Argon Dewar Required Relief Flow Capacity

J.B. Fitzpatrick

9/28/87

D-Zero Engineering note 3740.512-EN-111

REVISED 10/22/87

Approved: Tom Peterson
INTRODUCTION:

This report calculates the required fire relief valve flow capacity, the required vaporizer failure relief valve flow capacity, and the required loss of vacuum relief valve flow capacity of the liquid argon storage tank in use at the D-Zero site.

REQUIRED FIRE RELIEF FLOW CAPACITY:

The required flow capacity under fire conditions is given by the largest of the following values for Q, since the annular space may consist of any of these gases under different failure conditions:

\[
\begin{align*}
Q_{\text{air}} &= G_{\text{argon}} \times U_{\text{air}} \times A^{0.82} \\
Q_{\text{nitrogen}} &= G_{\text{argon}} \times U_{\text{nitrogen}} \times A^{0.82} \\
Q_{\text{argon}} &= G_{\text{argon}} \times U_{\text{argon}} \times A^{0.82}
\end{align*}
\]

where \( Q \) is the flow capacity in cubic feet per minute of free gas (SCFM), \( G \) is the gas factor, \( U \) equals the thermal conductivity (denoted by \( K \)) (Btu/hr-ft-°F) of one atmosphere of 1200°F gas divided by the annular space (denoted as \( \Delta R \)) (in.), and \( A \) is the surface area of the inner vessel (ft²).

REQUIRED VAPORIZER FAILURE RELIEF FLOW CAPACITY:

The vaporizer is sized to maintain a constant pressure in the inner vessel while a maximum of 40 GPM of liquid Argon is being removed. Thus, it vaporizes a small amount of liquid to provide a maximum of 40 GPM of Argon gas. If it gets "stuck" at full flow when no liquid is being withdrawn, this 40 GPM of gas would have to be relieved.
REQUIRED LOSS OF VACUUM FLOW CAPACITY, WITH INSULATION:

This case involves the heat transfer by conduction through air (at one atmosphere and ambient temperature through a distance equal to the annular space (ΔR)) to the inner vessel of surface area A, filled with L_{Ar}, that may boil off and create a pressure that must be relieved.

using; \[ \text{Heat Transfer (conduction)} = U \times A \times ΔT \]

and the latent heat of vaporization of Argon and its density, the flow capacity can be calculated.

CALCULATED REQUIRED FLOW CAPACITIES

<table>
<thead>
<tr>
<th>Condition</th>
<th>Q (SCFM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Conditions</td>
<td>202.2 (AIR)</td>
</tr>
<tr>
<td>Vaporizer Failure</td>
<td>6.89 (AIR)</td>
</tr>
<tr>
<td>Loss of Vacuum</td>
<td>27.75 (AIR)</td>
</tr>
</tbody>
</table>
METHOD OF CALCULATIONS FOR FIRE CONDITIONS:

The largest value for $Q$ results in the case of $Q_{\text{nitrogen}}$. The following explains this worst case calculation. The other cases are attached for comparison at the end of this report.

Proceed as follows using:

1. $Q = G_1 \times U \times A^{0.82}$
2. $T_R = T_F + 459.67$
3. $U = K/A_R$

1) Gas constant, $G_1 = 10.2$ (see ref. 1)

2) Thermal conductivity, $K = 0.0313 \text{ Btu/(hr \cdot \circ F \cdot ft^2)}$ (see ref. 5)

Due to the fact that, according to ref. 5, their exists a near direct linear relationship between temperature and thermal conductivity, a linear extrapolation of the data in ref. 5, will reveal the above stated value for $K$ (see calculations)

3) Annular space, $A_R = 0.350 \text{ ft.}$

The annular space is calculated via the capacity of the inner vessel given in ref. 3, and involves the solution of a cubic equation (see calculations)

4) $U = 0.0376 \text{ Btu/(hr \cdot \circ F \cdot ft^2)}$, $U = K/A_R$

5) Area, $A = 1688.6 \text{ ft.}^2$

The area $A$ was computed considering the inner vessel to be a cylinder with semi-ellipsoidal heads, and using surface area = (overall length + $0.3 \times \text{O.D.} \times \text{O.D.} \times \pi$; Note this area is the safest approximation while we are not given any information on the nature of the heads (i.e. hemispherical, semi-ellipsoidal, etc...)

