Fermilab

SSC DETECTOR SOLENOID DESIGN NOTE #123

TITLE: Pressure Drop and Heat Load Analysis #1 for the Single Loop Helium System

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DATE: December 7, 1990

ABSTRACT: This design note contains the first set of calculations for the single loop helium system.

SUMMARY: The results of the calculations are summarized on the process flow sheet on page 2.

The piping heat leak is based on using superinsulation without a LN2 or helium shield. The total heat load with this type piping and also with Tevatron type piping are noted on the process flow sheet.

The calculated heat loads for the SDC and CDF systems are compared.

The required supply pressure with the charging load included is 27.2 psia as shown on the process flow sheet. The supply pressure increases to 28.13 psia for the same mass flow rate without the charging load. Without the charging load, pressure drop decreases and the average density in the return line increases due to lower quality. The supply pressure increases because the decrease in pressure drop does not offset the increase in the pressure caused by the difference in elevation.

CONCLUSION: Heat transfer in the solenoid's cooling coil must be checked and compared to the requirements.

SUBJECT: PRESSURE DROP AND HEAT LOAD ANALYSIS #1 FOR THE SINGLE LOOP HELIUM SYSTEM

NAME: A. M. STEFANIK

DATE: 11/30/90 | REVISION DATE:

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FERMILAB ENGINEERING NOTE

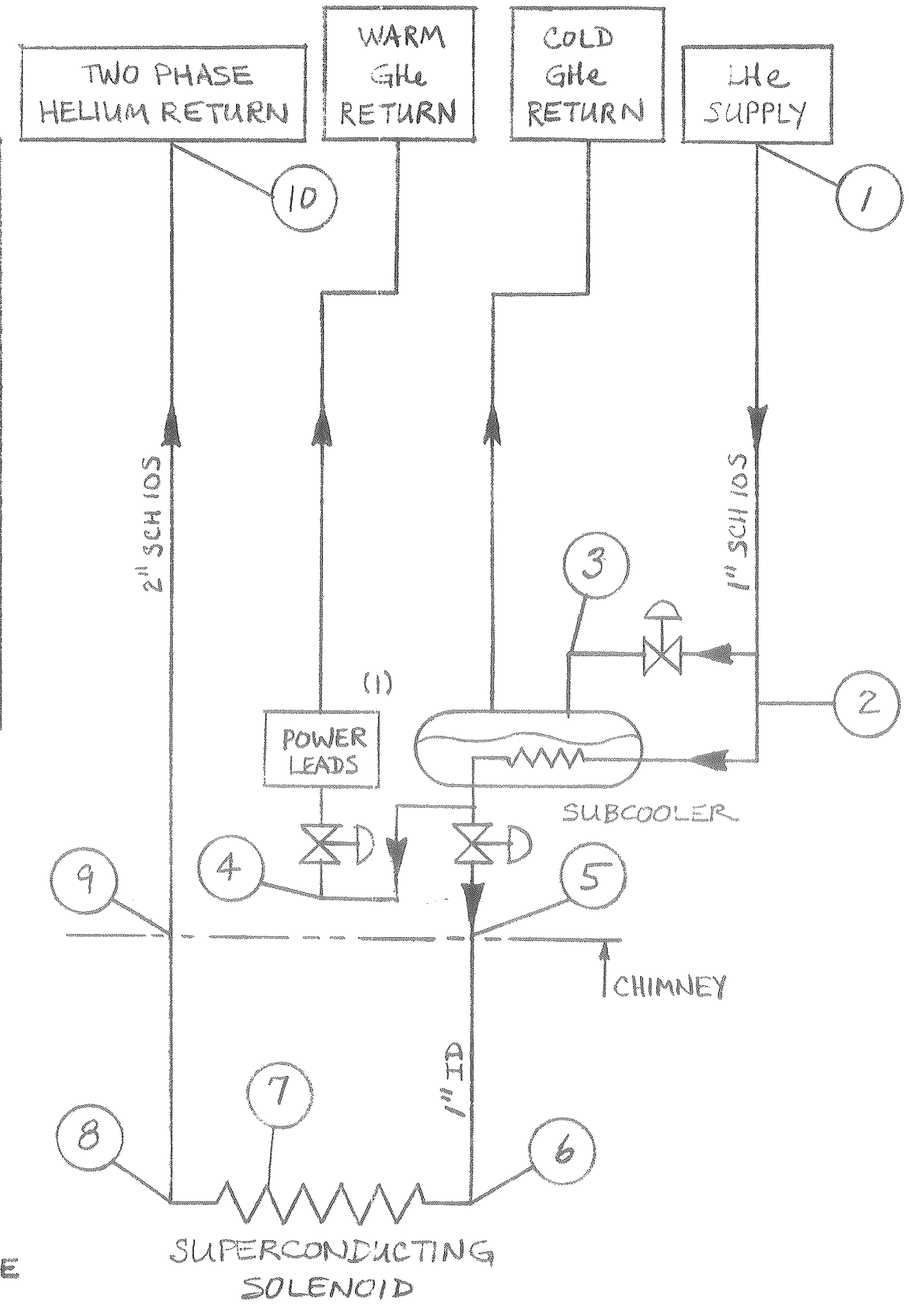
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
2.1	SDC		21

SUBJECT: SINGLE LOOP HELIUM SYSTEM WITH CHARGING LOAD

NAME: AMS

DATE: 12/3/90 REVISION DATE: 1/18/91

SYSTEM DATA FOR POINT No. →		1	2	3 (2)	4 (3)	5 (3)	6	7	8	9	10
FLUID	–	He	He	He	He	He	He	He	He	He	He
FLOW	G/SEC	100	91.7	8.3	1.2	90.5	90.5	90.5	90.5	90.5	90.5
PRESSURE	PSIA	27.2	32.3	16.5	32	29.6	31.1	25.2	21.7	20.2	16.5
SATURATION PRESSURE	PSIA	17.3	21.1	16.5	20.1	20.1	20.2	25.2	21.7	20.2	16.5
TEMPERATURE	K	4.4	4.63	4.35	4.57	4.57	4.58	4.85	4.67	4.58	4.35
QUALITY	%	0	0	9	0	0	0	0	16.4	18.8	33
HEAT LEAK	W	–	130.3	15 (4)	–	16.5	5.1	152.4	87.9	5.1	224.6
FRICTION HEAT LOAD	W	–	14.7	–	–	1	1.3	33.5	25.2	3.8	2.1



NOTES

1) HELIUM VAPOR FROM THE SUBCOOLER MAY BE USED TO COOL THE POWER LEADS.

2) THE TEMPERATURE IN THE SUBCOOLER COULD BE AS LOW AS 4.25 K IF A COLD COMPRESSOR IS PROVIDED AT THE SUBCOOLER.

3) FURTHER SUBCOOLING IS POSSIBLE AT POINTS 4 AND 5.

4) SUBCOOLER HEAT LEAK = 15 W.

5) AS NOTED IN THE CALCULATIONS, LINE HEAT LEAK IS BASED ON USING SUPERINSULATED PIPING WITHOUT AN LN_2 OR He SHIELD. THE HEAT LEAK FOR THIS LINE IS ABOUT 4.4 W/m^2. HEAT LEAK FOR THE TEVATRON TRANSFER LINE, WHERE THE HELIUM LINE IS SHIELDED BY A PIPE FULL OF LN_2, THE HEAT LEAK IS 0.27 W/m^2. REFERENCE 3 SUGGESTS USING 2.3 W/m^2 TO ESTIMATE HEAT LEAK FOR A LN_2 SHIELDED HELIUM LINE.

TOTAL HEAT LOAD SUMMARY: (WITH 220 W CHARGING LOAD INCLUDED)

720 W FOR SUPERINSULATED PIPING WITHOUT A SHIELD
391 W FOR TEVATRON TYPE PIPING
638 W FOR REFERENCE 3 ESTIMATE

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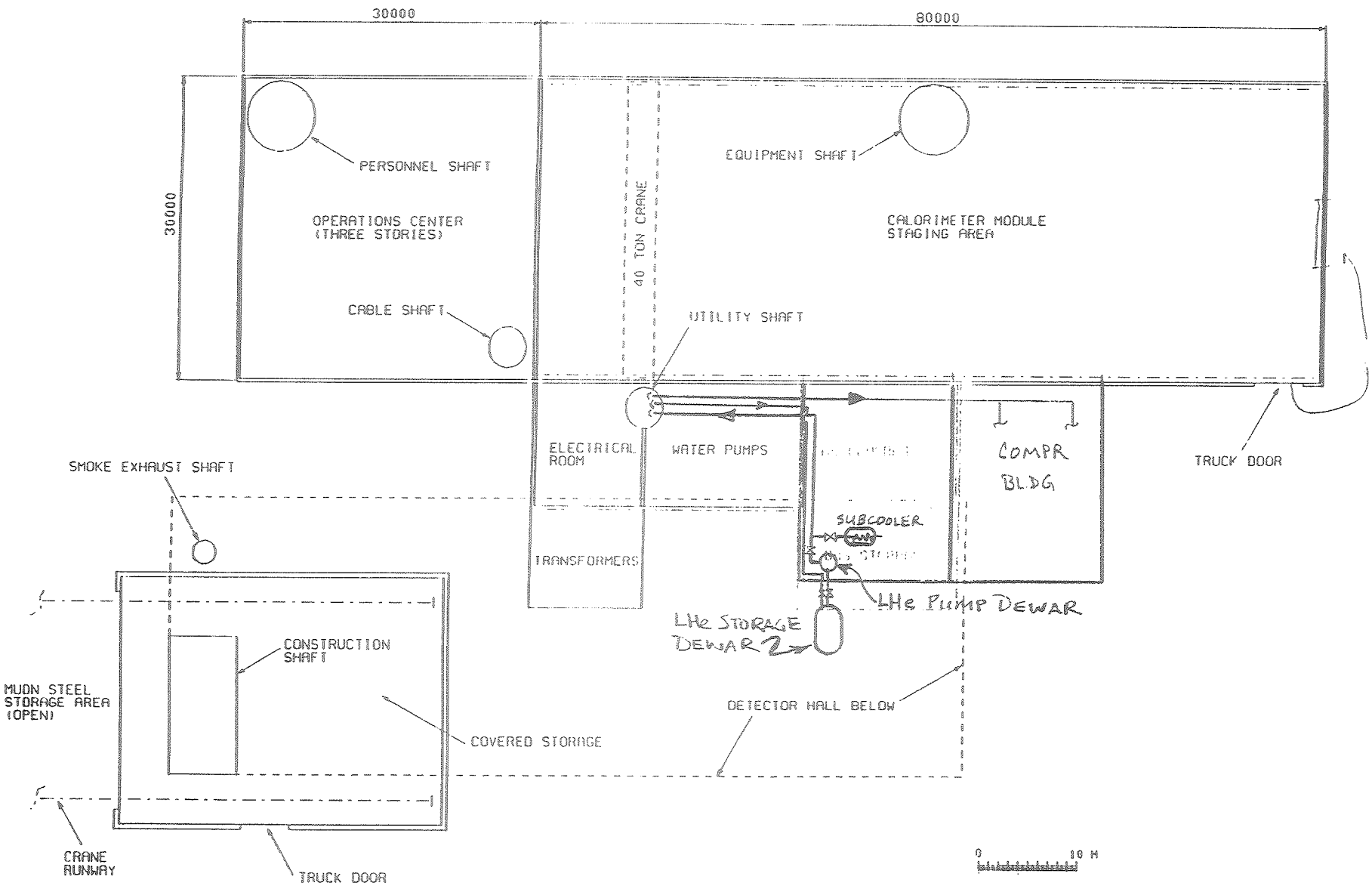
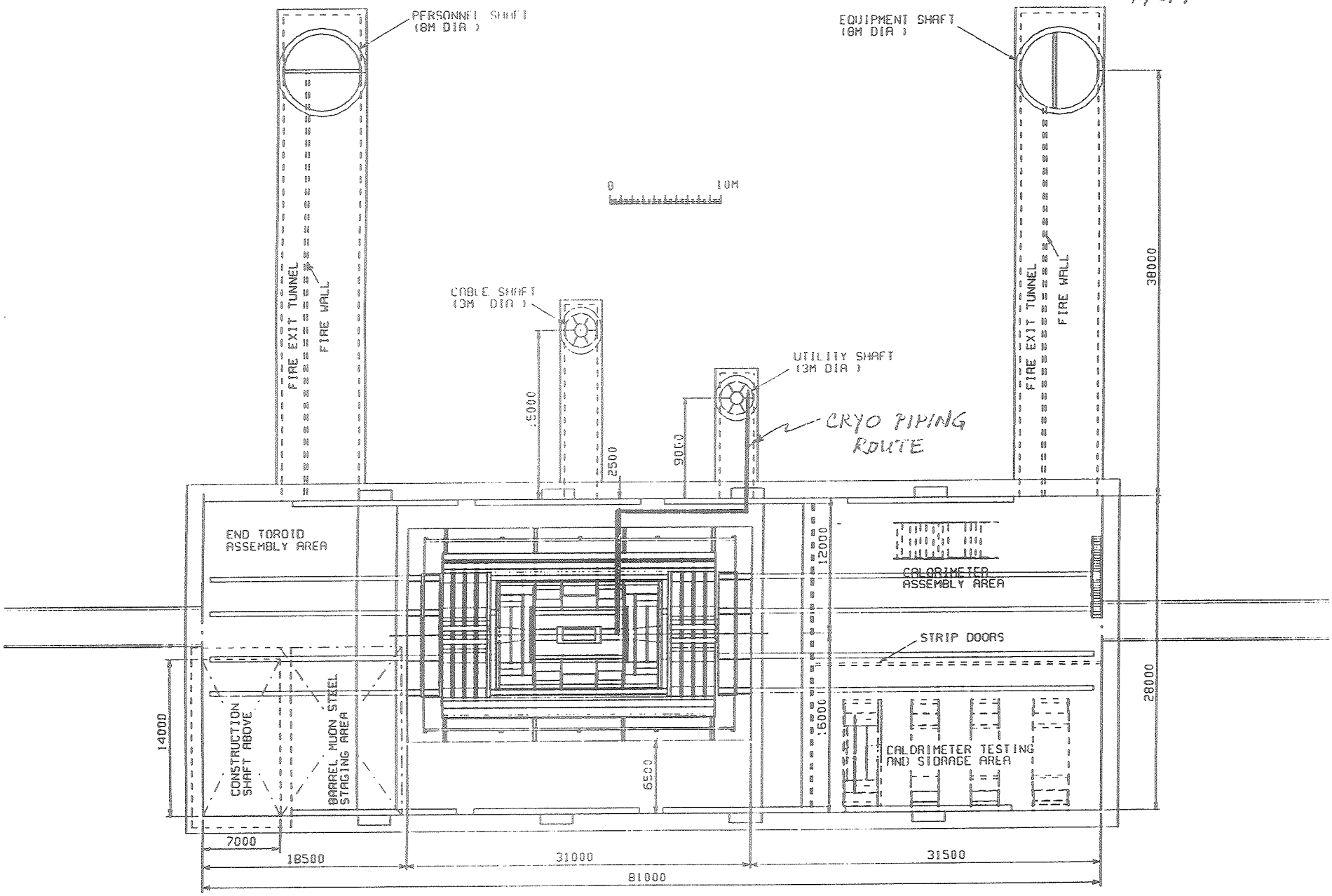


