LUNAR AUGER DRYER ISRU (LADI) MECHANICAL TESTING AND SUPPORTING MODELS.

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In 2009, the Lunar Reconnaissance Orbiter (LRO) and Lunar Crater Observation and Sensing Satellite (LCROSS) provided definitive proof of water in the Lunar's southern permanently shadowed region (PSR)[1]. Both the 2020 NASA Technology Taxonomy[2] and the Lunar Surface Innovation Initiative (LSII) team identified capability gaps in icy regolith transfer and reactor processing in Permanently Shadowed Region (PSR) environmental conditions. A water processing plant operating from inside the PSR can continuously process water (and volatiles) for both breathable air and propellant. NASA's Johnson Space Center (JSC) began development of the primary subsystem for a Mars plant in 2017 and fabricated a unique breadboard test stand for validating the feasibility of this concept. This testing was postponed with the redirection of NASA's mission from Mars to Moon. A JSC led trade study[3] in FY20 formulated a plan to leverage existing hardware to test concept feasibility, developed a lunar auger dryer sizing tool, and identified that both physical flow and thermal models are required to develop an Engineering Development Unit (EDU) for environmental testing. Beginning in FY21, the Game Changing Development Program (GCDP) funded a three-year technology development project to increase the Technology Readiness Level (TRL) of the Lunar Auger Dryer ISRU (LADI) subsystem to TRL 5.

The major subsystems of a lunar water processing plant include a.) an upstream excavation rover and a hopper/size-sorter, b.) an auger dryer, and c.) a downstream cold trap used for ice deposition (water vapor to ice). The top-level concept of operations begins with the excavator digging up icy regolith and delivering it to a stationary ISRU processing plant (inside PSR), size sorting the feed to remove large rocks, and then discharging into a hopper. The hopper feeds the regolith to an auger-dryer which extracts water from the soil and then sends it to a cold trap subsystem. The dried regolith is collected, dumped (potentially processed for waste heat), and the excavator repeats the process. Ice deposition occurs in the cold trap as vapor is converted into ice, impurities removed, and the product stored on a tanker. This tanker will either travel out of the PSR to a stationary electrolyzing processing plant located on the crater ridge or the tank will be pressurized, and liquid water pumped to the plant via flex hose. At the crater ridge, the water is cleaned, electrolyzed into oxygen and hydrogen, liquefied, and finally stored.

The key design features of the auger dryer design is operating below the triple point of water and using a variable pitch auger to create a 100% full regolith plug-seal at the inlet and outlet of the auger with a 15% full heated section. These features maintain low internal pressure (easier to sustain regolith plug), prevent liquid water (increases motor torque and initiates equilibrium chemistry with impurities), and eliminate the need for isolation valves. Isolation valves increase system height, mass, complexity, and reduces reliability.

The breadboard auger dryer, shown in Figure 1, has the unique capability to operate with either a clear or stainless-steel casing supporting both mechanical and thermal test requirements. The test stand was setup in JSC's dust containment test cell.

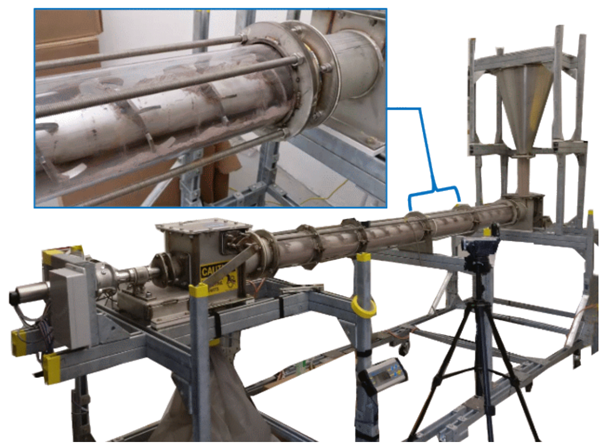

Figure 1 – LADI Breadboard (clear casing installed)

Nineteen mechanical test runs were completed using Exolith Lab's Lunar Highlands Simulant (LHS-1). Five unique auger geometries, shown in Figure 2, and three motors configurations were used to optimize steady state flow. Torque, RPM, mass flow rate, gate angle, and power were measured while observing discharge plug behavior.

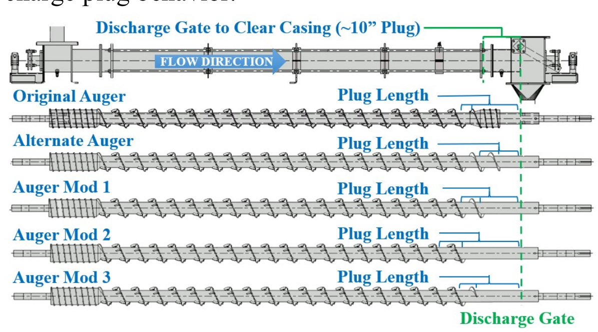

Figure 2 – Auger Configurations Tested

The max regolith plug pressure was determined for each configuration by injecting nitrogen gas into the casing to simulate water vapor formation until plug failure. Plug pressures above water's triple point were deemed successful due to the downstream cold trap's design operating pressure. The effect of frozen simulant inside the casing was also observed by mixing 5% (wt. %) water with simulant. As water melted into mud, both torque and plug strength increased. In addition, high-density cryogenic blasting dry ice (carbon dioxide) was mixed into the lunar simulant to observe sublimation effects on the plug at room temperature. The feasibility of using a plug to maintain pressure inside casing below the triple point at steady state in a laboratory environment was proven feasible increasing the subsystem TRL to 4 mechanically.

