Pressure drop through fast vent line (to vacuum tank) D. Shuman July 19, 2012

From Flow of Fluids , Crane Technical manual TP410M, compressible fluid flow through pipe :

Mass flow rate

This is given by the modified Darcy formula, which includes a net expansion factor Y to account for expansion along the pipe.

$$w := 1.111 \cdot 10^{-6} \cdot Y \cdot d^2 \cdot \sqrt{\frac{\Delta P}{K \cdot V_1}}$$ for pipe ID d in mm, w in kg/s, ΔP in bar, V1 in m^3/kg eq 1-11

or in consistent units:

$$w := 1.111 \cdot Y \cdot d^2 \cdot \sqrt{\frac{\Delta P}{K \cdot V_1}}$$

Specific volume

$$V_1 := \rho_{Xe}^{-1} \qquad V_1 = 0.011 \frac{m^3}{kg} \qquad \rho_{Xe} = 0.091 \frac{gm}{cm^3}$$

Dimensions

length of pipe to tank line inner diameter , standard IPS 3.5 inch (90 mm) schedule 10s (300psi rated)

$$L_v := 4m \qquad D_v := 95.5mm \quad d := D_v$$

seismic loop length diameter

$$L_{sl} := 1m \qquad d_{sl} := 4in$$

Resistance coefficients, K

These are dimensionless and represent equivalent lengths of pipe in units of (nom. vent pipe diameter*friction factor).

entrance and exit coefficients are limiting cases of 0.5 (entrance) and 1.0 (exit)

$$K_{en} := 0.5 \qquad K_{ex} := 1$$

nozzle pipe, ID, length:

$$d_n := 50mm \qquad L_n := 1m$$

friction factor, table on pg A-26, 3.5 inch commercial steel pipe, assume complete turbulence

$$f_{tn} := .018$$

$$K_n := f_{tn} \cdot \frac{L_n}{d_n} \qquad K_n = 0.36$$

since the nozzle diameter is different from the nominal vent pipe diameter, it must be adjusted using the following formula:

$$K_{ne} := K_n \cdot \left(\frac{D_v}{d_n}\right)^4 \qquad K_{ne} = 4.791$$ eq 2-5

pipe, main vent line to tank

$$f_t := .017$$

$$K_p := f_t \cdot \left(\frac{L_v}{D_v}\right) \qquad K_p = 0.712$$

seismic loop, bellows sections, assume no liner absolute roughness

$\varepsilon_{sl} := 5\text{mm}$

relative roughness

$$\varepsilon ovrd := \frac{\varepsilon_{sl}}{D_v} \qquad \varepsilon ovrd = 0.052$$

from Moody chart, friction factor:

$f_{sl} := .07$

$$K_{sl} := f_{sl} \cdot \frac{L_{sl}}{D_v} \qquad K_{sl} = 0.733$$

<u>vent valve</u>

for typ globe valve:

$K_{v\_gv} := 340 f_t \quad K_{v\_gv} = 5.78$

but we can convert mfrs. given flow coefficient as follows:

Danfoss gives flow coefficients for their ICS solenoid valves (80mm and 100mm exit dia, respectively):

$$C_{v\_ics80} := 98 \frac{\text{gal}}{\text{min} \cdot \text{psi}} \qquad C_{v\_ics100} := 161 \frac{\text{gal}}{\text{min} \cdot \text{psi}}$$

We choose the 80mm valve, which is much smaller and lighter than the 100mmm valve.

Crane gives a conversion formula:

$$C_v := \frac{29.9 d^2}{\sqrt{K}}$$

for Cv in gal(water@60F)/(min*psi) d ID in inchs

K is then dimensionless when d is expressed in same units as pipe

$$K_v := \frac{891 \cdot d^4}{C_v^{\,2}} \qquad K_v := \frac{891 \cdot \left(\frac{d}{\text{in}}\right)^4}{98^2} \qquad K_v = 18.54$$

<u>Bends</u>, each bend creates an additional flow resistance

number of bends (in units of 90 deg)

$n_b := 6$ for each bend: $K_b := 20 f_t$

bend total:

$K_{bt} := n_b \cdot K_b \qquad K_{bt} = 2.04$

Total Flow coefficient

$K_t := K_{en} + K_{ne} + K_v + K_{sl} + K_p + K_{bt} + K_{ex} \quad K_t = 28.3$

Net expansion factor

$Y := .72$ invariant with increasing γ @ K=20, of charts on page A-22

Maximum operating pressure

$MOP = 15\,\text{bar}$ absolute

Sonic pressure limit (choked flow)

$\Delta PovrP'_1 := .86$ est. by extrapolating to $\gamma = 1.67$ (monatomic gas); K=20, of charts on page A-22

$\Delta P := \Delta PovrP'_1 \cdot MOP \qquad \Delta P = 12.9\,\text{bar}$

Mass flow rate, initial

$$w := 1.111 Y \cdot d^2 \cdot \sqrt{\frac{\Delta P}{K_t \cdot V_1}} \qquad w = 14.9 \frac{kg}{s}$$

This flow is less than the original crude estimate of 25 kg/s, which would save ~80% of the Xe if the valve was actuated immediately on sensing a leak of ~4 kg/s through a broken 41 pin multipin feedthrough (high pressure on one side and outside ambient air on the other).

However we now do not have, nor forsee using any of these feedthroughs in such a configuration, so the risk of a sudden high flow leak is greatly reduced. The ribbon cable feedthroughs and the HV feedthroughs,are both made of ductile materials, and are designed with integral positive mechanical stops, and so are not likely to fail catastrophically, should they fail. Further, they both have leak check ports and should show leakage well before any gross failure occurs.

To gain an increase in vent flow we would need to use a larger valve and increase the piping diameter dowstream from the valve. This will move the lead shielding extensions further out, increasing their size and weight. My current feeling is that this is not warranted.