Fermilab

# Particle Physics Division
# Mechanical Department Engineering Note

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Project Internal Reference:

Project: MicroBoone

Title: MicroBoone Purge System Sizing

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Reviewer(s):

Key Words: MicroBoone, Purge System

Applicable Codes:

Abstract Summary:

The following note determines the header and drilled nozzle sizes for the MicroBoone purge system, based on applicable gage pressures

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## Discussion

- Fluid is liquid Argon
- Supply line Pressure is 10 psig
- Tank pressure is 3 psig (max)
- Nozzles are holes drilled in the header
- Flow rate at largest cross-section of the tank should be 4 ft/hr
- Piping is schedule 10S
- Local $P_{Atm} = 14.35$ psi
- $P_{Header} = P_{Atm} + P_{Gage} = 14.35 + 10 = 24.35$ psi
- Equations and coefficients from Crane 410

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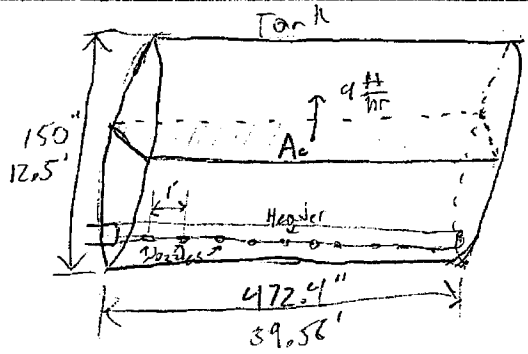
→ Mass Flow




→ Area of largest cross-section

→ $A_c = 12.5 \times 39.56 = 492\ ft^2$

→ $\dot{V} = A_c V = 492 ft^2 \times 4 ft/hr = \boxed{1968\ \frac{ft^3}{hr}}$

→ $\rho_{Ar}$ @ 17.35 psia $= 0.12235\ \frac{lb}{ft^3}$

→ $\dot{m} = \dot{V}\rho = 1968\ \frac{ft^3}{hr} \times .12235\ \frac{lb}{ft^3} = \boxed{241\ \frac{lbm}{hr}}$

→ $\dot{V} = 1968\ \frac{ft^3}{hr} = 3401280\ \frac{in^3}{hr} \times \frac{.004329\ gal}{1\ in^3}$

$\dot{V} = 14724\ \frac{gal}{hr} \times \frac{1\ hr}{60\ min} = \boxed{237\ gpm}$

→ Header Length = 39.56'

39.56'/1' = 39.56

→ set 38 nozzles &

38 sections of header

→ Mass Flow through each nozzle

$\dot{m}_N = \dot{m}/38 = \boxed{6.35\ \frac{lb}{hr}}$

→ Nozzle Sizing

- Since the Pressure in the header is 10 psig and the maximum Pressure for the tank is set at 3 psig; the necessary Pressure drop across each nozzle is 7 psig

→ Mass Flow through an orifice

$$\dot{M}_v = 1891\, Y d_o^2 C \sqrt{\frac{\Delta P}{v}}$$

solving for the orifice diameter:

$$d_o = \left[\frac{\dot{M}_v}{1891\, Y C \sqrt{\frac{\Delta P}{v}}}\right]^{\frac{1}{2}}$$ ; where:

- $d_o$ = orifice diameter (in)
- $\dot{M}_v$ = mass flow rate through the nozzle ($\frac{lbm}{hr}$)
- $Y$ = Net expansion factor
- $C$ = Flow Coefficient
- $\Delta P$ = Pressure change
- $v$ = specific volume = $\frac{1}{\rho}$

