Vacuum Solutions for Ion Thruster Testing

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Application & Product Support

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Vacuum Solutions for Ion Thruster Testing

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### Ion Thruster Testing - Requirements

**Q.:** Why ion thrusters? Why Xe?

**A.:** - Keeping satellites in position  
- Moving space crafts to Mars, Jupiter and beyond

<table>
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<tr>
<th>Typical Parameters</th>
<th>Xe flow</th>
<th>process pressure</th>
<th>pumping speed</th>
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<tr>
<td></td>
<td>1 mg/s</td>
<td>$1 \cdot 10^{-5}$ mbar</td>
<td>19'000 l/s</td>
</tr>
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</table>

- TMPs are too small/expensive; rotor becomes hot through Xe pumping
- Diffusion pump oil contaminates Xe thrusters
- standard cryopumps have less than 50 % of their nominal pumping speed for Xe
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Condensing gases

saturation vapour pressure $p$ (mbar)

condensation temperatures

$20\, K$  $80\, K$

$N_2$, $Ar$, $O_2$, $CH_4$, $Xe$, $CO_2$, $H_2O$
Standard Cryopumps - Working Principle

- **Vacuum chamber**: \( \approx 10 - 20 \text{ K} \)
- **Activated charcoal**: \( \approx 80 \text{ K} \)

- Condensed at higher temperatures: \( \text{H}_2\text{O}, \text{CO}_2 \)
- Condensed at low temperatures: \( \text{N}_2, \text{Ar}, \text{Xe}, \text{O}_2 \)
- **Adsorbed** on activated charcoal: \( \text{H}_2, \text{He}, \text{Ne} \)
### Efficiency of the cryopump

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Molar Mass (g/mol)</th>
<th>S / A (l/s*cm²)</th>
<th>Mean Velocity $\bar{c}$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>2</td>
<td>44.0</td>
<td>1761</td>
</tr>
<tr>
<td>He</td>
<td>4</td>
<td>31.1</td>
<td>1245</td>
</tr>
<tr>
<td>H₂O</td>
<td>18</td>
<td>14.7</td>
<td>587</td>
</tr>
<tr>
<td>N₂</td>
<td>28</td>
<td>11.8</td>
<td>471</td>
</tr>
<tr>
<td>Ar</td>
<td>39.9</td>
<td>9.9</td>
<td>394</td>
</tr>
<tr>
<td>Xe</td>
<td>131.3</td>
<td>5.4</td>
<td>217</td>
</tr>
</tbody>
</table>

\[
\bar{c} = \sqrt{\frac{8 \cdot R \cdot T}{\pi \cdot M}}
\]

Nominal pumping speed:
- 10'000 l/s for nitrogen
- 4'600 l/s for xenon

\[
\sqrt{\frac{M(N₂)}{M(Xe)}} = \sqrt{\frac{28}{131.3}} = 0.46
\]

$\Rightarrow$ 4'600 l/s for xenon
# Vacuum Solutions for Ion Thruster Testing

## 1 Ion Thruster Testing - Requirements

## 2 Standard Cryopumps

## 3 Cryo Panels for Ion Thrusters

## 4 Vacuum Systems for Thruster Testing
Cryogenic Options for Xenon Pumping

- COOLPOWER 140 T + cryo panel
  - 10'300 l/s for xenon

- Standard cryopump
  - 4'600 l/s for xenon
Design of Cryo Panel

- chamber wall
- cold head
- heater
- Ni-plated copper
- MLI

Xenon gas from thruster (at room temperature)
Theoretical Pumping Speed for Xe

\[ S = A_K \ 3.64 \ \alpha_c \ \sqrt{\frac{T_G}{M}} \left(1 - \frac{p_K}{\alpha_c \ p_G \ \sqrt{\frac{T_G}{T_K}}}\right) \]

- \( p_G \) = process pressure
- \( p_K \) = saturation vapour pressure
- \( T_G \) = gas temperature
- \( T_K \) = temperature of cryo panel (K)
- \( S \) = pumping speed of cryo panel (l/s)
- \( A_K \) = area of cryo-panel in (cm²)
- \( \alpha_c \) = Sticking coeffizient
- \( M \) = molar mass (g/mol)

For \( p_G >> p_K \), \( \alpha_c \approx 1 \) \( \Rightarrow S = 3.64 \times A \times \sqrt{\frac{T_G}{M}} \)

