Outgassing and Permeation

31 March 2003

Outgassing and Permeation

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Outgassing and Permeation

Permeation occurs when there is a pressure difference created across the wall of a vacuum vessel that results in a net transport of molecules.

The transport mechanism is pressure-driven diffusion...

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Diagram showing the process of permeation with molecules moving from high pressure to low pressure through a barrier.
Outgassing and Permeation

Molecules then desorb from the inside surface of the vessel and participate in the net gas load.

Low pressure \hspace{1cm} High pressure

Permeation Happens!

Helium Party Balloons
Latex versus Mylar Balloons
Automobile Tires
Hydrogen Purification
Calibrated Leaks
Outgassing and Permeation

Model of a Semi-infinite solid with volatile impurities

Sources of Outgassing

- General
  - Adsorbed Water and other gases
- Metal surfaces
  - Bulk Impurity diffusion
  - Surface Impurities
  - Crystal boundaries
- Nonmetal surfaces
  - Base material volatilization
  - Thermal and Radiation Damage
- Search engine: http://outgassing.nasa.gov
Outgassing and Permeation

Beware: Outgassing and Permeation are often merged in casual vacuum discussions.

The devil is in the details:
- virtual leaks
- real leaks
- Permeation
- Semi-infinite De-Volatilization
- Thermal decomposition
- Surface gas desorption.

Effects on Ultimate Base Pressure

- Outgassing and permeation from o-rings often constrain the ultimate base pressure of a vacuum system.
- The outgassing rate of an o-ring can be reduced by baking or time.
- The permeation rate of an o-ring usually remains constant, but is steeply temperature dependent.
Outgassing and Permeation

Elastomers for Vacuum

- **Viton** has best mechanical properties, bakeability (to 180°C), with low permeation and low volatility.
- **Buna N (Nitrile)** lower cost than Viton with same benefits except poorer bakeout resistance.

Post-Curing Elastomer O-rings

- Manufacturers of Viton o-rings don’t know where their product is going.
- If base pressure is an issue, post cure in air oven at 140°C for 48h, or purchase from vendor post-cured.
- **Vendor**: www.uccomponents.com
Outgassing and Permeation

Alternative Elastomers

- FFKM materials (Kalrez 8575, Chemraz 630) are expensive, chemistry resistant but have higher permeation rates than Viton
- MFQ materials often have select chemical resistance, but high permeation rates.

Outgassing and surface roughness

A high quality surface finish is often equated with a low outgassing rate.
Effective surface area is reduced when high quality surface finishes are employed, but this influence is not profound.
Surface finish usually does not drive fabrication costs in small vessels, but frequently does in large.
Outgassing and Permeation

Surfaces for Vacuum service may need attention of the following issues:

- Alloy specification
- Cutting fluids
- Machine tooling
- Post-machine cleaning
- Surface protection and packaging

The goal is low base pressure

- Often the purpose of a smoother surface is cleanability or inspectability.
- Machining of vacuum components is best accomplished with a sharp, single point tool.
- Cutting fluids should not contain sulfur based lubricants.
Outgassing and Permeation

Outgassing rates for Common Vacuum materials

Courtesy LLNL

Outgassing Data alternatively given in form of 4 coefficients

\[
\begin{bmatrix}
Q_1, Q_{10}, a_1, a_{10}
\end{bmatrix}
\]

\[
Q_{<1 \text{hour}} = Q_1 (3600 / t)^{a_1}
\]

\[
Q_{1-10 \text{hours}} = Q_1 (3600 / t)^{\log Q_1 - \log Q_{10}}
\]

\[
Q_{>10 \text{hours}} = Q_{10} (3600 / t)^{a_{10}}
\]
Outgassing and Permeation

Example of Outgassing Data (Courtesy PEC)

<table>
<thead>
<tr>
<th>Condition</th>
<th>A1</th>
<th>A10</th>
<th>Q1</th>
<th>Q10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (fresh)</td>
<td>1.0</td>
<td>1.0</td>
<td>6.30E-09</td>
<td>6.00E-10</td>
</tr>
<tr>
<td>Aluminum (degassed 24-h)</td>
<td>3.2</td>
<td>0.9</td>
<td>4.14E-09</td>
<td>3.06E-10</td>
</tr>
<tr>
<td>Aluminum (3-h in air)</td>
<td>1.9</td>
<td>0.9</td>
<td>6.64E-09</td>
<td>4.74E-10</td>
</tr>
<tr>
<td>Aluminum (anodized)</td>
<td>0.9</td>
<td>0.9</td>
<td>2.75E-07</td>
<td>3.21E-08</td>
</tr>
<tr>
<td>Aluminum (baked 15h @250C)</td>
<td>0.0</td>
<td>0.0</td>
<td>3.97E-13</td>
<td>3.97E-13</td>
</tr>
<tr>
<td>Aluminum (baked 20h @ 100C)</td>
<td>0.0</td>
<td>0.0</td>
<td>3.97E-14</td>
<td>3.97E-14</td>
</tr>
</tbody>
</table>

Outgassing.xls (downloadable)

Outgassing of Common Vacuum Construction Materials

- Silicone
- Aluminum, 3h in Air
- Aluminum, 30h @ 250C
- Vilon, 12h @ 200C
- Pyrex, 1 month in Air
- Anodized Aluminum
Outgassing and Permeation

Permeation for a given material and gas is

Proportional to
- Pressure differential (usually 1 atm)
- Effective Area
- Partial Pressure of Gas Species

Inversely Proportional to
- Thickness

Like outgassing, it is another source.

