacuum Chamber
- Chiller
  - Thermo Neslab ULT-80: Cold case (-30°C)
  - Polystat 36 R3 Chiller: Hot case (20°C)

Instrumentation

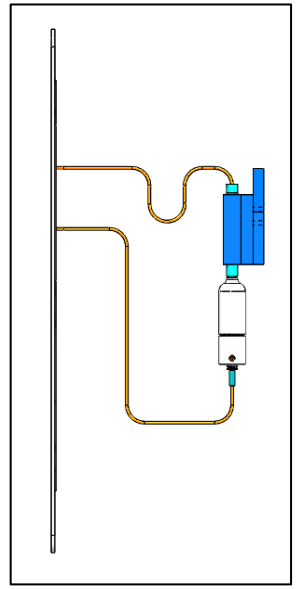
- Evaporator
  - Center of heat input
    - Plunger thermocouple
  - Saddle adjacent to wick
  - Sleeve at vapor end
  - Sleeve at liquid end
- Reservoir
  - LRL attachment
  - Reservoir top
- Transport Line
  - Vapor outlet
  - Vapor Line near Radiator
  - 4 spots along the Condenser Line
  - Liquid Line near Radiator
  - Liquid Line at Reservoir
- Radiator
  - 3 intermediate spots
    - Including the last leg of Liquid Lin



Reservoir	Evaporator	Vapor line	Condenser	Liquid Line	Radiator	Coolant In-Out	MLI	VC Wall
T1-T4	T5-T7	T9-T10	T11-T14	T15-T16	T17-T21	T22-T23	T24	T25

Minimum Heat Load for Successful Start-Up for Different Orientations

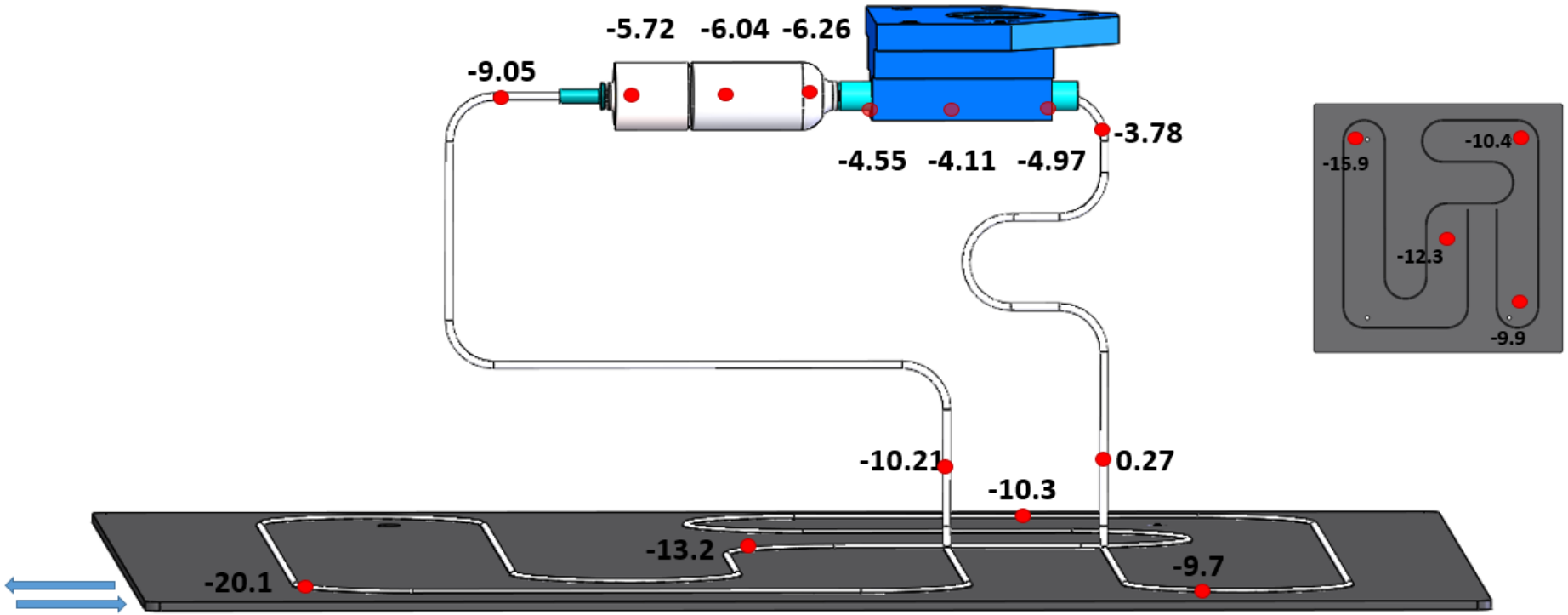
Power (w)	Vertical		Horizontal		
	Case 1	Case 2	Case 3	Case 4	Case 5
Hot[a]	1	1	5[b]	No[c]	5[b]
Cold[a]	1	1	1	No[c]	1



[a] Hot: sink temperature= 20 °C; Cold: sink temperature=-30 °C.
[b] After 1 Watt applied 30 minutes, no indication of starting; then heat load increased to 5 Watt.
[c] Four heat loads were applied: 1 Watt, 5 Watt, 10 Watt, and 20 Watt. For each heat load, 30 minutes passed and no indication of starting.

