MASTER

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THERMAL ANALYSIS OF LOFT WASTE GAS PROCESSING SYSTEM
NITROGEN SUPPLY FOR PROCESS LINE PURGE AND BLOWER SEAL

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DEPARTMENT OF ENERGY

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Title: THERMAL ANALYSIS OF LOFT WASTE GAS PROCESSING SYSTEM
NITROGEN SUPPLY FOR PROCESS LINE PURGE AND BLOWER SEAL

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IDAHO NATIONAL ENGINEERING LABORATORY
LOFT TECHNICAL REPORT
LOFT PROGRAM

TITLE Thermal Analysis of LOFT Waste Gas Processing System		REPORT NO. LTR 1122-4
Nitrogen Supply for Process Line Purge and Blower Seal		RE-A-78-276
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		RSB Mgr.

SUMMARY

The LOFT Waste Gas Processing System uses gaseous nitrogen (GN_2) to purge the main process line and to supply pressure on the blower labyrinth seal. The purpose of this analysis was to determine the temperature of the GN_2 at the blower seals and the main process line. Since these temperatures were below 32°F the heat rate necessary to raise these temperatures was calculated. This report shows that the GN_2 temperatures at the points mentioned above were below 10°F . A heat rate into the GN_2 of 389 Watts added at the point where the supply line (Figure 1) enters the vault would raise the GN_2 temperature above 32°F .

DISPOSITION OF RECOMMENDATIONS: The SWR number that will cover the recommendations is 52219. The GN_2 supply line is being heat traced to provide a total of 500 watts to the pipe in order to meet the requirements of this LTR.

THERMAL ANALYSIS OF LOFT WASTE GAS PROCESSING SYSTEM NITROGEN SUPPLY FOR PROCESS LINE PURGE AND BLOWER SEAL

I. INTRODUCTION

The LOFT Waste Gas Processing System (WGPS) uses gaseous nitrogen to purge the main process line and to supply pressure on the blower labyrinth seal. This nitrogen is supplied from a liquid nitrogen tank and an ambient vaporizer supplies heat to change the liquid nitrogen into a gas. This analysis is concerned with the nitrogen gas temperature at the main process line and blower seals. If the gas temperature at this point is below 32°F, there is a possibility of a problem related to the freezing of moisture. The gaseous nitrogen (GN_2) temperature at the blower seals and main process line and the necessary heat flux into the gas to raise its temperature above 32°F will be determined under worst case conditions.

II. ANALYSIS

The worst case conditions are an outside ambient temperature of -40°F and a vault ambient temperature of 45°F . The nitrogen temperature out of the ambient vaporizer is -70°F ^[1]. The line from the vaporizer to the vault is insulated and considered adiabatic. Calculations start where the GN_2 supply line (Fig. 1) enters the vault with a GN_2 temperature of -70°F and a flow rate of 12 scfm. Line Z branches into three other lines, two of which are considered in this report. Line B is shown in Fig. 2 and has a 12 scfm flow rate. Line H has a 4 scfm flow rate and is shown in Fig. 3^[1]. The piping is divided into sections and a ΔT is calculated for each section. The procedure used to determine the temperature drop of the GN_2 across each section is described in the Appendix.

If the temperature of the GN_2 gas is below 32°F at the blower seal or main process line, the heat rate needed to raise the GN_2 temperature above acceptable limits will be calculated. This will be calculated under the condition that the heat is added at the point where line Z enters the vault (GN_2 temperature = -70°F) in order to be conservative.

III. CONCLUSIONS

With the present system the temperature of the GN_2 gas at the main process line and blower seals will be below 10°F . It would take 389 Watts of heat addition to the GN_2 to raise its temperature to 32°F from -70°F if the heat was added at the point where Line Z enters the vault. If the heat was added downstream of this point, less heat flux would be required. However, the calculations in this report should not be used to determine the heat flux necessary downstream because the effects of condensation and icing on the exterior of the piping inside the vault was not included.

IV. REFERENCE

1. Personal conversations with Carl Yrene, November 1978.
2. J. P. Holman, Heat Transfer, 4th Edition, McGraw Hill Book Co., Inc., New York (1976).
3. Y. S. Touloukion, Thermophysical Properties of Matter, IFI/Plenum, New York (1970).

Fig. 1 Line Z, GN_2 Supply Line.

Fig. 2 Isometric of Line B, Supplies GN_2 to Purge Main Process Line.

Fig. 3 Isometric of Line H, Supplies Pressure to Blower Seals.

APPENDIX

Method of Solution.

- A) Divide the piping into finite sections.
 B) Calculate the mass flow rate $\dot{m}$ for each line, these values are a function of flow rate and pipe dimensions only. The wall resistance is calculated only once for each line since it's influence is small.

→ For each section using T_{out} of previous section as T_{in}

- 1) Calculate inside film coefficient (h_i) from
 Dittus Boelter $h_i/d_i = 1.023 (Re)^{.8} (\mu/\mu_s)^{.14} (Pr)^{.4} (Pr_s)^{.16}$

- 2) Calculate outside film coefficient (h_o) from
Holman ^[2] Vertical pipe ($> 1'$ length) =

$$h_o = 2.653 (10^{-2}) \Delta T^{1/3}$$

Horizontal

$$h_o = 9.697 (10^{-2}) \left(\frac{\Delta T}{d_o} \right)^{.25}$$

ΔT - OF d_o = outside dia in inches
 h is in Btu/s in² OF

- 3) Using h_o, h_i and pipe wall resistance calculate
 ON Overall heat transfer coefficient (U_o)

$$U_o = \left(\frac{1}{h_o} + R_{wall} + \frac{1}{h_i} \left(\frac{d_o}{d_i} \right) \right)^{-1}$$

- 4) Calculate heat transferred to gas

$$\dot{Q} = U A \Delta T \quad \text{assuming a } T_{avg} \text{ that is verified later.}$$

- 5) Calculate the temperature of nitrogen exiting the section (T_{out}) and average temp (T_{avg})

$$T_{out} = T_{in} + \frac{q}{\dot{m} c_p} ; T_{avg} = \frac{T_{in} + T_{out}}{2}$$

compare T_{avg} with that assumed in step 4 and iterate if necessary

- 6) Calculate a outside wall temperature. It was found that the temp. gradient across the wall was negligible i.e. Assume T_{wall} inside is equal to T_{wall} outside.

$$T_{wall} = T_{avg} + \frac{q}{h_i A_i}$$

Compare with T_{wall} assumed in step 2 and iterate if necessary

- 7) Use T_{out} of this section as T_{in} of next section.

