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

Diane Linne, Julie Kleinhenz, Steve Bauman,
and Kyle Johnson

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Mars Design Reference Architecture 5.0

- 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

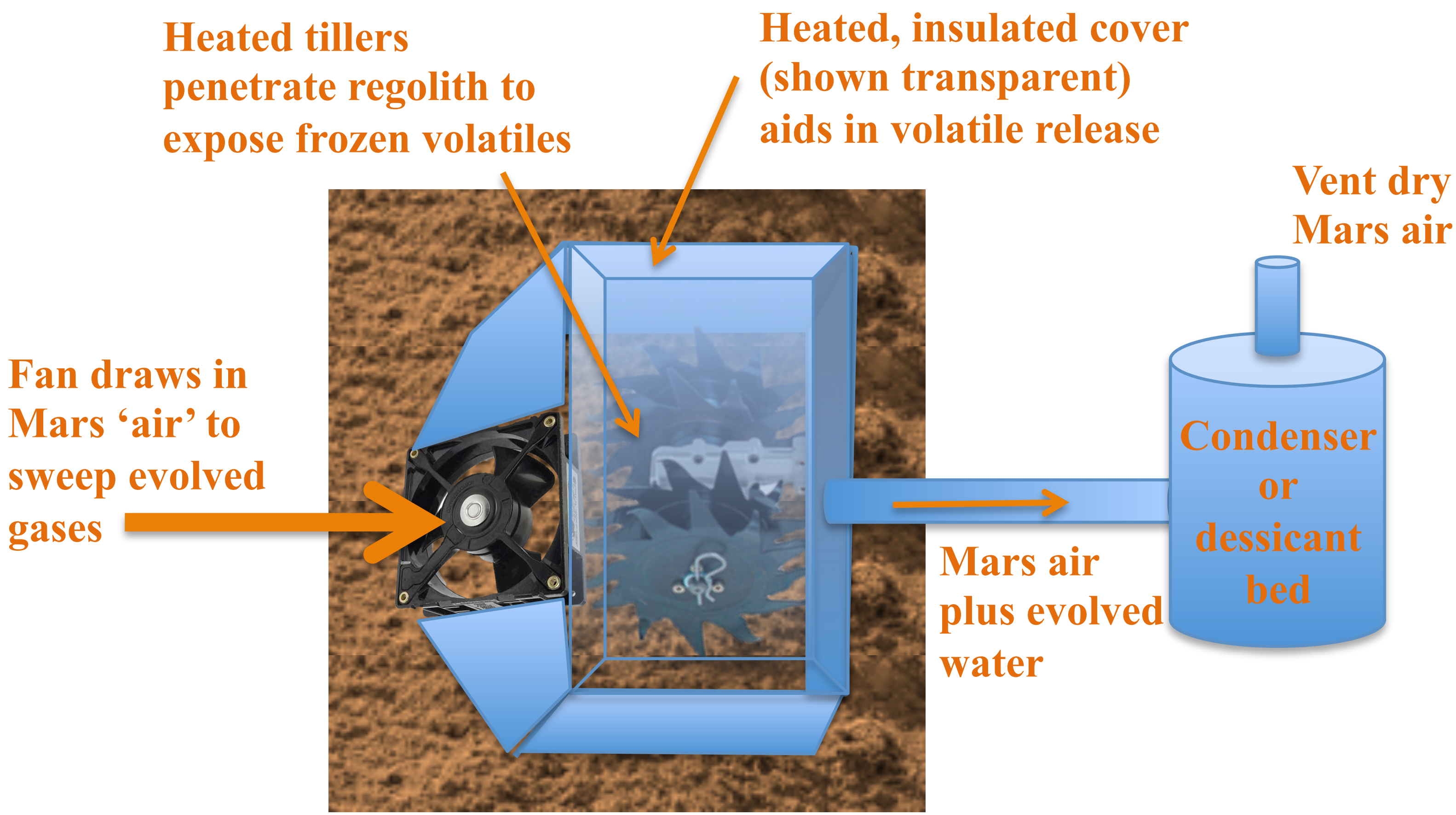
"Limited Concept Evaluation to Date"

