SOLENOID HELIUM RESERVOIR
PRESSURE VESSEL ENGINEERING NOTE

D-ZERO ENGINEERING NOTE # 3823.111-EN-511

April 15, 1999

Author: Russ Rucinski
PPD/ETT/D-Zero Upgrade project

**PRESSURE VESSEL ENGINEERING NOTE
PER CHAPTER 5031**

Prepared by: RUSS RUCINSKI
Preparation date: 1-5-98

1. Description and Identification
Fill in the label information below:

This vessel conforms to Fermilab ES&H Manual Chapter 5031	
Vessel Title <u>NO SOLENOID LIQUID HELIUM RESERVOIR</u>	
Vessel Number <u>PPD-10051A</u>	
Division/Section _____	
Vessel Drawing Number <u>TOSHIBA DRG. 2KN002346 REV. E</u>	
Maximum Allowable Working Pressures (MAWP):	
Internal Pressure	<u>150</u> PSIA
External Pressure	<u>NOT APPLICABLE</u> PSIA
Working Temperature Range <u>-452</u> OF <u>100</u> OF	
Contents <u>LIQUID HELIUM</u>	
Designer/Manufacturer <u>TOSHIBA CORPORATION</u>	
<u>KEIWIN PRODUCT OPERATIONS</u>	
Test Pressure (if tested at Fermi)	Acceptance Date: <u>N/A</u>
<u>N/A</u> PSI, Hydraulic <u>N/A</u> Pneumatic <u>N/A</u>	
Accepted as conforming to standard by _____	

of Division/Section _____	Date: <u>3/4/99</u>

Obtain from Safety Officer

Document per Chapter
5034 of the Fermilab
ES&H Manual

Actual signature required

NOTE: Any subsequent changes in contents, pressures, temperatures, valving, etc., which affect the safety of this vessel shall require another review.

Reviewed by: [Signature] Date: Aug 28 1998

Director's signature (or designee) if the vessel is for manned areas but doesn't conform to the requirements of the chapter.

Date: _____

Amendment No.: _____

Reviewed by: _____

Date: _____

Lab Property Number(s): _____

Lab Location Code: RPIS-325 (DAB) (obtain from safety officer)

Purpose of Vessel(s): SUBCOOLING LHe SUPPLY TO DØ SOLENOID

Vessel Capacity/Size: 1.2 FT³ Diameter: 12.75 " Length: 17.95 "

Normal Operating Pressure (OP) 4.4 PSIG

MAWP-OP = 130.6 PSI

List the numbers of all pertinent drawings and the location of the originals.

Drawing #

Location of Original

TOSHIBA # 2KN002346 REV. E

D-ZERO ASS'Y BUILDING

TOSHIBA # 2KN109148 REV. E, SHT. 1

" " "

TOSHIBA # 2KN109148 REV. E, SHT. 2

" " "

NOTE: THESE DRAWINGS ARE PROPRIETARY TO TOSHIBA AND SHOULD NOT BE
CIRCULATED OUTSIDE OF FERMILAB.

2. Design Verification

Does the vessel(s) have a U stamp? Yes X No _____. If "Yes", fill out data below and skip page 3; if "No", fill out page 3 and skip this page.

Staple photo of U stamp plate below.

Copy "U" label details to the side

Copy data here:

NATIONAL BD No. 5

CERTIFIED BY TOSHIBA CORPORATION

KEITH IN PRODUCT OPERATIONS.

SHELL SIDE TUBE SIDE

MAWP INTERNAL PRESS. 150psi @ 100°F 150psi @ 100

EXTERNAL PRESS. — 150 psi @ 100

MIN. DESIGN METAL TEMP. -452°F AT 150 psi -452°F

MANUFACTURER'S SERIAL No. U96001

YEAR BUILT 1996

SEE NEXT PAGE

3. System Venting Verification Provide the system schematic in the Appendix.

Is it possible to isolate the relief valves by a valve from the vessel?

Yes ☐ No ☒

If "Yes", the system must conform to code rules. Provide an explanation on the appended schematic. (An isolatable vessel, not conforming to code rule is non-compliant under this chapter.)

Is the relief cracking pressure set at or below the M.A.W.P.?

Yes ☒ No ☐ Actual setting 126 PSIG = 140.8 PSIA
(A "No" response violates this chapter.)

Is the pressure drop of the relief system at maximum anticipated flow such that vessel pressure never rises above the following? (UG 125)

Yes ☒ No ☐
110% of MAWP (one relief)
116% of MAWP (multiple reliefs)
121% of MAWP (unexpected heat source)

Provide test or calculational proof in the Appendix.

(Non-conforming pressure rises is non-compliant under this Chapter.)

List of reliefs and settings:

<u>Manufacturer</u>	<u>Model #</u>	<u>Set Pressure</u>	<u>Flow Rate</u>	<u>Size</u>
ANDERSON GREENWOOD	BISF68-4	100 PSIG	91 scfm AIR	3/4"
FIKE RUPTURE DISC	CPV	126 PSIG	1261 scfm AIR	1"

Does the primary relief device follow UG-129? Yes ☒ No ☐
(A "No" response is non-compliant under this chapter)

4. Operating Procedure

Is an operating procedure necessary for the safe operation of this vessel?

Yes ☐ No ☒ (If "Yes", it must be appended)

5. Welding Information

Has the vessel been fabricated in a non-code shop? Yes ☐ No ☒

If "Yes", append a copy of the welding shop statement of welder qualification (Procedure Qualification Record, PQR) which references the Welding Procedure Specification (WPS) used to weld this vessel.

6. Exceptional, Existing, Used and Unmanned Area Vessels

Is this vessel or any part thereof in the above categories?

Yes _____ No X

If "Yes", follow the Engineering Note requirements for documentation and append to Note.

LHe Reservoir Relief Summary**Cases** (See Appendix C)**Capacity Requirement**

1.) Loss of vacuum	84 scfm Air
2.) Loss of vacuumw/ air condensation	29 scfm Air
3.) Fire.	271 scfm Air
4.) Operator error	282 scfm Air

Relief Capacities (See Appendix B)

1" Fike Rupture disc. Burst Press. = 126 psig	1261 scfm Air
AGCO relief valve, Set Press.= 100 psig	91scfm Air

Inlet Pressure Drop Calcs. (See Appendix D)

At maximum flow, the pressure drop of inlet piping = 2.1 psi

TABLE OF CONTENTS FOR APPENDICES

Appendix A: Form U-1, Manufacturer's Data report for ASME coded vessel

Appendix B: Rupture Disc relief capacity calculation
Purchase requisition for rupture disc
Relief valve certificate of conformance and test report

Appendix C: Required relief capacity calculations

Appendix D: Relief inlet piping pressure drop calculation

Appendix E: Operator error relief case, raw calculations

FORM U-1 MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by Toshiba Corporation Keihin Product Operations 2-4 Suehiro-cho, Tsurumi-ku, Yokohama, Japan 230
(Name and address of Manufacturer)

2. Manufactured for Toshiba International Corporation 280 Utah Avenue South San Francisco, CA 94080 U.S.A
(Name and address of Purchaser)

3. Location of installation Fermi National Accelerator Laboratory D0 Department Batavia, IL 60510 U.S.A
(Name and address)

4. Type: Vert. Vessel U96001
(Horiz., vert., or sphere) (Tank, separator, jkt. vessel, heat exch., etc.) (Mfg's serial No.)

N/A 2KN002346 Rev.E 5 1996
(CRN) (Drawing No.) (Mat'l. Bd. No.) (Year built)

5. ASME Code, Section VIII, Div. 1 1992 Edition, 1994 Addenda N/A N/A
Edition and Addenda (date) Code Case No. Special Service per UG-120(d)

Items 6-11 incl. to be completed for single wall vessels, jackets of jacketed vessels, shell of heat exchangers, or chamber of multi-chamber vessels.

6. Shell (a) No. of course(s): 1 (b) Overall length (ft & in.): 17.95 in

Course(s)			Material		Thickness		Long. Joint (Cat. A)			Circum. Joint (Cat. A, B, & C)			Heat Treatment	
No.	Diameter, in.	Length (ft & in.)	Spec./Grade or Type		Nom.	Corr.	Type	Full. Spot. None	Eff.	Type	Full. Spot. None	Eff.	Temp.	Time
1	OD 12.75	17.95 in	SA-312 TP304L		0.180	0	Seamless	N/A	1.0	UW-13.2 (d)	N/A	N/A	N/A	N/A

7. Heads: (a) SA-240 304L H.T -- None (b) SA-240 304L H.T -- None
(Mat'l Spec. No., Grade or Type) H.T. -- Time & Temp. (Mat'l Spec. No., Grade or Type) H.T. -- Time & Temp.

	Location (Top, Bottom, Ends)	Thickness (in)		Radius		Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure		Category A		
		Min.	Corr.	Crown	Knuckle					Convex	Concave	Type	Full. Spot. None	Eff.
(a)	Top	0.924	0	N/A	N/A	N/A	N/A	N/A	OD 12.75	N/A	N/A	N/A	N/A	N/A
(b)	Bottom	0.924	0	N/A	N/A	N/A	N/A	N/A	OD 12.75	N/A	N/A	N/A	N/A	N/A

removable, bolts used (describe other fastening) None
(Mat'l Spec. No., Grade, size, No.)

8. Type of jacket N/A Jacket closure N/A
(Describe as ogee & weld, bar, etc.)

If bar, give dimensions N/A If bolted, describe or sketch.

9. MAWP 150 N/A psi at max. temp. 100 N/A °F Min. design metal temp. -452 °F at 150 psi.
(internal) (external) (internal) (external)

10. Impact test Yes, Shell, Flat Heads and Nozzle Necks.
(Indicate yes or no and the component(s) impact tested)

11. Hydro., ~~proof~~ test press. 225 psi Proof test N/A

Items 12 and 13 to be completed for tube sections.

12. Tubesheet: N/A N/A N/A N/A N/A
Stationary (Mat'l Spec. No.) Dia., in. (subject to press.) Noml. thk., in. Corr. Allow., in. Attachment (welded or bolted)

N/A N/A N/A N/A N/A
Floating (Mat'l Spec. No.) Dia., in. Noml. thk., in. Corr. Allow., in. Attachment

13. Tubes: SA-213 TP304L 0.681 0.0472 in 1 Coil
Mat'l Spec. No., Grade or Type O.D., in. Noml. thk., in. or gauge Number Type (Straight or U)

Items 14-18 incl. to be completed for inner chambers of jacketed vessels or channels of heat exchangers. -- N/A --

14. Shell (a) No. of course(s) (b) Overall length (ft & in.):

Course(s)			Material		Thickness		Long. Joint (Cat. A)			Circum. Joint (Cat. A, B, & C)			Heat Treatment	
No.	Diameter, in.	Length (ft & in.)	Spec./Grade or Type		Nom.	Corr.	Type	Full. Spot. None	Eff.	Type	Full. Spot. None	Eff.	Temp.	Time

15. Heads: (a) (b)
(Mat'l Spec. No., Grade or Type) H.T. -- Time & Temp. (Mat'l Spec. No., Grade or Type) H.T. -- Time & Temp.

	Location (Top, Bottom, Ends)	Thickness		Radius		Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure		Category A		
		Min.	Corr.	Crown	Knuckle					Convex	Concave	Type	Full. Spot. None	Eff.
(a)														
(b)														

If removable, bolts used (describe other fastening)
(Mat'l Spec. No., Grade, size, No.)

APPENDIX A

FORM U-1 (Back)

A2

6. MAWP (internal) (external) psi at max. temp. (internal) (external) °F. Min. design metal temp. °F at psi.

7. Impact test

(Indicate yes or no and the component(s) impact tested)

18. Hydro., pneu., or comb. test press.

Proof test

19. Nozzles, inspection, and safety valve openings:

Purpose (Inlet, Outlet, Drain, etc.)	No.	Diameter (in) or Size	Flange Type	Material		Nozzle Thickness (in)		Reinforcement Material	How Attached		Location (Insp. Open.)
				Nozzle	Flange	Nom.	Corr.		Nozzle	Flange	
Current 1 (U)	2	2	W.E	SA-479 304L	N/A	0.266	0	Inherent	Welded	N/A	N/A
Relief & Inst.	2	1	Do.	Do.	N/A	0.207	0	Do.	Do.	N/A	N/A
Current 1 (B)	2	1	Do.	Do.	N/A	0.207	0	Do.	Do.	N/A	N/A
Isola. Valve	1	1/2	Do.	Do.	N/A	0.153	0	Do.	Do.	N/A	N/A
JT Valve	1	3/4	Do.	Do.	N/A	0.122	0	Do.	Do.	N/A	N/A
LHe. Return	1	1/2	Do.	Do.	N/A	0.153	0	Do.	Do.	N/A	N/A
LHe. Supply	1	3/4	Do.	Do.	N/A	0.122	0	Do.	Do.	N/A	N/A

20. Supports: Skirt No (Yes or no) Lugs No (No.) Legs No (No.) Others Supported by piping Attached N/A (Where and how)

21. Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report:
(List the name of part, item number, mfg's. name and identifying number)

None

22. Remarks:

1. None corrosion service.
2. Hydrostatic test was conducted by the vertical position.
3. Tube was not impact tested in accordance with UHA-51(d).
4. Tube MAWP: Int'l and Ext'l 150psi at max temp' 100°F, MDMT: -452°F at 150psi.

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1.

U Certificate of Authorization No. 14,502 Expires March 14, 19 99

Date April 18 1996 Name Toshiba Corporation Keihin Product Operations Signed H. YOSHIOKA (Representative)

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of IL and employed by H.S.B.I & I. Co. of CONN have inspected the pressure vessel described in this Manufacturer's Data Report on April 18, 19 96, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 4/18/96 Signed H. KAWABATA (Authorized Inspector) Commissions NB# 10145 (A)(N)(S) (Nat'l Board incl. endorsement, State, Province and No.)

CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE

We certify that the statements on this report are correct and that the field assembly construction of all parts of this vessel conforms with the requirements of ASME Code, Section VIII, Division 1.

U Certificate of Authorization No. Expires , 19

Date Name Signed (Assembler) (Representative)

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of and employed by have compared the statements in this Manufacturer's Data Report with the described pressure vessel and state that parts referred to as data items , not included in the certificate of shop inspection, have been inspected by me and to the best of my knowledge and belief, the Manufacturer has constructed and assembled this pressure vessel in accordance with ASME Code, Section VIII, Division 1. The described vessel was inspected and subjected to a hydrostatic test of psi. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date Signed (Authorized Inspector) Commissions (Nat'l Board incl. endorsement, State, Province and No.)

SUBJECT

APPENDIX B
RUPTURE DISC RELIEF CAPACITY

NAME

RUSS RUCINSKI

DATE

7-22-98

REVISION DATE

MATH CHK'D BY J. J. Jode 7/29/98

THE INSTALLED RUPTURE DISC IS A 1" FIKE RUPTURE DISC
TYPE CPV-BT, SIZE = 1". IT'S BURST PRESSURE
IS 126.13 PSIG.

FLOW WILL BE SONIC.

$$P_e/P_0 = \frac{14.7 \text{ PSIA}}{126.13 + 14.7 \text{ PSIA}} \quad 0.1044 < \left[\frac{2}{k+1} \right]^{\frac{k}{k-1}} = \left[\frac{2}{2.666} \right]^{\frac{1.66}{.66}} = .49$$

(REFERENCE: FIKE RUPTURE DISC SIZING BULLETIN)

$$a = \frac{Q_{sa}}{11.4 P_0} \sqrt{\frac{t+460}{520}} \sqrt{\frac{29}{M}} \text{ IN}^2 \quad \text{EQN. 11}$$

WHERE

Q_{sa} = THE FLOW RATE SCFM AIR

t = TEMP OF FLOWING MEDIA

M = MOLEC. WT

SINCE I DESIRE TO KNOW THE CAPACITY IN UNITS OF

SCFM AIR; $t = 60^\circ\text{F}$, $M = 29$ & $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (1 \text{ IN})^2 = .7854 \text{ IN}^2$

REARRANGING EQN 11:

$$Q_{sa} = (a) 11.4 P_0 \sqrt{\frac{520}{t+460}} \sqrt{\frac{M}{29}}$$

$$Q_{sa} = (.7854 \text{ IN}^2) (11.4) (126.13 + 14.7 \text{ PSIA})$$

$$Q_{sa} = 1261 \text{ SCFM AIR}$$

AT THE BURST
PRESSURE OF
126.13 PSIG

NOTE: THIS IS LESS THAN
MAWP

D0 Purchase Requisition

Requestor Information:

Name: Rucinski, Russell A
ID No.: 8351
E-mail: rucinski@fnal.gov
Phone: 2888

Vendor Information:

Name: Fike Metal Products Div.
Phone: 847-640-1180
Fax: 847-640-1372
Street 1: 415 East Golf Rd
Street 2: Suite 114
Attn: Keith Drager
City State, Zip Arlington Heights IL 60005
Buyers Note:

Requisition Information:

Requestor ID: D0988678
Entry Date: 02/19/1998
Previous PO: 507503-0
Project Description :
Short Description of intended use: SOLENOID CONTROL DEWAR
Status : PENDING
Urgency : No Rush
Desired Delivery Date: 03/05/1998

Line Items:

Qty	Type	Description	Unit Price	Total	WBS	% of Cost Est.	Budget Code
4	Good	FIKE RUPTURE DISC, TYPE CPV WITH VACUUM SUPPORT, 1" SIZE,	105.00	420.00	3.1.1.3.6.3	0.00	EEG
0	Good	MAXIMUM STAMPED BURST PRESSURE = 135 PSIG AT 72 DEGREES F.	0.00	0.00		0.00	
0	Good	MINIMUM STAMPED BURST PRESSURE = 120 PSIG* AT 72 DEGREES F.	0.00	0.00		0.00	
0	Good	NICKEL DISC MATERIAL WITH URETHANE SEALS. INCLUDE CERTIFICATION SHEET	0.00	0.00		0.00	
0	Good	FOR CONFORMANCE TO ASME VIII DIV. 1 SPECIFICATION. FOR G1 HOLDER	0.00	0.00		0.00	
0	Good	DISC TO BE PRIMARY RELIEF ON ASME PRESSURE VESSEL WITH MAWP = 135 PSIG.	0.00	0.00		0.00	
0	Good	NORMAL VESSEL OPERATING PRESSURE WILL BE LESS THAN 60 PSIG.	0.00	0.00		0.00	

*CHANGED TO 115 PSIG IN PURCHASING

3950 Greenbriar, Stafford, Texas 77477

KEYSTONE

Anderson, Greenwood & Co.

December 27, 1995

ANDERSON, GREENWOOD & CO.
S/O: S169030000.001

UNIT PROCESS COMPANY
P/O: F07844/724230

CERTIFICATE OF CONFORMANCE

I hereby certify that the one (1) 81SF68-4 *for Reservoir* Spring Operated Safety Relief Valve, Serial Number: 95-50635, furnished on the above referenced purchase order was manufactured to Quality Control Standards and meets the requirements of the purchase order for which it is supplied.

ANDERSON, GREENWOOD & CO.