→ Y (Crane 410, A-21)

$$\frac{\Delta P}{P_A} = \frac{7}{29.35} = .29 \Rightarrow Y = .81$$

→ C (Crane 410, A-20) → $\frac{d_o}{d_{header}}$ will be << .2

$$C \approx .97$$

$$d_o = \left[\frac{6.34}{1891(.97)(.81)\sqrt{7 \cdot .17135}}\right]^{\frac{1}{2}} = \boxed{0.06243''}$$

orifice diameter

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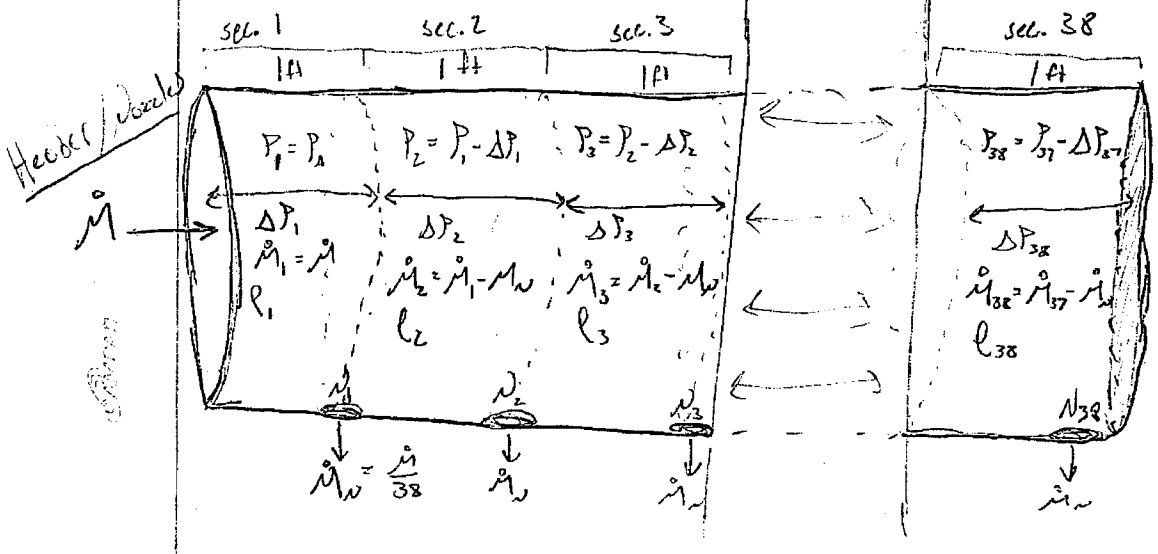


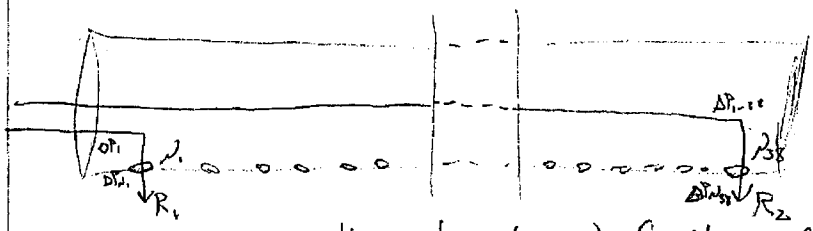

- Pressure Loss through straight Pipe

$\rightarrow \Delta P = .000216 \frac{f L \rho Q^2}{d^5}$ ; where

- $f$ = friction factor
- $L$ = Length b/w nozzles (ft)
- $\rho$ = density at absolute Pres.
- $Q$ = flow rate (Gpm)
- $d$ = Pipe diameter

- $P_{A\,initial} = P_{Atm} + P_G = 14.35 + 10 = 25.35$ psia

$P_{A\,final} = P_{A\,initial} - \Delta P_{1-38}$




$\rightarrow$ By adjusting the closest and furthest flows to equalize Pressure Losses, the difference in nozzle flows can be found

- Calculations were done for every section using an excel spreadsheet
- First and last sections will be shown as an example
- Density's at different pressures were determined using the relationship: $-.0007\left[\frac{P_A - 24.6}{-.1}\right] + .1731 = \rho(P_A)$
  → found from graphing $\rho$ as a function of $P_A$