- Lunar regolith O_2 extraction processing experience
  - Lunar regolith is heated to high temperature and fluidized with H_2 to produce H_2O 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

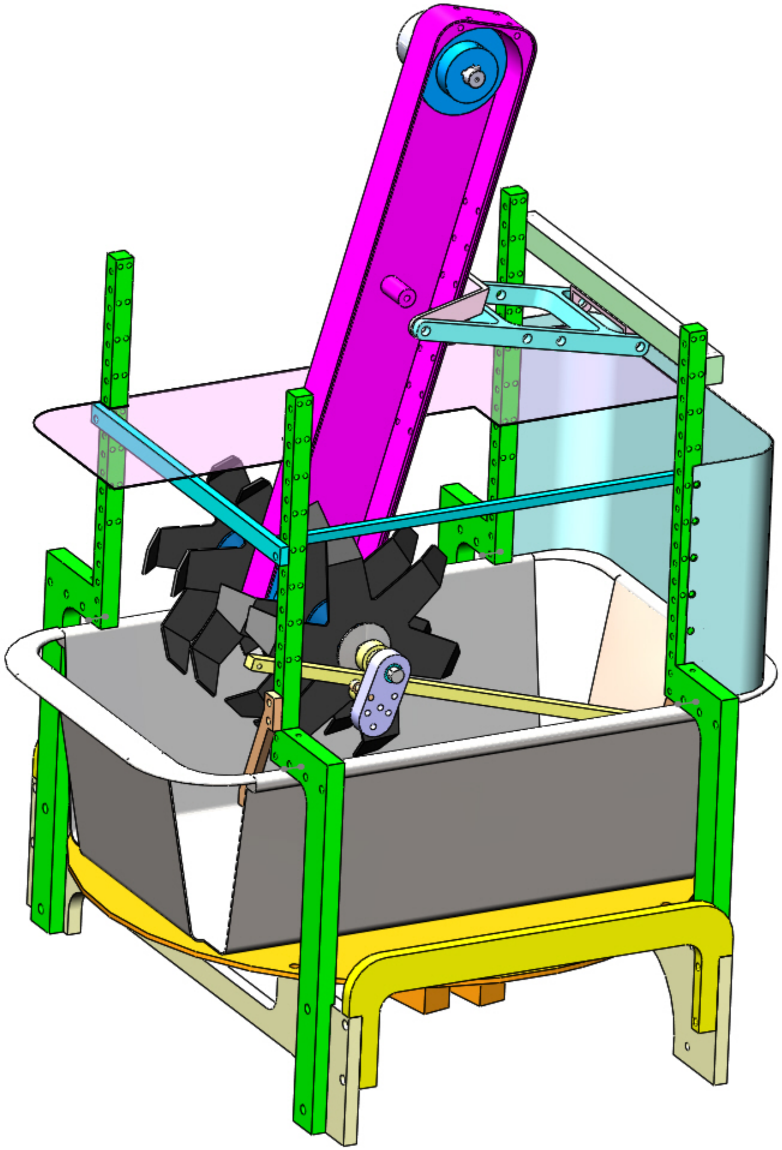