Kelly Migl

Kelly Migl
QA Data Specialist

JOB NO. M221136 KE 0020
DWG NO. 3KN114724P001
O/# KWH363100

CUSTOMER: Unit Process Company CUST. P.O. #: E07844/724230 CUST. WITHTEL: DATE WITHTEL:				ANDERSON, GREENWOOD & CO. FUNCTIONAL TEST REPORT DIRECT SPRING LOADED VALVES (1)				AGO 8/05: 516203000.001 DATE: 12-23-95 VALVE TYPE: B/SF68-4 GAUGE NO.: 206-7			
--	--	--	--	---	--	--	--	---	--	--	--

SERIAL NO.	TAG NO.	INLET HYDRO (3)	ASSY (4)	ASME 90# HP (5)	NAMEPLATE SET PRESSURE (5)	CRACKING PRESSURE (5) 95	ACTUAL SET PRESSURE (5) 102	SPECIFIED RESEAT (5)	ACTUAL RESEAT (4) (5)	LEAK RATE (2)	TEST (6)
1) 95-50035		N/A	6	N/A	100	95	102	93	95	0	8
2)											
3)											
4)											
5)											
6)											
7)											

TRACEABILITY REQUIREMENTS - HEAT/CODE NUMBERS FOR TRACEABLE COMPONENTS										
	BODY	BASE	BONNET	INL. FLG.	OUT. FLG.	NOZZLE	STUB ENDS		X-RAY NO.	X-RAY NO.
1)	ECC									
2)										
3)										
4)										
5)										
6)										
7)										

(1) REFER TO FUNCTIONAL TEST DOCUMENT FOR PROCEDURE AND TOLERANCES. (2) BUBBLES PER MINUTE. (3) ASME, CUSTOMER (CUST) OR N/A. (4) WHERE TEST DRUM SIZE IS NOT ADEQUATE TO READ TRUE BLOWDOWN, ENTER N/A. (5) PRESSURE IS (PSIG) UNLESS OTHERWISE SPECIFIED. (6) TECHNICIAN PERFORMING THESE OPERATIONS WILL INITIAL TO INDICATE COMPLETION.	TEST MEDIUM AIR ☒ H2O ☐ STEAM ☐	DEC 26 1995 INSPECTOR #18 VERIFIED BY / DATE
--	--	--

B6

TEST DOCUMENTATION CODE STAMPED RELIEF VALVES

This form should be used for relief valves returned from a vendor to check the accuracy and quality of the vendor's work. It should also be used to check code stamped valves for the 6 year test. Valves that pass this test can be put in service if the original seal from a vendor is still in place and not broken.

All valves should be bubble tight at 90% of set pressure while increasing pressure, lift within the code requirement, and reset bubble tight. Reset pressure as a percent of set pressure would vary, depending on the blowdown setting.

The valve should be connected to the appropriate test chamber with adapters as required being careful not to choke the valve with fittings smaller than the valve inlet.

Date - August 19, 1998

Vessel number (from silver sticker) - PPD - 10051

Physical location and valve number - DØ - SV-3216-H

Manufacturer - Anderson Greenwood

Model number - 81 SF 68-4

Serial number - 95/50635

Valve size - 3/4

Seal intact - yes

Set pressure - 100 psig

Bubble tight at 90% set pressure - yes

Valve lift within +/- 2 psig for settings 70 psig and below or within 3% for higher settings? Tolerances defined by UG- 134(d) (1)

Test 1 - 101.5 psig Test 2 - 99.0 psig Test 3 - 98.5 psig

Bubble tight at reset - yes

If valve passed test attach a brass tag to valve with "TEST ONLY", date, and tester's initials.

Signed John H. Somolezny
Date 8-19-98

Appendix C: Required Relief Capacity for Liquid Helium reservoir

PURPOSE

To determine the required relief capacity of the for the failure conditions of loss of vacuum, fire, and operator errors per CGA S-1.3, 1995 [1].

CASES

1. Loss of vacuum
2. Loss of vacuum with air condensation
3. Fire
4. Operator error: Warm Ghe flowing thru and into a full subcooler
5. Operator error: Liquid helium put into a warm vessel

DEWAR PARAMETERS

Vessel Capacity	9 gal (1.2 ft ³)
Vessel outside dimensions	Cylindrical: 1.063 ft. dia x 1.640 ft high
Vacuum shell inside dims.	Cylindrical: 2.756 ft. dia. x 5.217 ft high
Inner Vessel MAWP	150 psia
Normal Operating Pressure	19.1 psia

FLOW RATING PRESSURES

Paragraph 4.3.3 of CGA S-1.3 states that the flow rating pressure under loss of insulating vacuum shall be 110% of the inner vessel MAWP, and for fire condition shall be 121% of the inner vessel MAWP.

$$\text{Loss of Vacuum: } P_{f.r.} = (1.10)(150 \text{ psia}) = 165.0 \text{ psia}$$

$$\text{Fire Condition: } P_{f.r.} = (1.21)(150 \text{ psia}) = 181.5 \text{ psia}$$

CALCULATIONS

Loss of insulating vacuum

The minimum required capacity of the primary relief device in scfm of air is given in paragraph 5.2.2 of CGA S-1.3 as:

$$Q_a = \frac{(590 - T)}{4(1660 - T)} FG_i UA \quad (\text{eqn. A-1})$$

where, T = temperature per CGA par. 5.1.3, degrees Rankine
F = correction factor
G_i = gas factor for insulated containers
U = Overall heat transfer coefficient, Btu/hr-ft²-°F
A = mean surface area of insulation, square feet

Per paragraph 5.1.3, the temperature to use in equation A-1 is the temperature at which the function $\sqrt{v} \left[\frac{\partial h}{\partial v} \right]_p$ is a maximum. Data for this function can be obtained by using HePak

computerized helium tables. At 165 psia, this function is a maximum value at 9.46 K (17.03 °R). Per Note 3 of Table 1 in CGA S-1.3, the gas factor, G_i, for super critical helium is to be determined as in Appendix 6A of *Technology of Liquid Helium* [2].

$$G_i = \frac{0.097(1200 - t)}{L'} \sqrt{ZT} \quad (\text{eqn. A-2})$$

where, t = -443.0°F (9.46 K)
L' = 19.265 Btu/lb efflux (From HePak)
T = 17.03 °R (9.46 K)
Z = 0.749 compressibility factor (From HePak)

Substituting into eqn. A-2:

$$G_i = \frac{0.097(1200 + 443.0)}{19.265} \sqrt{(0.749)(17.03)} = 29.55$$

The overall heat transfer coefficient, U, is that of the insulating material of the container when saturated with gaseous helium or air at atmospheric pressure and 100 °F, whichever is greater. From Table A-4 in *Fundamentals of Heat and Mass Transfer* [5], k_{He} = 0.14654 W/m-K (0.0847 Btu/hr-ft-°F).

Math Checked
S. McDade
8/17/98

A simplified approach to calculating U is by taking credit for the 1" of superinsulation that surrounds the vessel:

$$U = \frac{k_{He}}{t_{insulation}} = \frac{0.0847 \text{ Btu/hr} \cdot \text{ft} \cdot ^\circ\text{F}}{1/12 \text{ ft}} = 1.016 \text{ Btu/hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}$$

The surface areas of the vessel and vacuum shell are given by:

$$A_{cylinder} = 2 \left[\frac{\pi(d^2)}{4} \right] + \pi dL$$

$$A_{vessel} = 7.25 \text{ ft}^2$$

$$A_{shell} = 57.10 \text{ ft}^2$$

$$A = A_{mean} = (A_{vessel} + A_{shell})/2 = 32.2 \text{ ft}^2$$

Finally, F = 1.0 since the uninsulated portion of the upstream piping is less than 2 feet long. Substituting into eqn. A-1:

$$Q_a \Big|_{\text{loss of vacuum}} = \frac{(590 - 17.0)}{4(1660 - 17.0)} (1.0)(29.55)(1.016)(32.2) = 84.3 \text{ scfm air}$$

Loss of vacuum, air conduction with condensation

Depending upon the insulation thickness, the heat load on the inner vessel due to air conduction with condensation on the insulation could be greater than the heat load under fire conditions. This is assuming a rupture in the vacuum vessel.

$$q_{total} [\text{Btu/hr}] = q_{conduction} + q_{condensation} \quad (\text{eqn. A-3})$$

$$q_{conduction} = UA(100 - t)$$

A simplified approach to calculating U is by taking credit for the 1" of superinsulation that surrounds the vessel:

$$U = \frac{k_{air}}{t_{insulation}} = \frac{0.0157 \text{ Btu/hr} \cdot \text{ft} \cdot ^\circ\text{F}}{1/12 \text{ ft}} = 0.1884 \text{ Btu/hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}$$

$$q_{conduction} = (0.1884)(32.2)(100 + 443.0) = 3294 \text{ Btu/hr}$$

From Figure C-2 with $A_{vessel} = 7.3 \text{ ft}^2$ and assuming worst case 1" super insulation, the heat flux due to air condensation is $q_{condensation} = 3,200 \text{ Btu/hr}$. Substituting into eqn. A-3:

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$$q_{\text{total}} = 3294 \text{ Btu/hr} + 3200 \text{ Btu/hr} = 6494 \text{ Btu/hr}$$

The following equation for the minimum required relief capacity in scfm of air is presented in Appendix 6A in *Technology of Liquid Helium*.

$$Q_a = \frac{18.3 \cdot q_{\text{total}}}{378 \cdot L} \sqrt{\frac{ZT}{4.00}}$$

$$Q_a \left| \begin{array}{l} \text{air conduction} \\ + \text{condensation} \end{array} \right| = \frac{(18.3)(6494)}{(378)(19.3)} \sqrt{\frac{(0.749)(17.03)}{4.00}} = 29.1 \text{ scfm air}$$

Fire condition

The minimum required capacity of the primary and secondary relief devices in scfm of air is given in paragraph 5.3.3 of CGA S-1.3 as:

$$Q_a = FG_i UA^{0.82} \quad (\text{eqn. A-4})$$

where,
 F = correction factor
 G_i = gas factor for insulated containers
 U = Overall heat transfer coefficient, Btu/hr-ft²-K
 A = mean surface area of insulation, square feet

The temperature at which to evaluate this equation is per par 5.1.3, where the function

$\frac{\sqrt{v}}{v \left[\frac{\partial h}{\partial v} \right]_p}$ is a maximum. This function can be obtained by using data from HePak

computerized helium tables. At 181.5 psia, this function is a maximum value at 9.86 K (17.75°R). Per Note 3 of Table 1 in CGA S-1.3, the gas factor for super critical helium is to be determined as in Appendix 6A of *Technology of Liquid Helium*.

$$G_i = \frac{0.097(1200 - t)}{L'} \sqrt{ZT} \quad (\text{eqn. A-5})$$

where,
 t = -442.3 °F (9.86 K)
 L' = 20.11 Btu/lb efflux (from HePak)
 T = 17.75 R (9.86 K)
 Z = 0.776 compressibility factor (from HePak)

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 8/17/00

Substituting into eqn. A-5:

$$G_i = \frac{0.097(1200 + 442.3)}{20.11} \sqrt{(0.776)(17.75)} = 29.40$$

The overall heat transfer coefficient, U, is that of the insulating material of the container when saturated with gaseous helium or air at atmospheric pressure and the mean temperature, whichever is greater. Helium has a greater thermal conductivity. Detailed evaluation of U has been done using traditional heat transfer analysis techniques for conduction, convection, and radiation. From Appendix G;

$$U = 1.783 \text{ Btu/hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}$$

Finally, F = 1.0 since the uninsulated portion of the upstream piping is less than 2 feet long. Substituting into eqn. A-4:

$$Q_a|_{fire} = (1.0)(29.40)(1.783)(32.2)^{0.82} = 903.5 \text{ scfm air}$$

Credit can be taken for recognizing the impossibility of a fire engulfing the vessel. In our case the vessel is supported 30 feet in the air on open grating. No flammable material is near the vessel. CGA paragraph 5.3, case c notes this case and allows reducing the required fire flow capacity to 30% of that calculated in 5.3.2. Therefore;

$$Q_a|_{fire} = 0.30 \times (903.5 \text{ scfm air}) = 271 \text{ scfm air}$$

Operator error: Warm Ghe directed thru and into full subcooler

The solenoid's helium system is provided with a gas helium cool down/warm up supply line in parallel with the liquid helium supply line from the Lhe refrigerator. This feature allows the gradual cool down and warm up of the system before and after steady state operations. The source of the gas helium comes directly from compressor discharge at 285 psig.

The worst case scenario hypothesizes that an operator decides to warm up a cold solenoid system at the maximum possible rate. The chosen method to accomplish the task is to force gas helium through the cool down/warm up supply line into the solenoid system. The supplied fluid boils off the liquid in the reservoir at a certain rate as it passes through the subcooling coils in the reservoir. The heat input rate is calculated and then converted to a required relief capacity. The supplied fluid passes through the solenoid and enters the reservoir vessel and also has to pass out the relief.

The detailed calculations for this case are included in appendix E. I will summarize them below. Two cases were examined. The first case considers the cool down heat exchanger to be full of LN2 in which case it cools the helium to 90 K. The second case considers the cool down heat exchanger to be empty in which case the helium is supplied at 290 K.

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The total required relief capacity is the sum of two components:

$$Q_{\text{total}} [\text{scfm air}] = Q_{\text{heat input}} + Q_{\text{incoming he}}$$

where:

$$Q_{\text{heat input}} = \frac{18.3 \cdot q_{\text{total}}}{378 \cdot L} \sqrt{\frac{ZT}{4.00}} \quad (\text{Relief requirement from boiling away reservoir, scfm air})$$

$Q_{\text{incoming he}}$ is the relief requirement to account for the added gas coming into the reservoir.

Both components, Q , are dependent on the flow rate of the warm-up gas from the cool down heat exchanger. The physical delivery line has been built and the flow resistance was calculated. The flow rate was then determined using the flow resistance, pressure drop equations, and the inlet conditions of Case 1 and Case 2. In case 1, 13 g/s of 90 K helium gas can be supplied through the pipes to the solenoid. In case 2, 12.1 g/s of 290 K helium gas can be supplied. The rates are somewhat close because the major restriction in the flow path is a valve up stream of the cool down heat exchanger.

The rate of heat transfer to boil away L_{he} in the reservoir is limited by the heat capacity of the incoming gas. The gas can only be cooled to the temperature of the liquid helium in the reservoir. In case 1, the 90 K gas at 13 g/s transfers 5.7 kW to the reservoir bath as it is cooled down to 9.46 K. In case 2, 17.9 kW is transferred to cool the 290 K to the bath temperature.

The mass flow rate of the incoming gas (now at 9.46 K) passes through the solenoid and is injected into the reservoir to be relieved along with the boiled off gas. This incoming gas mass flow rate is converted to an equivalent scfm by equation 6A-1 of *Technology of Liquid Helium*.

$$Q_a = \frac{13.1 \cdot W \cdot C_a}{60 \cdot C} \sqrt{\frac{Z \cdot T \cdot M_a}{M \cdot Z_a \cdot T_a}}$$

where,

W = Flow rate of the gas (lbm/hr)

C_a = Gas constant = 356 for air

C = Gas constant for helium = 377

Z_a = Compressibility factor for air, std conditions = 1.0

Z = Compressibility factor, 0.749 from HePak properties program

M_a = Molecular weight of air = 28.97

M = Molecular weight of helium = 4.0

T_a = Temperature of air at std. Conditions = 520 Rankine

T = Temperature of helium = 17.0 Rankine

The components for case 1 (cold 90 K gas supplied) were,

$$Q_{\text{total}} [\text{scfm air}] = Q_{\text{heat input}} + Q_{\text{incoming he}} = 86.8 \text{ scfm} + 8.9 \text{ scfm} = 95.7 \text{ scfm air}$$

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The components for case 2 (warm 290 K gas supplied) were,

$$Q_{\text{total}} [\text{scfm air}] = Q_{\text{heat input}} + Q_{\text{incoming he}} = 273.5 \text{ scfm} + 8.3 \text{ scfm} = 281.8 \text{ scfm air}$$

Case 2 has the larger relieving requirement and is reported as the relief capacity requirement for the case of operator error.

SUMMARY

Hazard Condition	Required Capacity, Q_a
loss of insulating vacuum	84 scfm air
air conduction + condensation	29 scfm air
fire	271 scfm air
operator error, warm Ghe supplied	282 scfm air

REFERENCES

1. CGA S-1.3, *Pressure Relief Device Standards-Part 3-Stationary Storage Containers for Compressed Gases*, Compressed Gas Association, Inc., Arlington, VA, 1995
2. NBS Monograph 111, *Technology of Liquid Helium*, U.S. Government Printing Office, Washington, D.C., 1968
3. NIST Tech. Note 1334, *Thermophysical Properties of Helium-4 from 0.8 to 1500 K with Pressures to 2000 MPa*, U.S. Government Printing Office, Washington, D.C., 1989
4. J. Howell, R. Buckius, *Fundamentals of Engineering Thermodynamics*, McGraw-Hill, Inc., New York, 1992
5. F. Incropera, D. DeWitt, *Fundamentals of Heat and Mass Transfer*, John Wiley and Sons, New York, 1990

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PRESSURE [bar]	TEMP [K]	VOLUME [m3/Kg]	ENTHALPY [J/Kg]	DHDV*V [J/Kg]	SQRT(V)/DHDV*V
11.224	5.00	6.86E-03	17053	53061	1.56102E-06
11.224	5.20	6.96E-03	17788	51871	1.60806E-06
11.224	5.40	7.06E-03	18558	50739	1.65632E-06
11.224	5.60	7.18E-03	19366	49653	1.70622E-06
11.224	5.80	7.30E-03	20214	48603	1.75819E-06
11.224	6.00	7.44E-03	21105	47580	1.81272E-06
11.224	6.20	7.59E-03	22043	46579	1.87022E-06
11.224	6.40	7.75E-03	23032	45599	1.93101E-06
11.224	6.60	7.93E-03	24074	44643	1.99528E-06
11.224	6.80	8.13E-03	25174	43720	2.06293E-06
11.224	7.00	8.36E-03	26336	42845	2.13352E-06
11.224	7.20	8.60E-03	27562	42036	2.20623E-06
11.224	7.40	8.87E-03	28854	41318	2.27964E-06
11.224	7.60	9.17E-03	30212	40719	2.35181E-06
11.224	7.80	9.50E-03	31633	40265	2.42045E-06
11.224	8.00	9.85E-03	33111	39977	2.48321E-06
11.224	8.20	1.02E-02	34638	39867	2.53814E-06
11.224	8.40	1.06E-02	36202	39936	2.58398E-06
11.224	8.60	1.11E-02	37792	40176	2.62001E-06
11.224	8.80	1.15E-02	39399	40568	2.64686E-06
11.224	9.00	1.20E-02	41013	41093	2.66522E-06
11.224	9.20	1.25E-02	42627	41730	2.67621E-06
11.224	9.40	1.30E-02	44235	42461	2.68089E-06
11.224	9.60	1.35E-02	45834	43270	2.68024E-06
11.224	9.80	1.39E-02	47419	44143	2.67534E-06
11.224	10.00	1.44E-02	48990	45071	2.66681E-06
11.224	10.20	1.49E-02	50546	46045	2.65536E-06
11.224	10.40	1.55E-02	52085	47057	2.64152E-06
11.224	10.60	1.60E-02	53607	48103	2.62581E-06
11.224	10.80	1.65E-02	55112	49177	2.60848E-06
11.224	11.00	1.70E-02	56600	50276	2.58993E-06
11.224	11.20	1.75E-02	58072	51395	2.57048E-06
11.224	11.40	1.79E-02	59528	52533	2.55028E-06
11.224	11.60	1.84E-02	60968	53685	2.52966E-06
11.224	11.80	1.89E-02	62394	54850	2.50868E-06
11.224	12.00	1.94E-02	63805	56026	2.48747E-06
11.224	12.20	1.99E-02	65203	57211	2.46617E-06
11.224	12.40	2.04E-02	66587	58404	2.44493E-06
11.224	12.60	2.09E-02	67960	59602	2.42382E-06
11.224	12.80	2.13E-02	69320	60806	2.40282E-06
11.224	13.00	2.18E-02	70669	62013	2.38207E-06

Expanding on temperature range around 9.4 Kelvin...

