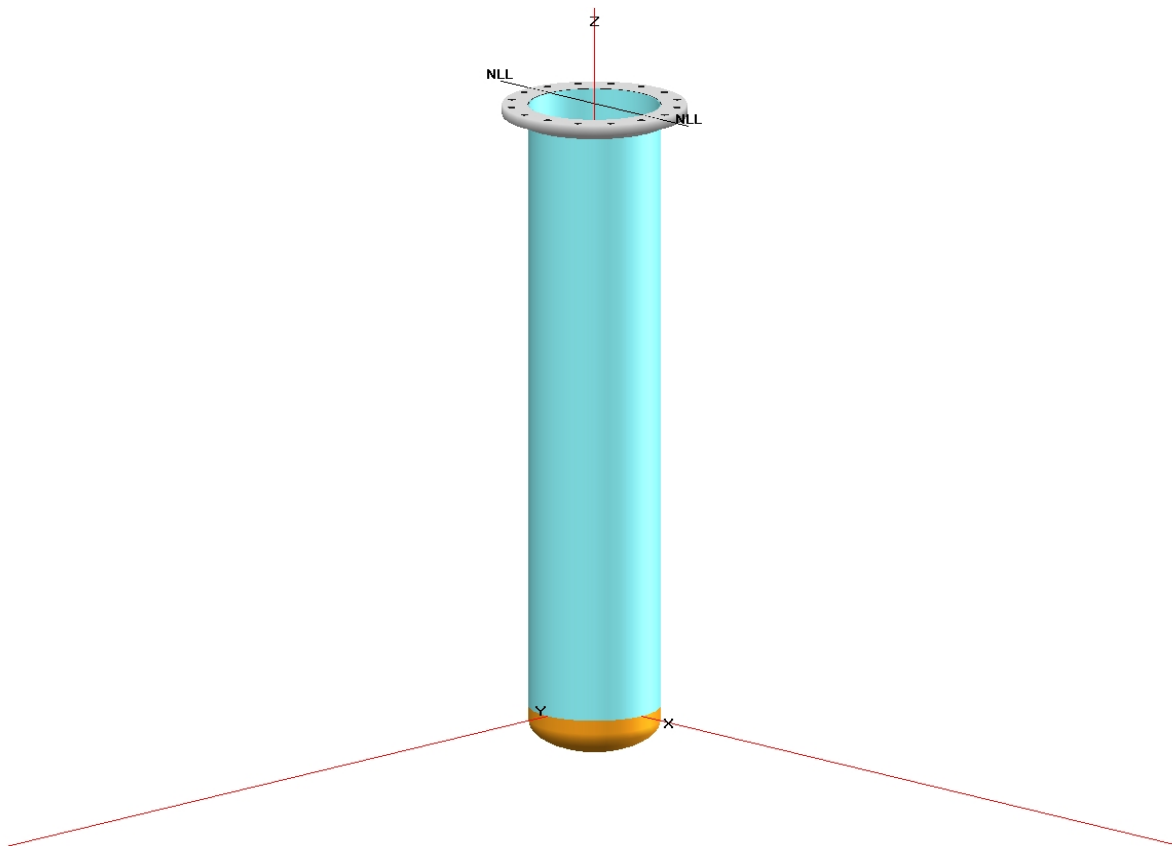


PHPK Technologies

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COMPRESS Pressure Vessel Design Calculations

Item: DES Pressure Vessel
Customer: Fermi National Accelerator laboratory
Diameter/Thk 18" Sch 10S Pipe (.188 Wall)
Design Pressure 165 psig
Revision Date July 26, 2007

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Nozzle Schedule

Nozzle mark	Service	Size	Materials								
			Nozzle	Impact	Norm	Fine Grain	Pad	Impact	Norm	Fine Grain	Flange

Nozzle Summary

Nozzle mark	OD (in)	t_n (in)	Req t_n (in)	$A_1?$	$A_2?$	Shell			Reinforcement Pad		Corr (in)	A_a/A_r (%)
						Nom t (in)	Design t (in)	User t (in)	Width (in)	t_{pad} (in)		

t_n : Nozzle thickness

Req t_n : Nozzle thickness required per UG-45/UG-16

Nom t: Vessel wall thickness

Design t: Required vessel wall thickness due to pressure + corrosion allowance per UG-37

User t: Local vessel wall thickness (near opening)

A_a : Area available per UG-37, governing condition

A_r : Area required per UG-37, governing condition

Corr: Corrosion allowance on nozzle wall

Pressure Summary

Pressure Summary for Chamber bounded by Ellipsoidal Head #1 and Top of vessel

Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MAEP (psi)	T _e external (°F)	MDMT (°F)	MDMT Exemption	Total Corrosion Allowance (in)	Impact Test
Cylinder #1	165.0	120.0	263.45	266.06	34.75	120.0	-320.0	Note 1	0.000	No
Straight Flange on Ellipsoidal Head #1	165.0	120.0	355.44	358.10	47.94	120.0	-320.0	Note 1	0.000	No
Ellipsoidal Head #1	165.0	120.0	250.85	253.64	73.96	120.0	-320.0	Note 2	0.000	No
Flange #1	165.0	120.0	266.00	275.00	N/A	120.0	-55.0	Note 3, 4	0.000	No