Proceed to next section

Line Z is analyzed first and the output of Z feeds either line B or lines H & I.

I was not analyzed

Properties are from Ref. 2 & 3

Line Z Introduction

Nitrogen enters vault at -70°F at 12 scfm

Line Z is 1" sch 40 stainless steel

$$d_i = 1.049 \text{ in} \quad d_o = 1.315 \text{ in} \quad \text{Area} = .00600 \text{ ft}^2$$

$$\dot{m} = 12 \text{ scfm} \times S_{\text{TP}} \times \frac{1 \text{ min}}{60 \text{ s}}$$

$$\dot{m} = 12 \text{ ft}^3/\text{min} \times \frac{1 \text{ min}}{60 \text{ s}} \times 7.246 (10^{-2}) \text{ lb}_m/\text{ft}^3$$

$$\dot{m} = \underline{1.450 (10^{-2}) \text{ lb}_m/\text{s}}$$

$$P \dot{V} = 12 \text{ scfm} \cdot \frac{S_{\text{TP}}}{S_{\text{PR}}} \times \frac{1}{A} \cdot S_{\text{PR}} \cdot \frac{1 \text{ min}}{60 \text{ s}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

$$= \dot{m}/A = 1.450 (10^{-2}) \text{ lb}_m/\text{s} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} (.00600 \text{ ft}^2)$$

$$= \underline{1.677 (10^{-2}) \text{ lb}_m/\text{in}^2 \cdot \text{s}}$$

$$\text{Wall resistance} = d/2k (\ln d_o/d_i)$$

$$K_{ss} \text{ at } -70^{\circ}\text{F} = 1.77 (10^{-4}) \text{ Btu}/\text{in} \cdot \text{s} \cdot ^{\circ}\text{F}$$

$$\text{Wall Res.} = \frac{1.315}{2(1.77/10^{-4})} \left(\ln \frac{1.315}{1.049} \right) = \underline{839.5 \frac{\text{in}^2 \cdot \text{s} \cdot ^{\circ}\text{F}}{\text{Btu}}}$$

Line 2

2

Section 2 58 1/2 in Vert Pipe
 Drawing # 158156 $T_m = -70^\circ\text{F}$ Surface Area = $1.315\pi \times 58.5\text{ in}$
 $A_s = 2.417(10^2)\text{ in}^2$

$$1) \quad h_i = \frac{k}{d} \cdot 0.023 Re^{.8} Pr^{.4} \quad \text{Prop. at } -70^\circ\text{F (Nit.)}$$

$$Re = \frac{1.667(10^{-2}) \cdot 1.049 / 7.708(10^{-9})}{2.282(10^{-4})} \quad k = 2.66(10^{-2}) \text{ Btu/in}^2 \cdot \text{ft} \cdot ^\circ\text{F}$$

$$d = 1.049 \text{ in}$$

$$\mu = 7.708(10^{-7}) \text{ lbm/in} \cdot \text{s}$$

$$Pr = .73$$

$$h_i = \frac{2.66(10^{-2}) \cdot (0.023) \cdot (2.282(10^{-4})^{.8} \cdot (.73)^{.4})}{1.049} \quad \rho = 1.667(10^{-2}) \text{ lbm/in}^3$$

$$c_p = .2490$$

$$h_i = 1.577(10^{-5}) \text{ Btu/in}^2 \cdot \text{ft} \cdot ^\circ\text{F}$$

$$2) \quad h_o = 2.653(10^{-9}) \Delta T^{1/3} \quad \text{Assume } T_w = -55^\circ\text{F} \quad \Delta T = 100$$

$$h_o = 1.230(10^{-6}) \text{ Btu/in}^2 \cdot \text{ft} \cdot ^\circ\text{F}$$

$$3) \quad U_o = \left(\frac{1}{h_o} + \text{Wall Resistance} + \frac{1}{h_i} \left(\frac{A_o}{A_i} \right) \right)^{-1} \quad \text{Res}_{\text{wall}} = \frac{d_o}{2k} \ln \left(\frac{d_o}{d_i} \right)$$

$$= 839.5$$

$$U_o = \left(\frac{1}{1.230(10^{-6})} + 839.5 + \frac{1}{1.577(10^{-5})} \left(\frac{2.315}{1.049} \right) \right)^{-1}$$

$$= 8.123(10^5) + 839.5 + 7.949(10^2)$$

$$U_o = 1.20(10^{-6}) \text{ Btu/in}^2 \cdot \text{ft} \cdot ^\circ\text{F}$$

$$4) \quad \dot{q} = U A \Delta T; \quad \text{Assume } T_{\text{avg Nit.}} = -65.0^\circ\text{F} \quad \Delta T = 110^\circ\text{F}$$

$$\dot{q} = 1.20(10^{-6}) (2.417(10^2)) (110) = 2.97(10^{-2}) \text{ Btu/s}$$

$$5) \quad T_{\text{out}} = T_m + \dot{q} / m c_p = -70 + 2.97(10^{-2}) / 1.450(10^{-2}) \cdot 2490$$

$$T_{\text{out}} = -61.8^\circ\text{F} \quad T_{\text{avg}} = -65.9 \quad \text{Assumption 1) valid}$$

$$6) \quad \text{Find } T_{\text{wall}} \quad \text{Assume } T_{\text{inside}} = T_{\text{wall outside}}$$

$$T_{\text{wall}} = T_{\text{avg}} + \dot{q} / h_i A_i \quad A_i = 58.5\pi \cdot 1.049 = 192.8$$