PRESSURE [bar]	TEMP [K]	VOLUME [m3/Kg]	ENTHALPY [J/Kg]	DHDV*V [J/Kg]	SQRT(V)/DHDV*V
11.224	9.30	1.27E-02	43432	42085	2.67925E-06
11.224	9.32	1.28E-02	43593	42159	2.67959E-06
11.224	9.34	1.28E-02	43754	42233	2.68003E-06
11.224	9.36	1.29E-02	43914	42308	2.68039E-06
11.224	9.38	1.29E-02	44075	42384	2.68068E-06
11.224	9.40	1.30E-02	44235	42461	2.68089E-06
11.224	9.42	1.30E-02	44396	42539	2.68103E-06
11.224	9.44	1.31E-02	44556	42617	2.68116E-06
11.224	9.46	1.31E-02	44716	42696	2.68121E-06
11.224	9.48	1.32E-02	44876	42776	2.68120E-06
11.224	9.50	1.32E-02	45036	42857	2.68111E-06

PRESSURE [Pa]	TEMP [K]	VOLUME [m3/Kg]	ENTHALPY [J/Kg]	DHDV*V [J/Kg]	PV/RT [-]	SQRT(V)/DHDV*V
1.25E+06	9.00	1.09E-02	40010	43616	0.73212	2.39775E-06
1.25E+06	9.20	1.13E-02	41555	44036	0.74191	2.41717E-06
1.25E+06	9.40	1.17E-02	43108	44567	0.75203	2.43058E-06
1.25E+06	9.60	1.21E-02	44662	45196	0.76232	2.43867E-06
1.25E+06	9.80	1.26E-02	46215	45909	0.77266	2.44204E-06
1.25E+06	10.00	1.30E-02	47761	46692	0.78293	2.44153E-06
1.25E+06	10.20	1.34E-02	49300	47535	0.79306	2.43777E-06
1.25E+06	10.40	1.39E-02	50829	48431	0.803	2.43103E-06
1.25E+06	10.60	1.43E-02	52346	49370	0.81268	2.42209E-06
1.25E+06	10.80	1.47E-02	53852	50347	0.82208	2.41127E-06
1.25E+06	11.00	1.52E-02	55344	51357	0.83118	2.39880E-06
1.25E+06	11.20	1.56E-02	56824	52396	0.83996	2.38499E-06
1.25E+06	11.40	1.61E-02	58290	53459	0.84841	2.37012E-06
1.25E+06	11.60	1.65E-02	59743	54544	0.85652	2.35445E-06
1.25E+06	11.80	1.69E-02	61184	55647	0.86431	2.33816E-06
1.25E+06	12.00	1.74E-02	62611	56767	0.87177	2.32135E-06

Expanding on temperature range around 9.8 Kelvin...

PRESSURE [Pa]	TEMP [K]	VOLUME [m3/Kg]	ENTHALPY [J/Kg]	DHDV*V [J/Kg]	PV/RT [-]	SQRT(V)/DHDV*V
1.25E+06	9.70	1.24E-02	45439	45543	0.76749	2.44091E-06
1.25E+06	9.72	1.24E-02	45594	45615	0.76852	2.44120E-06
1.25E+06	9.74	1.24E-02	45749	45687	0.76956	2.44148E-06
1.25E+06	9.76	1.25E-02	45904	45760	0.77059	2.44169E-06
1.25E+06	9.78	1.25E-02	46060	45834	0.77162	2.44194E-06
1.25E+06	9.80	1.26E-02	46215	45909	0.77266	2.44204E-06
1.25E+06	9.82	1.26E-02	46370	45984	0.77369	2.44213E-06
1.25E+06	9.84	1.27E-02	46525	46060	0.77472	2.44225E-06
1.25E+06	9.86	1.27E-02	46679	46137	0.77575	2.44231E-06
1.25E+06	9.88	1.27E-02	46834	46214	0.77678	2.44227E-06
1.25E+06	9.90	1.28E-02	46989	46292	0.77781	2.44227E-06
1.25E+06	9.92	1.28E-02	47144	46371	0.77883	2.44221E-06
1.25E+06	9.94	1.29E-02	47298	46450	0.77986	2.44204E-06
1.25E+06	9.96	1.29E-02	47453	46530	0.78088	2.44191E-06
1.25E+06	9.98	1.30E-02	47607	46611	0.78191	2.44173E-06
1.25E+06	10.00	1.30E-02	47761	46692	0.78293	2.44153E-06

FIGURE 6A-2. Heat absorbed per pound efflux for a helium container relieving above the critical pressure.
Relief pressures of 40, 50, 88, 100, and 160 psia are indicated.

FIGURE C-1 : HEAT ABSORBED PER POUND EFFLUX,
FROM TECHNOLOGY OF LIQUID HELIUM

SAFE AND EFFICIENT USE OF LIQUID HELIUM

FIGURE 6.3. Estimated total heat flux versus area for air condensation and fire conditions in multilayer (SI) insulated liquid helium containers.

FIGURE C-2: HEAT FLUX vs. AREA, FROM
TECHNOLOGY OF LIQUID HELIUM

Table 3 Thermal conductivity for refrigerated (cryogenic fluids) at the mean temperature between saturation and 1200 °F (649 °C) at 14.7 psia (101.325 kPa abs.)		
FLUID	BTU/(hr.FT.°F)	kJ/(hr.m.°C)
Air (-130 °F to 1200 °F)	0.024573	0.153069
Argon	0.015812	0.098495
Carbon Dioxide	0.022819	0.142143
Carbon Monoxide	0.022342	0.139171
Helium	0.121838	0.758945
Hydrogen	0.1254	0.781133
Methane	0.043032	0.268052
Neon	0.03882	0.241815
Nitrogen	0.023236	0.14474
Oxygen	0.025041	0.155984

TABLE C-1 : THERMAL CONDUCTIVITY of He
FROM CGA STANDARDS

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ENGINEERING NOTE

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PPD/ETT

D7

PROJECT

SOLENOID

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SUBJECT

APPENDIX D

RELIEF INLET PIPING: PRESSURE
DROP CALC.

NAME

RUSS RUCINSKI

DATE

7-22-98

REVISION DATE

MATH CHK'D J7McDade 7/29/98

THIS CALCULATION WILL ENSURE THAT THE INLET
PIPING PRESSURE DROP AT MAXIMUM RELIEF
CAPACITY IS NOT SIGNIFICANT. THE PRESSURE
DROP MUST BE SUCH THAT THE VESSEL
PRESSURE DOES NOT EXCEED 110% MAX/P

$$P_{\text{BURST PRESSURE}} + \Delta P_{\text{INLET PIPING}} \leq 110\% (150 \text{ PSIA})$$

$$\Delta P_{\text{INLET PIPING}} \leq 165 \text{ PSI} - (126.13 \text{ PSIG} + 14.7)$$

$$\Delta P_{\text{INLET PIPING}} \leq 24.17 \text{ PSI TO MEET SAFETY CODES}$$

MAXIMUM FLOW RATE TO BE ENCOUNTERED IS;

$$Q_{\text{MAX}} = 282 \text{ scfm air (OPERATOR ERROR CASE, APPENDIX C)}$$

CONVERTING THIS TO AN EQUIVALENT FLOW RATE OF HELIUM @

$$165 \text{ PSIA AND } 9.46 \text{ K (17.03}^\circ\text{R)}^*$$

THIS IS THE TEMPERATURE AT WHICH

$$\sqrt{\frac{V}{\left[\frac{\partial h}{\partial V}\right]_P}} \text{ IS MAXIMUM.}$$

$$Q_a = \frac{13.1 W C_a}{60 C} \left(\frac{Z T M_a}{M Z_a T_a} \right)^{1/2}$$

EQN 6A "TECHNOLOGY OF LIQUID
HELIUM" NBS
MONOGRAPH 111.

SOLVING FOR W;

$$W = \frac{Q_a 60 C}{13.1 C_a} \left(\frac{M Z_a T_a}{Z T M_a} \right)^{1/2}$$

*REF. PAGE C2 FOR Z, T

$$W = \frac{(282 \text{ scfm air}) 60 (378)}{13.1 (356)} \left[\frac{4.0 (1.0) (520^\circ\text{R})}{.749 (17.03^\circ\text{R}) 28.97} \right]^{1/2}$$

$$W = 3,254 \text{ lbm/hr HELIUM @ 165 PSIA @ 17}^\circ\text{R}$$

FERMILAB
ENGINEERING NOTE

SECTION
FPD/ETT
DO

PROJECT
SOLENOID

SERIAL-CATEGORY
3823.111

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D2

SUBJECT

RELIEF INLET PIPING PRESSURE DROP CALC.

NAME

RUSS RUCINSKI

DATE

7-23-98

REVISION DATE

MATH CHK'D JMcDade 7/24/98

THE INLET PIPING CONSISTS OF; (REF. 1 KNO02370 SH7.2 & 3)
 $\approx 34''$ STRAIGHT LENGTH OF 34mm OD $\times$ 1.65 WALL PIPE (1.209" ID)
 1 $\sim 90^\circ$ ELBOW WITH $\frac{1}{4}$ RAD. ≈ 2.81 INCHES.
 1 CHECK VALVE, DRG 3KN115434 & 4KN116760

THE ELBOW & CHECK VALVE NEED TO BE PUT IN TERMS OF AN EQUIVALENT LENGTH OF 1.209" ID PIPE.

REYNOLDS $\times$ FOR FLOW IN PIPE: {REF. CRANE TECHNICAL PAPER# 410

$$Re = 6.31 \frac{W}{d\mu} = 6.31 \frac{(3254 \text{ lbm/hr})}{1.209" (.00321 \text{ cp})} = 5.29 \times 10^6$$

FROM THE PAK;

$$P = 165.0 \text{ PSI}$$

$$T = 17.03^\circ \text{R}$$

$$\rho = 4.825 \text{ lb/ft}^3$$

$$P_r = 1.071$$

$$\text{VISCOSITY} = .216 \times 10^{-5} \text{ lbm/ft}^2 \cdot \text{s}$$

$$h = 19.16 \text{ BTU/lb}$$

$\epsilon = .00015$ FOR COMM'L PIPE (PG. A-23 OF CRANE)

$$D = 1.209'' / 12''/\text{ft}$$

FRICTION FACTOR

$$\epsilon/D = .00149$$

$$\Rightarrow F = .020$$

MOODY DIAGRAM
CRANE PG. A-24

• THE ELBOW HAS $r/d = 2.31 / 1.209'' = 2.32$

RESISTANCE COEFFICIENT IS $K = 12 f_r = .24$

PAGE A-29,
CRANE

$$K = \frac{fL}{D} \Rightarrow L = \frac{K \cdot D}{F} = \frac{.24 (1.209'' / 12)}{.020} = 1.209 \text{ ft} = 14.5'' \text{ OF PIPE.}$$

• CHECK VALVE

FLOW AREA AROUND PLUG, 40mm SQUARE
IN 57.2mm ID TUBE. LENGTH UP PLUG
IS ABOUT 40mm.

$$D_{\text{HYDRAULIC AROUND PLUG}} = 4A/P = \frac{4 \left(\frac{\pi}{4} (57.2)^2 - (40\text{mm})^2 \right)}{\pi (57.2\text{mm}) + 4(40\text{mm})} = 11.42 \text{ mm}$$

$$A_{\text{CROSS SECTION}} = 1.503 \text{ in}^2$$

$$D_{\text{HYD}} = 0.4496''$$

SOUNDS OK

SUBJECT

RELIEF INLET PIPING PRESSURE DROP

NAME

RUSS RUCINSKI

DATE

7-23-98

REVISION DATE

8-17-98 ¹

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7/25/98

THE SIDE FLOW AREAS ARE;

$$A_{\text{total}} = 4 \text{ HOLES} \left[(25\text{mm})(20\text{mm}) - \left[(10\text{mm})(10\text{mm}) - \frac{\pi}{4} (10\text{mm})^2 \right] \right]$$

$$= 1914 \text{ mm}^2 = 2.97 \text{ in}^2$$

$$D_{\text{HYD}} = \frac{4A}{P} = \frac{2.97 \text{ in}^2 \cdot \frac{25.4 \text{ mm}}{1 \text{ in}}}{[2(15\text{mm} + 10\text{mm}) + \pi(10\text{mm})]}$$

$$D_{\text{HYD}} = 0.9266 \text{ in} \quad \triangle 1 \text{ REV.}$$

FOR COMPARISON:

$$A_{\text{PIPE}} = \frac{\pi}{4} (1.120 \text{ in})^2 = 1.148 \text{ in}^2$$

WEIGHT OF TEFLON PLUG;

$$\rho_{\text{TEFLON}} = 2.150 \text{ g/cm}^3$$

$$\text{VOLUME PLUG} \approx (40\text{mm})(40\text{mm})(50\text{mm}) - \frac{\pi}{4} (30\text{mm})^2 (40\text{mm}) = 51,726 \text{ mm}^3$$

$$= 51.73 \text{ cm}^3$$

$$W = \rho V = 2.150 \text{ g/cm}^3 (51.73 \text{ cm}^3) = 111.2 \text{ g} = 0.245 \text{ lbs}$$

$$\Delta P_{\text{LIFT PLUG}} = \frac{0.245 \text{ lbs}}{\frac{\pi (1.102 \text{ in})^2}{4}} = 0.257 \text{ psi}$$

^{REV.} ¹

$$\Delta P_{\text{AROUND PLUG}} \approx 3.36 \times 10^{-6} \frac{f_{\text{L-PLUG}} \left(\frac{1}{4} W \right)^2}{\rho d_{\text{HYD}}^5}$$

↑ OF 1/4 FLOW PATH

$$\Delta P_{\text{AROUND PLUG}} = 3.36 \times 10^{-6} \frac{(0.029) (0.164 \text{ ft}) \left(\frac{1}{4} 3254 \frac{\text{lb}}{\text{hr}} \right)^2}{(4.825 \frac{\text{lb}}{\text{ft}^3}) (0.4496 \text{ in})^5}$$

$$\Delta P_{\text{AROUND PLUG}} = 0.119 \text{ psi}$$

$$\Delta P_{\text{CHECK VALVE TOTAL}} = \Delta P_{\text{LIFT PLUG}} + \Delta P_{\text{AROUND PLUG}} = 0.376 \text{ psi}$$

SUBJECT

TOSHIBA CHECK VALVE, ΔP CALC.

NAME

RUSS RUCINSKI

DATE

8-14-98

REVISION DATE

A CONSERVATIVE ESTIMATE OF PRESSURE DROP WOULD BE TO MODEL IT AS A FLOW THRU BRANCH TEE.

$$K = 60 f_T \quad \text{PG. A-29 OF CRANE TECHNICAL PAPER \#410}$$

FROM PG. D2 $d_{HYD} = .4496''$ FOR EACH OF THE PATHS AROUND THE PLUG

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

$$Re = \frac{6.31 \left(\frac{1}{4} \cdot 3254 \frac{\text{lbm}}{\text{hr}} \right)}{(.4496 \text{ in}) (.00321 \text{ cp})} = 3.557 \times 10^6$$

$$\epsilon_f = \frac{.00015}{.4496} \times \frac{12 \text{ in}}{\text{ft}} = .004 \quad \rightarrow \quad f_T = .0285 \quad \text{COMPLETE TURBULENCE}$$

$$K = 60 f_T = 1.71 \quad \& \quad K = \frac{fL}{D}$$

$$\Delta P = 2.8 \times 10^{-7} \frac{KW^2 \sqrt{V}}{D^5}$$

3-14 CRANE

$$\Delta P = \frac{(2.8 \times 10^{-7})(1.71) \left(\frac{3254 \text{ lbm/hr}}{4} \right)^2}{(4.825 \frac{\text{lbm}}{\text{ft}^3})(.4496 \text{ in})^4}$$

$$\Delta P = 1.61 \text{ psi}$$

TRY ANOTHER WAY;

$$K = \frac{fL}{D} \Rightarrow L = \frac{KD}{f} = \frac{1.71 \left(\frac{.4496 \text{ in}}{12} \right)}{.0285} = 2.248 \text{ ft.}$$

$$\Delta P = 3.36 \times 10^{-6} \frac{fLW^2}{D^5} = 3.36 \times 10^{-6} \frac{(.029)(2.248 \text{ ft}) \left(\frac{3254 \text{ lbm/hr}}{4} \right)^2}{(4.825 \frac{\text{lbm}}{\text{ft}^3})(.4496 \text{ in})^5}$$

$$\Delta P = 1.635 \text{ psi}$$

$$\Delta P_{\text{CHECK VALVE TOTAL}} = \Delta P_{\text{LIFT PLUG}} + \Delta P_{\text{AROUND PLUG}} = 0.26 \text{ psi} + 1.61 \text{ psi} = 1.87 \text{ psi}$$

FERMILAB

ENGINEERING NOTE

SECTION
PDD/ETT
DØPROJECT
SOLENOIDSERIAL-CATEGORY
3823-111PAGE
D5

SUBJECT

RELIEF INLET PIPING PRESSURE DROP
CALC.

NAME

RUSS RUCINSKI

DATE

7-24-98

REVISION DATE

A 8-17-98

$$\Delta P_{\text{STRAIGHT PIPE} + \text{ELBOW}} = 3.36 \times 10^{-6} \frac{(.020)(2.83 \text{ ft} + 1.209 \text{ ft})(3254 \frac{\text{lb}_m}{\text{hr}})^2}{(4.825 \frac{\text{lb}_m}{\text{ft}^3})(1.209 \text{ in})^5}$$

$$\Delta P_{\text{PIPE}} = 0.2308 \text{ psi}$$

$$\Delta P_{\text{TOTAL}} = \Delta P_{\text{PIPE}} + \Delta P_{\text{CHECK VALVE TOTAL}}^{\text{REV.}} = .231 + 1.87 \text{ psi} = 2.1 \text{ psi}$$

$$\Delta P_{\text{INLET PIPING}} = 2.1 \text{ psi} \quad \Delta^{\text{REV.}}$$

MAX. PRESSURE POSSIBLE IN RESERVOIR

$$P_{\text{MAX RESER.}} = P_{\text{BURST PRESS}} + \Delta P_{\text{INLET}}^{\text{REV.}} = 126.13 \text{ psig} + 2.1 = 128.2 \text{ psig.}$$

$$P_{\text{MAX}} < \text{MAWP} < 110\% \text{ MAWP}$$

= 150 PSIG

∴ INLET PIPING IS OKAY.

