Microwave Extraction of Volatiles for Mars Science and ISRU. E. C. Ethridge[1] and W. F. Kaukler[2], ([1]MSFC NASA, Huntsville, AL 35812 ed.ethridge@nasa.gov [2]University of Alabama Huntsville, Huntsville AL 35899 william.f.kaukler@nasa.gov).

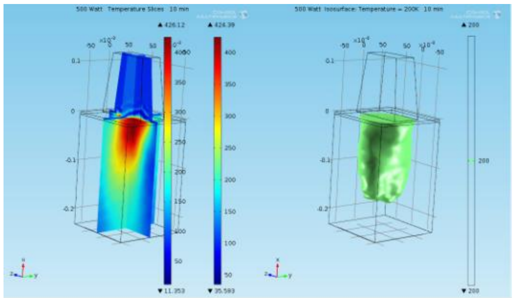
The greatest advantage of microwave heating for volatiles extraction is that excavation can be greatly reduced. Surface support operations would be simple consisting of rovers with drilling capability for insertion of microwaves down bore holes to heat at desired depths. The rovers would also provide support to scientific instruments for volatiles analysis and for volatiles collection and storage. The process has the potential for a much lower mass and a less complex system than other in-situ processes. Microwave energy penetrates the surface heating within with subsequent sublimation of water or decomposition of volatile containing minerals. On Mars the volatiles should migrate to the surface to be captured with a cold trap. The water extraction and transport process coupled with atmospheric CO2 collection could readily lead to a propellant production process, H2O + CO2 -> CH4 + O2.

For the past 7 years we have been developing the use of microwaves for the extraction of volatiles from regolith. In 2005 we demonstrated the proof of principle that microwaves (2.45 GHz) will couple with lunar regolith permafrost simulant at cryogenic temperatures in a vacuum resulting in rapid sublimation of water and collection on an external cold trap. Recently we completed a 4 year ROSES-LASER project [1]. Experiments included heating of a simulant bed with a microwave horn beamed into the surface and temperatures were measured with fiber optic sensors. The resulting heating is consistent with theoretical calculations.

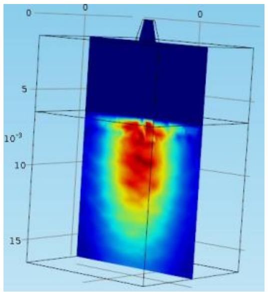
In order to perform realistic calculations of microwave heating, the complex electric permittivity and magnetic permeability of regolith simulants were measured at 0.9. 2.45 And 10 GHz. Having the regolith materials properties, finite element multiphysics analysis models were developed to simulate the microwave absorption and heating of lunar and Mars regolith simulant.

Models for different types of microwave launchers have been developed to test simulations of different kinds of experiments and processing conditions. Calculations at different microwave frequencies illustrate the dramatic difference in depth of heating. Lower frequencies penetrate deeper while the higher frequencies heat shallower depths to much higher temperatures.

The simplest microwave delivery method is to beam the energy into the surface with a microwave horn. A bore hole is not necessary. This method could be useful for analysis of water concentrations in the shallow subsurface of Mars. The figure below illustrates the heating of the lunar surface with an initial temperature of 100K. Microwaves (2.45GHz) from the horn penetrate and heat the regolith. A planar slice illustrates the heating with color isotherms. On the right, is an isothermal surface containing a volume heated 100K above the initial temperature. Essentially all of the water ice within this volume would sublime.

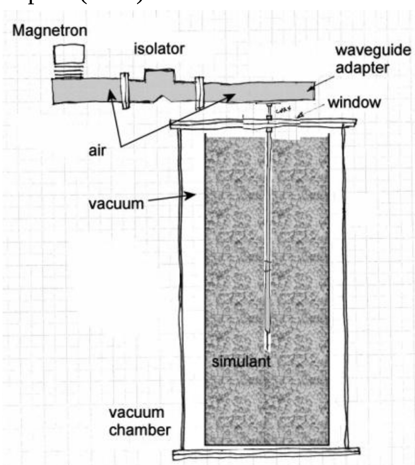


Minerals containing volatiles could be heated to higher temperatures and decomposed using higher microwave frequencies. Parameterization of the FEM model geometry can permit more rapid development of models at different processing frequencies. An example is shown in the next figure, a simulation of a 24 GHz microwave horn to beaming 100W into a 1 cm cube. The temperature slice after 30 min shows temperatures from the initial 100K to greater than 1500K.



