Stennis Space Center (SSC) LOX Hydrocarbon Issue

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Background

- LOX Vendor is required to provide a Certificate of Analysis with each delivered LOX Trailer:
  - Purity
  - Moisture
  - Total Hydrocarbon Content (THC)

- Recent SSC samples of LOX Barges and Test Stand run tanks indicate elevated Total Hydrocarbon Content (THC): Methane
  - Procurement (per MIL Spec 25508) and Site Limit (per MSFC 3535) THC = 50 PPM Max
  - Customer Limit: J-2X, RS-68, AJ-26, SLS Core Stage THC = 75 PPM Max
  - Barges sampled as high as 63 PPM and E1 run tank as high as 103 PPM
THC Analyses SSC LOX Barges
CY 2010 thru Jul 29, 2013

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Samples</th>
<th>Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>34</td>
<td>1</td>
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<tr>
<td>2011</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>2012</td>
<td>47</td>
<td>6</td>
</tr>
<tr>
<td>2013</td>
<td>42</td>
<td>16</td>
</tr>
</tbody>
</table>

Limit = 50 PPM

THC Data with Trend Line (Solid Black Line)
LOX Hydrocarbon Issue

E1 LOX Run Tank THC

Customer Limit = 75 PPM
Vendor Certifications: LOX Trailer THC
Contract Start (July, 2009) to Present

Total Hydrocarbon Content (PPM)

Number of Trailers

<<Mid CY12: Began Low Readings

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<<Mid CY12: Began Low Readings
P-T Diagram for Methane and Oxygen

- THC concentration increase due to Oxygen boiloff is documented in:
  - Study of Liquid Oxygen Contamination, R. H. Foster, Air Products and Chemicals, 1961

- 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.
Multiple Methane Samples of LOX Tank During Boiloff
(Factor of ~8 decrease in Volume = Factor of ~3 Increase in CH4)
(From 1961 Air Products Report)

17 PPM
11000 Gallons

45 PPM
1400 Gallons
E1 LP LOX Run Tank (11,500 Gallon)
Total Hydrocarbon Content (THC)
Stennis Space Center

LOX Hydrocarbon Issue

Sampling

- Initial SSC sampling of 48 vendor delivered trailers indicated THC consistently above vendor provided certification:
  - SSC samples of trailers indicated ~42 PPM average, Max = 59.5 PPM (3 trailers > 50 PPM Max Allowed)
  - Vendor Certifications indicated ~ 27 PPM, Max = 39 PPM, Multiple identical readings

- After discussions with vendor, an internal audit was performed at the LOX production plant in mid July, 2013.
  - Also, site audit at vendor performed by NASA KSC/SSC on 8/20/13.
    - Found issues with sampling:
      - No notification for THC Analyzer off line
      - Calibration gas not manually valved off

- Some improvement as results of audits:
  - LOX deliveries post audits have reduced THC by ~ 40%
    - Now ~25-30 PPM)
  - Vendor certs more accurate:
    - 6 PPM average delta
    - 12 PPM Max delta

Cosmodyne Sampler
THC Analyses of Vendor LOX Trailers
NASA SSC Samples vs Vendor Samples

Max Allowable = 50 PPM

Vendor Internal Audit (Late July 2013)

NASA Site Audit (August 20, 2013)
LOX Hydrocarbon Issue

Recommendations

• Reduce SSC sampling of vendor trailers:
  • Sample trailer if Vendor Cert > 35 PPM (margin to protect from > 50 PPM)
  • Reject trailer if > 50 PPM
  • Sample 1 Trailer/week (continue to monitor for THC increase)

• NASA SSC considering increasing Site Limit (i.e., SSC Barges) from 50 to 55 PPM to allow for hydrocarbon concentration due to Oxygen boiloff as documented in numerous studies:
  • MIL Spec limit based on least soluble hydrocarbon (isobutylene), not Methane which is highly soluble
  • SSC data indicates 55 PPM Barge limit will satisfy customer 75 PPM limit with sufficient margin.

• To better understand E1’s THC increase, NASA SSC considering a test project to understand operational mitigations:
  • Various sampling techniques, long term boiloff, transfer operations, prechill warm tanks/lines, sampling static vs stirred tank, subcooled LOX, etc

• Include requirements in next LOX Delivery Contract
  • THC analysis accuracy and verification
Backup
LOX Hydrocarbon Issue

LOX Barges THC vs B-1 LOX Run Tank THC

Figure 6

If LOX Barge limit is increased to 55 PPM, Run Tank will still remain well below 75 PPM.
Vendor LOX Trailer Certifications vs SSC LOX Barge Samples
Total Hydrocarbon Content (THC) - April 2012 to Present

Barge Loadings vs THC

Barge Readings > 50 PPM Required Resamples

15-20 PPM Average Delta

SSC Barge THC
Vendor Trailer Cert Average THC
Linear (SSC Barge THC)
Linear (Vendor Trailer Cert Average THC)
"Post Audit"
~5 PPM Delta