MATH CHK'D JMcDade
7-29-98

OPERATOR ERROR CASE;

- WARM GHE THRU & INTO SUBCOOLER VESSEL.

WORST CASE SCENARIO;

1. SUBCOOLER FULL OF LHE.
2. SPECIFIC VALVE LINE UP ALLOWS MYCOM DISCHARGE @ 285 PSIG TO (GO THRU COOLDOWN LINE) SUBCOOLER.
3. RETURN PIPING ISOLATED FROM VESSEL.

① $P = 285 \text{ PSIG}$
 $\dot{m} = ?$
 $T = 290 \text{ K}$

② $P = 110\% \text{ MAWP} = 165 \text{ PSIA} = 150 \text{ PSIG.}$

INITIALLY THE INCOMING GHE WOULD BOIL AWAY THE LHE IN THE VESSEL. THE MAXIMUM HEAT TRANSFER RATE WOULD BE EQUIVALENT TO THE RATE AT WHICH (FULL MYCOM) FLOW = $57 \frac{3}{5}$ IS COOLED FROM 290K TO THE FLUID TEMPERATURE IN THE RESERVOIR AT 165 PSIA. FOLLOWING OTHER CASES IN CALCULATING RELIEF CAPACITIES, ASSUME THE RESERVOIR FLUID IS AT 9.46 K, 17.03°R. [REF. CGA 51-3, 5.1.3 $\sqrt{\frac{2h}{V_{LOV}}}$ MAXIMUM VALVE]

$$Q_{\text{MAX}} = \dot{m} \left[h \Big|_{\substack{P=285 \text{ PSIG} \\ T=290 \text{ K}}} - h \Big|_{\substack{P=150 \text{ PSIG} \\ T=9.46 \text{ K}}} \right] =$$

$$= \left(57 \frac{3}{5} \right) \left[.15279 \times 10^7 \frac{\text{J}}{\text{kg}} - 44568 \frac{\text{J}}{\text{kg}} \right] \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \text{ HePaK}$$

$$= 84,550 \text{ WATTS}$$

UNREALISTIC MODEL, UNREALISTIC ANSWER. HEAT TRANSFER RATE WILL BE LIMITED BY THE MAXIMUM HEAT TRANSFER RATE OF THE SUBCOOLER COILS.

ALSO MASS FLOW RATE WILL BE LIMITED BY THE SUPPLY PIPING SIZE.

ESTIMATING A MORE REALISTIC MAXIMUM MASS FLOW RATE;

1/27/98

- I WILL TALLY THE RESISTANCE COEFFICIENTS FOR ALL THESE FLOW COMPONENTS. USE $d = 0.59"$ AS BASIS OF CALCS.

PV-2013 & EVMF; $C_v = \frac{29.9 d^2}{\sqrt{K}}$ EQN. 2-6 CRANE.

$$K = \left(\frac{29.9 d^2}{C_v} \right)^2 = \left[\frac{29.9 (.59)^2}{0.32} \right]^2 = 1058 \text{ EACH VALVE}$$

COILS IN COOLDOWN HX

$$K = f \frac{L}{D} = (.027) \frac{(27)}{\frac{.436}{12}} = 20.06 \text{ BASED ON } .436" \text{ ID}$$

ADJUST FOR $d = .59"$

$$K_{.59} = K_{.436} \left(\frac{.59}{.436} \right)^4$$

EQN. 2-5 IN CRANE TECHNICAL PAPER #410

$$K_{.59} = (20.06) \left(\frac{.59}{.436} \right)^4 = 67$$

GHe COOLDOWN SUPPLY PIPE

$$K_{.674} = .027 \frac{(70)}{\frac{.674}{12}} = 33.6$$

$$K_{.59} = (33.6) \left[\frac{.59}{.674} \right]^4 = 20$$

MV 3024-H

$$K = \left[\frac{29.9 (.59)^2}{5.9} \right]^2 = 3$$

He SUPPLY PIPING

$$K_{.527} = (.027) \frac{(100)}{\frac{.527}{12}} = 61.5$$

$$K_{.59} = (61.5) \left[\frac{.59}{.527} \right]^4 = 97$$

COILS IN RSVR & COIL & CHIMNEY

MATH CHK'D

T. Hanger 1.27.98

$$K_{.59} = f \frac{L}{D} = .027 \frac{(40.4 \text{ ft} + 285 \text{ ft})}{\frac{.59 \text{ "}}{12}} = \boxed{179}$$

$$K_{\text{SUBCOOLER COILS}} = 22$$

$$K_{\text{SOLENOID CHIMNEY COIL}} = 157$$

SUMMING UP RESISTANCES

$$\sum K = 1058 + 67 + 20 + 3 + 97 + 179 + 1058 = \boxed{2482}$$

EQN. 3-14 CRAPS;

$$\Delta P = .000 \ 000 \ 280$$

$$\frac{K W^2 \sqrt{V}}{D^4}$$

PRESSURE DROP THRU SYSTEM

RE-ARRANGING & SOLVING FOR W;

$$W = \sqrt{\frac{\Delta P d^4}{K \sqrt{V} (2.8 \times 10^{-7})}}$$

(AVERAGE FLUID PROPERTIES:

$$\bar{P} = 217.5 \text{ PSIG.}$$

$$T = 290 \text{ K}$$

$$\Rightarrow \bar{V} = 6.073 \frac{\text{ft}^3}{\text{lb.}}$$

$$W = \sqrt{\frac{(285 \text{ PSIG} - 150 \text{ PSIG}) (.59 \text{ "})^4}{2482 (6.073 \frac{\text{ft}^3}{\text{lb}}) (2.8 \times 10^{-7})}} = 62.26 \frac{\text{lb}}{\text{hr}}$$

$$\dot{m} = 62.26 \frac{\text{lbm}}{\text{hr}} \times \frac{1000 \text{ g}}{2.2 \text{ lbm}} \times \frac{1 \text{ hr}}{3600 \text{ s}} = \boxed{7.86 \frac{\text{g}}{\text{s}}}$$

MATH CHK'D

T. Nguyen 1. 27.98

DETERMINATION OF MASS FLOW RATE FOR 2 CASES.

CASE 1. COOLDOWN HX COOLS GHE TO 90K

CASE 2. COOLDOWN HX WARM GHE 290K TO
SUBCOOLER COILS

$$\Delta P = (2.8 \times 10^{-7}) \frac{K W^2 \bar{V}}{d^4}$$

GENERAL EQN 314 FROM CRANE.

WHERE K - RESISTANCE COEFF
W - MASS FLOW lbm/hr
 $\bar{V}$ - SPECIFIC VOL. ft³/lbm
d - DIA. = .59"

CASE 1.

$$\Delta P_{TOTAL} = \frac{2.8 \times 10^{-7} W^2}{d^4} \left[K_{PV2013} \bar{V}_{290K, P=285 PSIG} + [K_{COOLDOWN HX} + K_{CLON SUPPLY} + K_{MV3024} + K_{HE SUPPLY PIPING}] \bar{V}_{90K, 215 PSIG} + [K_{SUBCOOLER COILS} + K_{EVME} + K_{CHWNEY COIL}] \bar{V}_{10K, 185 PSIG} \right]$$

$$\Delta P_{TOTAL} = \frac{2.8 \times 10^{-7} W^2}{d^4} \left[(1058) 4.711 \frac{ft^3}{lb} + [67 + 20 + 3 + 97] 1.937 \frac{ft^3}{lb} + [22 + 1058 + 157] .1908 \right]$$

$$W^2 = \frac{\Delta P_{TOTAL} d^4}{2.8 \times 10^{-7} (5582)}$$

$$W = \sqrt{\frac{(285-150)(.59)^4}{2.8 \times 10^{-7} (5582)}} = 102.3 \frac{lbm}{hr}$$

$$\dot{m} = 102.3 \frac{lbm}{hr} \times \frac{1000}{2.2 lbm} \times \frac{1 hr}{3600 s} = 12.92 \frac{g}{s} \approx 13 \frac{g}{s}$$

CASE 2.

$$\Delta P_{TOTAL} = \frac{2.8 \times 10^{-7} W^2}{d^4} \left[K_{PV2013} \bar{V}_{290K, P=285 PSIG} + [K_{CLON HX} + K_{CLON SUPPLY} + K_{MV3024} + K_{HE SUPPLY PIPING}] \bar{V}_{290K, 215 PSIG} + [K_{SUB COILS} + K_{EVME} + K_{CHIN.}] \bar{V}_{10K, 185 PSIG} \right]$$

$$\Delta P_{TOTAL} = \frac{2.8 \times 10^{-7} W^2}{d^4} \left[(1058) 4.711 + [67 + 20 + 3 + 97] 6.131 + [22 + 1058 + 157] .1908 \right]$$

$$W = \sqrt{\frac{(285-150)(.59)^4}{2.8 \times 10^{-7} (6367)}} = 95.8 \frac{lbm}{hr}$$

$$\dot{m} = 12.1 \frac{g}{s}$$

MAXIMUM HEAT TRANSFER RATE

REFERENCE TFF-071 TOSHIBA HEAT EXCHANGER CALCS.

COIL SIZE, 17mm OD x 1.2mm WALL x 12.7m LONG.

HEAT FLUX LIMITED BY THE FREE CONVECTION HEAT TRANSFER COEFFICIENT ON THE OUTSIDE OF THE COILS IN THE SUPERCRITICAL HELIUM FLUID.

A CORRELATION BETWEEN NUSSELT # (Nu) AND RAYLEIGH # (Ra) IS GIVEN IN PG. 218 OF HELIUM CRYOGENICS BY STEVEN VAN SCIVER.

$$Ra_D = \frac{g \beta (T_s - T_\infty) D^3}{\nu \alpha}$$

 ν = KINEMATIC
= VISCOSITY
 α = THERMAL DIFFUSIVITY

$$g = 9.81 \text{ m/s}^2$$

$$\beta = \frac{1}{150 \text{ K}} = .0067 \text{ K}^{-1}$$

$$T_f = \frac{T_s + T_\infty}{2} = \frac{280 \text{ K} + 9.5}{2} = 150 \text{ K}$$

$$D = 17 \times 10^{-3} \text{ m}$$

USING He PAK', TEMP = 150 K PRESS = 150 PSIG = 1135,254 Pa;

$$\mu = 0.126 \times 10^{-4} \text{ Pa-s}$$

$$\alpha = .5224 \times 10^{-5} \text{ m}^2/\text{s}$$

$$K = .9783 \times 10^{-1} \text{ W/m-K}$$

$$\nu = \frac{\mu}{\rho} = \frac{.126 \times 10^{-4} \frac{\text{N-s}}{\text{m}^2}}{3.6036 \frac{\text{kg}}{\text{m}^3}} = 3.4965 \times 10^{-6} \text{ m}^2/\text{s}$$

$$\frac{\text{kg} \cdot \text{m} \cdot \text{s}}{\text{s}^2 \cdot \text{m}^2} \cdot \frac{\text{m}^3}{\text{kg}} = \frac{\text{m}^2}{\text{s}}$$

$$Ra_D = \frac{(9.81 \frac{\text{m}}{\text{s}^2})(.00667 \frac{1}{\text{K}})(280 \text{ K})(17 \times 10^{-3} \text{ m})^3}{(3.4965 \times 10^{-6} \frac{\text{m}^2}{\text{s}})(.5224 \times 10^{-5} \frac{\text{m}^2}{\text{s}})}$$

$$Ra_D = 4.928 \times 10^6$$

$$Nu = 0.615 Ra^{0.258}$$

EQN. 6.26 IN VAN SCIVER HELIUM CRYOGENICS

$$Nu = 32.8$$

$$Nu = \frac{hD}{K} \Rightarrow h = \frac{Nu K}{D} = \frac{(32.8)(.09783 \frac{\text{W}}{\text{m-K}})}{.017 \text{ m}}$$

$$h = 189 \text{ W/m}^2\text{K}$$

FREE CONVECTION
COEFFICIENT.
(NOTE: VERY HIGH)
PER USUAL COEFF.TOTAL HEAT TRANSFER CAN BE CONSERVATIVELY
CALCULATED BY

$$Q = hA(T_s - T_\infty)$$

THIS IS CONSERVATIVE BECAUSE

- 1) THE CONVECTION COEFF. IS DETERMINED WHERE $T_s - T_\infty$ IS A MAXIMUM.
- 2) NEGLECTS INSIDE CONVECTION COEFFICIENT
- 3) NEGLECTS $T_s - T_\infty$ DECREASING ALONG LENGTH OF PIPE.

$$A_{\text{SURFACE}} = \pi D L = \pi (.017 \text{ m})(12.3 \text{ m}) = 0.657 \text{ m}^2$$

 MATH CHECK'D
 ✓ 1.2.

$$Q_{\text{MAX}} = h A \Delta T = (189 \frac{\text{W}}{\text{m}^2 \text{K}})(0.657 \text{ m}^2)(290 \text{ K} - 10 \text{ K})$$

$$Q_{\text{MAX}} = 34,768 \text{ WATTS.} = 34768 \text{ W} \times \frac{\text{Btu/h}}{.293071 \text{ W}}$$

$$Q_{\text{MAX}} = 118,635 \text{ Btu/h. THIS RATE IS TOO HIGH TO HANDLE.}$$

I WILL REDUCE CONSERVATIVENESS BY INCLUDING THE INSIDE CONVECTION COEFFICIENT & THE TUBE CONDUCTIVE RESISTANCE

WHERE;

$$R_i = \frac{1}{h_i A_i} \quad R_{\text{tube}} = \frac{\ln(\frac{OD}{ID})}{2\pi L K} \quad R_o = \frac{1}{h_o A_o}$$

$i = \text{SUBSCRIPT INSIDE}$
 $o = \text{" OUTSIDE}$

THIS WILL BE AN ITERATIVE PROCESS. TO START

ASSUME $T_{s,i} = 200 \text{ K}$, $T_{s,o} = 180 \text{ K}$ (AS A GUESS)

CALCULATE h_i ; $Nu = 0.023 Re_D^{0.8} Pr^{2/5}$ REF. PG. 251 OF VAN SUGER.

$Re = \frac{\rho V L}{\mu}$ EVALUATE THE PROPERTIES @ $\approx 185 \text{ PSIG} = 1,376,504 \text{ Pa}$
 AND $T_f = \frac{200 + 290}{2} = 245 \text{ K}$.

FROM HEPK; $v = .3681 \frac{\text{m}^3}{\text{kg}}$ $\mu = .1729 \times 10^{-4} \text{ Pa}\cdot\text{s}$ $K = .1355 \frac{\text{W}}{\text{m}\cdot\text{K}}$ $Pr = .6628$

$\dot{m} = \rho V A \Rightarrow V = \frac{\dot{m}}{\rho A} = \frac{7.86 \frac{\text{kg}}{\text{s}} (.3681 \frac{\text{m}^3}{\text{kg}})}{(\frac{\pi (.0146 \text{ m})^2}{4}) \frac{1 \text{ kg}}{1000 \text{ g}}} = 17.28 \text{ m/s}$

$Re_D = \frac{(17.28 \text{ m/s})(.0146 \text{ m})}{(.3681 \frac{\text{m}^3}{\text{kg}})(.1729 \times 10^{-4} \text{ Pa}\cdot\text{s})} = 39,640$

SUBSTITUTE INTO Nu EQ'N.

$Nu_i = .023 (39,640)^{0.8} (.6628)^{2/5} = 93$

$h_i = \frac{Nu_i K}{D} = \frac{(93)(.1355 \frac{\text{W}}{\text{m}\cdot\text{K}})}{.0146 \text{ m}} = 864 \frac{\text{W}}{\text{m}^2 \text{K}}$

(NOTE; IT SEEMS TOO HIGH?)

$A_i = \pi (ID) L = \pi (.0146 \text{ m})(12.3 \text{ m}) = .5642 \text{ m}^2$

$R_i = \frac{1}{h_i A_i} = .00205 \frac{\text{K}}{\text{W}}$

$$R_{TUBE}; K_{SS} = 12.75 \frac{W}{m \cdot K}$$

 REF. CRYOGENIC SYSTEMS
 BY RANDALL BARRON

$$R_{TUBE} = \frac{\ln \left(\frac{17 \text{ mm}}{14.6 \text{ mm}} \right)}{2\pi (12.3 \text{ m}) (12.75 \frac{W}{m \cdot K})} = .000154 \frac{K}{W}$$

 • R_o , CALCULATE h_o (REF. PG. 4 OF CALCS.)

$$Ra_o = \frac{9 \beta (T_s - T_{\infty}) D^3}{\nu \alpha}$$

$$T_F = \frac{180 \text{ K} + 10 \text{ K}}{2} = 95 \text{ K}$$

$$P = 150 \text{ PSIG} = 1,135,254 \text{ Pa}$$

FROM HEPAK

$$\rho = 5.655 \frac{kg}{m^3}, Pr = .6921, \alpha = .2454 \times 10^{-5} \frac{m^2}{s}, \mu = .9603 \times 10^{-5} \text{ Pa} \cdot s, K = .7228 \times 10^{-7}$$

$$Ra_o = \frac{(9.81 \frac{m}{s^2}) (\frac{1}{95 \text{ K}}) (180 \text{ K} - 10 \text{ K}) (.017 \text{ m})^3}{\frac{(.9603 \times 10^{-5} \text{ Pa} \cdot s)}{5.655 \frac{kg}{m^3}} (.2454 \times 10^{-5} \frac{m^2}{s})} = 2.0696 \times 10^7$$

$$Nu = .615 Ra_o^{.258} = 47.5$$

$$h = \frac{Nu K}{D} = \frac{47.5 (.07228 \frac{W}{m \cdot K})}{.017 \text{ m}} = 202 \frac{W}{m^2 \cdot K}$$

$$R_o = \frac{1}{h_o A} = \frac{1}{(202 \frac{W}{m^2 \cdot K}) (.657 \text{ m}^2)} = .00754 \frac{K}{W}$$

• PLUGGING VALUES INTO RESISTANCE MODEL

$$R_{TOTAL} = R_i + R_{TUBE} + R_o = .00205 \frac{K}{W} + .000154 + .00754 \frac{K}{W}$$

$$R_{TOTAL} = .00975 \frac{K}{W}$$

$$Q_{TOTAL} = \frac{\Delta T}{R_{TOTAL}} = \frac{280 \text{ K}}{.00975 \frac{K}{W}} = 28,730 \text{ WATTS.}$$

$$T_{Si} = 290 \text{ K} - (28,730 \text{ W}) (.00205 \frac{K}{W}) = 231 \text{ K.}$$

$$T_{So} = 10 \text{ K} + (28,730 \text{ W}) (.00754 \frac{K}{W}) = 227 \text{ K}$$

 COMPARE TO GUESS/ASSUMPTION $T_{Si} = 200 \text{ K}$ $T_{So} = 180 \text{ K}$

CALCULATED VALUES NOT TOO FAR OFF FROM ASSUMED.

 DO ONE MORE ITERATION WITH NEW T_{Si} & T_{So} .

RUSS RUCINSKI 1/15/98 E(7)

• R_i PROPERTIES @ 185 PSIG & $T_f = \frac{T_c + T_{si}}{2} = \frac{290 + 231}{2} = 260.5 \text{ K}$ MATHG
T 1/15/98

$\rho = 2.525 \frac{\text{kg}}{\text{m}^3}$ $Pr = .6621$ $\alpha = .1086 \times 10^{-4} \frac{\text{m}^2}{\text{s}}$ $\mu = .1816 \times 10^{-4} \text{ Pa}\cdot\text{s}$ 1.27.

