Three Lunar Regolith Conveying Methods Being Developed for ISRU. Jason B. Noe[1], Paul van Susante[2], Laurent Sibille[3], and Ben Wiegand[4], [1]Planetary Surface Technology Development Laboratory, Department of Mechanical Engineering – Engineering Mechanics, Michigan Technological University, 1400 Townsend Dr, Houghton, MI 49931, jnoe@mtu.edu, [2]Planetary Surface Technology Development Laboratory, Department of Mechanical Engineering – Engineering Mechanics, Michigan Technological University, 1400 Townsend Dr, Houghton, MI 49931, pjvansus@mtu.edu, [3]Southeastern Universities Research Association (SURA), Swamp Works Granular Mechanics and Regolith Operations, NASA Kennedy Space Center, Florida 32899, laurent.sibille-1@nasa.gov, [4]Planetary Surface Technology Development Laboratory, Department of Mechanical Engineering – Engineering Mechanics, Michigan Technological University, 1400 Townsend Dr, Houghton, MI 49931, bdwiegan@mtu.edu

Introduction: With the return of humanity to the surface of the moon with NASA's Artemis program, technology development has become a key factor in making that goal a reality. Technology currently being developed is meant to ensure long-term and sustainable human presence on the lunar surface. One key technology branch that has a lot of promise in that domain is In-Situ Resource Utilization or what is commonly called ISRU. The underlying idea of ISRU is to use, or transform, what the environment provides to sustain or supplement a mission. Recently, ISRU technologies have been focused on construction [1], resource extraction [2], and refinement [3]. For lunar applications this means taking lunar regolith, the loose and unconsolidated rocky material the covers the surface of moon, and using it to, for example, construct habitats, landing/launch pads, or to extract oxygen from it [1, 3]. The common element for all of these technology examples is the handling, storage, and transportation of lunar regolith that will be required to automate these systems so they can operate on a usable scale.

Lunar regolith has very fine particle size distribution that ranges from smaller than 20 μm to several millimeters in diameter [4]. Lunar regolith is also very abrasive and can cause significant wear due to hard materials, like olivine, being present [5]. Because some of the particle sizes are on the micrometer scale, they can get through seals in motors and machinery, potentially causing damage to the internal systems. Triboelectric charging and the angular shape of the particles also allow lunar regolith particles to adhere to surfaces easily, making it difficult to keep surfaces clean [4, 6]. All these factors make lunar regolith handling, storage, and transportation non-trivial, and are necessary design considerations for ISRU technologies.

Conveying Methods: Several lunar regolith transportation methods have been proposed like pneumatic systems, screw conveyors, vibratory conveyors, mechanical conveying, and tubular drag conveyors to name a few [7, 8]. All these systems have benefits and drawbacks when considering their suitability for lunar regolith transportation. This research initially conducted an extensive literature review of nine conveying methods for delivery into a Molten Regolith Electrolysis (MRE) reactor. During the literature review, it was found that most conveying methods suitable for lunar regolith have had little to no testing in vacuum. One of the primary goals of this research is test three of these delivery methods in vacuum and determine what difference, if any, occur between their vacuum and atmospheric states.

The delivery constraints for the MRE reactor were set at 100 kg in 20 min (5 kg/min ± 250 g) and for the regolith delivery area to be in the temperature range of 1600-1700°C. It should also be noted that the conveying methods selected are also applicable for a wider range of ISRU technologies outside of MRE. The top three, chosen based on a variety of factors like Technology Readiness Level (TRL), mass landed, size, power consumption, and mass flow rate were a screw conveyor, a vibratory conveyor, and a piston conveyor.

Test Plan and Deliverables:

Screw Conveyor. The screw conveyor proposed testing will start in an atmosphere enclosed lunar regolith simulant sandbox.. Mass flow rate of the lunar regolith simulant will be measured by timing the duration of conveyance and then weighing the delivered mass. Power consumption during testing will be measured by monitoring the current draw of the motor rotating the screw conveyor. It is expected that the power consumption and mass flow rate will change depending on the percent fill of the screw conveyor and compaction of the regolith in the screw conveyor. These two factors are planned to be explored.

