

Pressure drop through fast vent line (to vacuum tank)

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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.

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

or in consistent units:

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

Specific volume

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

Dimensions

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

$$L_v := 4\text{m} \quad D_v := 95.5\text{mm} \quad d := D_v$$

seismic loop length diameter

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

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)

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

nozzle pipe, ID, length:

$$d_n := 95\text{mm} \quad L_n := 1\text{m}$$

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

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

$$K_n := f_{tn} \cdot \frac{L_n}{d_n} \quad K_n = 0.189$$

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

$$K_{ne} := K_n \cdot \left(\frac{D_v}{d_n} \right)^4 \quad K_{ne} = 0.193 \quad \text{eq 2-5}$$

pipe, main vent line to tank

$$f_t := .017$$

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

seismic loop, bellows sections, assume no liner

absolute roughness

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

relative roughness

$$\epsilon_{ovrd} := \frac{\epsilon_{sl}}{D_v} \quad \epsilon_{ovrd} = 0.052$$

from Moody chart, friction factor:

$$f_{sl} := .07$$

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

vent valve

for typ globe valve:

$$K_{v_gv} := 340f_t \quad K_{v_gv} = 5.78$$

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):

$$C_{v_ics80} := 98 \frac{\text{gal}}{\text{min} \cdot \text{psi}} \quad C_{v_ics100} := 161 \frac{\text{gal}}{\text{min} \cdot \text{psi}} \quad \text{We choose the 80mm valve, which is much smaller and lighter than the 100mm valve.}$$

Crane gives a conversion formula:

$$C_v := \frac{29.9d^2}{\sqrt{K}} \quad \text{for } C_v \text{ in gal(water@60F)/(min} \cdot \text{psi)} \quad d \text{ ID in inches}$$

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

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

Bends, each bend creates an additional flow resistance

number of bends (in units of 90 deg)

$$n_b := 6 \quad \text{for each bend: } K_b := 20f_t$$

bend total:

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

Total Flow coefficient

$$K_t := K_{en} + K_{ne} + K_v + K_{sl} + K_p + K_{bt} + K_{ex} \quad K_t = 23.7$$

Net expansion factor

$$Y := .72 \quad \text{invariant with increasing } \gamma @ K=20, \text{ of charts on page A-22}$$

Maximum operating pressure

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

Sonic pressure limit (choked flow)

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

$$\Delta P := \Delta P_{ovrP'_1} \cdot \text{MOP} \quad \Delta P = 12.9 \text{ bar}$$

Mass flow rate, initial

$$w := 1.111Y \cdot d^2 \cdot \sqrt{\frac{\Delta P}{K_t \cdot V_1}} \quad w = 16.2 \frac{\text{kg}}{\text{s}}$$

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 foresee 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 downstream 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.