6) Fire Flow Capacity, $Q = 170.0 \text{ SCFM-argon} = 202.2 \text{ SCFM-air}$, via formula (see ref. 6 also)
METHOD OF CALCULATIONS FOR VAPORIZER FAILURE CONDITIONS:

\[ Q = 6.22 \text{ SCFM-argon} = 6.89 \text{ SCFM-air} \]

If the vaporizer were "stuck" at full flow, delivering 40 GPM of vapor to the inner vessel, and liquid Argon was not being withdrawn, a 40 GPM volume of Argon gas would have to be relieved. This is a simple conversion from gallons per minute of gas to standard cubic feet per minute of gas. (see calculations and ref. 6)

METHOD OF CALCULATIONS FOR LOSS OF VACUUM CONDITION:

\[ Q = 25.03 \text{ SCFM-argon} = 27.75 \text{ SCFM-air} \]

Using the previously stated formula's, the above results were obtained. (see calculations)

CONCLUSIONS:

Based on the calculations presented in this report, a relief device for the liquid argon dewar needs to handle a flow of 202.2 SCFM-air when considering an unexpected condition such as fire. The primary relief device that handles expected modes of failure should be sized to handle a flow of 27.75 SCFM-air when considering loss of vacuum or vaporizer failure independently.
REFERENCES


7. Cryenco, Cryogenic Data Chart, Denver, Colorado.
CALCULATE $\Delta R$, THE ANNULAR SPACE

Given capacity is 29,000 gal for inner vessel (Ref. 4)

or: $29,000 \text{ gal} \times \frac{3.785 \times 10^{-3} \text{ m}^3}{1 \text{ ft}^3} \times \frac{35.33}{1 \text{ m}^3} = 2674.77 \text{ ft}^3$

So: $V = 2674.77 = (L_o - 2\Delta R)\pi (O.D. - \Delta R)^2$

$L_o = 50.75 \text{ ft. (Outer vessel length from blueprint)}$

$O.D. = 10 \text{ ft.} \therefore \text{So O.R = 50.0 ft.}$

So: $2674.77 = (50.75 - 2x)\pi (5.00 - x)^2$

Solve for $\Delta R$ (let $\Delta R = x$)

$2674.77 = (50.75 - 2x)\pi (5.00 - x)^2$

$851.41 = (50.75 - 2x)(5.00 - x)^2$

$= 50.75(5.00-x)^2 - 2x(5.00-x)^2$

$= 50.75(25.00 - 10.00x + x^2)$

$- 2x(25.00 - 10.00x + x^2)$

$851.41 = 1263.75 - 507.5x + 50.75x^2 - 50x + 20x^2 - 2x^3$

$0 = 2x^3 - 70.75x^2 + 557.5x - 417.34$

$0 = x^3 - 35.38x^2 + 278.75x - 208.67$

By Trial & Error: 

$x_i = 0 \quad \quad x_f = 0.7486 \quad \quad x_i = 0.7486 \quad \quad x_f = 0.8182$

$x_f = 0.8316 \quad \quad x_f = 0.8343 \quad \quad x_f = 0.8348 \quad \quad x_f = 0.8349 \quad \quad x_f = 0.8349$

Take $x = 0.8350$

So $\Delta R = 0.8350 \text{ ft.}$
**Area Considerations**

1. Consider a cylindrical container with hemispherical heads.
   \[ A = L_o \times (O.D.) \times \pi \]
   \[ = 50.75 \times (10.00) \times \pi \]
   \[ = 1594.36 \text{ ft}^2 \]

2. Consider a cylindrical container with semi-ellipsoidal heads.
   \[ A = (L_o + 0.3(O.D.)) \times (O.D.) \times \pi \]
   \[ = [50.75 + 0.3(10.0)] \times (10.0) \times \pi \]
   \[ = 1688.6 \text{ ft}^2 \]

3. Consider just a cylinder with flat ends.
   \[ A = L_i \times (2\pi)(I.R.) + 2\pi(I.R.)^2 \]
   \[ L_i = L_o - 2\Delta R = 50.75 - 2(8.350) = 49.08 \text{ ft} \]
   \[ I.R. = O.R. - \Delta R = 5.00 - 8.350 = 4.165 \text{ ft} \]
   \[ A = (49.08)(2\pi)(4.165) + 2\pi(4.165)^2 \]
   \[ A = 1393.39 \text{ ft}^2 \]