Additionally, the screw conveyor will be tested at several inclinations to determine its capabilities conveying up and down hill. CAD of the screw conveyor can be seen below in Figure 1.

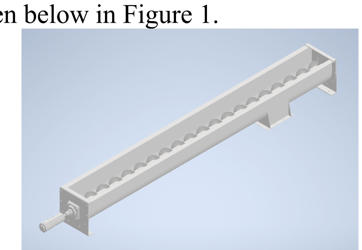

Figure 1: CAD of Proposed Screw Conveyor

After the atmospheric testing has been completed, vacuum testing of the system will start by using the in-house Dusty Thermal Vacuum Chamber (DTVAC). This testing will repeat the mass flow and power consumption tests under vacuum, determining the differences between atmospheric and vacuum capabilities of the system.

A long duration test (>24 hours) will be conducted in atmospheric and vacuum conditions. This test will require two screw conveyors, in parallel, feeding into one another. This setup will allow for a continuous flow of regolith, eliminating the need for a large reservoir of lunar regolith simulant. The power draw for each motor will also be monitored to determine if there is any change to the simulant particles (rounding, etc.) or if there is wear accumulation in the system. Visual inspection of the simulant particles and system parts will also be conducted using a microscope.

Vibratory Conveyor. The proposed test plan for the vibratory conveyor is very similar to the screw conveyor. The plan is to test the vibratory conveyor, in atmospheric conditions, in the lunar regolith simulant sandbox. Here, mass flow rate and power consumption will be measured and collected the same way it is planned for the screw conveyor. An image of the initial vibratory conveyor can be seen below in Figure 2.

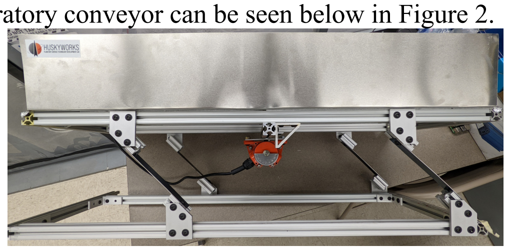

Figure 2: Initial Vibratory Conveyor

One major difference in testing is with the sampling of lunar regolith simulant, before and after tests, to determine if beneficiation is occurring during the vibratory conveyance. These samples will then be analyzed for their particle size distribution. Once atmospheric testing has been completed, testing of the vibratory conveyor in the DTVAC will occur. This test will also measure mass flow rate, power consumption, and beneficiation for comparison to atmospheric conditions.

Long duration testing for the vibratory conveyor will also take place in a similar fashion to the screw conveyor with two parallel systems feeding into one another. A difference between the two systems will be how the vibratory conveyor delivers material up an inclination. Steps will be added to the bed of the vibratory conveyor, allowing the regolith simulant particles to rest between each hop, providing the particles a more consistent way to transit up inclines. Power draw of the motors and wear of system components will be measured and monitored.

Piston Conveyor. Piston conveying is the most novel of the three methods. It works by having a motor turn a linear actuator which then drives a blade that pushes the regolith simulant forward. After the initial push, the blade is retracted and fresh regolith simulant is poured in from a hopper above. A visual example of this system works would be a coin-pusher from an arcade. This system was specifically designed to withstand the high temperatures present in the MRE reactor.

Like the other two systems, it will first be tested in the lunar regolith simulant sandbox under atmosphere. The mass flow rate and power consumption will be measured the same way as the previous two methods (weighing and motor power draw). Before and after testing in atmospheric and vacuum conditions, the blade will also be inspected for any wear using a microscope.

Testing the mass flow rate and power consumption under vacuum in the DTVAC will be similar.

Timeline: Final designs of the three systems are expected to be done by mid-April 2022. The latter part of April and early May 2022 are set aside for assembly and initial testing of the three systems. From mid-May to the end of August 2022, extensive testing of the three systems, in atmospheric and vacuum conditions, will be performed.

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References:

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