Thermal Performance

Cold start, 20W@-30°C, Vertical Orientation case 1 **TVAC**



Thermal Performance: Max Load

	Vertical		Horizontal		
	Case 1	Case 2	Case 3	Case 4	Case 5
Hot	20[a]	20[a]	20[a]	N/A[c]	20[a]
Cold	20[a]	30[b]	20[a]	N/A[c]	25[d]

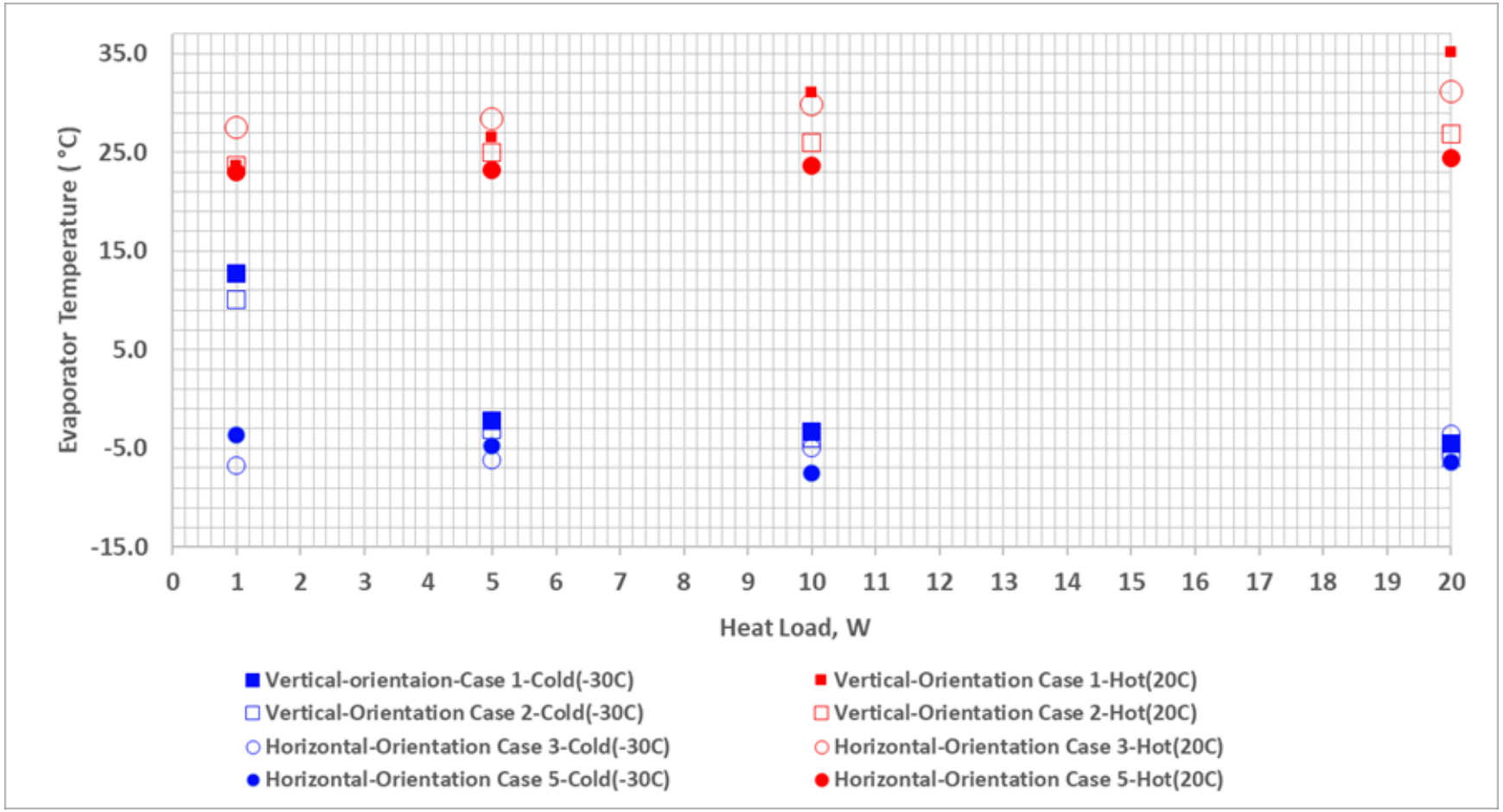
[a] deprime at 25W heat load;

