Design Calculations for Ultimate Pressure and System Gas Load Due to Outgassing for Pumpdown
2.75" Conflat High Vacuum System
Design Iteration #4

1.) Determination that Selected Pump is Appropriately Sized for System

a.) Molecular Flow

$S_{pump} \geq 2S_e$

$S_{pump} = 600\ L/s$

$S_e = 17.043\ L/s\ for\ Water\ Vapor\ @\ 20C$

$\mathbf{600 \geq 34.086}$ → ***VALID***

b.) Transitional Flow

$S_{pump} \geq 2S_e$

$S_{pump} = 100\ L/s$

$S_e = 19.100\ L/s\ for\ Water\ Vapor\ @\ 20C\ @10^{-2}\ Torr$

$\mathbf{100 \geq 38.200}$ → ***VALID***

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

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

$$P_u = \frac{1}{P_w}$$

$\boldsymbol{P_u}$ **(Ultimate Pressure, Torr)**	$\boldsymbol{P_w}$ **(Working Pressure, Torr)**
$\mathbf{1x10^{-8}}$	$\mathbf{1x10^{-7}}$
$\mathbf{1x10^{-7}}$	$\mathbf{1x10^{-6}}$
$\mathbf{1x10^{-6}}$	$\mathbf{1x10^{-5}}$
$\mathbf{1x10^{-5}}$	$\mathbf{1x10^{-4}}$
$\mathbf{1x10^{-4}}$	$\mathbf{1x10^{-3}}$
$\mathbf{1x10^{-3}}$	$\mathbf{1x10^{-2}}$

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

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

$S_e = 17.043\ L/s\ for\ Water\ Vapor\ @\ 20C$

$\boldsymbol{P}$ **(Pressure, Torr)**	$\boldsymbol{q}$ **(Max Allowable Gas Load, Torr · L/s)**
$\mathbf{1x10^{-8}}$	$\mathbf{1.704\ x\ 10^{-7}}$
$\mathbf{1x10^{-7}}$	$\mathbf{1.704\ x\ 10^{-6}}$
$\mathbf{1x10^{-6}}$	$\mathbf{1.704\ x\ 10^{-5}}$
$\mathbf{1x10^{-5}}$	$\mathbf{1.704\ x\ 10^{-4}}$
$\mathbf{1x10^{-4}}$	$\mathbf{1.704\ x\ 10^{-3}}$

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

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

$S_e = 19.100\ L/s\ for\ Water\ Vapor\ @\ 20C$

$\boldsymbol{P}$ ($\boldsymbol{Pressure, Torr}$)	$\boldsymbol{q}$ ($\boldsymbol{Max\ Allowable\ Gas\ Load, Torr \cdot L/s}$)
$\mathbf{1x10^{-3}}$	$\mathbf{1.910\ x\ 10^{-2}}$
$\mathbf{1x10^{-2}}$	$\mathbf{1.910\ x\ 10^{-1}}$

3.) Total Gas Load

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

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

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

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

$$Q_{outgas} = \sum_{1}^{n} q_{outgas} \times A$$

a.) Gas Load of Diffusion Pump O-Ring

$A_{o\_ring} = 87.553\ cm^2\ (viton)$

$L_{o\_ring} = 43.888\ cm\ (viton)$

i. Unbaked, Pumped 1hr

$QR_{outgas\_rate\_viton} = 8 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_o\_ring} = 7.004 \times 10^{-5}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 2.787 \times 10^{-6}\ Torr \cdot L/s$

$\boldsymbol{Q_{diff\_o\_ring\_total} = 7.283 \times 10^{-5} Torr \cdot L/s}$

ii. Unbaked, Pumped >24hr

$QR_{outgas\_rate\_viton} = 2 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_o\_ring} = 1.751 \times 10^{-6}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 2.787 \times 10^{-6}\ Torr \cdot L/s$

$\boldsymbol{Q_{diff\_o\_ring\_total} = 4.538 \times 10^{-6}\ Torr \cdot L/s}$

iii. Baked, Pumped >24hr

$QR_{outgas\_rate\_viton} = 5 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_o\_ring} = 4.380 \times 10^{-8}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 2.787 \times 10^{-6}\ Torr \cdot L/s$

$\boldsymbol{Q_{diff\_o\_ring\_total} = 2.831 \times 10^{-6}\ Torr \cdot L/s}$

b.) Gas Load of Water Cooled Baffle Adapter:

