GAS CHARACTERIZATION DURING THERMAL TREATMENT OF REGOLITH SIMULANTS IN A VACUUM ENVIRONMENT.

L. G. Somervill[1], C. Franco[2], J. A. Fischer[3], J. L. Smith[4], K. Engeling[5], A. Meier[6], and D. Essumang[7], [1]Bennett Aerospace (LASSOII-008; lucy.g.somervill@nasa.gov), [2]Noetic Strategies (LASSOII-008; carolina.franco@nasa.gov), [3]Aetos Systems (LASSOII-008; jason.a.fischer@nasa.gov), [4,5,6,7]NASA Kennedy Space Center (UB-E; jackson.l.smith@nasa.gov, kenneth.engeling@nasa.gov, annie.meier@nasa.gov, and deborah.essumang@nasa.gov).

Introduction: In-situ resource utilization (ISRU) capabilities are key to increasing human presence extraterrestrially and maintaining sustainable livable spaces on the moon and Mars. Lunar soil, i.e. regolith, is an abundant material from which various commodities can be realized including agriculture, additive manufacturing, habitat construction, and propellant production [1-5]. Current technologies are being developed to process lunar soil by utilizing regolith simulant for ground system demonstrations and verification purposes. Lunar simulants are intended to replicate the elemental composition and mineralogy of lunar soil samples. Due to the inherent limitations of native material, species undetected in lunar surface samples have been observed in simulants [6,7]. This study characterizes gas evolution during the thermal treatment of differing regolith simulants in a vacuum environment.

Regolith Simulants: This study investigated the outgassing behavior of five regolith simulants: (1) Lunar Highlands Simulant (LHS-1), a high-fidelity, mineral-based simulant sourced from Exolith Labs/Space Resource Technologies [8]; (2) Lunar Simulant JSC-1, derived from basaltic volcanic ash with a likeness to the Low-Ti Mare lunar region, developed by NASA Johnson Space Center [9]; (3) Black Point Basalt (BP-1) sourced from NASA Kennedy Space Center, corresponding to Low-Ti Mare lunar region [10,11]; (4) ICN-LHT-1G (also known as CSM-LHT-1G) manufactured by Colorado School of Mines to represent the Lunar Highlands region [12]; and (5) UCF's Exolith Lab-sourced DSI-CL-2 (DSI) simulant, comparable to Orgueil meteorite samples [13]. Figure 1 displays the composition of lunar simulant and mission samples.

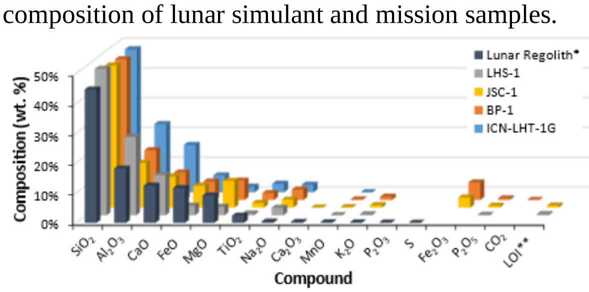

Figure 1. Regolith Composition. *Values averaged over samples collected from Apollo 15, 16, and 17, and Luna 20 and Luna 24 [14]; **Loss on ignition

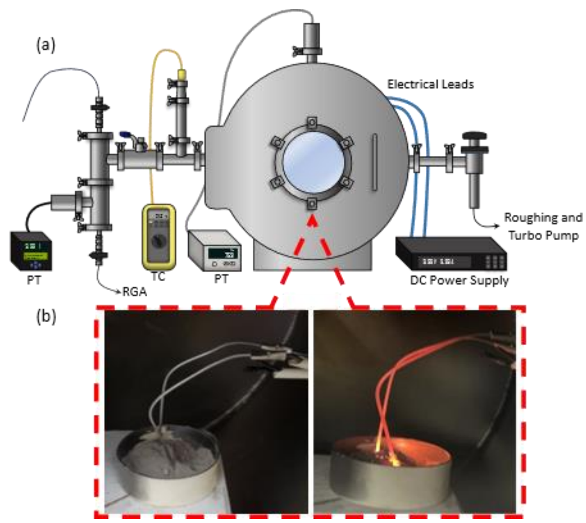

Figure 2. Testing apparatus of (a) vacuum chamber setup and (b) sample loading in crucible before (left) and during (right) heating.

Experimental Design: The test apparatus, Figure 2(a) consisted of a horizontal vacuum chamber outfitted with electric-power feedthroughs. On the outside of the chamber, the electrical leads were connected to a DC power supply (80V/18A and 1.44 kW). The chamber was connected to a residual gas analyzer (RGA), roughing pump, and turbo pump. The RGA was operated where the signal was displayed alongside mass per unit charge (m/z). During operations, system pressure was monitored using a rough vacuum gauge (10^{3}–10^{-4} Torr) and an ionization high vacuum gauge (10^{-4}–10^{-10} Torr).