SURFACE FACILITIES

11 JUL 90

AMS
11/6/90

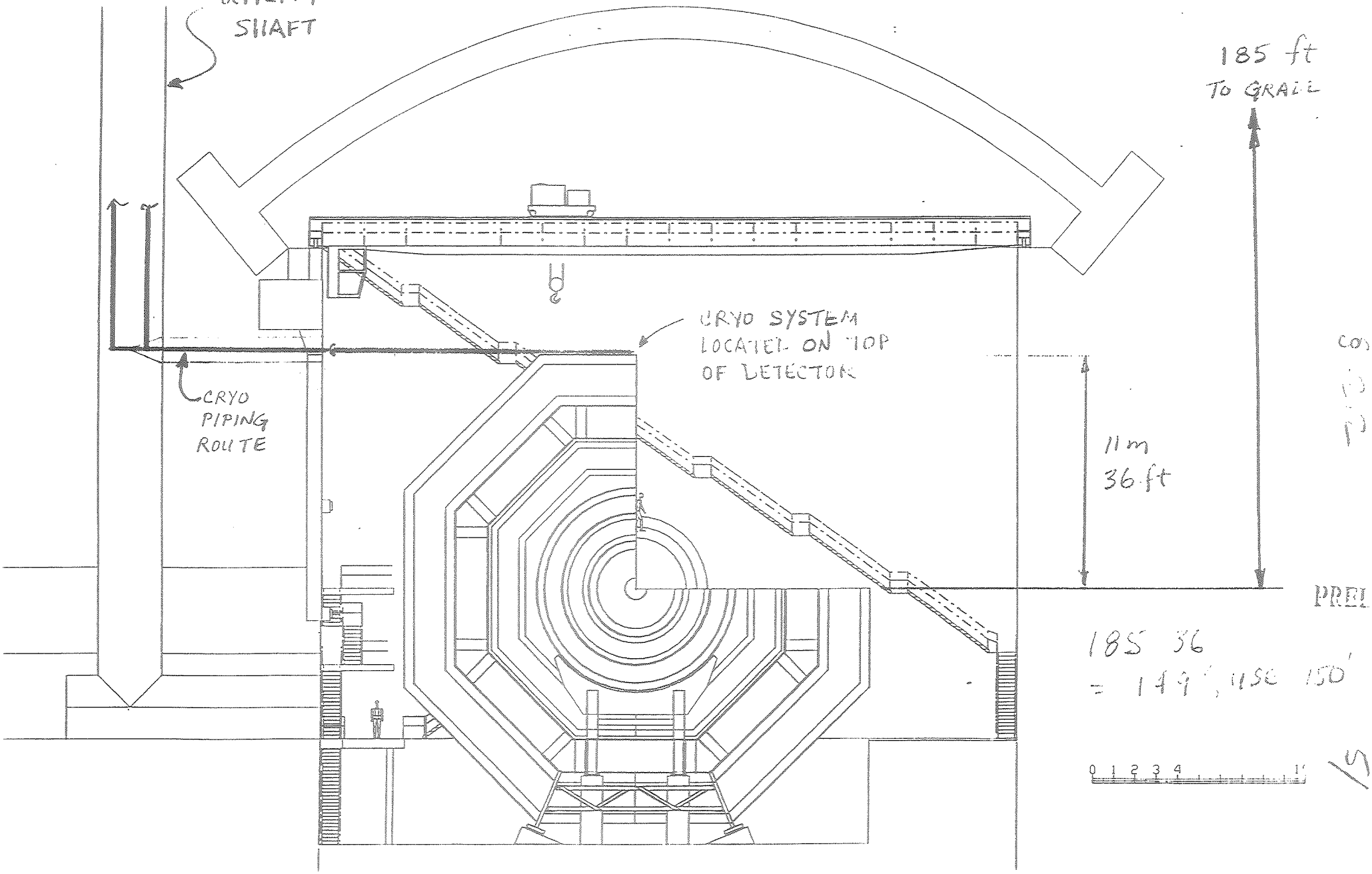


DETECTOR HALL FLOOR PLAN

MUON STEEL AND CALORIMETER ASSEMBLY ARRANGEMENT

7 JUL 90

AMS
11/6/90


UTILITY SHAFT
185 ft
TO GRADE
CRYO SYSTEM LOCATED ON TOP OF DETECTOR
CRYO PIPING ROUTE
11 m
36 ft
PREL
185 36
= 149', use 150'
0 1 2 3 4

FERMILAB ENGINEERING NOTE	SECTION 2.2	PROJECT SDC	SERIAL-CATEGORY	PAGE 61

SUBJECT	NAME	
SUMMARIZE PIPING SYSTEM FROM HELIUM REFR TO TOP OF DETECTOR	AMS	
	DATE 11/6/90	REVISION DATE

4 - BLOCK VALVES

14 - 90° SHORT RADIUS ELBOWS

2 - TEE BRANCH BRANCHES

1 - CONTROL VALVE (IF LOCATED UPSTREAM OF SUBCOOLER)

2 - U-TUBES (2 ELBOWS FOR EACH U-TUBE ARE INCLUDED ABOVE.)

1 - SUBCOOLING COIL AT DETECTOR

4 - BAYONETS

PIPE LENGTH:

FROM PUMP / SUBCOOLER TO UTILITY SHAFT	120 ft
DOWN UTILITY SHAFT	150 ft
OVER TO TOP OF DETECTOR	120 ft
U-TUBES (10 ft EACH FOR ELEVATION CHANGES. HORIZONTAL LENGTH IS INCLUDED IN ABOVE LENGTHS.)	20 ft
SUBCOOLING COIL	20 ft
$\Sigma =$	430 ft

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FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
2.2	SDC		7

SUBJECT: SUMMARIZE DETECTOR PIPING (BETWEEN SUBCOOLER AND CHIMNEY)

NAME: AMS

DATE: 11/6/90

REVISION DATE:

2 - BAYONETS

1 - U-TUBES (REFER TO PAGE 55 FOR DETAILS OF THIS U-TUBE)

1 - BLOCK VALVE

LENGTHS :

SUPPLY TUBE	35'	(SINGLE PHASE)
COIL (INCLUDES ELBOWS, INTERCEPTS AND MISC)	1,480'	(TWO PHASE) FROM PG. 45
RETURN TUBE	35'	(TWO PHASE)

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FERMILAB ENGINEERING NOTE	SECTION 2.2	PROJECT SDC	SERIAL-CATEGORY	PAGE 8/
SUBJECT: SUMMARIZE PIPING SYSTEM FROM TOP OF DETECTOR TO HELIUM REFR	NAME: JMS	DATE: 11/6/90	REVISION DATE	

5 - BLOCK VALVES (THERE ARE PROBABLY ONLY 4.)

16 - 90° SHORT RADIUS ELBOWS

1 - TEE BRANCH

4 - BAYONETS

2 - U-TUBES (2 ELBOWS FOR EACH U-TUBE ARE INCLUDED ABOVE.)

1 - CONTROL VALVE (IF LOCATED DOWNSTREAM OF SUBCOOLER)

PIPE LENGTH:

OVER TO UTILITY SHAFT	120 ft
UP UTILITY SHAFT	150 ft
FROM UTILITY SHAFT TO LHe STORAGE DEWAR	140 ft
U-TUBES (10 ft EACH FOR ELEVATION CHANGES. HORIZONTAL LENGTH IS INCLUDED IN ABOVE LENGTHS.)	20 ft
$\Sigma =$	430 ft

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ENGINEERING NOTE

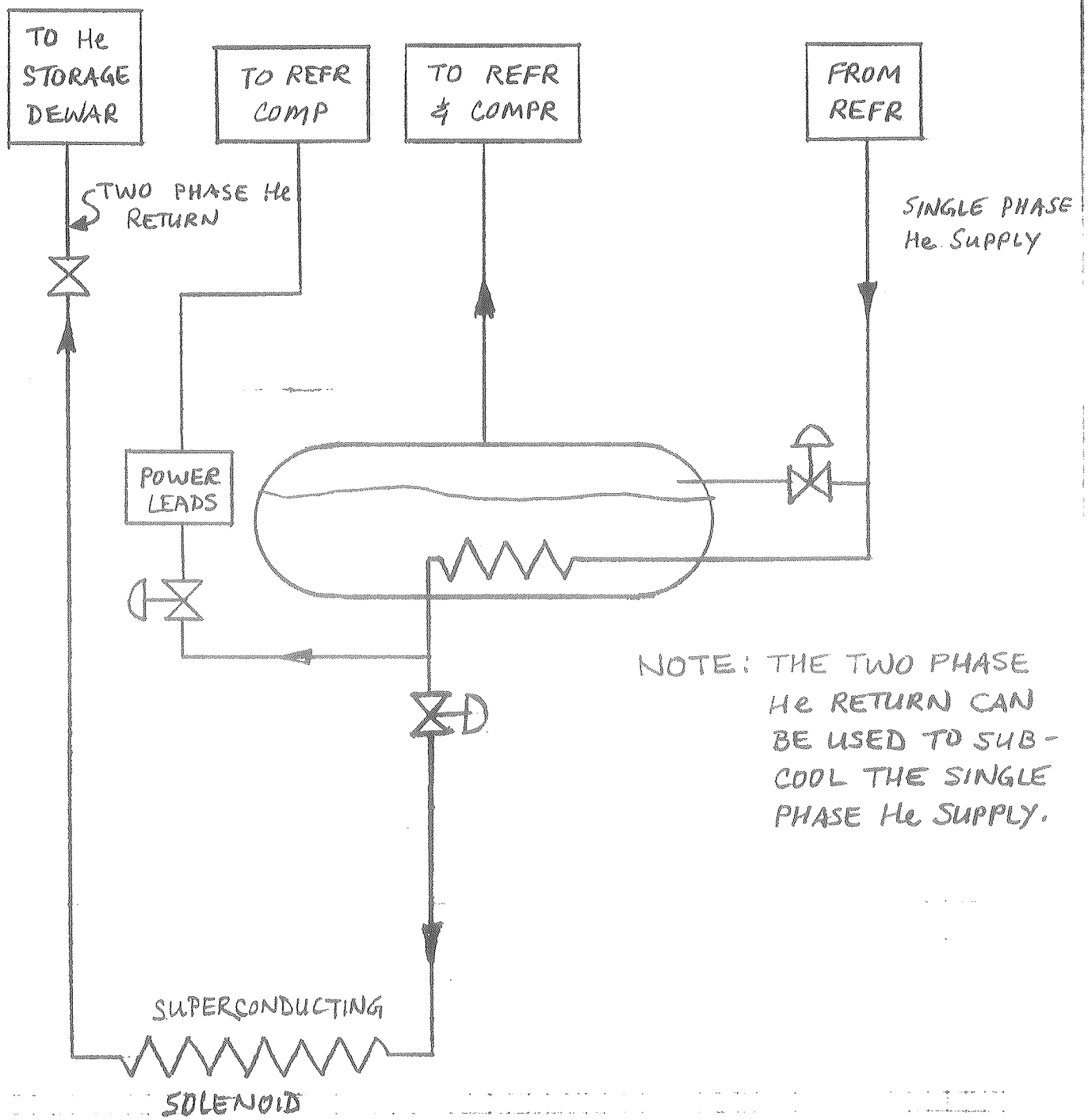
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
2.2	SDC		9/

SUBJECT: HELIUM SYSTEM ON TOP OF DETECTOR (LHe PUMPS IN REFR BLDG)

NAME: AMS

DATE: 11/6/90

REVISION DATE:



NOTE: THE TWO PHASE He RETURN CAN BE USED TO SUB-COOL THE SINGLE PHASE He SUPPLY.

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FERMILAB ENGINEERING NOTE	SECTION 2.3	PROJECT SDC	SERIAL-CATEGORY	PAGE 10/

SUBJECT: PRESSURE DROP AND HEAT LOAD FOR THE SUPPLY LINE FROM THE HELIUM REFR TO THE TOP OF THE DETECTOR

NAME: AMS

DATE: 11/7/90

REVISION DATE:

1.0 PRESSURE OR PUMP TRANSFER

TRY 1" ϕ SCH 10S PIPE → $d = 1.097''$

1.1 SUPPLY LINE PRESSURE DROP AND HEAT LOAD UP TO FLOW CONTROL VALVE

FLOW IN THE SUPPLY LINE IS SINGLE PHASE LIQUID.

REFER TO NBS TECHNICAL NOTE 631 - R.D. McCARTY FOR PROPERTIES.

ASSUME REFRIGERATOR OUTPUT IS 4.35 K.

ASSUME THE HIGH PRESSURE HELIUM STREAM IS SUBCOOLED TO WITHIN 0.05 K OF THE 4.35 K, WHICH IS 4.4 K.

$\mu = 0.004$ cp AT 4 ATM $\quad P_{SAT} = 1.174$ ATM $= 17.25$ psia

$h_f = 10.66$ J/g $= 4.6$ Btu/Lbm
$\rho = 0.12$ g/cc $= 7.5$ Lbm/ft^3
$h_{fg} = 19.32$ J/g $= 8.3$ Btu/Lbm
} SATURATED AT 4.4 K.

DETERMINE THE FLOW RATE DURING A CHARGE CYCLE:

STEADY STATE HEAT LOAD AT THE DETECTOR IS ESTIMATED AT 70 W IN §1.0. USE 100 W.

HEAT LOAD DUE TO CHARGING IS 220 W. (SEE ENGR NOTE 119)

ASSUME RETURN LINE HEAT LOAD ≐ 100 W

LEAD FLOW IS 28 ℓ/hr FOR A 10 KA PAIR. USE 35 ℓ/hr.

TOTAL COOLING DUTY IS $100 + 220 + 100 = 420$ W

ASSUME 25% OF THE LHe FLOW VAPORIZES AS IT RETURNS TO THE LHe STORAGE DEWAR DUE TO THE 420 W LOAD.

CALCULATE LHe FLOW FOR THE 420 W LOAD:

$$\dot{m} = \frac{Q}{h_{fg}} = 420 \frac{J}{s} * 19.32 \frac{g}{J} * \frac{1}{0.25} = 87 \text{ g/s}$$

CALCULATE LHe FLOW FOR THE LEADS:

$$35 \frac{\ell}{hr} * \frac{hr}{3600 s} * 1000 \frac{cc}{\ell} * 0.12 \frac{g}{cc} = 1.2 \text{ g/s}$$

Σ LHe FLOW $= 87 + 1.2 = 88.2$ g/s → 2,646 ℓ/hr

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SUBJECT

NAME AMS

DATE 11/7/90 | REVISION DATE

BASE THE CALCULATION ON A LHe FLOW OF 100 g/s.

$$100 \frac{g}{s} * 2.2046 \frac{Lbm}{1000g} * \frac{3600\ s}{hr} = 794\ Lbm/hr$$

CALCULATE EQUIVALENT LENGTH OF SUPPLY LINE –

LINE IS 1"ϕ SCH 10S. $d = 1.097"$

$$Re = 6.31 \frac{W}{d\mu} \quad \text{REF 1, EQN 3-3}$$

$$= \frac{6.31\ (794\ Lbm/hr)}{(1.097in)(0.004cp)} = 1.14 \times 10^6 \Rightarrow f \doteq 0.023$$

MINOR LOSSES

- 4 – BLOCK VALVES, CVI GLOBE VALVE $C_v = 14$

$$\Delta P = \left(\frac{Q}{C_v}\right)^2 \frac{\rho}{62.4} \quad \text{REF 1, EQN 3-16}$$

$$Q = 794 \frac{Lbm}{hr} * \frac{hr}{60min} * \frac{ft^3}{7.5\ Lbm} * 7.481 \frac{gal}{ft^3} = 13.2\ gpm$$

$$\Delta P_{PER\ VALVE} = \left(\frac{13.2}{14}\right)^2 \frac{7.8}{62.4} = 0.11\ psi$$

$$\Delta P_{FOR\ 4\ VALVES} = 4(0.11) = \underline{0.44\ psi}$$

- 14 – 90° SHORT RADIUS ELBOWS $K_{SCH\ 40} = 20 f_T = 20(0.023) = 0.46$

$$K_{SCH\ 10} = K_{SCH\ 40} \left(\frac{d_{SCH\ 10}}{d_{SCH\ 40}}\right)^4 \quad \text{REF 1, EQN 2-5}$$

$$= 0.46 \left(\frac{1.097}{1.049}\right)^4 = 0.55$$

$$14 \times 0.55 = \underline{7.7}$$

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- 2 - TEE BRANCHES $K_{SCH40} = 2(60) f_T = 120(0.023) = 2.76$

$$K_{SCH\,10} = 2.76 \left(\frac{1.097}{1.049}\right)^4 = \underline{3.3}$$

- 1 - CHECK VALVE

ASSUME FULL PORT, LIFT TYPE

$K_{SCH\,40} = 600 f_T = 600(0.023) = 13.8$

$$K_{SCH\,10} = 13.8 \left(\frac{1.097}{1.049}\right)^4 = \underline{16.5}$$

MINIMUM PIPE VELOCITY FOR FULL DISC LIFT $= 40 \beta^2 \sqrt{1/\rho}$

$$= 40 (1)^2 \sqrt{\frac{1}{7.5}} = 14.6 \text{ fps}$$

- 4 - BAYONETS

$\underline{\Delta P \doteq 0}$

- 1 - SUBCOOLING COIL

2 - 90° SHORT RADIUS ELBOWS $K_{SCH\,10} = 2(0.55) = 1.1$

1 - CLOSE PATTERN RETURN BENDS $K_{SCH\,40} = 50 f_T = 50(0.023) = 1.15$

$$K_{SCH\,10} = 1.15 \left(\frac{1.097}{1.049}\right)^4 = 1.4$$

$\Sigma = 1.1 + 1.4 = \underline{2.5}$

- CONTROL VALVE

ALLOW 20% OF FRICTIONAL LOSS

$\Sigma K = 7.7 + 3.3 + 2.5 = 13.5$

$K = \frac{fL}{D} \Rightarrow L_m = \frac{KD}{f} = \frac{13.5\,(1.097/12)\,ft}{0.023} = 54\,ft$

FLOW VELOCITY $= 794\,\frac{Lbm}{hr} * \frac{hr}{3600\,sec} * \frac{ft^3}{7.5\,Lbm} * \frac{1}{0.00656\,ft^2}$

$= 4.5\,fps$

EQUIVALENT LENGTH $\equiv L_e = 430 + 54 = 484\,ft$

ΔP FROM HELIUM REFRIGERATOR TO TOP OF DETECTOR $\equiv \Delta P_S$

$$\Delta P_S = \frac{f L_e}{D}\frac{v^2}{2g}\gamma + \Delta P_{VALVE} = \frac{0.023\,(484\,ft)\,(4.5)^2\,ft^2/sec^2\,(7.5\,Lbf/ft^3)}{(1.097/12)\,ft\,(2)\,(32.2\,ft/sec^2)\,144\,in^2/ft^2} + 0.44 = \underline{2.44\,psi}$$

FROM PAGE 15

ELEVATION HEAD $(h\gamma) = 150\,ft * \left(\frac{7.5+7.2}{2}\right)\frac{Lbf}{ft^3}\,\frac{ft^2}{144\,in^2} = 7.6\,psi$

AVERAGE DENSITY

VELOCITY HEAD $= \frac{v^2}{2g}\gamma = 4.5^2\,\frac{ft^2}{sec^2}\,\frac{sec^2}{2\,(32.2)\,ft} * 7.2\,\frac{Lbf}{ft^3} * \frac{ft^2}{144\,in^2}$

$= 0.016\,psi$

FROM PAGE 15

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CALCULATE FRICTIONAL HEAT LOAD

$Q_f = 1.5\ Q\ \Delta P = 1.5\ (13.2\ gpm)(2.44\ psi)$

$\doteq$ 50 Btu/hr

CALCULATE LINE HEAT LEAK, Q_l

- 4- BLOCK VALVES, CVI GLOBE VALVE

  4.5 Btu/hr FOR EACH VALVE

  4 x 4.5 = 18 Btu/hr

- 14- 90° ELBOWS

  L_{eq} = 14 (5 ft) = 70 ft REF: LINDE TABLE NO. 1 (APP)

- 2- TEE BRANCHES

  L_{eq} = 2(7.4) $\doteq$ 15 ft REF: LINDE TABLE NO. 1 (APP)

- 1 - CONTROL VALVE, CVI GLOBE VALVE

  4.5 Btu/hr

- 2- U-TUBES

  25 ft OF LINE PLUS 2 ELBOWS. THE 2 ELBOWS ARE INCLUDED ABOVE. THE 25' IS ALREADY INCLUDED IN THE LINE LENGTH.