$A_{baffle\_adapter} = 42.563\ cm^2\ (aluminum)$
$A_{o\_ring} = 57.457\ cm^2\ (viton)$
$L_{o\_ring} = 38.402\ cm\ (viton)$

i. Unbaked, Pumped 1hr

$QR_{outgas\_rate\_aluminum} = 8 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$
$QR_{outgas\_rate\_viton} = 8 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$
$Q_{outgas\_baffle\_adapter} = 8.002 \times 10^{-5}\ Torr \cdot L/s$
$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$
$Q_{permeation\_o\_ring} = 2.439 \times 10^{-6}\ Torr \cdot L/s$
$\boldsymbol{Q_{baffle\_adapter\_total} = 8.246 \times 10^{-5} Torr \cdot L/s}$

ii. Unbaked, Pumped >24hr

$QR_{outgas\_rate\_aluminum} = 1 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$
$QR_{outgas\_rate\_viton} = 2 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$
$Q_{outgas\_baffle\_adapter} = 1.153 \times 10^{-6}\ Torr \cdot L/s$
$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$
$Q_{permeation\_o\_ring} = 2.439 \times 10^{-6}\ Torr \cdot L/s$
$\boldsymbol{Q_{baffle\_adapter\_total} = 3.589 \times 10^{-6}\ Torr \cdot L/s}$

iii. Baked, Pumped >24hr

$QR_{outgas\_rate\_aluminum} = 5 \times 10^{-13}\ Torr \cdot L/s \cdot cm^2$
$QR_{outgas\_rate\_viton} = 5 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$
$Q_{outgas\_baffle\_adapter} = 2.870 \times 10^{-8}\ Torr \cdot L/s$
$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$
$Q_{permeation\_o\_ring} = 2.439 \times 10^{-6}\ Torr \cdot L/s$
$\boldsymbol{Q_{baffle\_adapter\_total} = 2.468 \times 10^{-6}\ Torr \cdot L/s}$

c.) Gas Load of Water Cooled Baffle:

$A_{baffle} = 179.454\ cm^2\ (stainless\ steel)$
$A_{o\_ring} = 46.968\ cm^2\ (viton)$
$L_{o\_ring} = 39.24\ cm\ (viton)$

i. Unbaked, Pumped 1hr

$QR_{outgas\_rate\_stainless\_steel} = 5 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$
$QR_{outgas\_rate\_viton} = 8 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$
$Q_{outgas\_baffle} = 4.655 \times 10^{-5}\ Torr \cdot L/s$
$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$
$Q_{permeation\_o\_ring} = 2.492 \times 10^{-6}\ Torr \cdot L/s$
$\boldsymbol{Q_{baffle\_total} = 4.904 \times 10^{-5}\ Torr \cdot L/s}$

ii. Unbaked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 1 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 2 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_baffle} = 9.573 \times 10^{-7}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 2.492 \times 10^{-6}\ Torr \cdot L/s$

$\boldsymbol{Q_{baffle\_total} = 3.449 \times 10^{-6}\ Torr \cdot L/s}$

iii. Baked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 3 \times 10^{-13}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 5 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_baffle} = 2.350 \times 10^{-8}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 2.492 \times 10^{-6}\ Torr \cdot L/s$

$\boldsymbol{Q_{baffle\_total} = 2.516 \times 10^{-6}\ Torr \cdot L/s}$

d.) Gas Load of Plate Adapter

$A_{plate\_adapter} = 29.186\ cm^2\ (aluminum)$

$A_{o\_ring} = 18.281\ cm^2\ (viton)$

$L_{o\_ring} = 13.657\ cm\ (viton)$

i. Unbaked, Pumped 1hr

$QR_{outgas\_rate\_aluminum} = 8 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 8 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_plate\_adapter} = 3.797 \times 10^{-5}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 8.672 \times 10^{-7}\ Torr \cdot L/s$

$\boldsymbol{Q_{plate\_adapter\_total} = 3.884 \times 10^{-5}\ Torr \cdot L/s}$

ii. Unbaked, Pumped >24hr

$QR_{outgas\_rate\_aluminum} = 1 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 2 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_plate\_adapter} = 3.685 \times 10^{-7}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 8.672 \times 10^{-7}\ Torr \cdot L/s$

