CHARACTERIZATION OF VOLATILES FROM SIMULATED LUNAR HIGHLAND MELTS UNDER VACUUM.

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Introduction: As part of the Artemis program that returns humans to the Moon for sustained presence, the in-situ resource utilization (ISRU) pilot plant is developing hardware to test systems in relevant lunar environments. As this evolves, the ever-growing field of interest requires in-depth understanding of the environment for operations. Lunar regolith contains compounds that can be harvested as resources such as fuel, or life support and construction feedstocks. Therefore, this necessitates an understanding of its constituents and processed by-products under some of the extreme conditions imposed for resource extraction. In addition to thermophysical properties characterization of the various regolith [1,2], this requires experimental data on the nature and kinetics of evolution of volatile specie over a range of conditions, The Molten Regolith Electrolysis (MRE) team at Kennedy Space Center is investigating the Lunar Highlands Simulant (LHS-1) from Exolith Labs at the University of Central Florida under molten regolith conditions in simulated lunar environment. Previous work investigated the feasibility of using various starter devices to obtain melts of LHS-1 at atmospheric pressure under the NASA GaLORE Project[3]. The starter devices included resistive and inductive heating techniques. These experiments identified the melt formation, void development, trapping of gases, and assisted in down-selection of starter device technologies. Current work from the Gaseous Lunar Oxygen by Regolith Electrolysis (GaLORE) has evolved into the NASA Molten Regolith Electrolysis project, which seeks to use test data and modeling to scale up the technology and test in a vacuum environment. Some early testing in a ≈40 cm tall x 50 cm diameter vacuum chamber with regolith were performed at increased temperatures to observe melt behavior and test gas analysis systems to prepare for expected off-gassing rates and understand the risks to the MRE systems.

The work presented here provides results on the investigation of the formation and properties of melts (70 g) under a high vacuum environment (10^{-6} – 10^{-3} Torr) with monitoring of the evolved gases. During the high temperature treatment of the regolith, a residual gas analyzer with differential pumping was used to continuously monitor gas constituents during the heating of the regolith. Controlled measurements on small samples of LHS-1 were performed by thermogravimetric analysis (TGA) and data was correlated with chemical compositional analyses. Off-gassing volatiles primarily included water vapor (18 amu), a peak at 44 amu (FeO_2 – expected), and atomic oxygen (16 amu), among a series of other compounds (Mg, Cl, SiO_2) as the solid regolith transitions to liquid phase. Tests were performed for approximately 60 minutes, with a ramp rate of ≈ 1 ampere/3 min. This corresponds to a temperature increase of 47 ℃ /min. Temperature measurements were performed in the near vicinity to the regolith as submerged diagnostics would be expended. During regolith heating in the vacuum environment, the majority of offgassing occurred in the first 100 degrees of processing. This is easily attributed to increased offgassing of water vapor that has been absorbed in the regolith and chamber. Prior to testing, regolith was heated for two hours in a vacuum oven at 200 ℃ to mitigate these effects. Several control tests were also performed to eliminate which byproducts may have been present evolving during the off-gassing of surrounding hardware and subsequent interactions. At this time, high temperature volatiles characterization data has not yet been available for most terrestrially made lunar simulants and is needed for developing the system for oxygen extraction and post processing of gaseous products. The results also add to the body of knowledge needed for technology development of in-situ lunar volatiles measurements by providing an understanding of how volatiles evolve from well-known complex mineral compounds upon heating at very low pressures over a very wide range of temperatures.

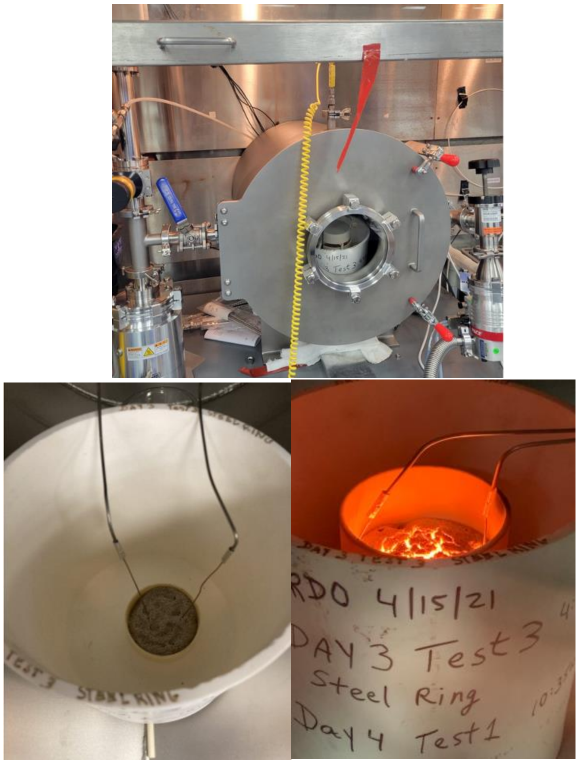

Figure 1: (Top) Vacuum chamber used for the off-gas testing and volatile analysis. (Bottom-left) Experimental setup pre-heating. (Bottom-right) Image of the heated LHS-1 simulant during the off-gas testing in a vacuum environment.

References:

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[3] Grossman, K.D., Sibille, L., Bell, E., Petersen, E., Toro Medina, J.A., Williams H., Newbold, T., Zacny, K., and Bates, I. 2021. *ASCEND 2021 Conference.* Nov. 15-17. Las Vegas, Nevada.