$K = .1425 \frac{\text{W}}{\text{m}\cdot\text{K}}$

$V = 17.28 \frac{\text{m}}{\text{s}} \quad \frac{2.71665 \frac{\text{m}^3}{\text{s}}}{2.525 \frac{\text{kg}}{\text{m}^3}} = 18.59 \frac{\text{m}}{\text{s}}$

$Re_D = \frac{(18.59 \frac{\text{m}}{\text{s}})(.0146 \text{ m})(2.525 \frac{\text{kg}}{\text{m}^3})}{(.1816 \times 10^{-4} \text{ Pa}\cdot\text{s})} = 37,741$

$Nu = .023(37,741)^{0.8}(.6621)^{.4} = 89.4$

$h_i = \frac{Nu K}{D} = \frac{(89.4)(.1425 \frac{\text{W}}{\text{m}\cdot\text{K}})}{.0146 \text{ m}} = 873 \frac{\text{W}}{\text{m}^2\cdot\text{K}}$

$R_i = \frac{1}{h_i A_i} = .00203 \frac{\text{K}}{\text{W}}$

• R_{TUBE} $K_{ss}|_{T=230\text{K}} = 13.6 \frac{\text{W}}{\text{m}\cdot\text{K}}$ $R_{TUBE} = .00014 \frac{\text{K}}{\text{W}}$

• R_o PROPERTIES @ 150 PSIG & $T_f = \frac{T_{so} + T_w}{2} = \frac{227 + 10 \text{ K}}{2} = 118.5 \text{ K}$

$\rho = 4.548 \frac{\text{kg}}{\text{m}^3}$ $Pr = .6735$ $\alpha = .3534 \times 10^{-5} \frac{\text{m}^2}{\text{s}}$ $\mu = .1082 \times 10^{-4} \text{ Pa}\cdot\text{s}$ $K = .8359 \times 10^{-1}$

$Ra_D = \frac{(9.81 \frac{\text{m}}{\text{s}^2})(\frac{1}{118.5 \text{ K}})(227 \text{ K} - 10 \text{ K})(.017 \text{ m})^3}{\frac{(.1082 \times 10^{-4} \text{ Pa}\cdot\text{s})}{4.548 \frac{\text{kg}}{\text{m}^3}} (.3534 \times 10^{-5} \frac{\text{m}^2}{\text{s}})} = 1.05 \times 10^7$

$Nu = .615 Ra_D^{.258} = 39.8$

$h = \frac{Nu K}{D} = \frac{(39.8)(.08359)}{.017} = 196 \frac{\text{W}}{\text{m}^2\cdot\text{K}}$

$R_o = \frac{1}{h_o A_o} = .00777 \frac{\text{K}}{\text{W}}$

$R_{TOTAL} = .00994 \frac{\text{K}}{\text{W}}$

$Q_{TOTAL} = \frac{\Delta T}{R_{TOTAL}} = \frac{280 \text{ K}}{.00994 \frac{\text{K}}{\text{W}}} = 28,170 \text{ WATTS}$

$T_{si} = 290 - (28,170)(.00203 \frac{\text{K}}{\text{W}}) = 233 \text{ K}$ COMPARE TO 231 K

$T_{so} = 10 \text{ K} + (28,170)(.00777) = 229 \text{ K}$ " 227 K

ITERATED TEMPERATURES MATCH CALCULATED OK

RUSS RUCINSKI 1/16/98 E(8)
MATH CHK'D

HEAT INPUT TO RESERVOIR IS ALSO LIMITED BY THE HEAT CAPACITY OF THE INCOMING GAS. 1.27.98
THE INCOMING GAS CAN ONLY BE COOLED TO 9.46K.

CASE 1: INCOMING GAS IS ALREADY 90 K.

$$\begin{aligned} Q_{\text{MAX INPUT CASE 1}} &= \dot{m}_{\text{CASE 1}} \left[h_{185 \text{ PSIG. } T=90 \text{ K}} - h_{185 \text{ PSIG. } T=10 \text{ K}} \right] \\ &= \left(102.3 \frac{\text{lbm}}{\text{hr}} \right) \left[209.1 \frac{\text{Btu}}{\text{lbm}} - 20.12 \frac{\text{Btu}}{\text{lbm}} \right] \\ Q_{\text{MAX INPUT CASE 1}} &= 19,333 \text{ Btu/hr.} = 5666 \text{ WATTS.} \end{aligned}$$

CASE 2: INCOMING GAS IS 290 K.

$$\begin{aligned} Q_{\text{MAX INPUT CASE 2}} &= \left(95.8 \frac{\text{lbm}}{\text{hr}} \right) \left[655.9 \frac{\text{Btu}}{\text{lbm}} - 20.12 \frac{\text{Btu}}{\text{lbm}} \right] \\ &= 60,908 \text{ Btu/hr.} = 17,850 \text{ WATTS} \end{aligned}$$

REQUIRED RELIEF CAPACITY

MATH CHK'D

T. Nguyen

1. 27.98

$$Q_a = Q_{a \text{ HEAT INPUT}} + Q_{a \text{ MASS FLOW OF INCOMING HE}}$$

$$Q_{a \text{ HEAT INPUT}} \text{ GIVEN BY } Q_a = \frac{18.3 \text{ g}_{\text{TOTAL}}}{378 \text{ L}} \sqrt{\frac{ZT}{4.00}} \quad \text{APPENDIX 6A TECHNOLOGY OF LHE}$$

THE L & T WILL BE TAKEN AT $\frac{\sqrt{V}}{\sqrt{\left[\frac{\partial h}{\partial v}\right]_P}}$ MAXIMUM

CASE 1

INCOMING GAS 90K

$$Q_{a \text{ HEAT INPUT}} = \frac{(18.3)(19.333 \frac{\text{Btu}}{\text{hr}})}{(378)(19.265 \frac{\text{Btu}}{\text{lb}})} \sqrt{\frac{(.749)(17.03)}{4.00}} = \boxed{86.8 \text{ scfm AIR}}$$

$$Q_{a \text{ MASS FLOW OF INCOMING HE}} = \frac{13.1 \text{ W } C_a}{60 C} \left(\frac{Z T M_a}{M Z_a T_a} \right)^{1/2} \quad \text{EQN. 6A-1 TECHNOLOGY OF LHE}$$

$$W = 102.3 \frac{\text{lb}}{\text{hr}} \text{ FROM PG. 3 OF CALCS.}$$

$$C_a = 356 \text{ GAS CONSTANT}$$

$$C = 377 \quad (C_p/C_v = 1.66 \text{ REF. AGCO SIZING FORMULAS})$$

$$Z = .749$$

$$T = 17.03 \text{ R (NOTE; HEAT INPUT COOLED INCOMING GAS TO THIS TEMP)}$$

$$M_a = 28.97$$

$$M = 4.0$$

$$Z_a = 1.0$$

$$T_a = 520 \text{ R}$$

$$Q_{a \text{ MASS FLOW OF INCOMING HE}} = \frac{13.1 (102.3 \frac{\text{lb}}{\text{hr}}) (356)}{60 (377)} \sqrt{\frac{(.749)(17.03 \text{ R})(28.97)}{(4.0)(1.0)(520 \text{ R})}}$$

$$Q_{a \text{ MASS FLOW OF INCOMING HE}} = \boxed{8.9 \text{ scfm AIR}}$$

CASE 1

$$Q_a = Q_{a \text{ HEAT INPUT}} + Q_{a \text{ MASS FLOW OF INCOMING HE}} = 95.7 \text{ scfm AIR}$$

MATH CARD

T. RUCINSKI

6.27.98

CASE 2 INCOMING GAS IS 290 K

$$Q_a = Q_{a \text{ HEAT INPUT}} + Q_{a \text{ MASS FLOW OF INCOMING AIR}}$$

$$Q_{a \text{ HEAT INPUT}} = 86.8 \text{ scfm AIR} \times \frac{60,908 \frac{\text{Btu}}{\text{hr}}}{19,333 \frac{\text{Btu}}{\text{hr}}} = 273.5 \text{ scfm AIR}$$

$$Q_{a \text{ MASS FLOW OF INCOMING}} = (8.9 \text{ scfm AIR}) \times \frac{95.8}{102.3} = 8.3 \text{ scfm AIR}$$

$$Q_{a \text{ TOTAL}} = Q_{a \text{ HEAT INPUT}} + Q_{a \text{ MASS FLOW INCOMING}} = 281.8 \text{ scfm AIR}$$

FERMILAB ENGINEERING NOTE

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SUBJECT

HELIUM RESERVOIR
DETERMINATION OF U - LOSS OF VACUUM CASE

NAME

RUSS RUCINSKI

DATE

8-11-98

REVISION DATE

LOSS OF VACUUM CASE; U DEFINED ON PAGE 17, CGA 51.3-1995

MODEL:

U - OVERALL HEAT TRANSFER COEFFICIENT. {REF. HEAT & MASS X-FER, INCROPERA & DEWITT, 2nd ED.}

$$U = \frac{1}{R_{tot} \cdot A}$$

AND

$$Q_{TOTAL} = U A_{MEAN} \Delta T \quad \text{WHERE } Q = \text{TOTAL HEAT TRANSFER TO INNER VESSEL (EQU. 3-16 + INCROPERA & DEWITT)}$$

$$Q_{TOTAL} = Q_{TOP} + Q_{BOTTOM} + Q_{SIDE} = (U_{TOP} A_{TOP \text{ MEAN}} + U_{BOTTOM} A_{BOTTOM \text{ MEAN}} + U_{SIDE} A_{SIDE \text{ MEAN}}) \Delta T$$

BY SUBST-TUN;

$$U_{TOTAL \text{ AVG. CGA}} = U_{TOP} \frac{A_{TOP \text{ MEAN}}}{A_{MEAN}} + U_{BOTTOM} \frac{A_{BOTTOM \text{ MEAN}}}{A_{MEAN}} + U_{SIDE} \frac{A_{SIDE \text{ MEAN}}}{A_{MEAN}}$$

WHERE

$U_{TOTAL \text{ AVG}}$ IS THAT USED IN THE CGA EQUATION IN SECTION 5.2.2 OF CGA 51.3-1995, P. 17.

CALCS FOR TOP

NOTE; RADIATION IS MADE INTO A PSEUDO RESISTANCE

$$U_{TOP} = \frac{1}{R_{TOTAL \text{ TOP}} A_{MEAN \text{ TOP}}}$$

$$R_{TOTAL \text{ TOP}} = \left(\frac{1}{R_{SPACE \text{ CONDUCTION TOP}}} + \frac{1}{R_{SPACE \text{ RADIATION TOP}}} \right) + R_{MLI \text{ CONDUCTION ONLY TOP}}$$

MATH CHK'D
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8-17-98

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$$R_{\text{SPACE CONDUCTION TOP}} = \frac{L}{K A_{\text{MEAN TOP}}} = \frac{(21.5" - 1" \text{MLI}) \frac{1 \text{ ft}}{12 \text{ in.}}}{\left(.0847 \frac{\text{Btu}}{\text{hr-ft}^2-\text{F}} \right) \left(\frac{\pi}{4} \right) \left(\frac{2.756^2 + 1.063^2}{2} \right)}$$

$$= 5.936 \frac{\text{hr-F}}{\text{Btu}}$$

T_{SHELL} 130°F = 590°R
"STABLE"
T_{VESSEL} 17°R

$$R_{\text{SPACE RADIATION TOP}}; \quad \delta_{ij} = \frac{\sigma (T_i^4 - T_j^4)}{\frac{1 - \epsilon_i}{\epsilon_i A_i} + \frac{1 - \epsilon_j}{\epsilon_j A_j}}$$

F_{ij} - VIEW FACTOR FOR COAXIAL PARALLEL DISKS.
LET L BE SHELL J BE VESSEL

USING FIG. 13.5 FROM INCROPERA & DEWITT

$$L = 20.5" = 1.708 \text{ ft.} \quad r_j/L = \frac{.5315 \text{ ft}}{1.708 \text{ ft}} = 0.311$$

$$L/r_i = \frac{1.708 \text{ ft}}{1.378 \text{ ft}} = 1.239$$

$$F_{ij} = 0.05 \text{ FROM FIG. 13.5.}$$

$$A_i = \frac{\pi}{4} (D_{\text{SHELL}})^2 = \frac{\pi}{4} (2.756 \text{ ft})^2 = 5.9655 \text{ ft}^2$$

$$\sigma = 0.1714 \times 10^{-8} \frac{\text{Btu}}{\text{hr-ft}^2-\text{R}^4}$$

SUBSTITUTING INTO δ_{ij} EQN.

$$\delta_{ij} = \frac{(.1714 \times 10^{-8} \frac{\text{Btu}}{\text{hr-ft}^2-\text{R}^4}) [590^4 - 17^4]}{\frac{1 - .22}{.22 (5.9655 \text{ ft}^2)} + \frac{1}{(5.9655 \text{ ft}^2)(0.05)} + \frac{1 - .06}{.06 (.8875 \text{ ft}^2)}} = 9.616 \frac{\text{Btu}}{\text{hr}}$$

$$R'_{\text{SPACE RADIATION TOP}} = \frac{\Delta T}{\delta} = \frac{590^{\circ}\text{R} - 17^{\circ}\text{R}}{9.616 \frac{\text{Btu}}{\text{hr}}} = 59.59 \frac{\text{hr-F}}{\text{Btu}}$$

$$R_{\text{MLI CONDUCTION ONLY TOP}} = \frac{L_{\text{MLI}}}{K_{\text{He}} A_{\text{MLI}}} = \frac{1/12 \text{ ft}}{\left(.0847 \frac{\text{Btu}}{\text{hr-ft}^2-\text{F}} \right) \left(\frac{\pi}{4} (1.063 \text{ ft})^2 \right)}$$

$$= 1.109 \frac{\text{hr-F}}{\text{Btu}}$$

MATH CHK'D
S. M. Dade
8-17-98

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$$R_{TOTAL TOP} = \left(\frac{1}{R_{SPACE CONVECTION TOP}} + \frac{1}{R_{SPACE RADIATION TOP}} \right)^{-1} + R_{MLI CONDUCTION TOP} \quad \text{FROM PG. F1}$$

$$= \left(\frac{1}{5.886 \frac{hr \cdot ^\circ F}{Btu}} + \frac{1}{59.59 \frac{hr \cdot ^\circ F}{Btu}} \right)^{-1} + 1.109 \frac{hr \cdot ^\circ F}{Btu}$$

$$= 5.357 + 1.109$$

$$R_{TOTAL TOP} = 6.466 \frac{hr \cdot ^\circ F}{Btu}$$

$$U_{TOP} = \frac{1}{R_{TOTAL TOP} \cdot A_{TOP MEAN}} = \frac{1}{(6.466 \frac{hr \cdot ^\circ F}{Btu}) (3.4265 ft^2)}$$

$$U_{TOP} = 2.0451 \frac{Btu}{hr \cdot ^\circ F \cdot ft^2}$$

CALCS FOR BOTTOM

$$U_{BOTTOM} = \frac{1}{R_{TOTAL BOTTOM} \cdot A_{MEAN BOTTOM}}$$

$$R_{TOTAL BOTTOM} = \left(\frac{1}{R_{SPACE CONVECTION BOTTOM}} + \frac{1}{R_{SPACE RADIATION BOTTOM}} \right)^{-1} + R_{MLI CONDUCTION ONLY BOTTOM}$$

→ NOTE THAT RADIATION & CONDUCTION ARE SAME VALUES AS FOR TOP CALCS.

$$R_{SPACE CONVECTION BOTTOM} = \frac{1}{h_{SHELL WARM} A_{SHELL}} + \frac{1}{h_{VESSEL COLD} A_{VESSEL COLD}}$$

$T_{VES} = 17^\circ R$
VESSEL/MLI

SHELL
 $T_{SHELL} = 590^\circ R$

FREE CONVECTION CASE, REF. SEE 9.6.2 OF INCROPERA & DEWITT

$$L \equiv \frac{A_s}{p} \quad \text{CHARACTERISTIC LENGTH FOR USE IN RAYLEIGH NUMBER}$$

FOR UPPER SURFACE OF HEATED PLATE OR LOWER SURFACE OF COOLED PLATE

$$\overline{Nu}_L = 0.54 Ra_L^{1/4} \quad (10^4 \leq Ra_L \leq 10^7) \quad \text{EQN. 9.30 OF H&M x FER}$$

$$\overline{Nu}_L = 0.15 Ra_L^{1/3} \quad (10^7 \leq Ra_L \leq 10^{11}) \quad \text{EQN. 9.31}$$

$$Ra_L = \frac{g \beta (T_s - T_\infty) L^3}{\nu \alpha}$$

2x

MATH CHK'D
J. McDade
8-17-98

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FOR EASE OF CALCULATION I WILL USE SI UNITS UNTIL I GET $R_{\text{SPACE CONVECTION BOTTOM}}$

$$\frac{\lambda}{C} = 2.81 \text{ m/s}^2 \quad R = \frac{1}{T_{\text{film}}} \quad T_{\text{film}} = \frac{(T_s + T_{\infty})}{2}$$

FIRST, $h_{\text{SHELL WARM}}$ $T_s = 590^\circ\text{R} = 327.8\text{K}$ $T_{\infty} = \frac{590^\circ\text{R} + 17^\circ\text{R}}{2} = 303.5^\circ\text{R} = 168.6\text{K}$

$$T_{\text{film}} = \frac{(T_s + T_{\infty})}{2} = \frac{(327.8\text{K} + 168.6\text{K})}{2} = 248.2\text{K}$$

I WILL USE 250K IN THE PROPERTY TABLES & $P = 1.01325 \text{ MPa}$

$$\beta = \frac{1}{T_{\text{film}}} = .00403 \frac{1}{\text{K}}$$

$$L_{\text{SHELL WARM}} = \frac{A_{\text{SHELL}}}{P_{\text{SHELL}}} = \frac{\pi D^2}{4} = \frac{D}{4} = \frac{2.756 \text{ ft} (.3048 \text{ m/ft})}{4} = 0.210 \text{ m}$$

$$\nu = \frac{\mu}{\rho} = \frac{17.53 \times 10^{-6} \text{ Pa}\cdot\text{s}}{.1953 \text{ kg/m}^3} = 8.976 \times 10^{-5} \frac{\text{N}\cdot\text{s}}{\text{m}^2} \cdot \frac{\frac{\text{kg}\cdot\text{m}}{\text{s}^2}}{\frac{\text{kg}}{\text{m}^3}} = \text{m}^2/\text{s}$$

UNITS OK

$$\alpha = 1.3595 \times 10^{-4} \text{ m}^2/\text{s}$$

THERMAL DIFFUSIVITY

SUBSTITUTING VALUES INTO R_{aL} EQ'N;

$$R_{aL} = \frac{(9.31 \text{ m/s}^2)(.00403 \frac{1}{\text{K}})(327.8\text{K} - 168.6\text{K})(.210\text{m})^3}{(8.976 \times 10^{-5} \text{ m}^2/\text{s})(1.3595 \times 10^{-4} \text{ m}^2/\text{s})}$$