[b] deprime at 35W heat load;

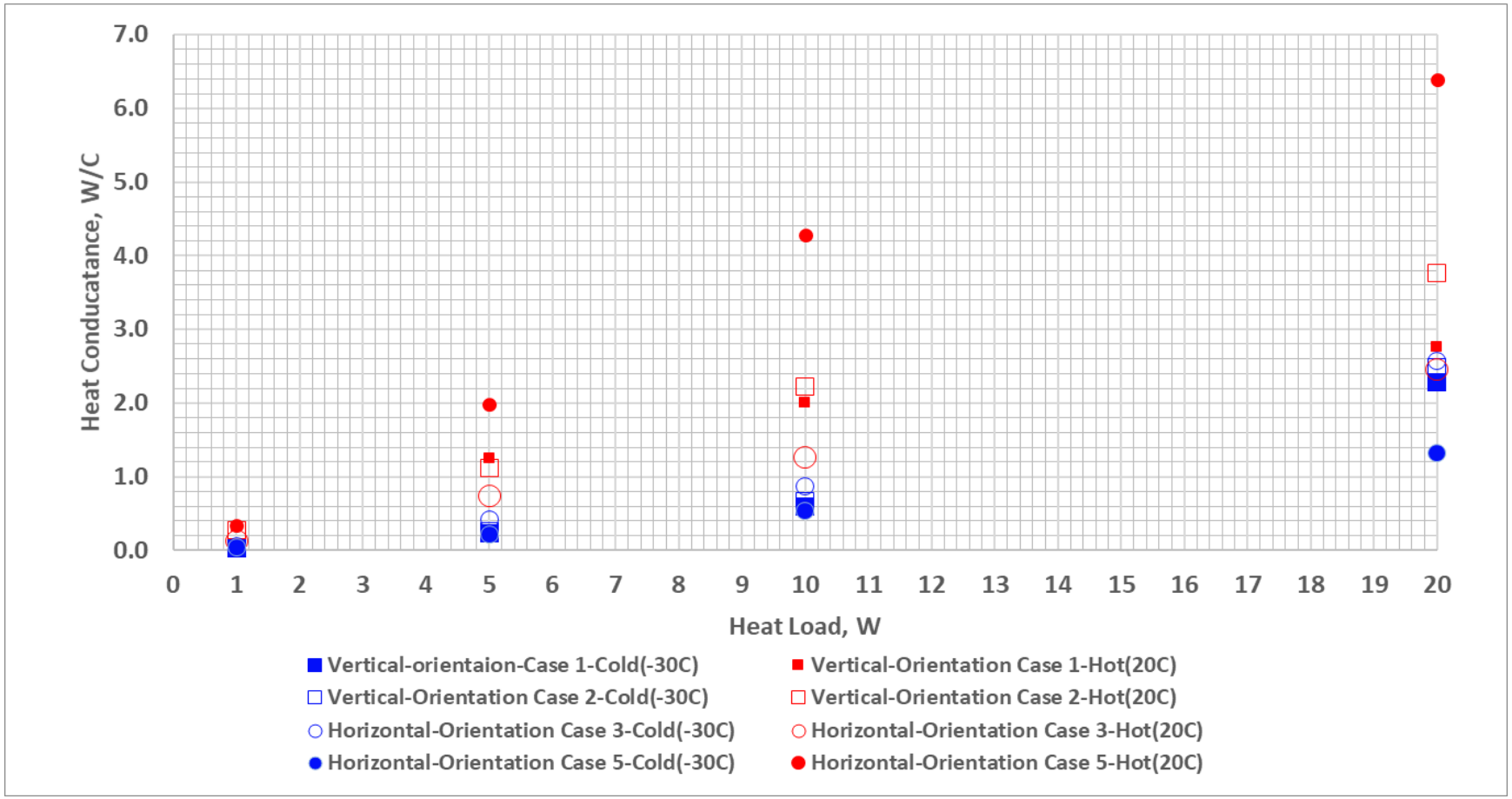
[c] LHP didn't start up;

