Investigation of Transient Volatile Migration in Lunar Regolith for the Lunar Volatile Scout. A. Smolka[1], C. Gscheidle[1] and J. Biswas[1], [1]Chair of Astronautics, Technical University of Munich (Boltzmannstr. 15, 85748 Garching, Germany, c.gscheidle@tum.de)

Introduction: The Lunar Volatile Scout (LVS) [1], a novel soil sampling and analysis instrument developed jointly by the Institute of Astronautics at the Technical University of Munich, OHB Systems AG, and the Open University, aims to shed light on spatial distribution of volatiles at the Lunar poles. It is an in-situ tool to access and characterize lunar volatiles consisting of two main sections, the hollow drill acting as a sampler, and the attached volatile analyzer, a mass spectrometer. Figure 1 displays a schematic view of the instrument. A heating element is mounted in the center of the drill, which will be driven into the soil to a depth of 100-150 mm. Thus, the regolith inside will be mostly undisturbed inside of the hollow drill-shell, which is advantageous in contrast to other sampling instruments. Through heating, the volatiles bound to the regolith will desorb [2] and diffuse through the surrounding sample. A mass spectrometer analyses those that travelled upwards to the top of the instrument.

Need for Simulation: Lunar resources are considered the key for future, long-duration explorations of the Moon. Its regolith [3] contains significant quantities of oxides, metals, and highly volatile elements including water. These volatiles, which are thought to persist in cold traps in significant quantities near the lunar poles could be an accessible and versatile resource for further exploration. In. addition, the investigation of such cold traps can provide a record from the formation of the solar system. For these reasons, they have become a top priority in lunar exploration. In-situ extraction of the volatile components from regolith involves thermal processing and strongly depends on the heat and mass transfer inside of the lunar soil. While these processes are influenced by a large number of physical properties like the porosity and the tortuosity of the sample, the respective gas density, and its temperature and pressure, the description of the interaction between heat and gas transfer and sorption mechanisms poses a difficult problem.

In this context, coupled heat and mass transport simulation considered necessary to develop a design that meets the instruments high requirements within its constraints. The LVS must reach high temperatures within its large sample volume to release volatiles while consuming only little power. On one hand, temperatures of the regolith, especially temperature distribution, are hard to measure making interpretation of the transient results very challenging. Besides, the LVS has by design no closed sample volume. Thus, it is possible for some volatiles to escape through the lower end, lowering the confidence in the mass spectrometer readings. Therefore, the correct interpretation of the pressure response of the sample requires an in-depth knowledge of the internal gas transport.

Numerical Setup: The current study uses the LVS as baseline for a computational model to further analyze the extraction mechanism of water in lunar regolith. With the software COMSOL Multiphysics and MATLAB, a combined model for the heat and mass transfer as well as the desorption mechanism, was developed based on the model by Reiss [4]. The physics were modelled in COMSOL using partial differential equations (PDE) in coefficient form, based on the diffusion-convection equation. The evaluation of the

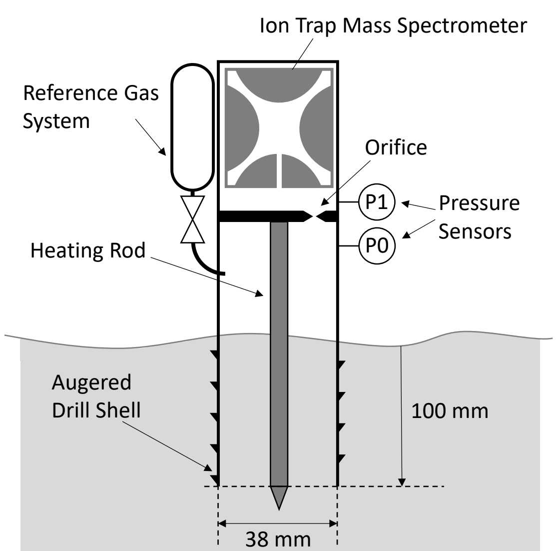

Figure 1: Schematic of the Lunar Volatiles Scout

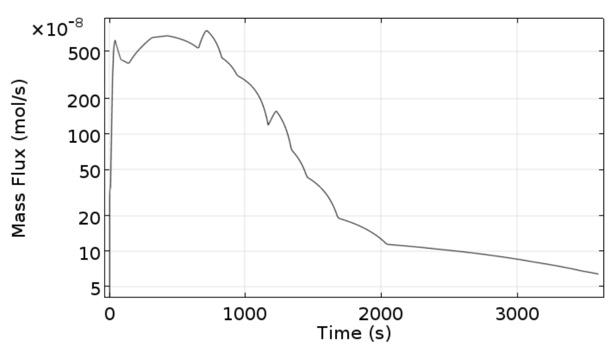

Figure 2: Flux of desorbed water over the regolith's upper boundary inside of the enclosure.