$$T_{\text{wall}} = -65.9 + 2.97(10^{-2}) / 1.58(10^{-5}) 192.8$$

$$T_{\text{wall}} = -56.1^\circ\text{F} \quad \text{Assumption 2) valid}$$

Line Z

Section 2 63 IN Horiz Pipe
 Drawing # 158156 Surface Area = $1.315 \text{ IN} \times 63 \text{ IN} = 260(100) \text{ IN}^2$

$$T_{in} = -61.8^\circ\text{F}$$

Prop. at $-50^\circ\text{F} \approx 230^\circ\text{K}$
 $k = 2.77(10^{-2}) \text{ B/IN}^\circ\text{F}$
 $\mu = 7.64(10^{-2}) \text{ lb/IN}$
 $P_r = .73$
 $c_p = .249 \text{ B/lbm}^\circ\text{F}$

$$1) R_i = 1.687(10^{-2}) 1.099/764(10^{-8})$$

$$= 2.289(10^{-4})$$

$$h_i = \frac{2.27(10^{-2})}{1.099} (1.022(2.289(10^{-4}))^{.7} (.73)^{.4})$$

$$h_i = 1.646(10^{-5}) \text{ B/IN}^\circ\text{F}$$

$$2) h_o = 9.699(10^{-2}) (\Delta T/d)^{1/4} \text{ Assume } T_w = -45^\circ\text{F } \Delta T = 90^\circ\text{F}$$

$$h_o = 9.694(10^{-2}) (90/1.315)^{1/4} = 2.789(10^{-6}) \text{ B/IN}^\circ\text{F}$$

$$3) U_o = \left(\frac{1}{2.789(10^{-6})} + \frac{839}{3.585(10^5)} + \frac{1}{1.646(10^{-5}) \left(\frac{1.315}{1.099} \right)} \right)^{-1}$$

$$U_o = 2.296(10^{-6}) \text{ B/IN}^\circ\text{F}$$

$$4) \dot{q} = U_o A \Delta T \text{ Assume } T_{avg} = -50^\circ\text{F } \Delta T = 95^\circ\text{F}$$

$$2.296(10^{-6}) 260(10^2) (95^\circ\text{F}) = 5.671(10^{-2}) \text{ B/s}$$

$$5) T_{out} = T_{in} + \dot{q} / \dot{m} c_p = -61.8 + 5.671(10^{-2}) / 1.450(10^{-2}) (.249)$$

$$T_{out} = -46.0^\circ\text{F} \quad T_{avg} = -54.0^\circ\text{F} \text{ Ass. 4 Valid}$$

6) Find T_{wall}

$$T_{wall} = T_{avg} + \dot{q} / h_i A$$

$$T_{wall} = -54.0^\circ\text{F} + 5.671(10^{-2}) / 1.646(10^{-5}) 207.4$$

$$T_{wall} = -36.5^\circ\text{F} \text{ Ass 2) Valid}$$

Line Z is considered ended at this point
 with an outlet temp of -46°F 12scfm

Nitrogen enters Line B at -46°F at 12 scfm.
B is 1" sch 40 S.S. Parameters of Line Z
apply to B

$$d_i = 1.049 \text{ in } d_o = 1.315 \text{ in } A = .00600 \text{ ft}^2$$

$$\dot{m} = 1.450 (10^{-3}) \text{ lbm/s}$$

$$PV = 1.677 (10^{-3}) \text{ lbm/in}^2\text{-s}$$

Wall Resistance: Assume equal to that of line Z

$$839.5 \text{ in}^2\text{-s} \cdot ^{\circ}\text{F/Btu} \text{ this is conservative}$$

because with higher temp. k increases

Section ① 42 in Vert Pipe
 Drawing 158160 Surface Area = $1.315 \pi 42 \text{ in} = 173.5 \text{ in}^2$
 $T_{in} = -46^\circ \text{F}$

1) $h_i = \frac{k}{d} (1.023) R_r^{-0.8} P_r^{-0.4}$ Prop at -46°F (Nit.) $\approx 2300 \text{ K}$
 Same As Line Z Sect. ②

$$h_i = 1.646 (10^{-5}) \text{ B/s-in}^2 \cdot ^\circ \text{F} \quad (\text{Same as Z-Sect. 2})$$

2) $h_o = 2.653 (10^{-7}) \text{ AT}^{1/3}$ Assume $T_w = -25^\circ \text{F}$ $\text{AT} = 70^\circ \text{F}$

$$h_o = 1.092 (10^{-6}) \text{ B/s-in}^2 \cdot ^\circ \text{F}$$

3) $U_o = \left(\frac{1}{1.092 (10^{-6})} + \frac{1}{1.646 (10^{-5})} \right)^{-1} =$

$$U_o = 1.007 (10^{-6}) \text{ B/s-in}^2 \cdot ^\circ \text{F}$$

4) $q = UA \Delta T$ Assume $T_{avg} \text{ Nit.} = -40^\circ \text{F}$ $\text{AT} = 85^\circ \text{F}$

$$q = 1.007 (10^{-6}) 173.5 (85) = 1.503 (10^{-2}) \text{ B/s}$$

5) $T_{out} = T_{in} + q / \dot{m} c_p$

$$T_{out} = -46 + 1.503 (10^{-2}) / (1.45 (10^{-3}) \cdot 249)$$

$T_{avg} = -43.9$ $T_{out} = -41.8$ Assumption 1) is conservative

6) $T_{wall} = T_{avg} + q / h_i A$

$$= -43.9 + 1.503 (10^{-2}) / (1.646 (10^{-5}) (138.4 \text{ in}))$$

$T_{wall} = -37.4^\circ \text{F}$ Assumption 2) is conservative

Section ② 23 in Horiz pipe

$$\text{Surface Area} = 23 \text{ in} \times 1.315 \text{ in} = 95.0 \text{ in}^2$$

