Mars Regolith Water Extractor

Pioneer Astronautics
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MRWE Background

- *Mars Direct and the 1993 JSC Design Reference Mission plans call for acquisition of CO_2 from the Mars atmosphere for production of return CH_4 and O_2 propellant via Sabatier-electrolysis using H_2 imported from Earth.*
  - *This requires that H_2 in a modest amount equal to only about 5% of the total return propellant mass be transported from Earth.*
  - *However, the required cryogenic storage properties of liquid H_2 impose significant mission design complexities.*
  - *In addition, a reverse-water-gas-shift reactor system is required to fulfill the total propellant O_2 requirement.*

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MRWE Background (continued)

- *If water could be obtained on Mars, issues related to H_2 transport and supplemental O_2 production via RWGS would vanish.*
  - *Launch and transport of liquid H_2 across interplanetary space would be no longer be required.*
  - *Extra O_2 requirements would be met by electrolysis of water at the same time that it yields the necessary H_2 for the Sabatier reaction.*
- *Small ISRU process leaks can be tolerated since no Earth make up is needed.*

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MRWE Background (continued)

- *Where can water be obtained on Mars?*
  - *Nearly pure water ice exists near the poles, but such locations present challenges to operations and exclude many regions of interest for exploration.*
  - *Water exists in the Mars atmosphere in concentrations on the order of about 0.01 percent, making acquisition too energy intensive.*
  - *Water equivalent Hydrogen Abundance data from the Mars Odyssey Neutron Spectrometer shows equatorial water content between 2 and 10 percent by weight, providing a significant extractable concentration in regions of interest.*

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MRWE Background (continued)

- *Potential Water Forms*
  - *Free Ice/Water/Frozen Mud*
  - *Hydrates*
  - *Clays*

MRWE Background (continued)

- *Water Extraction Temperature & Energy Requirement*

Free Ice/Water:

$H_2O_{(s)} \Rightarrow H_2O_{(l)}$	0°C	$\Delta H = 6.0$ kJ
$H_2O_{(l)} \Rightarrow H_2O_{(g)}$	100°C	$\Delta H = 40.9$ kJ

MRWE Background (continued)

- *Water Extraction Temperature & Energy Requirement*

Free Ice/Water:

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Hydrated Salt:

$MgSO_4 \bullet H_2O \Rightarrow MgSO_4 + H_2O_{(g)}$	150°C	$\Delta H = 75.7$ kJ
$MgSO_4 \bullet 4H_2O \Rightarrow MgSO_4 + 4H_2O_{(g)}$	~200°C	$\Delta H = 230.6$ kJ
		(57.7 kJ/H_2O)

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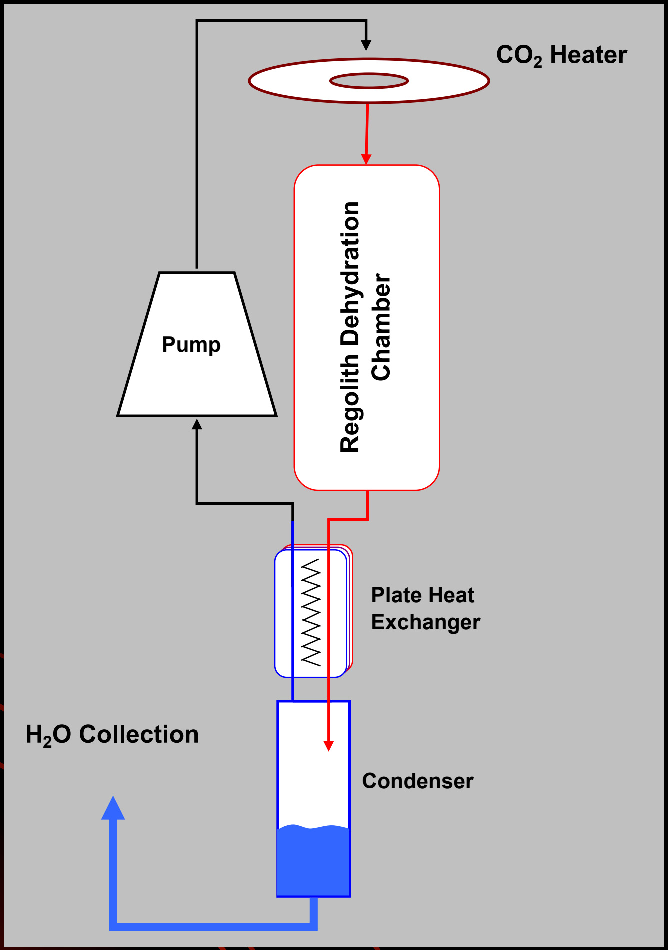
MRWE Process Description

