Experimental Results of Ice Formation at Low Temperatures and Pressures

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Introduction: For NASA's mission of sustained presence on the lunar surface and beyond, reduction of payload weight and frequency of resupply missions are vital. One useful means of reducing weight and resupply frequency is the use of in-situ resource utilization (ISRU) technology. Since the discovery of ice in the permanently shadowed regions of the moon [1], the availability of water for life support and rocket fuel has increased focus in technology development for the extraction and transport of water on the moon. To investigate an efficient process to capture and store water, an experiment is being developed as a water handling task for NASA's Game Changing Development FLEET project.

A test setup was designed to measure the rate at which water vapor desublimates onto a test plate at lunar conditions. Previously, the experiment was conducted near the critical point and showed very favorable ice growth conditions [2,3]. The goal of this experiment is to determine if the ice growth rates remain the same at lower temperatures and pressures. While a model has been developed that can predict the growth rates at these conditions, it is unclear if the highly dense ice will still form at lower temperatures and pressures. Additionally, at temperatures close to the triple point, water vapor may undergo a condensation phase if the local partial pressure is greater than the triple point, which may have contributed to the densities seen previously. By running the experiment at lower temperatures and pressures, this phenomenon can be ruled out. Thus, in addition to the ice growth rate, the bulk density will also be a primary objective of the test campaign.

Test Apparatus: The test apparatus consists of an aluminum test plate, positioned in a vacuum chamber and cooled with liquid nitrogen. The vacuum chamber is first pumped down, and then water vapor is introduced into the chamber from a reservoir via a pressure-regulator controlled water vapor line. Water vapor desublimates on a horizontal, flat test plate, and measurements are taken to determine ice layer height and density. The temperature and final pressure setpoint are varied over the duration of the test campaign to examine the impact of varying test plate temperature and partial pressure of water vapor on the ice growth characteristics. The test setup is shown in Figure 1.

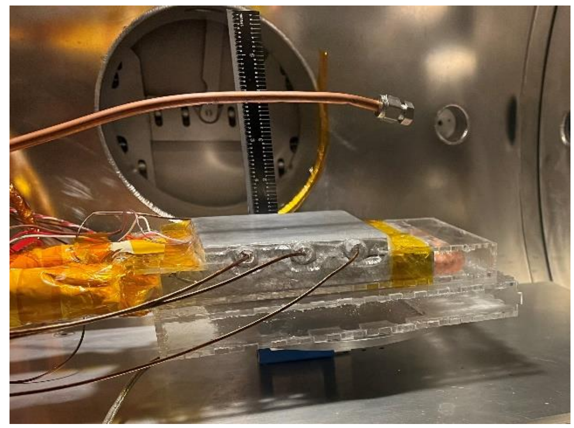

Figure 1. The experiment configuration, installed in the 2-foot vacuum chamber at NASA Glenn Research Center.

Test Procedures: The chamber is pumped down slowly, starting with the roughing pump, and then a diffusion pump. When the chamber reaches 10^{-3} torr, the pumps are turned off and the water vapor introduction valve is opened, allowing water vapor to accumulate in the chamber. As the test continues, the ice forms on the test plate, and its height is measured with a camera recording over the duration of the test. As the ice layer height begins to plateau, the test is concluded, and the chamber is repressurized. Bulk density measurements

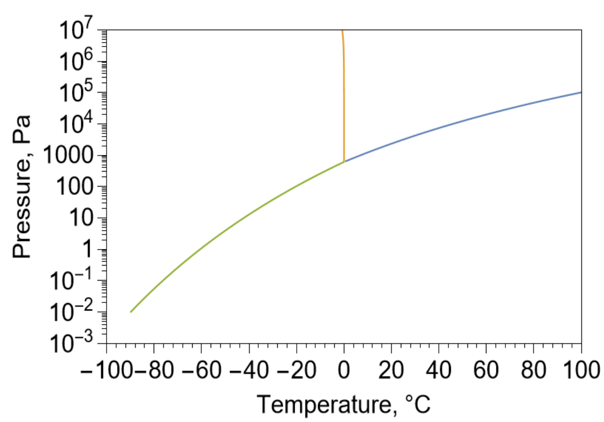

Figure 2. Phase change diagram for water. The green line indicates the vapor-solid phase change, the orange line is the solid-liquid phase change, and the blue line indicates the liquid-vapor phase change.

are then taken by removing samples from the chamber and measuring their volume displacement and mass to determine an average density of the sample. Previous experiments indicated the density was uniform across the entire ice growth region. The side profile camera images are then analyzed to determine the height measurements throughout the duration of the test.

Results: At the time of this abstract, the tests have not been completed. Preliminary data indicates that the density may be much lower at the liquid nitrogen temperatures, which will have large impacts on the growth rates of the ice layer. The phase diagram for water is shown in Figure 2, which demonstrates the phase change pressure with varying temperature. The current test campaign is examining lower temperatures and pressures on the solid-vapor phase diagram, targeting between -50°C and -100°C test plate temperatures. The previous campaign conducted tests between -5°C and -18°C, which is much closer to the triple point of water.

Discussion: Results from the test campaign will better inform the cold trap model that is used to predict ice growth in the lunar water extraction infrastructure. Results are expected to be similar to the previous experiments with a period of linear increase in height as the partial pressure of water vapor in the chamber increases. Then the height is expected to converge as the pressure approaches the setpoint and the desublimation rate slows down. The density of the ice layer is expected to have a high impact on the ice growth dynamics.

References: [1] Li, Shuai, et al. "Direct evidence of surface exposed water ice in the lunar polar regions." *Proceedings of the National Academy of Sciences* 115.36 (2018): 8907-8912. [2] Compton, Beau M., Timothy S. Krause, and Leah M. Struchen Deans. "An Experimental Study on Low Pressure Frost Formation for Lunar Polar Water Capture." *52nd International Conference on Environmental Systems (ICES)*. 2023. [3] Krause, Timothy, Beau M. Compton, and Leah M. Struchen Deans. "Thermal Model of Ice Growth in Vacuum for Lunar Water Production." *ASCEND 2023*. 2023. 4761.