R_{aL} SHELL WARM

$$R_{aL} = 4.7765 \times 10^6$$

R_{aL} SHELL WARM

$$Nu = \frac{hL}{k}$$

$$Nu_L = 0.54 R_{aL}^{1/4} = 25.24$$

$$\bar{h}_{\text{SHELL WARM}} = \frac{Nu \cdot k}{L} = \frac{25.24 \cdot (.1375 \frac{\text{W}}{\text{m}\cdot\text{K}})}{(.210\text{m})} = 16.5 \frac{\text{W}}{\text{m}^2\text{K}}$$

ORDER OF MAGNITUDE OK

NOW, $h_{\text{SHELL COLD}}$

$$T_s = 17^\circ\text{R} = 9.5\text{K} \quad T_{\infty} = 168.6\text{K}$$

$$T_{\text{film}} = \frac{(9.5\text{K} + 168.6\text{K})}{2} = 89.0\text{K}$$

$$\beta = .01123 \frac{1}{\text{K}}$$

$$L_{\text{VESSEL COLD}} = A_p = \frac{D}{4} = \frac{1.063 \text{ ft} (.3048 \text{ m/ft})}{4} = .081 \text{ m}$$

$$\nu = \frac{\mu}{\rho} = \frac{8.9365 \times 10^{-6} \text{ Pa}\cdot\text{s}}{.54785 \text{ kg/m}^3} = 1.6312 \times 10^{-5} \text{ m}^2/\text{s}$$

I WILL USE 90K IN THE PROPERTY TABLES & $P = 1.01325 \text{ MPa}$

MATH CHECK'D

J. M. Dade
8-17-98

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$$\alpha = 2.4615 \times 10^{-5} \text{ m}^2/\text{s}$$

SUBSTITUTING VALUES INTO R_{aL} EQN;

$$R_{aL}^{\text{VESSEL COLD}} = \frac{(9.81 \text{ m/s}^2)(.01123 \text{ m})(9.5 \text{ K} - 168.6 \text{ K})(.081 \text{ m})^3}{(1.6312 \times 10^{-5} \text{ m}^2/\text{s})(2.4615 \times 10^{-5} \text{ m}^2/\text{s})}$$

$$R_{aL}^{\text{VESSEL COLD}} = 2.32 \times 10^7$$

$$Nu_L = 0.15 R_{aL}^{1/3} = 42.8$$

$$h_{\text{VESSEL COLD}} = \frac{Nu_L \cdot k}{L} = \frac{42.8 (6.862 \times 10^{-2} \text{ W/m} \cdot \text{K})}{.081 \text{ m}} = 36.3 \text{ W/m}^2 \cdot \text{K}$$

$$R_{\text{SPACE CONVECTION BOTTOM}} = \frac{1}{h_{\text{STEEL BOT.}} A_{\text{STEEL BOT.}}} + \frac{1}{h_{\text{VESSEL BOT.}} A_{\text{VESSEL BOT.}}}$$

$$= \frac{1}{(16.5 \text{ W/m}^2 \cdot \text{K})(.55421 \text{ m}^2)} + \frac{1}{(36.3 \text{ W/m}^2 \cdot \text{K})(.08245 \text{ m}^2)}$$

$$= .10936 \text{ K/W} + .33412 \text{ K/W} = 0.44348 \text{ K/W}$$

$$R_{\text{SPACE CONVECTION BOTTOM}} = .44348 \text{ K/W} \cdot \frac{1 \text{ watt}}{3.4129 \text{ Btu/hr}} \times \frac{1.8^\circ \text{R}}{1 \text{ K}} = 0.2339 \frac{\text{hr} \cdot ^\circ \text{R}}{\text{Btu}}$$

$$R_{\text{TOTAL BOTTOM}} = \left(\frac{1}{R_{\text{SPACE CONVECTION}}} + \frac{1}{R_{\text{SPACE RADIATION BOTTOM}}} \right)^{-1} + R_{\text{MLI CONDUCTION}}$$

$$= \left(\frac{1}{.2339} + \frac{1}{59.59} \right)^{-1} + 1.109 \frac{\text{hr} \cdot ^\circ \text{F}}{\text{Btu}}$$

$$= 0.233 + 1.109 = 1.342 \frac{\text{hr} \cdot ^\circ \text{F}}{\text{Btu}}$$

$$U_{\text{BOTTOM}} = \frac{1}{R_{\text{TOTAL MEAN BOTTOM}}} = \frac{1}{(1.342 \frac{\text{hr} \cdot ^\circ \text{F}}{\text{Btu}})(3.4265 \text{ ft}^2)} = 0.2175 \frac{\text{Btu}}{\text{hr} \cdot ^\circ \text{F} \cdot \text{ft}^2}$$

MATH CHK'D
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8-17-98

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CALCS FOR SIDE

$$T_{SIDE} = \frac{1}{R_{TOTAL} \cdot A_{MEAN SIDE}}$$

$$R_{TOTAL SIDE} = \left(\frac{1}{R_{SPACE CONVECTION SIDE}} + \frac{1}{R_{SPACE RADIATION}} \right) + R_{MLI CONVECTION ONLY SIDE}$$

- CONVECTION TERM:

$$R_{CONV} = \frac{\Delta T}{q_{CONVECTION}}$$

FREE CONVECTION CASE.

CHECK $D/L \geq \left(\frac{35}{Gr^{1/4}} \right)$

$$\frac{D_{SHELL}}{L_{SHELL}} = \frac{2.756 ft}{5.217 ft} = .528$$

$$Gr_L = \frac{Ra_L}{Pr} \quad \text{GUESS } Ra \approx 4 \times 10^6 \text{ \& } Pr \approx .66 \Rightarrow Gr_L \approx 6 \times 10^6$$

$$D/L \geq \frac{35}{Gr^{1/4}}$$

$$.528 \not\geq \frac{35}{49.6} = 0.71 \quad \text{NO} \quad \therefore \text{SHOULD NOT USE VERTICAL PLATE CORRELATION EQN. 9.26 IN HAN X FGR}$$

FOR THE VESSEL; $D/L \geq \frac{35}{Gr^{1/4}}$

$$\frac{1.063 ft}{1.640 ft} \geq \frac{35}{\left(\frac{2 \times 10^7}{.66} \right)^{1/4}}$$

$$.648 \geq .472 \quad \checkmark \text{ OK}$$

OK TO USE VERTICAL PLATE CORRELATION.

MODEL AS A RECTANGULAR CAVITY, HEATED ON ONE SIDE, COOLED ON OTHER.

$$H/L = \frac{VESSEL HT}{ANNULUS} = \frac{1.640 ft \left(\frac{12 in}{ft} \right)}{10.2 in - 1 in MLI} = 2.14$$

$$3'' = h(T_1 - T_2) \quad T_1 = 590^\circ R \quad T_2 = 17^\circ R$$

$$\text{FOR } 1 < H/L < 10 \quad Nu_L = 0.22 \left(\frac{Pr}{0.2 + Pr} Ra_L \right)^{0.28} \left(\frac{H}{L} \right)^{-1/4} \quad \text{EQN 9.38}$$

PROPERTIES ARE EVALUATED AT $T \equiv (T_1 + T_2)/2 = 303.5^\circ R = 168.6 K$

I WILL USE $T = 170 K$ FOR PULLING VALUES OUT OF THE TABLES. $P = 1 \text{ ATM}$

$$Pr = .6598$$

MATH CHK'D
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$$Ra_L = \frac{g \beta (T_1 - T_2) L^3}{\alpha \nu} \quad \text{FOR THIS CASE}$$

$$\alpha = 7.105 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\nu = \frac{\mu}{\rho} = \frac{13.405 \times 10^{-6} \text{ Pa}\cdot\text{s}}{0.2877 \text{ kg/m}^3} = 4.6594 \times 10^{-5} \text{ m}^2/\text{s}$$

$$Ra_L = \frac{(9.81 \text{ m/s}^2) (168.6 \text{ K}) (327.8 \text{ K} - 9.5 \text{ K}) (9.2 \text{ m} \times \frac{0.0254 \text{ m}}{12})^3}{(7.105 \times 10^{-5} \text{ m}^2/\text{s}) (4.6594 \times 10^{-5} \text{ m}^2/\text{s})}$$

$$Ra_L = 7.1387 \times 10^7$$

$$Ra_L < 10^{10} \quad \therefore \text{CORRELATION VALID}$$

$$Pr < 10^5 \quad 2 < \mu_L < 10$$

$$\overline{Nu}_L = 0.22 \left(\frac{0.6598}{0.2 + 0.6598} (7.1387 \times 10^7) \right)^{0.28} (2.14)^{-0.25}$$

$$\overline{Nu}_L = 26.71$$

$$\overline{h} = \frac{\overline{Nu}_L k}{L} = \frac{(26.71) (0.10555 \text{ W/m}\cdot\text{K})}{(9.2 \text{ m} \times 0.0254 \text{ m})} = 12.06 \text{ W/m}^2\cdot\text{K}$$

$$R_{\text{CONV. SIDES}} = \frac{\Delta T}{q_{\text{CONV.}}} = \frac{(T_1 - T_2)}{\overline{h} (T_1 - T_2) (A_{\text{MEAN SIDES}})}$$

TDL + TTDL
2
NOTE USING A MEAN
APPLIES THE HEAT
TRANSFER TO A HEIGHT
LARGER THAN THE
VESSEL.

$$R_{\text{CONV. SIDES}} = \frac{1}{(12.06 \text{ W/m}^2\cdot\text{K}) \left[\frac{(1.063)(1.640) + (2.756)(5.217)}{2} \right] \pi \left(\frac{3048}{2} \right)}$$

$$R_{\text{CONV. SIDES}} = 0.0352 \text{ K/W}$$

$$A_{\text{MEAN SIDE}} = 25,323 \text{ ft}^2$$

$$R_{\text{CONV. SIDES}} = 0.0352 \text{ K/W} \cdot \frac{1 \text{ W}}{3.4129 \text{ Btu/hr}} \cdot \frac{1.8^\circ \text{R}}{1 \text{ K}} = 0.0186 \frac{\text{hr}\cdot^\circ \text{R}}{\text{Btu}}$$

RADIATION TERM

CONCENTRIC CYLINDERS

$$F_{ij} = \frac{A_j}{A_i}$$

$$q_{\text{R}} = \frac{G (T_i^4 - T_j^4)}{\frac{1 - \epsilon_i}{\epsilon_i A_i} + \frac{1}{A_i F_{ij}} + \frac{1 - \epsilon_j}{\epsilon_j A_j}}$$

EQN 13.25

WHERE i - SHELL SURFACE
 j - VESSEL SURFACE

REF. PAGE F2, TOP RADIATION CALCS, ALSO

MATH CHK'D
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8-17-98

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$$q_{Lj} = \frac{(.1714 \times 10^{-8} \frac{\text{Btu}}{\text{hr-ft}^2 \cdot \text{R}^4}) [590^4 - 17^4]}{1 - .22} + \frac{1}{.22 (\pi) (5.217 \text{ ft}) (2.756 \text{ ft})} + \frac{1}{\pi (5.217) (2.756) \frac{(1.063)(1.640)\pi}{(5.217 \times 2.756)\pi}} + \frac{1 - .06}{.06 \pi (1.063)(1.640)}$$

$$207.691 \frac{\text{Btu}}{\text{hr-ft}^2}$$

$$q_{Lj} = .078491 \text{ ft}^2 + .182588 \text{ ft}^2 + 2.86055 \text{ ft}^2$$

$$q_{Lj} = 66.53 \frac{\text{Btu}}{\text{hr}}$$

$$R_{\text{SPACE RADIATION SIDES}} = \frac{\Delta T}{q} = \frac{590 - 17 \text{ } ^\circ\text{R}}{66.53 \frac{\text{Btu}}{\text{hr}}} = 8.612 \frac{\text{hr} \cdot ^\circ\text{R}}{\text{Btu}}$$

$$R_{\text{MLI CONDUCTION ONLY SIDE}} = \frac{L_{\text{MLI}}}{K_{\text{MLI}} \cdot A_{\text{MLI}}} = \frac{1/12 \text{ ft}}{.0847 \frac{\text{Btu}}{\text{hr-ft} \cdot ^\circ\text{F}} (\pi 1.063 \text{ ft}) (1.640 \text{ ft})}$$

$$= .1796 \frac{\text{hr} \cdot ^\circ\text{R}}{\text{Btu}}$$

$$R_{\text{TOTAL SIDE}} = \left(\frac{1}{R_{\text{SPACE CONDUCTION SIDE}}} + \frac{1}{R_{\text{SPACE RADIATION SIDE}}} \right)^{-1} + R_{\text{MLI CONDUCTION SIDE}}$$

$$= \left(\frac{1}{.0186 \frac{\text{hr} \cdot ^\circ\text{R}}{\text{Btu}}} + \frac{1}{8.612 \frac{\text{hr} \cdot ^\circ\text{R}}{\text{Btu}}} \right)^{-1} + .1796 \frac{\text{hr} \cdot ^\circ\text{R}}{\text{Btu}}$$

$$= 0.1982 \frac{\text{hr} \cdot ^\circ\text{R}}{\text{Btu}}$$

$$U_{\text{SIDE}} = \frac{1}{R_{\text{TOTAL SIDE}} \cdot A_{\text{MEAN SIDE}}} = \frac{1}{.1982 \frac{\text{hr} \cdot ^\circ\text{R}}{\text{Btu}} (25.323 \text{ ft}^2)}$$

$$U_{\text{SIDE}} = 0.1993 \frac{\text{Btu}}{\text{hr} \cdot ^\circ\text{R} \cdot \text{ft}^2}$$

$$U_{\text{TOTAL AVG CGA}} \text{ FROM EQN ON F1} \quad U_{\text{TOTAL}} = U_{\text{TOP}} \frac{A_{\text{TOP MEAN}}}{A_{\text{MEAN}}} + U_{\text{BOT}} \frac{A_{\text{BOT MEAN}}}{A_{\text{MEAN}}} + U_{\text{SIDE}} \frac{A_{\text{SIDE MEAN}}}{A_{\text{MEAN}}}$$

$$U_{\text{TOTAL AVG CGA}} = .0451 \frac{3.43 \text{ ft}^2}{32.2 \text{ ft}^2} + .2175 \frac{3.43 \text{ ft}^2}{32.2 \text{ ft}^2} + .1993 \frac{25.323 \text{ ft}^2}{32.2 \text{ ft}^2}$$

$$U_{\text{TOTAL AVG CGA}} = 0.1847 \frac{\text{Btu}}{\text{hr} \cdot ^\circ\text{R} \cdot \text{ft}^2}$$

1ST ITERATION ASSUMES OUTER SURFACE OF MLI = 17°R FOR SPACE R_t ANALYSIS, GHe @ 100°F FOR MLI ANALYSIS.

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THE ANALYSIS OF U CAN BE REFINED NOW BY USING A BETTER ESTIMATE OF THE MLI OUTER WRAP TEMPERATURE. IT WILL DECREASE U .

BY FIRST ANALYSIS;

$$U_{TOP} = .0451 \frac{Btu}{hr \cdot ^\circ F \cdot ft^2} \Rightarrow Q_{TOTAL} = U_{TOP} A_{MEAN} \Delta T$$

$$Q_{TOTAL} = (.0451 \frac{Btu}{hr \cdot ^\circ F \cdot ft^2}) (3.4265 ft^2) (590^\circ R - 17^\circ R) = 88.55 \frac{Btu}{hr}$$

$$\Delta T_{ACROSS} = Q_{TOTAL} \cdot R_{MLI} = 88.55 \frac{Btu}{hr} \cdot 1.109 \frac{hr \cdot ^\circ F}{Btu} = 98.2^\circ F$$

$$T_{MLI \text{ OUTER SURFACE TOP}} = T_{VESSEL} + \Delta T_{MLI} = 17^\circ R + 98.2^\circ R = 115^\circ R$$

RE-EVALUATING RESISTANCES BASED ON THIS TEMP.;

$$R_{SPACE \text{ CONDUCTION TOP}} = \left(5.396 \frac{hr \cdot ^\circ F}{Btu} \right) \frac{K_{HE 100^\circ F}}{K_{HE 353^\circ R} = 196K \approx 200K}$$

↑ AVG. OF 590°R & MLI TEMP.

$$= 5.886 \frac{hr \cdot ^\circ F}{Btu} \cdot \frac{(.0847 \frac{Btu}{hr \cdot ft \cdot ^\circ F})}{(.0682 \frac{Btu}{hr \cdot ft \cdot ^\circ F})} = 7.310 \frac{hr \cdot ^\circ F}{Btu}$$

RADIATION;

$$q_{ij} = 9.616 \frac{Btu}{hr} \cdot \frac{(590^\circ R^4 - 115^\circ R^4)}{(590^\circ R^4 - 17^\circ R^4)} = 9.60 \frac{Btu}{hr}$$

VERY LITTLE CHANGE.
USE SAME R FOR RADIAT.

$$R_{MLI \text{ CONDUCTION ONLY TOP}} = 1.109 \frac{hr \cdot ^\circ F}{Btu} \cdot \frac{K_{HE 100^\circ F}}{K_{HE 66^\circ R} = 37K \approx 43K}$$

← AVG. OF MLI OUTER SURF. TEMP 115°R & VESSEL TEMP 17°R

$$= 1.109 \frac{hr \cdot ^\circ F}{Btu} \cdot \frac{(.0847 \frac{Btu}{hr \cdot ft \cdot ^\circ F})}{(.02338 \frac{Btu}{hr \cdot ft \cdot ^\circ F})} = 4.018 \frac{hr \cdot ^\circ F}{Btu}$$

$$R_{TOTAL \text{ TOP}} = \left(\frac{1}{R_{SPACE \text{ COND. TOP}}} + \frac{1}{R_{MLI \text{ CONDUCTION TOP}}} \right)^{-1} + R_{MLI \text{ CONDUCTION TOP}} = 10.529 \frac{hr \cdot ^\circ F}{Btu}$$

$$U_{TOP} = .0277 \frac{Btu}{hr \cdot ^\circ F \cdot ft^2} \quad \text{WITH 1 ITERATION}$$

$$\Delta T_{ACROSS} = (.0277 \frac{Btu}{hr \cdot ^\circ F \cdot ft^2}) (3.4265 ft^2) (590 - 17^\circ R) (4.018 \frac{hr \cdot ^\circ F}{Btu}) = 219^\circ R$$

$$T_{MLI \text{ OUTER SURF.}} = 236^\circ R$$

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LAST ITERATION: RE-EVALUATE RESISTANCES BASED IN THIS TEMP.

$$R_{\text{SPACE}} = 7.310 \frac{\text{hr} \cdot ^\circ\text{F}}{\text{Btu}} \cdot \frac{.0632 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}}}{(.0723 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}})} = 6.345 \frac{\text{hr} \cdot ^\circ\text{F}}{\text{Btu}}$$

$\uparrow$
 $K_{\text{SIDE}} = 590 + 219R$

$$R'_{\text{RADIATION}} = 52.59 \quad \text{JUST USE 1500}$$

$$R_{\text{MLI COND TOP}} = 4.018 \frac{\text{hr} \cdot ^\circ\text{F}}{\text{Btu}} \cdot \frac{.02358 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}}}{.03196 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}}} = 2.936 \frac{\text{hr} \cdot ^\circ\text{F}}{\text{Btu}}$$

$\uparrow$
 $K_{\text{SIDE}} = 21180R$

$$R_{\text{TOTAL}} = 2.076 \frac{\text{hr} \cdot ^\circ\text{F}}{\text{Btu}}$$

$$U_{\text{TOP}} = .03215 \frac{\text{Btu}}{\text{hr} \cdot ^\circ\text{F} \cdot \text{ft}^2}$$

BY FIRST ANALYSIS;

$$U_{\text{BOTTOM}} = 0.2175 \frac{\text{Btu}}{\text{hr} \cdot ^\circ\text{F} \cdot \text{ft}^2} \quad \text{THIS WAS DOMINATED BY THE MLI CONDUCTION COMPONENT.}$$

THE SPACE OFFERED ONLY $\frac{.233}{1.342} (100) = 17\%$ OF THE THERMAL RESISTANCE IN THE HEAT PATH OF THE SHELL TO THE VESSEL.