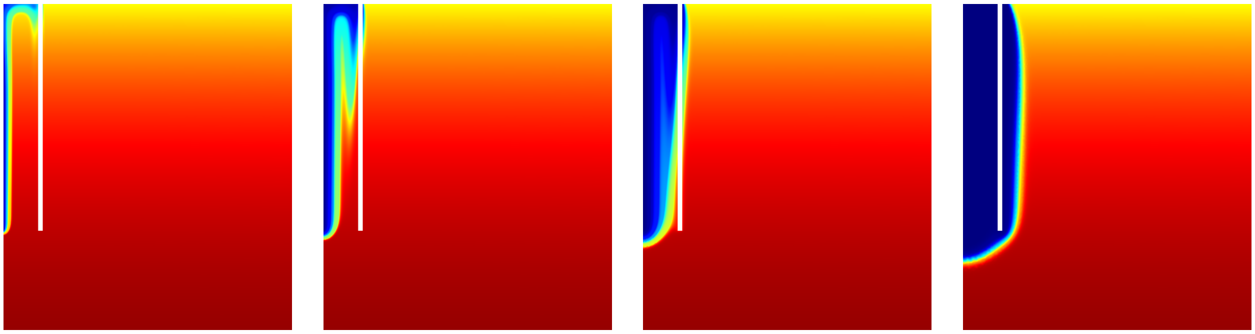

Figure 3: Adsorbed water concentration inside the lunar regolith at different times of the simulation. Blue area represents a concentration of zero.

temperature and pressure dependent thermal conductivity and gas diffusivity at every time step was done externally in MATLAB.

In order to verify the computational model, several auxiliary studies were performed. The initial conditions study evaluated the starting values of the temperature and the water concentration as a function of the surface temperature, the estimated water ratio, and the regolith depth. A mesh and domain study was performed in order to estimate the numerical error that originates from the discretization of the geometry. Using measurement from previous test [1], correlations of the model's results to measured heater temperatures and pressures within the drill shell were conducted.

Results: The main study used the verified model to simulate the volatile transport inside of the lunar regolith. The results show the transient temperature and pressure distribution as well as the extraction of the water vapor from the soil. Results were produced for numerous parameters including initial water content and desorption energy.

Figure 2 depicts the molar flux over the surface of the lunar soil inside of the enclosure. The respective simulation has been performed with a water content of 0.25 % by mass bound to the regolith. The flux quickly increases to reach its maximum value shortly after the start of the simulation. After about 20 minutes the rate starts to decrease until the end of the simulation. This coincides with the results for the adsorbed water concentration, shown in the Figure 3.

Figure 3 illustrates the distribution of the adsorbed species for four timesteps during the simulation, in this case water. The area with no adsorbed water, shown in blue, steadily increases with time and even expands over the enclosure of the LVS (see Figure 3 (d)). Transport mechanisms then distribute the desorbed water with some diffusing over the surface of the enclosure, see Figure 2.

Preliminary results gained from the model also include an estimate of the loss of volatiles through the LVS's open lower end and the transient temperature distribution. By comparing the thermal distributions from simulations with and without mass transport as well as the measured data, the significance of considering both heat and mass transport are highlighted. In the future, the results can aid to ease interpretation of measurements with the LVS on the Moon.

References: [1] J. Biswas, et al. (2020) *Planet. Space Sci., 181*. [2] M. J. Poston, et al. (2013) *J. Geophys. Res. Planets, 118,* 105-115 [3] P. O. Hayne, et al. (2007) *J. Geophys. Res. Planets, 122*, 2371– 2400. [4] P. Reiss (2018) *Icarus*, 306.