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# SIZING OF LIQUID AND GASEOUS HELIUM & LIQUID NITROGEN VALVES AND PIPING OF THE CHL FACILITY

PREPARED UNDER FERMILAB SUBCONTRACT NO. 92690
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FOR

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# SIZING OF LIQUID AND GASEOUS HELIUM & LIQUID NITROGEN VALVES AND PIPING OF THE CHL FACILITY

Flow rate from CHL to helium dewar:

$P$ = 164.6 psia (11.2 atm)

$T$ = -448.82 (60°K)

$H$ = 20.76 J/gr

$M$ = 351.04 g/sec (27,836 lb/hr)

Return flow from dewar to CHL:

$P$ = 20.5 psia (1.4 atm)

$T$ = 4.6°K

$H$ = 29.57 J/gr

$M$ = 193.54 g/sec (1,534.7 lb/hr)

$\rho$ = 1.53 lb/cft

$V_s$ = 40.73 cc/gr

Liquefaction rate is 157.5 g/sec

= 4,536 liters/hr

Calculate pressure drop in gaseous return line:

Line is 2 in. IPS, Sch. 10.

Area for flow is 3.65 sq in. (.025 $ft^2$).

$$G = \frac{1534.7 \times 144}{3.65} = 60{,}564 \text{ lb/hr}$$

At 20% flow rate G = 12,100 lb/hr. Numbers shown in parenthesis below are for the reduced flow rate.

$\mu$ = .00346 lb/ft hr

$d_h$ = 2.156 in. = .18 ft

Re = $3.15 \times 10^6$ ($.63 \times 10^6$)

$j$ = .00115 (.0016)

$f$ = .0023 (.0032)

$\rho$ = 1.53 lb/cft

$$\frac{\Delta P}{L} = \frac{.0023 \times (16.82)^2}{193 \times 2.156 \times 1.53} = 1.0 \times 10^{-3} \text{ psig/ft} \quad (.56 \times 10^{-4})$$

$$\text{Velocity is: } \frac{60564}{1.53 \times 3600} = 11 \text{ ft/sec} \quad (2.2) \qquad \text{okay!}$$

$$1/2\rho v^2 = \frac{.02455}{2} \times 121 \times 930 \times 10^{-6} = .00138 \text{ atm}$$

$$= .020 \text{ psig} \quad (.0008)$$

Length of line is 140 ft.

Number of 90° ells is 10.

Number of entrances and exits is 2.

Calculate on basis of:

$L = 150$ ft

$N_{ells} = 12$

Exits $= 4$

$$\Delta P_{tot} = 150 \times 1.0 \times 10^{-3} + 12 \times .75 \times .020 + 4 \times .020 =$$

$$= .15 + .18 + .08 = .41 \text{ psia.} \qquad \text{okay!}$$

We do a little better with Schedule 5 pipe.

Then:

$$\Delta P_{tot} = .818 \times .15 + .923 \times (.18 + .08) = .1227 + .2400 =$$

$$= .3627 \text{ psig}$$

Liquid line from liquefier:

3 in. IPS, Sch. 5 with 2 in. IPS, Sch. 5 line inside.

ID $= 3.334$ in.

$$\text{Area} = [(3.334)^2 - (2.375)^2] \times .785 = 4.298 \text{ sq in.}$$

$$= .0298 \text{ ft}^2$$

$$G = \frac{2783.6}{.0298} = 93{,}409 \text{ lb/hr ft}^2 \quad (52{,}103)$$

$$d_h = \frac{4 \times 4.298}{\pi(3.334 + 2.375)} = .958 \text{ in.} = .08 \text{ ft}$$

Calculate pressure drop for all liquid flow:

$\mu = .0074$

$\rho = 7.5$ lb/cft

$Re = 1.01 \times 10^6$ (.56)

$f = .0029$ (.0033)

$$\frac{\Delta P}{L} = \frac{.0029 \times (25.95)^2}{193 \times .958 \times 7.5} = .0014 \text{ psig/ft} \quad (.0005)$$

$L = 150$ ft

Number of ells is 12.

