Atmospheric Processing Module for Mars Propellant Production

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Outline

• Introduction
• Project Goals
• Design and Construction
• Testing
• Current Status
• NASA Plans for Mars ISRU
Introduction

- **ISRU** – In Situ Resource Utilization
  - **ISPP**: In Situ Propellant Production
  - Produce Mars Sample Return launch propellant
  - Demonstrate to reduce risk for human Mars missions

- **MARCO POLO** - Mars Atmosphere and Regolith COllector/PrOcessor for Lander Operations

- The Mars Atmospheric Processing Module (APM)
  - Mars CO₂ Freezer Subsystem
  - Sabatier (Methanation) Subsystem

- Collect, purify, and pressurize CO₂
- Convert CO₂ into methane (CH₄) and water with H₂
- Other modules mine regolith, extract water from regolith, purify the water, electrolyze it to H₂ and O₂, send the H₂ to the Sabatier Subsystem, and liquefy/store the CH₄ and O₂
What is MARCO POLO?

- **Mars Atmosphere and Regolith COLlector/PrOcessor for Lander Operations**
- First generation integrated Mars soil and atmospheric processing system with mission relevant direct current power
  - 10 KW Fuel Cell for 14 hrs of daytime operations
  - 1KW Fuel Cell for 10 hrs of night time operations
- Demonstrates closed loop power production via the combination of a fuel cell and electrolyzer.
  - The water we make and electrolyze during the day provides the consumables for the 1KW Fuel Cell that night
- Planned for remote and autonomous operations
Lander at Critical Design Review

Atmo Processing Module:
- CO2 capture from Mixed Mars atmosphere (KSC)
- Sabatier converts H2 and CO2 into Methane and water (JSC)

C&DH/PDU Module: (JSC)
- Central executive S/W
- Power distribution

Soil Processing Module:
- Soil Hopper handles 30kg (KSC)
- Soil dryer uses CO2 sweep gas and 500 deg C to extract water (JSC)

Liquefaction Module: (TBD)
- Common bulkhead tank for Methane and Oxygen liquid storage

Water Processing Module: (JSC)
- Currently can process 520g/hr of water (max 694 g/hr)

Water Cleanup Module: (KSC)
- Cleans water prior to electrolysis
- Provides clean water storage

Life Detection Drill:
- (ARC-Honeybee)
  - Replaces excavator mockup
  - Takes core samples
  - Provides some feed to Soil Dryer

1KW Fuel Cell and consumable storage (JSC & GRC)
- Using metal hydride for H2 storage due to available
- 1KW No Flow Through FC (GRC)
- 10KW FC not shown (JSC)

3m x 3m octagon lander deck
**APM Goals/Requirements**

- Collect and purify 88 g CO$_2$/hr (>99%)
  - From simulated Martian atmosphere
  - 10 mbar; 95% CO$_2$, 3% N$_2$, 2% Ar
- Supply 88 g CO$_2$/hr at 50 psia to the Sabatier reactor
- Convert CO$_2$ to 31.7 g CH$_4$/hr and 71.3 g H$_2$O/hr
- Operate autonomously for up to 14 hr/day
- Minimize mass and power
- Fit within specified area and volume
  - 9,000 cm$^2$ hexagon
  - 44 inches tall (112 cm, same as Water Processing Module)
- Support MARCO POLO production goals of 444 g CH$_4$/day and 1.77 kg O$_2$/day (50% of O$_2$) for a total of 2.22 kg propellant/day
- Sufficient for a Mars Sample Return Mission
Atmospheric Processing Module

- Sabatier Reactor
- Methane Dryer (Future)
- CO₂ ballast tanks not shown
- Chiller
- CO₂ Freezers
- Vacuum Pump
- Mixed Mars Gas Input
- Electrochemical Methane Separator
- [Replaced by Recycle Pump and Membrane Module]
Atmospheric Processing Operations

Ballast tank
- CO₂ freezer

Ballast tank
- CO₂ freezer

Sabatier Reactor (<600 deg C)
- 88 g/hr CO₂ @ 50 PSI
- 2 g/hr H₂
- 71.3 g/hr H₂O
- 31.7 g/hr CH₄
- 2 g/hr H₂

CH₄/H₂ Separator

Condenser
- H₂O
- CH₄
- H₂
- Water Cleanup Module

Electrolysis Stacks
- H₂O

Mars Mix

Water Processing Module

CH₄ Dryer

CH₄ storage

95% CO₂, 3% N₂, 2% Ar at 10.8 mbar
Mars Atmosphere
95% CO2, 3% N2, 2% Ar
~700 psig max

CO2 Freezer – Final Design

2 - Cryocoolers with Freezing Chambers
11 - Magnetic Latching Solenoid Valves
1 - Chiller with 4-Way Dual Solenoid Valve
1 - Vacuum Pump
1 - CO2 Pump
2 - CO2 Ballast Tanks
2 - Vacuum Back Pressure Regulators
3 - Pressure Relief Valves
1 - Flow Controller
1 - Flow Meter
3 - Thermocouples and 2 RTDs
3 - Pressure Transducers, etc.
CO\textsubscript{2} Freezer