- *The Mars Regolith Water Extractor acquires water by passing a heated stream of CO_2 through a vessel containing freshly excavated Martian soil.*
  - *CO_2 would be acquired from the Mars atmosphere via compression or other means.*
  - *CO_2 heating would be provided by solar energy or waste heat from a nuclear reactor or RTG.*
  - *H_2O extracted from the Martian soil would be condensed from the CO_2, which is recycled to extract more water from the soil.*

MRWE Process Description

- *Temperatures required to vaporize water from hydrated sulfates are significantly lower than those resulting in sulfate decomposition*
  - *$MgSO_4$ decomposition begins slowly above 600°C and is complete at about 1100°C*
  - *CO_2 does not replace SO_4 during water extraction.*

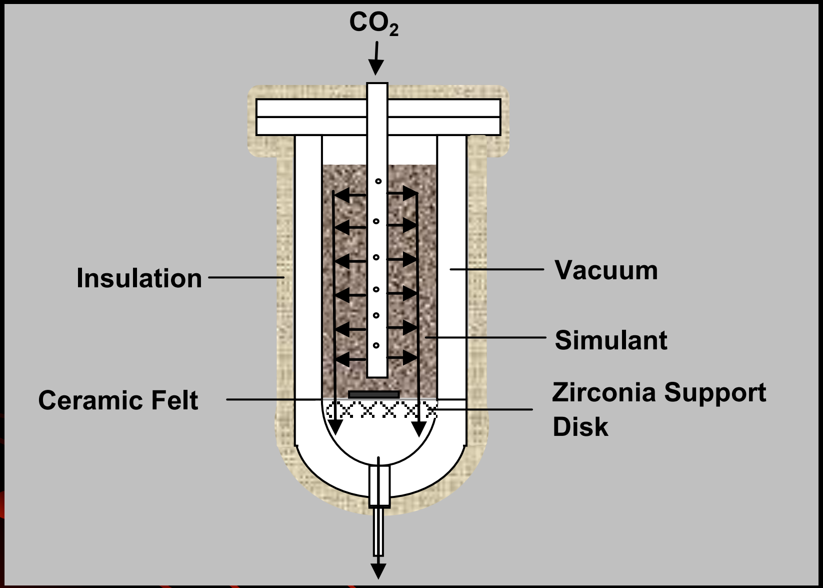
MRWE Schematic



MRWE Process Schematic

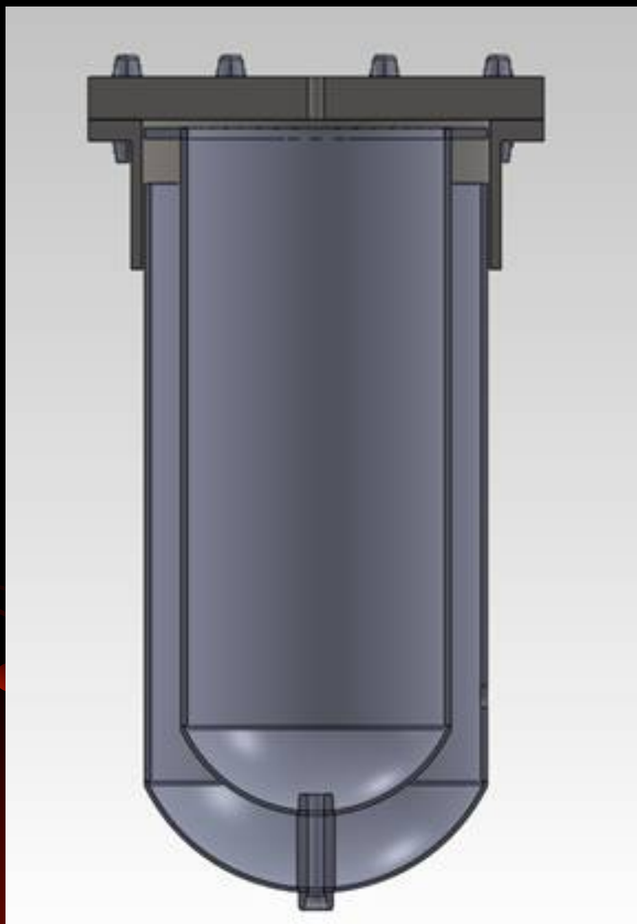
- *The pump flows dry CO_2 through the gas heater and then the extraction vessel.*
- *Pre-heated CO_2 heats the soil and vaporizes water from the regolith.*
- *Heat is recovered from the vessel exhaust gas via exchange with recycled CO_2.*
- *H_2O is condensed and separated from CO_2 for feed to electrolysis.*

