

APPLIED ION SYSTEMS

High Vacuum Engineering Calculations

Integrated High Vacuum Test Stand - High Vacuum Pumping Assembly
 Ultimate Pressure and System Gas Load Due to Outgassing for Pumpdown

1.) Maximum Theoretical Gas Loads for Ultimate Operating Pressures at Various Flows

a.) Ultimate Pressure vs. Working Pressure – Ideal Minimum Ratio

$$P_u = \frac{P_w}{10}$$

P_u (Ultimate Pressure, Torr)	P_w (Working Pressure, Torr)
1×10^{-8}	1×10^{-7}
1×10^{-7}	1×10^{-6}
1×10^{-6}	1×10^{-5}
1×10^{-5}	1×10^{-4}
1×10^{-4}	1×10^{-3}
1×10^{-3}	1×10^{-2}

b.) Pressure vs. Maximum Allowable Gas Load – Molecular Flow

$$S_e = \frac{q}{P_u} \rightarrow q = S_e \times P_u$$

$$S_e = 241.062 \text{ L/s for Water Vapor @ } 20\text{C}$$

P (Pressure, Torr)	q (Max Allowable Gas Load, Torr · L/s)
1×10^{-8}	2.411×10^{-6}
1×10^{-7}	2.411×10^{-5}
1×10^{-6}	2.411×10^{-4}
1×10^{-5}	2.411×10^{-3}
1×10^{-4}	2.411×10^{-2}

c.) Pressure vs. Maximum Allowable Gas Load –Transitional Flow

$$S_e = \frac{q}{P_u} \rightarrow q = S_e \times P_u$$

$$S_e = 93.771 \text{ L/s for Water Vapor @ } 20\text{C}$$

P (Pressure, Torr)	q (Max Allowable Gas Load, Torr · L/s)
1×10^{-3}	9.377×10^{-2}
1×10^{-2}	9.377×10^{-1}

2.) Total Gas Load

$$Q_{total} = Q_{volume} + Q_{leak} + Q_{outgas} + Q_{diffusion} + Q_{permeation} + Q_{backstreaming} + Q_{process}$$

→ assuming pumpdown ($Q_{volume} = 0$ for bulk material), $Q_{leak} = 0$, $Q_{diffusion} = 0$, $Q_{backstreaming} = 0$, $Q_{process} = 0$, and long term steady state pumping,

$$Q_{total} = Q_{outgas} + Q_{permeation}$$

$Q_{outgas} = \text{Total Sum of Outgassing Load} \times \text{Area per n Materials in System}$

$$Q_{outgas} = \sum_1^n q_{outgas} \times A$$

a.) Gas Load of Diffusion Pump O-Ring

$$A_{o_ring} = 87.553 \text{ cm}^2 \text{ (viton)}$$

$$L_{o_ring} = 43.888 \text{ cm (viton)}$$

i. Unbaked, Pumped 1hr

$$QR_{outgas_rate_viton} = 8.000 \times 10^{-7} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_o_ring} = 7.004 \times 10^{-5} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 2.787 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{diff_o_ring_total} = 7.283 \times 10^{-5} \text{ Torr} \cdot \text{L/s}$$

ii. Unbaked, Pumped >24hr

$$QR_{outgas_rate_viton} = 2.000 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_o_ring} = 1.751 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 2.787 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{diff_o_ring_total} = 4.538 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

iii. Baked, Pumped >24hr

$$QR_{outgas_rate_viton} = 5.000 \times 10^{-10} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_o_ring} = 4.380 \times 10^{-8} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 2.787 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{diff_o_ring_total} = 2.831 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

b.) Gas Load of Water Cooled Baffle Adapter:

$$A_{baffle_adapter} = 195.996 \text{ cm}^2 \text{ (aluminum)}$$

$$A_{o_ring} = 71.895 \text{ cm}^2 \text{ (viton)}$$

$$L_{o_ring} = 64.819 \text{ cm (viton)}$$

i. Unbaked, Pumped 1hr

$$QR_{outgas_rate_aluminum} = 8.000 \times 10^{-7} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_baffle_adapter} = 1.568 \times 10^{-4} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 8.000 \times 10^{-7} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 5.752 \times 10^{-5} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 4.116 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{baffle_adapter_total} = 2.144 \times 10^{-4} \text{ Torr} \cdot \text{L/s}$$

