Total Hydrocarbon Content (THC) testing in Liquid Oxygen (LOX)

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THC testing in LOX

• Background
• Test Facility
• Test Hardware
• Test Results
• Conclusions
THC testing in LOX

• Background
  • Limits on THC levels in LOX are based on customer requirements
  • THC levels in LOX delivered to SSC
    • Vendor sample analysis not in agreement with SSC sample analysis
      • SSC analysis showed HIGHER THC values compared to vendor reported data
      • Increased lab analysis of LOX; increased SSC costs
  • THC levels in storage/run tanks
    • Increased over time
    • Consequences
      • LOX losses due to dumping of out of spec commodity
      • Increased commodity costs due to additional sample analysis
      • Program testing delays
  • Mitigation opportunities
THC Testing in LOX

SSC E1 Test Stand – LOX Storage Tank
THC Testing in LOX

SSC Test Stand LOX Run Tank

June 30, 2015  CEC Conference, Tucson, AZ
Flanged Interface

Dip Tube Valving

THC Testing in LOX
<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Parahydrogen</th>
<th>Nitrogen</th>
<th>Oxygen</th>
<th>Methane</th>
<th>Krypton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal boiling point (NBP)</td>
<td>°F</td>
<td>-423.18</td>
<td>-320.43</td>
<td>-297.33</td>
<td>-258.67</td>
<td>-244.16</td>
</tr>
<tr>
<td>Density</td>
<td>lbm/ft³</td>
<td>4.42</td>
<td>50.32</td>
<td>71.24</td>
<td>26.37</td>
<td>150.86</td>
</tr>
<tr>
<td>Heat of vaporization</td>
<td>Btu/lbm</td>
<td>191.89</td>
<td>85.69</td>
<td>91.66</td>
<td>219.76</td>
<td>46.06</td>
</tr>
<tr>
<td>Specific Heat, Cₚ</td>
<td>Btu/lbm-°R</td>
<td>2.325</td>
<td>0.488</td>
<td>0.406</td>
<td>0.832</td>
<td>0.124</td>
</tr>
<tr>
<td>Viscosity</td>
<td>lbm/ft-sec</td>
<td>8.957E-06</td>
<td>1.079E-04</td>
<td>1.308E-04</td>
<td>7.849E-05</td>
<td>2.742E-04</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>Btu/hr-ft-°F</td>
<td>0.05981</td>
<td>0.0837</td>
<td>0.08717</td>
<td>0.10623</td>
<td>0.06354</td>
</tr>
<tr>
<td>Critical temperature</td>
<td>°F</td>
<td>-400.38</td>
<td>-232.52</td>
<td>-181.42</td>
<td>-116.65</td>
<td>-82.61</td>
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<tr>
<td>Critical pressure</td>
<td>psia</td>
<td>186.49</td>
<td>492.52</td>
<td>731.43</td>
<td>667.06</td>
<td>801.33</td>
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<tr>
<td>Temperature at triple point</td>
<td>°F</td>
<td>-434.82</td>
<td>-346.00</td>
<td>-361.82</td>
<td>-296.42</td>
<td>-251.28</td>
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<tr>
<td>Pressure at triple point</td>
<td>psia</td>
<td>1.02</td>
<td>1.82</td>
<td>0.02</td>
<td>1.70</td>
<td>10.67</td>
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</table>

SSC Gas & Materials Science
# THC Data (LOX Run Tank)

## THC Values (ppm) - ALL VALUES

<table>
<thead>
<tr>
<th>Sample Date</th>
<th>Elapsed Time From Initial Fill (Days)</th>
<th>DT 1 (85% Full)</th>
<th>DT 2 (70% Full)</th>
<th>DT 3 (55% Full)</th>
<th>DT 4 (40% Full)</th>
<th>DT 5 (25% Full)</th>
<th>DT 6 (15% Full)</th>
<th>DT 7 (5% Full)</th>
<th>Tank Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>03/12/15</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/16/15</td>
<td>4</td>
<td>39.3</td>
<td>38.5</td>
<td>39</td>
<td>40.6</td>
<td>39.1</td>
<td>39.2</td>
<td>37.9</td>
<td>43.9</td>
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<td>03/23/15</td>
<td>11</td>
<td>13.9</td>
<td>40.1</td>
<td>43.1</td>
<td>41.3</td>
<td>40.9</td>
<td>41.1</td>
<td>40.3</td>
<td>41.6</td>
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<td>03/31/15</td>
<td>19</td>
<td>14.97</td>
<td>33.12</td>
<td>39.3</td>
<td>41.7</td>
<td>40</td>
<td>42.2</td>
<td>40.1</td>
<td>52.4</td>
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<tr>
<td>04/06/15</td>
<td>25</td>
<td>15.9</td>
<td>32.7</td>
<td>44.9</td>
<td>43.1</td>
<td>43.7</td>
<td>43.8</td>
<td>43.7</td>
<td>50.2</td>
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<tr>
<td>04/13/15</td>
<td>32</td>
<td>17</td>
<td>34.1</td>
<td>16.8</td>
<td>52.3</td>
<td>48.7</td>
<td>48.9</td>
<td>50</td>
<td>55.5</td>
</tr>
<tr>
<td>04/21/15</td>
<td>40</td>
<td>18.9</td>
<td>27.7</td>
<td>19</td>
<td>52.7</td>
<td>52.8</td>
<td>54.4</td>
<td>52.8</td>
<td>65.5</td>
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<tr>
<td>04/27/15</td>
<td>46</td>
<td>20.8</td>
<td>27.1</td>
<td>20.8</td>
<td>20.6</td>
<td>64.2</td>
<td>66.8</td>
<td>61.7</td>
<td>74.4</td>
</tr>
<tr>
<td>05/04/15</td>
<td>53</td>
<td>23.2</td>
<td>26.3</td>
<td>23.4</td>
<td>23.4</td>
<td>69.6</td>
<td>71.2</td>
<td>73.7</td>
<td>88.7</td>
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<tr>
<td>05/11/15</td>
<td>60</td>
<td>28.3</td>
<td>34.3</td>
<td>28.1</td>
<td>28</td>
<td>28.2</td>
<td>95.3</td>
<td>92.3</td>
<td>120</td>
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<td>05/18/15</td>
<td>67</td>
<td>36.7</td>
<td>42.6</td>
<td>36.3</td>
<td>35.6</td>
<td>36.3</td>
<td>36.7</td>
<td>132.4</td>
<td>135.1</td>
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<tr>
<td>05/26/15</td>
<td>75</td>
<td>66.9</td>
<td>68.64</td>
<td>65.59</td>
<td>67.46</td>
<td>71.3</td>
<td>72.46</td>
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<td></td>
</tr>
<tr>
<td>05/29/15</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>133</td>
<td>699</td>
</tr>
</tbody>
</table>