MRWE Vessel



- *The MRWE vessel was designed to direct the system's energy toward the regolith and its contained water.*
    - *A double-walled design incorporated a vacuum insulation barrier and limited heat conduction paths to the outer shell.*
    - *Exterior insulation was applied to further minimize heat losses to the surroundings.*
- *Gas flow was designed to emit radially from the CO_2 injection tube and then downward through the soil mass.*

MRWE Vessel



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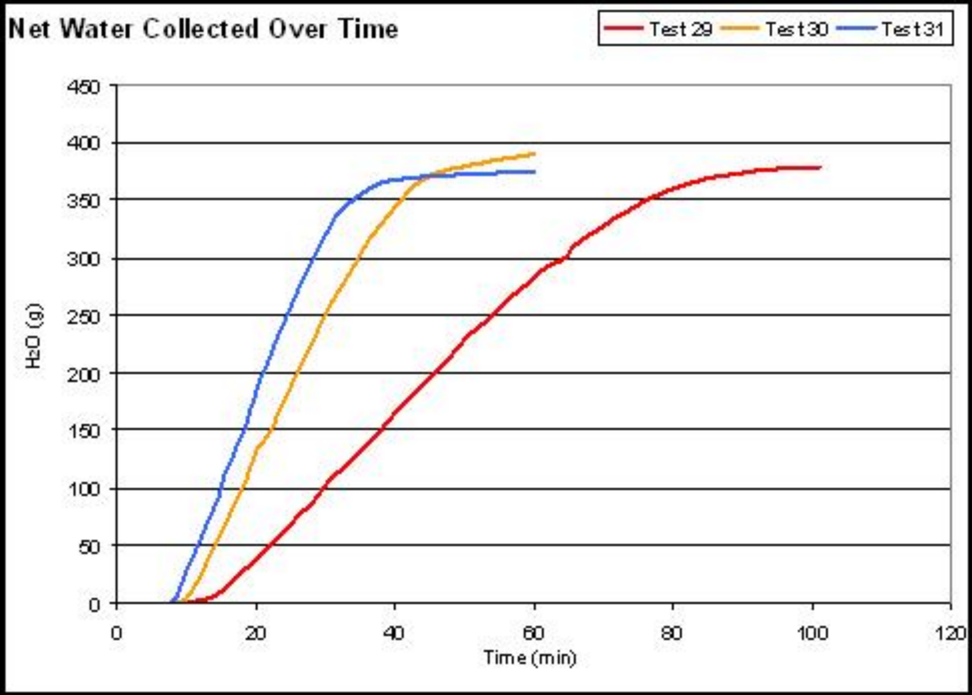
MRWE Experimental Program

- *About 4 kg of JSC Mars-1 soil simulant was spiked with water in the five to ten percent concentration range prior to each experiment.*
- *Recirculating CO_2 was heated to temperatures between 200 and 400°C at the extraction vessel inlet.*
- *CO_2 inlet pressures up to 5 bar were used.*
- *CO_2 flow rates up to 300 SLPM were used.*
- *Parameters such as thermal input, water extraction rate, and pressure drop were recorded.*

MRWE Test Results



- *Higher operating pressures significantly increased water extraction rates.*
- *Pressure drops of only about 0.5 bar were noted at conditions resulting in the highest water extraction rates (5 bar system pressure).*
- *Up to 90 percent of the water in the soil was extracted in 60 minutes at an average rate of about 6 grams per minute.*

MRWE Systems Analysis

- *Batch cycle times of 30 to 60 minutes are optimal.*

- *About 1 kWe is required to operate the CO_2 recycle pump while generating about 6 g H_2O per minute (about 360 g H_2O/kWe-h).*

- *The Pioneer Phase I MRWE is about one-third scale of the NASA Design Reference Mission requirement (30 metric tonnes of liquid methane/oxygen propellant). A MRWE module would require about 3 kWe of the total 33 kWe for a complete Sabatier/Electrolysis system.*

- *The Pioneer Phase I MRWE is about one-tenth scale for the Mars Direct mission architecture. The Phase I MRWE is oversized for a sample return mission.*