Entries - exits is 4.

$$1/2 \rho v^2 = \frac{.1208}{2} \times (3.46)^2 \times 930 \times 10^{-6} =$$

$$= .00067 \text{ atm} = .01 \text{ psig} \quad (.0031)$$

$$\Delta P_{tot} = 150 \times \overset{(.0005)}{.0014} + 12 \times .75 \times \overset{(.0031)}{.01} + 4 \times \overset{(.0031)}{.01} =$$

$$= .21 + .09 + .04 = .34 \text{ psig} \quad (.115)$$

Flow rate is two-phase and at 1/2 - 1/2 liquid-gas $\Delta P$ typically is 10 times higher than liquid flow only.

$\Delta P_{tot} = 3$ psig.

We can tolerate this kind of pressure drop.

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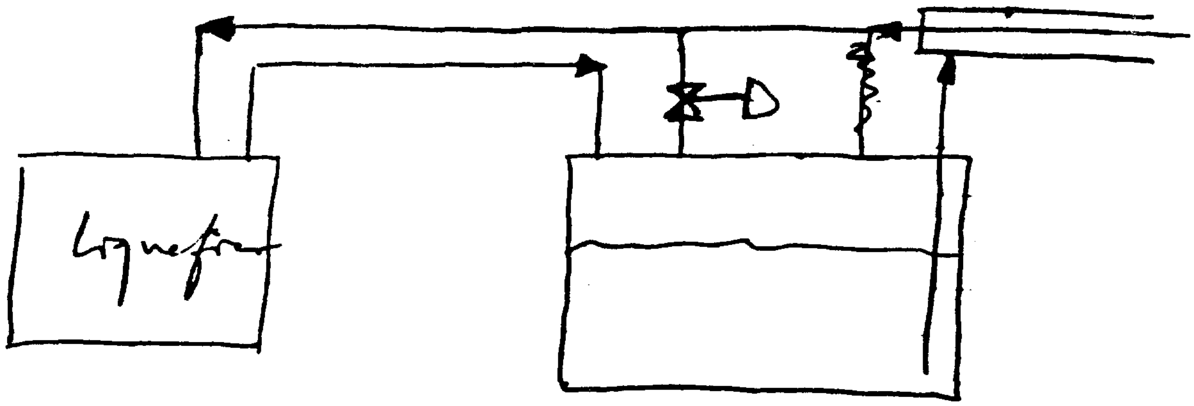
Does it make any sense to put a separator right next to the liquefier and reduce the flow of gas and liquid through the long transfer line? Separator schematic is as follows:




Separator is a simple dewar of large enough diameter to accomplish vapor-liquid separation. In order to accomplish this, vapor velocities will be limited to 10 cm/sec.

Vapor flow rate = 1,535 lb/hr

$$= \frac{1535 \times 454 \times 40.7}{3600}$$

$$= 7{,}878 \text{ cc/sec}$$

Area of vessel $\geqslant$ 788 $cm^2$ = 122 sq in.

Diameter = 12.5 in.

Use a 14 in. pipe, 8 ft deep.

Permissible velocity

$$U = K_v \sqrt{\frac{\rho_L - \rho_g}{\rho_L}} = .15 \sqrt{\frac{7.3 - 1.54}{7.3}} =$$

$$= .133 \text{ ft/sec} = 4 \text{ cm/sec}$$

Velocity is: $\frac{7878}{147.2 \times 6.45}$ = 8.3 cm/sec

We need to increase the diameter of the vessel by a factor $\sqrt{2}$.
Make diameter 20 in.

Valve in vapor stream. Size for $\Delta P$ = 1-3 psig.

Flow rate = 1500 lb/hr

$$C_v = \frac{730\ W\ g}{\sqrt{G\ P_2\ \Delta P}} \left( \frac{\sqrt{T}}{22.8} \right)$$