**NOTE:** Values in Yellow are from Vapor samples
THC Testing in LOX

LOX Run Tank (Dip Tube THC Values)
(Tank Filled: 03/12/15)

- DT 1 (Tank 85% Full)
- DT 2 (Tank 70% Full)
- DT 3 (Tank 55% Full)
- DT 4 (Tank 40% Full)
- DT 5 (Tank 25% Full)
- DT 6 (Tank 15% Full)
- DT 7 (Tank 5% Full)
- Tank Bottom

LIQUID VALUES ONLY

Days (Post Fill)

( % Tank Fill)
LOX Run Tank (Dip Tube THC Values)  
(Tank Filled: 03/12/15)

- DT 1 (Tank 85% Full)
- DT 2 (Tank 70% Full)
- DT 3 (Tank 55% Full)
- DT 4 (Tank 40% Full)
- DT 5 (Tank 25% Full)
- DT 6 (Tank 15% Full)
- DT 7 (Tank 5% Full)
- Tank Bottom

Day 78: Tank 5% Level Melon Sample

THC (ppm)

Days (Post Fill)

( % Tank Fill)
THC Testing in LOX

LOX Run Tank
THC & CH4 Analysis

CH4 values not available; analyzer out of service
THC Testing in LOX

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THC Testing in LOX

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Mitigation of THC values

- Dilution method developed
- Based on simple chemistry of solutions
- Does not account for potential transfer losses or boil-off

<table>
<thead>
<tr>
<th>Initial Volume (gallons)</th>
<th>Initial Volume THC (ppm)</th>
<th>Added Volume (gallons)</th>
<th>Added Volume THC (ppm)</th>
<th>Final Volume (gallons)</th>
<th>Final Volume THC (ppm) [PREDICTED]</th>
<th>Final Volume THC (ppm)</th>
<th>% Diff (Predicted vs Measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank 1 (Horizontal)</td>
<td>9800</td>
<td>55.6</td>
<td>12300</td>
<td>18</td>
<td>22100</td>
<td>34.1</td>
<td>34.7</td>
</tr>
<tr>
<td>Tank 2 (Horizontal)</td>
<td>35400</td>
<td>112.4</td>
<td>12200</td>
<td>57.1</td>
<td>47600</td>
<td>101.7</td>
<td>99</td>
</tr>
</tbody>
</table>
THC testing in LOX

• SUMMARY
  • THC values increase over time in tanks due to boil-off
  • Stratification of THC in tanks may be present
    • May occur when tank volume is less than 50%
  • Mitigations
    • Work with vendor to consistently obtain LOX with lower THC
    • Dumping of some LOX from tanks and/or dilution with low THC LOX
    • Using LOX with a high THC value to chill run lines followed by tank dilution with low THC LOX
  • Modeling of THC rise in tanks and projected THC levels over time can assist engine test programs
  • Replicate testing of LOX Run Tank in progress
Acknowledgements

• Stennis Space Center
  • Bartt Hebert for support and guidance
  • LOX Test Stand Personnel (Rosa Obregon, Skip Roberts, et al)
  • Gas & Materials Science Laboratory Personnel (H.R. Ross, et al)
  • LOX Sample personnel
  • Steve Taylor, Phil Kopfnger, Billy Davis

• Kennedy Space Center
  • Barry Meneghelli
  • Eric Dirschka
  • Jared Sass
  • Claire Offer
Backup Information
• LOX temperature at the normal boiling point (NBP) is -297.33°F and is lower than the methane fusion temperature of -296.38°F at 14.7 psia; hence methane may be in the solid state when LOX is at the NBP. Also, Methane NBP = -259°F so LOX will boil first.
Cosmodyne TYPE TTU-131 Cryogenic Sampler