Argon Dewar Relief
Set Pressure
Modification

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Overview:

This engineering note documents the calculations of Kelly Dixon, used to determine the maximum allowable set pressure for the argon dewar low relief valve, tag number PSV620A, Anderson Greenwood Type 526J. The original setting was 16 psig. This value was chosen in order to protect against cryostat overpressurization by the source dewar (see DØ Engineering Note 115), however, the following calculations will show that the set pressure can be raised to approximately 18.5 psig, which would result in a faster filling of the cryostat, along with a higher level of liquid argon. Three other engineering notes were revised to reflect the change in set pressure according to this note. They are notes 115, 219, and 263.

Revision, 4/2/91: Previously, it was determined that the set pressure could be raised to approximately 18.5 psig without problems. However, later on there was a concern for the heat leak caused by the internal geometry of the EC's. Basically, the results in this note hold true for the CC because as the argon gas flows up to the cryostat relief valve, it has more tendency to flow around the outside of the array within the cryostat, rather than between plates in the modules. The geometry of the EC's allows more argon to flow between module plates in the cryostats, which results in a much greater heat leak because of the large surface area. Therefore, the decision was made to keep the dewar relief set pressure at a smaller value, chosen at this time to be the original 16 psig. Consequently, engineering notes 115, 219, and 263 were not revised as stated above, and this note serves merely as a reference for future considerations. It should also be noted that the heat leak is significantly reduced if the EC's are cooled first. This option was not pursued at this time.

Explanation of Calculations:

The first two pages estimate the initial exit temperature when flashing liquid on the CC bottom. This is necessary in order to find the mass flow rate at the correct temperature. The resulting temperature is

$$T_e = 113K = 203^{\circ}R$$

On page 3, the maximum flow rate at the CC cryostat relief valve is calculated. The original flow rate was calculated at $170^{\circ}R$ by Russ Rucinski (see engineering note 263). This was converted to the mass flow rate at the correct temperature calculated above. That mass flow rate was then converted to the corresponding volume flow rate in gallons per minute.

$$q = 13.1 \text{ gpm}$$

Page 4 shows the calculation of the friction factor, f , which will be needed later to find the loss coefficient.

$$f = 0.027$$

Pages 5 and 6 show the calculation of the equivalent length of piping including all valves and other instruments on the line between the argon dewar and the CC cryostat. The sum of the equivalent lengths of piping and fittings is

$$L_{eq} = 386 \text{ ft}$$

Page 7 finds the total loss coefficient, or the resistance coefficient, ΣK . This will be used later in the pressure drop equation for incompressible fluids,

$$\Delta p_{\text{piping}} = \frac{\rho v^2}{2g_c} \Sigma K$$

The loss coefficient is calculated using the equivalent piping length, along with the friction factor, f , and the pipe diameter. The resulting total loss is

$$\Sigma K = 100.7$$

On page 8, various Δp pressure differences are calculated. First, the Δp due to the difference in elevation is found. Then the Δp_{op} and Δp_{rel} are found. The operating pressure difference is not necessary for calculations, but is included for completeness. The maximum operating flow can be shown to be 27.2 gpm. Δp_{filter} is calculated based on numbers from actual experience. The $\Delta p_{\text{available}}$ can then be found in terms of P_{dewar} , which is the unknown maximum relief set pressure.

$$\Delta p_{\text{available}} = P_{\text{dewar}} - 15.7 \text{ psi}$$

Conclusion:

Based on the calculations, the argon dewar low relief valve set pressure can be raised to a maximum of approximately 18.5 psig. This new setting will not affect the safety aspects of the argon dewar or the cryostat. As stated in the 2nd revision note appended to engineering note 219, with respect to the argon dewar, the inlet and exit pressure drops will increase. However, the valve will not chatter since the pressure is sensed remotely. In addition, the calculations done for the CC cryostat show that the maximum flow rate of 13.1 gpm for the CC relief valve corresponds to a differential pressure of 18.7 psig. The result of the higher setting will be a slightly increased flow through the relief, and mainly an increased flow to the CC during filling, and a higher level of liquid argon attainable.

$$Nu_{av} = \frac{h_{av} l}{k} = 0.664 Re_L^{1/2} Pr^{1/3}$$

$$= (0.664)(3.5 \times 10^5)^{1/2} (0.669)^{1/3}$$

$$= 344$$

eqn. 8.46a.