Xenon (\( M = 131.3 \) g/mol; \( T_G = 293 \) K) \( \Rightarrow S/A = 5.44 \ell/s \ cm^2 \)
Theoretical Pumping Speed for Xe

\[
S \text{ (l/s*cm}^2) \quad T \text{ (K)}
\]

\[
10^{-6} \text{ mbar}
\]

\[
56 \text{ K}
\]

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Theoretical Pumping Speed for Xe

![Graph showing the theoretical pumping speed for Xe as a function of temperature and pressure. The graph includes a logarithmic scale for pressure and a linear scale for temperature. Key points include:

- A horizontal line at 5.5 S (l/s*cm²) for all T (K) values.
- A curve starting from high pressure and decreasing sharply with increasing temperature, indicating the pumping speed decreases as temperature increases.

The graph also shows two pressure levels: 10⁻⁵ mbar and 10⁻⁶ mbar, with corresponding temperature ranges for each.]

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Theoretical Pumping Speed for Xe

![Graph showing theoretical pumping speed for Xe](image)

- Horizontal axis: Temperature $T$ (K)
- Vertical axis: Pumping speed $S$ (l/s cm$^2$)

Inset graph showing the pumping speed for various gases at different temperatures.

- $N_2$, $Ar$, $O_2$, $CH_4$, $Xe$, $CO$, $H_2O$
- Temperature range: 10 to 150 K
- Pressure levels: $10^{-4}$, $10^{-5}$, $10^{-6}$ mbar

Key points:
- $65$ K
- $10^{-4}$ mbar
- $10^{-5}$ mbar
- $10^{-6}$ mbar

Legend:
- Yellow shade: Depicts a specific aspect of the graph.
Theoretical Pumping Speed for Xe

![Graph showing theoretical pumping speed for Xe with temperature (K) on the x-axis and pumping speed (l/s*cm²) on the y-axis. The graph indicates a decrease in pumping speed as temperature increases, with specific points labeled at 53 K, 58 K, and 10⁻⁵ mbar.]
COOLPOWER 140 T – Load Map

- Required temperature range for xenon

![Graph showing cooling capacity versus temperature for COOLPOWER 140 T](image)
maximum load at 45 K for CP 140 T: \( Q_{\text{th}} \sim 85 \text{ W} \)

surrounding temperature: \( T = 300 \text{ K} \)

very thick Xenon layers: \( \varepsilon_r \sim 0.9 \)

Thermal law of radiation: \( Q_{\text{th}} = \sigma \ T^4 \ A \)

\[ Q_{\text{th}} / A = 0.041 \text{ W} / \text{cm}^2 \]

\[ \text{max. surface of cryopanel:} \quad A \sim 85 / 0.041 \text{ cm}^2 \sim 2,100 \text{ cm}^2 \]

\[ \text{pumping speed:} \quad S_{\text{Xe}} \sim 2,100 \cdot 5.44 \text{ l/s} \sim 11,400 \text{ l/s} \]

COOLVAC 10'000 iCL: \( S_{\text{Xe}} \sim 4,600 \text{ l/s} \)
Cryo Panel measurement

- mass spectrometer
- gas inlet
- hot cathode gauge
- TMP + backing pump
- PMMA disc
- PNEUROP vessel
- metal disc
- silicon diode
- electrical heater
- electrical feedthrough
- to helium compressor
- cold head motor cable

11'400 ℓ/s - 10 %
10'300 ℓ/s

safety margin

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Cryo Panel vs Standard Cryopump

- no additional high vacuum pumps required
- heating of the first stage to prevent xenon hangup is necessary or
- severe reduction of baffle temperature while enhancing the corresponding cooling capacity is necessary
- low capacity of hydrogen and helium (TMP → infinite "capacity")

- simple concept - much larger pumping speed in comparison to standard cryo pumps
- usually more pumping speed per Euro in comparison to standard cryo pumps
- no capacity issue concerning hydrogen and helium due to use of TMPs
- additional high vacuum pumps (usually TMP) are needed
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Vacuum Systems for Thruster Testing

Simulation Chamber
Typical configuration

- chamber size?
- material / desorption rate?
- heat?
Vacuum diagram for a 1.5 m³ Chamber

Unistat
-65°C
+80 °C

COOLPOWER 140 T

COOLPAK 6000 H

MAG 2800

WSU 251

D 65 B
Thank you for your attention

Our booth: No. 108 (Tent)

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