- 4- BAYONETS

  16 Btu/hr FOR EACH BAYONET, CRYOLAB DATA

  (CVI CALCULATED HEAT LEAK IS 10.1 Btu/hr)

  4 x 16 = 64 Btu/hr

- 10- FIELD JOINTS, ASSUME 1 JOINT EVERY 40 ft.

  390 ft * 1 JOINT/40 ft $\doteq$ 10 JOINTS

  L_{eq} = 10 JOINTS * 20 ft/JOINT = 200 ft

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EQUIVALENT LENGTH = 430 + 70 + 15 + 200 = 715

HEAT LOAD FROM REFRIGERATOR TO TOP OF DETECTOR = Q_S

$$Q_S = 715\ ft * 0.5\ \frac{Btu}{hr\text{-}ft} + (50 + 18 + 4.5 + 64)\ \frac{Btu}{hr}$$

$$= 357.5 + 50 + 86.5 = \underline{494\ \frac{Btu}{hr}} = \underline{145\ W}$$

CALCULATE LHe SATURATION CONDITIONS AT END OF SUPPLY LINE:

THE LHe IS SUBCOOLED.

ENTHALPY INCREASE $= 145\ \frac{J}{s} * \frac{s}{100\ g} = 1.45\ J/g$

INITIAL ENTHALPY = 10.66 J/g (PG 10)

ENTHALPY AT TOP OF DETECTOR = 10.66 + 1.45 = 12.11 J/g

AT THIS ENTHALPY THE SATURATION CONDITIONS ARE:

$T_{SAT} \doteq 4.63\ K$ $\quad P_{SAT} \doteq 1.434\ ATM = 21.074\ psia = 6.4\ psig$

$\rho_f = 0.1154\ g/cc = 7.2\ lbm/ft^3$

CALCULATE LHe PRESSURE AT END OF SUPPLY LINE:

USE BERNOULLI'S EQUATION WITH LOSSES -

$$P_1 + \frac{v_1^2 \gamma_1}{2g} + z_1 \gamma_1 = P_2 + \frac{v_2^2 \gamma_2}{2g} + z_2 \gamma_2 + LOSSES$$

SUBSCRIPT 1 ≡ LHe STORAGE DEWAR
SUBSCRIPT 2 ≡ END OF SUPPLY LINE

$$17.3\ psia + 0 + 0 = P_2 + \underbrace{0.016\ psi - 7.6\ psi + 2.44\ psi}_{\text{FROM PAGE 13}}$$

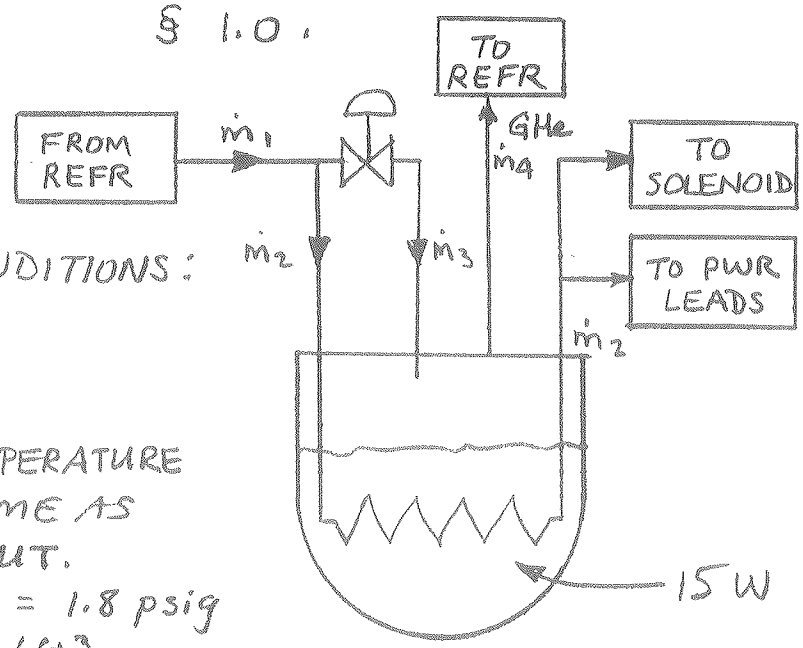
$$17.3 - 0.016 + 7.6 - 2.44 = P_2 = 22.444\ PSIA$$

∴ THE SUPPLY LHe IS SUBCOOLED BY 22.444 − 21.074 = 1.37 psi. NOTE: THE DEGREE OF SUBCOOLING WILL INCREASE AFTER THE SUPPLY PRESSURE IS CALCULATED; THE SATURATION PRESSURE WAS USED AT THIS POINT TO CHECK SUBCOOLIN

1.2 SUBCOOLER ON TOP OF THE DETECTOR

PART OF THE LHe FLOWING DOWN THE SUPPLY LINE WILL BE DIRECTED TO THE POOL BOILING SUBCOOLER TO SUBCOOL THE LHe FLOW TO THE SOLENOID AND TO REMOVE SUBCOOLER HEAT LEAK.

SUBCOOLER HEAT LEAK = 15 W THIS IS THE ESTIMATED HEAT LOAD FOR A PUMP DEWAR CALCULATED IN § 1.0.



SUBCOOLER OPERATING CONDITIONS:

ASSUME AN OPERATING TEMPERATURE OF 4.35 K. THIS IS THE SAME AS THE REFRIGERATOR OUTPUT.

$P_{SAT} = 1.123$ ATM $= 16.5$ psia $= 1.8$ psig

$\rho_{g\,SAT} = 0.01909$ g/cc $= 1.2$ Lbm/ft^3

PRESSURE DUE TO ELEVATION CHANGE $= 150\ ft \times 1.2\ \frac{Lbf}{ft^3} \times \frac{ft^2}{144\ in^2}$

$\doteq 1.25$ psi MAXIMUM

ASSUME COMPRESSOR SUCTION PRESSURE IS 0.2 psig.

ALLOWABLE FRICTIONAL ΔP FROM SUBCOOLER TO COMPRESSOR IS $1.8 - 1.25 - 0.2 = 0.35$ psi (LOOKS SMALL AT THIS STAGE)

ASSUME THE HIGH PRESSURE HELIUM STREAM IS SUBCOOLED TO WITHIN 0.05 K OF THE 4.35 OPERATING TEMP, WHICH IS 4.4 K.

∴ ALL OF THE SUPPLY LINE HEAT LOAD MUST BE REMOVED IN THE SUBCOOLER.

NOTE: A COMPRESSOR CAN BE ADDED AT THE SUBCOOLER TO LOWER THE OPERATING PRESSURE & SUPPLY TEMP TO THE SOLENOID

REFERRING TO THE SKETCH ON THE PREVIOUS PAGE:

$\dot{m}_1 = \dot{m}_2 + \dot{m}_3$

FLASH FRAC. FOR $\dot{m}_3 = \dfrac{h_1 - h_{SAT}}{h_{fg_3}} = \dfrac{(12.11 - 10.37)\ J/g}{19.67\ J/g} = 0.09$

ENERGY BALANCE EQUATION:

$F_\ell \dot{m}_3 h_{fg_3} = \dot{m}_2 \Delta h_2 + \text{SUBCOOLER HEAT LEAK} \equiv Q_s$

$\dot{m}_3 = \dot{m}_1 - \dot{m}_2$

$F_\ell (\dot{m}_1 - \dot{m}_2) h_{fg_3} = \dot{m}_2 \Delta h_2 + Q_s$

$(1 - 0.09)\ (100 - \dot{m}_2)\ g/s\ (19.67\ J/g) = (\dot{m}_2)\ g/s \left[12.11 - 10.66\right] J/g + 15\ J/s$

$1789.97 - 17.8997\ \dot{m}_2 = 1.45\ \dot{m}_2 + 15$

$91.7\ g/s \doteq \dot{m}_2$

$\therefore m_3 = 100 - 91.7 = 8.3\ g/s$

FLOW TO THE POWER LEADS = 1.2 g/s (PAGE 10)

FLOW TO THE SOLENOID = 91.7 − 1.2 = 90.5 g/s

$90.5\ g/s * \dfrac{60\ s}{min} * \dfrac{cc}{0.12\ g} * \dfrac{1\ \ell}{1000\ cc} * \dfrac{ft^3}{28.32\ \ell} * 7.481\ \dfrac{gal}{ft^3} = 12\ gpm$

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SUBJECT: PRESSURE DROP AND HEAT LOAD FOR THE RETURN LINE FROM THE TOP OF THE DETECTOR TO THE HELIUM REFRIGERATOR

NAME: AMS

DATE: 11/12/90

REVISION DATE:

1.3 RETURN LINE PRESSURE DROP AND HEAT LOAD UP TO CHIMNEY EXIT. TRY 2"ϕ SCH 10S PIPE $\rightarrow d = 2.157''$

FLOW IN THE RETURN LINE IS TWO PHASE.

AS ASSUMED ON PAGE 10, REFRIGERATOR OUTPUT IS 4.35 K.

LHe IN THE STORAGE DEWAR IS AT REFRIGERATOR OUTPUT CONDITIONS: 4.35K AND 16.5 PSIA (1.8 PSIG).

TWO PHASE HELIUM RETURNING FROM THE COIL RETURNS TO THE LHe STORAGE DEWAR.

FROM PAGE 17, 90.5 g/s FLOWS THROUGH THE COIL AND RETURNS TO THE LHe STORAGE DEWAR.

ESTIMATE QUALITY OF RETURN FLOW AT LHe STORAGE DEWAR:

FIRST CALCULATE RETURN LINE HEAT LEAK AND ESTIMATE THE FRICTIONAL HEAT LOAD. CALCULATE THE RETURN FLOW QUALITY AND FLOW REGIME AT THE LHe DEWAR AND THEN DO THE PRESSURE DROP CALCULATIONS.

SUBJECT

NAME AMS

DATE 11/12/90 | REVISION DATE

CALCULATE RETURN LINE HEAT LEAK, Q_ℓ

- 5 - BLOCK VALVES, CVI GLOBE VALVE

  16 Btu/hr FOR EACH VALVE

  5 x 16 = 80 Btu/hr

- 16 - 90° ELBOWS

  Leq = 16 (3.8 ft) = 61 ft REF: LINDE TABLE NO. 1 (APP)

- 1 - TEE BRANCH

  Leq = 6 ft REF: LINDE TABLE NO. 1 (APP)

- 4 - BAYONETS

  37 Btu/hr FOR EACH BAYONET, CRYOLAB DATA

  4 x 37 = 148 Btu/hr

- 2 - U-TUBES

  25 ft OF LINE PLUS 2 ELBOWS FOR EACH U-TUBE. THE ELBOWS ARE INCLUDED ABOVE. THE PIPE LENGTH IS INCLUDED IN THE LINE LENGTH.

- 1 - CONTROL VALVE, CVI GLOBE VALVE

  4.5 Btu/hr (1" VALVE)

- 10 - FIELD JOINTS, ASSUME 1 JOINT EVERY 40 ft.

  410 ~~ft~~ * 1 JOINT/40 ~~ft~~ ≐ 10 JOINTS

  Leq = 10 JOINTS * 15.2 ft/JOINT = 152 ft

EQUIVALENT LENGTH = 430 + 61 + 6 + 152 = 649 ft

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RETURN LINE HEAT LEAK, Q_ℓ

$$Q_\ell = 649\ ft \times 0.83\ \frac{Btu}{hr\text{-}ft} + (80 + 148 + 4.5)\ Btu/hr$$

$$= 538.67 + 232.5 = 771.17\ Btu/hr = 226\ W$$

ASSUME THE FRICTIONAL PRESSURE DROP IS 1.5 PSI FROM THE SUPPLY CONTROL VALVE THROUGH THE SOLENOID TO THE LHe STORAGE DEWAR.

CALCULATE FRICTIONAL HEAT LOAD

$$Q_f = 1.5\, Q\, \Delta P = 1.5\ (12\ gpm)(1.5\ psi) = 27\ Btu/hr$$

$\therefore$ RETURN LINE HEAT LOAD $= 771.17 + 27 = 798.17\ Btu/hr$

$\doteq$ 235 W

THE TOTAL COOLING DUTY FROM THE CONTROL VALVE, THROUGH THE SOLENOID TO THE LHe STORAGE DEWAR IS:

235 W	– RETURN LINE HEAT LOAD	
100 W	– SOLENOID AND CHIMNEY HEAT LOADS	PAGE
220 W	– CHARGING HEAT LOAD	
555 W		

BREAKDOWN

SOLENOID	20 W
CHIMNEY	10.2 W
MISC	~70 W

CALCULATE MIXTURE ENTHALPY AND QUALITY –

$$\Delta h = 555\ J/s \div 90.5\ g/s = 6.133\ J/g$$

$h_R \equiv$ MIXTURE ENTHALPY AT LHe STORAGE DEWAR

$$h_R = 10.66\ J/g + 6.133\ J/g = 16.793\ J/g$$

$$X_R = \frac{(16.793 - 10.37)\ J/g}{19.67\ J/g} = 0.33$$

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SUBJECT

NAME AMS

DATE 11/12/90 | REVISION DATE

FOLLOW REF 2 FOR PRESSURE DROP CALCULATION.

DETERMINE FLOW REGIME — REF 2 PG 514

THE RETURN HELIUM FLOW IS SATURATED AT 4.35 K AS IT ENTERS THE LHe STORAGE DEWAR.

PROPERTIES OF SATURATED HELIUM AT 4.35 K:

$\rho_g = 0.01909\ g/cc = 1.2\ Lbm/ft^3 \Rightarrow v_g = 0.84\ ft^3/Lbm$

$\rho_f = 0.1224\ g/cc = 7.64\ Lbm/ft^3 \Rightarrow v_f = 0.13\ ft^3/Lbm$

$h_{fg} = 30.04 - 10.37 = 19.67\ J/g = 8.46\ Btu/Lbm$

$\sigma = 0.087$ dyne/cm $\quad \mu_f = 0.0031$ cp $\quad P_{SAT} = 1.123$ ATM $= 16.5$ psia

$$\lambda = \left(\frac{\rho_g}{0.075}\ \frac{\rho_f}{62.3}\right)^{1/2} = \left(\frac{1.2}{0.075}\ \frac{7.64}{62.3}\right)^{1/2} = 1.4$$

$$\psi = \frac{73}{\sigma}\left[\mu_L \left(\frac{62.3}{\rho_L}\right)^2\right]^{1/3} = \frac{73}{0.087}\left[0.0031\left(\frac{62.3}{7.64}\right)^2\right]^{1/3} = 496$$

2" ϕ SCH 10 FLOW AREA = 0.02538 ft^2

$$\dot{m} = 90.5\ \frac{g}{s} \times 3600\ \frac{s}{hr} \times \frac{2.2046\ Lbm}{1000\ g} = 719\ Lbm/hr$$

$$L = \frac{\dot{m}_{LIQ}}{\text{FLOW AREA}} = \frac{719\ Lbm/hr\ (1-0.33)}{0.02538\ ft^2} = 18{,}980\ \frac{Lbm}{hr\text{-}ft^2}$$

$$G = \frac{\dot{m}_{VAP}}{\text{FLOW AREA}} = \frac{719\ (0.33)}{0.02538} = 9{,}350\ \frac{Lbm}{hr\text{-}ft^2}$$

$G/\lambda = 9350 / 1.4 = 6{,}680$

$\lambda L \psi / G = 1.4\ (18{,}980)(496) / 9{,}350 = 1{,}410$

$\Rightarrow$ ENTER BAKER DIAGRAM

FROM THE BAKER DIAGRAM, THE RETURN FLOW IS IN THE BUBBLE REGIME.

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PRESSURE DROP FOR HELIUM IN THE BUBBLE FLOW REGIME CAN BE CALCULATED WITH THE HOMOGENEOUS MODEL, REF 2, PG 516.