Permeation is gas-species sensitive

- Identify the materials constituting the vacuum vessel walls
- Identify the permeation gas of interest (e.g., N₂, O₂, H₂O, Tritium)
- Estimate the permeation surface area and thickness
- Apply Dalton's Laws of Partial Pressure (if applicable)
- Look up the permeation rate for each material and gas
- Calculate the permeation gas load for each material
- Sum them for the total permeation gas load
Equation for Calculating the permeation rate

\[ Q = 10 \frac{k_p A (\Delta P)}{d} \]

- \( Q \): leak rate, t-liter/sec
- \( k_p \): permeation, m²/sec
- \( A \): Area, cm²
- \( \Delta P \): Pressure, Torr
- \( d \): Thickness, cm

Pressure differential is equal to 1 atmosphere for many cases

<table>
<thead>
<tr>
<th>Low pressure</th>
<th>Atmospheric pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.76 Torr</td>
<td>760 Torr</td>
</tr>
<tr>
<td>101 Pa</td>
<td>101,000 Pa</td>
</tr>
</tbody>
</table>

\[ \Delta P = (P_{Atm} - P_{vac}) \]

\[ \Delta P = (760 - 0.76) = 759.24 \text{ Torr} \]

\[ \Delta P = (101,000 - 101) = 100,899 \text{ Pa} \]
Outgassing and Permeation

Useful Unit Conversions for Permeation

1333.2 Watts/sq-meter = 1 torr-liter/sec/sq-cm

A Watt is a unit of energy per time, just like a torr-liter/sec!

Permeation data is usually tabulated in square-meters/sec!

Outgassing Rates are influenced by surface preparation

Courtesy Howard Patton
Outgassing and Permeation

Permeation data is dependent on:
- gas species present
- material
- history
- temperature

<table>
<thead>
<tr>
<th>Material</th>
<th>sq-cm/sec</th>
<th>sq-meter/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buna-N (high value for CO2)</td>
<td>4.80E-07</td>
<td>4.80E-11</td>
</tr>
<tr>
<td>Buna-N (High value for Helium)</td>
<td>6.00E-08</td>
<td>6.00E-12</td>
</tr>
<tr>
<td>Buna-N (High value for Nitrogen)</td>
<td>2.00E-08</td>
<td>2.00E-12</td>
</tr>
<tr>
<td>Buna-N (high value for Oxygen)</td>
<td>6.00E-08</td>
<td>6.00E-12</td>
</tr>
<tr>
<td>Buna-N (low value for CO2)</td>
<td>5.70E-08</td>
<td>5.70E-12</td>
</tr>
<tr>
<td>Buna-N (low value for Helium)</td>
<td>5.20E-08</td>
<td>5.20E-12</td>
</tr>
<tr>
<td>Buna-N (low value for Nitrogen)</td>
<td>2.00E-09</td>
<td>2.00E-13</td>
</tr>
<tr>
<td>Buna-N (low value for Oxygen)</td>
<td>7.00E-09</td>
<td>7.00E-13</td>
</tr>
<tr>
<td>Buna-N (water)</td>
<td>7.50E-06</td>
<td>7.60E-10</td>
</tr>
</tbody>
</table>

Permeation is geometry dependent
O-ring is most common feature

Conservative Assumptions

Permeation Area is \( t \times \text{Length of O-ring} \)

Permeation thickness is \( \frac{1}{2} t \)
Calculating the permeation distance (half the o-ring thickness)

\[ d = \frac{t}{2} = \frac{0.125''}{2} = 0.063'' \]

\[ 0.063'' \times 2.54\text{cm/in} = 0.16\text{cm} \]

Calculate the AREA of the O-ring the gas is permeating through for thickness \( t \) and Diameter \( D \):
Outgassing and Permeation

Calculating the AREA of a circular O-ring

\[ A = \pi D t \]

D is the inside diameter

\( t \) is the thickness

Warning: Units Trap!

39.37 inches per meter

2.54 cm per inch

Ways to reduce Permeation

- Use metal seals where economically feasible.
- Use a pair of o-rings and differentially pump the trapped volume.
  - Example: UHV Monochromator seal detail.
- Deploy low permeability gases and materials where possible
- Be wary of water in particular. It has a high permeation rate