High Vacuum System Engineering Calculations
2.75" Conflat High Vacuum System
Design Iteration #2
Molecular Flow with Air at 20C

CONDUCTANCE CALCULATIONS – MOLECULAR FLOW
(For Use in Standardized System Benchmark Comparisons @ <10^-3 Torr)

1.) Diffusion Pump

→ Max Pumping Speed of Diffusion Pump (Air)

→ $\boldsymbol{S_{diff} = 600\ l/sec}$

2.) Diffusion Pump to 2.75" Conflat Adapter Plate

→ Conductance of a Tube

$$C_m = 3.8(\frac{T}{M})^{\frac{1}{2}}\frac{D^3}{L}$$

C_m = conductance (l/sec)
T = temperature (K) = 293.15
M = molecular mass = 28.971 (average AMU of air)
D = diameter (cm) = 3.556
L = length (cm) = 2.54

$$\boldsymbol{C_m = 213.992\ l/sec}$$

→ Conductance of a Short Tube

$$C_{short} = C_m(1 + \frac{4}{3}\frac{D}{L})^{-1}$$

C_{short} = conductance of short tube (l/sec)
C_m = conductance of a long tube (l/sec) = 213.992
D = diameter (cm) = 3.556
L = length (cm) = 2.54

$$\boldsymbol{C_{short} = 74.649\ l/sec}$$

→ for L/D < 5, above equation is valid for short pipes, with error

$L/D = 0.714$
~+12% error max:

$$C_{shortFinal} = C_{short} \times 0.88$$

$$\boldsymbol{C_{shortFinal} = 65.691\ l/sec}$$

→ $\boldsymbol{C_{adapter} = 65.691\ l/sec}$

3.) 2.75" Conflat Inline Poppet Valve

→ Conductance of a Tube

$$C_m = 3.8(\frac{T}{M})^{\frac{1}{2}}\frac{D^3}{L}$$

C_m = conductance (l/sec)
T = temperature (K) = 293.15

M = molecular mass = 28.971 (average AMU of air)
D = diameter (cm) = 3.556
L = length (cm) = 4.336
$\boldsymbol{C_m = 125.355\ l/sec}$

→ Conductance of a Short Tube

$C_{short} = C_m(1 + \frac{4}{3}\frac{D}{L})^{-1}$

C_{short} = conductance of short tube (l/sec)
C_m = conductance of a long tube (l/sec) = 125.355
D = diameter (cm) = 3.556
L = length (cm) = 4.336
$\boldsymbol{C_{short} = 59.879\ l/sec}$

→ for L/D < 5, above equation is valid for short pipes, with error

$L/D = 1.219$

~+12% error max:

$C_{shortFinal} = C_{short} \times 0.88$

$\boldsymbol{C_{shortFinal} = 52.693\ l/sec}$

→ for L/D < 5, max +8% error for equivalent length straight tube

$L/D = 1.219$

~+8% error max:

$C_{shortFinal} = C_{short} \times 0.92$

$\boldsymbol{C_{shortFinal} = 48.478\ l/sec}$

→ Total Conductance of x2 Equivalent 90 Degree Bends in Series

$C_{poppet\_valve} = \frac{C_{bend\_1} \times C_{bend\_2}}{C_{bend\_1} + C_{bend\_2}}$

$C_{bend\_1} = C_{bend\_2} = C_{ShortFinal} = 48.478\ l/sec$

$\boldsymbol{C_{poppet\_valve} = 24.239\ l/sec}$

→ $\boldsymbol{C_{poppet\_valve} = 24.239\ l/sec}$

4.) 2.75" Conflat Butterfly Valve

→ Conductance of a Tube

$C_m = 3.8(\frac{T}{M})^{\frac{1}{2}}\frac{D^3}{L}$

C_m = conductance (l/sec)
T = temperature (K) = 293.15
M = molecular mass = 28.971 (average AMU of air)
D = diameter (cm) = 3.556
L = length (cm) = 2.54
$\boldsymbol{C_m = 213.992\ l/sec}$

→ Conductance of a Short Tube

$C_{short} = C_m(1 + \frac{4}{3}\frac{D}{L})^{-1}$

C_{short} = conductance of short tube (l/sec)