THE RETURN LINE MUST BE DIVIDED INTO THREE SECTIONS FOR THE ΔP CALCULATION: SURFACE PIPING, VERTICAL UTILITY SHAFT PIPING AND PIPING AT THE DETECTOR.

SURFACE PIPING

FITTINGS:

3 - BLOCK VALVES

9 - 90° ELBOWS

2 - BAYONETS

1 - U-TUBE (THE 2 ELBOWS FOR THE U-TUBE ARE INCLUDED ABOVE.)

PIPE LENGTH: 140 ft + 10 ft = 150 ft
(10 ft FOR U-TUBE)

CALCULATE LINE HEAT LEAK - REFER TO PAGE 19 FOR DETAILS.

- 3 - BLOCK VALVES, $3 \times 16 = 48$ Btu/hr
- 9 - 90° ELBOWS, $L_{eq} = 9 \times 3.8$ ft $= 34.2$ ft
- 2 - BAYONETS, $2 \times 37 = 74$ Btu/hr
- 3 - FIELD JOINTS, $L_{eq} = 3 * 15.2 = 45.6$ ft

EQUIVALENT LENGTH $= 150 + 34.2 + 45.6 \doteq 230$ ft

HEAT LEAK FOR THIS SECTION $= 230\,\text{ft} * 0.83 \frac{\text{Btu}}{\text{hr-ft}} + [48 + 74] \frac{\text{Btu}}{\text{hr}}$

$= 312.9 \frac{\text{Btu}}{\text{hr}} = 91.7$ W

CALCULATE THE FRICTIONAL EQUIVALENT LENGTH -

THE LINE IS 2" ϕ SCH 10S. $d = 2.157''$

$$Re = \frac{6.31\,W}{d\,\mu} \quad \text{REF 1, EQN 3-3}$$

$$= \frac{6.31\,(719)}{2.157\,(0.0031)} = 6.8 \times 10^5 \Rightarrow f = 0.02$$

MINOR LOSSES

- 3 - BLOCK VALVES, CVI GLOBE VALVE $C_v = 60$

CONVERT THE C_v TO A RESISTANCE COEFFICIENT.

$$K = \frac{891\,d^4}{C_v^2} \quad \text{REF 1, EQN 3-16}$$

$$K = \frac{891\,(2.157)^4}{60^2} = 5.4 \text{ FOR EACH VALVE}$$

$$K = 3\,(5.4) = \underline{16.2} \text{ FOR 3 VALVES}$$

- 9 - 90° ELBOWS

$$K_{SCH\,40} = 20\,f_T = 20\,(0.019) = 0.38$$

$$K_{SCH\,10} = K_{SCH\,40}\left(\frac{d_{SCH\,10}}{d_{SCH\,40}}\right)^4 \quad \text{REF 1, EQN 2-5}$$

$$= 0.38\left(\frac{2.157}{2.067}\right)^4 = 0.45 \text{ FOR EACH ELBOW}$$

$$9 \times 0.45 = \underline{4.05} \text{ FOR 9 ELBOWS}$$

- 2 BAYONETS $\Delta P \doteq 0$

$$\Sigma K = 16.2 + 4.05 = 20.25$$

$$L_m = \frac{KD}{f} = \frac{20.25\,(2.157/12)\,ft}{0.02} = 182\,ft$$

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EQUIVALENT LENGTH $\equiv L_e = 130 + 182 = \underline{312\ ft}$

THIS IS AN ITERATIVE CALCULATION BECAUSE THE FLOW IS TWO PHASE.

FIRST, CALCULATE THE FRICTIONAL PRESSURE DROP, ΔP_f, USING THE EXIT MIXTURE SPECIFIC VOLUME.

SUBSCRIPT 1 REFERS TO THE INLET TO THE SECTION OF LINE, SUBSCRIPT 2 TO THE EXIT.

$X_2 = 0.33$ FROM PAGE 20

$$v_2 = v_{f_2} + X_2 (v_{g_2} - v_{f_2}) = 0.13 + 0.33(0.84 - 0.13) = 0.37\ ft^3/Lbm$$

$$\dot{m} = 719 \frac{Lbm}{hr} \times \frac{hr}{3600\,s} = 0.2\ Lbm/sec$$

$$\frac{\dot{m}}{A} = 719 \frac{Lbm}{hr} \times \frac{hr}{3600\,s} \times \frac{1}{0.02538\ ft^2} = 7.87 \frac{Lbm}{sec\text{-}ft^2}$$

$$V_2 = \frac{\dot{m}}{A} v_2 = 7.87 \frac{Lbm}{sec\text{-}ft^2} \times 0.37 \frac{ft^3}{Lbm} = 2.9\ fps$$

CALCULATE ΔP_f BASED ON EXIT CONDITIONS

$$\Delta P_f = \frac{f L_e}{D}\left(\frac{\dot{m}}{A}\right)^2 \frac{v_2}{2g} = \frac{0.02\,(312\ ft)}{(2.157/12)\ ft}\left(\frac{7.87^2\ Lbm^2}{sec^2\text{-}ft^2}\right) 0.37 \frac{ft^3}{Lbm} \frac{sec^2\ Lbf}{2(32.2\ ft)}$$

$$= 12.4\ Lbf/ft^2 = 0.09\ psi$$

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$$\left(\frac{dh_f}{dp}\right)_{SAT} = \frac{(12.99 - 10.37)\ J/g}{1.582 - 1.123\ ATM} = 5.7\ \frac{J}{g\text{-}ATM}$$ BETWEEN 4.35 & 4.75K

$$5.7\ \frac{\cancel{J}}{\cancel{g}\ \cancel{ATM}} * \frac{1\ \cancel{ATM}\text{-}\cancel{in^2}}{14.696\ Lbf} * \frac{1000\ \cancel{g}}{2.2046\ Lbm} * \frac{\cancel{cal}}{4.186\ \cancel{J}} * \frac{ft^2}{144\ \cancel{in^2}} * \frac{Btu}{252\ \cancel{cal}}$$

$$= 0.0012\ \frac{Btu\text{-}ft^2}{Lbm\text{-}Lbf}$$

ESTIMATE THE INLET QUALITY, X_1, ASSUMING THE MOMENTUM PRESSURE DROP, ΔP_m, IS NEGLIGIBLE.

$$\Delta P = \Delta P_f + \Delta P_m = \frac{(X_2 h_{fg_2} - X_1 h_{fg_1}) + \frac{V_2^2 - V_1^2}{2g_c} + \frac{g}{g_c}(z_2 - z_1) - \dot{Q}/\dot{m}}{(dh/dp)_{SAT}}$$

FOR A HORIZONTAL LINE WITH NEGLIGIBLE ΔP_m, THIS EQUATION REDUCES TO

$$\Delta P = \Delta P_f = \frac{(X_2 h_{fg_2} - X_1 h_{fg_1}) - \dot{Q}/\dot{m}}{(dh/dp)_{SAT}}$$

THE INLET CONDITIONS ARE NOT KNOWN AT THIS POINT. ASSUME $h_{fg_1} \doteq h_{fg_2}$ AND SOLVE FOR X_1

$$\Delta P_f = \frac{h_{fg_2}(X_2 - X_1) - \dot{Q}/\dot{m}}{(dh/dp)_{SAT}}$$

$$\frac{\left(\frac{dh}{dP}\right)_{SAT} \Delta P + \frac{\dot{Q}}{\dot{m}}}{h_{fg_2}} = X_2 - X_1$$

$$X_1 = X_2 - \frac{\left(\frac{dh}{dP}\right)_{SAT} \Delta P + \dot{Q}/\dot{m}}{h_{fg_2}}$$

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NOW, SOLVE FOR X_1 WITH $h_{fg2} \neq h_{fg1}$ FOR A HORIZONTAL LINE WITH NEGLIGIBLE ΔP_m.

$$\left(\frac{dh}{dp}\right)_{SAT} \Delta P + \dot{Q}/\dot{m} = X_2 h_{fg2} - X_1 h_{fg1}$$

$$X_1 = \frac{X_2 h_{fg2} - \left(\frac{dh}{dp}\right)_{SAT} \Delta P - \dot{Q}/\dot{m}}{h_{fg1}}$$

ASSUME $\Delta P = 0.1$ psi $= 14.4$ Lbf/ft^2

THEN: $P_1 = 1.123$ ATM $+ 0.1/14.696 = 1.13$ ATM

$T_{SAT_1} \doteq 4.357$ K

$\rho_{f1} = 0.1222$ g/cc $= 7.63$ Lbm/ft$^3 \Rightarrow v_{f1} = 0.13$ ft^3/Lbm

$\rho_{g1} = 0.01922$ g/cc $= 1.2$ Lbm/ft$^3 \Rightarrow v_{g1} = 0.833$ ft^3/Lbm

$h_{fg1} = 19.62$ J/g $= 8.44$ Btu/Lbm

SOLVE FOR X_1:

$$X_1 = 0.33\,(8.46)\,\frac{\text{Btu}}{\text{Lbm}} - 0.0012\,\frac{\text{Btu-ft}^2}{\text{Lbm-Lbf}}\left(14.4\,\frac{\text{Lbf}}{\text{ft}^2}\right) - \frac{312.9\,\frac{\text{Btu}}{\text{hr}}}{719\,\frac{\text{Lbm}}{\text{hr}}}$$

$$8.44\ \text{Btu/Lbm}$$

$X_1 = 0.278$

$v_1 = v_{f1} + X_1\,(v_{g1} - v_{f1}) = 0.13 + 0.278\,(0.833 - 0.13) = 0.33$ ft^3/Lbm

$$v_m = \frac{v_1 + v_2}{2} = \frac{0.33 + 0.37}{2} = 0.35 \text{ ft}^3/\text{Lbm}$$

$$V_1 = \frac{\dot{m}}{A} v_1 = 7.87\,\frac{\text{Lbm}}{\text{sec-ft}^2} * 0.33\,\frac{\text{ft}^3}{\text{Lbm}} = 2.6 \text{ fps}$$

$$V_2 = \frac{\dot{m}}{A} v_2 = 7.87\,(0.37) = 2.9 \text{ fps}$$

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$$\Delta P_f = \frac{f L_e}{D}\left(\frac{\dot m}{A}\right)^2 \frac{v_m}{2g_c} = \frac{0.02(312)\,ft}{(2.157/12)\,ft}\left(7.87^2\,\frac{Lbm^2}{sec^2\,ft^4}\right)\left(0.35\,\frac{ft^3}{Lbm}\right)\frac{Lbf\text{-}sec^2}{2*32.2\,ft\,Lbm}$$

$$= 11.7\ Lbf/ft^2 = 0.081\ psi$$

$$\Delta P_m = \frac{\dot m}{A}\,\frac{V_2 - V_1}{g_c} = 7.87\,\frac{Lbm}{sec\text{-}ft^2}\left(2.9 - 2.6\,\frac{ft}{sec}\right)\frac{sec^2\,Lbf}{32.2\,ft\text{-}Lbm}$$

$$= 0.073\ Lbf/ft^2 = 0.0005\ psi$$

$\Delta P = \Delta P_f + \Delta P_m = 0.081 + 0.0005 = \underline{0.082}\ psi \doteq$ THE ASSUMED VALUE OF 0.1 psi OK

FROM PAGE 25, FOR $Z_2 = Z_1$

$$\Delta P = \left[\left(0.33*8.46 - 0.278*8.44\right)\frac{Btu}{Lbm} + \frac{(2.9^2 - 2.6^2)\,\frac{ft^2}{sec^2}}{2(32.2)\,\frac{ft\text{-}Lbm}{Lbf\text{-}sec^2}} * \frac{Btu}{778.16\,ft\text{-}Lbf} + \cancel{\frac{g}{g_c}(Z_2 - Z_1)}^{\,0} - \frac{312.9\,\frac{Btu}{hr}}{719\,\frac{Lbm}{hr}}\right] \Big/ \left(0.0012\,\frac{Btu\text{-}ft^2}{Lbm\text{-}Lbf}\right)$$

$$\Delta P = 8.6\,\frac{Lbf}{ft^2} = 0.06\ psi \doteq 0.082\ psi \quad \underline{OK}$$

∴ PRESSURE AT TOP OF THE VERTICAL SECTION OF RETURN LINE IN THE UTILITY SHAFT = LHe STORAGE DEWAR PRESSURE + ΔP.

$$P_1 = 1.123\ ATM + 0.1\ psi * \frac{1\ ATM}{14.696\ psi} = 1.13\ ATM$$

$$= 16.6\ psia$$

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VERTICAL UTILITY SHAFT

FITTINGS: NONE

PIPE LENGTH: 150 ft

CALCULATE LINE HEAT LEAK -

4- FIELD JOINTS, $L_{eq} = 4 * 15.2 = 60.8$ ft

EQUIVALENT LENGTH $= 150 + 60.8 \doteq 211$ ft

HEAT LEAK FOR THIS SECTION $= 211 \text{ ft} * 0.83 \frac{\text{Btu}}{\text{hr-ft}} = 175 \frac{\text{Btu}}{\text{hr}}$

$= 51.3 \text{ W}$

PIPE LENGTH FOR ΔP CALCULATION = 150 ft

AS IN THE PREVIOUS CALCULATION FOR THE SECTION OF SURFACE PIPING, SUBSCRIPT 1 REFERS TO THE INLET TO THE SECTION OF LINE AND SUBSCRIPT 2 TO THE EXIT.

$X_2 \doteq 0.278$ FROM PAGE 26

FLUID PROPERTIES AT THE EXIT ARE ALSO ON PAGE 26

SOLVE THE GENERAL ΔP EQUATION ON PAGE 25 FOR X_1 FOR VERTICAL PIPING WITH NEGLIGIBLE ΔP_m.

$$x_2 h_{fg_2} - x_1 h_{fg_1} = \left(\frac{dh}{dp}\right)_{SAT} \Delta P - \frac{g}{g_c}(z_2 - z_1) + \dot{Q}/\dot{m}$$

$$x_1 = \frac{x_2 h_{fg_2} - \left(\frac{dh}{dp}\right)_{SAT} \Delta P + \frac{g}{g_c}(z_2 - z_1) - \dot{Q}/\dot{m}}{h_{fg_1}}$$

ESTIMATE THE SATURATION CONDITIONS AT THE CHIMNEY EXIT TO SEE IF TWO PHASE FLOW EXISTS ALONG THE ENTIRE LENGTH OF THE RETURN LINE.

$Q = 100 + 220 = 320\ W$

$$\Delta h_{SOLENOID} = 320 \frac{J}{s} * \frac{s}{90.5 g} = 3.54\ J/g$$

$$h_{SOLENOID\ EXIT} = 10.66\ J/g + 3.54\ J/g = 14.2\ J/g$$

WITH $h_{SAT} = 14.2\ J/g$, $P_{SAT} = 1.75\ ATM = 25.71\ psia$
$= 11\ psig$

$T_{SAT} = 4.875\ K$

USING $v_m = 0.3\ ft^3/Lbm$, THE PRESSURE AT THE INLET TO THE RETURN LINE AND THE CHIMNEY EXIT IS ABOUT:

$$P_{CHIMNEY\ EXIT} \doteq \begin{bmatrix}\text{PRESSURE AT TOP OF} \\ \text{VERTICAL UTILITY SHAFT}\end{bmatrix} + \begin{bmatrix}\text{PRESSURE DUE TO} \\ \text{ELEVATION CHANGE}\end{bmatrix}$$

$$= \underbrace{\left[1.13\ ATM * \frac{14.696\ psi}{ATM}\right]}_{\text{PAGE}} + \underbrace{\left[150\ ft * \frac{Lbf}{0.3\ ft^3} * \frac{ft^2}{144\ in^2}\right]}_{=3.5\ psi}$$

$= 20.1\ psia$

SINCE $20.1\ psia < P_{SAT} = 25.71\ psia$, TWO PHASE FLOW EXISTS IN THE ENTIRE RETURN LINE AND IN THE CHIMNEY RETURN LINE.

THE PRESSURE DIFFERENCE DUE TO THE 150 ft ELEVATION CHANGE IS ABOUT 3.5 PSI AS CALCULATED ON THE PREVIOUS PAGE.