Mars Atmosphere Chemistry Simulator (MACS) Chamber

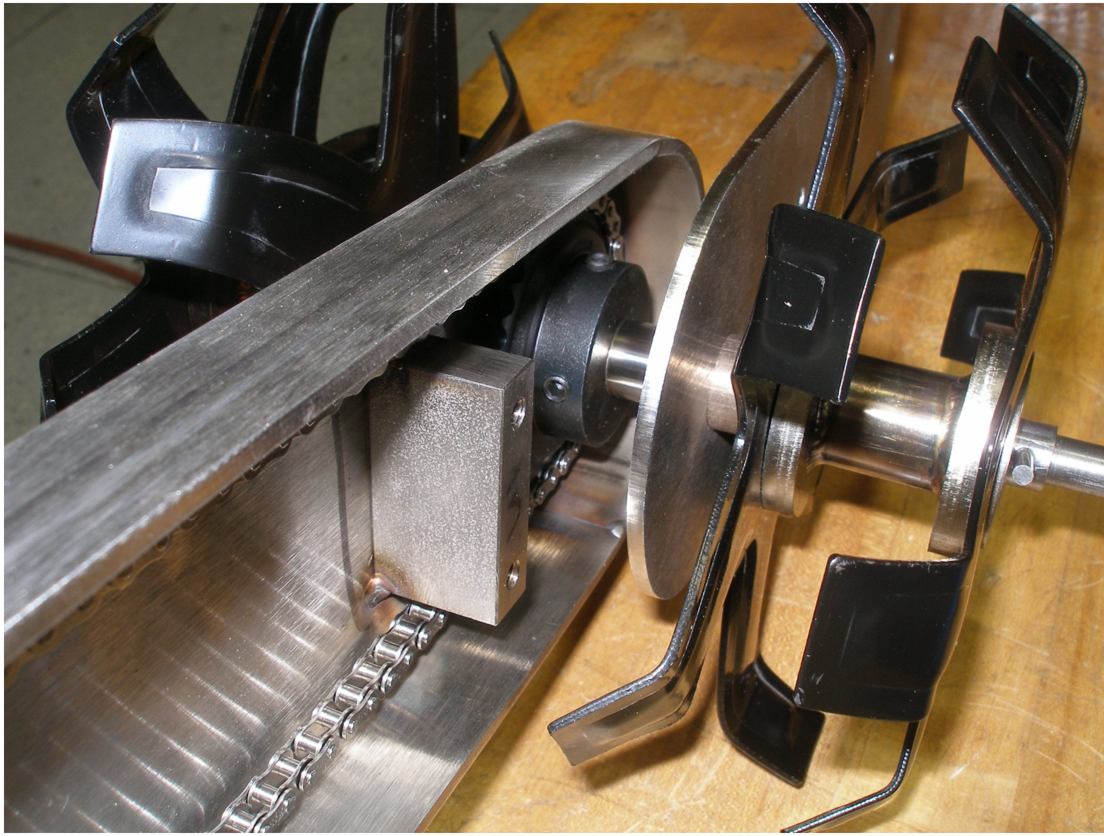
- Mars pressure
  - 5 to 10 Torr
- Mars gas mixture (CO_2, N_2, Ar)
- Chamber pressure maintained dynamically with back-pressure valve controlling the evacuation through scroll pump

