Poly-hydrated sulfate mining and water extraction on Mars; experimental results and system requirements.
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Introduction: Water has been identified on Mars in many forms and locations and can be converted to rocket propellant or be used as a consumable for life support systems, food production and daily use by astronauts. Buried glacial ice is the top candidate for low energy and high quantity water production. Concepts for mining buried glacial ice are being developed currently. If buried glaciers are not accessible or nearby, an alternate source of water can be found in the form of hydrated minerals such as poly-hydrated sulfates [1]. Of those, gypsum is the most promising hydrated mineral since it contains 20.9% water by weight and the crystalline bound water disassociates at temperatures between 150 C and 210 C with virtually no other byproducts. This makes gypsum a prime candidate for extracting water.

Michigan Technological University and Honeybee Robotics have been awarded a NASA Early Stage Innovation grant (ESI17 Award: 80NSSC18K0252) to study excavating hard rock gypsum and the water extraction process [2, 3]. This paper will give an update on the project progress, experimental and modeling results as well as system requirements based on the research. Our gypsum-saturated water excavation and pumping test setup can be seen in Figure 1.

Figure 1: Gypsum-saturated excavation test setup

By circulating gypsum pre-saturated water, the smallest gypsum particles produced by the water jet process do not dissolve and can be measured as part of the particle size distribution test. We tested impact angle on the rock surface, various nozzle geometries, distance of nozzle to rock surface, pressure and stationary vs. motion patterns for the water jet. Gypsum rock was sourced from two gypsum quarries, representing two different gypsum deposit types; deep basin deposit and sabkha tidal flat deposits. Figure 2 shows some typical rock examples of the two different deposit types. The deep-basin gypsum has distinct layering from seasonal variations during deposition whereas the sabkha tidal flat deposit consists of gypsum nodules that have grown until they filled up all available space resulting in the cauliflower look.

Figure 2: Sabkha gypsum deposit (top) and deep-basin deposit (bottom)

US Gypsum provided gypsum rock samples from their Tawas City and Fort Dodge quarries. We found there was large natural variation in the rocks leading to a large range of production rates. For our final year one testing we used 2700 psi (19 MPa) pressure with a zero-degree nozzle that continuously rotated in a 25-degree cone. This resulted in a production rate of

4.2 kg of gypsum / hr which corresponds to 840 g H2O/hr at 100% purity and recovery.

Enclosure and thermal and fluid losses: The water jet excavation system requires an enclosure to maintain a minimum pressure and temperature to keep the water liquid and minimize losses to the atmosphere. After several tests at Michigan Technological University and Honeybee Robotics with silicone bristles, inflatable rubber seals and a sandbag approach on natural surfaces it was concluded that no sufficient seal could be created using the natural surface. An alternative method was devised which consists of cutting a ring-shaped trench in the gypsum and then inflating a ring-shaped membrane to push against the smoothly cut surface. This results in allowing much higher forces on the seal surface as well as a smooth surface which should allow for maintaining a 3 kPa pressure within the enclosure. A prototype of this will be constructed and tested during year two of the grant. In addition to losses through the seal of the enclosure, losses can occur also through the rock to be cut below the enclosure. To estimate the losses, the rock cracks, thermal and permeability properties were studied and put into both an analytical solution for the steady-state far field and in a pore network model for the area just underneath the enclosure. The pore network model allows for estimation of the thermal and fluid flows through the rock surface and for material removal to simulate changes in geometry due to excavation. Modeling and rock testing suggest that no significant thermal or fluid losses will occur through the rocks if no pre-existing large cracks exist in the excavation location.

System Requirements: The overall system will need to be able to produce 16 metric tons of water in 480 sols which is an average of 1.4 kg/hr of water. Gypsum rock's unconfined compressive strength was determined as being less than 30 MPa for deep-basin deposits. Tidal flat deposits have an even lower strength and often more other minerals mixed in. A water jet pressure of 31 MPa is chosen for the next system design iteration. Other gypsum rock properties such as permeability, porosity, thermal conductivity, and diffusivity resulted in modeling estimates of fluid and thermal losses being very low if the seal between the enclosure and rock can be maintained for an internal pressure and temperature of 3 kPa and 20 C respectively. Slurry pumping of gypsum particles mixed with water can be successfully done if sufficient pressure differential can be generated to pump it to the desired height of the settlement reservoir. To separate most liquid water from the gypsum particles, a settling tank can settle out any particles larger than 20 microns in under 1 hour. 20 microns is a limit of the particles many pumps can tolerate without causing wear and jamming. The gypsum particles and any water in the pores will be transferred to the extraction chamber. In the chamber both the gypsum slurry will be heated until the liquid water and crystalline bound water are all driven off and transported by airflow to the condensing unit. The airflow will retun and pass by the thermal recovery chamber where the anhydrite will remain for one cycle to recover much of the stored heat in the anhydrite mass. The water will be stored in liquid form in a reservoir and can be drawn upon for the water jet and replenish the water that went into the reactor as the liquid part of the slurry.

The initial startup process will consist of using heat to liberate the crystalline bound water from the gypsum at the surface. This will continue until sufficient water is captured to start the water jet procedure. Current studies are looking at the excavation pattern and placement of the enclosure to maximize extraction while mitigating the risk of a wall breach by excavating too close to a previous excavation site. Rock quality, expected number of cracks and expected pressure on the rock wall relates to the required wall thickness between excavation sites. Overall recovery efficiency is being determined as well as the effect on the mobility system when creating a pattern of excavation pits.

Additional factors being considered and tested include using an impactor rod during water jet excavation, adding particles to the water jet stream to increase the impact energy, and pulsing the water jet. These are all promising approaches to increase production rate, but their added complexity are still being evaluated. In addition, tests are being done to study effectiveness of the water jet approach to break up and harvest cryogenic water ice mixed with lunar regolith simulant.

References:

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