LIQUID & GAS NITROGEN LINE SIZING
FOR
D-ZERO UPGRADE

D-ZERO ENGINEERING NOTE # 3823.115 -EN- 431

Sept. 14, 1995

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RD/DØ Mech.

Approved : _____

A large, stylized handwritten signature in black ink, likely belonging to Russ Rucinski, is written over a horizontal line. The signature is cursive and somewhat abstract, with long, sweeping strokes.

Introduction

This engineering note documents the calculations done to properly size the liquid/gas nitrogen piping system for the D-Zero refrigerator, solenoid, and VLPC upgrade.

Summary and Results

See the line sketch of the system on the next page. The sketch shows the chosen line sizes, estimated lengths of piping runs, estimated steady state flow rates and pressure drops for each pipe section.

Discussion

The raw calculations are attached as an appendix. The estimated steady state flow rates were developed in D-Zero EN-421, "Helium and LN2 Storage Requirements for the D-Zero Upgrade". The pressure drop calculations take into account the two phase property of the fluid on the inlet piping. The outlet piping is sized for saturated vapor. These calculations supplement sizing that was done in D-Zero EN-416, rev. 6/26/95, "Pipe Sizing for Solenoid/VLPC Cryogenic Systems". EN-416 only looked at the Solenoid and VLPC sections of the system. In a previous EN-430, "LN2 control valve sizing", a calculation was done to address the cool down flow rate necessary. The minimum cooldown flow rate needed for a simultaneous, serial cooldown of the refrigerator, solenoid and VLPC system was 6.4 g/s. This warm flow would get choked by an opening less than 0.175" in diameter. All the piping/tubing sizes exceed this size, so cooldown will not be a problem.

The available pressure drop for the VLPC and solenoid control valves was calculated to be 5.5 psid and 27 psid respectively. The actual delta P is expected to be larger because the conservativeness of using maximum flow rates and fluid properties that yield pressure drops on the high side.

SUBJECT

LN₂ / GN₂ LINE SIZING, ΔP'S
FOR STEADY STATE

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RUSS RUCINSKI

DATE

5-8-95

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THE FLOWRATES SKETCHED ON PAGE 1 ARE ESTIMATED MAXIMUMS. I WILL TRY TO CHOOSE PIPE SIZES SUCH THAT THE PRESSURE DROP ACROSS THE SOLENOID, $\Delta P_{\text{SOLENOID}}$, AND THE VALVE ΔP_{VALVE} ARE AT LEAST 5 psig.

SECTION (A)

200 ft. LONG. 1.1 gpm TRY 1 1/2" SCH. 10 SIZE. ID = 1.682"

$$\Delta P = 200 \text{ ft} \times .0002 \text{ PSI/ft}$$

USING CVI PRESSURE DROP CURVES p.43

$$\Delta P = .04 \text{ psi}$$

CHECK 1" SCH. 10 SIZE. ID = 1.097 in

$$\Delta P = .002 \text{ PSI/ft} \times 200 = \boxed{.4 \text{ psi}}$$

1" SCH 10 IS A REASONABLE SIZE.

$$P_2 = 35.0 - .4 \text{ psig} = \underline{34.6 \text{ psig}}$$

SECTION (B)

TRY 1/2" SCH. 10 IN A 1 1/2" SCH. 10 PIPE ID = .674 in

$$Re = 6.31 \frac{W}{d \mu}$$

$$W = 35 \frac{\text{gal}}{\text{hr}} \times \frac{6.745 \text{ lbs}}{\text{gal. liquid}} = 236 \frac{\text{lb}}{\text{hr}}$$

$$Re = 6.31 \frac{(236)}{(0.674)(.105)}$$

$$\mu = 1049.77 \mu \frac{\text{g}}{\text{cm} \cdot \text{s}} \times \frac{100 \text{ cp}}{1 \text{ g} \frac{\text{cm}}{\text{s}}} \times \frac{10^{-6}}{\mu} = .105 \text{ cp}$$

$$Re = 21,047$$

$$f = .032$$

$$\Delta P = 3.36 \times 10^{-6} \frac{f L W^2}{\rho d^5}$$

$$\rho = 0.75586 \frac{\text{g}}{\text{cm}^3} \times 62.428 \frac{\text{lb/ft}^3}{\text{g/cm}^3} = 47.2 \frac{\text{lb}}{\text{ft}^3}$$

$$\Delta P = 3.36 \times 10^{-6} \frac{(.032)(50 \text{ ft})(236 \frac{\text{lb}}{\text{hr}})^2}{(47.2 \frac{\text{lb}}{\text{ft}^3})(.674 \text{ in})^5} = .046 \text{ psi} \leftarrow \text{VERY LOW ESTIMATE}$$

