High Vacuum System Engineering Calculations
2.75” Conflat High Vacuum System
Design Iteration #2
Molecular and Transitional Flow with Deuterium at 20C

CONDUCTANCE CALCULATIONS – MOLECULAR FLOW
(For Use with Injected Deuterium Beam Neutron Systems @ <10^-3 Torr)

1.) Diffusion Pump

→ Max Pumping Speed of Diffusion Pump (Hydrogen)

→ $\boldsymbol{S_{diff} = 800\ l/sec}$

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 = 2.014 (average AMU of deuterium)
D = diameter (cm) = 3.556
L = length (cm) = 2.54

$\boldsymbol{C_m = 811.616\ l/sec}$

→ 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) = 811.616
D = diameter (cm) = 3.556
L = length (cm) = 2.54

$\boldsymbol{C_{short} = 283.122\ l/sec}$

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

$L/D = 0.714$

~+12% error max:

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

$\boldsymbol{C_{shortFinal} = 249.147\ l/sec}$

→ $\boldsymbol{C_{adapter} = 249.147\ l/sec}$

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 = 2.014 (average AMU of deuterium)
D = diameter (cm) = 3.556
L = length (cm) = 4.336
$\boldsymbol{C_m = 475.439\ l/sec}$

→ 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) = 475.439
D = diameter (cm) = 3.556
L = length (cm) = 4.336
$\boldsymbol{C_{short} = 227.105\ l/sec}$

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

$L/D = 1.219$
~+12% error max:
$C_{shortFinal} = C_{short} \times 0.88$
$\boldsymbol{C_{shortFinal} = 199.852\ l/sec}$

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

$L/D = 1.219$
~+8% error max:
$C_{shortFinal} = C_{short} \times 0.92$
$\boldsymbol{C_{shortFinal} = 183.864\ l/sec}$

→ Total Conductance of x2 Equivalent 90 Degree Bends in Series

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

$C_{bend\_1} = C_{bend\_2} = C_{ShortFinal} = 183.864\ l/sec$
$\boldsymbol{C_{poppet\_valve} = 91.932\ l/sec}$

→ $\boldsymbol{C_{poppet\_valve} = 91.932\ l/sec}$

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 = 2.014 (average AMU of deuterium)
D = diameter (cm) = 3.556
L = length (cm) = 2.54
$\boldsymbol{C_m = 811.616\ l/sec}$

→ 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) = 811.616
D = diameter (cm) = 3.556
L = length (cm) = 2.54
$\boldsymbol{C_{short} = 283.122\ l/sec}$

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

$L/D = 0.714$
~+12% error max:
$C_{shortFinal} = C_{short} \times 0.88$
$\boldsymbol{C_{shortFinal} = 249.147\ l/sec}$

→ 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

$C_{butterfly\_valve} = C_{short\_final} \times Ratio_{butterfly\_valve\_to\_unimpeded\_pipe}$
$C_{butterfly\_valve} = 249.147 \times 0.658$
$\boldsymbol{C_{butterfly\_valve} = 163.939\ l/sec}$

→ $\boldsymbol{C_{butterfly\_valve} = 163.939\ l/sec}$

5.) 2.75" Conflat 4-Way Cross

→ 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 = 2.014 (average AMU of deuterium)
D = diameter (cm) = 3.556
L = length (cm) = 12.492
$\boldsymbol{C_m = 165.026\ l/sec}$

→ 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) = 37.054

D = diameter (cm) = 3.556

L = length (cm) = 12.492

$\boldsymbol{C_{short} = 119.623\ l/sec}$

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

$L/D = 3.5$

~+9% error max:

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

$\boldsymbol{C_{shortFinal} = 108.857\ l/sec}$

→ $\boldsymbol{C_{cross} = 108.857\ l/sec}$

6.) TOTAL SYSTEM CONDUCTANCE

→ **Conductance of Pipeline**

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

$$\frac{1}{C_{pipeline}} = \frac{1}{249.147} + \frac{1}{91.932} + \frac{1}{163.939} + \frac{1}{108.857}$$

$$\boldsymbol{C_{pipeline} = 33.137\ l/sec}$$

→ $\boldsymbol{C_{pipeline} = 33.137\ l/sec}$

→ **Effective Pumping Speed of the System**

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

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

$C_{pipeline} = 33.137\ l/s$

$S_{diff} = 800\ l/s$

$\boldsymbol{S_e = 31.819\ l/s}$

→ $\boldsymbol{S_e = 31.819\ l/sec}$