Two-Phase Thermal Control Technology for Small Spacecraft Exploration

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: System Level Integration for Small Satellite Components**

Objectives

The objective of this task was to advance a two-phase mechanically pumped fluid loop for spacecraft thermal control to TRL 5. Achieving this goal required designing, building and testing a brassboard system in a relevant environment and demonstrating a sound understanding of the system behavior through physics-based based models.

Background

JPL's SoP thermal management systems cannot accommodate high heat fluxes and high heat densities associated with the emerging wave of miniaturized spacecraft electronics. To do so while maintaining science-driven temperature stability requirements would result in prohibitively large mass, power, and volume resources. The two-phase mechanically pumped fluid loop developed under this task addresses the current shortcomings of SoP thermal management systems to enable the next generation of spacecraft.

Approach and Results

Over the course of the year, a brassboard system was designed, built and tested. In addition, a numerical model of the two-phase mechanically pumped fluid loop was developed and validated with test data with our academic partners at University of Michigan. The test program was significantly impacted by COVID 19, and consequently a full characterization of the testbed was not completed. However, the freezable radiator was demonstrated and shown to significantly reduce heat loss through the radiator (approximately 2 orders of magnitude reduction), and the evaporator was shown to accommodate heat loads up to 200 W while maintaining a high degree of isothermality (temperature gradients of less than 2 K). Models were developed that adequately predict the regime of stable performance.

Significance/Benefits to JPL and NASA

The task has demonstrated that such a system could reduce the required mass and power to transport heat. In addition the system has demonstrated an ability to accommodate high heat fluxes (>10 W/cm2) and transport of high heat loads (0.9 kW) with a high degree of isothermality, which is critical for many instruments. Finally the demonstration of freezable radiator enables significant power savings for missions that must conserve heat such as lunar rovers and outer planet missions. These demonstrated capabilities make the system relevant to a host of JPL and NASA missions.