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



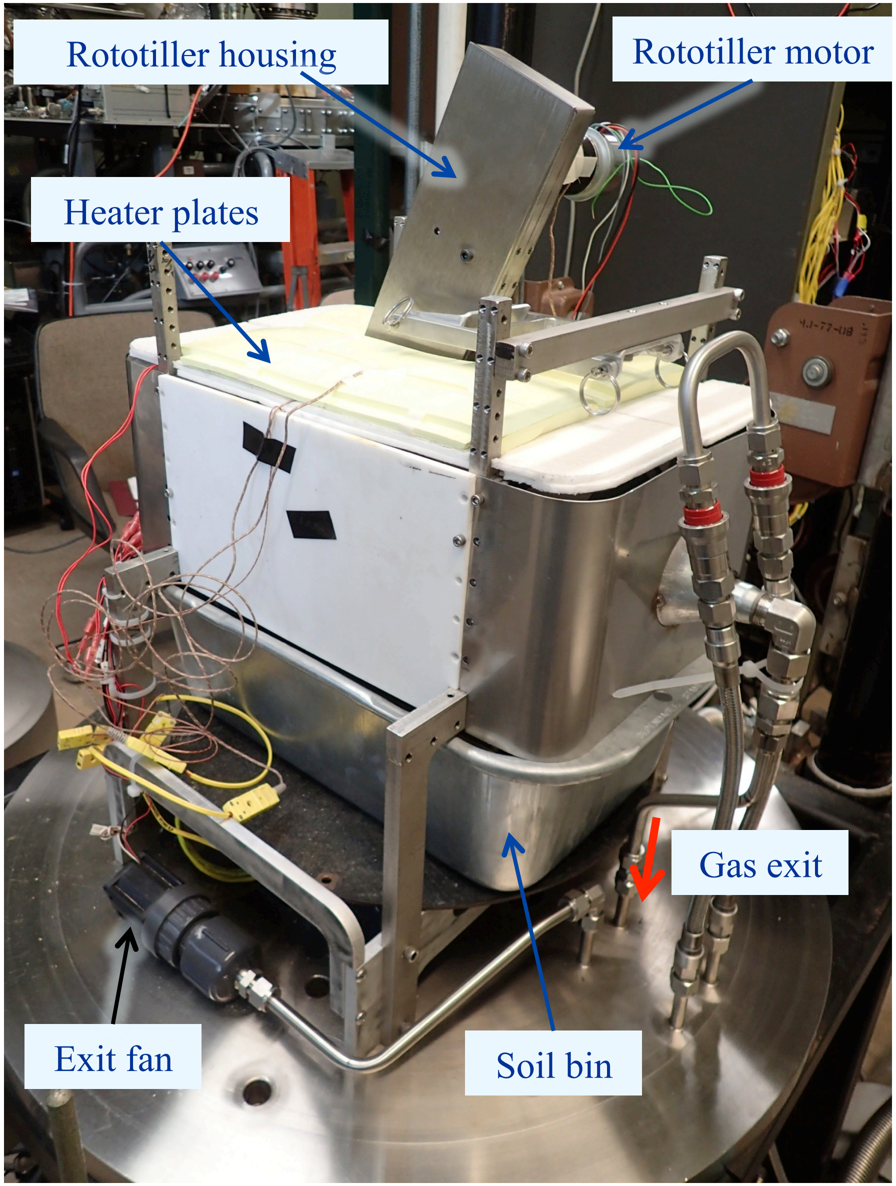
SolidWorks model of full assembly



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



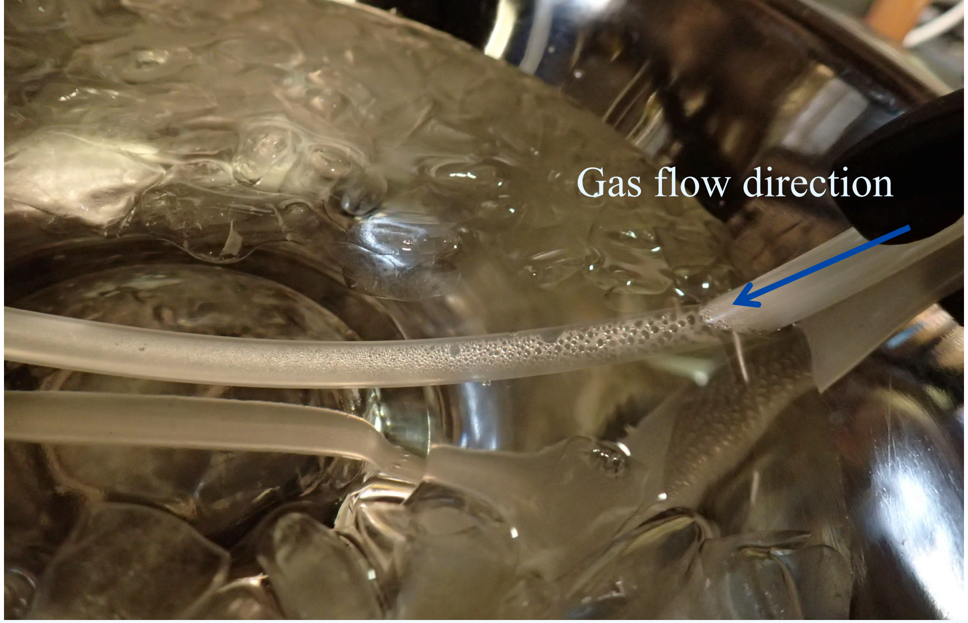
Complete Mars Soil Water assembly mounted in test chamber