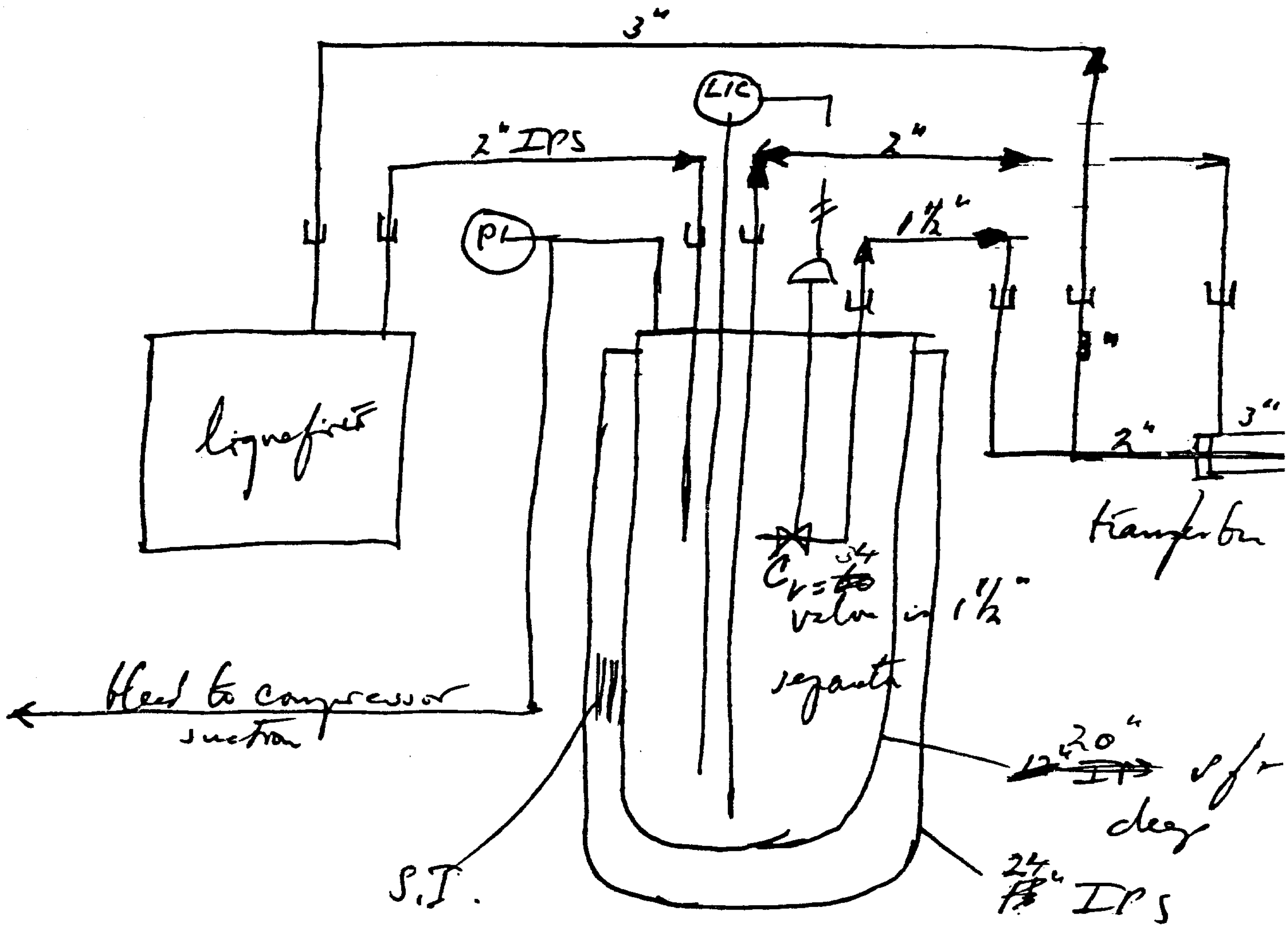
$\Delta P$ = 1.5 psig

T = 8°R

Wg = .4 lb/sec

G = 1/7

$P_2$ = 17 psia




<u>Flow Sheet of System</u>

$$C_v = \frac{730 \times .4}{\sqrt{.143 \times 17 \times 1.5}} \quad \frac{\sqrt{8}}{22.8} = 19.3$$

If we select a 1 in. CV1 valve, $C_v = 14$ and $\Delta P = \left(\frac{19.3}{14}\right) \times 1.5 =$

$= 2.85$ psig; 1-1/2 in. CV1 valve, $C_v = 34$.

Liquid $N_2$ Line to CHL from $N_2$ Tank:

Flow rate = 2,500 liters/hr = 4,400 lb/hr.