$$T_{in} = -41.8^\circ \text{F}$$

$$\text{Prop. at } 40^\circ \text{F} \approx 2360 \text{ K}$$

$$1) h_i = 1.646 (10^{-5})^{B/510^\circ \text{F}}$$

Same as previous Section

$$2) h_o = 9.697 (10^{-2}) (AT/D)^{1/4} \quad \text{Assume } T_{wall} = -25^\circ \text{F } AT = 70^\circ \text{F}$$

$$h_o = 9.697 (10^{-2}) / (70/1.315)^{0.25} = 2.619 (10^{-6})^{B/5-100^\circ \text{F}}$$

$$3) U_o = (1/2.619 (10^{-6}) + 839.5 + 1/1.646 (10^{-5}) (\frac{1.315}{1.049}))^{-1}$$

$$U_o = 2.179 (10^{-6})^{B/5-100^\circ \text{F}}$$

$$4) \dot{Q} = U A AT \quad \text{Assume } T_{avg} = -38.0^\circ \text{F } AT = 83^\circ \text{F}$$

$$\dot{Q} = 2.179 (10^{-6}) / 95.0 / (83.0) = 1.718 (10^{-2})^{B/5}$$

$$5) T_{out} = T_{in} + \dot{Q} / \dot{m} c_p$$

$$= -41.8 + 1.718 (10^{-2}) / 1.450 (10^{-2}) (-249)$$

$$T_{out} = -37.0^\circ \text{F} \quad T_{avg} = -39.4^\circ \text{F} \quad \text{Assumption 1) is conservative.}$$

$$6) T_{wall} = -39.4 + 1.718 (10^{-2}) / 1.646 (10^{-5}) / 75.8$$

$$T_{wall} = -25.7^\circ \text{F} \quad \text{Assumption 2) Valid}$$

Section 3 58 in Vert pipe

$$\text{Surface area} = 58 \text{ in } \pi 1.315 = 239.6 \text{ in}^2$$

$$T_{in} = -37.0^\circ\text{F}$$

$$1) h_i = \frac{2.84(10^{-2})}{1.049} \text{ Nre}^8 \text{ Pr}^4$$

$$\text{Nre} = \frac{6677(10^{-2})}{8.33(10^{-9})} = \frac{2.099(10^4)}{8.33(10^{-9})}$$

$$\text{Prop. at } 240^\circ\text{K}$$

$$k = 2.84(10^{-2}) \text{ B/s-in-}^\circ\text{F}$$

$$\mu = 8.33(10^{-9}) \text{ lb/s-in}$$

$$\text{Pr} = .73$$

$$C_p = .249$$

$$h_i = \frac{2.84(10^{-2})}{1.049} (2.01(10^4))^8 (.73)^4$$

$$h_i = 1.537(10^{-5}) \text{ B/s-in-}^\circ\text{F}$$

$$2) h_o = 2.653(10^{-2}) \text{ AT}^{1/3} \quad \text{Assume } T_{wall} = -20^\circ\text{F} \quad \Delta T = 65^\circ\text{F}$$

$$h_o = 2.653(10^{-2}) (65)^{1/3} = 1.065(10^{-4}) \text{ B/s-in-}^\circ\text{F}$$

$$3) U_o (1/1.065(10^{-4}) + 839.5 + 1/1.537(10^{-5}) \frac{1.315}{1.049})^{-1}$$

$$9.793(10^{-7}) \text{ B/s-in-}^\circ\text{F}$$

$$4) \dot{q} = U A \Delta T \quad \text{Assume } T_{avg} = -32^\circ\text{F} \quad \Delta T = 67.7^\circ\text{F}$$

$$\dot{q} = 9.793(10^{-7}) (2396) (67.7) = 1.589(10^{-2}) \text{ B/s}$$

$$5) T_{out} = T_{in} + \dot{q} / m C_p$$

$$-37.0 + 1.589(10^{-2}) / (1.45(10^{-2}) (1.249))$$

$$T_{out} = -32.6^\circ\text{F} \quad T_{avg} = -34.8^\circ\text{F} \quad \text{Ass. 4 Valid!}$$

$$6) T_{wall} = -34.8 + 1.589(10^{-2}) / (1.537(10^{-5}) (191.1))$$

$$T_{wall} = -29.4^\circ\text{F} \quad \text{Assumption 2) conservative}$$

Line B
Section 4 - 100 IN Horiz pipe

$$\text{Surface Area} = 100\pi \cdot 1.315 = 413.1$$

$$T_{in} = -32.6^\circ\text{F} =$$

Prop at 2400R
Same as Section 3

$$1) h_i = 1.537(10^{-5}) B/5-10^\circ\text{F}$$

$$2) h_o = 9.697(10^{-7}) \left(\frac{AT}{D}\right)^{1/4} \quad \text{Assume } T_w = -20^\circ\text{F} \quad AT = 65^\circ\text{F}$$

$$h_o = 9.697(10^{-7}) \left(\frac{65}{1.315}\right)^{1/4} = 2.571(10^{-6}) B/5-10^\circ\text{F}$$

$$3) U_o \left(\frac{1}{2.571(10^{-6})} + 839.5 + \frac{1}{1.537(10^{-5}) \frac{1.315}{1.094}} \right)^{-1} =$$

$$U_o = 2.122(10^{-6}) B/5-10^\circ\text{F}$$

$$4) q = UAAT \quad \text{Assume } T_{avg} = 25.0^\circ\text{F} \quad AT = 70^\circ\text{F}$$

$$q = 2.122(10^{-6}) 413.1 (70^\circ\text{F}) = 6.135(10^{-2}) B/5$$

$$5) T_{out} = T_{in} + q/\dot{m}c_p$$

$$= -32.6 + 6.135(10^{-2}) / (1.45(10^{-2}) (1.249))$$

$$T_{out} = -15.6^\circ\text{F} \quad T_{avg} = -24.1^\circ\text{F} \quad \text{Ass. 4 valid}$$

