DØ VENT STACKS

J.D. Fuerst
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Approved: ________________________
INTRODUCTION

There are two nitrogen/argon exhaust headers in the D0 cryogenic piping system, one for the liquid argon dewar and another for the three argon calorimeters. These headers serve two functions, venting both nitrogen exhaust from the cooling loops and cold argon gas should any argon vessel blow a relief. These headers are vacuum jacketed until they exit the building. At that point, uninsulated exhaust stacks direct the flow into the atmosphere (fig. 1). This note deals with the these stacks.

DISCUSSION

Design of these stacks must take into account both pressure drop requirements across the stack and possible ODH problems resulting from the discharge of nitrogen and argon into the atmosphere. A review of J. Kilmer's "Argon Spill Test for E706" shows that, with a properly elevated vent stack (20-25ft.), large volume flow rates may be tolerated without creating hazardous conditions at ground level. Kilmer's test further concluded that it was unnecessary for the E706 argon vent stack to extend above all obstructions or contain an air mixing scheme. On this basis it is decided that the D0 vent stack terminations can be 25 ft. above ground level (6 1/2 ft. below roof line). They will be fitted with appropriate rain covers and drip legs. Additionally, each stack will have at its termination an equal-diameter low pressure burst disc in parallel with the rain cover to eliminate flow restrictions due to icing.

It is assumed that the vacuum jacketed portions of these exhaust headers are properly sized. New calculations have been done to size the uninsulated 20 ft. or so of vent stack dealt with in this note using the following assumptions:

- 100K gas at termination of vacuum jacketing (EN104 and assumption)
- 330 g/s max. continuous nitrogen flow out each stack due to vessel cooling loops (EN 78, 104)
- max. relief flows of 140 g/s argon for the dewar, 760 g/s argon for the calorimeters (EN 111, 100)
- forced convection heating of the stacks by the surroundings
- a maximum 1 psi pressure drop through the stack (argon flow, incl. rain cap).

Given these assumptions, estimates of stack exhaust temperature for different flow rates were made. These temperatures then specified densities which were used to find a gas exit velocity that yielded an acceptable pressure drop. From this velocity and known flow rate, stack diameter was calculated (see the appendix for details).
The liquid argon dewar vent stack will see a maximum flow of either 140 g/s argon (fire condition coupled with a nitrogen cooling loop failure-no flow) or 330 g/s nitrogen (cooling loop failure - maximum flow. It should be noted that under fire conditions the nitrogen cooling loop, if functioning properly or stuck full open, will fully condense the gaseous argon generated by the fire condition). A failure resulting in the combined discharge of 140 g/s argon and 330 g/s nitrogen is not possible the way this system is configured.

Maximum nitrogen flow out of the 2” dewar stack creates about 10 psi backpressure in the vent line. While this does corrupt the argon relief points, it is argued that this is inconsequential. Anytime enough nitrogen is venting to generate this kind of back pressure, the possibility of the argon pressure building to proper relieving levels is eliminated.

Rupture discs located in parallel with the exhaust caps will be sized at 7 psi (dewar line) and 5 psi (cryostat line) burst pressure. These are the minimum available burst pressures for composite 2” and standard 6” discs, respectively. Given the envisioned pressure drops in the vent lines and stacks, these burst pressures will still allow the argon vessels to vent at their proper relief pressures.

CONCLUSIONS:

Stack heights 25’ above ground level
Inlet gas temp. 100K
Exhaust gas temp. (330 g/s) ~200K (nitrogen flow only - would be colder with argon venting also).