$\boldsymbol{Q_{plate\_adapter\_total} = 1.236 \times 10^{-6}\ Torr \cdot L/s}$

iii. Baked, Pumped >24hr

$QR_{outgas\_rate\_aluminum} = 5 \times 10^{-13}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 5 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_plate\_adapter} = 9.200 \times 10^{-9}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 8.672 \times 10^{-7}\ Torr \cdot L/s$

$$\boldsymbol{Q_{plate\_adapter\_total} = 8.764 \times 10^{-7}\ Torr \cdot L/s}$$

e.) Gas Load of Cross:

$Assuming\ two\ blanked\ ports\ on\ the\ sides\ for\ simplicity,$

$A_{cross\_main} = 218.032\ cm^2\ (stainless\ steel)$

$A_{cross\_blanks} = 2 \times 10.509\ cm^2\ (stainless\ steel)$

$A_{cross\_total} = 239.050\ cm^2\ (stainless\ steel)$

i. Unbaked, Pumped 1hr

$QR_{outgas\_rate\_stainless\_steel} = 5 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$

$$\boldsymbol{Q_{cross\ total} = 1.195 \times 10^{-5}\ Torr \cdot L/s}$$

ii. Unbaked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 1 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$$\boldsymbol{Q_{cross\ total} = 2.391 \times 10^{-8}\ Torr \cdot L/s}$$

iii. Baked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 3 \times 10^{-13}\ Torr \cdot L/s \cdot cm^2$

$$\boldsymbol{Q_{cross\ total} = 7.172 \times 10^{-11}\ Torr \cdot L/s}$$

f.) Gas Load of Valve:

$A_{valve} = 58.221\ cm^2\ (stainless\ steel)$

$A_{o\_ring} = 18.281\ cm^2\ (viton)$

$L_{o\_ring} = 13.657\ cm\ (viton)$

i. Unbaked, Pumped 1hr

$QR_{outgas\_rate\_stainless\_steel} = 5 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 8 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_valve} = 1.754 \times 10^{-5}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 8.672 \times 10^{-7}\ Torr \cdot L/s$

$$\boldsymbol{Q_{valve\ total} = 1.841 \times 10^{-5}\ Torr \cdot L/s}$$

ii. Unbaked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 1 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 2 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_valve} = 3.714 \times 10^{-7}\ Torr \cdot L/s$

$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$

$Q_{permeation\_o\_ring} = 8.672 \times 10^{-7}\ Torr \cdot L/s$

$$\boldsymbol{Q_{baffle\_valve} = 1.239 \times 10^{-6}\ Torr \cdot L/s}$$

iii. Baked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 3 \times 10^{-13}\ Torr \cdot L/s \cdot cm^2$

$QR_{outgas\_rate\_viton} = 5 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$

$Q_{outgas\_valve} = 9.200 \times 10^{-9}\ Torr \cdot L/s$
$QR_{permeation\_rate\_viton} = 6.35 \times 10^{-8}\ Torr \cdot L/s \cdot cm$
$Q_{permeation\_o\_ring} = 8.672 \times 10^{-7}\ Torr \cdot L/s$
$\boldsymbol{Q_{valve\ total} = 8.764 \times 10^{-7}\ Torr \cdot L/s}$

g.) Gas Load of Chamber:

$A_{chamber\_main} = 314.578\ cm^2\ (stainless\ steel)$
$A_{glass\_viewport} = 10.509\ cm^2\ (glass)$

i. Unbaked, Pumped 1hr

$QR_{outgas\_rate\_stainless\_steel} = 5 \times 10^{-8}\ Torr \cdot L/s \cdot cm^2$
$QR_{outgas\_rate\_glass} = 1 \times 10^{-7}\ Torr \cdot L/s \cdot cm^2$
$\boldsymbol{Q_{cross\ total} = 1.678 \times 10^{-5}\ Torr \cdot L/s}$

ii. Unbaked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 1 \times 10^{-10}\ Torr \cdot L/s \cdot cm^2$
$QR_{outgas\_rate\_glass} = 5 \times 10^{-9}\ Torr \cdot L/s \cdot cm^2$
$\boldsymbol{Q_{cross\ total} = 2.098 \times 10^{-7}\ Torr \cdot L/s}$

