Extraction Techniques - Oxygen

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Lecture 13

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There are Obvious Needs for Oxygen in a Lunar Base Scenario

- Tonnes of LOX Make-up for Life Support To Lunar Surface From LEO Per 10 Person-Years Per Tonne of Payload
Lunar Soil Composition

- Oxygen: 42%
- Silicon: 21%
- Iron: 13%
- Calcium: 8%
- Aluminum: 7%
- Magnesium: 6%
- Other: 3%
<table>
<thead>
<tr>
<th></th>
<th>Solid/Gas Interaction</th>
<th>Silicate/Oxide Melt</th>
<th>Pyrolysis</th>
<th>Aqueous Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Most Favored</strong></td>
<td>Ilmenite Reduction With H₂</td>
<td>Molten Silicate Electrolysis</td>
<td>Vapor Phase Reduction</td>
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<td></td>
<td>Glass Reduction With H₂</td>
<td>Fluxed Silicate Electrolysis</td>
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<tr>
<td><strong>Possible</strong></td>
<td>Ilmenite Reduction C/CO</td>
<td>Caustic Dissolution &amp; Electrolysis</td>
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<td></td>
<td>Ilmenite Reduction CH₄</td>
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<td></td>
<td>Plasma Reduction Cl₂</td>
<td>Carbothermal Reduction</td>
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<td></td>
<td>Reduction H₂S</td>
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<td><strong>Long Shot</strong></td>
<td>Carbochlorination</td>
<td>Magma Partial Oxidation</td>
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<td>HF, H₂SO₄</td>
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<tr>
<td></td>
<td>Extraction with F₂</td>
<td>Li or Na Reduction of Ilmenite</td>
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</tr>
</tbody>
</table>
The Feedstocks for Oxygen Production Can Come From Different Locations and Host material

Pyroclastics
- Glass reduction with H₂
- Reduction with H₂S
- Extraction with F₂
- Carbochlorination
- Cl₂ Plasma reduction

High Titanium MARE
- Ilmenite reduction with H₂
- Ilmenite reduction with C/CO
- Cl₂ Plasma reduction of ilmenite
- Li or Na reduction of ilmenite
- Magma partial oxidation

MARE
- H₂SO₄ acid dissolution
- Plasma reduction of ilmenite

Highlands
- Molten Silicate Electrolysis
- Fluxed Silicate Electrolysis
- Caustic dissolution & electrolysis
- Carbothermic reduction
- Vapor phase reduction
- Ion plasma separation
- HF acid dissolution
It is Hardest to Extract Oxygen from Ca and Easiest from Fe

The Use of Hydrogen to Reduce Ilmenite for the Production of Oxygen Was First Proposed by Williams in 1979

- Ideal formula-FeTiO₃
- Actual Ilmenite composition-Apollo-12
  
<table>
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<tr>
<th>Component</th>
<th>Composition</th>
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</thead>
<tbody>
<tr>
<td>TiO₂</td>
<td>52-54%</td>
</tr>
<tr>
<td>FeO</td>
<td>45%</td>
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<tr>
<td>Al₂O₃</td>
<td>0.3-0.4%</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.2-0.4%</td>
</tr>
<tr>
<td>MgO</td>
<td>0.1-0.4%</td>
</tr>
<tr>
<td>MnO</td>
<td>0.3-0.4%</td>
</tr>
</tbody>
</table>

(Can be beneficiated from Mare Basalt rocks and Mare soils)

**Reduction Reaction**

\[ \text{FeTiO}_3 + \text{H}_2 \rightleftharpoons \text{Fe} + \text{TiO}_2 + \text{H}_2\text{O} \]
Carbotek, Inc. has Patented a Hydrogen-Reduction Technique Using a Fluidized Bed
Patent # 4,938,946, July 3, 1990

Simplified Schematic of the Carbotek Process
The Yield of Oxygen from Lunar Soils in Contact with High Temperature Hydrogen is Strongly Dependent on the Initial Iron Content

After McKay and Allen, AIAA 96-0488, 1996
17 different samples each subjected to 1,050 °E for 3 hrs
Lunar Glass May be One of the Best Sources of Oxygen

- Some glass, particularly from the mare regions, can contain FeO up to 20 wt%
- Thermodynamically, the glass is considerably more unstable than the silicate materials from which it is formed.

\[ \text{FeO (glass)} + \text{H}_2 \rightleftharpoons \text{Fe}^0 + \text{H}_2\text{O} \]

\[ 2\text{H}_2\text{O} \rightleftharpoons 2\text{H}_2 + \text{O}_2 \]

- There are parts of the Moon that have blankets of pyroclastic volcanic glass 1 to 4 meters deep

The Release of Oxygen From Lunar Volcanic Glass 74220 is Quite Rapid and Temperature Dependent

Carbon Compounds Can Also be Used to Extract Oxygen from Lunar Materials

• **Carbon Monoxide Cycle**
  - \( \text{FeTiO}_3 + \text{CO} \rightleftharpoons \text{Fe} + \text{TiO}_2 + \text{CO}_2 \)
  - \( 2 \text{ CO}_2 \rightleftharpoons 2 \text{ CO} + \text{O}_2 \)

• **Methane Cycle**
  - \( \text{FeTiO}_3 + \text{CH}_4 \rightleftharpoons \text{Fe} + \text{TiO}_2 + \text{CO} + 2\text{H}_2 \)
  - \( 2 \text{ CO} + 6\text{H}_2 \rightleftharpoons 2 \text{ CH}_4 + 2 \text{ H}_2\text{O} \)

  • \( 2 \text{ H}_2\text{O} \rightleftharpoons 2\text{H}_2 + \text{O}_2 \)
Oxygen Can Be Extracted From Molten Silicates

- Advantages: No moving parts, one step oxygen production
- Disadvantages: High temperatures, 1300-1700 ℃, corrosion

Many Other Useful Products Can be Derived From the Molten Silicate Process

The Fluxed Molten Silicate Process Can Produce Oxygen More Efficiently at Lower Temperatures

Reduction by Al-1,000°C

Al & Silicate Electrolysis

Al Electrolysis

Exhaustive Al Electrolysis

Oxygen

Ca Electolysis

CaO

Al
Vapor Phase Reduction Utilizes Temperatures From 2,000 to 10,000 °K

The Metals in Lunar Material Ionize at Lower Temperatures Than Oxygen

After W. F. Carroll, JPL-83-36 (1983)
Plasma Separation Processes Rely on the Fact That Metals Remain Ionized at Lower Temperatures Than Non-Metals

After W. H. Steurer, JPL Pub. 82-41 (1982)
The Majority of Lunar Oxygen Producing Schemes Require Between 20-50 kWh per kg of Oxygen Collected

After L. W. Mason, p. 1139, in Space 92, ASCE (1992)
The Ilmenite-Based Processes Require the Highest Mass Throughput and Power Consumption

Basis-1,000 tonnes of Oxygen/year

After L. W. Mason, p. 1139, in Space 92, ASCE (1992)
Conclusions

• There are many ways to produce Oxygen on the lunar surface
• Hydrogen could play an important role in oxygen production
• Most of the methods could be tested on the Earth
References