Copper Cold Head

CO\textsubscript{2} Tanks

Chiller

Cryocoolers

Avionics
Sabatier Subsystem Design

To be added:
- Recycle Pump (Custom KNF N022 24 VDC)
- Air Products Membrane Module
Sabatier Subsystem

JSC Sabatier Reactor

Recycle Pump

Membrane Module (Cut-Away View)
Atmospheric Processing Module
Water Cleanup Module (KSC)

• Tested with Water Processing Module at JSC last summer
• Used to recycle fuel cell water from the MMSEV to $\text{H}_2$ and $\text{O}_2$
• MMSEV = Multi Mission Space Exploration Vehicle

Membrane separator not included in the final version
Lander and Soil Processing Module (KSC)

Van Townsend (KSC/ESC) with MARCO POLO lander and Soil Processing Module (under construction)

RASSOR (Regolith Advanced Surface Systems Operations Robot) will feed the hopper.
CO₂ Freezer Testing

- Avg. Capture Rate = 100.3 g/hr at 1.2 SLPM (1.4 hr test)
- Avg. Sublimation Rate = 93.8 g/hr (1.4 hr test)
- Avg. Capture Fraction = 76%
- Exceeds 88 g/hr requirement
- Better performance than test stand!

88 g/hr Requirement

△ % CO₂ Capture
● CO₂ Collection Rate, g/hr
◆ CO₂ Sublimation Rate in 1.4 hr, g/hr

Mars Atmosphere Simulant Flow Rate, SLPM
JSC Sabatier Testing

- JSC Testing was successful (>99% conversion at 4.5:1 H₂/CO₂ ratio)
- First three KSC tests overheated
  - >600°C
- One test did not overheat (top) at 250 sccm CO₂ vs. 747 sccm desired (1000 sccm H₂)
  - Duplicate run did overheat (middle)
- Twelve tests at various flow rates overheated
- Two tests with simulated recycle gases (N₂/H₂/CO₂ = 6.0/3.35/0.75 SLPM) was slower to overheat, but still did so (bottom)
- Decided to build redesigned Sabatier reactor
Current Status

- **CO₂ Freezer Subsystem essentially complete**
  - Fully automated and fluid system functional
  - Need replacement CO₂ pump to reach 100 psi for overnight storage capability (KNF NPK09 rocking piston pump leaks - normal for design)
  - Chiller being returned by vendor after inspection showed no defects

- **Sabatier Subsystem**
  - Fluid system automated and functional
  - New reactor being designed
    - Based on proprietary design by Pioneer Astronautics
  - Need to add recycle pump and membrane module
  - Testing needed to verify operation

- Plan integrated MARCO POLO testing in Swamp Works “Big Bin” regolith bin
  - Date TBD

- Testing will support Mars ISRU design studies

- Long Term Goal is to continue to refine the ISRU technologies for potential 2018 robotic Mars mission using a SpaceX ‘Red Dragon’ capsule as part of an Ames-led science effort
NASA Plans for Mars ISRU

- Mars 2020 Mission Science Definition Team Report (July 1, 2013):
  - “The highest priority HEOMD payload is the demonstration of CO₂ capture and dust size characterization for atmospheric ISRU” p. 63
  - “Collect atmospheric carbon dioxide. Analyze dust (size, shape, number) during CO₂ collection. Produce small quantities of oxygen and analyze its purity (option).” p. 61
  - “Reduces risk for human missions and possible Mars sample return” p. 61

<table>
<thead>
<tr>
<th>Instrument/Demo</th>
<th>Purpose</th>
<th>SKG Addressed</th>
<th>P-SAG Priority</th>
<th>HAT Priority</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ production from atmosphere</td>
<td>Collect atmospheric carbon dioxide. Analyze dust (size, shape, number) during CO₂ collection. Produce small quantities of oxygen and analyze its purity (option).</td>
<td>B6-1: Atm. ISRU B4-2: Dust properties</td>
<td>H</td>
<td>H</td>
<td>Reduces risk for human missions and possible Mars sample return</td>
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Table 5-4. Spacecraft resource requirements for candidate HEOMD Payloads

<table>
<thead>
<tr>
<th>Instrument/Demo</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
<th>Operational Concept</th>
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<tbody>
<tr>
<td>MEDLI+</td>
<td>15.1</td>
<td>10</td>
<td>Operates during EDL</td>
</tr>
<tr>
<td>Surface weather station</td>
<td>1.3</td>
<td>10</td>
<td>Sampling (approximately 24 times a day)</td>
</tr>
<tr>
<td>Atmospheric ISRU demo</td>
<td>10</td>
<td>30-60</td>
<td>Operate 7 to 8 hrs per sol, and as many sols as possible. Operate CO₂ capture and O₂ production on separate days to maximize production rate</td>
</tr>
<tr>
<td>- CO₂ capture + dust</td>
<td>20</td>
<td>100-150</td>
<td></td>
</tr>
<tr>
<td>- CO₂ capture + O₂ production</td>
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Future MARCO POLO Historic Marker?
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Any Questions?

Ultimate Destination - Mars