Inside the chamber, a Kanthal-1A wire was attached to the electrical leads and contained a 1" length of 1/8" (ID) coiling (approx. 7 turns) which was lowered into a crucible holding 60.0 ± 0.5 g of regolith. The coiled portion of the wire was fully covered by simulant and able to provide resistive heating, as seen in Figure 2(b). An in-line thermocouple (TC) was used to measure the temperature at the bottom of the crucible. The regolith samples were heated by gradually increasing the current (~0.5–1.0 A/min) up to 17.25 A, which was then maintained for 15 minutes. Experiments were run in triplicate.

Characterization of Evolved Gases: Thermal treatment led to gaseous production that was measured by the RGA spectra and allowed for monitoring of gaseous compounds that evolved whilst heating. Note the RGA was uncalibrated for the unknown species so the following data is qualitative, rather than quantitative for species identification/confirmation. Atomic mass units (AMU's) and the suspected corresponding species are shown in Table 1.

Table 1. AMU and related chemical species

AMU	Species	AMU	Species
2	H_2	34	H_2S
14	N, CH_2	35	Cl
16	O, CH_4, NH_2	36	HCl, H_2S^+
17	OH, NH_3	37	$^{37}Cl^+$
18	H_2O	40	Ar
28	N_2, C_2H_4, CO, Si	44	CO_2
32	O_2, S	64	SO_2

Figure 3 displays the RGA signal of relevant AMU's over the test durations. AMU 18, associated with water, was relatively high in signal with prominent peaks from DSI, BP-1, and ICN-LHT-1G. AMU's 34 and 64 reflect the detection of hydrogen sulfide and sulfur dioxide, respectively, and were observed in each simulant with the largest signal from DSI. These compounds were detected in small quantities, and would likely scale-up to levels that that may have detrimental impacts on hardware, such as material corrosion. The remaining simulants showed smaller peaks, shown on the right axis, between 60 and 80 minutes. Additionally, LHS-1 had the strongest signal for AMU 34. BP-1 and DSI show AMU 44 peaks with high intensity, indicating the formation of carbon dioxide. The mentioned AMU's, 18, 34, 44, and 64, suggest simulants contain hydrogen, sulfur, and carbon. While these compounds may appear as impurities, LCROSS mission data found trace amounts of sulfates and carbonates in the lunar soil [15].

Future Work: This study examined the evolution of gaseous species across five regolith simulants during heating. RGA data collected during thermal treatment suggests the potential presence of sulfur-based compounds which can be hazardous to health, the environment, and hardware. Future tests should not only detect, but quantify and identify compounds within simulant outgassing.

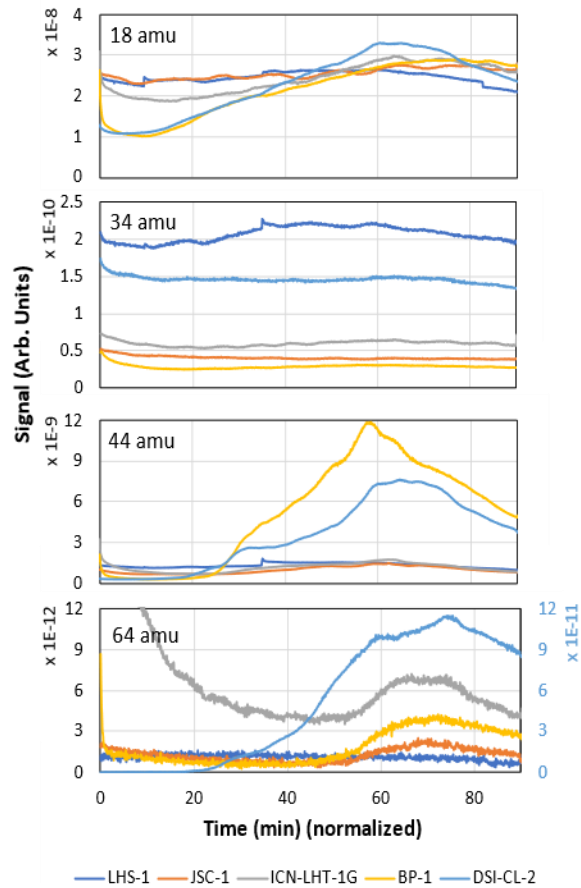

Figure 3. RGA Acquisition during the thermal treatment of regolith simulants for AMU 18, 34, 44, and 64, with the right axis of AMU 64 for DSI-CL-2. AMU signal is averaged from runs in triplicate.

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