ASSUME $\Delta P = 0.035\ psi = 5\ Lbf/ft^2$

THEN: $\Delta P_{TOTAL} = 3.5 + 0.035 = 3.535\ psi = 509.04\ Lbf/ft^2$

$P_1 = 16.6\ psia + 3.535 = 20.135\ psia = 1.37\ ATM$

$\rho_f = 0.117\ g/cc = 7.3\ Lbm/ft^3 \Rightarrow v_f = 0.137\ ft^3/Lbm$

$\rho_g = 0.024\ g/cc = 1.5\ Lbm/ft^3 \Rightarrow v_g = 0.67\ ft^3/Lbm$

$h_{fg} = 17.89\ J/g = 7.69\ Btu/Lbm$

$T_{SAT} \doteq 4.58\ K$

FROM PAGE 26 THE EXIT CONDITIONS ARE:

$$\begin{cases} X_2 = 0.278 \\ v_2 = 0.33\ ft^3/Lbm \\ V_2 = 2.6\ fps \end{cases} \qquad h_{fg_2} = 8.44\ Btu/Lbm$$

SOLVE FOR X_1 USING THE EQUATION ON PAGE 28

$$X_1 = \Big[0.278\,(8.44)\frac{Btu}{Lbm} - 0.0012\,\frac{Btu\text{-}ft^2}{Lbm\text{-}Lbf} * 509.04\,\frac{Lbf}{ft^2}$$

$$+ 32.2\,\frac{ft}{sec^2}\,\frac{Lbf\text{-}sec^2}{32.2\,ft\,Lbm}\,[150\,ft]\,\frac{Btu}{778.16\,ft\text{-}Lbf}$$

$$- 175\,\frac{Btu}{hr} * 719\,\frac{hr}{Lbm}\Big] \Big/ 7.69\ Btu/Lbm$$

$= 0.239$ (THIS SHOULD HAVE BEEN 0.219)

THEN $v_1 = v_{f_1} + X_1(v_{g_1} - v_{f_1}) = 0.137 + 0.239(0.67 - 0.137)$

$= 0.264\ ft^3/Lbm$

$$v_m = \frac{v_1 + v_2}{2} = \frac{0.264 + 0.33}{2} \doteq 0.3\ ft^3/Lbm$$

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$$\Delta P_f = \frac{fL}{D}\left(\frac{\dot{m}}{A}\right)^2 \frac{v_m}{2g_c}$$

$$= \frac{0.02\,(150\,\cancel{ft})}{(2.157/12)\,\cancel{ft}}\left(7.87^2\,\frac{\cancel{Lbm}^2}{\cancel{sec^2}\text{-}ft^4}\right)\left(0.3\,\frac{\cancel{ft^3}}{\cancel{Lbm}}\right)\frac{Lbf\text{-}\cancel{sec^2}}{(2)(32.2)\,ft\,\cancel{Lbm}}$$

$$= 4.8\ Lbf/ft^2 = 0.034\ psi$$

$$V_1 = \frac{\dot{m}}{A}\,v_1 = 7.87\,\frac{\cancel{Lbm}}{sec\text{-}\cancel{ft^2}} \times 0.264\,\frac{\cancel{ft^3}}{\cancel{Lbm}} = 2.1\ fps$$

$$\Delta P_m = \left(\frac{\dot{m}}{A}\right)\frac{V_2 - V_1}{g_c} = 7.87\,\frac{\cancel{Lbm}}{\cancel{sec}\,ft^2}\left(2.6 - 2.1\right)\frac{\cancel{ft}}{\cancel{sec}}\ \frac{\cancel{sec^2}\text{-}Lbf}{32.2\,\cancel{ft}\,\cancel{Lbm}}$$

$$= 0.12\ Lbf/ft^2 = 0.0009\ psi$$

$$\Delta P_{ELEV} = 150\ \cancel{ft} \times \frac{Lbf}{0.3\ ft^{\cancel{3}2}} = 500\ Lbf/ft^2 = 3.47\ psi$$

$$\Delta P_{TOTAL} = \Delta P_f + \Delta P_m + \Delta P_{ELEV}$$

$$= 4.8 + 0.12 + 500 = 504.92\ Lbf/ft^2$$

$$= 3.51\ psi \doteq$$ THE ASSUMED VALUE OF 3.535 psi OK

∴ PRESSURE AT BOTTOM OF THE VERTICAL SECTION OF RETURN LINE IN THE UTILITY SHAFT = PRESSURE AT THE TOP OF THE VERTICAL SECTION + ΔP.

$P_1 = 20.135$ psia $= 1.37$ ATM FROM THE PREVIOUS PAGE.

PIPING AT THE DETECTOR

FITTINGS :

2 - BLOCK VALVES

7 - 90° ELBOWS

1 - TEE BRANCH

2 - BAYONETS

1 - U-TUBE (THE 2 ELBOWS FOR THE U-TUBE ARE INCLUDED ABOVE.)

PIPE LENGTH : 120 ft + 10 ft = 130 ft
FOR U-TUBE

CALCULATE LINE HEAT LEAK - REFER TO PAGE 19 FOR DETAILS.

- 2 - BLOCK VALVES, $2 \times 16 = 32$ Btu/hr
- 7 - 90° ELBOWS, $L_{eq} = 7 \times 3.8$ ft $= 26.6$ ft
- 1 - TEE BRANCH, $L_{eq} = 6$ ft
- 2 - BAYONETS, $2 \times 37 = 74$ Btu/hr
- 3 - FIELD JOINTS, $L_{eq} = 3 \times 15.2 = 45.6$ ft

EQUIVALENT LENGTH $= 130 + 26.6 + 6 + 45.6 \doteq 208$ ft

HEAT LEAK FOR THIS SECTION $= 208 \text{ ft} \times 0.83 \frac{\text{Btu}}{\text{hr-ft}} + [32 + 74] \frac{\text{Btu}}{\text{hr}}$

$= 278.6 \frac{\text{Btu}}{\text{hr}} = \underline{81.6 \text{ W}}$

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SUBJECT

NAME: AMS

DATE: 11/14/90 | REVISION DATE

CALCULATE THE FRICTIONAL EQUIVALENT LENGTH - THE LINE IS 2"φ SCH 105. d = 2.157"

REFER TO PAGE 23 FOR DETAILS.

$f = 0.02$

MINOR LOSSES

- 2 - BLOCK VALVES, CVI GLOBE VALVE

  $K = 2(5.4) = 15.8$ FOR 2 VALVES

  SHOULD HAVE BEEN 10.8

- 7 - 90° ELBOWS

  $K = 7 * 0.45 = 3.15$ FOR 7 ELBOWS

- 1 - TEE BRANCH

  $K_{SCH\ 40} = 60\ ft = 3(20\ ft) = 3(K \text{ FOR } 90° \text{ ELBOW})$

  $K = 3(0.45) = 1.35$

- 2 - BAYONETS $\Delta P \doteq 0$

$\Sigma K = 15.8 + 3.15 + 1.35 = 20.3$

$$L_m = \frac{KD}{f} = \frac{20.3\ (2.157/12)\ ft}{0.02} = 183\ ft$$

EQUIVALENT LENGTH = 130 + 183 = 313 ft

AS IN THE PREVIOUS CALCULATION FOR THE OTHER TWO SECTIONS OF THE RETURN LINE, SUBSCRIPT 1 REFERS TO THE INLET TO THE SECTION OF LINE AND SUBSCRIPT 2 TO THE EXIT.

$X_2 = 0.239$ FROM PAGE 30

FLUID PROPERTIES AT THE EXIT ARE ALSO ON PAGE 30.

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ASSUME $\Delta P = 0.07$ psi $= 10.08$ lbf/ft^2

THEN : $P_1 = 20.135$ psia $+ 0.07$ psi $= 20.205$ psia $= 1.375$ ATM

$\rho_f = 0.1168$ g/cc $= 7.3$ Lbm/ft^3 $\Rightarrow v_f = 0.137$ ft^3/Lbm

$\rho_g = 0.024$ g/cc $= 1.5$ Lbm/ft^3 $\Rightarrow v_g = 0.67$ Lbm/ft^3

$h_{fg} = 17.85$ J/g $= 7.68$ Btu/Lbm

$T_{SAT} = 4.58$ K

FROM PAGES 30 & 31 THE EXIT CONDITIONS ARE :

$$\begin{cases} X_2 = 0.239 \\ v_2 = 0.264 \text{ ft}^3/\text{Lbm} \\ V_2 = 2.1 \text{ fps} \\ h_{fg} = 7.69 \text{ Btu/Lbm} \end{cases}$$

SOLVE FOR X_1 USING THE EQUATION ON PAGE

$$X_1 = \left[(0.239)\, 7.69 \frac{\text{Btu}}{\text{Lbm}} - \left(0.0012 \frac{\text{Btu-ft}^2}{\text{Lbm-Lbf}} * 10.08 \frac{\text{Lbf}}{\text{ft}^2}\right) - 278.6 \frac{\text{Btu}}{\text{hr}} \left(\frac{\text{hr}}{719\ \text{Lbm}}\right) \right] \Big/ 7.68 \ \text{Btu/Lbm}$$

$$= 0.188$$

THEN $v_1 = v_{f_1} + x_1 (v_{g_1} - v_{f_1}) = 0.137 + 0.188\,(0.67 - 0.137)$

$= 0.237$ ft^3/Lbm

$$v_m = \frac{v_1 + v_2}{2} = \frac{0.237 + 0.264}{2} = 0.251 \text{ ft}^3/\text{Lbm}$$

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$$\Delta P_f = \frac{fL}{D}\left(\frac{\dot{m}}{A}\right)^2 \frac{v_m}{2g_c}$$

$$= \frac{0.02\,(313\,\cancel{ft})}{(2.157/12)\,\cancel{ft}}\left(7.87^2\,\frac{\cancel{Lbm^2}}{\cancel{sec^2\text{-}ft^2}}\right) 0.251\,\frac{\cancel{ft^3}}{\cancel{Lbm}}\;\frac{\cancel{Lbf\text{-}sec^2}}{(2)(32.2)\,ft\,\cancel{Lbm}}$$

$$= 8.4\ Lbf/ft^2 = 0.058\ psi$$

$$V_1 = \left(\frac{\dot{m}}{A}\right)v_1 = 7.87\,\frac{\cancel{Lbm}}{sec\text{-}\cancel{ft^2}} * 0.251\,\frac{\cancel{ft^3}}{\cancel{Lbm}} = 1.98\ fps$$

$$\Delta P_m = \left(\frac{\dot{m}}{A}\right)\frac{V_2 - V_1}{g_c} = 7.87\,\frac{\cancel{Lbm}}{\cancel{sec}\text{-}ft^2}\,(2.1 - 1.98)\,\frac{\cancel{ft}}{\cancel{sec}}\left(\frac{\cancel{sec^2}\text{-}Lbf}{32.2\,\cancel{ft}\text{-}\cancel{Lbm}}\right)$$

$$= 0.03\ Lbf/ft^2 = 0.0002\ psi$$

$\Delta P = \Delta P_f + \Delta P_M = 0.058 + 0.0002 \doteq 0.0582\ psi \doteq$ THE ASSUMED VALUE OF 0.07 psi. OK

$\therefore$ PRESSURE AT THE INLET OF THE RETURN LINE = PRESSURE AT THE EXIT OF THE CHIMNEY RETURN LINE = 20.205 psia = 1.375 ATM FROM THE PREVIOUS PAGE.

SUBJECT

NAME AMS

DATE 11/14/90 | REVISION DATE

PRESSURE DROP AND HEAT LOAD SUMMARY FOR THE RETURN LINE:

SECTION OF RETURN LINE	ΔP FRICTION (PSI)	ΔP MOMENTUM (PSI)	ΔP ELEVATION (PSI)	HEAT LEAK (Btu/hr)
SURFACE	0.081	0.0005	–	312.9
VERTICAL	0.034	0.0009	3.5	175
DETECTOR	0.058	0.0002	–	278.6
Σ	0.173	0.0016	3.5	766.5
			(CONTROL VALVE) →	+ 4.5
				771.0

AGREES WITH TOTAL CALCULATED ON PAGE 20

522703

1.4 PRESSURE DROP AND HEAT LOAD IN THE CHIMNEY AND SOLENOID COIL.

INNER DIAMETER OF COOLING TUBE = 1"

FLOW AREA = $\frac{\pi d^2}{4} = \frac{\pi 1^2}{4} = 0.7854\ in^2 = 0.0054\ ft^2$

THE PIPING IS DIVIDED INTO THREE SECTIONS FOR THE ΔP CALCULATION: CHIMNEY RETURN LINE, SOLENOID COIL AND CHIMNEY SUPPLY LINE.

CHIMNEY RETURN LINE

ELEVATION CHANGE = 36 ft FROM TOP OF DETECTOR TO HORIZONTAL CENTERLINE OF SOLENOID COIL.

FITTINGS:

2 - 90° SHORT RADIUS ELBOWS

PIPE LENGTH = 40 ft

CALCULATE LINE HEAT LEAK -

THE CHIMNEY IS NITROGEN SHIELDED.

ESTIMATE THE PIPE HEAT FLUX:

THE PIPE IS A 30 mm SQUARE ALUMINUM EXTRUSION.

THE OVERALL DIMENSIONS WITH THE SUPERCONDUCTING LEADS ATTACHED ARE 30 mm BY (30 + 2x4.83) mm = 39.66 mm.

USE THE OVERALL DIMENSIONS OF 35 mm x 45 mm TO CALCULATE THE HEAT LEAK.

THE PIPE SURFACE AREA PER UNIT LENGTH IS

$$\frac{A_s}{\ell} = \left\{\left[2(35) + 2(45)\right] mm * \frac{m}{1000 mm}\right\} * \frac{1m}{1m} = 0.16 \frac{m^2}{m}$$

$$= 0.525 \frac{ft^2}{ft}$$

$$\therefore \frac{\text{HEAT LEAK}}{\text{UNIT AREA}} \doteq 0.35 \frac{Btu}{hr\text{-}ft} = 2.22 \, W/m^2$$

ESTIMATED HEAT FLUX VALUE FOR LN_2 SHIELDED LHe LINE WITH 0.5 ft^2/ft SURFACE AREA. REF 3.

FROM PAGE 14

EQUIVALENT LENGTH FOR THE TWO ELBOWS $\equiv L_{eq} = 2(5 ft) = 10 ft$

EQUIVALENT LENGTH = 40 ft + 10 ft = 50 ft

HEAT LEAK FOR THIS SECTION = $50 ft * 0.35 \frac{Btu}{hr\text{-}ft} = 17.5 Btu/hr$

$= 5.1 W$

CALCULATE THE FRICTIONAL EQUIVALENT LENGTH —

$$Re = \frac{6.31 W}{d\mu} = \frac{6.31 (719 Lbm/hr)}{(1 in)(0.0031 cp)} = 1.4 \times 10^6 \Rightarrow f = 0.023$$

MINOR LOSSES

2 - 90° ELBOWS

$K_{SCH 40} = 20 f_T = 2(0.023) = 0.46$

$$K_{1''} = K_{SCH 40}\left(\frac{d_{1''}}{d_{SCH 40}}\right)^4 = 0.46\left(\frac{1}{1.049}\right)^4 = 0.38$$

$2 \times 0.38 = \underline{0.76}$

1" TO 2.157" SUDDEN EXPANSION $K_{SCH 40} = (1-\beta^2)^2$ REF 1, PG A-26

$\beta = d_1/d_2 = 1.049/2.157 = 0.48$; $K_{1''} = (1-0.48^2)^2 (1/1.049)^4 = 0.48$

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$$L_m = \frac{KD}{f} = \frac{(0.48+0.76)(1/12)\,ft}{0.023} \doteq 5\ ft$$

$$L_e = 40\ ft + 5\ ft = 45\ ft$$

AS IN THE CALCULATIONS FOR THE RETURN LINE ΔP, SUBSCRIPT 1 REFERS TO THE INLET TO THE SECTION OF LINE AND SUBSCRIPT 2 TO THE EXIT.

ESTIMATE THE PRESSURE DIFFERENCE DUE TO THE 36 ft ELEVATION CHANGE:

ASSUME $v_m \doteq 0.22\ ft^3/Lbm$ WHICH IS SOMEWHAT LOWER THAN THE EXIT SPECIFIC VOLUME.

$$36\ \cancel{ft} * \frac{Lbf}{0.22\ \cancel{ft^3}} * \frac{\cancel{ft^2}}{144\ in^2} = 1.14\ psi$$

FROM PAGES 34 & 35, THE EXIT CONDITIONS ARE:

$X_2 = 0.188$

$v_2 = 0.237\ ft^3/Lbm$

$V_2 = 1.98\ ft/sec$ FOR $d = 2.157''$

$P_2 = 20.205\ psia$

$h_{fg} = 7.68\ Btu/Lbm$

THESE CONDITIONS MUST BE ADJUSTED FOR THE SMALLER DIAMETER.

$$V_2 = 719\ \frac{\cancel{Lbm}}{\cancel{hr}} * \frac{\cancel{hr}}{3600\ sec} * 0.237\ \frac{ft^3}{Lbm} * \frac{1}{0.0054\ \cancel{ft^2}} = 8.77\ fps$$

SUBJECT

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USE BERNOULLI'S EQUATION TO CALCULATE THE PRESSURE IN THE 1" LINE UPSTREAM OF THE EXPANSION TO 2.157" LINE!

$$P_u + \frac{v_u^2 \gamma_u}{2g} + \cancel{z_u \gamma_u} = P_D + \frac{v_D^2 \gamma_D}{2g} + \cancel{z_D \gamma_D} + \text{EXPANSION LOSS}$$

$$\frac{K v_1^2 \gamma_1}{2g}$$

$$P_u + \frac{8.77^2 \frac{ft^2}{sec^2} \frac{Lbf}{0.237 ft^3} * \frac{ft^2}{144 in^2}}{2\,(32.2\ ft/sec^2)} = 20.205 \text{ psia}$$

$$+ \frac{1.98^2 \frac{ft^2}{sec^2} \frac{Lbf}{0.237 ft^3} \frac{ft^2}{144 in^2}}{2(32.2\ ft/sec^2)} + \frac{(0.48)\left(8.77^2 \frac{ft^2}{sec^2}\right)\left(\frac{Lbf}{0.237 ft^3}\right)\frac{ft^2}{144 in^2}}{2(32.2\ ft/sec^2)}$$

$$P_u + 0.035 = 20.205 + 0.0018 + 0.017$$

$$P_u = 20.19 \text{ PSIA}$$

SINCE $P_{UPSTREAM} \equiv P_u \doteq P_D \equiv P_{DOWNSTREAM}$, VELOCITY IS THE ONLY EXIT CONDITION THAT CHANGES.