Publications

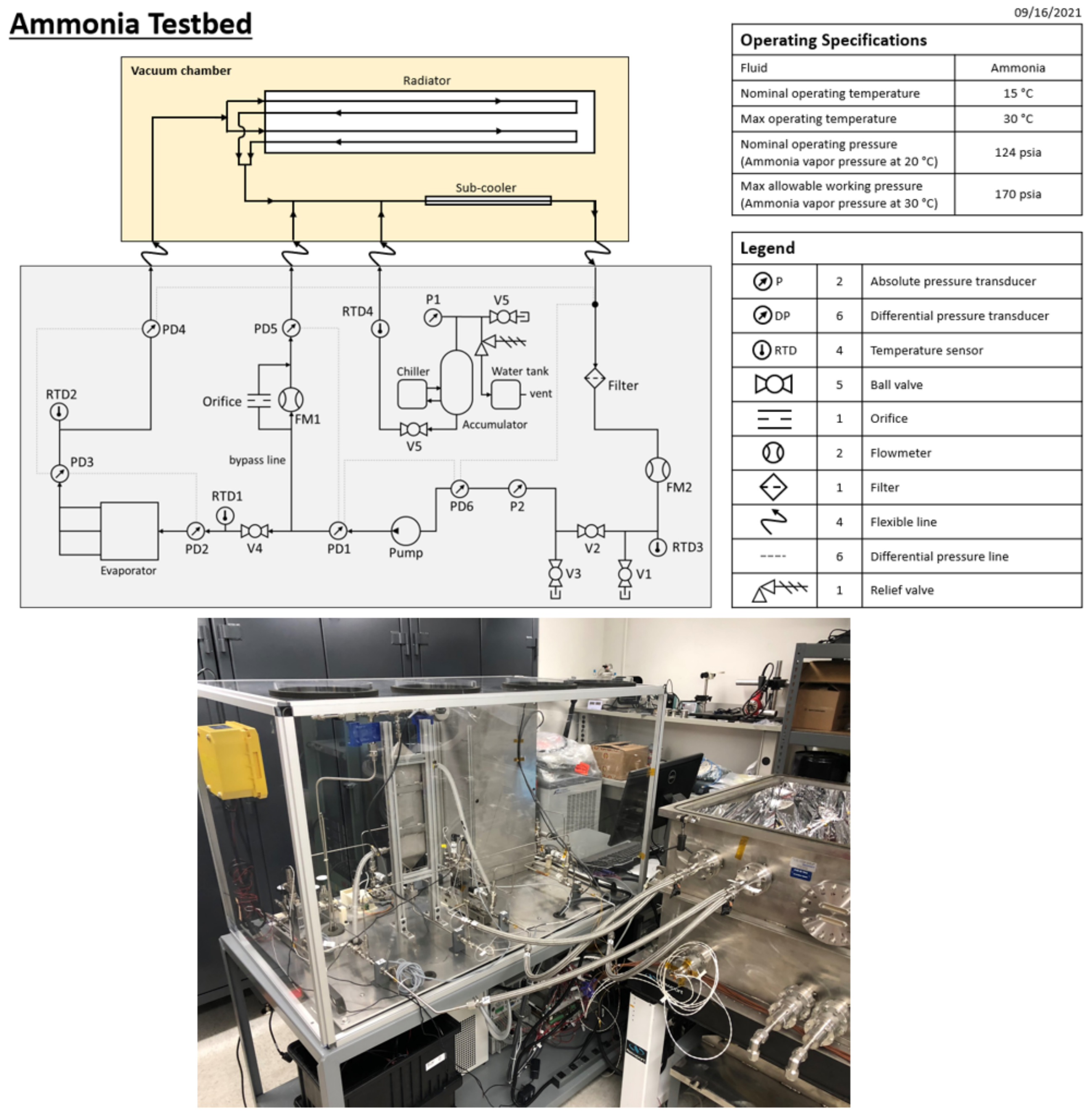
[A] Sunada, Eric, et al. "A two-phase mechanically pumped fluid loop for thermal control of deep space science missions." 46th International Conference on Environmental Systems, 2016.

[B] Furst, Benjamin, et al. "A mechanically pumped two-phase fluid loop for thermal control based on the capillary pumped loop." (2019).

[C]Valdarno, Luca, et al. "Heat Transfer Modeling in the Wick Structure of an Innovative Evaporator for a Two-Phase Mechanically Pumped Loop." ICES. Vol. 403. 2020.

[D] Furst, Benjamin, et al. "An additively manufactured evaporator with integrated porous structures for two-phase thermal control." 48th International Conference on Environmental Systems, 2018.

[E] Ferrer, Julio, et al. "A Two-Phase Mechanically Pumped Fluid Loop: Experiments and Modelling". Submitted to International Journal of Heat and Mass Transfer.



Operating Specifications	
Fluid	Ammonia
Nominal operating temperature	15 °C
Max operating temperature	30 °C
Nominal operating pressure (Ammonia vapor pressure at 20 °C)	124 psia
Max allowable working pressure (Ammonia vapor pressure at 30 °C)	170 psia

Legend		
P	2	Absolute pressure transducer
DP	6	Differential pressure transducer
RTD	4	Temperature sensor
⋈	5	Ball valve
═	1	Orifice
⊘	2	Flowmeter
◇	1	Filter
∿	4	Flexible line
----	6	Differential pressure line
△	1	Relief valve

Figure 1. Schematic (top) and image (bottom) of the two-phase mechanically pumped fluid loop brassboard testbed. The radiator/condenser/subscooler are housed in a vacuum chamber with a Liquid Nitrogen Shroud to simulate the space thermal environment.