**Conclusion:** Use the largest area in calculations.
Calculate THE Fire Relief Flow capacity of Argon Denua

**Case 1:** \( Q_{\text{air}} = (G_{\text{argon}}, (U_{\text{air}})(A^{0.82}) \)

\[
U_{\text{air}} = \frac{K_{\text{air}}(1200\ F^o)}{\Delta R} \quad \text{(See Ref. 2)}
\]

\[
K_{\text{air}}(1200\ F^o) = K_{\text{air}}(1000\ F^o) + \left[ \frac{(K_{\text{air}}(1500\ F^o) - K_{\text{air}}(1000\ F^o))}{500\ F^o} \right] \times \frac{200\ F^o}{500\ F^o}
\]

\[
K_{\text{air}}(1200\ F^o) = .0351 \ \frac{\text{Btu}}{\text{hr-ft-F}^o}
\]

\[
U_{\text{air}} = .0351 = .0470 \ \frac{\text{Btu}}{\text{hr-F}^o}
\]

\[
A^{0.82} = (1688.6)^{0.82} \approx 443.2
\]

\[
[Q_{\text{air}}] = (10.2)(.0470)(443.2) = 189.9 \text{ ScFM-air}
\]

**Case 2:** \( Q_{\text{nitrogen}} = (G_{\text{argon}}, (U_{\text{nitrogen}})(A^{0.82}) \)

\[
G_{\text{argon}} = 10.2
\]

\[
U_{N_2} = \frac{K_{N_2}(1200\ F^o)}{\Delta R} \quad \text{(See Ref. 2)}
\]

\[
K_{N_2}(1200\ F^o) = K_{N_2}(1000\ F^o) + \left[ (K_{N_2}(1500\ F^o) - K_{N_2}(1000\ F^o)) \times \frac{200\ F^o}{500\ F^o} \right]
\]

\[
K_{N_2}(1200\ F^o) = .0367 \ \frac{\text{Btu}}{\text{hr-ft-F}^o}
\]

\[
U_{N_2} = .0367 = .0439 \ \frac{\text{Btu}}{\text{hr-F}^o}
\]

\[
A^{0.82} = 443.2
\]

\[
[Q_{N_2}] = (10.2)(.0439)(443.2) = 198.7 \text{ ScFM-N}_2 \times \frac{\sqrt{29}}{\sqrt{28}} \times \frac{35}{35} = 202.2 \text{ ScFM-Air}
\]
CASE 3: \((G_{\text{argon}})(U_{\text{argon}})(A^{0.82})\)

\(G_{\text{argon}} = 10.2\)

\[ U_{\text{argon}} = \frac{K_{\text{argon}}(1200 \, ^\circ F)}{\Delta R} \]

(See Ref. 5)

\[ K_{\text{argon}}(1200 \, ^\circ F) = \frac{0.1021}{1660 \, ^\circ R} \]

\[ K_{\text{argon}}(1200 \, ^\circ F) = 0.0313 \]

\[ U_{\text{argon}} = \frac{0.0313}{8350} = 0.000376 \, \frac{\text{Btu}}{\text{hr-ft-F}} \]

\(A^{0.82} = 443.2\)

\[ \sqrt[3]{Q_{\text{argon}}} = (10.2)(0.0376)(443.2) = 170.0 \, \text{scfm-Ar} \]

\[ 170.0 \, \text{scfm-Ar} \times \frac{\sqrt[3]{40}}{\sqrt[3]{29}} \times \frac{356}{377} = 188.5 \, \text{scfm-Ar} \]

Conclusion: worst case of flow is an equivalent of 202.2 scfm-air, for C6A fire conditions under 5.3.5 & 5.3.6.3 in Ref. 1.
Problem: Calculate the Vaporizer Relief Flow Capacity

