VAPoR Breadboard Development: First Pyrolysis Results

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What is VAPoR?

VAPoR:
Volatile Analysis by Pyrolysis of Regolith
suitcase sized pyrolysis mass spectrometer

keywords:
volatile, Moon, regolith, atmosphere, astrobiology, solid solar system bodies
Key Science Objectives

1) Determine the composition, abundance, spatial distribution, and source of lunar volatiles associated with polar hydrogen deposits.

2) Characterize the native lunar atmosphere at the poles.

3) Understand the processes by which terrestrial organics or volatiles are dispersed and/or destroyed on the Moon.

4) Evaluate the potential of the polar regolith for future in situ resource utilization (ISRU).

5) Identify potentially hazardous volatiles (e.g. radon)
Potential Sources of Lunar Volatiles

- **Earth**
  - (contamination, possible terrestrial meteorites)

- **Solar wind**
  - (implanted H, C, N, He, Ne)

- **Moon**
  - (radioactive decay, outgassing)

- **Comets and Asteroids**
  - (water-ice, organics?)

- **Interplanetary dust particles**
Lunar Atmospheric Composition Experiment (LACE)

Magnetic deflection mass spectrometer (1 to 110 amu)

Measured surface atmospheric composition during Apollo 17

Detected H₂, He, Ne, Ar and trace levels of CH₄, NH₃, H₂O and CO₂

Sources: chemical reactions with solar wind implanted ions, outgassing, and/or exchange with cold traps

LACE PI: John Hoffman

Surface regolith samples not analyzed by LACE
VAPoR is a Miniature Version of SAM

<table>
<thead>
<tr>
<th></th>
<th>VAPoR</th>
<th>SAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>7-15 kg</td>
<td>40 kg</td>
</tr>
<tr>
<td>Power</td>
<td>20-25 W</td>
<td>60-80 W</td>
</tr>
<tr>
<td>Data rate</td>
<td>1 kbps</td>
<td>&lt;100 kbps</td>
</tr>
<tr>
<td>Volume</td>
<td>19 dm$^3$</td>
<td>68 dm$^3$</td>
</tr>
</tbody>
</table>

| Sample Analysis at Mars (SAM) |

Sample Inlets

Atmospheric Inlet

Pyrolysis Unit

Volatile Analysis by Pyrolysis of Regolith (VAPoR)
ROSES-2007 NNH07ZDA001N-ASTID VAPoR PI: GLAVIN

Heated under vacuum from ambient to 1200°C at 4ºC/min (Fig. 3). This ASTID will not include a sample inlet tube since this component has already been developed and tested for the SAM.

The following sections will be addressed by this ASTID:

B.3. Proposed VAPoR Instrument Design

The system includes a solid sample inlet tube, a pyrolysis oven with 6 individually heated cups, an atmospheric inlet, an ion extractor optics, a vacuum housing, and a time-of-flight mass spectrometer.
### Instrument requirements