ASSUME $\Delta P = 0.4$ psi $= 57.6$ Lbf/ft^2

THEN $\Delta P_{TOTAL} = 1.14 + 0.4 = 1.54$ psi $= 221.76$ Lbf/ft^2

$P_1 = 20.19 + 1.54 = 21.73$ psia $= 1.479$ ATM

$\rho_{f_1} = 0.1144$ g/cc $= 7.14$ Lbm/ft$^3 \Rightarrow 0.14$ ft^3/Lbm $= v_{f_1}$

$\rho_{g_1} = 0.02629$ g/cc $= 1.64$ Lbm/ft$^3 \Rightarrow 0.61$ ft^3/Lbm $= v_g$

$h_{fg_1} = 17$ J/g $= 7.31$ Btu/Lbm

$T_{SAT_1} = 4.67$ K

$$\frac{\dot{m}}{A} = 71.9 \frac{Lbm}{hr} * \frac{hr}{3600 sec} * \frac{1}{0.0054 ft^2} = 37 \frac{Lbm}{sec\text{-}ft^2}$$

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SOLVE FOR X_1 USING THE EQUATION ON PAGE 28

$$X_1 = \Big[0.188\left(7.68 \frac{Btu}{Lbm}\right) - 0.0012 \frac{Btu - ft^2}{Lbm - Lbf} * 221.76 \frac{Lbf}{ft^2}$$

$$+ 32.2 \frac{ft}{sec^2} \; 32.2 \frac{Lbf\, sec^2}{ft\, Lbm} \left[36\, ft\right] \frac{Btu}{778.16\, ft\text{-}Lbf}$$

$$- 17.5 \frac{Btu}{hr} * 719 \frac{hr}{Lbm}\Big] \Big/ 7.31 \; Btu/Lbm$$

$X_1 = 0.164$

THEN $v_1 = v_{f_1} + X(v_{g_1} - v_{f_1}) = 0.14 + 0.164(0.61 - 0.14)$

$= 0.217 \; ft^3/Lbm$

$$v_m = \frac{v_1 + v_2}{2} = \frac{0.217 + 0.237}{2} = 0.227 \; ft^3/Lbm$$

$$\Delta P_f = \frac{fL}{D}\left(\frac{\dot{m}}{A}\right)^2 \frac{v_m}{2g_c}$$

$$= \frac{0.023\,(45\, ft)}{(1/12)\, ft}\left(37^2 \frac{Lbm^2}{sec^2 - ft^4}\right)\left(0.227 \frac{ft^3}{Lbm}\right)\left(\frac{Lbf - sec^2}{2 * 32.2\, ft\text{-}Lbm}\right)$$

$= 59.93 \; Lbf/ft^2 = 0.42$ psi $\doteq$ THE ASSUMED VALUE OF 0.4 PSI. OK

$$V_1 = \left(\frac{\dot{m}}{A}\right) v_1 = 37 \frac{Lbm}{sec\text{-}ft^2} * 0.217 \frac{ft^3}{Lbm} = 8.03 \; fps$$

$$\Delta P_m = \left(\frac{\dot{m}}{A}\right) \frac{V_2 - V_1}{2g_c} = \left(\frac{37\, Lbm}{sec\, ft^2}\right)(8.77 - 8.03)\frac{ft}{sec} * \frac{Lbf\text{-}sec^2}{32.2\, ft\text{-}Lbf}$$

$= 0.85 \; Lbf/ft^2 = 0.006$ psi

$$\Delta P_{ELEV} = 36\, ft * \frac{Lbf}{0.227\, ft^3} = 158.59 \frac{Lbf}{ft^2} = 1.1 \text{ psi}$$

$\Delta P_{TOTAL} = \Delta P_f + \Delta P_m + \Delta P_{ELEV}$

$= 0.42 + 0.006 + 1.1 = 1.526$ psi $\doteq$ THE ASSUMED VALUE OF 1.54 psi

OK

∴ PRESSURE AT THE LOWER END OF THE CHIMNEY RETURN LINE, WHICH IS ASSUMED TO BE AT THE HORIZONTAL CENTERLINE OF THE SOLENOID, = PRESSURE AT THE TOP END OF THE RETURN LINE + ΔP_{TOTAL}.

$P_1 = 21.73$ psia $= 1.479$ ATM AS CALCULATED ON PAGE 40.

SUBJECT

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SOLENOID COIL

CALCULATE COOLING COIL EQUIVALENT LENGTH FOR THE ΔP CALCULATION.

COIL LENGTH $\equiv L_c$

RATIO CDF LENGTH BY SUPPORT CYLINDER SURFACE AREAS.

CDF COOLING COIL LENGTH $\equiv L_{CDF}$

$L_{CDF} = 150$ m FROM PAGE 241 OF THE CDF DESIGN REPORT

SUPPORT CYLINDER DIMENSIONS:

	CDF	SDC
OUTER DIAMETER (m)	3.038	4.028
LENGTH (m)	4.905	8.72

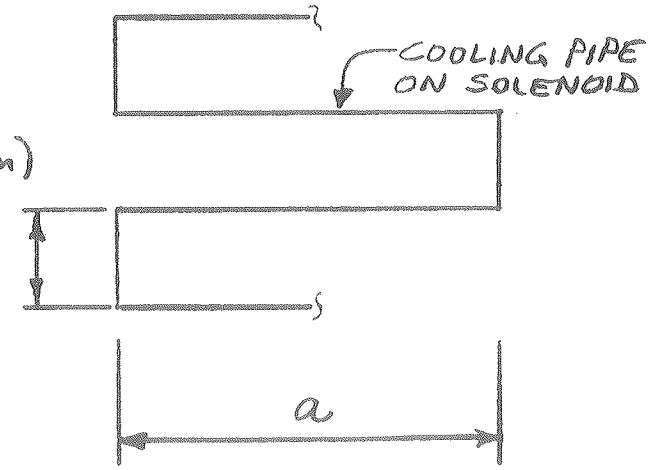
$$L_c = 150\text{ m}\ \frac{\cancel{\pi}\,(4.028\text{ m})(8.72\text{ m})}{\cancel{\pi}\,(3.038\text{ m})(4.905\text{ m})} \doteq 355\text{ m}$$

$$= 1{,}165\text{ ft}$$

MINOR LOSSES (DUE TO THE 180° RETURN BENDS)

ASSUME THE COIL ROUTE IS THE SAME AS CDF.

a = SUPPORT CYLINDER LENGTH
−3" ON EACH END



$$a = 8.72\,m \times 3.281\,\frac{ft}{m} \times \frac{12\,in}{ft} - 2(3\,in)$$

$$\doteq 337\,in$$

$L_c = 1{,}165\,ft = 13{,}980\,in$

SUPPORT CYLINDER OUTER CIRCUMFERENCE $\equiv C_s$

$$C_s = \pi\, 4.028\,m \times 3.281\,\frac{ft}{m} = 41.52\,ft \doteq 498\,in$$

NUMBER OF "a" LENGTHS $= \dfrac{13{,}980}{337} \doteq 42$

SPACING BETWEEN "a" LENGTHS $= \dfrac{498\,in}{42} \doteq 12'' = b$

EACH "a" LENGTH HAS 2 SHORT RADIUS 90° ELBOWS.

TOTAL NUMBER OF ELBOWS $= 2 * 42 = 84$

$K_{1''} = 0.38$ FOR EACH ELBOW FROM PAGE 38

$K = 84(0.38) = 31.92$ FOR 84 ELBOWS

$$L_m = \frac{KD}{f} = \frac{31.92\,(1\,in)}{0.023} \doteq 1{,}400\,in$$

Σ OF THE "b" LENGTHS $= 42\,(12) = 504\,in = L_b$

ESTIMATE LENGTH FOR INTERCEPT CIRCUIT

$L_I = 2 \times C_s = 2\,(498) \doteq 1000\,in$

COOLING PIPE EQUIVALENT LENGTH $\equiv L_e$

$L_e = (L_c + L_m + L_b + L_I)\,1.05$ ← FOR MISC LOSSES

$L_e = (13{,}980 + 1{,}400 + 504 + 1{,}000)\,1.05$

$= 17{,}728 \text{ in} \doteq 1{,}480 \text{ ft}$

AS IN THE PREVIOUS CALCULATION FOR THE CHIMNEY RETURN LINE, SUBSCRIPT 1 REFERS TO THE INLET TO THE SECTION OF LINE AND SUBSCRIPT 2 TO THE EXIT.

$X_2 = 0.164$ AND $P_2 = 21.73$ PSIA FROM PAGES 40 & 41.

FLUID PROPERTIES AT THE EXIT ARE ON PAGE 40.

THE COIL MUST BE DIVIDED INTO TWO SECTIONS, THE TWO PHASE SECTION AND THE SINGLE PHASE SECTION.

TWO PHASE SECTION

SOLENOID HEAT LOAD = 20 + 220 = 240 W = 820 Btu/hr

ASSUME THIS HEAT LOAD IS DISTRIBUTED UNIFORMLY ALONG THE LENGTH OF THE COOLING PIPE.

$P_1 = P_{CRITICAL} = 2.245$ ATM = 33 PSIA MAXIMUM

$\Delta P = 33 - 21.73 = 11.27 \text{ psi} = 1622.88 \text{ Lbf/ft}^2$

THEN: $\rho_{f_1} = 0.06964 \text{ g/cc} = 4.35 \text{ Lbm/ft}^3 \Rightarrow v_{f_1} = 0.23 \frac{\text{ft}^3}{\text{Lbm}}$

$\rho_{g_1} = 0.06964 \text{ g/cc} = 4.35 \text{ Lbm/ft}^3 \Rightarrow v_{g_1} = 0.23 \text{ ft}^3/\text{Lbm}$

$T = 5.2$ K

$$v_m = \frac{v_1 + v_2}{2} = \frac{0.23 + 0.217}{2} = 0.224 \text{ ft}^3/\text{Lbm}$$

$$V_1 = \left(\frac{m}{A}\right) v_1 = 37 \frac{\text{Lbm}}{\text{sec ft}^2} * 0.23 \frac{\text{ft}^3}{\text{Lbm}} = 8.51 \text{ fps}$$

$X_1 = 0$

$$\Delta P = \Delta P_f + \Delta P_m = \left[\left(x_2 h_{fg_2} - \cancel{x_1 h_{fg_1}} \right) + \frac{V_2^2 - V_1^2}{2 g_c} + \cancel{\frac{g}{g_c}(z_2 - z_1)} - \dot{Q}/\dot{m} \right] \Big/ \left(\frac{dh}{dP} \right)_{SAT}$$

$$= \left[0.164 \left(7.31 \frac{Btu}{Lbm} \right) + \left[\left(8.03^2 - 8.51^2 \right) \frac{ft^2}{sec^2} * \frac{Lbf\text{-}sec^2}{2(32.2)\,Lbm\text{-}ft} * \frac{Btu}{778.16\,ft\text{-}Lbf} \right. \right.$$

$$\left. - 820 \frac{Btu}{hr} * \frac{hr}{719\,Lbm} \right] \Big/ \left\{ \left(\frac{dh}{dP} \right)_{SAT} \frac{Btu\text{-}ft^2}{Lbm\text{-}Lbf} \right\}$$

$$\left(\frac{dh}{dp} \right)_{SAT} = \frac{(21.36 - 12.37)(J/g)}{(2.245 - 1.479)(ATM)} = 11.736 \frac{J}{g\text{-}ATM}$$ BETWEEN 4.67 & 5.2 K

$$11.736 \frac{J}{g\text{-}ATM} * \frac{ATM}{14.696\,Lbf} * \frac{in^2}{ft^2} * \frac{1000\,g}{2.2046\,Lbm} * \frac{cal}{4.186\,J} * \frac{Btu}{252\,cal}$$

$$= 0.0024 \frac{Btu\text{-}ft^2}{Lbm\text{-}Lbf}$$

SUBSTITUTING THIS VALUE OF $(dh/dP)_{SAT}$ INTO THE ABOVE EQUATION YIELDS:

$\Delta P = 24.25\ Lbf/ft^2 = 0.17\ psi$ < THE ASSUMED VALUE OF 11.27 PSI. ∴ MUST REVISE ΔP AND Q AND RECALCULATE

FRICTIONAL HEATING HAS NOT BEEN INCLUDED IN THE PREVIOUS TWO PHASE CALCULATIONS BECAUSE THE PRESSURE LOSSES HAVE BEEN SMALL. IT WILL BE INCLUDED IN THIS CALCULATION.

ASSUME $\Delta P = 3.5\ psi = 504\ Lbf/ft^2$

CALCULATE THE L_e THAT GIVES A ΔP OF 3.5 psi.

$$\Delta P_f = \frac{fL}{D} \left(\frac{\dot{m}}{A} \right)^2 \frac{v_m}{2 g_c}$$

$$504 \frac{Lbf}{ft^2} = \frac{0.0231\,(L_e)\,ft}{(1/12)\,ft} \left(37^2 \frac{Lbm^2}{sec^2\text{-}ft^4} \right) \left(0.1825 \frac{ft^3}{Lbm} \right) \frac{Lbf\text{-}sec^2}{2(32.2)\,ft\text{-}Lbm}$$

$$470\ ft = L_e$$

CALCULATED ON THE NEXT PAGE

THEN: $P_1 = 21.73\ psia + 3.5 = 25.23\ psia = 1.717\ ATM$

$\rho_{f_1} = 0.1082\ g/cc = 6.76\ Lbm/ft^3 \Rightarrow v_{f_1} = 0.148\ ft^3/Lbm$

$\rho_{g_1} = 0.03221\ g/cc = 2.01\ Lbm/ft^3 \Rightarrow v_{g_1} = 0.5\ ft^3/Lbm$

$T_{SAT} = 4.85\ K \quad h_{f_1} = 13.83\ J/g$

$X_1 = 0 \qquad v_m = (0.148 + 0.217)/2 = 0.1825\ ft^3/Lbm$

CALCULATE THE HEAT LOAD FOR THE 470 ft USING THE ASSUMPTION OF UNIFORM HEAT DISTRIBUTION ALONG THE LENGTH OF THE COOLING PIPE MADE ON PAGE 45.

$$\frac{Q}{\ell} = \frac{820\ Btu/hr}{\dfrac{[(13{,}980 + 504 + 1000)]}{12}\ ft} = 0.6355\ \frac{Btu}{hr\text{-}ft}$$

$$Q_{470ft} = 470\ ft\left(0.6355\ \frac{Btu}{hr\text{-}ft}\right) = 300\ Btu/hr$$

$$V_1 = \left(\frac{\dot{m}}{A}\right) v_1 = \frac{37\ Lbm}{sec\text{-}ft^2}\left(0.1825\ \frac{ft^3}{Lbm}\right) = 6.753\ ft/sec$$

$$\left(\frac{dh}{dp}\right)_{SAT} = \frac{(14.3 - 12.24)\ J/g}{(1.784 - 1.457)\ ATM} = 6.3\ \frac{J}{g\text{-}ATM}$$ BETWEEN 4.65 & 4.9 K

$$6.3\ \frac{J}{g\text{-}ATM} \times \frac{ATM\ in^2}{14.696\ Lbf} \times \frac{ft^2}{144\ in^2} \times \frac{1000\ g}{2.2046\ Lbm} \times \frac{cal}{4.186\ J} \times \frac{Btu}{252\ cal}$$

$$= 0.0013\ \frac{Btu\ ft^2}{Lbf\ Lbm}$$

$$Q = 719\ \frac{Lbm}{hr} \times \frac{hr}{60\ min} \times 0.1825\ \frac{ft^3}{Lbm} \times 7.481\ \frac{gal}{ft^3} = 16.4\ gpm$$

$$Q_f = 1.5\ (16.4\ gpm)(3.5\ psi) = 86.1\ Btu/hr$$

FERMILAB ENGINEERING NOTE	SECTION 2.6	PROJECT SDC	SERIAL-CATEGORY	PAGE 48/
SUBJECT		NAME AMS		
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RECALCULATE ΔP USING THE FORMULA ON TOP OF PAGE 46:

$$\Delta P = \left[0.164\,(7.31) + \left\{ (8.03^2 - 6.753^2)\,\frac{1}{2(32.2)(778.16)} \right\} - \frac{(86+300)}{719} \right] \Big/ 0.0013$$

$\Delta P = 509.5$ lbf/ft^2 $= 3.54$ psi $\doteq$ THE ASSUMED VALUE OF 3.5 psi, OK

522703

CHECK THE MOMENTUM PRESSURE DROP —

$$\Delta P_M = \left(\frac{\dot m}{A}\right)\frac{V_2 - V_1}{2g_c} = 37\ \frac{Lbm}{sec\ ft^2}\left(8.03 - 6.753\right)\frac{ft}{sec} * 32.2\ \frac{Lbf\text{-}sec^2}{ft\text{-}Lbm}$$

$$= 1.47\ Lbf/ft^2 = 0.01\ psi$$

$$\Delta P = \Delta P_f + \Delta P_M$$

$$= 3.54 + 0.01 = 3.55\ psi \doteq 3.5\ psi \quad \underline{OK}$$

∴ PRESSURE AT THE SINGLE PHASE/TWO PHASE TRANSITION POINT = 1.717 ATM AS CALCULATED ON PAGE 47.