ii. Unbaked, Pumped >24hr

$$QR_{outgas_rate_aluminum} = 1.000 \times 10^{-10} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_baffle_adapter} = 1.960 \times 10^{-8} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 2.000 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 1.438 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 4.116 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{baffle_adapter_total} = 5.574 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

iii. Baked, Pumped >24hr

$$QR_{outgas_rate_aluminum} = 5.000 \times 10^{-13} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_baffle_adapter} = 9.800 \times 10^{-11} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 5.000 \times 10^{-10} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 3.590 \times 10^{-8} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 4.116 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{baffle_adapter_total} = 4.152 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

c.) Gas Load of Water Cooled Baffle

$$A_{baffle} = 2374.241 \text{ cm}^2 \text{ (stainless steel)}$$

$$A_{o_ring} = 72.528 \text{ cm}^2 \text{ (viton)}$$

$$L_{o_ring} = 65.389 \text{ cm (viton)}$$

i. Unbaked, Pumped 1hr

$$QR_{outgas_rate_stainless_steel} = 5.000 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_baffle} = 1.190 \times 10^{-4} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 8.000 \times 10^{-7} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 5.800 \times 10^{-5} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 4.150 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{baffle_total} = 1.810 \times 10^{-4} \text{ Torr} \cdot \text{L/s}$$

ii. Unbaked, Pumped >24hr

$$QR_{outgas_rate_stainless_steel} = 1.000 \times 10^{-10} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_baffle} = 2.370 \times 10^{-7} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 2.000 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 1.450 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 4.150 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{baffle_total} = 5.840 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

iii. Baked, Pumped >24hr

$$QR_{outgas_rate_stainless_steel} = 3.000 \times 10^{-13} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_baffle} = 7.120 \times 10^{-10} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 3.630 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 8.000 \times 10^{-7} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 4.150 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{baffle_total} = 4.190 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

d.) Gas Load of Plate Adapter

$$A_{plate_adapter} = 366.655 \text{ cm}^2 \text{ (aluminum)}$$

$$A_{o_ring} = 34.872 \text{ cm}^2 \text{ (viton)}$$

$$L_{o_ring} = 36.820 \text{ cm (viton)}$$

i. Unbaked, Pumped 1hr

$$QR_{outgas_rate_aluminum} = 8.000 \times 10^{-7} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_plate_adapter} = 2.933 \times 10^{-4} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 8.000 \times 10^{-7} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 2.790 \times 10^{-5} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 2.338 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{plate_adapter_total} = 3.236 \times 10^{-4} \text{ Torr} \cdot \text{L/s}$$

ii. Unbaked, Pumped >24hr

$$QR_{outgas_rate_aluminum} = 1.000 \times 10^{-10} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_plate_adapter} = 3.667 \times 10^{-8} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 2.000 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 6.974 \times 10^{-7} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 2.338 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{plate_adapter_total} = 3.072 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

iii. Baked, Pumped >24hr

$$QR_{outgas_rate_aluminum} = 5.000 \times 10^{-13} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_plate_adapter} = 1.833 \times 10^{-10} \text{ Torr} \cdot \text{L/s}$$

$$QR_{outgas_rate_viton} = 5.000 \times 10^{-10} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{outgas_viton} = 1.744 \times 10^{-8} \text{ Torr} \cdot \text{L/s}$$

$$QR_{permeation_rate_viton} = 6.350 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}$$

$$Q_{permeation_o_ring} = 2.338 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

$$Q_{plate_adapter_total} = 2.356 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

e.) Gas Load of Blank:

$$A_{blank} = 103.085 \text{ cm}^2 \text{ (stainless steel)}$$

i. Unbaked, Pumped 1hr

$$QR_{outgas_rate_stainless_steel} = 5 \times 10^{-8} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{blank_total} = 5.154 \times 10^{-6} \text{ Torr} \cdot \text{L/s}$$

ii. Unbaked, Pumped >24hr

$$QR_{outgas_rate_stainless_steel} = 1 \times 10^{-10} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{blank_total} = 1.031 \times 10^{-8} \text{ Torr} \cdot \text{L/s}$$