Liquid nitrogen flows between two concentric lines shielding the liquid helium transfer lines. Liquid nitrogen dewar pressure is maintained at 30 psia and contains saturated liquid. Liquid nitrogen flows out of the tank through a subcooler. Consider the need for the subcooler:

Conditions into subcooler:

$P = 2$ atm

$T = 83.78°K$

$H = 42.66$ J/gr

$V_s = 1.29$ cc/gr

Conditions out of subcooler:

$P = 2.0$ atm

$T = 81°K$

$H = 36.945$

$V_s = 1.265$ cc/gr

Rate of Cooling:

$$\frac{2500 \times 800}{3600} \times (42.66 - 36.95) = 3,172 \text{ W}$$

The subcooler requires:

$$\frac{3172}{230 - 42.66} = 17.0 \text{ g/sec of liquid}$$

$$= 76 \text{ liters/hr} = 134 \text{ lb/hr}$$

Subcooler design is shown on Dwg. No. 1650-MD-107037:

Flow Rate = 4400 lb/hr

Area = $.011 \text{ ft}^2$

$G$ = $400{,}000 \text{ lb/hr ft}^2$

$d_h$ = .06 ft

$\mu$ = .324 lb/ft hr

Re = 74,074

$C_p$ = .5 Btu/lb °R

$j$ = .00244

$f$ = .00488

Pr = 2.26

$Pr^{2/3}$ = 1.72

$$h = \frac{.00244 \times 400000 \times .5}{1.722} = 283 \text{ Btu/hr ft}^2 \text{ °F}$$

$$\frac{\Delta P}{L} = \frac{.00488 \times (111)^2}{193 \times .71 \times 50} = .00878 \text{ psig/ft}$$

Entrance loss and exit loss equal $1/2 \rho v^2$.

$$V = \frac{400000}{50 \times 3600} \times 30.5 = 67.8 \text{ cm/sec}$$

$$\Delta P = \rho v^2 = .8 \times (67.8)^2 \times 10^{-6} \times 14.7 = .054 \text{ psig}$$

<u>Boiling Liquid</u>

Assume P = 20 psia

T = 144.1°R = 80.05°K

Coefficients are of the order of 80 Btu/hr $ft^2$ °F

$$\Delta T_m = \frac{(83.78 - 80.05) - (81.0 - 80.05)}{\ln \frac{3.73}{.95}} \times 1.8 =$$

$$= 3.66°F$$

$$UA = \frac{3172 \times 3.43}{3.66} = 2,974$$

$$\frac{1}{U} = \frac{1}{.845 \times 283} + \frac{1}{80} = .00418 + .01250 = .01668$$

$$U = 60$$

$$A = 50 \text{ ft}^2$$

**Design is a set of coiled tubes in a vertical bath. Use 12 in. IPS sch. 5 st. stl. pipe for bath. Use four parallel 3/4 in. OD, .035 in. wall copper tubes, coiled on a 10 in. IPS mandril.**

Length per turn is: $\frac{11.5 \times \pi}{12} = 3.0$ ft

Surface area on boiling side is: $\frac{.75 \times \pi}{12} = .196 \text{ ft}^2$

Provide a total of 200 ft (4 x 50)

$N = 67$

$L_{bundle} = 65$ in.

$A = 200 \times .196 = \underline{\underline{39.2 \text{ ft}^2}}$

Boiling coefficient is at least twice as high,
Say h = 120

Then $1/U = .0125$

$U = 80$

$UA = 2,974$

$A = 37.2 \text{ ft}^2$ Okay

Liquid Line and Valve:

Flow Rate = 134 lb/hr

$\Delta P$ = 10 psig

$\rho$ = 50 lb/cft

We will flow subcooled liquid through the line to the valve. Calculate $C_v$ on the basis of all liquid flow.

$$C_v = \frac{7.2\ W\ L}{\sqrt{G \Delta P}} = \frac{7.2 \times 134}{3600\ \sqrt{.8 \times 10}} = .094$$

Select $C_v$ = 1.0

Valve can be 1/4 in.

Line to valve is 1/2 in. IPS, Sch. 10.