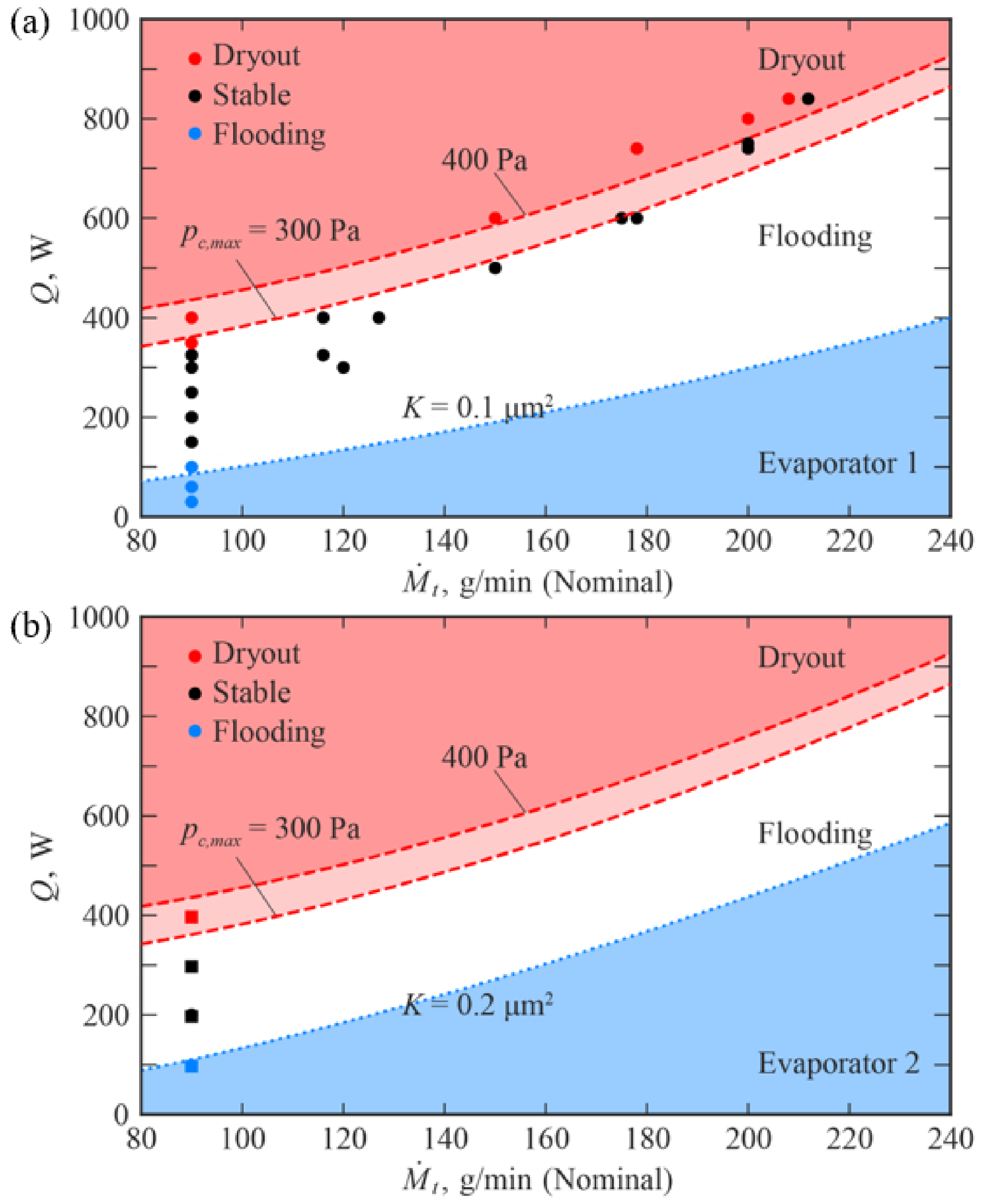


Figure 2. A comparison of the physics-based model predictions and the test data. The model predicts the envelope of stable operation (white region), as well as two modes of failure (dryout and flooding). The data is in good agreement with the model.