$$6) T_{wall} = T_{avg} - q/h_i A$$

$$-24.1^\circ\text{F} - 6.135(10^{-2}) / (1.537(10^{-5}) (389.5))$$

$$T_{wall} = -12.0^\circ \quad \text{Ass. 2 error} = 5\% - \text{OK}$$

Section 5

 $T_{in} = -156^{\circ}\text{F}$ 45 7/8 in Horiz pipe Surface Area 189.5 in²

$$1) h_i = \frac{2.973(10^{-3})}{1.049} (1.023) (2.62(10^4))^{.8} (.73)^{.4}$$

$$h_i = 1.599(10^{-5}) \text{ Btu/s-in}^2\text{-}^{\circ}\text{F}$$

$$k = 2.973(10^{-3}) \text{ Btu/s-in}^2\text{-}^{\circ}\text{F}$$

$$\mu = 8.664(10^{-7}) \text{ lbm/s-in}$$

$$Pr = .73$$

$$Cp = .249$$

$$N_{Re} = 2.02(10^4)$$

$$2) h_o = 9.697(10^{-2}) (AT/d)^{.14}$$

$$h_o = 9.697(10^{-2}) \left(\frac{45}{1.315}\right)^{.25} \text{ Assume } T_w = +0^{\circ}\text{F } \Delta T = 45^{\circ}\text{F}$$

$$h_o = 2.345(10^{-6}) \text{ Btu/s-in}^2\text{-}^{\circ}\text{F}$$

$$3) U_o = \left(\frac{1}{2.345(10^{-6})} + 839.5 + \frac{1}{1.599(10^{-5})} \left(\frac{1.315}{1.049} \right)^{.4} \right)^{-1}$$

$$U_o = 1.978(10^{-6}) \text{ Btu/s-in}^2\text{-}^{\circ}\text{F}$$

$$4) \dot{q} = U_o A \Delta T \text{ Assume } T_{avg} = -12^{\circ}\text{F } \Delta T = 57^{\circ}\text{F}$$

$$\dot{q} = 1.978(10^{-6}) (189.5) (57) = 2.136(10^{-2}) \text{ Btu/s}$$

$$5) T_{out} = -15.6 - 2.136(10^{-2}) / 1.45(10^{-2}) (.249)$$

$$T_{out} = -9.7^{\circ}\text{F } T_{avg} = -12.6^{\circ}\text{F } \text{Valid}$$

$$6) T_w = -12.6^{\circ}\text{F} - 2.136(10^{-2}) / 1.599(10^{-5}) \text{ Btu/s-in}^2\text{-}^{\circ}\text{F} (151.2)$$

$$T_w = -3.7^{\circ}\text{F } \text{Ass. 2 valid}$$

Section 6

99 in Vert. Pipe

Surface Area = 409 in²

$$T_{in} = 9.7^\circ F$$

$$1) \quad h_i = 1.599(10^{-5})^{1/5} \text{ Btu-in}^2 \text{ OF} \quad \text{prop at 250K}$$

Same as Sect. 5

$$2) \quad h_o = 2.653(10^{-4}) (AT)^{1/3}$$

$$h_o = 2.653(10^{-2}) (35)^{1/3}$$

$$\text{Assume } T_{wall} = 41.0^\circ F$$

$$AT = 35^\circ F$$

$$h_o = 8.677(10^{-2}) \text{ Btu-in}^2 \text{ OF}$$

$$3) \quad U_o = (1/8.677(10^{-2}) + 839.5 + (1/1.599(10^{-5}))1.25)^{-1}$$

$$U_o = 8.12(10^{-2}) \text{ Btu-in}^2 \text{ OF}$$

$$4) \quad \dot{Q} = U_o A AT \quad \text{Ass. } T_{avg} = -5^\circ F \quad AT = 50^\circ F$$

$$\dot{Q} = 8.12(10^{-2}) \text{ Btu-in}^2 \text{ OF} (409) 50 = 1.66(10^{-2}) \text{ Btu/s}$$

$$5) \quad T_{out} = -9.7 + 1.66(10^{-2}) / 1.45(10^{-2}) \cdot 299$$

$$T_{out} = 5.1 \quad T_{avg} = -7.4 \quad \text{4) Valid}$$

$$6) \quad T_{wall} = -7.4 + 1.66(10^{-2}) / 1.599(10^{-5}) (326.3)$$

$$T_{wall} = -4.2 - \text{Go Back to 2}$$

$$2) \quad \text{Assume } T_{wall} = 0^\circ F \quad AT = 45^\circ F$$

$$h_o = 2.653(10^{-2}) / (45)^{1/3} = 9.424(10^{-2}) \text{ Btu-in}^2 \text{ OF}$$

$$3) \quad U_o = 8.770(10^{-2})$$

$$4) \quad \text{Assume } T_{avg} = -5 \quad AT = 30$$

$$\dot{Q} = 1.793(10^{-2})$$

$$5) \quad T_{out} = -9.7 + 1.793(10^{-2}) / 1.45(10^{-2}) (1.244)$$

$$T_{out} = -4.7$$

Section 7

83 1/2 in. Horiz piping.

$$T_{in} = -4.7^{\circ}\text{F}$$

$$\text{Area} = 345.0 \text{ in}^2$$

Prop at 250°K

$$1) h_i = \frac{1.599 (10^{-5})}{\text{ft}^2 \cdot \text{in}^2 \cdot ^{\circ}\text{F}}$$

use previous section.