Area for flow: .3568 sq in.

$$G = \frac{134 \times 144}{.3568} = 54,080 \text{ lb/hr ft}^2$$

$\rho$ = 50 lb/cft

V = .3 ft/sec    Okay!

<u>Liquid $N_2$ Flow to CHL:</u>

Liquid flows through the space between a 4 in., Sch. 5 and a 5 in., Sch. 10 pipe.

Area:

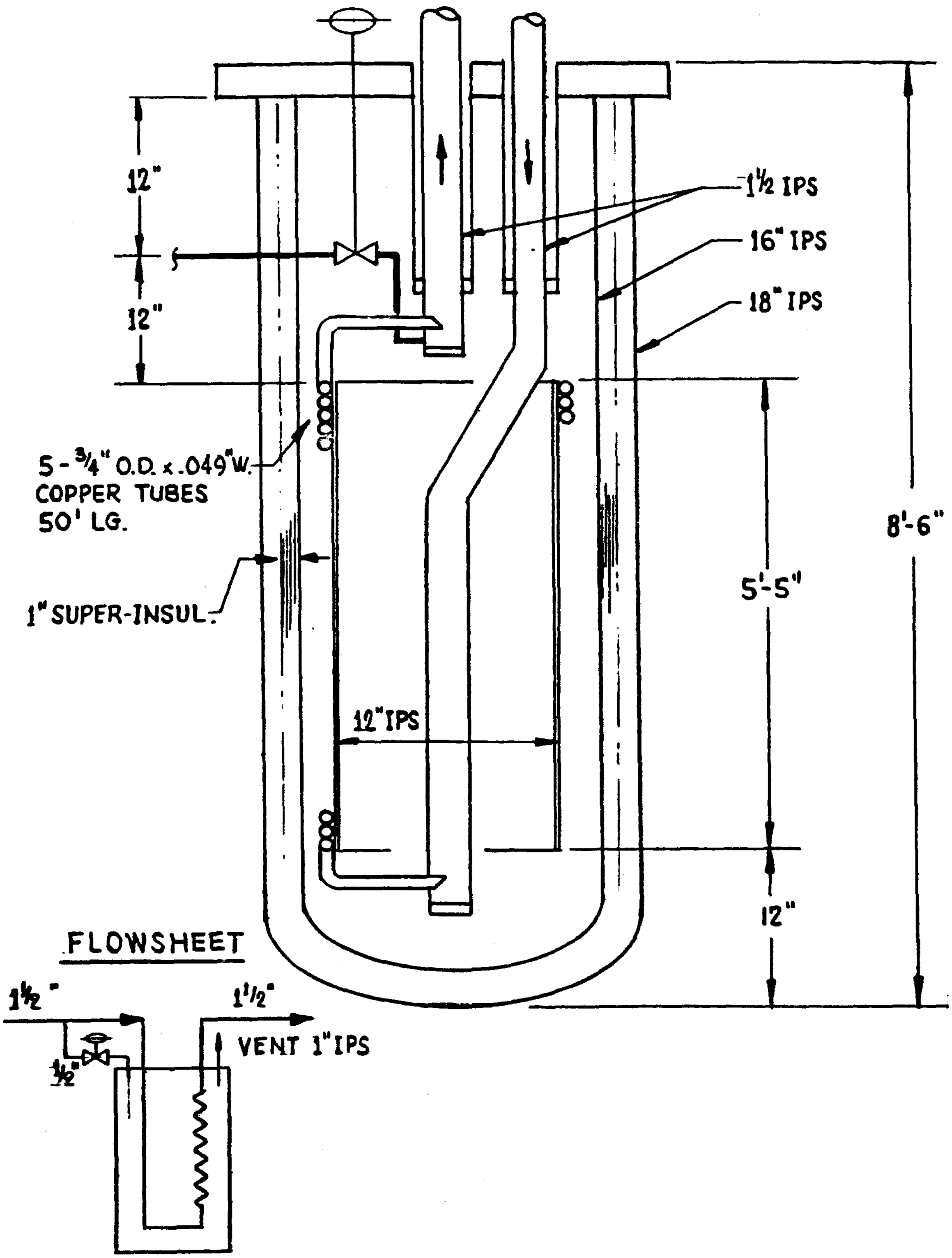
OD 4 in. = 15.896 sq in.

