RedWater: Scaled Ice Melting Probe – Martian Environment Testing for ISRU

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Introduction: In-Situ Resource Utilization (ISRU) on the moon and mars is critical for increasing space travel and exploration capabilities and offering reduced system complexities and risk. Ice is a coveted resource in space as it can be used to supplement and sustain water consumable processes as well as provide the combustible base elements oxygen and hydrogen. Shallow ground ice and subterranean glaciers have been discovered in non-polar regions of Mars by the Mars Reconnaissance Orbiter's Shallow Subsurface Radar (SHARAD). [1] This source of water will be key in achieving NASA's goal of human exploration of Mars. To extract this water from subterranean glaciers, up to 10 meters of overburden will need to be drilled through to reach the glacial bodies detected by SHARAD.

One of the methods being developed at Honeybee Robotics is similar in design and function to a Rodriguez Well, a method of water extraction from glaciers used in Antarctica to provide drinking water. [2] The Honeybee Robotics design consists of a drill capable of boring through the overburden to the glacial ice. Once the drill has reached its target depth, heaters within the drill will activate, and begin the ice melting process. Then, through the addition of heat energy and an active water agitation system, a melted cavity and pool of water will form, providing extractable liquid water. [3]

The Planetary Surface Technology Development Lab (PSTDL) at Michigan Technological University (MTU) began working with Honeybee Robotics to design a small-scale test setup capable of actuating a heated probe into a cryogenic clear ice block at Martian atmospheric conditions. This test setup was designed at the PSTDL to collect all necessary testing parameters, including probe power, probe temperature, ice block temperatures, probe displacement, and total volume melted. Honeybee Robotics will use this data to aid in the design and modeling of their larger RedWater heated drill.

Scaled Test Setup Objectives: A new test setup was designed to collect data on the performance of a small heat probe melting cryogenic ice under Martian atmospheric conditions. To accomplish this, a range of requirements were created. The setup needed to measure the temperature of the heated probe, power supplied, total energy consumed, temperatures of the surrounding ice, rate of probe displacement into the ice, and the total volume of ice melted. Ice block temperatures needed to be varied from 0ºC to -80ºC to be consistent with the glacial ice temperatures on Mars observed by the Shallow Subsurface Radar. To achieve these requirements all tests are being conducted in a small 18inch x 18inch x 18inch acrylic vacuum chamber capable of supplying liquid nitrogen to cool and maintain the ice block temperatures as well as maintain an environmental pressure of 7 Torr.

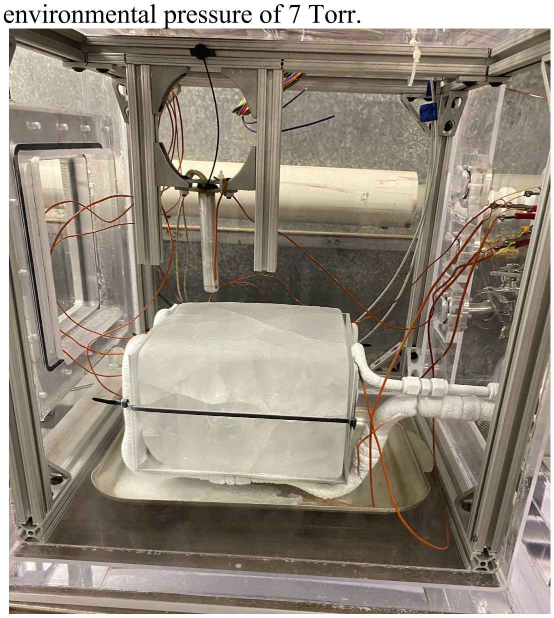

Figure 1: Passive heated probe actuation testing

Current tests are being conducted using a passive actuation probe assembly which allows testing of the heater probe during gravity-fed penetration.

Passive Actuation Procedure & Preliminary Results: During testing, the heater probe is kept at a constant power level. A range of constant power levels, 75 Watts, 100 Watts, and 125 Watts, are being tested to compare the rates of displacement, probe energy efficiencies, and total energy consumed per unit volume of ice melted. These values are then used to compare the heater's performance at different constant power levels. Typical probe melting behavior can be seen in

Figures 2 and 3. The temperature at the tip of the probe is measured using a thermocouple and the displacement data is measured using a string potentiometer. Ice block temperatures are maintained between -80ºC and -60ºC by the liquid nitrogen cooled shroud. The weight of the passive probe assembly is recorded at the start of each test along with the position of the probe relative to the edges of the ice block. Once the power is applied to the cartridge heater, data acquisition begins. The second subplot in Figure 3 shows the constant power supplied and the internal pressure of the vacuum testing chamber.

