

Models of Volatile loss during Lunar Resource Prospector Mission Sample Acquisition

L. F. A. Teodoro,¹ A. Colaprete,² T. Roush,² R. Elphic,² A. Cook,³ J. Kleinhenz,⁴ E. Fritzler,³ J. T. Smith,⁵ K. Zacny,⁶ ¹BEARI/NASA Ames Research Center, Moffett Field, CA 94035 (luis.f.teodoro@nasa.gov), ²NASA Ames Research Center, Moffett Field, CA 94035, ³Millennium Engineering, NASA Ames Research Center, Moffett Field, CA 94035, ⁴NASA Glenn Research Center, Cleveland, OH 44135, ⁵NASA Kennedy Space Center, Cocoa Beach, FL 32899, ⁶Honeybee Robotics Pasadena, Pasadena, CA 91103

Introduction: Here we present the modeling of volatiles transport in lunar regolith in the context of the NASA's Resource Prospector (RP). This mission to the high latitudes and permanently shadowed regions of the Moon has as its main goal the extraction and identification of volatile species in the top meter of the lunar regolith layer. Succinctly, RP consists of five elements: *i*) The Neutron Spectrometer System (NSS) will search for high hydrogen concentrations and in turn select optimum drilling locations; *ii*) The Near Infrared Volatile Spectrometer System (NIRVSS) will characterize the nature of the surficial water ice; *iii*) The Drill Sub-system will extract samples from the top meter of the lunar surface and deliver them to the Oxygen and Volatile Extraction Node (OVEN); *iv*) The OVEN will heat up the sample and extract the volatiles therein, that will be *v*) transferred to the Lunar Advanced Volatiles Analysis (LAVA) instrument [1].

A series of vacuum experiments have been carried out at NASA's Glenn Research Center with the aim of quantifying volatile loss during the RP drilling/sample acquisition phase and sample delivery to the crucibles steps [2]. Outputs of these experiments include: *i*) Pressure measurements of several chemical species (e.g. H₂O, OH, CO₂, N₂, Ar); *ii*) Temperature measurements within and on the surface of the lunar simulant using thermocouples; *iii*) Surficial temperature NIRVSS measurements; and *iv*) Temperature measurements at the tip of the drill.

We report on the numerical modeling we have been carrying out to understand the physics underpinning these experiments. This modeling contemplates two main parts: *i*) Reliable computation of temperature variation throughout the simulant container during the experiment as constrained by temperature measurements; and *ii*) Volatile molecular diffusion. The latter includes both Fick's (flight of the molecules in the porous) and Knudsen's (sublimation of volatile molecules at the grain surface) laws [3,4]. Furthermore, we also mimic the soil porosity in randomly allocating 75 microns particles (the size of the average lunar regolith grain) in the simulation volume.

To model the molecular diffusion of volatiles we have implemented a 3-D numerical code that track one 1 billion macro-particles (each macro-

particle represents a large number of water molecules) within the computational volume. At each instant one computes a time-step that takes into account the relevant time scales. The two types of diffusion aforementioned have the following time scales that depend strongly on temperature: *i*) Fick' law *flying time*: $\tau_F = v_{th}/l$ where v_{th} ($\propto T^{1/2}$) and l denote the thermal velocity and average grain size, respectively; *ii*) Knudsen's law *residence time*: $\tau_K \propto \exp[-Q/(KT)] * T^{1/2}$, where K and Q are the Boltzmann's constant and sublimation enthalpy [1]. As the temperature field is not uniform throughout the simulation volume and changes during the duration of the experiment, one chooses the time-step, Δt , at a given instant in time, t , as the largest of $\tau_F(\mathbf{r},t)$ and $\tau_K(\mathbf{r},t)$ within the simulation volume, where \mathbf{r} denotes position.

The probability of a super-particle departing from the surface of a grain at a given instant is then computed as the ratio of the local $\tau_K(\mathbf{r},t)$ by the global Δt at that same instant.

Temperature field: as seen above an accurate temperature knowledge is fundamental to track the macro-particles within the simulations volume. Temperatures are measured at a series of locations during the experiment. Hence, we have developed an interpolation scheme using the measured temperatures to create a field $T(\mathbf{r},t)$. Currently, we are generalizing this interpolation scheme with the aim of including the measurements at the surface and at the location of the drill's tip in a self-consistent manner.

Conclusions: We present the numerical results of large scale molecular simulations of water molecules during Resource Prospector sample acquisition. We also present the numerical modeling of the temperature field throughout the volume of regolith as constrained by the thermocouple measurements performed during the vacuum experiments. Previous calculations assuming a spatially uniform (and constant in time) temperature showed that both diffusion laws play a major role during the drilling phase. Our preliminary results with a more realistic temperature field $T(\mathbf{r},t)$ reiterate such a conclusion.

References:

- [1] D. R. Andrews, et al. (2014) Introducing the Resource Prospector (RP) Mission American Institute of Aeronautics and Astronautics
- [2] J. E. Kleinhenz, et al. (2015) Impact of Drilling Operations on Lunar Volatiles Capture: Thermal Vacuum Tests American Institute of Aeronautics and Astronautics
- [3] N. Schoerghofer, et al. (2007) Journal of Geophysical Research (Planets) 112(E11):2010
- [4] F. Reif (1965) Fundamentals of Statistical and Thermal Physics Waveland Press.