$$2) h_o = 9.697 (10^{-7}) \left(\frac{\Delta T}{d} \right)^{1/4}$$

$$\text{Assume } T_{wall} = 0^{\circ}\text{F} \quad \Delta T = 45^{\circ}\text{F}$$

$$h_o = \frac{2.345 (10^{-6})}{\text{ft}^2 \cdot \text{in}^2 \cdot ^{\circ}\text{F}}$$

$$3) U_o = \left(\frac{1}{2.345 (10^{-6})} + 839.6 + \frac{1}{1.599 (10^{-5}) (1.25)} \right)^{-1}$$

$$U_o = 1.978 (10^{-6}) \text{ Btu/s-in}^2 \cdot ^{\circ}\text{F}$$

$$4) \dot{Q} = U_o A \Delta T = 1.978 (10^{-6}) (345.0) (45^{\circ}\text{F})$$

$$\text{Ass } T_{avg} = 0^{\circ}\text{F}$$

$$= 3.071 (10^{-8}) \text{ Btu/s}$$

$$5) T_{out} = -4.7 + 3.071 (10^{-8}) / 1.45 (10^{-2}) (-249)$$

$$T_{out} = +3.8^{\circ}\text{F} \quad T_{avg} = -1.0^{\circ}\text{F}$$

$$6) T_{wall} = -1.0^{\circ}\text{F} + 3.071 (10^{-8}) / 1.599 (10^{-5}) (275.2)$$

$$T_{wall} = +6^{\circ}\text{F} \quad \text{error} = 3\% \text{ in } h_o$$

Line B

Section 8

46.25 in Vert

Surface Area = 191.1 in²

$$T_{in} = +3.8^{\circ}\text{F}$$

$$1) h_i = \frac{3.075(10^{-9})(.023)(2.03(10^4))^{-.8} .73^4}{1.049} \quad \text{Prop. At } 260^{\circ}\text{K}$$

$$h_i = 1.66(10^{-5}) \text{ B/S in}^2 \text{ }^{\circ}\text{F} \quad k = 3.075(10^{-2}) \text{ B/S in }^{\circ}\text{F}$$

$$\mu = 8.667(10^{-2}) \text{ lbm/S-in}$$

$$Pr = .73$$

$$C_p = .249$$

$$N_{Re} = 2.03(10^4)$$

$$2) h_o = 2.653(10^{-4}) (AT)^{1/3}$$

$$h_o = 8.677(10^{-4}) \text{ B/S in}^2 \text{ }^{\circ}\text{F} \quad \text{Assume } T_{wall} = 10^{\circ}\text{F}$$

$$AT = 35^{\circ}\text{F}$$

$$3) U_o = (1/8.677(10^{-4}) + 839.5 + (1/1.66(10^{-5})(1.25)))^{-1}$$

$$U_o = 8.138(10^{-4}) \text{ B/S in}^2 \text{ }^{\circ}\text{F}$$

$$4) \dot{q} = U_o A AT \quad \text{Ass. } T_{avg} = 6^{\circ}\text{F} \quad AT = 39^{\circ}\text{F}$$

$$\dot{q} = 8.138(10^{-4})(191.1) 39 = 6.06(10^{-3}) \text{ B/S}$$

$$5) T_{out} = 3.8 + 6.06(10^{-3}) / 1.4(10^{-2})(.249)$$

$$T_{out} = 5.5^{\circ}\text{F} \quad \text{Ass 4 convs.}$$

$$6) T_{wall} = 4.5^{\circ}\text{F} + 6.06(10^{-3}) / 1.66(10^{-5})(191.1)$$

$$T_{wall} = 6.4^{\circ}\text{F} \quad \text{error} = < 5\%$$

Temp Nitrogen into process line
 $= +5.50^{\circ}\text{F}$

Line H

Introduction

Nitrogen enters line H from line Z at
4.0 scfm - - 460°F

Line H is $\frac{1}{4}$ " (.035) wall tubing

$$d_i = .18 \text{ in} \quad d_o = .25 \text{ in} \quad \text{Area (interval)} = .025 \text{ in}^2$$

$$\dot{m} = 4 \text{ scfm} \times P_{stp} \times \frac{1 \text{ min}}{60 \text{ sec}}$$

$$= 4 \text{ ft}^3/\text{s} \times 7.246 (10^{-9})^{16} \text{ in}^3/\text{ft}^3 \times \frac{1}{60 \text{ s}}$$

$$\dot{m} = \frac{4.831 (10^{-3})^{16} \text{ in}^3/\text{s}}$$

$$P_o \vec{V} = \dot{m}/A = \frac{4.831 (10^{-3})^{16} \text{ in}^3/\text{s}}{.025 \text{ in}^2}$$

$$P_o \vec{V} = \underline{1.932 (10^{-1})}$$

Wall Resistance

$$K_{ss} (4000 \text{ R}) = 1.794 (10^{-9})^8 / \text{S-in-}^\circ\text{F}$$

$$\text{Wall Resistance} = \frac{1}{2K} (\ln(d_o/d_i))$$

$$= \frac{.25}{2 (1.794 (10^{-9})^8)} (\ln \frac{.25}{.18})$$

$$= \underline{696.8 \text{ S-in}^2\text{ }^\circ\text{F/R}}$$

Line H

Section ① 48" vert.
Drawing 158168

$$\text{Surface Area} = A_o = 37.7 \text{ in}^2$$

$$A_i = 27.1 \text{ in}^2$$

$$T_{in} = -46^\circ\text{F} = 414^\circ\text{R}$$

$$1) \quad Re = .1932 \times .18 / 7.64(10^{-9})$$

$$Re = 4.55(10^{-9})$$

$$h_i = 2.77(10^{-9}) / .18(1.023)(4.55(10^{-9}))^{.8}(.93)^{.4}$$

$$h_i = 1.66(10^{-9})^{.8} / 5-10^\circ\text{F}$$

$$\text{Prop. at } 230^\circ\text{F} = 414^\circ\text{R}$$

$$k = 2.77(10^{-9})^{.8} / 5-10^\circ\text{F}$$

$$\mu = 2.64(10^{-9})^{.16} / 14.5$$

$$Pr = .73$$

$$Cp = .249$$

$$2) \quad h_o = 2.653(10^{-9}) \Delta T^{.13} \quad \text{Assume } T_w = -35^\circ\text{F} \quad \Delta T = 80^\circ\text{R}$$

$$h_o = 2.653(10^{-9})(80)^{.133} = 1.143(10^{-6})^{.8} / 5-10^\circ\text{F}$$

$$3) \quad U_o = (1/1214(6) + 696.8 + 1/1.66(10^{-9})(1.39))^{-1}$$

$$U_o = 1.13(10^{-6})^{.8} / 5-10^\circ\text{F}$$

$$4) \quad \dot{Q} = U A \Delta T \quad \text{Assume } T_{avg} = -43^\circ\text{F} \quad \Delta T = 88^\circ\text{F}$$