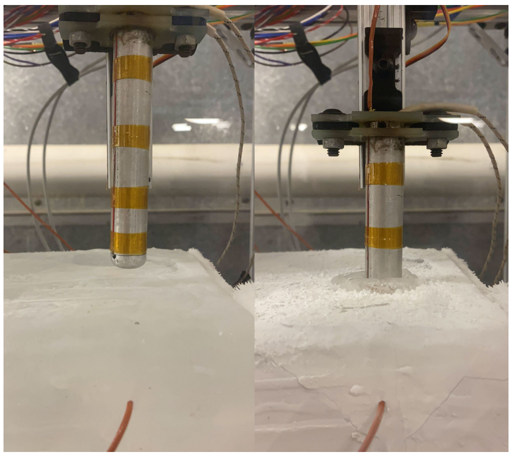

Figure 2: Passive actuation ice melting observation

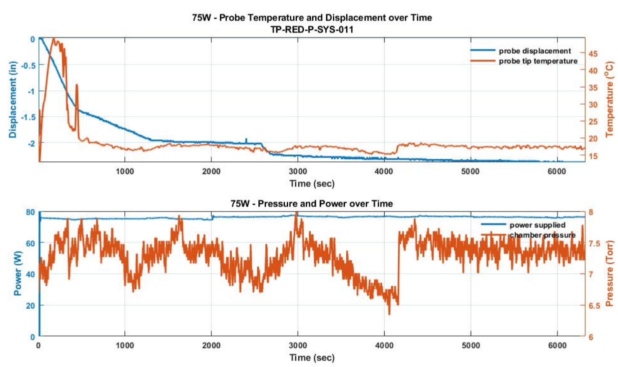

Figure 3: ***Top*** **Probe displacement (in) and probe tip temperature (ºC) over time;** ***Bottom*** **constant 75 Watt Test, average 7 Torr pressure.**

Results from these passive actuation tests have been hard to reproduce at most of the constant power levels tested. Under similar testing conditions, differences in probe tip temperature and rates of probe displacement behavior have been observed. Detailed notes are taken during each test, notes include major and minor ice crack formations, changes in the ice melting/boiling behavior, and changes in the melt cavity geometry. A randomized complete blocking design was used in the generation of the test matrix. Factors of interest are the selected constant power level, day of the test, ice block identifier, and location of the probe melting on the ice block. Testing with the active actuation is expected to reduce variability between each test and will likely result in more reproducibility.

Active Actuation Design: Plans for testing an active probe actuation assembly will show what effects of an active weight on bit will have on ice melting performance. The inclusion of a brushless stepper motor and a 5-lb capacity load cell will allow the heated probe's vertical position to be controlled and monitored. The load cell will be used as a form of feedback control, allowing for a set force to be applied to the heated probe during each test. These design improvements are important because most variabilities between each constant power passive actuation test have been inconsistent probe displacement behavior.

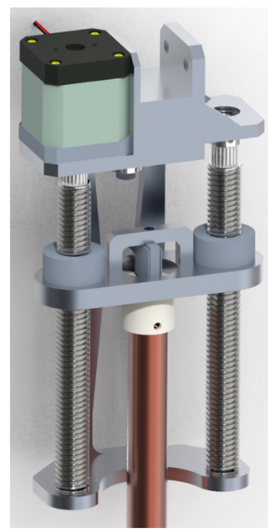

Figure 4: Active Actuation Assembly CAD Model

Assembly of the active actuation assembly has been completed and functionality has been verified. Preliminary atmospheric ice melting tests will be conducted before low-pressure testing begins.

References:

[1] A. M. Bramson, S. Byrne, and J. & Bapst, "Preservation of midlatitude ice sheets on mars," *Journal of Geophysical Research: Planets,* pp. 122, 2250-2266, 2017.

[2] S. J. Hoffman, A. D. Andrews, and K. D. Watts, "Simulated Water Well Performance on Mars," *AIAA Space and Astronautics Forum and Exposition,* September 2018.

[3] B. Mellerowicz, K. Zacny, J. Palmowski, and e. al., "RedWater: Extraction of Water from Mars' Ice Deposits," in *ASCEND*, Las Vegas, Nevada, 2021.