SINGLE PHASE SECTION

FROM PG 45

$$L_e = 1{,}480\ ft - 470\ ft = 1{,}010\ ft$$

FROM PG 46

HEAT LOAD IN THE TWO PHASE SECTION = 300 Btu/hr

HEAT LOAD IN THE SINGLE PHASE SECTION = 820 - 300 = 520 Btu/hr

CALCULATE TEMPERATURE AT THE INLET TO THE SOLENOID COOLING COIL —

$$\dot Q = \dot m\,\Delta h$$

$$520\ \frac{Btu}{hr} * \frac{hr}{719\ Lbm} = \Delta h = 0.72\ \frac{Btu}{Lbm} = 1.68\ J/g$$

$$h\ at\ inlet = 13.83\ J/g - 1.68 = 12.15\ J/g$$

PG

T_{SAT} AT INLET = 4.64 K

P_{SAT} AT INLET = 1.441 ATM = 21.177 psia

ρ AT INLET ≐ 7.2 Lbm/ft³ ⇒ 0.139 ft³/Lbm = v_f AT INLET

FERMILAB ENGINEERING NOTE	SECTION 2.6	PROJECT SDC	SERIAL-CATEGORY	PAGE 50/
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CALCULATE THE PRESSURE DROP BETWEEN THE INLET AND THE SINGLE PHASE / TWO PHASE TRANSITION POINT.

$$Re = \frac{6.31\,W}{d\mu} = \frac{6.31\,(719\ Lbm/hr)}{1\,in\ (0.0029\,cp)} = 1.56 \times 10^6 \Rightarrow f = 0.023$$

$$\Delta P_f = \frac{fL}{D}\left(\frac{\dot m}{A}\right)^2 \frac{v_m}{2g_c} \qquad v_m = \frac{0.139 + 0.148}{2} = 0.1435\ ft^3/Lbm$$

$$= \frac{0.023\,(1{,}010)\,ft}{(1/12)\,ft}\left(37^2\ \frac{Lbm^2}{sec^2 \cdot ft^4}\right)\left(0.1435\ \frac{ft^3}{Lbm}\right)\left(\frac{Lbf\text{-}sec^2}{2 \times 32.2\ ft \cdot Lb}\right)$$

$$= 850.35\ Lbf/ft^2 = 5.9\ psi$$

CALCULATE THE FRICTIONAL HEAT LOAD —

$$Q_f = 1.5\,Q\,\Delta P$$

$$Q = 719\ \frac{Lbm}{hr} * 0.1435\ \frac{ft^3}{Lbm} * \frac{hr}{60\,min} * 7.481\ \frac{gal}{ft^3} = 12.9\ gpm$$

$$Q_f = 1.5\ (12.9\ gpm)(5.9\ psi) = 114.2\ Btu/hr$$

RECALCULATE THE TEMPERATURE AT THE INLET TO THE SOLENOI COOLING COIL (TSAT AT INLET WAS CALCULATED AS 4.64 K ON THE PREVIOUS PAGE.) AND INCLUDE THE FRICTIONAL HEAT LOAD.

$$\dot Q = \dot m \Delta h$$

$$(520 + 114.2)\ Btu/hr * \frac{hr}{719\ Lbm} = \Delta h = 0.88\ \frac{Btu}{Lbm} = 2.05\ J/g$$

$$h\ at\ inlet = 13.83\ J/g - 2.05 = 11.78\ J/g$$

AT THE INLET: $T_{SAT} = 4.58\ K$

$P_{SAT} = 1.376\ ATM = 20.222\ psia$

$\rho_i = 7.3\ Lbm/ft^3 \Rightarrow 0.137\ ft^3/Lbm = v$

322703

$$v_m = \frac{0.137 + 0.148}{2} = 0.1425 \ ft^3/Lbm$$

USING $v_m = 0.1425$, ΔP RECALCULATES TO 5.86 psi.

5.86 ≐ 5.9 psi OK

∴ PRESSURE AT THE INLET TO THE COOLING COIL IS

25.23 psia + 5.9 psi = 31.13 psia = 2.12 ATM

NOTE

HEAT TRANSFER IN THE SOLENOID'S COOLING COIL WILL BE CHECKED IN A SEPARATE DESIGN NOTE.

COIL PRESSURE DROP HAS BEEN DETERMINED AT THE HORIZONTAL CENTERLINE OF THE COIL TO SIMPLIFY THIS PRELIMINARY ΔP CALCULATION. THE COIL'S ELEVATION DIFFERENCE WILL BE TAKEN INTO ACCOUNT WHEN THE HEAT TRANSFER IS CHECKED.

FERMILAB ENGINEERING NOTE	SECTION 2.6	PROJECT SDC	SERIAL-CATEGORY	PAGE 521
SUBJECT		NAME Ams		
		DATE 11/26/90	REVISION DATE	

CHIMNEY SUPPLY LINE

HEAT LEAK = 5.1 W SAME AS FOR THE CHIMNEY RETURN LINE

CALCULATE THE FRICTIONAL EQUIVALENT LENGTH —

MINOR LOSSES

- 2 - 90° ELBOWS

  $2 \times 0.38 = \underline{0.76}$ SAME AS CHIMNEY RETURN LINE

- 2.157" TO 1" SUDDEN CONTRACTION

  $K_{SCH\,40} = 0.5\,(1-\beta^2)$ REF 1, PG 4-26

  $\beta = 1.049/2.157 = 0.48$

  $K_{1''} = 0.5\,(1-0.48^2)\,(1/1.049)^4 = 0.32$

  $L_m = \frac{KD}{f} = \frac{(0.76+0.32)(1/12)\,ft}{0.023} = 4\,ft$

PIPE LENGTH = 40 ft

$L_e = 40 + 4 = 44\,ft$

AS IN THE PREVIOUS CALCULATIONS, SUBSCRIPT 1 REFERS TO THE INLET TO THE SECTION OF LINE AND SUBSCRIPT 2 TO THE EXIT.

$$\Delta P = \frac{fL}{D}\left(\frac{\dot m}{A}\right)^2 \frac{v_m}{2g_c}$$

$$= \frac{0.023\,(44)\,ft}{(1/12)\,ft}\left(37^2\,\frac{Lbm^2}{sec^2\,ft^4}\right)\left(0.137\,\frac{ft^3}{Lbm}\right)\left(\frac{Lbf\cdot sec^2}{2 \times 32.2\,ft\cdot Lbm}\right)$$

$$= 35.37\,Lbf/ft^2 = 0.25\,psi$$

$$Q = 719\,\frac{Lbm}{hr} \times 0.137\,\frac{ft^3}{Lbm} \times \frac{hr}{60\,min} \times 7.481\,\frac{gal}{ft^3} = 12.3\,gpm$$

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FERMILAB ENGINEERING NOTE	SECTION 2.6	PROJECT SDC	SERIAL-CATEGORY	PAGE 53
SUBJECT		NAME Ams		
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CALCULATE THE FRICTIONAL HEAT LOAD

$Q_f = 1.5\, Q\, \Delta P$

$Q_f = 1.5\,(12.3\ gpm)(0.25\ psi) = 4.6\ Btu/hr$

HEAT LEAK $= 5.1\ W = 17.5\ Btu/hr$

$Q = \dot{m}\,\Delta h$

$(17.5 + 4.6)\ \frac{Btu}{hr} * \frac{hr}{719\ Lbm} = \Delta h = 0.031\ \frac{Btu}{Lbm} = 0.07\ J/g$

$h = 11.78\ J/g - 0.07\ J/g = 11.71\ J/g$ AT THE INLET TO THE CHIMNEY SUPPLY LINE.

AND $T_{SAT} = 4.57\ K$
$P_{SAT} = 1.364\ ATM = 20.05\ psia$
$\rho = 0.1171\ g/cc = 7.31\ Lbm/ft^3 \Rightarrow v = 0.137\ ft^3/Lbm$

CALCULATE THE PRESSURE CHANGE DUE TO ELEVATION

ELEVATION CHANGE $= 36\ ft$ — SAME AS THE CHIMNEY SUPPLY LINE.

$\Delta P = 36\ ft * \frac{Lbf}{0.137\ ft^3} * \frac{ft^2}{144\ in^2} = 1.83\ psi$

PRESSURE AT THE INLET TO THE CHIMNEY SUPPLY LINE
$= 31.13\ psia + 0.25\ psi - 1.83\ psi = 29.55\ psia = 2$ ATM

$P_{SAT} = 20.05\ psia < P = 29.55\ psia \therefore$ FLOW IS SINGLE PHASE LIQUID.

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FERMILAB ENGINEERING NOTE	SECTION 2.6	PROJECT SDC	SERIAL-CATEGORY	PAGE 54/
SUBJECT		NAME AMS		
		DATE 11/27/90	REVISION DATE	

PRESSURE DROP AND HEAT LOAD SUMMARY FOR THE SOLENOID COOLING COIL AND CHIMNEY LINES:

SECTION	ΔP (PSI)	HEAT LOAD (Btu/hr)
RETURN LINE	0.43	17.5
COOLING COIL - TWO PHASE	3.54	300 + 86 = 386
COOLING COIL - SINGLE PHASE	5.9	520 + 114.2 = 634.2
SUPPLY LINE	0.25	17.5 + 4.6 = 22.1
Σ	10.12	1,059.8 Btu/hr = 310.5 W

FRICTIONAL HEATING VALUES

AGREES WITH THE 320 W LOAD ASSUMED ON PAGE 20.

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1.5 PRESSURE DROP AND HEAT LOAD IN THE LINE BETWEEN THE CHIMNEY AND THE SUBCOOLER

CONTROL VALVE HEAT LEAK = 4.5 Btu/hr FROM PAGE 19
= 1.3 W

ASSUME THIS SECTION IS A U-TUBE WITH BAYONET ENDS AND ONE BLOCK VALVE. 1" SCH 10S PIPE.

CALCULATE LINE HEAT LEAK - REFER TO PAGE 14 FOR DETAILS.

- 1 - BLOCK VALVE, 4.5 Btu/hr
- 2 - 90° ELBOWS, $L_{eq} = 2 \times 5$ ft = 10 ft
- 2 - BAYONETS, $2 \times 16 = 32$ Btu/hr

PIPE LENGTH = 20 ft

EQUIVALENT LENGTH = 20 + 10 = 30 ft

HEAT LEAK FOR THIS SECTION $= 30\,ft * 0.5 \frac{Btu}{hr\text{-}ft} + [4.5 + 4.5 + 32] \frac{Btu}{hr}$

= 56 Btu/hr = 16.5 W

CALCULATE THE FRICTIONAL EQUIVALENT LENGTH - REFER TO PAGE 11 FOR DETAILS

- 1 BLOCK VALVE, $\Delta P = \left(\frac{12.3\ gpm}{14}\right)^2 \frac{7.31}{62.4} = 0.09$ psi
- 2 90° ELBOWS, $K = 2 * 0.55 = 1.1$
- 2 - BAYONETS, $\Delta P \doteq 0$

$L_m = \frac{KD}{f} = \frac{1.1\ (1.097/12)}{0.023} \doteq 5$ ft

$L_e = 20 + 5 = 25'$

FLOW VELOCITY $= 719 \frac{Lbm}{hr} * \frac{hr}{3600\,sec} * 0.137 \frac{ft^3}{Lbm} * \frac{1}{0.00656\,ft^2}$

$= 4.17$ fps

$$\Delta P = \frac{f L_e}{D} \frac{V^2}{2g} \frac{1}{v} + \Delta P_{VALVE}$$

$$= \frac{0.023\,(25\,ft)\,(4.17^2)\,ft^2/sec^2}{(1.097/12)\,ft\,(2)(32.2\,ft/sec^2)\,0.137\,\frac{ft^3}{Lbf}\,(144\,in^2/ft^2)}$$

$+ 0.09 = 0.18$ psi

FRICTIONAL HEATING $= 1.5\,(12.3\,gpm)(0.18\,psi) = 3.3$ Btu/hr

TOTAL HEAT LOAD IS $56 + 3.3 = 59.3 \frac{Btu}{hr} = \underline{17.4\,W}$

$\Delta h = 59.3 \frac{Btu}{hr} * \frac{hr}{719\,Lbm} = 0.083$ Btu/Lbm $= 0.19$ J/g

$h = 11.71$ J/g $- 0.19$ J/g $= 11.52$ J/g

THEN $T_{SAT} = 4.54$ K

$P_{SAT} = 1.33$ ATM $= 19.546$ psia

$\rho_f = 0.1179$ g/cc $= 7.36$ Lbm/ft^3 $\Rightarrow v_f = 0.136$ ft^3/Lbm

PRESSURE DOWNSTREAM OF THE CONTROL VALVE IS

29.55 psia + 0.18 psi = 29.73 psia = 2.023 ATM.

$P_{SAT} = 19.546$ psia $< P = 29.73$ psia $\therefore$ FLOW IS SINGLE PHASE LIQUID.

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
2.8	SDC		57

SUBJECT

NAME: AMS

DATE: 11/29/9

REVISION DATE

COMPARE THE ASSUMED HEAT LOAD OF 555 W ON PAGE 20 TO THE CALCULATED HEAT LOAD.

SECTION	HEAT IN (Btu/hr)	$\dot{m}$ (Btu/hr)	ΔP_{FRIC} (psi)	FRICTION HEATING (Btu/hr) $= 1.5\,Q\Delta P$	Σ HEAT LOADS (Btu/hr)	COMMENTS
RETURN LINES:						
SURFACE	312.9	0.35	0.081	(3.81)	312.9	FRIC HEAT NOT INC.
RISER	175.0	0.3	0.034	(1.37)	175.0	"
DETECTOR	278.6	0.251	0.058	(1.96)	278.6	"
CHIMNEY RETURN	17.5	0.227	0.42	(12.82)	17.5	"
COIL:						
TWO PHASE	300	0.1825	3.54	86	386	
SINGLE PHASE	520	0.135	5.9	114.2	634.2	
CHIMNEY SUPPLY	17.5	0.137	0.25	4.6	22.1	
SUPPLY U-TUBE	56	0.136	0.18	3.3	59.3	
Σ	1,677.5 [492 W]		10.463	208.1 (19.96)	1,885.6 [553 W]	

NOT INCLUDING THE FRICTION HEATING LOAD NOTED IN PARENTHESES RESULTED IN A HEAT LOAD ERROR OF (19.96/1,885.6) * 100 = 1.1 %. THE HEAT LOAD SHOULD HAVE BEEN 1,885.6 + 19.96 = 905.56 Btu/hr ≐ 560 W. THE RETURN QUALITY WAS BASED ON THE ASSUMED LOAD OF 555 W, WHICH IS ≐ 553 W. OK

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FERMILAB ENGINEERING NOTE	SECTION 2.9	PROJECT SDC	SERIAL-CATEGORY	PAGE 58/
SUBJECT CALCULATE THE MINIMUM REQUIRED SUPPLY PRESSURE		NAME AMS		
		DATE 12/3/90	REVISION DATE	

USE BERNOULLI'S EQUATION –

S ≡ SUPPLY CONDITIONS

R ≡ RETURN CONDITIONS

$$P_S + \frac{v_S^2 \gamma_S}{2g} + z_S \bar{\gamma}_S = P_R + \frac{v_R^2 \bar{\gamma}_R}{2g} + z_R \bar{\gamma}_R + \text{LOSSES}$$

$v_S = 4.5$ fps PAGE 13

$\gamma_S = 7.5$ Lbf/ft³ PAGE 10

$z_S = \underset{\text{PG 6}}{150} + \underset{\text{PG 37}}{36} = 186$ ft

$\bar{\gamma}_S = (\underset{\text{PG 10}}{7.5} + \underset{\text{PG 50}}{7.3})/2 = 7.4$ Lbf/ft³ PAGE 13

$P_R = 16.5$ psia PAGE 18

$v_R = 2.9$ fps PAGE 24

$\bar{\gamma}_R = (\underset{\text{PG 24}}{1/0.37} + \underset{\text{PG 41}}{1/0.217})/2 = 3.7$ Lbf/ft³

$z_R = 186$ ft $= z_S$

LOSSES $= \overset{\text{PG 57}}{10.463}$ psi $+ \overset{\text{PG 13}}{2.44}$ psi $= 12.903$ psi

$$P_S + \left(4.5^2 \frac{ft^2}{sec^2} \times 7.5 \frac{Lbf}{ft^3} \times \frac{ft^2}{144\,in^2} \times 2(32.2 \frac{sec^2}{ft})\right) + \left(186\,ft \times 7.4 \frac{Lbf}{ft^3} \times \frac{ft^2}{144\,in^2}\right)$$

$= 16.5$ psia $+ (2.9^2 * 3.7/(144 * 2 * 32.2))$ psi $+ (186 * 3.7/144)$ psi

$+ (12.903$ psi$) * 1.2$ ← CONTROL VALVE ALLOWANCE, PG 12

$P_S = 27.19$ psia $= 12.5$ psig MINIMUM DURING CHARGING LOAD

$P_S - P_R = 27.19 - 16.5 = 10.69$ psi

DURING STEADY STATE OPERATION, WITHOUT THE CHARGING LOAD, THE AVERAGE DENSITY IN THE RETURN SIDE WILL BE GREATER AND THE ΔP LOSS IN THE RETURN SIDE WILL BE LESS. WHAT IS THE NET EFFECT ON P_S?