ID 5 in. = 22.021 sq in.

Flow Area = 6.125 sq in.

$$G = \frac{4400 \times 144}{6.125} = 103,445 \text{ lb/hr ft}^2$$

$$d_h = \frac{4 \times 6.125}{\pi \times (4.5 + 5.295)} = .796 \text{ in.}$$




$N_2$ Subcooler

$\mu$ = .36

Re = 19060

f = .0064

$$\frac{\Delta P}{L} = \frac{.0064 \times (30)^2}{193 \times .796 \times 50} = .00075 \text{ psig/ft}$$

L = 150 ft

$\Delta P$ = .112 psig

Liquid nitrogen flows part of the way in a 1-1/2 in. IPS, Sch. 5 line.

Flow rate is total output of the refrigerator. Say 60 tons/day or 5,000 lb/hr.

Area of pipe = 2.461 sq in.

$$G = \frac{5000 \times 144}{2.461} = 292{,}563 \text{ lb/hr ft}^2$$

$$Re = \frac{292563 \times 1.77}{12 \times .36} = 119{,}870$$

f = .00444

$$\frac{\Delta P}{L} = \frac{.00444 \times (81.27)^2}{193 \times 1.77 \times 50} = .00172 \text{ psig}$$

L = 50 ft

$\Delta P$ = .086 psig okay!

Valves in 1-1/2 in. lines:

$$C_v = \frac{7.2\ W_L}{\sqrt{G\ \Delta P}} = \frac{7.2 \times 1.39}{\sqrt{.8 \times \Delta P}} = 34$$

$$.2943 = \frac{.8 \times \Delta P}{\sqrt{.8\ \Delta P}}$$

$$\Delta P = \frac{.0866}{.8} = .01$$

Make PV-8000 1-1/2 in. valves with $C_v \geqslant 20$.

Vent line from liquid $N_2$ tank of helium dewar (valve MV-8041)

Flow rate with Q = 500 W is 11 liters/hr = 19.4 lb/hr.

Assume: T = 300°K

P = 1 atm

Try 1 in. IPS, Sch. 10 pipe

Area = .945 sq in.

$$G = \frac{19.4 \times 144}{.945} = 2{,}956 \text{ lb/hr ft}^2$$

$$\mu = 180 \times 2.42 \times 10^{-4} = .0436$$

$$d_h = 1.097 \text{ in.} = .091 \text{ ft}$$

$$Re = 6{,}198$$

$$f = .0080$$

$$\frac{\Delta P}{L} = \frac{.008 \times (.82)^2}{193 \times 1.097 \times .07} = 3.6 \times 10^{-4} \text{ psig}$$

Line needs to be large enough to handle flow in case of loss of vacuum. Assume flow rate is 20 times larger. Heat leak = 10 kW.

$$G = 59{,}120 \text{ lb/hr ft}^2$$

$$Re = 124{,}000$$

$$f = .0044$$

$$\frac{\Delta P}{L} = \frac{.0044 \times 400 \times (.82)^2}{193 \times 1.097 \times .10} = .056 \text{ psig/ft} \qquad \text{okay!}$$

Relief valve SV-8042.

Required flow rate is 400 lb/hr = 90 scfm of $N_2$

From Anderson-Greenwood catalog we need: E orifice (.196).

Select 1 in. x 2 in. valve Series 80.

Liquid $N_2$ Flow to Ring:

1. Magnet requirements are a maximum of 40 W per 20 ft length. Total for the ring is 40,000 W.

2. Shield of liquid helium transfer line is 18,325 $ft^2$ in surface area (3 in. IPS).
   Heat flux $\leqslant$ .1 $W/ft^2$ for Q = 1,832 W

Maximum flow rate to ring will be based on 50 kW of heat leak.

Flow is: $\frac{50000}{200}$ = 250 g/sec

= 1,982 lb/hr = 2,000 lb/hr

Try 1 in. IPS, Sch. 5 to pump dewar.

Area = 1.029 sq in.

G = 279,880

Velocity in line is 1.55 ft/sec okay!