iii. Baked, Pumped >24hr

$QR_{outgas\_rate\_stainless\_steel} = 3 \times 10^{-13}\ Torr \cdot L/s \cdot cm^2$
$QR_{outgas\_rate\_glass} = 2 \times 10^{-9}\ Torr \cdot L/s \cdot cm^2$
$\boldsymbol{Q_{cross\ total} = 2.110 \times 10^{-8}\ Torr \cdot L/s}$

h.) TOTAL GAS LOAD:

i. Unbaked, Pumped 1hr

$$Q_{total} = Q_{diff\_o\_ring\_total} + Q_{baffle\_adapter\_total} + Q_{baffle\_total} + Q_{plate\_adapter\_total} + Q_{cross\_total} + Q_{valve\_total} + Q_{chamber\_total}$$
$$Q_{total} = 7.283 \times 10^{-5} + 8.246 \times 10^{-5} + 4.904 \times 10^{-5} + 3.884 \times 10^{-5} + 1.195 \times 10^{-5} + 1.841 \times 10^{-5} + 1.678 \times 10^{-5}$$
$\boldsymbol{Q_{total} = 2.903 \times 10^{-5}\ Torr \cdot L/s}$

ii. Unbaked, Pumped >24hr

$$Q_{total} = Q_{diff\_o\_ring\_total} + Q_{baffle\_adapter\_total} + Q_{baffle\_total} + Q_{plate\_adapter\_total} + Q_{cross\_total} + Q_{valve\_total} + Q_{chamber\_total}$$
$$Q_{total} = 4.538 \times 10^{-6} + 3.589 \times 10^{-6} + 3.449 \times 10^{-6} + 1.236 \times 10^{-6} + 2.391 \times 10^{-8} + 1.239 \times 10^{-6} + 2.098 \times 10^{-7}$$
$\boldsymbol{Q_{total} = 1.428 \times 10^{-5}\ Torr \cdot L/s}$

iii. Baked, Pumped >24hr

$$Q_{total} = Q_{diff\_o\_ring\_total} + Q_{baffle\_adapter\_total} + Q_{baffle\_total} + Q_{plate\_adapter\_total} + Q_{cross\_total} + Q_{valve\_total} + Q_{chamber\_total}$$
$$Q_{total} = 2.831 \times 10^{-6} + 2.468 \times 10^{-6} + 2.516 \times 10^{-6} + 8.764 \times 10^{-7} + 7.172 \times 10^{-11} + 8.764 \times 10^{-7} + 2.110 \times 10^{-8}$$
$\boldsymbol{Q_{total} = 9.589 \times 10^{-6}\ Torr \cdot L/s}$

4.) Maximum Achievable Vacuum During Pumpdown

a.) Unbaked, Pumped 1hr

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

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

$S_e = 17.043\ L/s\, for\ Water\ Vapor\ @\ 20C\ in\ Molecular\ Flow$

$q = 2.903 \times 10^{-5}\ Torr \cdot L/s\ Unbaked, Pumped < 1hr$

$\boldsymbol{P_u = 1.703 \times 10^{-6}\ Torr}$

b.) Unbaked, Pumped >24hr

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

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

$S_e = 17.043\ L/s\, for\ Water\ Vapor\ @\ 20C\ in\ Molecular\ Flow$

$q = 1.428 \times 10^{-5}\ Torr \cdot L/s\ Unbaked, Pumped > 24hr$

$\boldsymbol{P_u = 8.379 \times 10^{-7}\ Torr}$

c.) Baked, Pumped >24hr

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

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

$S_e = 17.043\ L/s\, for\ Water\ Vapor\ @\ 20C\ in\ Molecular\ Flow$

$q = 9.589 \times 10^{-6}\ Torr \cdot L/s\ Baked, Pumped > 24hr$

$\boldsymbol{P_u = 5.626 \times 10^{-7}\ Torr}$

5.) Critical Factor Determination for Feasibility of Pumping System

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

$\rightarrow Critical\ Pumping\ Speed = 17.043\ \ L/s\ /873.561\ cm^2$

$\boldsymbol{\rightarrow Critical\ Pumping\ Speed = 0.020\ \ L/s/cm^2\ \ (only\ internal\ area)}$

$\rightarrow Critical\ Pumping\ Speed = 17.043\ \ L/s\ /1102.101\ cm^2$

$\boldsymbol{\rightarrow Critical\ Pumping\ Speed = 0.015\ \ L/s/cm^2\ \ (including\ o-ring\ area)}$

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