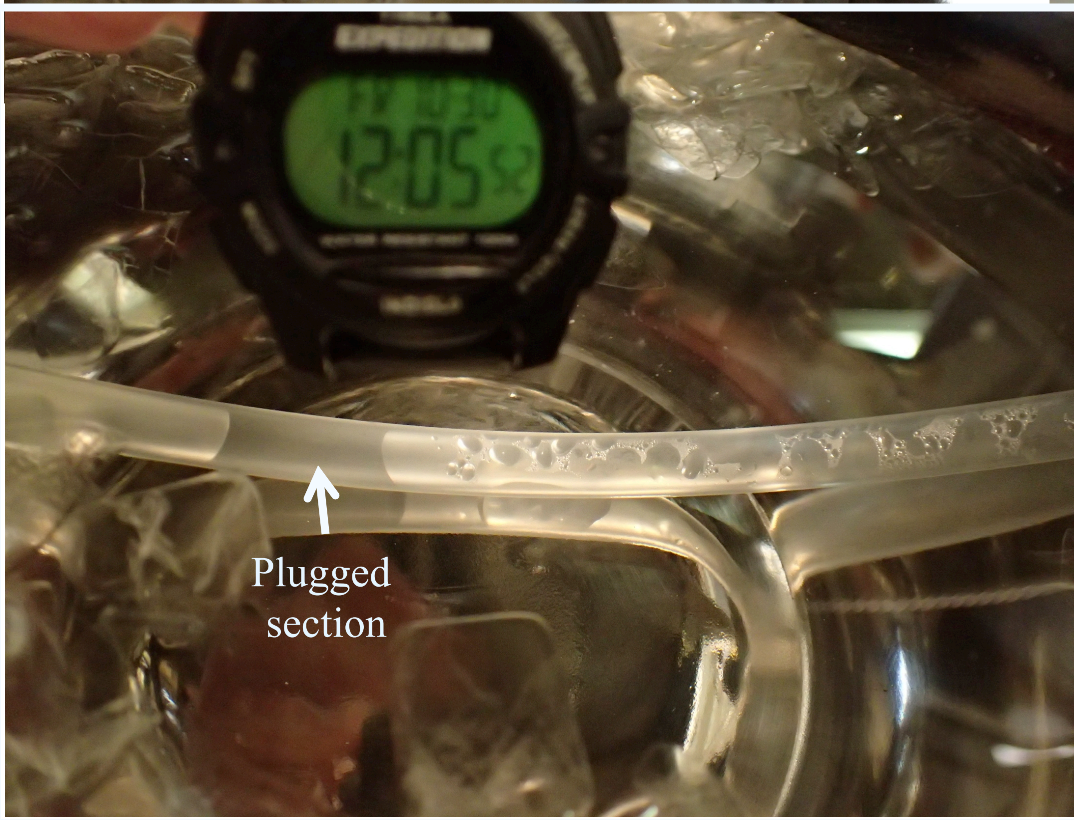
Flow Loop and Water Capture

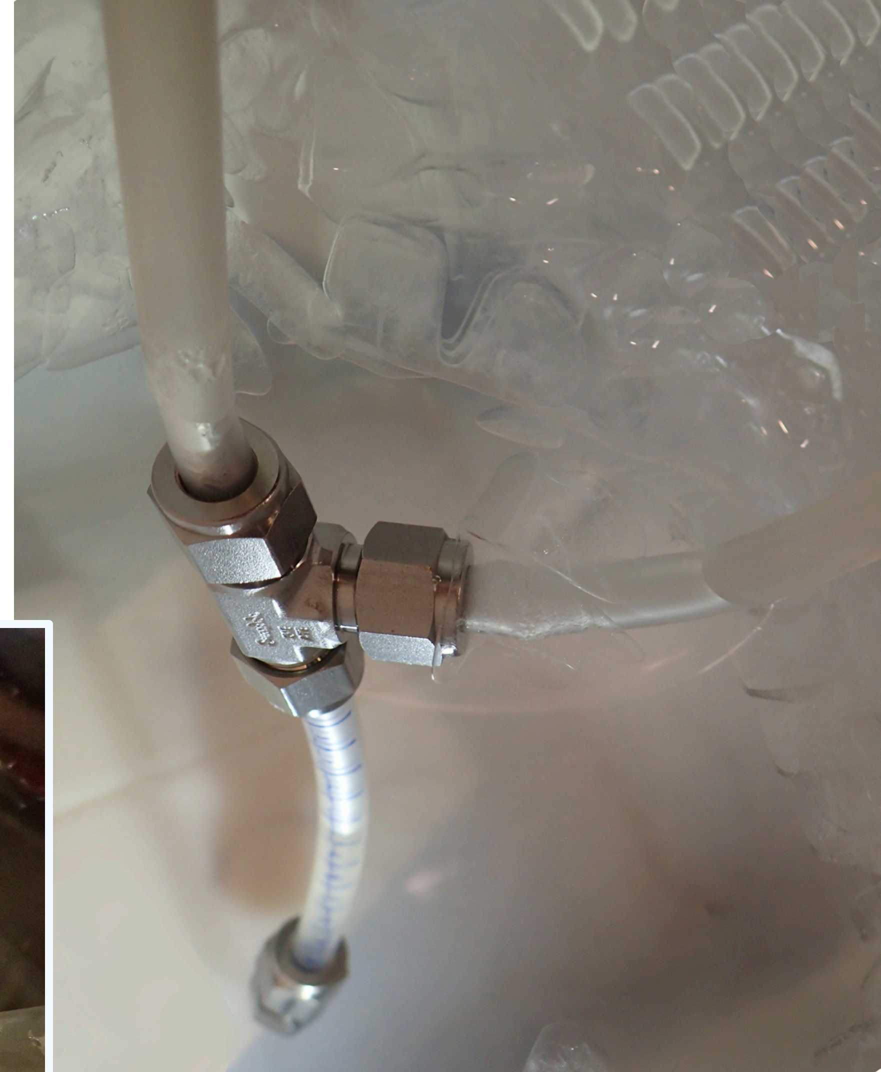
- 4-cm fan in one end wall to generate current across surface of the simulant bed
  - Second fan placed on the exit of the flow loop inside chamber to provide both a 'push' and 'pull' of the gas stream
- Initially tried dryer bed containing indicating desiccant
  - Also included several pressure transducers 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