Engineering Heat
Transfer, Karlekar
& Desmond, 1977

$$h_{av} = \frac{k Nu_{av}}{l} = \frac{(0.121 \times 10^{-3} \text{ W/cm} \cdot \text{K})(344)}{739 \text{ cm}}$$

$$= 5.63 \times 10^{-5} \text{ W/cm}^2 \cdot \text{K}$$

$$q = h_{av} A_s (T_m - T_u)$$

$$= (5.63 \times 10^{-5} \text{ W/cm}^2 \cdot \text{K})(3.0 \times 10^5 \text{ cm}^2)(95 \text{ K} - 290 \text{ K})$$

$$= -3290 \text{ W}$$

$$q' = q \times 2 \quad \text{since flow against "two flat plates"}$$

$$q' = 6580 \text{ W}$$

$$q' = \dot{m} c_p \Delta T \quad \Delta T = (95 - T_e)$$

$$\Delta T = \frac{q'}{\dot{m} c_p} \quad c_p = 0.60 \text{ J/g} \cdot \text{K} @ 100 \text{ K}$$

$$= \frac{-6580 \text{ W}}{(605 \text{ g/s})(0.6 \text{ J/g} \cdot \text{K})} =$$

$$\Delta T = -18 \text{ K}$$

$$\boxed{T_e = 113 \text{ K}}$$

Max. Flowrate at CC
Cryostat Relief Valve

$$\dot{m} = 9600 \text{ lbm/hr}$$

[maximum mass flow
rate of saturated argon
gas @ 170°R]

$$\dot{m}_{\text{actual}} = 9600 \text{ lbm/hr} \left(\frac{170^\circ\text{R}}{203^\circ\text{R}} \right)^{\frac{1}{2}} \quad \left[\text{max. flowrate} \right. \\ \left. @ 203^\circ\text{R} \right]$$

see Exit Temp. Calculation

$$= 8800 \text{ lbm/hr}$$

$$\rho_{\text{LAr @ 2.3 bars}} = 83.9 \text{ lbm/ft}^3 \quad \left[\text{density of} \right. \\ \left. \text{liquid argon} \right]$$

$$\dot{V}_{\text{liquid}} = \frac{8800 \text{ lbm/hr}}{83.9 \text{ lbm/ft}^3} = 105 \text{ ft}^3/\text{hr} = 13.1 \text{ gpm}$$

$$\Rightarrow \boxed{q = 13.1 \text{ gpm}}$$

Calculation of Friction Factor, f

$$R_{d \text{ relieving}} = \frac{\rho V_{rel} d}{\mu}$$

where R_d = Reynolds Number
 μ = viscosity

$$\mu = 0.0024 \frac{\text{g}}{\text{cm} \cdot \text{s}} \quad @ \quad P_{sat} = 1.3 \text{ bars}$$

$$= 0.58 \frac{\text{lb}_m}{\text{ft} \cdot \text{hr}}$$

$$= 1.61 \times 10^{-4} \frac{\text{lb}_m}{\text{ft} \cdot \text{s}}$$

$$V_{rel} = \frac{q_{rel}}{A}$$

$$= \frac{(13.1 \text{ gpm}) \left(\frac{1 \text{ ft}^3/\text{s}}{448.8 \text{ gpm}} \right)}{\frac{\pi (0.14 \text{ ft})^2}{4}}$$

$$R_d = \frac{(86 \frac{\text{lb}_m}{\text{ft}^3}) (1.90 \frac{\text{ft}}{\text{s}}) (0.14 \text{ ft})}{1.61 \times 10^{-4} \frac{\text{lb}_m}{\text{ft} \cdot \text{s}}}$$

$$R_d = 1.42 \times 10^5$$

$$\Rightarrow \boxed{f = 0.027}$$

Calculation of Equivalent Length of Piping

l_{eq} Calculation (cont.)

$$l_{\text{piping}} = l_{\text{total}}^{1.7" \phi} + l_{\text{total}}^{1" \phi}$$

$$l_{\text{total}}^{1.7" \phi} = 169 \text{ ft}$$

$$l_{\text{total}}^{1" \phi} = \left(\frac{1.68}{1.05} \right)^5 \times 4' = 42'$$

$$l_{\text{piping}} = 169 + 42 = 211 \text{ ft}$$

$$l_{\text{fittings}} = [(29 \times 30) + (5 \times 16) + (3 \times 20) + (4 \times 60)] 0.14 \text{ ft}$$

$$= 175 \text{ ft}$$

accounts
for
flowmeters

$$\Rightarrow \boxed{l_{eq} = 211 + 175 = 386 \text{ ft}}$$

Calculation of ΣK - Total Loss

$$\Delta P_{\text{piping}} = \frac{\rho V^2}{2g_c} \underbrace{\Sigma K}_{\text{total loss}}$$

$$K_{\text{piping + fittings}} = f \frac{L_{eq}}{d} \left[\text{Crane Technical Paper No. 410} \right. \\ \left. \text{p. 2-8, Eq. 2-4} \right]$$

where K = total loss

f = friction constant

L_{eq} = equivalent piping length

d = inner pipe diameter

$$f = 0.027$$

$$K_{\text{piping + fittings}} = (0.027) \frac{386}{0.140} = 74.4$$

$$K_{\text{inlet}} = 0.5 \quad \text{and} \quad K_{\text{outlet}} = 1.0$$

$$K_{\text{valves}} = \left(\frac{29.9 d^2}{C_v} \right)^2 \times 4 = \left(\frac{29.9 (1.682)^2}{34} \right)^2 \times 4$$