Max. flow through dewar stack 140 g/s Ar or 330 g/s N₂
Max. flow through calorimeter(s) stack 1100 g/s total Ar + N₂
Acceptable ΔP through each stack 1 psid (argon flow)
Req’d stack dia - dewar stack 2”
Calorimeter(s) stack 6”

The stacks will therefore be made of 20 ft. of 2” schedule 10 pipe for the dewar exhaust and 20 ft. of 6” schedule 10 for the calorimeters exhaust, with appropriate rain caps, drip legs, burst discs, etc.
Gases Temp. @ stack exhaust:

\[ T_o = 300K \]

\[ T_{in} \leftarrow L \rightarrow T_{exh} \]

\[ \Delta T = T_o - T_{wall,avg} \]

\[ A = \text{pipe surf. area} \]

\[ h = \frac{Nu \cdot k}{d} \]

\[ d = \text{pipe dia.} \]

\[ h = \text{Nusselt num} \]

**H.T. from \( \text{N}_2 \) to pipe:**

choose \( \dot{m}_n = 330 \text{ g/s} \), \( C_{p,n} \) @ \( 25^\circ C \), \( -150K = 1.048 \frac{\text{g/s}}{\text{K}} = 10.48 \times 10^{-6} \text{ cm}^3/\mu \text{g} \)

so \[ Q = (330 \text{ g/s}) \times (10.48 \times 10^{-6} \text{ cm}^3/\mu \text{g}) \times (T_{exh} - T_{in}) \]

\[ = (3.458 \times 10^{-8} \times T_{exh} - T_{in} ) \text{ g cm}^3/\mu \text{s} \]

**Note:** Power \( = [ML^2T^{-3}] \)

**H.T. from pipe to surroundings:** model the stacks as cylinders in cross-flow

\[ Nu = C Re^{m/3} \] where \( C, m \) are consds

pick a strong breeze, say 25 mph = 1120 cm/s

\[ \rho_{air} \approx \rho_{N_2} \text{ @ ambient} = 0.0014 \ \text{g cm}^{-3} \]

\[ U_{air} = \mu_{air} \text{ @ ambient} = 180 \times 10^{-6} \ \text{g cm s}^{-1} \]

For starters, choose \( \text{d} = 6'' \) (pipe dia.) = 15.24 cm

Then \[ Re = \frac{Ud}{\nu} = 1.1 \times 10^5 \]

giving \( C = 0.027 \) and \( m = 0.805 \)

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\[ P_r = \text{Prandtl} = \frac{C_p \nu}{k} \quad \text{where} \]
\[ C_p = C_{prK} \alpha_{300K} = 10.41 \times 10^5 \text{cm}^3 \text{s}^{-1} \text{K}^{-1} \]
\[ k = K_{mk} \alpha_{mk} = 26 \times 10^{-3} \text{Wcm}^{-1} \text{K}^{-1} = 2600 \frac{\text{gcm}}{\text{s}^3 \text{K}} \]
\[ P_r = 0.721 \]

\[ \text{Then } Nu = (0.027) (1.1 	imes 10^5) (0.721)^{1/2} = 2.77 \]

\[ \text{and } h = (2.77) (2600 \frac{\text{gcm}}{\text{s}^3 \text{K}}) / 15.24 \text{cm} = 472.57 \frac{\text{W}}{\text{cm}^2 \text{K}} \]

\[ A_{\text{pipe}} = \pi d L \quad \text{where } L = 20' \quad \text{so } A = 2.9190 \text{cm}^2 \]

Evaluating the h.t. from the rent gas to the pipe to the h.t. from the pipe to the ambient (actual h.t. in other direction), we have:

\[ (3.458 \times 10^9 \times \text{Texh} - \text{Tin}) \frac{\text{gcm}^2}{\text{s}^3} = (472.57 \frac{\text{W}}{\text{cm}^2 \text{K}}) (2.9190 \text{cm}^2) (T_0 - \text{Taqwall}) \]

where \[ \text{Taqwall} = \frac{(\text{Texh} + \text{Tin})}{2} \]

\[ T_0 = 300 \text{K} \]

\[ 2.507 (\text{Texh} - \text{Tin}) = 300 - \frac{\text{Texh} + \text{Tin}}{2} \]

\[ 5.014 (\text{Tin} - \text{Texh}) = 600 - \text{Texh} - \text{Tin} \quad \text{where } \text{Tin} = 100 \]

\[ 6.014 \text{ Texh} = 4.014(100) + 600 \]

\[ \text{Texh} = 167 \text{K} \quad \text{Ans.} \]

Because there won't always be 330°F flowing continuously, I will use a stack exhaust temp. of 200K to size the diameter.