LOCKHART MARTINELLI

$$X = .0324, L = 50 \text{ ft.}$$

$$\Delta P = \boxed{0.23 \text{ psi}}$$

MORE REASONABLE.

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CHECK SECTION (A) CALC. BY CRANE ESTIMATION. SAT. LN₂

$$Re = 6.31 \frac{W}{d\mu} = 6.31 \frac{(65 \text{ gph}) \left(\frac{6.745 \text{ lbs}}{\text{gal}} \right)}{(1.097 \text{ in}) (.105 \text{ cp})} = 24,017$$

$$f = .03$$

$$\Delta P_{\text{PER FOOT}} = 3.36 \times 10^{-6} \frac{f L W^2}{\rho d^5} = 3.36 \times 10^{-6} \frac{(.03)(1 \text{ ft.}) \left(438.42 \frac{\text{lb}}{\text{hr}} \right)^2}{(47.2 \frac{\text{lb}}{\text{ft}^3})(1.097 \text{ in})^5}$$

$$\Delta P_{\text{PER FOOT}} = .00026 \text{ PSI/FT. COMPARE TO } .002 \text{ PSI/FT. FROM CHART.}$$

FACTOR OF 10!

CALCULATE ΔP IF USE SATURATED VAPOR PROPERTIES.

$$Re = 6.31 \frac{W}{d\mu} = 6.31 \frac{(65 \text{ gph}) \left(\frac{6.745 \text{ lbs}}{\text{gal}} \right)}{(1.097 \text{ in}) (.006125 \text{ cp})} = 4.1 \times 10^5$$

$$f = .023$$

$$\Delta P_{\text{PER FOOT}} = 3.36 \times 10^{-6} \frac{(.023)(1 \text{ ft.}) \left(438.43 \frac{\text{lb}}{\text{hr}} \right)^2}{(0.800 \frac{\text{lb}}{\text{ft}^3})(1.097 \text{ in})^5} = 0.0117$$

SUMMARY OF CHECK AGAINST CVI CATALOG:

CRANE EQ'N'S

$$\Delta P_{\text{SAT LIQ. 3ATM}} = .00026 \text{ PSI/FT}$$

LOWER BOUND

$$\Delta P_{\text{SAT VAP. 3ATM}} = .0117 \text{ PSI/FT.}$$

UPPER BOUND

CVI PRESSURE
DROP CURVE

$$\Delta P = .002 \text{ PSI/FT.}$$

LOCKHART
MARTINELLI
VIA. TK SOLVER

$$\Delta P_{\text{2 PHASE}} \\ X = .0324$$

$$\Delta P = .0013 \text{ PSI/FT.}$$

⇒ CONCLUSION CVI CURVES TAKE INTO ACCOUNT 2Ø FLOW
AND IS A USEFUL NUMBER TO USE.

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• SECTION (C)

CHOOSE 1/2" SCH. 10 IN A 1 1/2" SCH. 10 PIPE

FLOW RATE $\approx$ SECTION B $\therefore \Delta P \approx$ SAME PER UNIT LENGTH
QUALITY MAY BE WORSE.

$$\Delta P_C = \frac{\Delta P_B}{50 \text{ ft}} \times 300 \text{ ft} \times 2 = \frac{23}{50} \times 300 \times 2 = \boxed{2.76 \text{ psi}}$$

↑
ADJUSTMENT
FOR QUALITY

• SECTION (D)ASSUME 1/2" OD. x .035" WALL TUBING 12 TURNS $\times 10' = 360'$ SAY 40 FT. USE $X = .030$ EVEN THOUGH
QUALITY GET'S BETTER & IS SUBCOOLED @ EXIT

$$\Delta P_D = 1.2 \text{ psig}$$

• SECTION (E)

USE 1/2" SCH. 10 IN A 1 1/2" SCH. 10 PIPE.