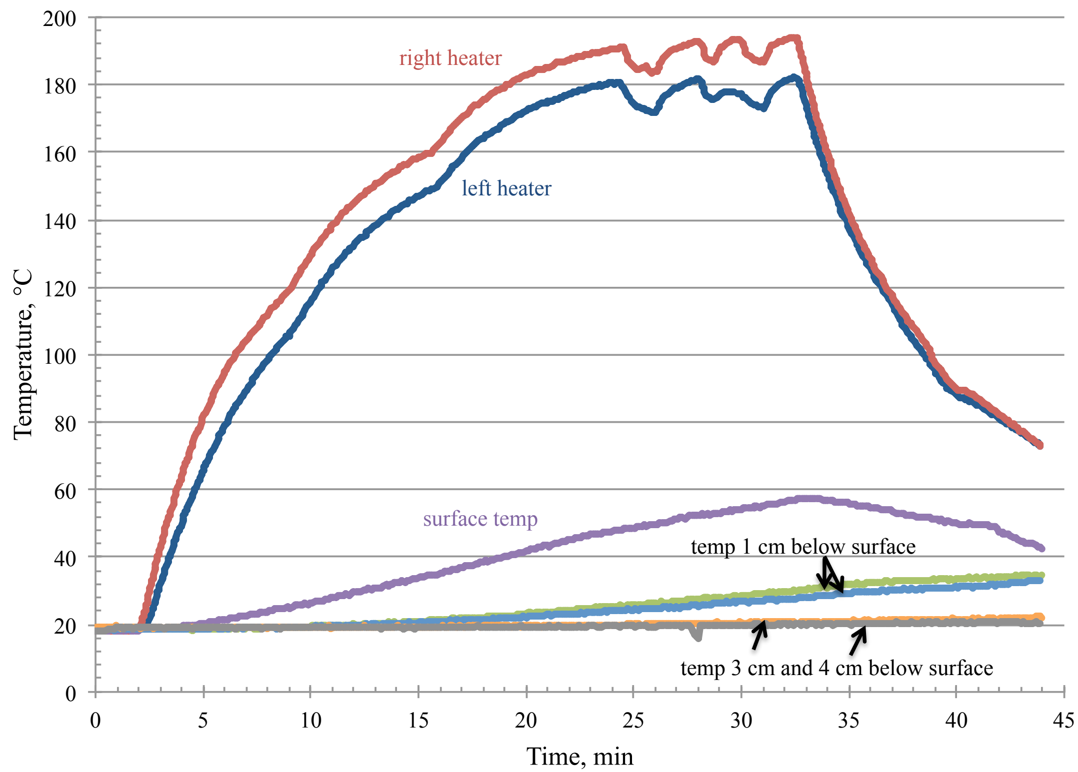




Final condenser with enlarged capture volume

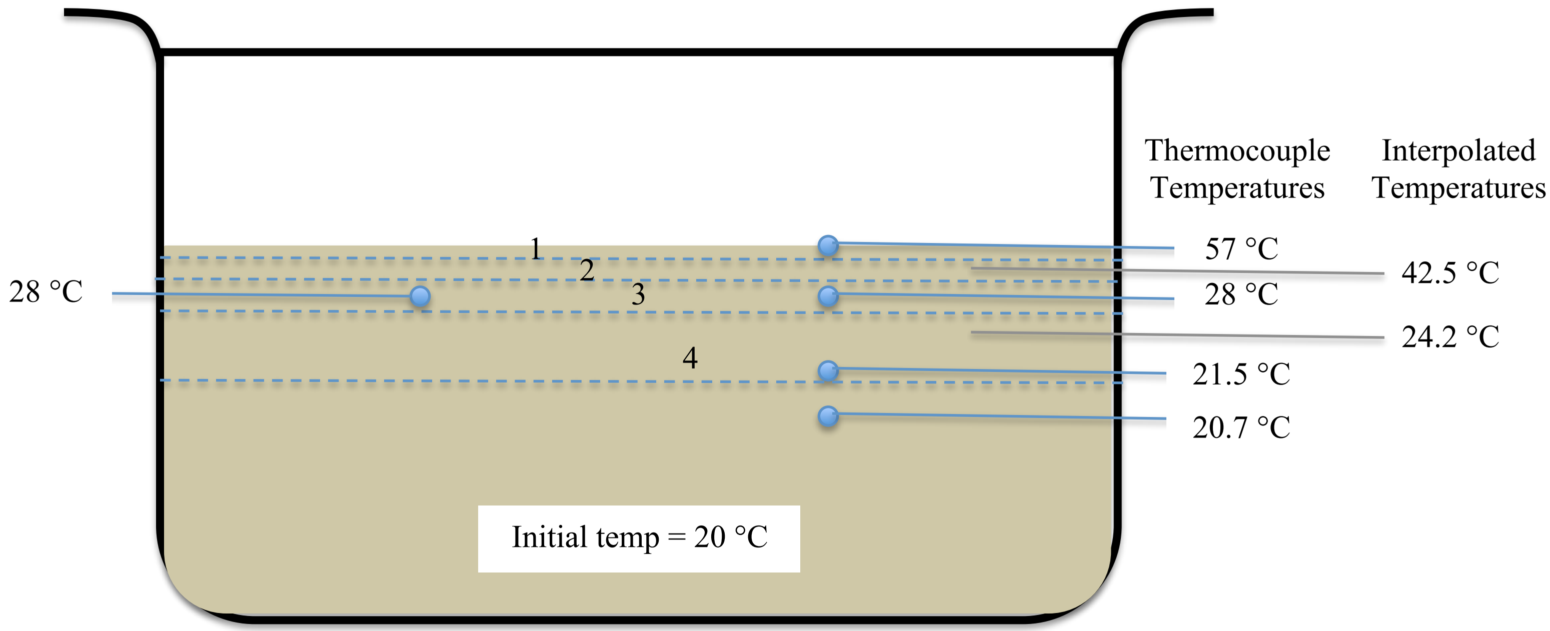
Soil Heating Results

- 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



