LUNAR AUGER DRYER ISRU (LADI) BREADBOARD TESTING AND MODEL VALIDATION.

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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 screw conveyor dryer system 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 a similar sub-system for Mars operation 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 a physical flow and thermal model is 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 the upstream Excavation rover and Hopper/Size-sorter subsystems, the Screw Conveyor Dryer (SCD), and a downstream Cold trap subsystem used to de-sublimate 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 (LADI) 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. The cold trap de-sublimates the vapor into ice, removes impurities, and then stores the product 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 but spread out and mix the regolith in the 15% full heated section as shown in Figure 1.

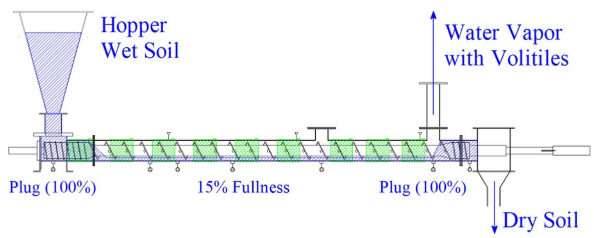

Figure 1 – Breadboard Auger Dryer with heaters (green) and 100% full inlet/outlet plug soil seal (blue)

These features maintain low internal pressure (easier to sustain regolith plug), prevent liquid water from forming (alters torque required from motor and allows equilibrium chemistry with impurities), and eliminate the need for isolation valves. Isolation valves significantly increase system height, mass, complexity, and reduces reliability.

The TRL 3 breadboard auger dryer, shown in Figure 2, will be tested in a laboratory environment using Exolith Lab's Lunar Highlands Simulant (LHS-1). The breadboard test stand has the unique capability to operate with either a clear or stainless steel casing.

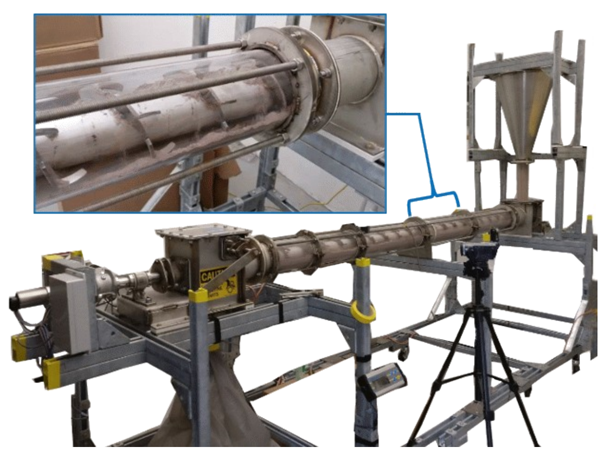

Figure 2 – Existing Mars Screw Conveyer Dryer Breadboard System (clear casing installed)

Mechanical testing at 100% and 50% production rates will be performed using the clear casing. This allows flow to be observed while measuring torque, RPM, mass flow rate, and power. The max regolith seal pressure will be determined and high-density cryogenic blasting dry ice will be mixed with the lunar simulant to observe sublimation at room temperature.

Thermal testing requires the stainless steel casing and resistance band heaters. These heaters can be reconfigured into either a long or short configuration as shown in Figure 3 and operate with three independent zones to manipulate the residence time.

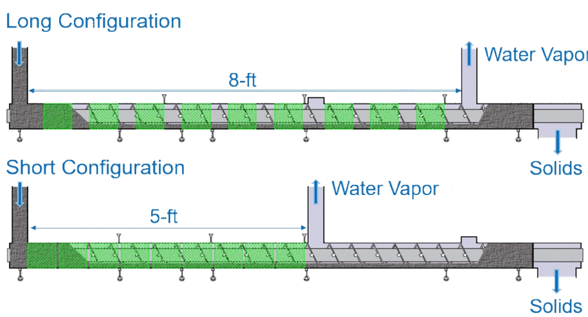

Figure 3 – Alternate Heater Configurations

The simulant will be prepared with a 5% to 8.5% water ice (weight %) mixture and heated until vaporization. A Commercial Off-The-Shelf (COTS) condenser will be used to liquefy the vapor and calculate the yield. The laboratory test data will be analyzed and compared with both a thermal and physics based model.

A Thermal Desktop thermal model will predict the residence time to sublimate ice, verify the feasibility of operation below the triple point of water (by estimating temperature and sublimated water's partial pressure), and predict heat transfer between bulk particle motion and the heated casing. This model will be run at both laboratory and lunar environmental conditions for a pilot plant and full-scale plant scenario. The preliminary Thermal Desktop model is shown in Figure 4 (without heaters and insulation).

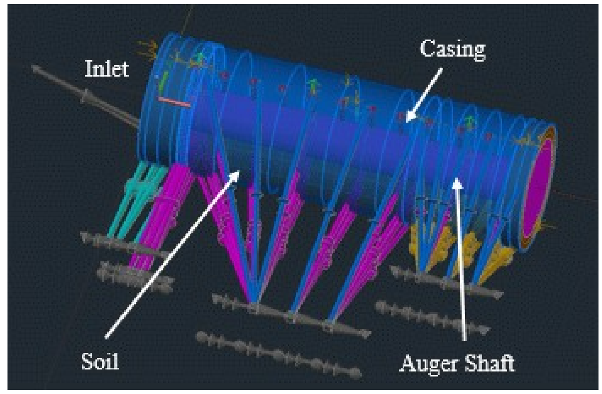

Figure 4 – Thermal Desktop Model

The paths are set to ice, ice/vapor, or liquid/vapor based on the temperature of the sub-models.

A Discrete Element Method (DEM) simulation will compare test observations performed with the clear casing with particle-scale numerical modeling. Figure 5 demonstrates the (as-built) breadboard test stand geometry and a 4-sphere tetrahedral cluster (not to scale).

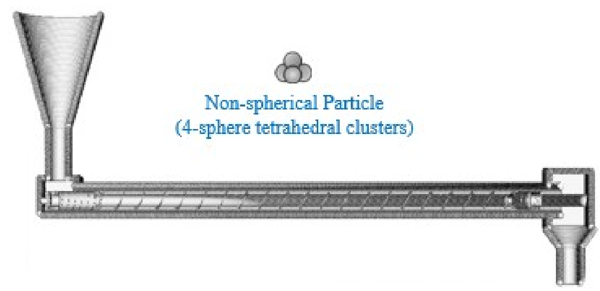

Figure 5 – DEM Model Geometry

The cluster adds fidelity by simulating a non-spherical particle while cohesion, particle size, and particle count will be varied until the model mimics the test results. 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.

The modelling, testing, and analysis performed in FY21 will be used to design an EDU for future environmental testing in JSC's 15-foot thermal vacuum chamber. The knowledge obtained on this project 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.*