MOSTLY TO MATCH OTHER VJ LINE (GHE COOLDOWN)

$$\Delta P_E \approx 0.20 \text{ psi OR LESS PROBABLY IF SUBCOOLER WORKS AS PLANNED.}$$

• SECTION (F)

NEGLECTIBLE PRESSURE DROP. LAMINAR FLOW.

$$\Delta P_F \approx 2.9 \text{ psi FROM DESIGN REPORT. JUST A NUMBER.}$$

• SECTION (G)

$$18 \text{ gph} = 121.41 \frac{\text{lb}}{\text{hr}} = 15.33 \text{ g/s, NEED TO KNOW INLET STATE}$$

STATE (4) $P_4 = P_1 - \Delta P_A - \Delta P_C - \Delta P_D = 35 \text{ psig} - .4 - 2.76 - 1.2 = 30.6 \text{ psig}$
 $= 45.3 \text{ psia} \approx 3.0 \text{ ATM.}$

$$T_4 = 79 \text{ K SUBCOOLED STATE}$$

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$$h_4 = -118 \frac{J}{g}$$

HEAT LOAD STATE 4 TO ENTRANCE OF SECTION G;

$$2 \text{ BAYONETS \& U-TUBE} = 3.6 \text{ W}$$

$$50 \text{ FT OF X-FER LINE} = .09 \text{ W/FT} \times 50 \text{ FT} = 4.5 \text{ W}$$

SAY ≈ 10 WATTS TO BE CONSERVATIVE.

$$h'_G = h_4 + \frac{Q_{4-G}}{\dot{m}} = -118 \frac{J}{g} + \frac{10 \text{ WATTS}}{15.33 \frac{g}{s}} = -117.3 \frac{J}{g}$$

CLEARLY STILL SUBCOOLED. ONLY A FRACTION OF A KELVIN WARMER THAN AT STATE 4.

CHOOSE $3/8$ " OD. $\times$.049" WALL CALCULATE USING $X = 0.0$
ID. = .277"

$$Re = 6.31 \frac{W}{d\mu} = 6.31 \frac{(121.4 \frac{lb}{hr})}{.277 (.105)} = 26,338$$

$$F = .036$$

$$\Delta P = 3.36 \times 10^{-6} \frac{FLW^2}{\rho d^5} = 3.36 \times 10^{-6} \frac{(.036)(100 \text{ FT})(121.4 \frac{lb}{hr})^2}{(47.2 \frac{lb}{ft^3})(.277 \text{ IN})^5}$$

$$\Delta P = 2.32 \text{ psi}$$

CHOOSE $1/2$ " OD. $\times$.049" WALL ID = .402"

$$Re = 26,338 \frac{.277}{.402} = 18,148 \Rightarrow F = .030$$

$$\Delta P_G = 3.36 \times 10^{-6} \frac{(.030)(100 \text{ FT})(121.4)^2}{(47.2)(.402)^5} = \boxed{0.30 \text{ psi.}}$$

SECTION (H)

$$\dot{m} = \frac{15.33}{2} = 7.67 \frac{g}{s}$$

HEAT LOAD TO SECTION H IS 1500 WATTS

REF EN-421

PAGE 1 LN₂ STORAGE
REQ'D MTS CALCS.

$$h_{H|EXIT} = -117.3 \frac{J}{g} + \frac{1500 \frac{J}{s}}{7.67 \frac{g}{s}} = \underline{78.39 \frac{J}{g}}$$