$$\dot{Q} = 1.33(10^{-6})(37.7)88 = 3.753(10^{-3})$$

$$5) \quad T_{out} = T_{in} + \dot{Q} / \dot{m} C_p$$

$$T_{out} = 414^\circ\text{R} + 3.75(10^{-3}) / 4.831(10^{-3}) \cdot 249$$

$$T_{out} = 417.1^\circ\text{R} \quad \text{Assumption 4) valid.}$$

$$T_{avg} = -44.5^\circ\text{F}$$

$$6) \quad T_{w,11} = T_{avg} + \dot{Q} / h_i A$$

$$= -44.5^\circ\text{F} + 3.753(10^{-3}) / 1.66(10^{-9}) 27.1$$

$$= T_{w,11} = -43.7^\circ\text{F} \quad \text{Assumption 2) valid}$$

Section ②

4.0 ft horiz. pipe Surface Area $A_o = 37.7$
 $A_i = 27.1$

$$T_{in} = 417.1^\circ R = -42.9^\circ F$$

Prop. at 2300R

$$1) \quad 1.66 (10^{-4})^{B/5 - 110^\circ F}$$

Same as Section 1

$$2) \quad h_o = 9.697 (10^{-2}) (AT/16)^{.25}$$

$$\text{Assume } T_{wall} = -37^\circ F \quad AT = 75^\circ F$$

$$h_o = 9.697 (10^{-2}) (75/.25)^{.25}$$

$$h_o = 9.04 (10^{-6})^{B/5 - 110^\circ F}$$

$$3) \quad U_o = (1/4.13(10^{-4}) + 696.8 + 1/1.66(10^{-4})(1.29))^{-1}$$

$$U_o = 3.894 (10^{-4})^{B/5 - 110^\circ F}$$

$$4) \quad \dot{Q} = UAAT \quad \text{Assume } T_{avg} = -36^\circ F \quad AT = 81^\circ F$$

$$\dot{Q} = 3.894 (10^{-4})^{B/5 - 110^\circ F} (37.7) (81) = 1.19 (10^{-2})^{B/5}$$

$$5) \quad T_{out} = -42.9^\circ F + 1.19 (10^{-2}) / 4.83 (10^{-3}) (.299)$$

$$T_{out} = -33.0^\circ F \quad T_{avg} = -37.9 - \underline{4 \text{ valid}}$$

$$6) \quad T_{wall} = 37.9 + 1.19 (10^{-2}) / 1.66 (10^{-4}) 27.1$$

$$T_{wall} = -35.2^\circ F \quad \underline{2 \text{ valid}}$$

Section ③ 5/16 Vert.

$$T_{in} = -33^{\circ}F$$

$$\text{Surface Area} = A_o = 41.6 \text{ in}^2$$

$$A_i = 30.0 \text{ in}^2$$

$$1) h_i = (2.84(10^{-3}) / (1.18)(.027)) (4.175(10^{-4})^8 (.73)^{-1/4}$$

Prop at 290°K

$$h_i = 4608(10^{-9}) \text{ B/s in}^2 \text{ OF}$$

$$k = 2.84(10^{-3}) \text{ B/s in OF}$$

$$\mu = 8.33(10^{-3}) \text{ lb/s-in}$$

$$Pr = .73$$

$$cp = .249$$

$$N_{Re} = 4.175(10^4)$$

$$2) h_o = 2.653(10^{-2}) AT^{1/3}$$

$$\text{Assume } T_{wall} = -30^{\circ}F$$

$$AT = 75^{\circ}F$$

$$h_o = 1.12(10^{-6}) \text{ B/s in}^2 \text{ OF}$$

$$3) U_o = (1/1.12(10^{-6}) + 696.8 + 1/4608(10^{-9})(1.39))^{-1}$$

$$U_o = 1.11(10^{-6}) \text{ B/s in}^2 \text{ OF}$$

$$4) \dot{Q} = U A \Delta T \quad \text{Assume } T_{avg} = -30^{\circ}F \quad \Delta T = 75^{\circ}F$$

$$\dot{Q} = 1.11(10^{-6})(41.6)(75^{\circ}F)$$

$$\dot{Q} = 3.45(10^{-3}) \text{ B/s}$$

$$5) T_{out} = -33.0 - 3.45(10^{-3}) / 4.83(10^{-3}) \cdot 249$$

$$T_{out} = -30.1^{\circ}F \quad T_{avg} = -31.5^{\circ}F \quad \text{Ass. 4 valid}$$

$$6) T_{wall} = -31.5 + 3.45(10^{-3}) / 1.61(10^{-9})(30.0)$$

$$T_{wall} = -30.8^{\circ} \quad 2) \text{ OK}$$

Section ④

121.5 in Horiz pipe

$$A_o = 95.43 \text{ in}^2$$

$$A_i = 68.65 \text{ in}^2$$

$$T_{in} = -30.80^\circ\text{F}$$

$$1) \quad h_i = 1.61(10^{-4})^{1/5} \text{ in}^2 \text{ of}$$

Prop at 240°R

$$2) \quad h_o = 9.697(10^{-2}) \left(\frac{\Delta T}{H} \right)^{.25}$$

Same as Sec. 3

$$\text{Assume } T_{wall} = -15^\circ\text{F} \quad \Delta T = 50^\circ\text{F}$$

$$h_o = 3.65(10^{-6})^{1/5} \text{ in}^2 \text{ of}$$

$$3) \quad U_o = \left(\frac{1}{3.65(10^{-6})} + 696.8 + \frac{1}{1.61(10^{-4})(1.39)} \right)^{-1}$$