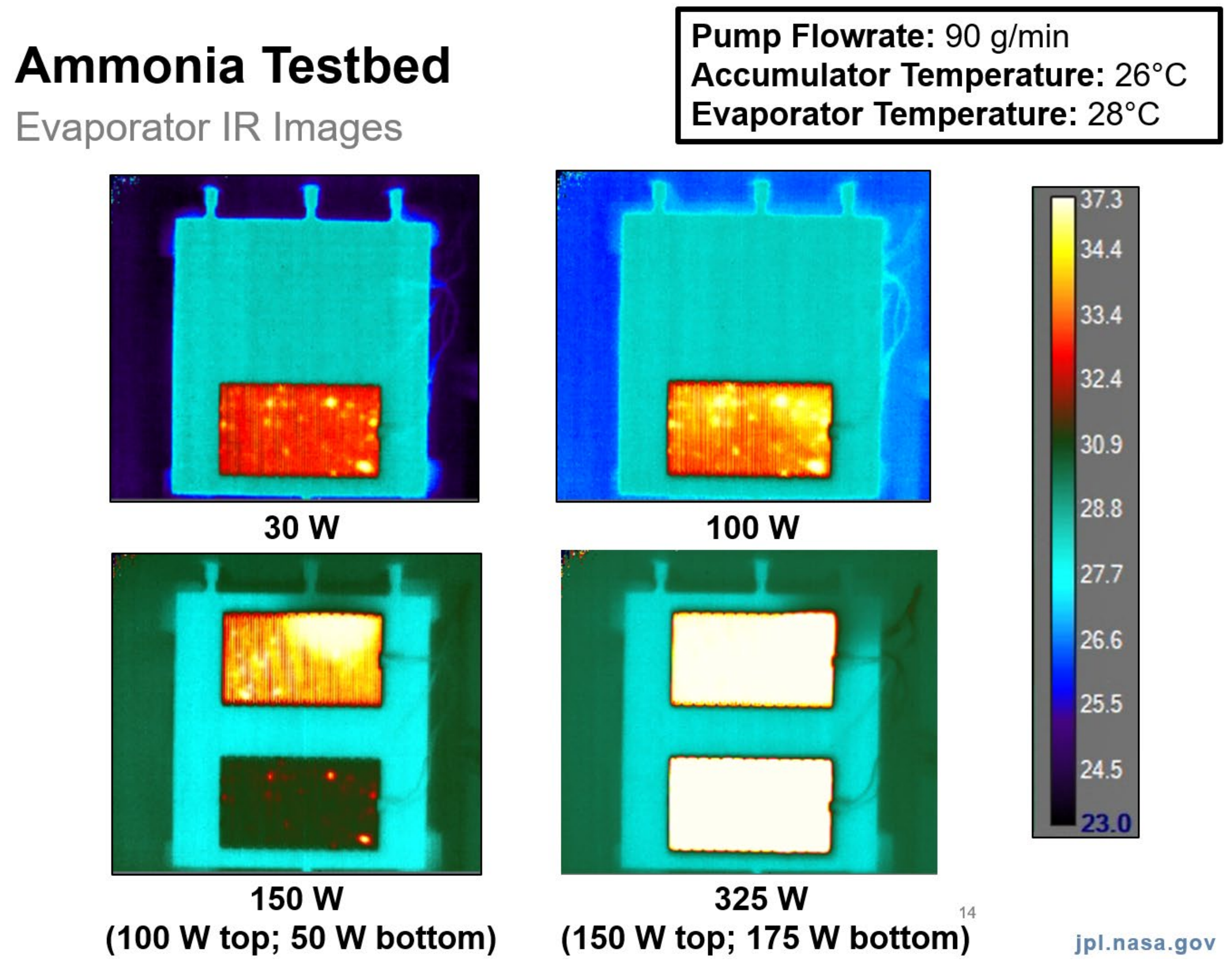


Figure 3. IR images of the evaporator (teal rectangle) accommodating a range of heat loads (smaller white/yellow/red rectangles). Note that the temperature of the evaporator is relatively invariant with heat load.

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