- *Most of the thermal energy input for the MRWE can be provided from solar or waste heat from an RTG. MRWE thermal energy is about 1/3 of the electrical energy requirement.*

MRWE Conclusions

- *MRWE provides a reliable, low-cost, low-mass, low-power technology to produce water, hydrogen, and liquid-oxygen on the surface of Mars using indigenous materials.*

- *The MRWE eliminates the requirement to transport hydrogen to make methane fuel and allows all propellant needed for a Mars-to-Earth return flight to be manufactured on Mars using a Sabatier/electrolysis cycle.*

- *Water extraction also supplies manned Mars missions with the second most massive logistic component: water. (The mass of water produced is about 100x the mass of MRWE hardware for the DRM.)*

- *Scaled down versions could make propellant for Mars sample return missions, making missions cheaper to launch and easier to land, as the landing mass limits of current systems will not be exceeded.*

- *The MRWE system can tolerate some leakage since all reagents can be replaced by readily available Mars indigenous materials.*

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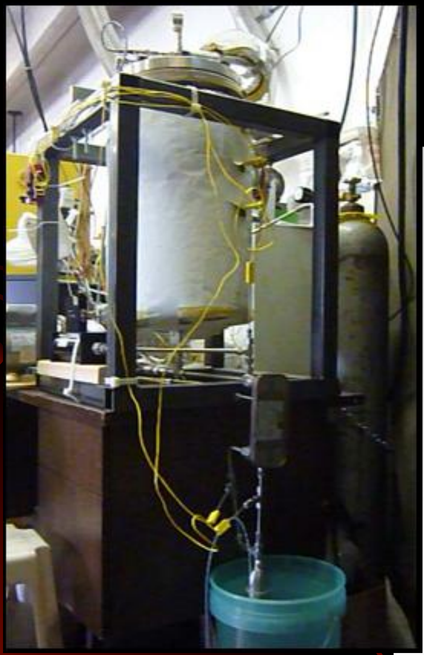

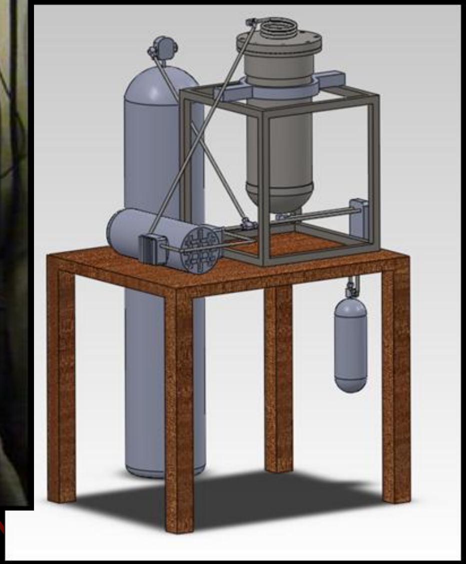

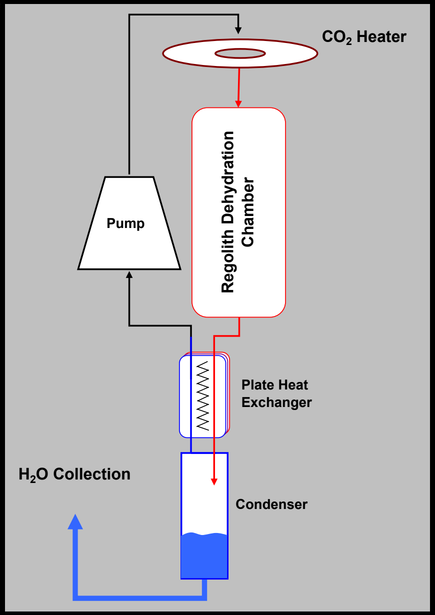

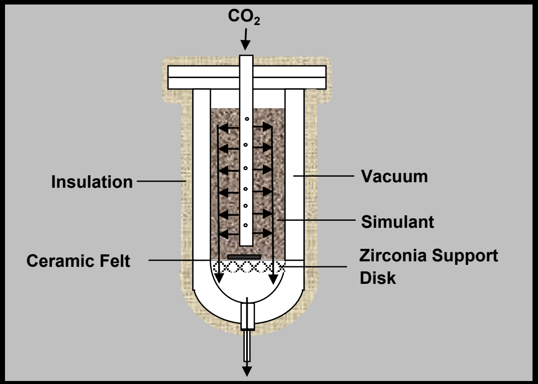

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