Hybrid Propulsion In-Situ Resource Utilization Test Facility Results

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Motivation

- What if we could fill our propellant tanks at OR on the way to Mars
Motivation, cont.

- What are the potential challenges for an ISRU MAV?
  - Throttling – hybrid performance at very low oxidizer mass flux rates
  - Packaging – how compact can the hybrid system be?
  - Performance with “ISRU” oxidizer – oxidizer could potentially be $O_2$ mixed with $CO_2$
Motivation, cont.

• What are the potential challenges for an ISRU MAV?
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Other objectives are “in process.”
Test Set Up – JPL Hybrid Lab

- N₂
- O₂
- Main Ox Valve
- ΔP
- Combustion Chamber
- Venturi
- Orifice
Fuel Properties

- There are many types of “paraffin wax,” so several chemical analyses were conducted to give a baseline to the fuel being discussed here.
- Looking beyond the current tests, two analyses were completed to inform IRSU missions:
  - Glass transition temperature (for low temperature conditions, e.g. Mars)
  - Volatiles analysis
Chemistry Analysis

Volatiles

- Why is thermogravimetric analysis necessary?
  - Volatiles will not be allowed in space environment
  - To enable other tests (ensure hardware isn’t damaged)

- No appreciable loss of volatiles
  - Thermal decomposition occurs at about 288 C for both samples
  - Mass loss of only 0.035% by 200 C

![Graph showing weight change vs. temperature for Neat Paraffin and Blackened Paraffin]
Chemistry Analysis
Phase Transition

- Differential Scanning Calorimetry (DSC) – Phase transition is indicated by a major change in the amount of heat required to keep the sample at the same temperature as a reference.
- Melt temperature of neat paraffin is 44.3 °C and blackened paraffin is 49.5 °C
  - The blackened paraffin was made by adding dye to the same batch of neat paraffin
- The melt temperature is taken as the onset for metals and organics (like paraffin) as opposed to the peak, which can be used for polymers.
Chemistry Analysis
Phase Transition & Coeff. of Thermal Expansion

- Thermomechanical Analysis
  - The melt point is confirmed by the peak of the curve (consistent with the DSC results)
  - Glass Transition cannot be determined, but likely a weak transition around -90 C

![Graphs showing dimension change vs temperature for Neat Paraffin and Blackened Paraffin](image-url)
## Hotfire Results

### Summary

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Test Date</th>
<th>Maximum Chamber Pressure ($P_c$, psia)</th>
<th>Nozzle</th>
<th>Oxidizer Mass Flow (g/s)</th>
<th>Oxidizer Mass Flux Range ($G_{o_r}$, g/cm²s)</th>
<th>Mass of Fuel Burned (g)</th>
<th>Burn Time (s)</th>
<th>O/F</th>
<th>Average* Regression Rate (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3/18/2015</td>
<td>122</td>
<td>Small</td>
<td>43</td>
<td>14.3-3.8</td>
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<td>13.6-7.0</td>
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<td>38</td>
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<td>1.8</td>
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<tr>
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<td>114</td>
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</tbody>
</table>
Supercritical Test
Test 5
Test Results
Supercritical Pressure

- Chugging – low oxidizer mass flux
- Higher frequency instability and longer ignition time believed to be due to secondary flow choking

Test 5, 43 g/s
Test 8, 45 g/s
Supercritical Test
Test Results
Supercritical Pressure

- Higher frequency instability is removed (single choke point)
- Slightly higher oxidizer mass flow (55 g/s)
- Chugging begins at oxidizer mass flux of about 7 g/cm²s
Subcritical Pressure Test
Test Results
Subcritical Pressure

- Long start up and early shut down

Test 6

Test 7
Subcritical Results
Flame Holding Instability

- Flame shedding out of chamber
Conclusions

• During deep throttling the following can be expected
  – Chuffing instabilities (low frequency) – still working to resolve limit at which this occurs
  – Higher fuel regression rate (up to 3 mm/s)
    • Thick liquid layer (HOWEVER, also lower melt temperature for this particular paraffin fuel)
  – Potential to eject the flame in the subcritical regime

• Very weak glass transition around -90 C.