Plasma Processing of Lunar and Planetary Materials

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Space exploration and colonization must include oxygen for propulsion and life support, as well as, structural materials for construction. To the extent possible, these should be derived from locally available planetary resources. We propose an extractive metallurgy and oxygen recovery process well-suited for resource utilization in space. Locally available minerals are placed in a radio frequency-generated hydrogen plasma. This is accomplished using a fluidized bed contacting device. Electromagnetic energy is coupled to the hydrogen gas forming a non-equilibrium plasma. The plasma produces the ideal reducing agent – atomic hydrogen – in direct and intimate contact with the solid particles. When using oxide minerals as a feed, atomic hydrogen extracts oxygen from the matrix through the formation of water. The water is subsequently split into oxygen and hydrogen (the hydrogen is then recycled back to the plasma reactor). The processed solids could then be refined to produce structural materials. A conceptual process flow diagram, which requires an initial charge of hydrogen, is given in Figure 1.

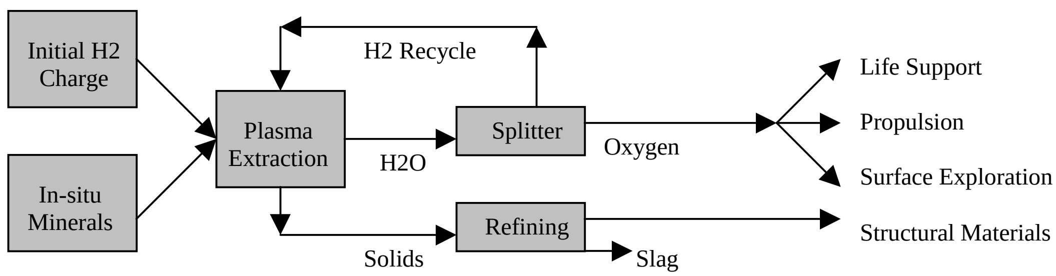

Figure 1. A cross-cutting oxygen extraction process. The oxygen could be used directly for life support or for propulsion (e.g. combustion of methane or in ion acceleration (plasma) propulsion schemes). It could also be used as a oxygen source for fuel cell powered robots engaged in surface exploration. The processed solids would be reduced from the oxides towards the base metals and could (with further refining) be used as structural materials.

Central to this process is the plasma fluidized bed (PFB) reactor. In such a device, gas flows upward through a bed of particles such that the upward hydrodynamic drag force on the particles counter-acts the gravitational forces. At this point the bed becomes "fluidized." We have shown that a plasma can be maintained in such devices under the proper flow regimes. We screened extractive chemistry in plasma fluidized beds using a hydrogen-argon plasma. The plasma was generated using a microwave applicator (2.45 GHz) coupled directly to a quartz tube (the tube passed through the waveguide). The bed was fitted with a port just the above the bed which allowed gas samples to be withdrawn for mass spectral analysis. We have successfully produced water from several surrogates of interest. As a lunar surrogate, we used $FeTiO_3$ (ilmenite). With this surrogate, water production from the hydrogen-argon plasma fluidized bed was fairly constant over time and significant changes in crystal structure were observed. These effects are shown in the mass spectra signal for water and in the x-ray diffraction pattern (Figure 2).

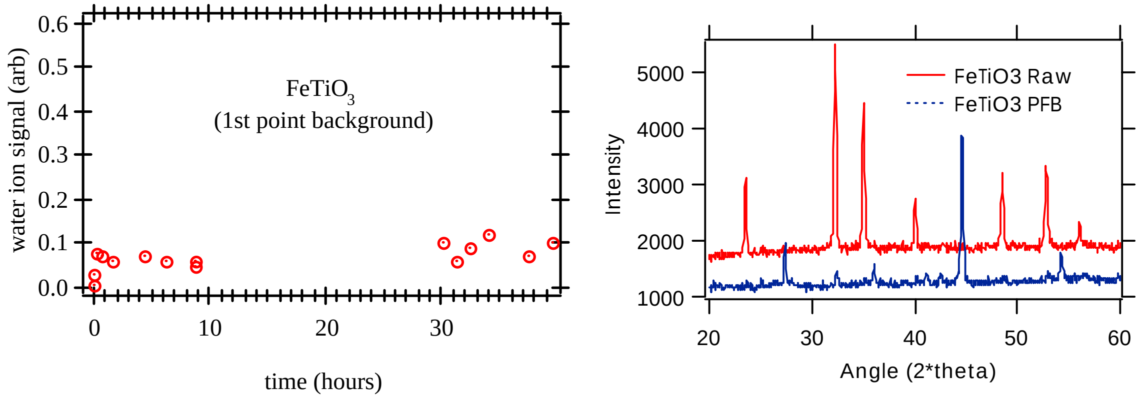

Figure 2. Mass Spectral signal for water. XRD pattern for raw and processed $FeTiO_3$.

As a Martian surrogate, we examined a more complicated magnesium silicate mineral (olivine). Again, we were able to produce water at a fairly constant rate over extended periods. We also observed changes to the crystal structure, as probed by XRD.

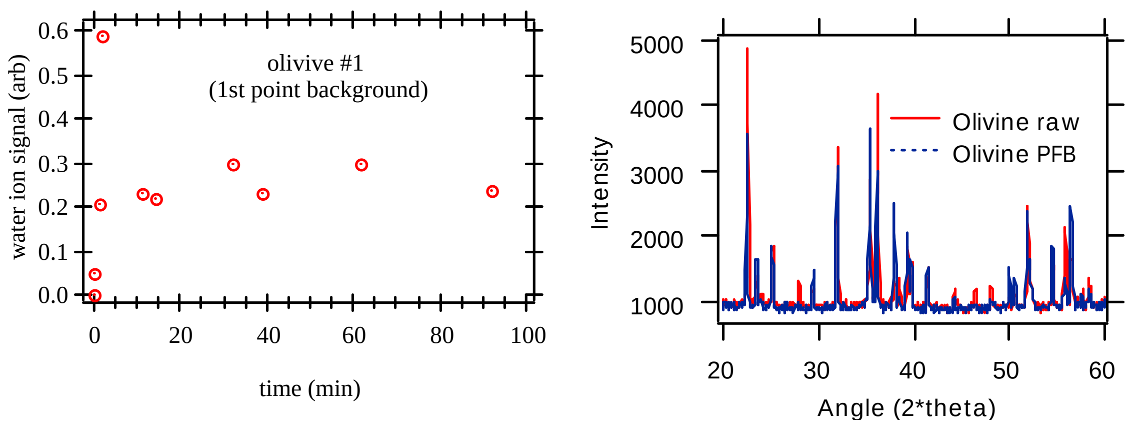

Figure 3. Mass Spectral signal for water derived from olivine. XRD pattern for raw and processed olivine.

Our other experiments in the plasma fluidized bed process indicate a general capability to form water from an even wider variety of oxide minerals. Also, unlike many conventional noncatalytic gas-solid reactions, this extraction technique does not appear to show a strong dependence on particle size. However, only a preliminary screening of these chemistries has been conducted and no concerted effort has yet been made to optimize the global kinetics. In order to do so, additional topics must addressed in order to produce a compact design for space-based applications. These include reactor design for higher plasma densities, optimization of the kinetics, exploration of particle dynamics in reduced-gravity fluidized beds, and integrated process design (including the required separators).

By reducing insulation requirements and by having a compact design for a plasma reactor, this relatively low temperature plasma process may offer advantages over high temperature (thermally activated) water extraction processes which use molecular hydrogen as a reactant.