GaLORE (Gaseous Lunar Oxygen from Regolith Electrolysis): Successful Demonstration of a Cold-Walled Molten Regolith Electrolysis Reactor Design in a vacuum environment.

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Introduction: On the lunar surface, production of commodities to support human presence, such as water, food and oxygen, and sustain the growth of a permanent outpost will likely require the use of local resources. The moon is covered almost entirely with fragmented oxide minerals known as regolith hundreds of meter thick. As a resource, it is rich in oxygen (> 42 wt.%) bound with a variety of metals in minerals and glass. The molten regolith electrolysis (MRE) reactor is a promising single-step technology for the production of gaseous oxygen and metals with high electrical efficiency and high yields from any lunar regolith composition that requires no consumable reagents and few replaceable hardware components. . This process involves melting regolith to ~1600°C then electrolyzing the molten pool to separate metal and oxygen ions that are then collected as liquid metal and gaseous oxygen at the respective electrodes.

Project description: Lab-scale demonstrations of the MRE technology have previously relied on external heating sources to bring the entirety of the reactor up to the operating temperature which creates corrosive interfaces between the molten regolith and the containment material in the reactor, limiting the overall lifespan of a reactor [1]. The Gaseous Lunar Oxygen from Regolith Electrolysis (GaLORE) project is focused on the development of a "cold-walled" or "Joule-heated" reactor design in which an internal heating source is used to selectively melt a pool of regolith between the electrodes of the reactor, leaving a shell of solidified regolith between the molten pool and the containment vessel of the reactor. This next generation reactor concept has been under development as molten oxide electrolysis (MOE) by MIT and Boston Metal for the production of iron from pure ores for terrestrial application [2]. The GaLORE project focused on early development of a cold-walled MRE reactor to demonstrate the creation of a localized melt between electrodes and transition to the electrolytic production of oxygen and metals in a vacuum chamber. The development effort will be presented including the experimental study of the most promising techniques for melting regolith within the constraints imposed by the lunar environment. Multiple melting tests in low pressure environment revealed the challenges arising from the low thermal conductivity of granular regolith and the range of viscosity of molten regolith with changing composition. The solutions to technical and operational challenges were investigated to identify an optimized melting approach that integrates well with the other reactor subsystems, can be repeated reliably using the power source available to the reactor. The design and integration of the selected induction-based melting device into an electrolysis cell scaled to a production rate on the order of 1 t O_2/year is presented. The production of monatomic and diatomic oxygen during electrolysis was confirmed with a residual gas analyzer and correlated with changes in input current. The melt state of the regolith was confirmed by direct temperature measurement. The melt was then sustained successfully by Joule heating using the electrolysis current. Several tests of increasing durations of multiple hours each were completed successfully to demonstrate the repeatability of the system and confirm the achievement of the cold-wall formation that protected the reactor shell. One test challenged the thermal limits of the design when increasing values of current raised the melt temperature and enabled the observation of melt behavior and the verification of previous melt models [3]. The solidified regolith mass and produced metal were removed for analysis after tests since the GaLORE reactor does not include subsystems for the withdrawal of molten oxide and metals

The GaLORE reactor test campaign produced new observations and operational lessons in a low pressure environmental chamber for this important technology. The project paves the way to the next generation of integrated MRE reactors capable of regolith feeding and product removal and delivery under vacuum during multiple production cycles.

[1] Sibille L., Sadoway D.R., Sirk A., Tripathy P., Melendez O., Standish E., Dominguez J. A., Stefanescu D.M., Curreri P.A., Poizeau S. (2009). "Recent advances in scale-up development of molten regolith electrolysis for oxygen production in support of a lunar base." AIAA 2009-659, 47th AIAA Aerospace Sciences Meeting, 5 - 8 January 2009, Orlando, FL. [2] Boston Metal, https://www.bostonmetal.com/moe-technology/#moe-process. [3] Schreiner S.S., Sibille L., Dominguez, J.A. & Hoffman, J.A. (2016) "A parametric sizing model for Molten Regolith Electrolysis reactors to produce oxygen on the Moon." Adv. Space Res., 57, 7,1585-1603.