

Characterisation of the LUVMI Volatile Extraction and Volatiles Analysis package.

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Introduction: Recent years have seen a growing interest in lunar exploration, with most international space agencies planning to return humans to the surface of the Moon, and to establish a long-term presence. In Situ Resource Utilisation (ISRU) offers the opportunity to make use of locally available resources and to potentially reduce the costs associated with transporting materials such as water, hydrogen and oxygen to the lunar surface. The polar regions of the Moon have long been known to be possible traps for solar system volatiles due to the low temperature of permanently shadowed areas [1,2]. Recent remote sensing missions have established the presence of volatiles (including water) at the surface and shallow sub-surface at these Polar Regions making them targets for in-situ missions to determine the ground-truth volatile inventory there. However, the Lunar Exploration Analysis Group (LEAG) Volatiles Specific Action Team (VSAT) findings state that there are enough uncertainties in the distribution of lunar volatiles from remote sensing techniques to imply that a non-mobile lander faces a significant risk of not finding volatiles or of “single data point” non-representative discoveries. To address the need for mobility, the Lunar Volatiles Mobile Instrumentation (LUVMI) [3,4] was developed (Figure 1).



Figure 1 - The LUVMI prototype rover during testing in December 2018

Instrumentation description: The key LUVMI science package, comprising of the Volatiles Sampler (VS) and the Volatiles Analyser (VA) was developed to address key the current un-answered questions of what volatiles are present and the distribution on (and below) the lunar surface.

Extraction of Volatiles: The VS consists of a hollow rotating drill shell and heating rod to penetrate approximately 10 cm into the lunar regolith. A central heating rod heats regolith inside the drill shell to release bound volatiles. The pressure within the drill

shell will be monitored allowing the bulk volatile release during heating to be determined. In addition, a capillary leak will connect the drill internal volume to the VA to allow sampling of the drill volume during heating to enable real-time volatile characterisation to be performed.

Volatiles Analyser: The VA is an ion trap mass spectrometer based upon the Ptolemy [5,6] flight-proven instrument (Figure 2). This is a low mass, compact and mechanically simple device capable of rapid detection of masses in the range of 10 to 150 m/z , enabling the detection of volatiles, including water, that may be released during regolith heating.

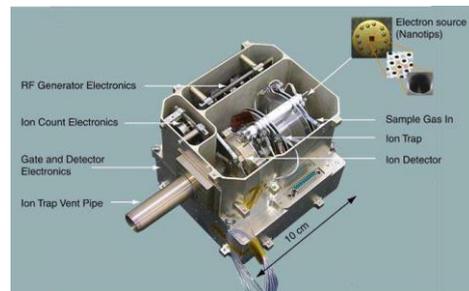


Figure 2 The Ptolemy Ion Trap Mass Spectrometer

Figure 3 shows the two instruments mounted in their flight configuration prior to volatile extraction testing.



Figure 3 VA & VS prior to volatile extraction testing at TUM

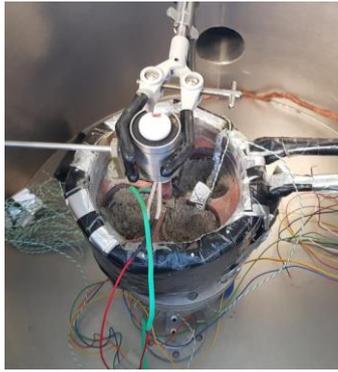


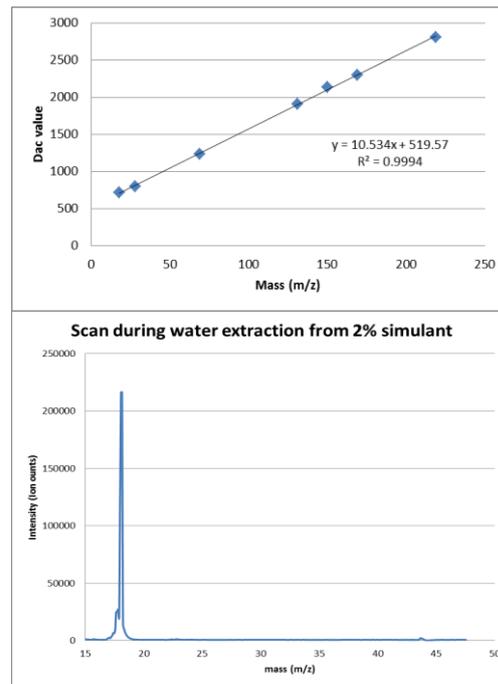
Figure 4 – Thermal vacuum system

Volatile extraction tests: A thermal vacuum system was developed to enable testing of the VA (Figure 4) and allow volatile extraction from simulated regolith material under representative thermal lunar conditions. 200g of NU-LHT-2M simulant were used and doped with water content in a range similar to those seen by the LCROSS mission, where water contents of $5.6 \pm 2.6\%$ were observed in the ejecta plume created from an impactor striking the South Pole crater Cabeus [7]. A series of samples were prepared with 0, 0.5, 1 and 2% water (by weight). Samples were cooled to -150°C and evacuated to $<1 \times 10^{-5}$ mbar for 3 hours to investigate volatile loss in the temperature and pressure environment that tests were conducted.

Extraction of volatiles by heating were conducted with an in-house developed extraction probe that mimics the operation of the VS extraction system. The probe was heated to $+300^{\circ}\text{C}$ and lowered into the surface of the simulant whilst the output from the VA mass spectrometer was recorded.

Results: The doped samples were left under vacuum for 3 hours and then brought back to atmospheric pressure. Analysis of the sample masses revealed that, when stored at temperatures below 150°C , minimal water vapour were lost (a maximum of 0.25% water mass from the 2% sample). Although a mass loss was observed, if end-to-end testing are conducted within a 3 hour period then the procedure used will allow minimal volatile loss thus allowing meaningful measurements to be conducted.

A typical mass spectrum obtained with the VA during a volatile extraction experiment is shown in (Figure 5). During the extraction experiment a partial pressure of 1×10^{-6} mbar was measured within the vacuum chamber. In addition to the m/z 18 peak due to water a peak at m/z (CO_2) is present.



Conclusion & Future Work: The VA results demonstrate that the mass spectrometer is capable of detecting and characterising volatiles evolved from simulated lunar regolith under representative thermal conditions. The VA is capable of detecting and characterising volatiles in the mass range of 10 to 220 amu and offers the opportunity to perform ground truth in-situ measurements. Preliminary results demonstrate a dynamic range sufficient to differentiate between water doped regoliths of 0.5 to 3%. Work will continue for the next 2.5 years under a new LUVMI-X grant.

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