A REFINEMENT WOULD BE NEGLIGIBLE.

USE

$$J_{\text{BOTTOM}} = 0.2175 \frac{\text{Btu}}{\text{hr} \cdot ^\circ\text{F} \cdot \text{ft}^2}$$

BY FIRST ANALYSIS;

$$U_{\text{SIDE}} = 0.1993 \frac{\text{Btu}}{\text{hr} \cdot ^\circ\text{F} \cdot \text{ft}^2}$$

IN THIS CASE THE SPACE OFFERED LITTLE THERMAL RESISTANCE ALSO. HOWEVER SINCE U_{SIDE} IS A LARGE TERM IN THE U_{TOTAL} EQ'N. A REFINEMENT SHOULD BE DONE.

MATH CHK'D

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REFINEMENT OF T_{J,OE} $\Delta T = CA \Delta T (R_{MLI})$

$$\Delta T_{MLI} = \left(\frac{0.003 \text{ Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \text{ft}} \right) (25.323 \text{ ft}^2) (590 - 17) \left(\frac{1}{1.796 \text{ Btu}} \right)$$

$$\Delta T_{MLI} = 519.4 \text{ }^\circ\text{R} \Rightarrow T_{OUTER, LAYER MLI} = 519.4 \text{ }^\circ\text{R} + 17 \text{ }^\circ\text{R} = 536.4 \text{ }^\circ\text{R}$$

LOOK @ CONVECTION RESISTANCE; $T_1 = 590 \text{ }^\circ\text{R}$ $T_2 = 536.4 \text{ }^\circ\text{R}$ $\bar{T} = 563.2 \text{ }^\circ\text{R} = 313 \text{ K}$

USE 300K FOR EASE IN THE TABLES

$$Pr = .6631$$

$$\alpha = .1848 \times 10^{-3} \text{ m}^2/\text{s}$$

$$\nu = \frac{\mu}{\rho} = \frac{19.92 \times 10^{-6} \text{ Pa} \cdot \text{s}}{.1625 \text{ kg/m}^3} = 1.22585 \times 10^{-4} \text{ m}^2/\text{s}$$

$$Ra_L = \frac{g \beta (T_1 - T_2) L^3}{\alpha \nu} = \frac{(9.81 \text{ m/s}^2) \left(\frac{1}{313 \text{ K}} \right) (590 \text{ }^\circ\text{R} - 536.4 \text{ }^\circ\text{R}) \left(\frac{1 \text{ K}}{1.8 \text{ }^\circ\text{R}} \right) (.234 \text{ m})^3}{(.1848 \times 10^{-3} \text{ m}^2/\text{s}) (1.22585 \times 10^{-4} \text{ m}^2/\text{s})}$$

$$Ra_L = 5.2787 \times 10^5$$

$$\bar{Nu}_L = 0.22 \left[\left(\frac{.6631}{.2 + .6631} \right) (5.2787 \times 10^5) \right]^{.28} (2.14)^{-.25}$$

$$\bar{Nu}_L = 6.762$$

$$\bar{h} = \frac{\bar{Nu}_L k}{L} = \frac{6.762 (.16055 \text{ W/m} \cdot \text{K})}{.234 \text{ m}} = 4.64 \text{ W/m}^2 \cdot \text{K}$$

$$R_{CONV, SIDES} = \frac{1}{h A_{MEAN, SIDES}} = \frac{1}{(4.64 \text{ W/m}^2 \cdot \text{K}) (25.323 \text{ ft}^2) \left(\frac{.3048 \text{ m}}{1 \text{ ft}} \right)^2}$$

$$R_{CONV, SIDES} = .0916 \text{ K/W} \times \frac{1 \text{ W}}{3.4129 \text{ Btu/hr}} \times \frac{1.8 \text{ }^\circ\text{R}}{\text{K}} = .048321 \text{ hr} \cdot \text{ }^\circ\text{R/Btu}$$

LOOK @ RADIATION

$$g_{ij} = 66.53 \frac{\text{Btu}}{\text{hr}} \frac{(590 \text{ }^\circ\text{R}^4 - 536.4 \text{ }^\circ\text{R}^4)}{(590 \text{ }^\circ\text{R}^4 - 17 \text{ }^\circ\text{R}^4)} = 21.03 \frac{\text{Btu}}{\text{hr}}$$

$$R'_{SPACE, RADIATION, SIDES} = \frac{\Delta T}{g} = \frac{590 - 536.4 \text{ }^\circ\text{R}}{21.03 \frac{\text{Btu}}{\text{hr}}} = 2.543 \frac{\text{hr} \cdot \text{ }^\circ\text{R}}{\text{Btu}}$$

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$$R_{MLI \text{ SIDE CONDUCTION}} = \frac{L}{K_{HE} A_{MLI}}$$

$$\rightarrow 2T_{AUG} = \frac{536.4^{\circ}R - 17^{\circ}R}{2} = 276.7^{\circ}R = 153.7 \text{ USE } 150 K$$

$$R_{MLI \text{ SIDE CONDUCTION}} = \frac{1/12 \text{ ft}}{(.0969 \frac{W}{M \cdot K})(\pi(1.063)(1.640 \text{ ft}))} \times \frac{1 W}{3.4129 \frac{Btu}{hr}} \times \frac{1 \text{ ft}}{.3048 m} \times \frac{1.8^{\circ}R}{1 K}$$

$$R_{MLI \text{ SIDE CONDUCTION}} = 0.2717 \frac{^{\circ}R \cdot hr}{Btu}$$

$$R_{TOTAL \text{ SIDE}} = \left(\frac{1}{R_{SPACE \text{ CONDUCTION SIDE}}} + \frac{1}{R_{SPACE \text{ RADIATION SIDE}}} \right) + R_{MLI \text{ SIDE CONDUCTION}} = 0.31913 \frac{hr \cdot ^{\circ}R}{Btu}$$

$$U_{SIDE} = \frac{1}{R_{TOTAL \text{ SIDE}} A_{MEAN \text{ SIDE}}} = 0.12374 \frac{Btu}{hr \cdot ^{\circ}R \cdot ft^2}$$

CHECK

$$\Delta T_{ACROSS \text{ MLI SIDE}} = U \Delta T (R_{MLI}) = .12374 \frac{Btu}{hr \cdot ^{\circ}R \cdot ft^2} [25.323 ft^2] [590 - 17^{\circ}R] .2717 \frac{^{\circ}R \cdot hr}{Btu}$$

$$\Delta T = 487.8^{\circ}R \rightarrow T_{OUTER \text{ LAYER MLI}} = 504.8^{\circ}R$$

CLOSE
ENOUGH TO
536.4^{\circ}R
USED IN
LAST
ITERATION.

* REFINED $U_{TOTAL \text{ AVG. CGA}}$

$$U_{TOTAL} = U_{TOP} \frac{A_{TOP \text{ MEAN}}}{A_{MEAN}} + U_{BOT.} \frac{A_{BOT. \text{ MEAN}}}{A_{MEAN}} + U_{SIDE} \frac{A_{SIDE}}{A_{MEAN}}$$

$$= .03215 \frac{3.43 \text{ ft}^2}{32.2 \text{ ft}^2} + .2175 \frac{3.43}{32.2} + .12374 \frac{25.323}{32.2}$$

$$U_{TOTAL \text{ AVG. CGA}} = 0.1239 \frac{Btu}{hr \cdot ^{\circ}R \cdot ft^2}$$

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8-17-98

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COMPARISON OF U BASED ON
INTERPRETATION OF CGA 51.3-1995

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I. INCORRECT INTERPRETATION;

$$U = \frac{K_{HE}}{t_{SPACE}}$$

$$U = \frac{0.0347 \text{ Btu/hr-ft}^2\text{-}^{\circ}\text{F}}{10.2 \text{ in.} \left(\frac{1 \text{ ft}}{12 \text{ in}} \right)} = 0.100 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^{\circ}\text{F}}$$

II. CORRECT INTERPRETATION, NEGLECT SPACE GAS CONDUCTION THRU MLI, NO RADIATION NO CONVECTION

$$U = \frac{K_{HE}}{t_{MLI}} = \frac{.0847 \text{ Btu/hr-ft}^2\text{-}^{\circ}\text{F}}{1 \text{ in.} \left(\frac{1 \text{ ft}}{12 \text{ in}} \right)} = 1.016 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^{\circ}\text{F}}$$

$K_{HE} @ 200^{\circ}\text{F} = 560^{\circ}\text{R}$

III. CORRECT INTERPRETATION, INCLUDE EFFECTIVENESS OF SPACE IN SERIES W/MLI

$$U = 0.124 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^{\circ}\text{R}}$$

FROM ANALYSIS PGS. F1 THRU F12

SUMMARY OF COMPONENTS: LOSS OF VACUUM

	GHE CONDUCTION THRU SPACE	GHE CONVECTION THRU SPACE	RADIATION THRU SPACE	GHE CONDUCTION THRU MLI { = TOTAL }
TOP	56.6 $\frac{\text{Btu}}{\text{hr}}$	NOT APPLIC.	6.5 $\frac{\text{Btu}}{\text{hr}}$	63.2 $\frac{\text{Btu}}{\text{hr}}$
BOTTOM	NOT APPLIC.	425.4 $\frac{\text{Btu}}{\text{hr}}$	1.7 $\frac{\text{Btu}}{\text{hr}}$	427 $\frac{\text{Btu}}{\text{hr}}$
SIDE	NOT APPLIC.	1763 $\frac{\text{Btu}}{\text{hr}}$	33.5 $\frac{\text{Btu}}{\text{hr}}$	1795 $\frac{\text{Btu}}{\text{hr}}$
TOTAL =				2285 $\frac{\text{Btu}}{\text{hr}}$

$$Q_{TOTAL} = U A \Delta T = .124 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^{\circ}\text{R}} (32.2 \text{ ft}^2) (590^{\circ}\text{R} - 17^{\circ}\text{R}) = 2288 \frac{\text{Btu}}{\text{hr}} = 670 \text{ W}$$

MATH CHK'D
J. McJade
8-17-98

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PRESSURE = 0.101325 (MPa)								
TEMP (K)	DENSITY (kg/m ³)	PV/RT (-)	ENERGY (J/g)	ENTHALPY (J/g)	ENTROPY (J/g·K)	C _v (J/g·K)	C _p (J/g·K)	VSOUND (m/s)
0.8000	146.9	0.4150	0.5653E-02	0.5954	0.4338E-02	0.2235E-01	0.2237E-01	244.9
1.000	146.9	0.3321	0.1649E-01	0.7063	0.1618E-01	0.1023	0.1023	244.9
1.200	146.9	0.2767	0.5582E-01	0.7456	0.5142E-01	0.3224	0.3224	245.3
1.400	146.9	0.2371	0.1619	0.8515	0.1322	0.7866	0.7872	245.4
1.600	147.0	0.2073	0.3954	1.065	0.2665	1.612	1.614	244.2
1.800	147.2	0.1841	0.8430	1.531	0.5481	2.953	2.959	240.6
2.000	147.5	0.1653	1.641	2.328	0.9658	5.228	5.250	234.0
2.068	147.7	0.1597	2.040	2.726	1.161	6.510	6.548	231.2
2.158	148.0	0.1527	2.765	3.450	1.503	10.47	10.63	227.2
2.167	148.1	0.1520	2.870	3.554	1.552	13.25	13.56	226.5
2.169	148.1	0.1519	2.894	3.578	1.563	8.102	8.148	227.1
2.178	148.1	0.1512	2.949	3.633	1.588	5.105	5.105	227.9
2.268	147.9	0.1454	3.256	3.941	1.727	2.699	2.749	229.8
2.400	147.4	0.1379	3.578	4.265	1.866	2.172	2.281	230.7
2.700	145.7	0.1240	4.232	4.927	2.126	1.995	2.258	226.2
3.000	143.4	0.1134	4.923	5.630	2.372	2.016	2.494	224.0
3.300	140.3	0.1053	5.721	6.443	2.630	2.195	2.940	216.9
3.600	136.6	0.9922E-01	6.659	7.401	2.908	2.352	3.460	207.1
3.900	131.8	0.9489E-01	7.763	8.532	3.209	2.465	4.109	194.7
4.200	125.5	0.9254E-01	9.096	9.904	3.548	2.546	5.145	178.4
4.222	124.9	0.9246E-01	9.208	10.02	3.575	2.552	5.255	177.0
4.222	16.84	0.6859	24.72	30.74	8.473	3.236	9.144	99.93
4.500	14.52	0.7463	26.09	33.07	9.007	3.205	7.788	108.1
4.800	12.84	0.7913	27.39	35.28	9.485	3.175	7.073	115.3
5.000	11.98	0.8145	28.21	36.67	9.767	3.159	6.770	119.5
5.100	11.60	0.8245	28.60	37.34	9.900	3.152	6.650	121.5
5.300	10.93	0.8423	29.37	38.65	10.15	3.141	6.452	125.3
5.500	10.34	0.8575	30.12	39.92	10.39	3.133	6.297	128.9
6.000	9.184	0.8872	31.94	43.00	10.92	3.119	6.025	137.0
6.500	8.257	0.9088	33.69	45.96	11.40	3.113	5.852	144.4
7.000	7.532	0.9251	35.40	48.86	11.83	3.111	5.732	151.2
8.000	6.433	0.9478	38.76	54.51	12.58	3.111	5.581	163.6
9.000	5.831	0.9625	42.04	60.04	13.23	3.113	5.469	174.7
10.00	5.016	0.9724	45.30	65.50	13.81	3.115	5.429	185.0
12.00	4.128	0.9846	51.73	76.27	14.79	3.118	5.355	203.7
15.00	3.273	0.9937	61.26	92.24	15.98	3.120	5.296	228.5
20.00	2.440	0.9995	77.06	118.6	17.50	3.121	5.251	264.3
25.00	1.948	1.002	92.77	144.8	18.66	3.120	5.229	295.5
30.00	1.622	1.002	108.4	170.9	19.62	3.120	5.218	323.8
40.00	1.216	1.003	139.7	223.0	21.12	3.119	5.208	373.4
50.00	0.9732	1.002	170.9	275.0	22.28	3.118	5.201	417.3
60.00	0.8112	1.002	202.1	327.0	23.22	3.116	5.198	456.9
80.00	0.6086	1.002	264.5	431.0	24.72	3.117	5.198	527.2
100.0	0.4871	1.001	326.8	534.9	25.86	3.117	5.194	589.3
120.0	0.4060	1.001	389.2	638.8	26.83	3.117	5.194	645.3
140.0	0.3481	1.001	451.5	742.6	27.83	3.116	5.193	698.9
160.0	0.3046	1.001	513.8	846.5	28.32	3.116	5.193	744.9
180.0	0.2708	1.001	576.2	950.4	28.93	3.116	5.193	790.0
200.0	0.2437	1.001	638.5	1054.	29.46	3.116	5.193	832.7
220.0	0.2216	1.001	700.8	1158.	29.97	3.116	5.193	873.3
240.0	0.2031	1.001	763.1	1262.	30.43	3.116	5.193	912.0
260.0	0.1875	1.001	825.4	1366.	30.84	3.116	5.193	949.2
280.0	0.1741	1.000	887.7	1470.	31.23	3.116	5.193	985.0
300.0	0.1625	1.000	950.1	1574.	31.58	3.116	5.193	1020.
350.0	0.1393	1.000	1106.	1833.	32.39	3.116	5.193	1101.
400.0	0.1219	1.000	1262.	2093.	33.08	3.116	5.193	1177.
500.0	0.9753E-01	1.000	1573.	2612.	34.24	3.116	5.193	1316.
600.0	0.8128E-01	1.000	1665.	3131.	35.18	3.116	5.193	1442.
700.0	0.6967E-01	1.000	2198.	3651.	35.98	3.116	5.193	1557.
800.0	0.6096E-01	1.000	2508.	4170.	36.68	3.116	5.193	1684.
900.0	0.5419E-01	1.000	2820.	4689.	37.29	3.116	5.193	1765.
1000.	0.4877E-01	1.000	3131.	5208.	37.84	3.116	5.193	1881.
1100.	0.4434E-01	1.000	3443.	5728.	38.33	3.116	5.193	1952.
1200.	0.4063E-01	1.000	3754.	6247.	38.78	3.116	5.193	2038.
1300.	0.3752E-01	1.000	4066.	6767.	39.20	3.116	5.193	2122.
1400.	0.3484E-01	1.000	4378.	7286.	39.58	3.116	5.193	2202.
1500.	0.3252E-01	1.000	4689.	7805.	39.94	3.116	5.193	2279.