Valve (PV-8000) $C_v$ = 14

$$\sqrt{G \Delta P} = \frac{7.2\ W_L}{C_v}$$

$$\sqrt{.8\ \Delta P} = \frac{7.2 \times .6}{14} = .309$$

$$.8\ \Delta P = .095$$

$$\Delta P = .12 \text{ psig} \qquad \text{okay!}$$

Liquid $N_2$ to shield of helium tank R.-

Flow rate is 400 gph (batch type)

= 2,500 lb/hr

Try 3/4 in. IPS, Sch. 5 line.

Area: .665 sq in.

$$G = \frac{2500 \times 144}{.665} = 541,353 \text{ lb/hr ft}^2$$

$$V = \frac{541353}{50 \times 3600} = 3.0 \text{ ft/sec} \qquad \text{okay!}$$

Liquid/Gaseous Helium Transfer Lines from Valve Box to Liquid Helium Tank (Valve PV-8005):

Flow 1,250 lb/hr of liquid helium, when gas-liquid separator is in operation. Try 1-1/2 in. pipe surrounding a 1 in. IPS gas return line for liquid flow. Try 3/4 in. pipe for gas return.

Gas Line:

3/4 in. IPS, Sch. 5

Area .665 sq in.

Gas flow rate - 500 lb/hr (max) or

150 lb/hr (normal)

$$G = \frac{500 \times 144}{.665} = 108{,}270 \text{ lb/hr ft}^2$$

$\mu$ = .00346

$d_h$ = .92 in. = .08 ft

$\rho$ = 1.53 lb/cft

Re = $2.4 \times 10^6$

f = .0024

$\frac{\Delta P}{L}$ = .008 psig/ft Okay!

Valve PV-8006 in Gaseous helium line.

We may want to maintain a differential of 1-3 psig. Flow rate could be as low as 20 lb/hr when maintaining liquid level in the tank and the ring operating, or as high as 200 lb/hr when the tank is being filled from the liquefier or by trailer.

Calculate $C_v$'s:

We can transfer liquid helium from the 5,000 gal dewar to the pump dewar at $\Delta P = 1$ psig.

a) Calculate then a gaseous flow rate of 20 lb/hr at $\Delta P = 1$ psig through valve PV-8006:

$$C_v = \frac{730 \quad W_g}{\sqrt{G\ P_2 \Delta P}} \qquad \frac{\sqrt{T}}{22.8}$$

$$= \frac{730 \times 20}{3600 \quad \sqrt{.07 \times 17 \times 1}} \times \frac{\sqrt{1.8 \times 4.4}}{22.8} =$$

$$= .46$$

b) Tank filling by trailer; flow rate is 200 lb/hr and $\Delta P = 3$ psig.

$$C_v = \frac{10}{\sqrt{3}} \times .46 = 2.66$$

Make PV-8006 a 3/4 in. IPS valve with $C_v = 8.0$. Plug is equal percentage.

Liquid Helium Line from CHL to Dewar:

Try 1 in. line in valve box.

Area = 1.029 sq in.

$$G = \frac{4500 \times 125}{454} \times \frac{144}{1.029} = 173{,}386 \text{ lb/hr ft}^2$$

$$\text{Velocity} = \frac{173386}{7.5 \times 3600} = 6.42 \text{ ft/sec}$$

$$1/2\rho v^2 = \frac{.125}{2} \times (6.42)^2 \times 930 = 2{,}396 \text{ dynes/cm}^2$$

$$= 2.4 \text{ cm } H_2O$$

Valve PV-8005 is 1 in. IPS.

$C_v = 14$

$$\sqrt{G \Delta P} = \frac{7.2\ W_L}{C_v} = \frac{7.2 \times .344}{14} = .177$$

$$\Delta P = \frac{.0313}{.125} = .25 \text{ psig} \qquad \text{Okay!}$$

Concentric Transfer Line to Dewar from Valve Box:

1-1/2 in. IPS, Sch. 5 surrounding 3/4 in. IPS.

