Electrostatic Evaluation of the Propellant Handlers Ensemble

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Agenda

- Background
- Electrostatic Testing
  - Surface & Volume Resistivity
  - Corona Charging
  - Triboelectric Charging
  - Spark Incendivity
- Summary
Background

- The Kennedy Space Center (KSC) uses Self-Contained Atmosphere Protective Ensemble (SCAPE) suits to protect technicians during hazardous fuel and oxidizer loading operations.
- Among the fuels are Hydrazine, monomethyl hydrazine (MMH), and unsymmetrical dimethyl hydrazine (UDMH) which are all very toxic as well as flammable.
- The SCAPE suit fabrics tested are: Chloroprene, VFH Copolymer, Chlorobutyl-coated Nomex, Bromobutyl, and PTFE-coated fabric.
- Also the boot and glove of the current PHE were tested for surface resistivity.
Background

- KSC has performed a variety of electrostatic evaluations on candidate Self-Contained Atmosphere Protective Ensemble (SCAPE) fabrics as well as the current Propellant Handlers Ensemble (PHE) fabric used at KSC for propellant operations [1].

- These tests are surface resistivity, volume resistivity, corona charging, triboelectric charging, and spark incendivity.

Electrostatic Testing – Surface & Volume Resistivity

- Surface resistance is the ratio of the DC voltage to the current flowing between two electrodes of specified configuration that contact the same side of the material and is expressed in ohms ($\Omega$).

Electrostatic Testing – Surface & Volume Resistivity

- Volume resistance is the resistance measured in ohms through the bulk of the material and is expressed in ohm-cm ($\Omega$-cm).

Surface & Volume Resistivity Test Equipment

PRS-801 Resistance measurement system

Concentric ring electrode per ESD test standards STM11.11 and 11.12
Surface & Volume Resistivity Tests – Example Data

Surface and volume resistivity tests for Chlorobutyl-coated Nomex Fabric
Material is highly insulative in both tests.

<table>
<thead>
<tr>
<th>12% RH</th>
<th>( \rho_s ) (Tan side, TΩ)</th>
<th>( \rho_s ) (Gray side, TΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average:</td>
<td>1.969</td>
<td>2.619</td>
</tr>
<tr>
<td>Max:</td>
<td>4.47</td>
<td>3.9</td>
</tr>
<tr>
<td>Min:</td>
<td>1.18</td>
<td>1.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>45% RH</th>
<th>( \rho_s ) (Tan side, TΩ)</th>
<th>( \rho_s ) (Gray side, TΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average:</td>
<td>3.51</td>
<td>4.24</td>
</tr>
<tr>
<td>Max:</td>
<td>5.13</td>
<td>13.2</td>
</tr>
<tr>
<td>Min:</td>
<td>2.6</td>
<td>2.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12% RH</th>
<th>( \rho ) (Tan side, TΩ-cm)</th>
<th>( \rho ) (Gray side, TΩ-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average:</td>
<td>1.97</td>
<td>2.62</td>
</tr>
<tr>
<td>Max:</td>
<td>4.47</td>
<td>3.90</td>
</tr>
<tr>
<td>Min:</td>
<td>1.18</td>
<td>1.14</td>
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<th>( \rho ) (Gray side, TΩ-cm)</th>
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</thead>
<tbody>
<tr>
<td>Average:</td>
<td>8.47E+4</td>
<td>7.12E+4</td>
</tr>
<tr>
<td>Max:</td>
<td>1.49E+5</td>
<td>1.43E+5</td>
</tr>
<tr>
<td>Min:</td>
<td>3.24E+4</td>
<td>5.44E+4</td>
</tr>
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</table>
Surface Resistivity of PHE Boot & Glove

All locations on the boot are static dissipative (GΩ) except for the top band at location 6 which is insulative (TΩ).

All locations on the glove are conductive (KΩ) except for location 3 which is insulative (TΩ).
Electrostatic Testing – Corona Charging

- Corona charging is when air molecules are ionized by a strong electric field, usually created at sharp needle electrodes energized at a high voltage, and placed near a target surface.

Corona Charging Test Equipment

JCI 155v5 (John Chubb Instruments)

±10,000 volts

Charge decay measurements (voltage decays to 1/e or 37% of maximum in one second or less)
Corona Charging Tests – Example Data

Corona Charging
Chlorobutyl-coated Nomex Fabric Sample 1 at 15% Relative Humidity

- Tan Side, +10Kv
- Gray Side, +10Kv
- Tan Side, -10Kv
- Gray Side, -10Kv
Corona Charging Tests – Application of Staticide™ Anti-static Compound

- To improve the charge decay of current PHE used at KSC, a commercial anti-static compound called Staticide™ is applied to the surface of the suit.

- However, Staticide™ is difficult to apply evenly and wears off quickly in field conditions at KSC.