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$$P_H = P_H - \Delta P_g = 45.3 \text{ psia} - 0.3 \text{ psia} \approx 3.0 \text{ ATM}$$

$$h_f = -98.938 \text{ J/g} \quad h_g = 84.167$$

$$\therefore \text{ STATE } H_{\text{EXIT}} \text{ IS 2\phi} \quad x = \frac{h - h_f}{h_g - h_f} = \frac{78.39 \text{ J/g} - -98.938}{84.167 - -98.938}$$

$$x_{H_{\text{EXIT}}} = \underline{0.968}$$

TO BE CONSERVATIVE CONSIDER ALL VAPOR FOR PRESSURE DROP CALC

$$\text{TRY } 3/8" \text{ O.D. } \times .049 \text{ WALL } (ID = .277") \times 100 \text{ FL.}$$

$$Re = 6.31 \frac{W}{d\mu} = 6.31 \frac{(60.705)}{(.277)(.0061)} = 227,000$$

$$f = .033$$

$$\Delta P = 3.36 \times 10^{-6} \frac{f L W^2}{p d^5} = 3.36 \times 10^{-6} \frac{(.033)(100 \text{ FL})(60.705)^2}{(.800 \frac{\text{lb}}{\text{ft}^3})(.277)^5}$$

$$\Delta P = 31.3 \text{ psi} \quad \text{— VERY CONSERVATIVE.}$$

BREAK SECTION H IN 2 PARTS

$$h_{H_{\text{MIDPOINT}}} = -19.52 \text{ J/g}$$

$$x_{H_{\text{MIDPOINT}}} = 0.43$$

FOR 1ST SECTION USE AVG. OF $x_H = 0.30$, $L = 50 \text{ FL.}$

$$\text{LOCKHART-MARTINGELLI, } \Delta P_{H_{\text{PART 1}}} = 7.43 \text{ psi}$$

FOR 2ND SECTION USE $x_H = .90$

$$\Delta P_{H_{\text{PART 2}}} = 9.44 \text{ psig}$$

$$\text{BAKER } x_{\text{axis}} = 2.1$$

$$y_{\text{axis}} = 46,000$$

$$\Delta P_{\text{TOTAL } H} = \boxed{16.9 \text{ psi}}$$

ANNULAR / MIST REGIME

SECTION H IS THE SERPENTINE SECTION & NEEDS TO BE SMALL DUE TO CRYOSTAT CONSTRUCTION.

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SECTION (I) ASSUME $K = 1.0$ USE $1/2"$ OD $\times .049$ WALL ID = .402

$$Re = 6.31 \frac{W}{d\mu} = 6.31 \frac{(121.4)}{.402 (.0061)} = 312,386$$

$$f = .0295$$

$$\Delta P = 3.36 \times 10^{-6} \frac{f L W^2}{P d^5} = 3.36 \times 10^{-6} \frac{(.0295)(100 \text{ ft})(121.4)^2}{(.800 \frac{\text{lb}}{\text{ft}})(.402)^5}$$

$$\Delta P = 17.4 \text{ psi. TOO LARGE.}$$

USE $1/2"$ SCH. 10 PIPE SIZE. ID = .674

$$Re = 312,386 \frac{(.402)}{.674} = 186,300 \Rightarrow f = .026$$

$$\Delta P = 3.36 \times 10^{-6} \frac{f L W^2}{P d^5} = 3.36 \times 10^{-6} \frac{(.026)(100 \text{ ft})(121.4)^2}{(.800)(.674)^5}$$

$$\Delta P_I = 1.16 \text{ psi}$$

$\nearrow$ @ 3 ATM ACTUALLY
BETTER TO USE $1 1/2$ ATM

$$\therefore \Delta P_I = 2.32 \text{ psi}$$

SECTION (J)

ASSUME SAT. VAPOR.

USE $\bar{P} = 1.20 \text{ ATM.}$ $L = 250 \text{ ft}$ $30 \text{ gph} = 202.35 \text{ lb/hr}$ USE $1 1/2"$ SCH. 10 PIPE $\times$ 3" SCH. 10 VJ.

$$Re = 6.31 \frac{202.35 \text{ lb/hr}}{(1.682)(.0054)} = 140,576 \Rightarrow f = .022$$

$$\Delta P_J = 3.36 \times 10^{-6} \frac{(.022)(250 \text{ ft})(202.35)^2}{(.34)(1.682 \text{ W})^5} = 0.15 \text{ psi}$$