Area: 2.461 - .865 = 1.596 sq in.

$$G = \frac{1240}{1.596} \times 144 = 111{,}880 \text{ lb/hr ft}^2$$

$$\text{Velocity} = \frac{111880}{3600} \times \frac{1}{7.5} = 4.14 \text{ ft/sec} \qquad \text{Okay!}$$

Liquid Helium Flow to the Magnet System:

1. The pump will maintain the transfer line around the ring full of liquid regardless of demand by the satellites. Normal operation requires 100 liters/hr per satellite or 2,400 liters/hr. However, demand may go up by 50% to 3,600 liters/hr. Size lines for 4,500 liters/hr (1,240 lb/hr).

   a) 5,000 Gal Dewar to Pump Dewar:

   Try 1-1/2 in. IPS

   Area = 2.461 sq in.

   $G = 72{,}495$ lb/hr ft$^2$

   $V = 2.68$ ft/sec

   $$1/2 \rho v^2 = \frac{.125}{2} \times (2.68)^2 \times 930 = 420 \text{ dynes/cm}^2$$

   $$= .42 \text{ cm } H_2O \qquad \text{okay!}$$

Valve PV-8010.

Select 1-1/2 in. IPS with $C_v$ = 34

$$\Delta P = \frac{14}{34} \times .25 = .10 \text{ psig}$$

b) <u>Gas Return Line from Pump Dewar</u>:

Line is 3/4 in. IPS.

Maximum flow rate is 500 lb/hr during cooldown of pump dewar.

From p. 15:

$$G = 108{,}270 \text{ lb/hr ft}^2$$

$$\frac{\Delta P}{L} = .008 \text{ psig/ft}$$

Velocity = 19.65 ft/sec

$$1/2\rho v^2 = \frac{.02}{2} \times (19.65)^2 \times 930 = 3{,}600 \text{ dynes/cm}^2$$

$$= 3.6 \text{ cm } H_2O$$

$$= .053 \text{ psig}$$

Normal flow rate from heat leak in the line, pump work, etc. is of the order of $\frac{400}{20}$ = 20 g/sec

$$= 160 \text{ lb/hr}$$

$$\Delta P = 1/2\rho v^2 = .0053 \text{ psig} \quad \text{Okay!}$$

Valve PV-8007 is 3/4 in. IPS with $C_v$ = 8.

Pressure drop in valve is:

$$\sqrt{G\, P_2 \Delta P} = \frac{730 \text{ Wg}}{C_v} \quad \frac{\sqrt{T}}{22.8}$$

$$= \frac{730 \times .0444}{8} \times .123 = .5$$

$$G\ P_2 \Delta P = .25$$

$$\Delta P = \frac{.25}{.14 \times 17} = .11 \text{ psig} \quad \text{Okay}$$

Pump Discharge Line:

Select 1-1/2 in. IPS.

Flow rate = 1,240 lb/hr

$G = 72{,}495$ lb/hr ft$^2$

Velocity = 2.68 ft/sec

$1/2 \rho v^2 = .42$ cm $H_2O$

Valve PV-8011 is 1/2 in. with $C_v = 34$.

$\Delta P = .1$ psig

Return of pumped liquid to 5,000 gal dewar.

We have some pressure available and can use $\Delta P = 1$ psig.

Try 3/4 in., IPS Sch. 5

Area is .665 sq in.

$$G = \frac{1240 \times 144}{.665} = 268{,}511 \text{ lb/hr ft}^2$$

$$\text{Velocity} = \frac{268{,}511}{7.5 \times 3600} = 10 \text{ ft/sec}$$

$$1/2 \rho v^2 = \frac{.125}{2} \times 100 \times 930 = 5{,}812 \text{ dynes/cm}^2$$

$$= 5.8 \text{ cm } H_2O$$

$$= .1 \text{ psig} \quad \text{Okay!}$$

Use 3/4 in. valve (PV-8013).

$C_v = 8$

$$\sqrt{G \Delta P} = \frac{7.2\ W_{L=}}{C_v} = \frac{7.2 \times .34}{8} = .306$$

$$\Delta P = \frac{.0936}{.125} = .75 \text{ psig} \qquad \text{Okay!}$$

Pump work at $\Delta P = 1$ psig.

$= 18$ ft of liquid helium

$W = 1240 \times 18 = 22{,}269$ ft lb/hr

$= 371$ ft lb/min $= .011$ bhp $= 8.4$ W

With $\eta = .5$

$W = 17$ W     Okay!