- A series of corona charging tests using mixtures of Staticide™ with a commercial liquid detergent and Isopropyl alcohol (IPA) were performed to determine if these formulations improve the coverage and longevity of Staticide™.
Corona Charging with Staticide™ Mixtures

- The use of full Staticide™ (no additive used, applied same day as use) is sufficient to bring the charge decay properties into acceptable limits (decay time to 1/e is under 1 sec).

- If the suit is to be used the next day after application of the Staticide™, use a mixture of 5 parts liquid detergent to every 100 parts Staticide. This mixture has significantly better charge decay properties than full Staticide™ applied 24 hours ahead of time.

- The use of IPA as an additive to Staticide™ has no significant positive affect on the properties of Staticide™, because of this it should not be used for this application.
Electrostatic Testing – Triboelectric Charging

- Triboelectric charging is caused by contact or rubbing of two materials together.
- This method records the charge decay after the test material is rubbed with either a wool or PTFE felt wheel.
- The KSC standard requires that the resulting voltage on a material decay below 350 volts in 5.0 seconds after separation from the rubbing wheel.
Triboelectric Test Apparatus

Test Conditions per MMA-1985-79:
- 30% & 45% relative humidity.
- 400 rpm.
- 5.0 lbs of force.
- 10 second rubbing period to saturate sample with charge.
Triboelectric Testing – Example Data

Chloroprene SCAPE Fabric Tribocharging Tests

Surface Potential (kv)

Time (sec)

Red Side, 45%RH
White Side, 45%RH
Red Side, 20%RH
White Side, 20%RH
Spark Incendivity Testing is commonly used throughout the industry to evaluate the electrostatic hazard for packaging/handling materials such as Flexible Intermediate Bulk Containers (FIBC’s).

The test is performed in accordance with Test Standard IEC:2003 61340-4-4, “Electrostatic classification of Flexible Intermediate Bulk Containers (FIBCs)”.}

Spark Incendivity probe
Spark Incendivity Testing Using Gas Probe

- The incendivity Probe was used with hydrogen gas which has a Minimum Ignition Energy (MIE) of 0.02 mJ.
- Ambient RH (50-60%) and low RH (20-25%)
- Samples mounted vertically in an Insulating Frame
Spark Incendivity Testing Using Gas Probe

- **Charging Methods**
  - Corona Charging – using a corona/static brush and a high-voltage power supply (negative polarity at 30kV DC).
  - Tribo-Charging – using a 5” diameter rotating “wool-covered” disc or PTFE disc.

- **Surface Potential Measurements**
  - Used a JCI 140 to characterize the surface potential applied to the surface after deposition of tribo charge or corona charge.
## Minimum Ignition Energies of Hypergolic Fuels used at KSC (In Air)

<table>
<thead>
<tr>
<th></th>
<th>Ignition Energy 33% Ignitions</th>
<th>Ignition Energy 100% Ignitions</th>
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<tbody>
<tr>
<td>2.2% MMH @ 300 (\Omega m) (monomethylhydrazine)*</td>
<td>2.8 mJ</td>
<td>3.4 mJ</td>
</tr>
<tr>
<td>4.3% UDMH @ 300 (\Omega m) (unsymmetrical dimethylhydrazine)*</td>
<td>2.7 mJ</td>
<td>3.2 mJ</td>
</tr>
<tr>
<td>5% Hydrazine 1 mm spacing **</td>
<td>4.4 mJ</td>
<td>9.6 mJ</td>
</tr>
</tbody>
</table>


Discharge Incendivity Testing Using Gas Probe

- Spark Incendivity Probe – Approach the charged sample several times to check for an ignition of the gas mixture of known MIE. (Approach at 0.5-1.0 m/s)
- Repeat Procedure – Repeat these steps at least 25 times per side.
Discharge Incendivity Testing Results

- No Ignitions were detected in any of the SCAPE suit fabrics.
- Ignitions were detected with the Chlorobutyl-coated Nomex fabric in the presence of a metal backing. The metal backing concentrated the electric field lines on the fabric surface.
- The fabrics by themselves, without the presence of a metal surface in the interior of the suit, should not produce any sparks with enough energy to ignite hypergolic fuels.
Summary

- All SCAPE fabrics tested for surface and volume resistivity are highly insulative.
- Most of the SCAPE suit fabrics tested to corona charge decay failed to discharge to 37% or $1/e$ of their initial voltage in less than one second.
- Both sides of the Chloroprene fabric passed the corona discharge requirement at both room and low humidity.
Summary

- Most of the SCAPE suit fabrics tested for triboelectric charge decay failed to discharge below 350 volts in five seconds.
- All the SCAPE suit fabrics passed the spark incendivity tests except for a few cases where metal backing was applied to the fabric.
- Despite being highly insulative and many failing the corona and triboelectric tests, the SCAPE fabrics passed the spark incendivity tests and are safe to use under their operating conditions at KSC.