**Stack Diameters:**

With exhaust gas density approximated @ 200K (0.00171 g/cm³ for N₂, 0.00241 g/cm³ for Ar), find the velocity out of the stacks for an acceptable \( \Delta p \) of 1 psi = 68950 g/cm²·s².

\[ \Delta p = \frac{1}{2} \rho A (V^2) + \rho g A Z + \frac{1}{2} \rho V^2 \left( \frac{f L}{d} + \Sigma K \right) \]

choose \( f = 0.015 \), \( L = 610 \text{cm} \), \( d = 10 \text{cm} \)
\[ \Sigma K: \text{minor losses at exhaust cap - treat cap as 2 tees and 2 elbows plus sharp exits} \]

\[
\begin{array}{c}
\text{actual} \\
\text{model}
\end{array}
\]

Tee's \( \Delta \) 1.5 ea., elbows \( \Delta \) 0.8 ea., sharp exits \( \Delta \) 1 ea. 
To be conservative, call \( \Sigma K = 8 \)

\[
\Delta p = \frac{1}{2} \left( \frac{0.0241 \text{cm}^3}{\text{s}^2} \right) (V^2 \text{cm}^2) + \left( \frac{0.0241 \text{cm}^3}{\text{s}^2} \right) (98 \text{cm}^3)(60 \text{cm}) + \frac{1}{2} \left( \frac{0.0241 \text{cm}^3}{\text{s}^2} \right) (V^2 \text{cm}^2) \left[ \frac{(0.05)(60 \text{cm})}{100 \text{cm}} + 8 \right]
\]

\[68950 \frac{\text{g}}{\text{cm}^2} = (0.00121) V^2 \frac{\text{g}}{\text{cm}^2} + 1442 \frac{\text{g}}{\text{cm}^2} + (0.01074) V^2 \frac{\text{g}}{\text{cm}^2}\]

\[67810 = 0.01195 V^2\]

\[V = 2.377 \text{ cm}^3\]

At full bore the cryostat's vent takes 1100 gal (EN 100, 104)

\[A_{\text{pipe}} = \frac{\rho V}{\mu} = \frac{1100 \text{g}}{(0.0241 \text{cm}^3)(2377)} = 192 \text{cm}^2 \Rightarrow \text{dia.} = 6.2'' \text{ Ans.}\]

If the dewar vent handles 140 gal argon (EN 111):

\[A_{\text{pipe}} = \frac{140}{(0.0241)(2377)} = 2.4.4 \text{ cm}^2 \Rightarrow \text{dia.} = 2.2'' \text{ Ans.}\]

If the dewar vent handles 330 gal nitrogen (EN 78) due to cooling loop failure, \( \Delta p \) is not as much of a concern.

For a 2.2'' I.D. stack, the \( \Delta p \) across the stack is:

\[\Delta p = \frac{1}{2} (0.00171)(V^2) + (0.00171)(98)(610) + \frac{1}{2} (0.00171)(V^2) \left( \frac{(0.05)(610)}{5} + 8 \right)\]

where \( V = \frac{\rho A}{\mu} = \frac{330 \text{g}}{(0.00171 \text{cm}^3)(234.4 \text{cm}^2)} = 7910 \text{ cm}^3 \text{/s}\)

\[ \Delta p = (53496 + 1023 + 525860) \frac{\text{N}}{\text{m}^2} \]
\[ = 580380 \frac{\text{N}}{\text{m}^2} \]
\[ = 580380 \text{ Pa} \]
\[ = 8.4 \text{ psid} \]

This \( \Delta p \) is tolerable if the venting fluid is nitrogen from the cooling coils (LAr dewar not involved directly).

So the cryostat's vent stack is 6" pipe and the dewar vent stack is 2" pipe - both continuations of their vacuum-jacketed diameters.