MARS REGOLITH WATER EXTRACTOR.

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Introduction: The Mars Regolith Water Extractor (MRWE) is a system for acquiring water from the Martian soil. In the MRWE, a stream of CO_2 is heated by solar energy or waste heat from a nuclear reactor and then passed through a vessel containing Martian soil freshly removed from the ground. The hot CO_2 causes water absorbed in the Martian soil to outgas, whereupon it is swept along by the CO_2 to a condenser where ambient Martian cold temperatures are used to condense the water from the CO_2. The Mars Odyssey Neutron Spectrometer data suggests concentrations of water greater than 2 percent in equatorial regions.

The MRWE eliminates the requirement to transport hydrogen to Mars in order to make methane/oxygen propellant, and allows all the propellant needed for a Mars to Earth return flight to be manufactured on Mars using a Sabatier/electrolysis (S/E) cycle, without any need for auxiliary oxygen production. By eliminating the need to transport fuel, oxygen, and water to Mars, the MRWE will have a major effect in reducing the mass, cost, and risk of human Mars exploration.

Pioneer Astronautics carried out a six-month, NASA Johnson Space Center SBIR Phase I program in 2011 to demonstrate proof-of-concept of the MRWE. Robert Zubrin was the Principal Investigator for Pioneer. Aaron Paz was the Contracting Officer's Technical Representative for NASA JSC.

Background: In the Mars Direct plan and the 1993 JSC Design Reference Mission, hydrogen required to support the S/E cycle is transported from Earth. This poses a modest mass issue for these plans, since both of them incorporate a Reverse Water Gas Shift reactor, and thus only need to transport an amount of hydrogen to Mars equal to about 5% of the total propellant produced. However the bulk and hard cryogenic properties of liquid hydrogen impose design complexities on the mission, so much so that some analysts, such as Sanders[1], have defined its transport as a tall-pole concern. However, if water could be obtained on Mars, all of the issues with the S/E cycle would vanish. There would be no need to launch or transport hydrogen across interplanetary space, and the extra oxygen the S/E cycle needs would be provided by electrolysis of the water at the same time that it yields the hydrogen. The question arises, where can we get water on Mars? There is nearly pure water ice near the poles, but we don't want to have to confine our operations to such regions. There is some water in the atmosphere, but only in such dilute quantities (0.01%) as to make its acquisition too energy-intensive to be practical. This leaves the soil.

Analyzing the 2003 water equivalent Hydrogen Abundance data from the Mars Odyssey Neutron Spectrometer shows the water content at the equator between 2 and 10 percent by weight. In approximately half of the equatorial regions of Mars there are areas of higher concentrations averaging 6 to 10 percent water by weight. Data is from The Global Distribution of Hydrogen on Mars[2]. Thermogravimetric experiments on clays (Na and Ca smectites) and a smectite (Chabazite) show that these minerals can load 10-22% of water by mass at the equatorial subsurface conditions of Mars, which may partially explain the observation of high water abundance.

MRWE Hardware: *Figure 1* schematically shows the MRWE system. The arrows correspond to the movement of the carbon dioxide through the MRWE. The pump forces CO_2 into the gas heater, where it is heated before entering the regolith dehydration chamber. The CO_2 then heats the regolith causing the water to vaporize. The mixture of CO_2 and water vapor then move toward the plate heat exchanger where heat transfers to the pure dried CO_2 moving in the opposite direction. The gaseous mixture then moves into the condenser, where the water drops out and moves to the collection tank. The pressure of the system is regulated by the CO_2 tank and thus the overall system pressure can be easily changed.

The MRWE vessel was designed and built in order to limit heat transfer to the regolith dehydration chamber and to concentrate the system's energy on the regolith and the water within that regolith. This regolith dehydration chamber incorporated a double-walled design, in which a vacuum could be pulled between the inner and outer shells (much the same as a thermos). By evacuating the space of all air particles, there are limited conduction paths for the heat to take into the outer, more massive shell. This design aims to reduce heat lost to the environment and to keep the vast majority of the energy in the regolith for vaporizing the water. Exterior insulation was installed on the vessel in order to limit losses from any conductive heat transfer along the inner-to-outer wall connection points.

