Oxygen Cleaning: Why a validated process is critical for safety

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Director of Engineering
What is Oxygen?

- Oxygen is an element
- Common stable form of Oxygen is O2
- Most common oxidizing gas and supports combustion – Highly Reactive
- Oxygen enriched atmosphere ≥ 25 mol% of Oxygen per ASTM G63.
- Most industrial applications require 90-93% pure or 99+ % pure
- The air we breathe is 21% Oxygen, 78% Nitrogen, and 1% other
- In 1991, over 470 Billion cu.ft of Oxygen were produced in the US.
- In 2014, over 1.5 Trillion cu.ft of Oxygen in the US and over 4 Trillion Cu. Ft globally
What is Industrial Oxygen used for?

- Steel making (Basic Oxygen Furnace)
- Water Pollution Countermeasures
  - Sewage treatment, Superfund site rehab, habitability
- Chemical processes
  - Vinyl Chloride, Nitric Acid, Epoxyethane, hydrogen peroxide,
What is Industrial Oxygen used for?

- Medical Treatment
- Life Support in harsh environments
- Industrial gasses for Welding and other processes
Why is Oxygen Cleaning important?

3 words: Safety, Safety, Safety.
Combustion needs only 3 things
Fuel, Oxidizer, and Ignition source

• Oxygen is the Oxidizer
• Possible ignition sources:
  - Particle high velocity Impingement impact
  - Adiabatic compression heating (Auto Ignition)
  - Electric Arcs
  - Collision of moving parts
• The fuel is the metal itself once ignited
Sources of Ignition

• Friction – Contact of materials within the enriched environment

• Impact – Heat generated due to the impact of particles or projectiles internal or external to the enriched environment.

• Electrical Arc – Including static discharge
Sources of Ignition (continued)

- Resonance – Vibration induced heating. Vibration or flow induced oscillations which cause local pressure spikes that otherwise would not occur.
- Internal flexing – heating caused by repeated deformation
- Heat of Compression – Heating caused by adiabatic compression of the fluid. This is the most common cause explosion due to contamination.
What is Autoignition?

• Auto ignition [aw-toh-ig-nish-uh n] is the phenomenon of spontaneous ignition of a fuel source in an oxidizing atmosphere due to the heat generated by the sudden compression of a gas or Heat of Compression (HoC).

• If the heat generated by the compression exceeds the Auto ignition temperature (AIT) the fuel will spontaneously combust.

• The theoretical maximum heat generated can be calculated as shown in ASTM G63.
Heat of Compression per ASTM G63-99

5.4.2.1 Equation—An equation that can be used to estimate the theoretical maximum temperature that can be developed when pressurizing oxygen rapidly from one pressure and temperature to an elevated pressure is as follows:

\[ \frac{T_f}{T_i} = \left[ \frac{P_f}{P_i} \right]^{(\frac{n-1}{n})} \]  \hspace{1cm} (1)

where:

- \( T_f \) = final temperature, abs,
- \( T_i \) = initial temperature, abs,
- \( P_f \) = final pressure, abs,
- \( P_i \) = initial pressure, abs, and
- \( n = \frac{C_p}{C_v} = 1.40 \) for oxygen,

where:

- \( C_p \) = specific heat at constant pressure, and
- \( C_v \) = specific heat at constant volume.

Table 2 gives the theoretical temperatures which could be obtained by compressing oxygen from one atmosphere (absolute) and 20°C to the pressures shown.
Heat of Compression is Significant

TABLE 2 Theoretical Maximum Temperature Obtained When Compressing Oxygen Adiabatically from 20°C and One Standard Atmosphere to the Pressures Shown $^A$

<table>
<thead>
<tr>
<th>Final Pressure, $P_f$ (kPa)</th>
<th>Pressure Ratio $P_f/P_j$</th>
<th>Final Temperature, $T_f$ (°C)</th>
<th>Final Temperature, $T_f$ (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>345</td>
<td>50</td>
<td>3.4</td>
<td>143</td>
</tr>
<tr>
<td>690</td>
<td>100</td>
<td>6.8</td>
<td>234</td>
</tr>
<tr>
<td>1000</td>
<td>145</td>
<td>9.9</td>
<td>291</td>
</tr>
<tr>
<td>1379</td>
<td>200</td>
<td>13.6</td>
<td>344</td>
</tr>
<tr>
<td>2068</td>
<td>300</td>
<td>20.4</td>
<td>421</td>
</tr>
<tr>
<td>2758</td>
<td>400</td>
<td>27.2</td>
<td>480</td>
</tr>
<tr>
<td>3447</td>
<td>500</td>
<td>34.0</td>
<td>530</td>
</tr>
<tr>
<td>5170</td>
<td>750</td>
<td>51.0</td>
<td>628</td>
</tr>
<tr>
<td>6895</td>
<td>1000</td>
<td>68.0</td>
<td>706</td>
</tr>
<tr>
<td>10000</td>
<td>1450</td>
<td>98.6</td>
<td>815</td>
</tr>
<tr>
<td>13790</td>
<td>2000</td>
<td>136.1</td>
<td>920</td>
</tr>
<tr>
<td>27579</td>
<td>4000</td>
<td>272.1</td>
<td>1181</td>
</tr>
<tr>
<td>34474</td>
<td>5000</td>
<td>340.1</td>
<td>1277</td>
</tr>
<tr>
<td>100000</td>
<td>14500</td>
<td>988.3</td>
<td>1828</td>
</tr>
<tr>
<td>1000000</td>
<td>145000</td>
<td>9883.9</td>
<td>3785</td>
</tr>
</tbody>
</table>