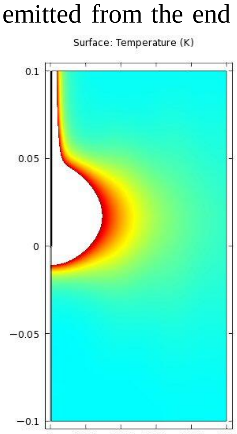
Knowing the temperature dependence of mineral decomposition (from DTA and TGA), it should be possible to predict the volatization rate from the heated volume with time. This in-situ thermo-gravinometric simulation is under development. Theoretically, the largest constraint would be the power available to heat the minerals to the decomposition. Flight qualified TWT amplifiers have greatly increased in efficiency in recent years (~50%) and higher efficiency solid state amplifiers are said to be under development.

Recently we have been performing experiments to heat regolith with microwave (2.45 GHz) probes down boreholes to demonstrate volatiles extraction from depths (>1m) below the surface.



Our current experimental setup has the vacuum system contained in a -77C scientific freezer that can simulate Martian conditions. Microwaves are delivered down a borehole to depths where water ice could be present. Heating at progressively deeper levels within the borehole would permit the determination of water concentrations with depth. Calculation of volatile mass flow rates is being developed to use with existing numerical models.

Assuming a drilling apparatus could provide the bore hole, microwaves could be delivered to significant depths (>3m) to determine water concentrations. The figure below shows an axi-symetrical EM heating analysis for illustration. The probe (down a borehole) is on the left, the Martian surface is up, and microwaves are emitted from the end of the probe. The regolith heats



radially with processing time. The diameter of the heated volume will be a function of the microwave frequency and time.

Systems could be designed to mine water from depths greatly exceeding those accessible by other ISRU capabilities since the overburden would not have to be removed.

A significant advantage of FEM numerical multiphysics analysis is that parametric analysis of different experimental processing conditions can be simulated prior to expending the time and expense of experiments at different frequencies. FEM Multiphysics parametric analysis (power, frequency, regolith porosity, temperature) will permit the simulation of experiments, design of experimental hardware, and optimization of planetary surface extraction scenarios. The expected power required to extract a unit mass of volatile could be estimated. The FEM analysis could be used to select the most appropriate processing parameters and define the hardware for volatiles extraction protocols. Ground based experiments could be designed to test the methods of extraction and to validate the numerical multiphysics analysis in a relevant planetary (Mars) testbed facility (at MSFC).

These methods address Challenge Area 1: Near term Instrumentation and Investigation Approaches for interrogating the shallow subsurface of Mars with surface probing of the top 10 cm or so. Also, it would be possible to evaluate water concentrations down to 3m or deeper using boreholes. The methods represent light weight and potentially low cost in situ methods that could be used to extract, identify, and triage high priority volatiles, especially H-ISRU. It also addresses Challenge Area 2: … Innovative Exploration Approaches. These microwave heating and volatiles extraction methods are relevant to MEPAG Goal 2A to characterize potential key resources including water to support ISRU. The volatiles prospecting and extraction techniques are directly adaptable to the Strategic Knowledge Gaps of Mars exploration. They are also applicable to volatiles extraction from the Lunar pole and asteroidal bodies. The light weight and low cost volatiles extraction techniques are suitable as secondary payloads to be carried on larger landed vehicles. Ground based experiments can be designed to test the methods of extraction while numerical multiphysics analysis could be performed to predict the extraction efficiencies.

References:

[1] Ethridge, E.C. and Kaukler, W. F. (2012) *AIAA Aerospace Sciences Meeting, Nashville, TN.*