C_m = conductance of a long tube (l/sec) = 213.992
D = diameter (cm) = 3.556
L = length (cm) = 2.54
$\boldsymbol{C_{short} = 74.649\ l/sec}$

→ for L/D < 5, above equation is valid for short pipes, with error

$L/D = 0.714$
~+12% error max:
$C_{shortFinal} = C_{short} \times 0.88$
$\boldsymbol{C_{shortFinal} = 65.691\ l/sec}$

→ Correction for Equivalent Cross-sectional Obstructed Area of Butterfly Valve at Max Open Position

$Area_{short\_tube} = \pi r^2$
r = 1.778 cm
$\boldsymbol{Area_{short\_tube} = 9.931\ cm^2}$

$Area_{butterly\_valve\_open\_cross\_section} = \pi r^2 - L_1 W_1 - L_2 W_2$
r = 1.778 cm
L_1 = cross-sectional length of butterfly valve shaft = 3.556 cm
W_1 = cross-sectional width of butterfly valve shaft = 0.397 cm
L_2 = cross-sectional length of butterfly valve in max open position from above = 3.556 cm
W_2 = cross-sectional width of butterfly valve in max open position from above = 0.556 cm
$\boldsymbol{Area_{butterly\_valve\_open\_cross\_section} = 6.543\ cm^2}$

$Ratio_{butterfly\_valve\_to\_unimpeded\_pipe} = Area_{butterfly\_valve\_open\_cross\_section} / Area_{short\_tube}$
$\boldsymbol{Ratio_{butterfly\_valve\_to\_unimpeded\_pipe} = 0.658}$

→ Corrected Conductance for Butterfly Valve at Max Open Position

$C_{butterfly\_valve} = C_{short\_final} \times Ratio_{butterfly\_valve\_to\_unimpeded\_pipe}$
$C_{butterfly\_valve} = 65.691 \times 0.658$
$\boldsymbol{C_{butterfly\_valve} = 43.225\ l/sec}$

→ $\boldsymbol{C_{butterfly\_valve} = 43.225\ l/sec}$

5.) 2.75" Conflat 4-Way Cross

→ Conductance of a Tube

$$C_m = 3.8\left(\frac{T}{M}\right)^{\frac{1}{2}} \frac{D^3}{L}$$

C_m = conductance (l/sec)
T = temperature (K) = 293.15
M = molecular mass = 28.971 (average AMU of air)
D = diameter (cm) = 3.556
L = length (cm) = 12.492
$\boldsymbol{C_m = 43.511\ l/sec}$

→ Conductance of a Short Tube

$C_{short} = C_m(1 + \frac{4}{3}\frac{D}{L})^{-1}$

C_{short} = conductance of short tube (l/sec)

C_m = conductance of a long tube (l/sec) = 43.511

D = diameter (cm) = 3.556

L = length (cm) = 12.492

$\boldsymbol{C_{short} = 31.540\ l/sec}$

→ for L/D < 5, above equation is valid for short pipes, with error

$L/D = 3.5$

~+9% error max:

$C_{shortFinal} = C_{short} \times 0.91$

$\boldsymbol{C_{shortFinal} = 28.701\ l/sec}$

→ $\boldsymbol{C_{cross} = 28.701\ l/sec}$

6.) Total System Conductance

→ Conductance of Pipeline

$$\frac{1}{C_{pipeline}} = \frac{1}{C_{adapter}} + \frac{1}{C_{poppet\_valve}} + \frac{1}{C_{butterfly\_valve}} + \frac{1}{C_{cross}}$$

$$\frac{1}{C_{pipeline}} = \frac{1}{65.691} + \frac{1}{24.239} + \frac{1}{43.225} + \frac{1}{28.701}$$

$$\boldsymbol{C_{pipeline} = 8.737\ l/sec}$$

→ $\boldsymbol{C_{pipeline} = 8.737\ l/sec}$

→ Effective Pumping Speed of the System

$$\frac{1}{S_e} = \frac{1}{C_{pipeline}} + \frac{1}{S_{diff}}$$

$$S_e = \frac{C_{pipeline} \times S_{diff}}{C_{pipeline} + S_{diff}}$$

$C_{pipeline} = 8.737\ l/s$

$S_{diff} = 600\ l/s$

$\boldsymbol{S_e = 8.612\ l/s}$

→ $\boldsymbol{S_e = 8.612\ l/sec}$