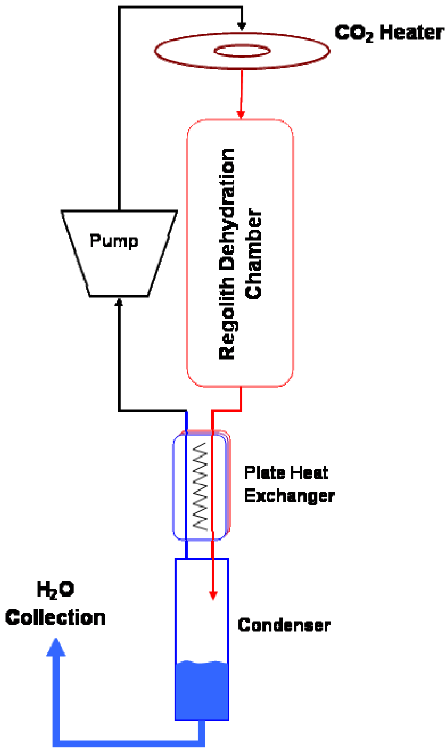

Figure 1: MRWE System Schematic

In order to encourage the heat to move from the center of the vessel through the bulk of the simulant toward the walls, a solid stainless steel disk of slightly smaller diameter than the vessel was added at the bottom of the regolith (resting above a porous zirconia support). *Figure 2* shows how this forces the gas to move radially outward from the gas injection tube and then down through the regolith bed.

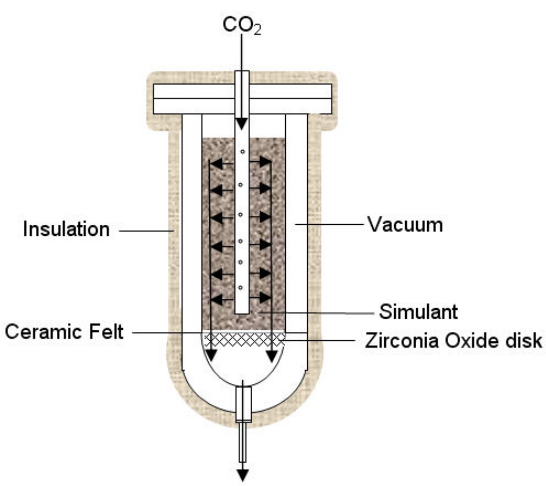

Figure 2: MRWE Vessel Schematic

Experimental: JSC Mars-1 simulant was spiked with water at target concentrations in the five to ten percent range. The water was thoroughly blended into the soil prior to feeding the extraction vessel.

The MRWE was tested over a range of CO_2 flow rates and operating pressures. Vessel temperatures between 240 and 400°C were targeted during the test program. Most of the observed water extraction took place during the first 30 to 60 minutes of a batch cycle.

Operating results showed that higher operating pressures significantly improved water extraction rates. In one of the later experiments at a vessel pressure of about 75 psi and a CO_2 flow, the average water production rate over 60 minutes was about 6 grams per minute. About 90 percent of the available water was extracted.

A systems analysis showed that the MRWE requires about 3 kWe of the total 33 kWe of a complete SE/electrolysis system scaled to support the NASA Design Reference Mission (30 metric tonnes of liquid methane/oxygen propellant). Much of the MRWE electrical power requirements are for the gas compression subsystem.

Conclusions: The Phase I MRWE system produced a maximum water production rate of 337g per hour or roughly 8 kg of water per day using a single pump and a simulant regolith with an initial water concentration of 5 percent. Supported by 1.04kW of electrical pump power, this system yielded a water production rate of 325 g per kWe-h. The MRWE would eliminate the requirement to transport hydrogen to Mars in order to make methane/oxygen propellant, and allow all the propellant needed for a Mars to Earth return flight to be manufactured on Mars using the S/E cycle without any need for auxiliary oxygen. A scaled down version of the MRWE could also produce all of the water needed to enable a Mars Sample Return using *In-Situ* Propellant Production.

The ability to extract water from Mars will also serve to supply the crew of a Mars missions with copious supplies of water itself, which after propellant, is the most massive logistical component of a Mars mission. Eliminating the need to transport fuel, oxygen, and water to Mars, will reduce the mass, cost, and risk of Mars exploration.

References:

[1] Sanders, G. “In-Situ Resource Utilization on Mars – Update from the DRA 5.0 Study,” AIAA 2010-799, 48th Aerospace Sciences Meeting, January 4-7, 2010, Orlando, Florida.

[2] Feldman W.C., T.H. Prettyman, W.V. Boynton, S.W. Squyres, D.L. Bish, R.C. Elphic, H.O. Funsten, D.J. Lawrence, S. Maurice, K.R. Moore, R.L Tokar, and D.T. Vaniman, “The global distribution of near-surface hydrogen on Mars”, Sixth International Conference on Mars, 2003, Pasadena, California.