iii. Baked, Pumped >24hr

$$QR_{outgas_rate_stainless_steel} = 3 \times 10^{-13} \text{ Torr} \cdot \text{L/s} \cdot \text{cm}^2$$

$$Q_{blank_total} = 3.093 \times 10^{-11} \text{ Torr} \cdot \text{L/s}$$

f.) TOTAL GAS LOAD:

i. Unbaked, Pumped 1hr

$$Q_{total} = Q_{diff_o_ring_total} + Q_{baffle_adapter_total} + Q_{baffle_total} + Q_{plate_adapter_total} + Q_{blank_total}$$

$$Q_{total} = 7.283 \times 10^{-5} + 2.144 \times 10^{-4} + 1.810 \times 10^{-4} + 3.236 \times 10^{-4} + 5.154 \times 10^{-6}$$

$$Q_{total} = 7.970 \times 10^{-4} \text{ Torr} \cdot \text{L/s}$$

ii. Unbaked, Pumped >24hr

$$Q_{total} = Q_{diff_o_ring_total} + Q_{baffle_adapter_total} + Q_{baffle_total} + Q_{plate_adapter_total} + Q_{blank_total}$$

$$Q_{total} = 4.538 \times 10^{-6} + 5.574 \times 10^{-6} + 5.840 \times 10^{-6} + 3.072 \times 10^{-6} + 1.031 \times 10^{-8}$$

$$Q_{total} = 1.903 \times 10^{-5} \text{ Torr} \cdot \text{L/s}$$

iii. Baked, Pumped >24hr

$$Q_{total} = Q_{diff_o_ring_total} + Q_{baffle_adapter_total} + Q_{baffle_total} + Q_{plate_adapter_total} + Q_{blank_total}$$

$$Q_{total} = 2.831 \times 10^{-6} + 4.152 \times 10^{-6} + 4.190 \times 10^{-6} + 2.356 \times 10^{-6} + 3.093 \times 10^{-11}$$

$$Q_{total} = 1.353 \times 10^{-5} \text{ Torr} \cdot \text{L/s}$$

3.) Maximum Achievable Vacuum During Pumpdown

a.) Unbaked, Pumped 1hr

$$S_e = \frac{q}{P_u}$$

$$P_u = \frac{q}{S_e}$$

$$S_e = 241.062 \text{ L/s for Water Vapor @ 20C in Molecular Flow}$$

$$q = 7.970 \times 10^{-4} \text{ Torr} \cdot \text{L/s Unbaked, Pumped} < 1\text{hr}$$

$$P_u = 3.306 \times 10^{-6} \text{ Torr}$$

b.) Unbaked, Pumped >24hr

$$S_e = \frac{q}{P_u}$$

$$P_u = \frac{q}{S_e}$$

$$S_e = 241.062 \text{ L/s for Water Vapor @ 20C in Molecular Flow}$$

$$q = 1.903 \times 10^{-5} \text{ Torr} \cdot \text{L/s Unbaked, Pumped} > 24\text{hr}$$

$$P_u = 7.896 \times 10^{-8} \text{ Torr}$$

c.) Baked, Pumped >24hr

$$S_e = \frac{q}{P_u}$$

$$P_u = \frac{q}{S_e}$$

$$S_e = 241.062 \text{ L/s for Water Vapor @ 20C in Molecular Flow}$$

$$q = 1.353 \times 10^{-5} \text{ Torr} \cdot \text{L/s Baked, Pumped} > 24\text{hr}$$

$$P_u = 5.612 \times 10^{-8} \text{ Torr}$$

4.) Critical Factor Determination for Feasibility of Pumping System

$$\rightarrow \text{Critical Pumping Speed} \geq 0.01 \text{ L/s/cm}^2$$

$$\rightarrow \text{Critical Pumping Speed} = 241.062 \text{ L/s} / 3039.977 \text{ cm}^2$$

$$\rightarrow \text{Critical Pumping Speed} = 0.079 \text{ L/s/cm}^2 \text{ (only internal area)}$$

$$\rightarrow \text{Critical Pumping Speed} = 241.062 \text{ L/s} / 3306.825 \text{ cm}^2$$

$$\rightarrow \text{Critical Pumping Speed} = 0.073 \text{ L/s/cm}^2 \text{ (including o - ring area)}$$

$$\rightarrow \text{Critical Pumping Speed IS VALID}$$