[d] 30 W or higher heat load was not tested

Thermal Performance: Evaporator Temperature

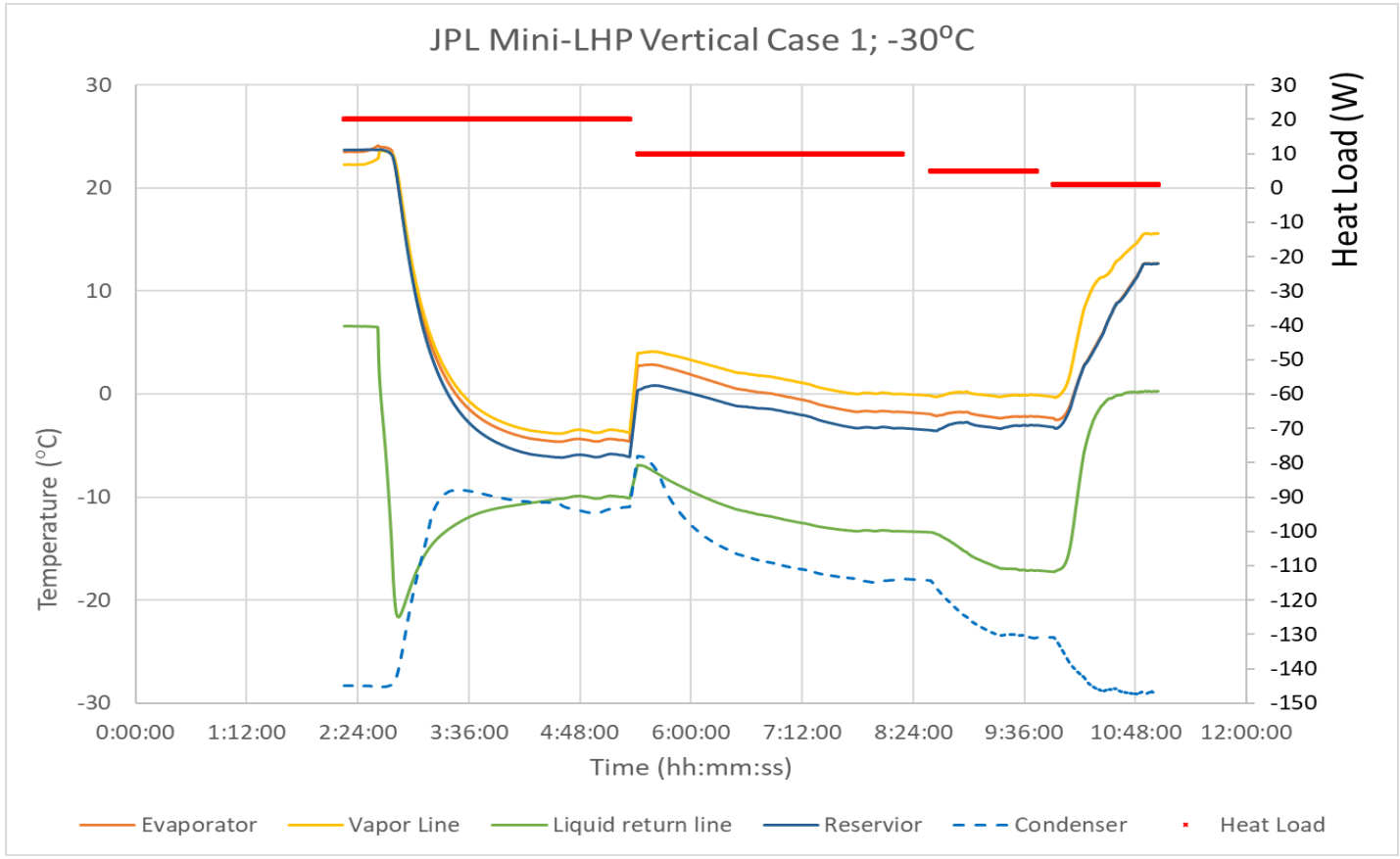


Thermal Performance: Conductance



Note: Conductance is calculated using average values of evaporator TCs (TC5, TC6, TC7) and condenser TCs (TC11, TC12, T13, TC14).

Power Cycle



Temperature profiles for vertical orientation 1 for cold case (-30C) at four heat loads: 20W, 10W, 5W and 1W.

Summary of the Miniature LHP Test Data

- The unit has performed well to meet the requirements of the system under different orientations for the two sink temperatures except Horizontal Case 4 where LHP can't be started;

- Elevation and tilt have strong effects on the startup of LHP. The unit can be started with as low as 1W power for vertical orientations (case 1 and case 2). For horizontal oriental case 4 where reservoir was located below evaporator, LHP couldn't be started with power as high as 20W;

- Evaporator temperatures with increase of heat load showed different trends for the two sink temperatures: evaporator temperatures decreased with increase of heat load for sink temperature of -30° C, but increased for sink temperature of 20° C;

- With increase of evaporator heat load, the difference of thermal conductance of the unit for different orientation increased. For all the orientations, the thermal conductance is higher for sink temperature of 20° C than sink temperature of -30° C. Particularly, the unit has peak conductance 6.6 W/° C for Case3 for sink temperature of 20° C.