F15

PRESSURE = 0.101325 [MPa]

TEMP (K)	$\left(\frac{T}{V} \frac{\partial V}{\partial T}\right)_P$	$\left(\frac{V}{C_V} \frac{\partial P}{\partial T}\right)_V$	$\left(\frac{P}{\rho} \frac{\partial \rho}{\partial P}\right)_T$	DIEL - 1	CONDUCT (W/m·K)	VISC (μPa·s)	THERM (m²/s)	PRANDTL
0.8000	0.4650E-03	1.558	0.1151E-01	0.5792E-01				
1.000	0.2956E-03	0.1733	0.1150E-01	0.5791E-01				
1.200	-0.7773E-03	-0.1209	0.1146E-01	0.5791E-01				
1.400	-0.3034E-02	-0.1658	0.1146E-01	0.5793E-01				
1.600	-0.6901E-02	-0.1593	0.1157E-01	0.5797E-01				
1.800	-0.1372E-01	-0.1490	0.1192E-01	0.5803E-01				
2.000	-0.2846E-01	-0.1484	0.1260E-01	0.5816E-01				
2.268	-0.3867E-01	-0.1527	0.1291E-01	0.5822E-01				
2.158	-0.6061E-01	-0.1614	0.1346E-01	0.5836E-01				
2.167	-0.1197	-0.2087	0.1367E-01	0.5838E-01				
2.169	-0.4398E-01	-0.1283	0.1334E-01	0.5839E-01				
2.178	0.3340E-03	0.1560E-02	0.1318E-01	0.5839E-01				
2.268	0.4671E-01	0.3950	0.1323E-01	0.5832E-01				
2.400	0.7175E-01	0.6977	0.1358E-01	0.5811E-01				
2.700	0.1241	1.080	0.1510E-01	0.5745E-01				
3.000	0.1880	1.261	0.1742E-01	0.5649E-01				
3.300	0.2847	1.283	0.2058E-01	0.5528E-01				
3.600	0.3697	1.274	0.2544E-01	0.5377E-01	0.1621E-01	3.546	0.3854E-07	0.6737
3.900	0.5310	1.257	0.3380E-01	0.5187E-01	0.1657E-01	3.441	0.3429E-07	0.7614
4.200	0.8323	1.226	0.5123E-01	0.4935E-01	0.1866E-01	3.278	0.2890E-07	0.9038
4.222	0.8662	1.223	0.5330E-01	0.4913E-01	0.1866E-01	3.263	0.2841E-07	0.9192
4.222	2.655	0.6889	1.701	0.6539E-02	0.9038E-02	1.242	0.5868E-07	1.257
4.500	2.072	0.6903	1.451	0.5637E-02	0.9449E-02	1.294	0.8353E-07	1.066
4.800	1.771	0.6933	1.323	0.4983E-02	0.9917E-02	1.353	0.1092E-06	0.9848
5.000	1.646	0.6946	1.269	0.4647E-02	0.1023E-01	1.392	0.1261E-06	0.9215
5.100	1.596	0.6950	1.248	0.4500E-02	0.1039E-01	1.412	0.1346E-06	0.9043
5.300	1.515	0.6957	1.213	0.4239E-02	0.1070E-01	1.452	0.1517E-06	0.8761
5.500	1.451	0.6959	1.166	0.4012E-02	0.1100E-01	1.492	0.1689E-06	0.8540
6.000	1.339	0.6957	1.137	0.3554E-02	0.1175E-01	1.590	0.2127E-06	0.8156
6.500	1.267	0.6945	1.106	0.3202E-02	0.1247E-01	1.686	0.2580E-06	0.7912
7.000	1.216	0.6931	1.084	0.2921E-02	0.1317E-01	1.779	0.3050E-06	0.7745
8.000	1.151	0.6899	1.056	0.2494E-02	0.1460E-01	1.959	0.4038E-06	0.7540
9.000	1.112	0.6870	1.039	0.2183E-02	0.1573E-01	2.130	0.5090E-06	0.7430
10.00	1.085	0.6845	1.028	0.1944E-02	0.1689E-01	2.293	0.6203E-06	0.7368
12.00	1.054	0.6807	1.015	0.1600E-02	0.1903E-01	2.598	0.8608E-06	0.7311
15.00	1.030	0.6771	1.008	0.1268E-02	0.2191E-01	3.014	0.1264E-05	0.7263
20.00	1.013	0.6737	1.000	0.9456E-03	0.2620E-01	3.624	0.2045E-05	0.7262
25.00	1.008	0.6719	0.9984	0.7549E-03	0.3009E-01	4.162	0.2954E-05	0.7233
30.00	1.003	0.6707	0.9976	0.6288E-03	0.3372E-01	4.649	0.3984E-05	0.7194
40.00	0.9998	0.6694	0.9974	0.4713E-03	0.4045E-01	5.520	0.6387E-05	0.7108
50.00	0.9989	0.6687	0.9975	0.3771E-03	0.4668E-01	6.298	0.9223E-05	0.7018
60.00	0.9985	0.6683	0.9978	0.3143E-03	0.5255E-01	7.015	0.1246E-04	0.6939
80.00	0.9985	0.6678	0.9982	0.2358E-03	0.6352E-01	8.330	0.2009E-04	0.6813
100.0	0.9988	0.6675	0.9985	0.1887E-03	0.7371E-01	9.543	0.2914E-04	0.6724
120.0	0.9988	0.6673	0.9988	0.1573E-03	0.8333E-01	10.69	0.3952E-04	0.6684
140.0	0.9989	0.6672	0.9989	0.1348E-03	0.9250E-01	11.80	0.5117E-04	0.6626
160.0	0.9990	0.6671	0.9991	0.1160E-03	0.1013	12.88	0.6404E-04	0.6604
180.0	0.9991	0.6671	0.9992	0.1049E-03	0.1098	13.93	0.7806E-04	0.6592
200.0	0.9992	0.6670	0.9993	0.9442E-04	0.1160	15.00	0.9322E-04	0.6602
220.0	0.9993	0.6670	0.9993	0.8584E-04	0.1260	16.03	0.1095E-03	0.6610
240.0	0.9993	0.6670	0.9994	0.7889E-04	0.1337	17.04	0.1288E-03	0.6617
260.0	0.9994	0.6669	0.9995	0.7264E-04	0.1413	18.02	0.1451E-03	0.6622
280.0	0.9994	0.6669	0.9995	0.6748E-04	0.1487	18.98	0.1645E-03	0.6627
300.0	0.9995	0.6669	0.9995	0.6296E-04	0.1580	19.92	0.1848E-03	0.6631
350.0	0.9998	0.6669	0.9998	0.5397E-04	0.1735	22.16	0.2399E-03	0.6638
400.0	0.9998	0.6668	0.9997	0.4723E-04	0.1904	24.35	0.3007E-03	0.6643
500.0	0.9997	0.6668	0.9997	0.3779E-04	0.2223	28.47	0.4389E-03	0.6650
600.0	0.9998	0.6668	0.9998	0.3149E-04	0.2524	32.34	0.5980E-03	0.6654
700.0	0.9998	0.6667	0.9998	0.2699E-04	0.2811	36.02	0.7768E-03	0.6656
800.0	0.9998	0.6667	0.9999	0.2362E-04	0.3085	39.55	0.9745E-03	0.6657
900.0	0.9998	0.6667	0.9999	0.2099E-04	0.3350	42.95	0.1190E-02	0.6658
1000.	0.9999	0.6667	0.9999	0.1890E-04	0.3608	46.24	0.1424E-02	0.6658
1100.	0.9999	0.6667	0.9999	0.1718E-04	0.3855	49.42	0.1674E-02	0.6658
1200.	0.9999	0.6667	0.9999	0.1575E-04	0.4097	52.53	0.1941E-02	0.6658
1300.	0.9999	0.6667	0.9999	0.1454E-04	0.4333	55.55	0.2224E-02	0.6658
1400.	0.9999	0.6667	0.9999	0.1350E-04	0.4564	58.51	0.2523E-02	0.6658
1500.	0.9999	0.6667	0.9999	0.1260E-04	0.4790	61.41	0.2837E-02	0.6657

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SUBJECT

HELIUM RESERVOIR
DETERMINATION OF U - FIRE CASE

NAME

RUSS RUCINSKI

DATE

8-14-98

REVISION DATE

FIRE CASE: U DEFINED ON PAGE 19, PAR. 5.3.3, CGAS1.3-1995
THE 1" OF MLI MYLAR INSULATION CANNOT BE CONSIDERED
EFFECTIVE AT 1200°F. MYLAR IS A POLYESTER FILM
THAT SOFTENS AT 425°F TO 450°F. REFERENCE DUPONT
WEB PAGE [#http://www.dupont.com/packaging/products/films/index.htm](http://www.dupont.com/packaging/products/films/index.htm)
mylar..

REFERENCE CALCS IN APPENDIX F FOR MORE DETAIL OF
DEFINITIONS. THE MODEL USED IN THIS ANALYSIS
WILL BE;

$$U_{TOTAL\ CGA} = \frac{Q_{TOTAL}}{A_{NG.\ MEAN} \Delta T}$$

I WILL CALCULATE THE HEAT TRANSFER OF THE TOP, BOTTOM, AND SIDE
OF THE VESSEL. THEN I WILL BACK CALCULATE A
U FOR USE IN THE CGA EQN OF PAR. 5.3.3

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DETERMINATION OF T_J - FIRE CASE

NAME

RUSS RUCINSKI

DATE

8-14-98

REVISION DATE

TOP SURFACE

• CONDUCTION,

$$Q_{\text{CONDUCTION}} = \frac{A_{\text{MEAN TOP}}}{L} \int_{T_{\text{R}}}^{1200^{\circ}\text{F}} K dT$$

$$Q_{\text{CONDUCTION}} = \frac{3.4265 \text{ ft}^2}{10.2 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}}} (.121838 \frac{\text{Btu}}{\text{hr-ft}^{\circ}\text{F}}) (1660^{\circ}\text{R} - 17.75^{\circ}\text{R})$$

$$Q_{\text{COND. TOP}} = 806.6 \frac{\text{Btu}}{\text{hr}} \quad \text{CONDUCTION TOP}$$

• RADIATION,

$$\epsilon_L = 0.40 \quad (\text{STN. SPR} \quad 1200^{\circ}\text{F})$$

REF. PAGE F2 CALLS FOR
DETAILS OF EMISS ETC.

$$\epsilon_j = 0.22 \quad \text{VESSEL}$$

$$g_{Lj} = \frac{G(T_i^4 - T_j^4)}{\frac{1 - \epsilon_i}{\epsilon_i A_i} + \frac{1}{A_i F_{ij}} + \frac{1 - \epsilon_j}{\epsilon_j A_j}}$$

$$= \frac{(0.1714 \times 10^{-8} \frac{\text{Btu}}{\text{hr-ft}^2 \cdot ^{\circ}\text{R}^4}) (1660^4 - 18^4)}{\frac{1 - 0.4}{.4 (5.9655 \text{ ft}^2)} + \frac{1}{(5.9655 \text{ ft}^2) (.05)} + \frac{1 - 0.22}{0.22 (.8875 \text{ ft}^2)}}$$

$$= \frac{13,015 \frac{\text{Btu}}{\text{hr-ft}^2}}{.251446 \frac{1}{\text{ft}^2} + 3.352611 \frac{1}{\text{ft}^2} + 3.944878 \frac{1}{\text{ft}^2}} =$$

$$g_{Lj} = 1713 \frac{\text{Btu}}{\text{hr}} \quad \text{RADIATION TOP}$$

BOTTOM SURFACE

CONVECTION

$$R_{\text{CONV}} = \frac{1}{h_{\text{SHELL}} A_{\text{SHELL}}} + \frac{1}{h_{\text{VESSEL}} A_{\text{VESSEL}}}$$

$$h_{\text{SHELL}}; \quad T_s = 1660^{\circ}\text{R}, \quad T_{\infty} = \frac{922\text{K} + 10\text{K}}{2} = 466\text{K}$$

$$T_{\text{FILM}} = \frac{T_s + T_{\infty}}{2} = 694\text{K}$$

I WILL USE 700 K IN TABLES

$$\nu_{\text{HE}, T_{\text{FILM}}} = \frac{\mu}{\rho} = \frac{36.02 \times 10^{-6} \text{ Pa}\cdot\text{s}}{.06967 \frac{\text{kg}}{\text{m}^3}} = 5.17 \times 10^{-4} \text{ m}^2/\text{s}$$

$$\alpha = .7768 \times 10^{-3} \text{ m}^2/\text{s}$$

$$Ra_L = \frac{g \beta (T_s - T_{\infty}) L^3}{\nu \alpha} = \frac{(9.81 \text{ m/s}^2) (\frac{1}{694\text{K}}) (922\text{K} - 466\text{K}) (.210\text{m})^3}{(5.17 \times 10^{-4} \text{ m}^2/\text{s}) (.7768 \times 10^{-3} \text{ m}^2/\text{s})} = 1.4864 \times 10^5$$

$$Nu_L = .54 Ra_L^{1/4} = 10.603$$

MATH CHK'D
J. Y. Jada
8-17-98

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$$h_{\text{BOTTOM SHELL}} = \frac{\bar{Nu}_L k}{L} = \frac{(10.603)(.2811 \frac{W}{m \cdot K})}{.210 m} = 14.2 \frac{W}{m^2 K}$$

$$h_{\text{VESSEL}}; T_s = 10 K, T_a = 466 K, T_{\text{film}} = \frac{T_s + T_a}{2} = 238 K$$

I WILL USE 240K IN TABLES

$$\mu_{\text{air film}} = \frac{17.04 \times 10^{-6} \text{ Pa} \cdot \text{s}}{.2031 \text{ kg/m}^3} = 8.390 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\alpha = .1268 \times 10^{-3} \text{ m}^2/\text{s}$$

$$Ra_L = \frac{(9.81 \text{ m/s}^2)(\frac{1}{238 K})(466 K - 10 K)(.081 m)^3}{(8.390 \times 10^{-5} \text{ m}^2/\text{s})(.1268 \times 10^{-3} \text{ m}^2/\text{s})} = 9.389 \times 10^5$$

$$\bar{Nu}_L = .54 Ra_L^{1/4} = 16.81$$

at 240K, P=1ATM

$$h_{\text{VESSEL BOTTOM}} = \frac{\bar{Nu}_L k}{L} = \frac{(16.81)(.1337 \frac{W}{m \cdot K})}{.081 m} = 27.75 \frac{W}{m^2 K}$$

$$R_{\text{conv.}} = \frac{1}{(14.2 \frac{W}{m^2 K})(.55421 m^2)} + \frac{1}{(27.75 \frac{W}{m^2 K})(.08245 m^2)}$$

$$R_{\text{conv.}} = 0.5642 \text{ K/W}$$

$$Q_{\text{CONVECTION}} = \frac{\Delta T}{R} = \frac{922 K - 10 K}{.5642 \text{ K/W}} = 1616.5 W$$

$$= 1616.5 W \times \frac{3.4129 \text{ Btu/hr}}{1 W} = 5517 \text{ Btu/hr}$$

CONVECTION
BOTTOM

$$q_{\text{Bottom}} = q_{\text{Top}} = 1713 \text{ Btu/hr}$$

RADIATION
BOTTOM

MATH CHK'D
J. McDade
8-17-98

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• SIDE

CONVECTION, USE SAME ANALYSIS METHOD AS ON PAGE F6 & F7

$$q_{conv.} = h(T_1 - T_2) A_{MEAN SIDES}$$

$$T_1 = 1660^\circ R \quad T_2 = 18^\circ R \quad \bar{T} = 466 K \quad \text{FOR DETERMINING PROPERTIES.}$$

$$922 K \quad = 10 K$$

$$Pr (P=1 atm, T=466 K) = .66476$$

$$\alpha = 3.92 \times 10^{-4} m^2/s$$

$$\nu = \mu/\rho = \frac{27.07 \times 10^{-6} Pa \cdot s}{.10582 kg/m^3} = 2.558 \times 10^{-4} m^2/s$$

NOTE ASSUMES
MLI IS MELTED
AWAY.

$$Ra_L = \frac{g(\beta)(T_1 - T_2)L^3}{\alpha \nu} = \frac{(9.81 m/s^2)(\frac{1}{466 K})(922 K - 10 K)(10.2 m \times \frac{0.0254 m}{in})^3}{(2.558 \times 10^{-4} m^2/s)(3.92 \times 10^{-4} m^2/s)}$$

$$Ra_L = 3.330 \times 10^6$$

$$Nu_L = .22 \left(\frac{Pr}{0.2 + Pr} \cdot Ra_L \right)^{.28} \left(\frac{\mu}{\mu_s} \right)^{-.14} = .22 \left(\frac{.66476}{.86476} (3.33 \times 10^6) \right)^{.28} (1.93)^{-.25}$$

$$Nu_L = 11.62$$

$$\bar{h} = \frac{Nu_L k}{L} = \frac{(11.62)(.21145 \frac{W}{m \cdot K})}{(10.2)(.0254 m)} = 9.484 \frac{W}{m^2 K}$$

$$q_{conv. SIDE} = h(T_1 - T_2) A_{MEAN} = 9.484 \frac{W}{m^2 K} (922 K - 10 K) (25.323 ft^2) \left(\frac{.3048 m}{ft} \right)^2$$

$$q_{conv. SIDE} = 20,348 W = \boxed{69,447 \frac{Btu}{hr}} \quad \text{CONVECTION SIDE}$$

RADIATION, $q_{ij} = \frac{\sigma(T_i^4 - T_j^4)}{\frac{1 - \epsilon_i}{\epsilon_i A_i} + \frac{1}{A_i F_{ij}} + \frac{1 - \epsilon_j}{\epsilon_j A_j}}$

$\epsilon_i = 0.40$ SHELL @ 1200°R

$\epsilon_j = .22$ STN. STL @ 18°R

$$q_{ij} = \frac{(.1714 \times 10^{-8} \frac{Btu}{hr \cdot ft^2 \cdot ^\circ R^4})(1660^4 - 18^4 \cdot e^4)}{\frac{1 - .4}{(.4)(\pi(5.217 ft)(2.756 ft))} + \frac{1}{\pi(5.217 ft)(2.756 ft) \frac{1.063(1.640)}{5.217(2.756)}} + \frac{1 - .22}{.22(\pi)1.063(1.640 ft)}}$$

$$q_{ij} = \frac{13,015 \frac{Btu}{hr \cdot ft^2}}{.033208 ft^2 + .182588 ft^2 + .647359 ft^2} = \boxed{15,078 \frac{Btu}{hr}} \quad \text{RADIATION SIDE}$$

MATH CHK'D
SYM Dade 8-17-98

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SUBJECT

HELIUM RESERVOIR

DETERMINATION OF U - FIRE CASE

NAME

RUSS RUCINSKI

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8-14-98

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SUMMARY OF COMPONENTS : FIRE CASE

	GHE CONDUCTION THRU SPACE	GHE CONVECTION THRU SPACE	RADIATION THRU SPACE	TOTAL
TOP	806.6 $\frac{\text{Btu}}{\text{hr}}$	N/A	1713 $\frac{\text{Btu}}{\text{hr}}$	2520 $\frac{\text{Btu}}{\text{hr}}$
BOTTOM	N/A	5517 $\frac{\text{Btu}}{\text{hr}}$	1713 $\frac{\text{Btu}}{\text{hr}}$	7230 $\frac{\text{Btu}}{\text{hr}}$
SIDE	N/A	69,447 $\frac{\text{Btu}}{\text{hr}}$	15,078 $\frac{\text{Btu}}{\text{hr}}$	84,525 $\frac{\text{Btu}}{\text{hr}}$
				94,275 $\frac{\text{Btu}}{\text{hr}}$

$$U_{\text{AVG CGA}} = \frac{Q_{\text{TOTAL}}}{A_{\text{AVG MEAN}} \cdot \Delta T} = \frac{94,275 \frac{\text{Btu}}{\text{hr}}}{32.2 \text{ ft}^2 (1660^\circ\text{R} - 18^\circ\text{R})}$$

$$U_{\text{AVG CGA FIRE}} = 1.783 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{R}}$$

COMPARISON OF U BASED ON INTERPRETATION OF CGA 51.3-1995

I. INCORRECT INTERPRETATION

$$U = \frac{k_{\text{HE}}}{t_{\text{SPACE}}} = \frac{.121838 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}}}{10.2 \text{ IN} \left(\frac{1 \text{ ft}}{12 \text{ IN}} \right)} = .144 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$

II. INCORRECT INTERPRETATION, NEGLECT SPACE ASSUME 1" MLI IS IN PLACE

$$U = \frac{k_{\text{HE}}}{t_{\text{MLI}}} = \frac{.121838 \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot ^\circ\text{F}}}{1 \text{ IN} \left(\frac{1 \text{ IN}}{12 \text{ IN}} \right)} = 1.462 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$

III CORRECT INTERPRETATION, EVALUATION OF EFFECTIVENESS OF SPACE, MLI MELTS / DISSAPPEARS

$$U = 1.783 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{R}}$$

MATH CHK'D
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