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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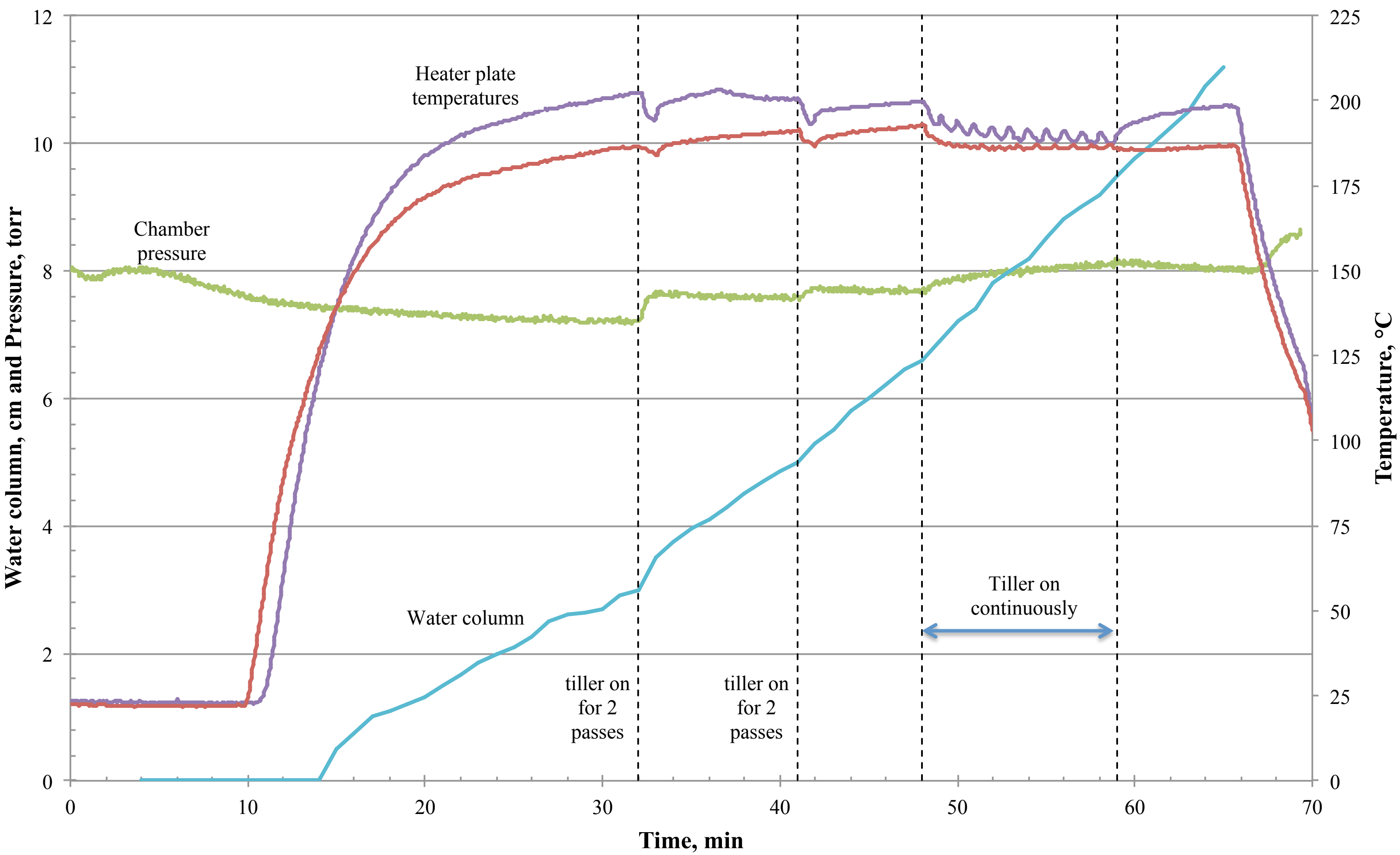
Water Extraction Results

- 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