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ESTIMATE THE MINIMUM REQUIRED SUPPLY PRESSURE DURING STEADY STATE OPERATION WITHOUT THE CHARGING LOAD.

ASSUME THE HELIUM FLOW RATE IS THE SAME AS THE FLOW RATE USED IN THE CALCULATION FOR THE CHARGING LOAD.

ASSUME THE PRES DROP IN THE COIL AND RETURN SIDE IS THE SAME AS THE PRES DROP IN THE CALCULATION FOR THE CHARGING LOAD, THE ACTUAL PRES DROP WOULD BE LESS.

ESTIMATE THE RETURN QUALITY:
FOLLOW THE CALCULATION ON PAGE 20 -
LOAD = 555 - 220 = 335 W

$\Delta h = 335 \frac{J}{s} * 90.5 \frac{s}{g} = 3.7\ J/g$

$h_R = 10.66 + 3.7 = 14.36\ J/g$

$X_R = \frac{(14.36 - 10.37)\ J/g}{19.67\ J/g} = 0.203$

$v_R = v_{f2} + X_R (v_{g2} - v_{f2}) = 0.13 + 0.203(0.84 - 0.13) = 0.274\ ft^3/Lbm$

REFER TO THE CALCULATION FOR $X_R = 0.33$ ON PAGE 24.
NEGLECT THE VELOCITY TERMS SINCE THEY'RE SMALL

ESTIMATE THE PRESSURE DROP IN THE SOLENOID COOLING COIL:
ASSUME SINGLE PHASE FLOW ALONG THE ENTIRE COIL LENGTH.
HEAT LEAK = 20 W PAGE 20
ASSUME FRICTIONAL HEAT LOAD = 86 + 114 = 200 Btu/hr = 58.6 W
FROM PAGE 57 (SAME AS CHARGING LOAD CASE)
TOTAL HEAT LOAD = 20 + 58.6 = 78.6 W
ENTHALPY AT THE COIL EXIT = 11.78 J/g + 78.6 J/s * $\frac{s}{90.5 g}$
PG 50

= 12.65 J/g

WITH $h = 12.65$ J/g: $P_{SAT} \doteq 1.525$ ATM = 22.42 psia
$T_{SAT} \doteq 4.1$ K
$\rho = 0.1132$ g/cc = 7.1 Lbm/ft³ ⇒ $v = 0.142 \frac{ft^3}{Lbm}$

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SUBJECT

NAME AMS

DATE 12/3/90 | REVISION DATE

CALCULATE COOLING COIL OUTLET PRESSURE:

COOLING COIL OUTLET PRESSURE ≐ LHe STORAGE DEWAR PRESSURE + PRESSURE DUE TO ELEVATION CHANGE.

$$\bar{\gamma}_R = (1/0.274 + 7.1)/2 \ Lbf/ft^3 = 5.38 \ Lbf/ft^3$$

PG 59

COOLING COIL OUTLET PRESSURE = 16.5 psia +

$$186 \ ft * 5.38 \frac{Lbf}{ft^3} * \frac{ft^2}{144 \ in^2}$$

$$= 23.45 \ psia$$

SINCE 23.45 psia > 22.42 psia = P_{SAT} FROM PAGE 59, THEN SINGLE PHASE FLOW EXISTS ALONG THE ENTIRE COIL LENGTH AS ASSUMED IN THE PRECEDING CALCULATION FOR P_{SAT} AT THE COIL OUTLET. OK

CALCULATE THE MEAN DENSITY IN THE COOLING COIL:

$$\rho_m = \frac{\rho_{INLET} + \rho_{OUTLET}}{2} = \frac{7.3 + 7.1}{2} = 7.2 \ Lbm/ft^3$$

CALCULATE COIL ΔP:

$$\text{FLOW VELOCITY} = 719 \frac{Lbm}{hr} * \frac{ft^3}{7.2 \ Lbm} * \frac{hr}{3600 \ sec} * \frac{1}{0.0054 \ ft^2}$$

$$= 5.14 \ fps$$

$$\Delta P = \frac{fL}{D}\left(\frac{\dot{m}}{A}\right)^2 \frac{1}{\rho_m 2 g_c}$$

PG 45

$$= \frac{0.023 \ (1{,}480 \ ft)}{(1/12) \ ft} * \left(37^2 \frac{Lbm^2}{sec^2 - ft^2}\right)\left(\frac{ft^3}{7.2 \ Lbm}\right)\left(\frac{1}{2 * 32.2 \ \frac{ft - Lbm}{Lbf - sec^2}}\right)$$

$$= 1{,}206 \ Lbf/ft^2 = 8.4 \ psi$$ ← THE ΔP OF 9.44 psi WITH THE CHARGING LOAD INCLUDED.

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CALCULATE THE FRICTIONAL HEATING -

$$Q = 719 \frac{\cancel{Lbm}}{\cancel{hr}} \div 7.2 \frac{\cancel{Lbm}}{\cancel{ft^3}} \div \frac{\cancel{hr}}{60\ min} \times 7.481 \frac{gal}{\cancel{ft^3}} = 12.45\ gpm$$

$$Q_f = 1.5\, Q\, \Delta P = 1.5\,(12.45\,gpm)(8.4\,psi)$$

$$= 157\ Btu/hr = 46\ W$$ < THE ASSUMED VALUE OF 58.6 W. OK (DON'T RECALC)

SOLVE FOR THE SUPPLY PRESSURE WITHOUT THE CHARGING LOAD INCLUDED.

USE BERNOULLI'S EQUATION -

$$P_S + \frac{V_S^2 \cancel{\gamma_S}}{2\cancel{g}} + z_S \gamma_S = P_R + \frac{V_R^2 \cancel{\gamma_R}}{2\cancel{g}} + z_R \gamma_R + LOSSES$$

$$P_S + (186 * 7.4/144) = 16.5 + (186 * 5.38/144) + (12.903 - 9.44 + 8.4)\,1.2$$

(SEE PAGE 58 FOR UNITS)

$P_S = 28.13\ psia = 13.43\ psig$

$P_S - P_R \quad 28.13 - 16.5 = 11.63\ psi$

AS ASSUMED ON PAGE 58, THE AVERAGE DENSITY IN THE RETURN SIDE IS GREATER AND THE ΔP LOSS IN THE RETURN SIDE IS LESS DURING STEADY STATE OPERATION WITHOUT THE CHARGING LOAD. THE NET EFFECT IS TO INCREASE THE SUPPLY PRESSURE BECAUSE THE DECREASE IN ΔP LOSS DOES NOT OFFSET THE INCREASE IN THE AVERAGE RETURN DENSITY.

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
2.10	SDC		62

SUBJECT: COMPARISON OF HEAT LOAD CALCULATIONS : CDF & SDC (HIGH H.L. CASE)

NAME: AMS

DATE: 1/10/91

REVISION DATE:

CDF

COMPONENT	COMPONENT HEAT LEAK (W)	COMPONENT HEAT LEAK (W/m)	QUANTITY	SYSTEM HEAT LOAD (W)
BAYONET PAIR	1.3	–	13	16.9
U-TUBE	–	0.328	6 x 4 m	7.872
STORAGE DEWAR	1.5	–	1	1.5
TRANSFER LINE	–	0.033 0.08 EFF	25 m	(0.825 CALC) 2 USED (2/0.825 = 2.4)
SUBCOOLER (CONTROL DEWAR)	1.4	–	1	1.4
CHIMNEY	–	0.033 (0.15 EFF)	2 x 3.25 m	(0.22 CALC) 1 USED (1/0.22 = 4.55)
MAGNET	9.9	–	1	9.9
FRICTION	–	–	–	0
BLOCK VALVES				
ELBOWS				
TEES				
CONTROL VALVE				
FIELD JOINTS				
HEAT LOAD WITHOUT CHARGING LOAD				40.6
PEAK CHARGING LOAD				+ 100
PEAK HEAT LOAD				140.6

SDC

COMPONENT	COMPONENT HEAT LEAK 1" SIZE (W)	1" SIZE (W/m)	1" SIZE (L_{eh})	2" SIZE (W)	2" SIZE (W/m)	2" SIZE (L_{eh})	QUANTITY 1" SIZE	QUANTITY 2" SIZE	SYSTEM HEAT LOAD (W)
BAYONET PAIR	4.688	–	–	10.841	–	–	6	4	71.5
U-TUBE	INCLUDED UNDER OTHER COMPONENTS SEE NOTE 1						3	2	–
STORAGE DEWAR	INCLUDED IN REFRIGERATOR'S SCOPE								–
TRANSFER LINE	–	0.48	–	0.8	–	–	137 m	131 m	170.6
SUBCOOLER (CONTROL DEWAR)	–	–	–	–	–	–	–	–	15
CHIMNEY	– –	0.34 –	– –	– –	– –	– –	2(12.2 + 3) = 30.4		10.2
MAGNET	–	–	–	–	–	–	–	–	20
FRICTION	–	–	–	–	–	–	–	–	81.6
BLOCK VALVES	1.3185	–	–	4.688	–	–	5	5	30
ELBOWS	–	–	1.5 m	–	–	1.2 m	16	16	26.9
TEES	–	–	2.3 m	–	–	1.8 m	2	1	3.7
CONTROL VALVE	1.3185	–	–	–	–	–	3	–	4
FIELD JOINTS	–	–	6.1 m	–	–	4.6 m	10	10	66.1
									499.6
								+	220
									719.6

NOTE 1: U-TUBE HEAT LEAK VALUES –

COMPONENT	1" SIZE	2" SIZE
6.1 m OF PIPE	2.928	4.88
2 ELBOWS	1.44	1.92
2 BAYONETS	9.376	21.682
HEAT LEAK (W)	13.744	28.482

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SUBJECT: HEAT LEAK WITH LN_2 SHIELDED PIPING: HEAT LEAK WITH TEVATRON TYPE PIPING

NAME: AMS

DATE: 1/18/91

REVISION DATE:

HEAT LEAK TO LINE, BAYONETS AND U-TUBES

$= 250\ W / 6{,}500\ m \doteq 0.04\ W/m$

$q' = 0.04\ \frac{W}{m} * 0.1515\ \frac{m}{m^2} \doteq 0.27\ W/m^2$

HEAT LEAK WITH TEVATRON TYPE PIPING:

		W
LINE, BAYONETS AND U-TUBES	$137\ m * 0.105\ \frac{m^2}{m} * 0.27\ \frac{W}{m^2} =$	3.9
	$131\ m * 0.19\ \frac{m^2}{m} * 0.27\ \frac{W}{m^2} =$	6.7
SUBCOOLER		15
CHIMNEY		10.2
MAGNET		20
FRICTION		81.6
BLOCK VALVES		30
CONTROL VALVE		4
STORAGE DEWAR	(INCLUDED IN REFRIGERATOR'S SCOPE)	–
HEAT LOAD WITHOUT CHARGING LOAD		171.4
PEAK CHARGING LOAD		220
PEAK HEAT LOAD		391.4

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SUBJECT: HEAT LEAK WITH LN_2 SHIELDED PIPING: HEAT LEAK WITH FLUX OF 2.3 W

NAME: AMS

DATE: 1/18/91

REVISION DATE:

KEEP U-TUBE HEAT LEAKS THE SAME.

1" LINE

$$Le_h = (137 - 3*6.1) + (16-6)(1.5) + 2(2.3) = 138.3\ m$$

$$Q = 138.3\ \cancel{m} * 0.105\ \frac{\cancel{m^2}}{m} * 2.3\ \frac{W}{\cancel{m^2}} = 33.4\ W$$

2" LINE

$$Le_h = (131 - 2*6.1) + (16-4)(1.2) + 1(1.8) = 135\ m$$

$$Q = 135\ \cancel{m} * 0.19\ \frac{\cancel{m^2}}{\cancel{m}} * 2.3\ \frac{W}{\cancel{m^2}} = 59\ W$$

HEAT LEAK WITH FLUX OF 2.3 W/m^2 = 719.6 − (170.6 + 26.9 + 3.7) + (33.4 + 59) + $\left[(3*6.1 + 6*1.5)\ \cancel{m} * 3.281\ \frac{\cancel{ft}}{\cancel{m}} * 0.5\ \frac{\cancel{Btu}}{\cancel{hr}-\cancel{ft}} * 0.293\ \frac{W-\cancel{hr}}{\cancel{Btu}}\right]$ + $\left[(2*6.1 + 4*1.2)\ 3.281\ (0.83)(0.293)\right]$ W

$$= 637.5\ W$$

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	SDC		

SUBJECT: REFERENCES

NAME: AMS

DATE: 11/29/90

REVISION DATE:

1) CRANE TECHNICAL PAPER NO. 410: FLOW OF FLUIDS THROUGH VALVES, FITTINGS AND PIPE

2) BARRON, CRYOGENIC SYSTEMS, 1966

3) CVI, INC. CATALOG: CRYOGENIC STANDARD PRODUCTS (80181)

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
2.0			

SUBJECT: APPENDIX

NAME: AMS

DATE: 11/30/90

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1) LINDE TABLE NO. 1

2) LINDE TABLE NO. 2

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TABLE NO. 1

UNIT EQUIVALENT LENGTHS FOR COOLDOWN, FRICTION, AND HEAT LEAK; LINDE VACUUM SI INSULATED PIPING COMPONENTS:

→ NO LN_2 OR He SHIELD

A. Welded Joints

The following data are equivalent lengths in feet of corresponding straight pipe for cooldown, friction, and heat leak:

Pipe Size	$\bar{L}_{ec}$	$\bar{L}_{ef}$	$\bar{L}_{eq}$
1"	0.0	0.0	19.6
2"	0.0	0.0	15.2
3"	0.0	0.0	14.7
4"	0.0	0.0	14.3
5"	0.0	0.0	13.4
6"	0.0	0.0	13.0
8"	0.0	0.0	12.5

B. 90° Elbows

The following data are equivalent lengths in feet of corresponding straight pipe for cooldown, friction, and heat leak:

Pipe Size	$\bar{L}_{ec}$	$\bar{L}_{ef}$	$\bar{L}_{eq}$
1"	3.2	1.9	5.0
2"	2.6	3.0	3.8
3"	2.2	4.0	3.7
4"	2.7	5.2	3.6
5"	2.7	6.3	3.4
6"	2.6	7.3	3.2
8"	3.0	9.2	3.1

C. Tees

1. Through run

The following data are equivalent lengths in feet of corresponding straight pipe for cooldown, friction, and heat leak when flow is through the run of the tee:

Pipe Size	$\bar{L}_{ec}$	$\bar{L}_{ef}$	$\bar{L}_{eq}$
1"	3.4	2.1	7.4
2"	3.1	3.4	5.7
3"	2.9	4.8	5.5
4"	2.9	5.8	5.3
5"	3.1	7.3	5.0
6"	3.2	8.4	4.9
8"	3.3	10.8	4.6

2. Through branch

The following data are equivalent lengths in feet of corresponding straight pipe for cooldown, friction, and heat leak when flow is through the 90° branch of the tee:

Pipe Size	$\bar{L}_{ec}$	$\bar{L}_{ef}$	$\bar{L}_{eq}$
1"	3.4	5.8	7.4
2"	3.1	10.8	5.7
3"	2.9	14.8	5.5
4"	2.9	19.8	5.3
5"	3.1	23.8	5.0
6"	3.2	28.8	4.9
8"	3.3	36.8	4.6

TABLE 2

AVERAGE UNIT HEAT LEAK AND COOLDOWN DATA (WITHOUT LN_2 OR He SHIELD)

The average unit heat leak rates ($\bar{H}_q$) below are for steady state heat leak and exclude joint effects. They may be used for LH_2, LO_2, or LN_2 for engineering accuracy. Although the temperature differential across the insulation is greater for LH_2 than for LO_2 or LN_2, the apparent "K" value of the insulation is lower and the two effects virtually cancel each other*. Both the heat leak rates and cooldown enthalpies must be multiplied by the time factors in Table No. 3 for durations of transfer less than 16 hours.

Pipe Size	$\bar{H}_q$, Btu's/ft./hr.	$\Delta\bar{H}_c$, Btu's/ft.		
		LH_2	LO_2	LN_2
1"	.46	37.1	34.4	35.4
2"	.79	68.3	63.3	65.2
3"	1.03	125.7	116.6	120.1
4"	1.22	161.2	149.5	154.0
5"	1.56	256.6	238.0	245.1
6"	1.85	303.0	281.0	289.4
8"	2.37	395.0	366.3	377.3

FOR LHe IN 1" LINE*:

$$\left(\frac{300-4.5}{300-20}\right) 0.46 \doteq 0.5 \ \frac{Btu}{hr\text{-}ft}$$

FOR LHe IN 2" LINE*:

$$\left(\frac{300-4.5}{300-20}\right) 0.79 \doteq 0.83 \ \frac{Btu}{hr\text{-}ft}$$

* *This has been confirmed empirically.*

*NOTE: THE ESTIMATED VALUES FOR LHe DO NOT INCLUDE RESIDUAL GAS CONDUCTION EFFECTS.