Given: Maximum Discharge Capacity = 40 GPM

\[
\frac{40 \text{ gal (gas)}}{\text{min}} \times \frac{4.404 \times 10^{-3} \text{ m}^3}{\text{gal (dry)}} \times \frac{(100)^3 \text{ cm}^3}{\text{m}^3} \times \frac{1 \text{ ft}^3}{1600 \text{ cm}^3} \\
\times \frac{1 \text{ ft}^3}{1000 \text{ m}^3} = 176.16 \frac{\text{L}}{\text{min}}
\]

\[
176.16 \frac{\text{L}}{\text{min}} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1 \text{ cm}^3}{1 \text{ mL}} \times \frac{1 \text{ ft}^3}{(100)^3 \text{ cm}^3} \\
\times \frac{1 \text{ ft}^3}{2.83 \times 10^{-2} \text{ m}^3} = 6.22 \frac{\text{ft}^3}{\text{min}} \text{ Argon gas}
\]
Conversion of ScFM - Argon to ScFM - Air
(See Ref 6)

Using: \[ A = \frac{V \sqrt{mTz}}{6.32 \text{ CKP}} \]

where:
- \( A \) = valve orifice area (in\(^2\))
- \( V \) = flow capacity (ScFM)
- \( m \) = molecular weight of flowing media
- \( T \) = inlet temperature (absolute)
- \( z \) = compressibility factor (\( \approx 1.00 \))
- \( C \) = gas constant based on ratio of specific heats at standard conditions
- \( K \) = valve coefficient of discharge (=.816)
- \( P_i \) = pressure at valve inlet during flow (psia)

Rearranging: \[ V = \frac{6.32 \text{ CKP} \cdot A}{\sqrt{mTz}} \]

All values except \( C \) & \( \sqrt{m} \) are independent of the gas under consideration.

\[ C_{\text{air}} = 356 \]
\[ \sqrt{m_{\text{air}}} = \sqrt{29} \]
\[ C_{\text{argon}} = 377 \]
\[ \sqrt{m_{\text{argon}}} = \sqrt{90} \]

So \[ V_{\text{air}} = V_{\text{argon}} \times \frac{\sqrt{m_{\text{argon}}}}{\sqrt{m_{\text{air}}}} \times \frac{C_{\text{air}}}{C_{\text{argon}}} \]

\[ V_{\text{air}} = 6.22 \times \frac{\sqrt{90}}{\sqrt{29}} \times \frac{356}{377} \]

\[ V_{\text{air}} = 6.89 \text{ ScFM} - \text{air} \]
CALCULATION OF FLOW RATE FOR LOSS OF VACUUM, WITH INSULATION

Assume vacuum space at 1 atm.

Use Kair since it is larger than Kα or Kγ at 80°F

\[
\text{Heat Transfer (conduction)} = U * A * \Delta T
\]

(See Ref. 2)

\[
\frac{U}{\Delta R} = \frac{K_{Air} (80°F)}{A} * \Delta T
\]

\[
= \frac{(0.01516)}{(1688.6)} (80-633)
\]

\[
= 11,741.9 \text{ Btu/hr}
\]

Now to get to a flow rate:

\[
Q_{\text{argon}} = \frac{1}{\text{Heat transfer (Btu/hr)}} * \left( \frac{1}{\text{Argon Latent Heat of Vaporization}} \right) * \left( \frac{1}{\text{Argon Density}} \right) * \left( \frac{1}{\text{Conversion}} \right)
\]

(See Ref. 7)

\[
= 11,742 \text{ Btu/hr} * \frac{1.85}{39.15} * \frac{7525 ft^3}{\text{BTU}} * \frac{1}{1.78 g/m} * \frac{1}{60 \text{ min}} \times \frac{1}{0.1337 \text{ ft}^3}{3.785 L}
\]

\[
= 25.03 \text{ ScfM - Argon}
\]

\[
25.03 \text{ ScfM - Argon} * \frac{\sqrt{40}}{\sqrt{29}} * \frac{356}{377} = 27.75 \text{ ScfM - Air}
\]
### TABLE 1

#### 5-1.3

VALUES OF G, AND G, FOR MINIMUM RECOMMENDED MAXIMUM AND COMMONLY USED FLOW RATING PRESURES (1)