$$= 24.8 \quad \left[\text{Crane Technical Paper No. 410} \right. \\ \left. \text{p. 2-8 Eq. 2-5} \right]$$

$$\Sigma K = 74.4 + 1.5 + 24.8$$

$$\Rightarrow \boxed{\Sigma K = 100.7}$$

Some Δp Calculations

$$\begin{aligned} \text{max. head available} &= 720.3' \text{ (dewar @ 16,000 gallons)} \\ &\quad - 715.2' \text{ (bottom of cell)} \\ &\quad \underline{\hspace{1cm}} \\ &\quad 5.1' \end{aligned}$$

$$\Delta p \text{ due to head} = 5.1 \text{ ft} \times 0.6 \frac{\text{psi}}{\text{ft}} = 3.1 \text{ psi}$$

$$\begin{aligned} \Delta p / \text{operational} &= (14 \text{ psig} + 14.7) - (1 \text{ psig} + 14.7) + 3.1 \text{ psi} \\ &= 16.1 \text{ psid} \end{aligned}$$

$$\begin{aligned} \Delta p / \text{max. relieving} &= (P_{\text{dewar}} + 14.7) - (18 \text{ psig} + 14.7) + 3.1 \text{ psi} \\ &= P_{\text{dewar}} - 14.9 \text{ psi} \end{aligned}$$

Actual experience shows @ 30 gpm flow, the Δp across a cryo filter is 4 psid.

$$\begin{aligned} \Delta p_{\text{filter}} &= \left(\frac{9 \text{ gpm}}{30 \text{ gpm}} \right)^2 4 \text{ psid} = \left(\frac{13.1}{30} \right)^2 4 \\ &= 0.763 \text{ psid} \end{aligned}$$

$$\begin{aligned} \Delta p_{\text{available}} &= \Delta p / \text{max. relieving} - \Delta p_{\text{filter}} \\ &= P_{\text{dewar}} - 14.9 - 0.763 \\ &= P_{\text{dewar}} - 15.7 \text{ psi} \end{aligned}$$

(cont.)

Δp Calculations (cont.)

$$\Delta p_{\text{piping}} = \frac{\rho v^2}{2g_c} \sum K$$

where ρ = density of argon in storage dewar @ $P_{\text{sat}} \approx 18.5 \text{ psig} \approx 1.3 \text{ bars}$

v = velocity in ft/s

$g_c = 32.2 \frac{\text{ft} \cdot \text{lb}_m}{\text{s}^2 \cdot \text{lb}_f}$ = conversion factor

$\sum K$ = total loss coefficient

$$v^2 = \frac{Q^2}{A^2} = \frac{16Q^2}{\pi^2 d^4}$$

$$\Delta p_{\text{piping}} = \frac{16Q^2 \rho}{2g_c \pi^2 d^4} \sum K = \frac{8Q^2 \rho \sum K}{g_c \pi^2 d^4} \quad \rho @ 1.3 \text{ bars}$$

$$= \frac{8(13.1 \text{ gpm})^2 \left(\frac{1 \text{ ft}^3/\text{s}}{448.8 \text{ gpm}} \right)^2 (86 \frac{\text{lb}_m}{\text{ft}^3} \times 100.7)}{\left(32.2 \frac{\text{ft} \cdot \text{lb}_m}{\text{s}^2 \cdot \text{lb}_f} \right) (\pi^2 (0.14 \text{ ft})^4)}$$

$$= 483.5 \frac{\text{lb}_f}{\text{ft}^2}$$

$$= 3.4 \text{ psi}$$

$$\Delta p_{\text{available}} = \Delta p_{\text{piping}}$$

$$P_{\text{dewar}} - 15.7 = 3.4$$

$$\Rightarrow P_{\text{dewar}} = 19.1 \text{ psig}$$

Analysis of Actual Data

point from graph with highest flow rate for smallest differential pressure is at
(2.74 psid, 8.43 gpm)

$$\text{let } \Delta P_{\text{actual}} = 2.74 \text{ psid}$$

$$q_{\text{actual}} = 8.43 \text{ gpm}$$

$$\text{from before, } \Delta P_{\text{driving}} = 4.2 \text{ psid}$$

$$q_{\text{maximum}} = 13.1 \text{ gpm}$$

let q_{calc} = calculated flow rate
scaled from actual data

$$q_{\text{calc}} = q_{\text{actual}} \sqrt{\frac{\Delta P_{\text{driving}}}{\Delta P_{\text{actual}}}} = 8.43 \sqrt{\frac{4.2}{2.74}}$$

$$= 10.44 \text{ gpm} < 13.1 \text{ gpm}$$

$q_{\text{calc}} < q_{\text{maximum}}$, so the actual flow rates are less than the maximum calculated, and

$P_{\text{dewar}} = 19.1 \text{ psig}$ is a conservative value.