<table>
<thead>
<tr>
<th>Objective</th>
<th>Requirements</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C,H,O,N-Volatiles</strong></td>
<td>Measure D/H in water</td>
<td>~10‰ (per mil)</td>
</tr>
<tr>
<td></td>
<td>Measure $^{13}$C/$^{12}$C ratio in CO$_2$ from regolith</td>
<td>~5‰</td>
</tr>
<tr>
<td></td>
<td>Measure $^{16}$O/$^{18}$O in CO$_2$</td>
<td>5‰</td>
</tr>
<tr>
<td></td>
<td>Measure $^{14}$N/$^{15}$N in N$_2$</td>
<td>5‰</td>
</tr>
<tr>
<td><strong>Noble Gases</strong></td>
<td>Measure Ne abundance and isotopes</td>
<td>10‰</td>
</tr>
<tr>
<td></td>
<td>Measure Ar abundance and isotopes</td>
<td>5‰</td>
</tr>
<tr>
<td></td>
<td>Measure Kr and Xe abundance and isotopes</td>
<td>5-20‰</td>
</tr>
<tr>
<td><strong>Organics</strong></td>
<td>Detect volatile hydrocarbons and measure abundance at ppb to ppm level</td>
<td>Mass range: 1-250 amu, LOD: sub ppm</td>
</tr>
<tr>
<td></td>
<td>Measure $^{13}$C/$^{12}$C ratio of CO$_2$ from organics combustion</td>
<td>~5‰</td>
</tr>
<tr>
<td><strong>Resources (ISRU)</strong></td>
<td>Measure abundance of H$_2$O, H$_2$, CO$_2$, CO/N$_2$, SO$_2$ in atmosphere and regolith</td>
<td>~ 1 ppm</td>
</tr>
<tr>
<td></td>
<td>Measure He abundance</td>
<td>$^3$He/$^4$He (TBD)</td>
</tr>
<tr>
<td></td>
<td>Measure abundance of O$_2$</td>
<td>&gt;1200ºC, 5% low conductance leak</td>
</tr>
<tr>
<td></td>
<td>Measure reduced inorganic gases (e.g. H$_2$S)</td>
<td>&lt; 20 ppb</td>
</tr>
</tbody>
</table>
**Vacuum Pyrolysis**

Highly efficient way to extract volatiles from regolith

<table>
<thead>
<tr>
<th>Species</th>
<th>Temperature Range(s) [°C]</th>
<th>Species</th>
<th>Temperature Range(s) [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volatile s</strong></td>
<td></td>
<td><strong>Sulfurous Species</strong></td>
<td></td>
</tr>
<tr>
<td>H₂</td>
<td>200-600³</td>
<td>CO</td>
<td>600-1300²</td>
</tr>
<tr>
<td>He</td>
<td>200-500⁴, -800⁵</td>
<td>CO₂</td>
<td>100-1200³</td>
</tr>
<tr>
<td>H₂O</td>
<td>0-1200¹, -800³</td>
<td>NO</td>
<td>200-700¹</td>
</tr>
<tr>
<td>N₂</td>
<td>600-1200³</td>
<td>NH₃</td>
<td>100-850³</td>
</tr>
<tr>
<td><strong>Noble Gases</strong></td>
<td></td>
<td><strong>Organics &amp; Contaminants</strong></td>
<td></td>
</tr>
<tr>
<td>Ne</td>
<td>300-1250³</td>
<td>CH₄</td>
<td>300-1000³</td>
</tr>
<tr>
<td>Ar</td>
<td>300-1250³, -1700⁷,⁸</td>
<td>C₆H₆</td>
<td>300-1000³</td>
</tr>
<tr>
<td>Rn</td>
<td></td>
<td>KREEP Volatiles</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>900-1200²</td>
<td>Na</td>
<td>800-1200²</td>
</tr>
<tr>
<td><strong>Pyrolysis Reaction Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>1100-1400²</td>
<td>O₂</td>
<td>1100-1300²</td>
</tr>
</tbody>
</table>

adapted from Gibson & Johnson, 1971

2. de Maria et al., 1971.
3. Holland et al., 1972.
VAPoR Breadboard - first tests

4 samples:
- JSC1A (current standard)
- GSC1 (Va, Paul Lowman)
- Murchison meteorite
- Apollo 16 - 64801.53

2 temperature profiles:
- Constant ramp:
  4 °C /min to 1200 °C
- Stepped:
  20 °C /min for 5 min, 15 min constant, to 1200 °C
Ramped heating - 800 °C

5 °C per minute to 1200 °C
Ramped heating - evolved gases
Stepped heating - evolved gases

Fig. 1. Gas release pattern for Apollo 11 soil 10086,16. Sample weight 242.94 mg. Heating rate 4°C/minute.

Fig. 2. Gas release pattern for Apollo 12 soil 12023,9. Sample weight 208.50 mg. Heating rate 4°C/minute.
Future Work

*) minimal sample size
*) power necessary for heating sample to 1200ºC
*) different pyrolysis temperature profiles
*) optimal oven configuration
*) condensation module
*) SMS
*) TOF-MS
Acknowledgments

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