$$3.527(10^{-6})^{1/5} \text{ in}^2 \text{ of}$$

$$4) \quad \dot{Q} = UA\Delta T$$

$$\text{Assume } T_{avg} = -20^\circ\text{F}$$

$$\Delta T = 65^\circ\text{F}$$

$$\dot{Q} = 3.53(10^{-6}) / 95.43 (65.0)$$

$$\dot{Q} = 2.19(10^{-2}) \text{ Btu/s}$$

$$5) \quad T_{out} = -30.8 + 2.19(10^{-2}) / 4.83(10^{-3}) (.249)$$

$$T_{out} = -12.6 \quad T_{avg} = -21.8 \quad \text{Assumptions 4: good}$$

$$6) \quad T_{wall} = -21.8^\circ\text{F} + 2.19(10^{-2}) / 1.61(10^{-4}) / 68.65$$

$$T_{wall} = -19.8^\circ\text{F} \quad \text{Ass, 2 good}$$

Section ⑤ 110.88 in Horiz. pipe $A_o = 87.08 \text{ in}^2$
 $A_i = 62.65 \text{ in}^2$
 $T_{in} = -12.6^\circ\text{F} = 248^\circ\text{K}$

1) $h_i = \frac{k}{d} (1.023) Re^{-.4} Pr^{-.4}$

Prop at 250°K

$h_i = 1.61(10^{-4}) B/5-110^\circ\text{F}$

$k = 2.973(10^{-7}) B/5-110^\circ\text{F}$

$\mu = 8.67(10^{-7}) B/5-110$

$Pr = .73$

$C_p = .249$

$N_{re} = 4.01(10^4)$

2) $h_o = 9.697(10^{-7}) (AT/d)^{.25}$

Assume $T_{wall} = -5^\circ\text{F}$

$d = .25$ $AT = 50^\circ\text{F}$

$h_o = 3.65(10^{-6}) B/5-110^\circ\text{F}$

3) $U_o = (1/3.65(10^{-6}) + 696.8 + 1/1.61(10^{-4})(1.39))^{-1}$

$U_o = 3.53(10^{-6}) B/5-110^\circ\text{F}$

4) $\dot{Q} = U A \Delta T$ Assume $T_{avg} = -5^\circ\text{F}$ $\Delta T = 50^\circ\text{F}$
 $= 3.53(10^{-6})(87.08)(50)$
 $\dot{Q} = 1.54(10^{-2}) B/5$

5) $T_{out} = -12.6 + 1.54(10^{-2}) / 4.83(10^{-3})(.249)$

$T_{out} = +0.2^\circ\text{F}$ $T_{avg} = -6.2^\circ\text{F}$ Ass 4 valid

6) $T_{wall} = -6.2 + 1.54(10^{-2}) / 1.61(10^{-4}) 62.65$

$T_{wall} = -4.7^\circ\text{F}$ Ass. 2 valid

Section ⑥ 96 IN Horiz.

$$A_o = 75.4 \text{ in}^2$$

$$A_i = 54.2 \text{ in}^2$$

$$T_{in} = 0.20^\circ\text{F}$$

1) $h_i = \frac{3.095(10^{-2})(0.023)(4.01(10^3))^{.73}}{.18} \cdot 73$ Prop at 260°K
 $h_i = 1.67(10^{-4}) \text{ B/s-in}^2\text{F}$ $k = 3.095(10^{-2}) \text{ B/s-in}^2\text{F}$
 $\mu = 8.667(10^{-2}) \text{ lbm/s-in}$
 $Pr = .73$
 $C_p = .249$
 $N_{Re} = 4.01(10^3)$

2) $h_o = 9.697(10^{-7}) / (dT/dx)^{.25}$
 Assume $T_{wall} = +5^\circ\text{F}$ $\Delta T = 40^\circ\text{F}$

$$h_o = 3.45(10^{-6}) \text{ B/s-in}^2\text{F}$$

3) $U_o = (1/3.45(10^{-6}) + 696.8 + 1/1.67(10^{-4})(1.39))^{-1}$

$$U_o = 3.34(10^{-6}) \text{ B/s-in}^2\text{F}$$

4) $q = U A \Delta T$ Assume $T_{avg} = 5^\circ\text{F}$ $\Delta T = 40$

$$q = 1.01(10^{-2}) \text{ B/s}$$

5) $T_{out} = 0.2 + 1.01(10^{-2}) / 4.83(10^{-3})(.249)$

$$T_{out} = 8.6^\circ\text{F} \quad T_{avg} = 4.4^\circ\text{F} \quad \text{Ass 4) OK}$$

6) $T_{wall} = 4.4^\circ\text{F} + 1.01(10^{-2}) / 1.67(10^{-4})(54.2)$

$$T_{wall} = 5.5 \quad \text{Ass 2) Valid}$$

$$T_{Line} \text{ Line } H = \underline{8.6^\circ\text{F}}$$

The Nitrogen temp. at the outputs of lines B & H are below acceptable limits. The amount of heat that should be added to the gas to raise the temp. to above the freezing temp. of water will be calculated at the point on line Z where it enters the vault. Calculating the heat added at this point is conservative because if the gas is heated above 32°F at this point it will require the largest temp. change and the heat transferred from the ambient air to the gas in the down stream piping become negligible

To heat Nitrogen Gas From -70°F to 32°F at 12 scfm the power input to the gas is

$$12 \text{ scfm} = 1.450 (10^{-2}) \frac{\text{lb}_m}{\text{s}}$$

$$c_p = .24943 (32^\circ\text{F}) \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}}$$

$$\dot{q} = \dot{m} c_p \Delta T$$

$$\dot{q} = 1.450 (10^{-2}) \frac{\text{lb}_m}{\text{s}} (.24943 \frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}}) (102^\circ\text{F})$$

$$\dot{q} = 3.69 (10^{-1}) \frac{\text{Btu}}{\text{s}} = 1.33 (10^3) \frac{\text{Btu}}{\text{hr}}$$

$$1 \text{ KW} = 3412 \frac{\text{Btu}}{\text{hr}}$$

$$\dot{q} = \underline{\underline{.387 \text{ KW}}}$$