Per ASTM G63-99
Heat of Compression by ASME Pressure Class

<table>
<thead>
<tr>
<th>ASME Class</th>
<th>Pmax, PSIG</th>
<th>Pf/Pi,</th>
<th>HoC Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>T (C)</td>
</tr>
<tr>
<td>150</td>
<td>290</td>
<td>20.7</td>
<td>424 C</td>
</tr>
<tr>
<td>300</td>
<td>750</td>
<td>52.0</td>
<td>633 C</td>
</tr>
<tr>
<td>600</td>
<td>1500</td>
<td>103.0</td>
<td>829 C</td>
</tr>
<tr>
<td>900</td>
<td>2250</td>
<td>154.1</td>
<td>963 C</td>
</tr>
<tr>
<td>1500</td>
<td>3750</td>
<td>256.1</td>
<td>1156 C</td>
</tr>
<tr>
<td>2500</td>
<td>6250</td>
<td>426.2</td>
<td>1380 C</td>
</tr>
<tr>
<td>4500</td>
<td>11250</td>
<td>766.3</td>
<td>1682 C</td>
</tr>
</tbody>
</table>
Where can I find data on compatibility of Non-Metallic with Gaseous (GOX) and Liquid Oxygen (LOX)?

- NASA Dwg No. 54000-GM30, Specification for Materials Used in LOX and GOX Service Exempt from Batch Test Requirements
## NASA Dwg No. 54000-GM30

<table>
<thead>
<tr>
<th>Code</th>
<th>Material Class or Chemical Name</th>
<th>Trade Name</th>
<th>Manufacturer</th>
<th>LOX Rating (PSIG)</th>
<th>GOX Rating (PSIG)</th>
<th>Remarks and Applicable Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO6</td>
<td>PERFLUOROPOLYALKYLEATHER (PFPAE) OIL</td>
<td>KRYTOX 1434C</td>
<td>E.I. DUPONT</td>
<td>AS1500</td>
<td>AS6700</td>
<td>ALSO CALLED PERFLUOROPOLYETHER (PFPE) PERFLUOROLKYLETHLE (PFKE)</td>
</tr>
<tr>
<td>101.1</td>
<td>PFPAE OIL WITH PTFE THICKENER</td>
<td>KRYTOX 240AC GREASE</td>
<td>E.I. DUPONT</td>
<td>AS10000</td>
<td>AS10000 (To +550°F)</td>
<td></td>
</tr>
<tr>
<td>101.1</td>
<td>PERFLUOROPOLYALKYLEATHER (PFPAE) OIL (PTFE THICKENER)</td>
<td>BRAYCOTE 601EF</td>
<td>CASTROL NORTH AMERICA</td>
<td>AS1500</td>
<td>AS6700</td>
<td></td>
</tr>
</tbody>
</table>
The Purpose of Oxygen Cleaning

• To reduce contaminants
• Reduce the chance of autoignition at a temperature much lower than expected by the material selection
Oxygen Cleaning: What are the contaminants we trying to remove?

• ASTM G93 categorizes contaminants into 3 types:
  - Organics
    • VOC compounds
    • Hydrocarbon based greases & oils
  - Inorganics
    • Nitrates
    • Phosphates
    • Waterbase detergents & cutting oils
    • Acids / Solvents
  - Particulate
    • Particles, lint and fibers
    • Dust
    • Weld slag
  - Basically anything that would promote combustion or impact product purity
How Clean is Clean?
Customer specifications vary on cleanliness level, methods, and validation.

<table>
<thead>
<tr>
<th>Customer</th>
<th>Residue Level</th>
<th>Cleaning Methods</th>
<th>Direct Inspection</th>
<th>Indirect Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mechanical Grit</td>
<td>Visual (White light)</td>
<td>Wipe Test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blasting, wire</td>
<td>Inspection</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>brush, grinding</td>
<td>White Light</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous Solvent</td>
<td>intensity</td>
<td></td>
</tr>
<tr>
<td>Customer 1</td>
<td>Total Residue</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>100 mg/m²</td>
<td>Particles</td>
<td>100 mg/m²</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>75 / sq.ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer 2</td>
<td>Total Residue</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>200 mg/m²</td>
<td>Particles</td>
<td>500 LUX/46.5 Ft Candles</td>
<td>(inaccessible areas)</td>
<td></td>
</tr>
<tr>
<td>75 / sq.ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer 3</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>125 mg/m²</td>
<td>Particles</td>
<td>500 LUX/46.5 Ft Candles</td>
<td>UV or Wipe test</td>
<td></td>
</tr>
<tr>
<td>50 mg/m²</td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Customer 4</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>1000 µW/cm² at 10 to 15 inches</td>
<td>N</td>
<td>-</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Customer 5</td>
<td>Total Residue</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>125 mg/m²</td>
<td>Particles</td>
<td>500 LUX/46.5 Ft Candles</td>
<td>(inaccessible areas)</td>
<td></td>
</tr>
<tr>
<td>50 mg/m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Cleaning Methods: Mechanical Cleaning