Chamber design MDMT is -320.00°F

Chamber rated MDMT is -55.00°F @ 250.85 psi

Chamber MAWP was used in the MDMT determination

Chamber MAWP hot & corroded is 250.85 psi @ 120.0°F

Chamber MAP cold & new is 253.64 psi @ 70.0°F

Chamber MAEP is 34.75 psi @ 120.0°F

Vacuum rings did not govern the external pressure rating.

Notes for MDMT Rating:

Note #	Exemption	Details
1.	Rated MDMT per UHA-51(d)(1)(a) = -320 °F	
2.	Straight Flange governs MDMT	
3.	Per UHA-51(d)(1)(a)	
4.	Flange rated MDMT = -320 °F	Bolts rated MDMT per Fig UCS-66 note (e) = -55 °F

Design notes are available on the [Settings Summary](#) page.

Revision History

No.	Date	Operator	Notes
0	6/28/2007	Steve Willming	New vessel created ASME Division 1 [Build 6252]

Settings Summary

COMPRESS Build 6252

Units: U.S. Customary

Datum Line Location: 0.00" from bottom seam

Design

ASME Section VIII Division 1, 2004 Edition, A06 Addenda

Design or Rating:	Get Thickness from Pressure
Minimum thickness:	1/16" per UG-16(b)
Design for cold shut down only:	No
Design for lethal service (full radiography required):	No
Design nozzles for:	Design P, find nozzle MAWP and MAP
Corrosion weight loss:	100% of theoretical loss
UG-23 Stress Increase:	1.20
Skirt/legs stress increase:	1.0
Minimum nozzle projection:	1.5000"
Juncture calculations for $\alpha > 30$ only:	Yes
Preheat P-No 1 Materials $> 1.25"$ and $\leq 1.50"$ thick:	No

Butt welds are tapered per Figure UCS-66.3(a).

Hydro/Pneumatic Test

Shop Hydrotest Pressure:	1.3 times vessel MAWP
Test liquid specific gravity:	1.00
Maximum stress during test:	90% of yield

Required Marking - UG-116

UG-116 (e) Radiography:	None
UG-116 (f) Postweld heat treatment:	None

Code Interpretations

Use Code Case 2547:	No
Apply interpretation VIII-1-83-66:	Yes
Apply interpretation VIII-1-86-175:	Yes
Apply interpretation VIII-1-83-115:	Yes
Apply interpretation VIII-1-01-37:	Yes
Disallow UG-20(f) exemptions:	No

UG-22 Loadings

UG-22 (a) Internal or External Design Pressure :	Yes
UG-22 (b) Weight of the vessel and normal contents under operating or test conditions:	No

UG-22 (c) Superimposed static reactions from weight of attached equipment (external loads): No
UG-22 (d)(2) Vessel supports such as lugs, rings, skirts, saddles and legs: No
UG-22 (f) Wind reactions: No
UG-22 (f) Seismic reactions: No

Note: UG-22 (b),(c) and (f) loads only considered when supports are present.

Thickness Summary

Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Joint E	Load
Cylinder #1	SA-312 TP304 Wld pipe	18.00 OD	90.00	0.1880	0.1175	0.8500	External
Straight Flange on Ellipsoidal Head #1	SA-240 304	18.00 OD	2.00	0.1880	0.1175	0.8500	External
Ellipsoidal Head #1	SA-240 304	18.00 OD	4.57	0.1325*	0.0881	0.8500	Internal

Nominal t: Vessel wall nominal thickness

Design t: Required vessel thickness due to governing loading + corrosion

Joint E: Longitudinal seam joint efficiency

* Head minimum thickness after forming

Load

internal: Circumferential stress due to internal pressure governs

external: External pressure governs

Wind: Combined longitudinal stress of pressure + weight + wind governs

Seismic: Combined longitudinal stress of pressure + weight + seismic governs

Weight Summary

Component	Weight (lb) Contributed by Vessel Elements						
	Metal New*	Metal Corroded*	Insulation & Supports	Lining	Piping + Liquid	Operating Liquid	Test Liquid
Cylinder #1	274.57	274.57	0.00	0.00	0.00	634.02	0.00
Ellipsoidal Head #1	20.29	20.29	0.00	0.00	0.00	35.18	0.00
TOTAL:	294.86	294.86	0.00	0.00	0.00	669.20	0.00

* Shells with attached nozzles have weight reduced by material cut out for opening.

