MARS Return Fuel Production Using Table Top Electrolysis & Sabatier Reaction

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Background

- Over 500,000 gallons of fuel required for the space shuttle Orbiter with an associated average cost of $450 million per mission: NASA [1]

- Challenges to a possible future manned mission to Mars: how to carry such a large quantity of return fuel to the Red Planet?

- Possibility: producing methane using local Martian resources.

- In 1997, images were released by NASA showing methane fuel propelled a prototype rocket.
Introduction

- **Sabatier reaction**: Production of methane (CH$_4$) and water (H$_2$O) using carbon dioxide (CO$_2$) and hydrogen (H$_2$) at high temperature and pressure along with a nickel or ruthenium catalyst. Abundance of CO$_2$ in the Martian atmosphere (95%). [9]

- Transportation cost. Hydrogen averages about 32% the cost of methane.

- Hydrogen vs. Methane: Overall mass of the spacecraft less by 20% to 45%. [6]

- Produce more hydrogen in the Mars using electrolysis.

- Solar power to power Sabatier and to run electrolysis.

- Water from Sabatier can be fed back into electrolysis to produce more H$_2$
Materials and Methods

1. **Table-Top Prototype: Sabatier Reactor**
   - 18” x 18” x 18” and 20lbs.
   - Chamber with Ruthenium (Ru) catalyst
   - Associated valves and piping to carry gases to and from
   - Catalyst Prep (Regeneration)
     \[ \text{He} (g) + \text{H}_2 (g) + \text{RuO} (s) \rightarrow \text{H}_2\text{O} (g) + \text{Ru} (s) + \text{He} (g) \]
     \[ 2\text{H}_2\text{O} (g) \rightarrow 2\text{H}_2\text{O} (l) \]
   - Flow rates = 4:1 \((\text{H}_2:\text{CO}_2)\)
     \[ [800\text{ml/min}: 200\text{ml/min}] \]
   - Reaction initiated by heat of the thermocouples.
   - PM controller: to maintain temperature at 375°C-400°C
   - Insulation!!
Materials and Methods

2. Electrolysis Apparatus:

- Initially Used: A Hoffman
- Our main Electrolysis Apparatus: 32-L Tank
  - The electrodes were rectangular, 1.01 in$^2$ and 1.18 in$^2$ in area,
  - unit frame (51 x 25 x 56 cm)
  - two 7.62 x 15.2 cm perforated stainless steel electrodes
  - Two cylindrical 14 cm diameter gas collecting acrylic tubes.
Materials and Methods

- Selection of an electrolyte: Sodium Hydroxide
  
  - Very low disassociation constant (pKb) value: the OH\(^-\) molecule will dissociate almost completely.
  
  - Inorganic base, NaOH, at 1 M (mol/L) is a cheap but strong base.

### Table 1 - Dissociation constants for various bases

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>pKb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>NH(_3)</td>
<td>4.75</td>
</tr>
<tr>
<td>Calcium Hydroxide</td>
<td>Ca(OH)(_2)</td>
<td>2.43</td>
</tr>
<tr>
<td>Lithium Hydroxide</td>
<td>LiOH</td>
<td>-0.36</td>
</tr>
<tr>
<td>Methylamine</td>
<td>CH(_3)NH(_2)</td>
<td>3.36</td>
</tr>
<tr>
<td>Ethyamine</td>
<td>C(_2)H(_5)NH(_2)</td>
<td>3.25</td>
</tr>
<tr>
<td>Potassium Hydroxide</td>
<td>KOH</td>
<td>0.5</td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>NaOH</td>
<td>0.2</td>
</tr>
<tr>
<td>Aniline</td>
<td>C(_6)H(_5)NH(_2)</td>
<td>9.4</td>
</tr>
</tbody>
</table>

A descriptive analysis of the various electrolytes would be to present each substance's associated cost in terms of dollars per mole. As we can see below, the price of one mol of NaOH is \(\frac{1}{4}\) of the price of one mol of LiOH.

1 kg LiOH x \(\frac{1000 \text{ g}}{1 \text{ mol LiOH}}\) x 23.93 g = 41.7885 mols LiOH \(\Rightarrow \frac{\$12.20}{\text{mol LiOH}}\)

1 kg NaOH x \(\frac{1000 \text{ g}}{1 \text{ mol NaOH}}\) x 40.0 g = 25 mols NaOH \(\Rightarrow \frac{\$3.42}{\text{mol NaOH}}\)
Materials and Methods

- Agitator: to maintain uniform concentration of solution in the tank.

- Displacement pump: for constant rate of H₂ into fed into Sabatier.
  - (1-200 rpm)
  - 1 rpm = 0.47 mL
Materials and Methods

3. **Solar Power**
   - The Solar kit by Chicago Electric Power Systems
   - Two 24V batteries with max. output: 15 W (14.5 V)
Results

1. Saba1er
   Trial
   Run
   Analysis

- Volume of H2O(l) collected = 10.2ml
- Time = 77.5 minutes
- Cryogenic separation: to separate the gases and get the methane in the liquid form.
- CH4 confirmed:
  i. Combustion
  ii. GC-MS Analysis
Results

2. Electrolysis Trial Run Analysis

- 2.0 molar solution of NaOH for optimal production of O₂ and H₂

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Time (min)</th>
<th>Height (cm)</th>
<th>Moles of H₂</th>
<th>Expected Volume (L)</th>
<th>Measured Volume (L)</th>
<th>With or Without Agitator</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.955</td>
<td>72</td>
<td></td>
<td>0.0438</td>
<td>1.2744</td>
<td>1.3300</td>
<td>With (12V)</td>
<td>5%</td>
</tr>
<tr>
<td>1.955</td>
<td>80</td>
<td></td>
<td>0.0486</td>
<td>1.4160</td>
<td>1.4624</td>
<td>With (12V)</td>
<td>3%</td>
</tr>
<tr>
<td>2.022</td>
<td>60</td>
<td></td>
<td>0.0377</td>
<td>1.0984</td>
<td>1.1545</td>
<td>Without</td>
<td>5%</td>
</tr>
<tr>
<td>2.106</td>
<td>61</td>
<td></td>
<td>0.0399</td>
<td>1.1631</td>
<td>1.1699</td>
<td>With (6V)</td>
<td>1%</td>
</tr>
</tbody>
</table>

Production of Hydrogen (g) Vs. Time

\[ y = 0.0187x + 0.0167 \]

\[ R^2 = 0.9979 \]

- mL of hydrogen gas per time (min)
- Linear (mL of hydrogen gas per time (min))
Composite Run

• April 20, 2012 (3pm to 7pm)

• Successfully ran a composite run

• H₂ gas produced from Solar Electrolysis fed into Saba1er and fed into the Saba1er with steady flow rate using the pump.

• Significant amount of water and methane collected.

• Amount of Methane couldn’t be quantified due to an unexpected accident!
Conclusion

✓ Silicate tanks are not NaOH resistant.

✓ Insulation of reaction chamber minimizes power requirement for the Sabatier (possibly could resulting near-self-sustaining reaction process)

✓ Successfully created a fully-functional Sabatier Reactor that produces methane using $H_2$ from solar electrolysis.
Further research

• Workable design for resupplying water from Sabatier into the Electrolysis tank

• More complete runs required to collect enough data to optimize the reaction process to maximize methane production.

• Measure the amount of energy flow through the system, starting at the solar panels up to the production of methane.

• Devise the sizes of Sabatier and electrolysis chamber, and the amount of energy required to produce enough methane for return trip from Mars.