<table>
<thead>
<tr>
<th>GAS</th>
<th>(5) Minimum Recommended MAXP Pressure (psi)</th>
<th>Flow Rating Pressure (psi)</th>
<th>Value of G,</th>
<th>Value of G,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anhydrous ammonia</td>
<td>265</td>
<td>318</td>
<td>2.80</td>
<td>22.1</td>
</tr>
<tr>
<td>Anhydrous dimethylamine</td>
<td>150</td>
<td>180</td>
<td>3.76</td>
<td>21.0</td>
</tr>
<tr>
<td>Anhydrous monomethylamine</td>
<td>150</td>
<td>180</td>
<td>3.55</td>
<td>29.4</td>
</tr>
<tr>
<td>Anhydrous trimethylamine</td>
<td>150</td>
<td>180</td>
<td>5.33</td>
<td>41.8</td>
</tr>
<tr>
<td>Argon pressurized liquid (2)</td>
<td>—</td>
<td>100</td>
<td>10.2</td>
<td>59.0</td>
</tr>
<tr>
<td>Butadiene, inhibited</td>
<td>100</td>
<td>120</td>
<td>4.17</td>
<td>35.8</td>
</tr>
<tr>
<td>Carbon dioxide (refrigerated) (See 173.315)</td>
<td>100</td>
<td>360</td>
<td>7.94</td>
<td>57.7</td>
</tr>
<tr>
<td>Carbon monoxide, liquefied (2)</td>
<td>—</td>
<td>200</td>
<td>11.8</td>
<td>69.0</td>
</tr>
<tr>
<td>Chlorine</td>
<td>225</td>
<td>270</td>
<td>6.74</td>
<td>54.3</td>
</tr>
<tr>
<td>Chlorodifluoromethane (R-142B)</td>
<td>100</td>
<td>120</td>
<td>6.82</td>
<td>55.7</td>
</tr>
<tr>
<td>Chlorodifluoromethane (R-22)</td>
<td>250</td>
<td>300</td>
<td>7.92</td>
<td>64.0</td>
</tr>
<tr>
<td>Dichlorodifluoromethane (R-12)</td>
<td>150</td>
<td>180</td>
<td>8.94</td>
<td>72.0</td>
</tr>
<tr>
<td>Dichlorodifluoromethane-difluoroethane mixture (R-500)</td>
<td>250</td>
<td>300</td>
<td>8.75</td>
<td>71.9</td>
</tr>
<tr>
<td>Dichlorodifluoromethane-dichlorotetrafluoroethane mixture (R-12/R-114 mixture)</td>
<td>150</td>
<td>180</td>
<td>9.34</td>
<td>81.0</td>
</tr>
<tr>
<td>Dichlorodifluoromethane-trichlorofluoro- methane mixture (R-12/R-11 mixture)</td>
<td>150</td>
<td>180</td>
<td>8.94</td>
<td>72.0</td>
</tr>
<tr>
<td>Difluoroethane (R-152A)</td>
<td>150</td>
<td>180</td>
<td>8.07</td>
<td>49.0</td>
</tr>
<tr>
<td>Ethylene, liquefied</td>
<td>—</td>
<td>100</td>
<td>5.42</td>
<td>36.8</td>
</tr>
<tr>
<td>Helium (3) (4)</td>
<td>—</td>
<td>200</td>
<td>55.2</td>
<td>—</td>
</tr>
<tr>
<td>Hydrogen, liquefied (3) (4)</td>
<td>—</td>
<td>50</td>
<td>8.6</td>
<td>45.8</td>
</tr>
<tr>
<td>Liquefied petroleum gas</td>
<td>See 173.315</td>
<td>300</td>
<td>6.56</td>
<td>33.6</td>
</tr>
<tr>
<td>Methyl chloride</td>
<td>150</td>
<td>180</td>
<td>4.96</td>
<td>40.4</td>
</tr>
<tr>
<td>Methyl mercaptan</td>
<td>100</td>
<td>120</td>
<td>6.05</td>
<td>51.2</td>
</tr>
<tr>
<td>Neon, pressurized liquid (4)</td>
<td>—</td>
<td>200</td>
<td>20.8</td>
<td>113.4</td>
</tr>
<tr>
<td>Nitrogen, pressurized liquid</td>
<td>—</td>
<td>300</td>
<td>28.0</td>
<td>153.0</td>
</tr>
<tr>
<td>Nitrous oxide (refrigerated) (See 173.315)</td>
<td>100</td>
<td>120</td>
<td>5.36</td>
<td>37.2</td>
</tr>
<tr>
<td>Oxygen, pressurized liquid (2)</td>
<td>—</td>
<td>200</td>
<td>11.8</td>
<td>69.0</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>150</td>
<td>180</td>
<td>4.84</td>
<td>40.0</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>150</td>
<td>180</td>
<td>5.61</td>
<td>46.8</td>
</tr>
</tbody>
</table>