1st section (setting Manifold n.d. at 2")

$$Re = 50.6\frac{Q_1 \rho_1}{\mu_1 d} = \frac{237(.17135)}{(.0000015045)2.157} = 63,319,960$$

$f = .019$

$$\Delta P_1 = .000216\frac{\overset{f_1}{(.019)}\overset{l}{(1)}\overset{\rho_1}{(.17135)}\overset{Q_1}{(237)^2}}{\underset{d}{(2.152)^5}} = .000846 \text{ psi}$$

→ Making the absolute pressure in section 2:

$P_A - \Delta P_1 = 24.35 - .000846 = 24.34815$ psia

And the flow $\dot{V}_1 - \dot{V}_N = 237 - 6.237 = \underline{230.76}$ gpm
sec. 2 Flow

→ Total $R_1$ $\Delta P = 7(\Delta P_{nozzle1}) + .000846(4\,\Delta P_{1\,pipe})$
$= 7.000846$ psi Loss in shortest route

## Last Section

$$Re = 50.6 \frac{Q_{38}\, l_{38}}{\mu_{38}\, d} = \frac{(6.24)(.17127)}{(.0000150444)(2.157)} = 1665667$$

→ $f = .19$ for all sections

$$\Delta P_{38} = \frac{f_{38} L\, l_{38}\, Q_{38}^2}{d^5} = \frac{(.019)(1)(.17127)(6.24)^2}{(2.152)^5} = 5.86e^{-7}$$

→ Making $P_{38} = P_{37} - \Delta P_{38} \Rightarrow 24.33886$ psia

Total $R_2\, \Delta P = \Delta P_{Nozzle\,38} + \Delta P_{1-38}$

$$\rightarrow \Delta P_{Nozzle\,38} = \left[\frac{\dot{m}_N}{1891\, Y d_1^2 C}\right]^2 v_{38} \quad \left(\frac{1}{\rho_{38}}\right)$$

$$= \left[\frac{6.34}{1891(.97)(.81)(2.157)^2}\right]^2 \frac{1}{.171272} = 7.003187 \text{ psi}$$

$$R_2\, \Delta P = \underbrace{7.003187}_{\Delta P_{N38}} + \underbrace{(.011139)}_{\Delta P_{1-38} \text{ found in spreadsheet}} = 7.014326 \text{ psi}$$ of

Loss felt in longest route

→ using the excel spreadsheet to adjust the first and last nozzle flow rates to equalize the total pressure losses felt ($R_1 \Delta P$, $R_2 \Delta P$), to within less than 1% of each other;

→ $\Delta P$ through Nozzle 1 = 7.007002 psi

→ $\Delta P$ through nozzle 38 = 6.996185 psi

→ a difference of .01081642 psi; or 0.15%

→ The difference in nozzle flows = $\sqrt{\%\Delta P \text{ diff}}$

$= \sqrt{.15\%} = .39\%$ diff. in flows

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→ The following was determined with an excel spread sheet using the same method previously described

| Nominal diameter (in) | inner diameter (in) | % difference flow through first and last nozzles |
|---|---|---|
| 2 | 2.157 | .15 |
| $1\frac{1}{2}$ | 1.682 | .40 |
| 1 | 1.097 | 2.13 |
| $\frac{3}{4}$ | 0.884 | 3.37 |
| $\frac{1}{2}$ | 0.674 | 5.92 |
| $\frac{3}{8}$ | 0.545 | 7.93 |
| $\frac{1}{4}$ | 0.41 | 9.13 |

→ With the nozzles drilled at $\boxed{.06243''}$; a header pipe $\boxed{\frac{3}{4}'' \text{ or larger}}$ is recommended to keep nozzle flow difference at < 5% of each other

→ Note: When the purge substance is air, the pressure in the evacuation pipe will be higher with the same size nozzles, due to its much lower density.

Pump

→ KNF Neuberger does not make a diaphram pump with a high enough flow rate ...

→ Ingersoll-Rand does: ARO 3" Pro Series Metallic w/ 237 Gpm capacity (897 Lpm)