- Mechanical cleaning is used to remove scale, coatings, paint, weld slag and other solid contaminants
  - Grit blasting
  - Ice blasting
  - Wire brushing
  - Grinding
Cleaning Methods: Aqueous Cleaning

• Hot Water & Steam Cleaning
  - Effective against water soluble contaminants
  - Usually used with detergent

• Alkaline cleaning –
  - Uses Caustic salt in water to create highly alkaline solution
  - Effective against Hydrocarbon oils, grease and waxes
  - Process is enhanced by agitation and/or jet spraying
  - Typical uses include industrial parts washers
  - Greatly enhanced by Ultrasonic agitation
  - Solvent residue be removed
Cleaning Methods: Semi-aqueous or Emulsion Cleaning

• Semi Aqueous cleaning uses hydrocarbon solvent and water emulsion
• Effective for removing heavy contaminants from parts like heavy grease wax or hard to remove soils
• Emulsion may require agitation to maintain mixture
• Parts must be rinsed before emulsion can dry or contaminants may re-deposit on part.
Cleaning Methods: Acid Cleaning

• Acid cleaning varies substantially based on the acid used
  - Hydrochloric Acid is used to remove scale, rust and oxides and to strip platings (chrome, zinc, cadmium, etc.) and other coatings
  - Chromic and Nitric Acid are used to for passivating, deoxidizing, brightening and removing Alkaline residues in addition to cutting oils
  - Phosphoric removes oxides, light rust and fluxes

• Acids must be removed completely from the part prior to drying and may need a neutralizing process depending on the acid strength.
Cleaning Methods: Solvent cleaning

- Solvents can be used without water dilution or emulsion.
- Alcohol is a common solvent often used to revisit areas of concern identified by the Black (UV) light inspection.
- Solvents like Alcohol evaporate completely leaving no residue.

Any combination of cleaning methods that achieve the desired cleanliness level is acceptable.
Cleaning Methods: Vapor Degreasing

- Vapor degreasing is a process in which the solvent is heated until it vaporizes while the part is maintained at a lower temperature. The solvent then condenses and dissolved contaminants. The part must be oriented so that the condensed solvent can drain from the part by gravity.
- Very effective for inaccessible areas on parts
- Requires a contained environment for the part during the process.
Inspection Methods: Direct Visual Inspection

• **White Light Visual Inspection**
  - Specify Intensity: 500 LUX / 46.5 Candle feet per
  - Effective in detecting contamination down to 500 mg/m^2

• **UV (black) Light Visual Inspection**
  - Identifies on contaminants that fluoresce
  - Specify Intensity of the light not power: 800 µW/cm^2 at 375 mm (per CGA 4.1)
  - Effective in detecting contamination down to 40 mg/m^2
Inspection Methods: Indirect Visual Inspection

• Wipe Test –
  - Identifies contaminants in visually accessible locations – no direct line of sight
  - Typically visually inspected with both White light and UV light
  - Effective in detecting contamination down to 30 mg/m^2

• Solvent Filtering
  - 100ml/sq.ft of low residue solvent
  - Inspect by filtering and using White Light and UV inspection.
Inspection Methods: Indirect Quantitative Inspection

- Solvent Extraction
  - 100 ml/sq.ft of low residue solvent
  - Inspect by evaporating the solvent and obtaining the weight of the remaining effluent
  - Acceptance criteria varies per ASTM G63
Additional Considerations when developing your internal Oxygen cleaning process

• Clean Room
  - Provides a designated location where the environment limits dust airborne particles
  - Provides a location to keep clean tools, clean assembly and test equipment
  - Provides controlled lighting for visual inspections

• Clean Test Equipment
  - Pressure test equipment contains contaminants in hoses and pumps. If you cannot dedicate a test machine for clean testing, give special consideration to cleaning of test equipment or alternate testing with clean gas.

• Packaging
  - Give specific instructions on how to package the product to preserve cleanliness in shipping and subsequent storage
  - Desiccant – Consider the role of desiccant as a possible contaminant. Use compatible products or control desiccant to prevent contamination.
  - Topworks - Consider the addition of actuation and accessories to the valve. Can the actuator be installed an set up without violating the protection? If the protection is compromised, are there procedural steps to identify and remediate any contamination?
Summary

• Oxygen Cleaning is used to remove contaminants that can significantly reduce the temperature of Autogeneous Ignition (Autoignition)
• There are many methods for doing the actual cleaning
• Any method that achieves the desired cleanliness level is acceptable
• Cleanliness levels are specified by the customer and vary.
• It is a good thing to know what your standard cleanliness process produces.
• Packaging and tagging should be part of your oxygen cleaning process
• Process validation using a quantitative measurement allows the supplier to have confidence in process quality when using qualitative inspections for production work.