Extraction and Capture of Water from Martian Regolith
Experimental Proof-of-Concept

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 Lists in-situ resource utilization (ISRU) as enabling for robust human Mars missions
  - ~25,000 kg oxygen from atmosphere for ascent propulsion and life support
  - Oxygen provides 75 – 80% of propellant for a $O_2/CH_4$ ascent vehicle

“ Atmospheric based ISRU processes less operationally complex than surface based”
  - “...limited concept evaluation to date and Mars surface water property and distribution uncertainty would not allow [Mars soil water processing] to be baselined at this time”
Mars DRA 5 ISRU Problem Statements

Challenge 1: Mars surface water property and distribution uncertainty

Challenge 2: Limited concept evaluation to date
Mars Surface Water Property and Distribution Uncertainty

- Mars missions such as Odyssey, Phoenix, and Curiosity have confirmed water can be found globally across the surface
  - Regions up to 8 to 10 percent water in top 1 m of regolith
- Loosely bound water release at < 100 °C
- Water release from hydrates occurs across broad peak centered at 300 °C
“Limited Concept Evaluation to Date”

• **Lunar regolith O\textsubscript{2} extraction processing experience**
  – Lunar regolith is heated to high temperature and fluidized with H\textsubscript{2} to produce H\textsubscript{2}O from iron-bearing minerals

• **Mars similarity concept:**
  – Soil placed in fluidized bed reactor
  – Heated to moderate temperatures
  – Inert gas flow used to fluidize the bed and help with water desorption

• **Challenges:**
  – High-temperature dusty seals
  – Working gas requires downstream separation and recycling to reduce consumables loss
  – Batch process heating thermally inefficient
New Mars Soil Water Capture Concept

• Eliminate need for repeated sealing of hot, dusty seals
  – Accept that not all evolved water will be captured
• Use Mars air as working gas
  – Do not have to recover/recycle as the air is ‘free’
• Continuous heating/water extraction
‘Open Air’ Mars Water Harvester Concept

Heated tillers penetrate regolith to expose frozen volatiles

Heated, insulated cover (shown transparent) aids in volatile release

Fan draws in Mars ‘air’ to sweep evolved gases

Condenser or dessicant bed

Mars air plus evolved water

Vent dry Mars air
Mars Atmosphere Chemistry Simulator (MACS) Chamber

- Mars pressure
  - 5 to 10 Torr
- Mars gas mixture (CO$_2$, N$_2$, Ar)
- Chamber pressure maintained dynamically with back-pressure valve controlling the evacuation through scroll pump
Excavation Implement

• Rototiller to bring ‘fresh’ moist soil to surface
• Four rotors with six tines each from commercial rototiller
  – Remaining plastic components rebuilt in SS to withstand up to 300 °C
  – 37 cm housing to keep drive motor mounted well above heated enclosure
• Double-hinge mounted to enclosure for flexibility of motion
• Gear and gear rack used to provide a straight, constant depth motion across the soil bin
SolidWorks model of full assembly

Rototiller housing (cover removed), chain, and sprocket drive
Enclosure

- Provides flow containment and radiative heat source
- Soil bin on cold plate
  - 25 x 43 x 14 cm deep
- Teflon side plates and curved aluminum end sheets
  - Total height of bin plus side plates is 30 cm
- Heater plates on top provide up to 500 W
  - Flat black paint on bottom to enhance emissivity
Complete Mars Soil Water assembly mounted in test chamber
Flow Loop and Water Capture

• 4-cm fan in one end wall to generate current across surface of the simulant bed
  – Second fan placed on the exit of the flow loop inside chamber to provide both a ‘push’ and ‘pull’ of the gas stream
• Initially tried dryer bed containing indicating desiccant
  – Also included several pressure transducers and a flow meter
  – Desiccant bed had 1/8” fittings (largest available)
  – Flow meter sized for low flow and therefore had small passages
• Moved to simple condenser consisting of 3/8” tube in ice bath
• Final configuration included an additional tube section connected at a T for larger water-capture volume
Water Capture Results

• Pan of heated water in place of soil bed
  – Boiling occurred during pump down and again upon heating

• No water captured in desiccant bed in several tests at Mars pressures (7 to 10 Torr)
  – Test run at gradually increasing pressure captured ~ 1 gm water at 120 Torr
  – Could not maintain flow at low pressure, and/or
  – Desiccant does not adsorb/react at low pressure

• Condensation visible immediately with condenser tube
  – More visible at entrance to ice bath; little seen at exit
  – Initial straight-line condenser became plugged with liquid water
Final condenser with enlarged capture volume

Gas flow direction

Plugged section
Soil Heating Results

- Soil bin filled with 9 cm of hand-compacted GRC-3
  - ‘Room-dry’ with Cp on order of 0.8 J/gm-K
- Total power into heater plates limited to 165 W due to temperature limitation
- Thermocouples at surface, and at 1, 3, and 4 cm below surface
Soil Heating Results

- Energy into soil estimated using combination of measured and interpolated temperatures
  - Approximately 45 kJ absorbed by soil compared to ~ 260 kJ put out by the heaters

Initial temp = 20 °C
Water Extraction Results

• Soil bin filled with 7 cm of hand-compacted GRC-3 at 5 weight-percent water
• Covered with 2 cm of ‘room-dry’ GRC-3
Water Extraction Results

- Water extracted even from ‘room-dry’ top layer
- Rate increased with heating and with tiller operation
Conclusions

- New concept for extraction of water from Mars soil using the Mars atmosphere as a sweep gas in an ‘open-air’ system
- Radiant heat source moderately increased soil surface temperature
  - More efficient heating required to process while moving and reach higher temperatures required for hydrated minerals
- Two off-the-shelf fans generated sufficient flow to sweep moist air into condenser
  - Need to minimize/eliminate any pressure drops in flow system
- Rototiller successfully exposed fresh moist soil to surface to increase rate of water extraction

Initial modest success indicates a basic feasibility of this novel water acquisition concept