Further optimization of the plug geometry and system flow effects can be performed with a Discrete Element Method (DEM) simulation. A particle-scale numerical model of the breadboard was recently completed as shown in Figure 3.

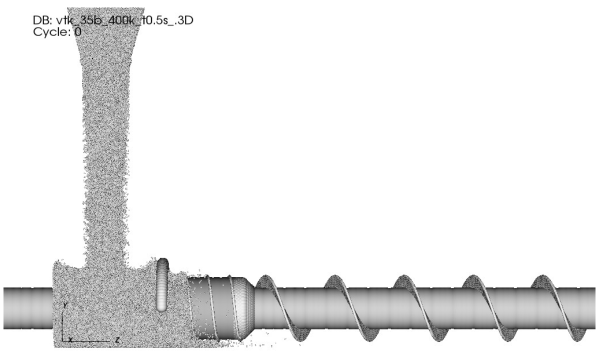

Figure 3 – DEM Breadboard Model Geometry

Several runs varying the cohesion, particle size, and particle count are currently in work to mimic test observations using the clear casing. After the model is validated, optimizations to the regolith plug seal, auger flight geometry, and flow rate can be performed. Moreover, the gravity can be reduced to lunar conditions to predict lunar performance.

Thermal testing is required to increase the auger subsystem to TRL 4. JSC recently installed the stainless-steel casing, resistance band heaters, and chillers for the condenser and hopper (to condense water vapor and maintain ice in hopper). The desired test matrix will include testing simulant water ice concentrations of 2.9%, 5.0%, and 8.5% (wt. %) to calculate yield over the full range of data measured on LCROSS mission. The heaters will also be reconfigured to both a long and short configuration as shown in Figure 4 to optimize the residence time by manipulating heat in three independent zones.

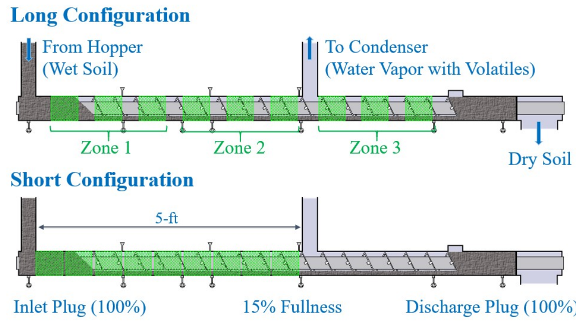

Figure 4 – Alternate Heater Configurations with heaters (green) and plug soil seals (grey)

A thermal model was created to predict the heater set points required in both laboratory and lunar environmental conditions to create water at the desired flow rates and verify feasibility of operation below the triple point of water. The laboratory test data will be analyzed to validate heat transfer coefficient and heat capacity assumptions between bulk particle motion and the heated casing. An example thermal model of a simple Commercial Lunar Payload Services (CLPS) lander is shown in Figure 5.

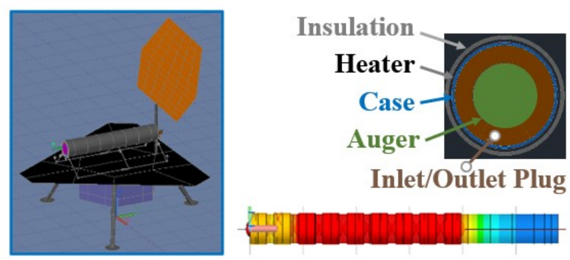

Figure 5 – Thermal Desktop Model

The thermal model was integrated with the screw conveyor sizing tool and imported into MATLAB to allow parametric system-level studies optimized for production targets, mass, power, or volume. This numerical analysis tool can be used to design either a subscale or full-scale EDU subsystem for environmental testing in JSC's 15-foot dirty thermal vacuum chamber. The tools and data obtained from this auger modelling and testing can be used as a stepping stone to develop a future Mars auger dryer (combined with a Sabatier reactor) to produce oxygen and methane.

[1] A. Colaprete et al. (2010) *Detection of Water in the LCROSS Ejecta Plume, Science, Vol 330*. [2] D. Terrier (2020) *NASA Technology Taxonomy*, *NASA*. [3] J. Collins and L. R. Erickson (2021) *Lunar Auger Dryer ISRU (LADI) FY20 Formulation Report, JSC-67579 Internal Note.* [4] J. Collins (2022) *Lunar Auger Dryer ISRU (LADI) FY21 Data Package, JSC-TBD Internal Note.*