STATE-OF-THE-ART OF MOLTEN REGOLITH ELECTROLYSIS: ONE-STEP OXYGEN AND METALS PRODUCTION ANYWHERE ON THE MOON.

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Introduction: The Molten Regolith Electrolysis (MRE) process has been demonstrated to produce raw feedstock materials and oxygen at high yield with lunar materials under KSC leadership with NASA's ISRU project funding in the 2000's [1]. Among current chemical processing techniques, MRE offers the only one-step process to produce oxygen and metals by direct electrochemical separation of molten metal oxides into oxygen and a glassy metallic product collected at opposite electrodes. Melting the regolith rather than involving chemical solvents (an approach used for the terrestrial production of aluminum) simplifies the design, greatly reduces contamination of the produced oxygen and metals, lowers overall landed mass and frees the technology from dependence on consumable components that may not be readily available in space. These attributes and its higher yields of oxygen and metal per unit mass of soil give MRE the edge over techniques requiring chemical compounds to react with mineral constituents. MRE is also the only existing technology to deliver molten metals in their raw form, flowing, moldable and available for processing to become stock for additive manufacturing (3D printing) to enable fabrication and repair techniques for sustained operations on the lunar surface. Previous work on MRE reactors characterized their nominal operations and the electrochemical reactions on which they operate (Sibille, 2009) and showed consistent performance with regolith of compositions from any locations on the moon. Though simple in principle, the reaction must occur at a temperature at which the regolith oxide mixture is molten to allow for the movement of newly formed ions toward their respective electrodes. Sustained operation at temperatures in excess of 1600°C creates a problem for reactor material design both thermally and chemically as molten iron and corrosive oxide melts must be contained. Advances in inert anode material have been made [2, 3] with much work remaining to solve longevity problems in the extremely corrosive conditions at high temperatures, and the inside walls of a reactor remain vulnerable. The solution proposed by Sibille and Sadoway [1] to protect the reactor from this corrosion is a cold-walled reactor design in which the pool of molten regolith is Joule-heated from the inside and the portion directly between the electrodes is molten while the regolith in contact with the inner walls of the reactor remain granular, preventing any contact with corrosive agents. This cold-walled reactor design must include a method to create the molten electrolyte pool exclusively at the center of a regolith bed and thermally manage the system to sustain this configuration. the electrical system must be designed to pass sufficient current to maintain Joule heating of the molten regolith. Joule heating relies on the electrical resistivity of the molten oxide pool to produce heat from an electrical current. The material selection for the reactor electrodes are also a subject of ongoing research. At high temperatures, with demanding electrical and mechanical requirements along with the need to withstand extremely corrosive environments from the molten metals as well as the produced oxygen, most metallic materials fail in one of the above areas. The leading candidates for inert anode materials are the platinum group metals, and chromium-based alloys which have been studied in extreme environments to varying degrees of success [2, 4].

Preliminary experiments have been performed to propose potential solutions for critical operations such as cold-wall reactor start, reactor continuous feed, molten material transfer. Lastly, we have identified a range of composition of ferrosilicon produced by MRE that is suitable for use as feedstock in additive manufacturing. Despite the many technical challenges it faces, the MRE reactor concept promises extremely high rewards for its successful development and operation [5].

References:

[1] Sibille, L., Sadoway, D.R., Sirk, A., Tripathy, P., Melendez, O., Standish, E., Dominguez, J.A., Stefanescu, D.M., Curreri, P.A. and Poizeau, S. (2009) *Proc., 47th AIAA Aerospace Sciences Meeting, American Institute of Aeronautics and Astronautics (AIAA), Reston, VA* (Vol. 2).

[2] Allanore, A., Yin L., & Sadoway D.R. (2013) Nature **497**, no. 7449 (May 8, 2013): 353-356.

[3] Sibille, L. & Dominguez, J. (2012) *50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*, p. 639.

[4] Sirk, A. H., Sadoway, D. R., Sibille, L. (2010) *ECS Transactions* **28**, 367-373.

[5] Schreiner, S. S., Dominguez, J. A., Sibille, L., Hoffman, J. A. (2015) *Advances in Space Research* **57**, 1585-1603.