Component	Weight (lb) Contributed by Attachments								
	Body Flanges		Nozzles & Flanges		Packed Beds	Ladders & Platforms	Trays & Supports	Rings & Clips	Vertical Loads
	New	Corroded	New	Corroded					
Cylinder #1	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ellipsoidal Head #1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL:	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Vessel operating weight, Corroded: 1,094 lb

Vessel operating weight, New: 1,094 lb

Vessel empty weight, Corroded: 425 lb

Vessel empty weight, New: 425 lb

Vessel test weight, New: 425 lb

Vessel center of gravity location - from datum - lift condition

Vessel Lift Weight, New: 425 lb

Center of Gravity: 56.08"

Vessel Capacity

Vessel Capacity** (New): 100 US gal

Vessel Capacity** (Corroded): 100 US gal

**The vessel capacity does not include volume of nozzle, piping or other attachments.

Hydrostatic Test

Shop test pressure determination for Chamber bounded by Ellipsoidal Head #1 and Top of vessel based on MAWP per UG-99(b)

Shop hydrostatic test gauge pressure is 326.103 psi at 70.00 °F (the chamber MAWP = 250.848 psi)

The shop test is performed with the vessel in the horizontal position.

Identifier	Local test pressure psi	Test liquid static head psi	UG-99 stress ratio	UG-99 pressure factor	Stress during test psi	Allowable test stress psi	Stress excessive?
Cylinder #1 (1)	326.103	0.000	1.0000	1.30	17,631	27,000	No
Flange #1	326.103	0.000	N/A	1.30	NI	NI	NI
Straight Flange on Ellipsoidal Head #1	326.103	0.000	1.0000	1.30	15,448	27,000	No
Ellipsoidal Head #1	326.103	0.000	1.0000	1.30	19,642	27,000	No

Notes:

- (1) Cylinder #1 limits the UG-99 stress ratio.
- (2) NI indicates that test stress was not investigated.
- (3) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

The field test condition has not been investigated for the Chamber bounded by Ellipsoidal Head #1 and Top of vessel.

Vacuum Summary

Component	Line of Support	Elevation above Datum (in)	Length Le (in)
-	Flange #1	90.19	N/A
-	Flange #1	90.19	N/A
Cylinder #1 Top	-	90.00	93.67
Cylinder #1 Bottom	-	0.00	93.67
Straight Flange on Ellipsoidal Head #1 Top	-	0.00	93.67
Straight Flange on Ellipsoidal Head #1 Bottom	-	-2.00	93.67
-	1/3 depth of Ellipsoidal Head #1	-3.48	N/A
Ellipsoidal Head #1	-	-6.57	N/A

Note
For main components, the listed value of 'Le' is the largest unsupported length for the component.

Cylinder #1**ASME Section VIII Division 1, 2004 Edition, A06 Addenda**

Component: Cylinder
 Material specification: SA-312 TP304 Wld pipe (II-D p. 86, ln. 11)
 Pipe NPS and Schedule: 18" Sch 10S
 Rated MDMT per UHA-51(d)(1)(a) = -320 °F

Internal design pressure: $P = 165$ psi @ 120°F
 External design pressure: $P_e = 15$ psi @ 120°F

Static liquid head:

$P_s = 2.6044$ psi (SG=0.8000, $H_s = 90.1880$ " Operating head)
 $P_{th} = 0.0000$ psi (SG=0.0000, $H_s = 17.9020$ ", Horizontal test head)

Corrosion allowance: Inner C = 0.0000" Outer C = 0.0000"

Design MDMT = -320.00°F No impact test performed
 Rated MDMT = -320.00°F Material is not normalized
 Material is not produced to
 Fine Grain Practice
 PWHT is not performed

Radiography: Longitudinal joint - Seamless No RT
 Top circumferential joint - N/A
 Bottom circumferential joint - None UW-11(c) Type 2

Estimated weight: New = 274.5746 lb corr = 274.5746 lb
 Capacity: New = 95.0450 gal corr = 95.0450 gal

OD = 18.0000"
 Length $L_c = 90.0000$ "
 $t = 0.1880$ "

Design thickness, (at 120.00°F) Appendix 1-1

$$\begin{aligned} t &= P \cdot R_o / (S \cdot E + 0.40 \cdot P) + \text{Corrosion} \\ &= 167.60 \cdot 9.0000 / (17000 \cdot 0.85 + 0.40 \cdot 167.60) + 0.0000 \\ &= 0.1040" \end{aligned}$$

Maximum allowable working pressure, (at 120.00°F) Appendix 1-1

$$\begin{aligned} P &= S \cdot E \cdot t / (R_o - 0.40 \cdot t) - P_s \\ &= 17000 \cdot 0.85 \cdot 0.1645 / (9.0000 - 0.40 \cdot 0.1645) - 2.6044 \\ &= 263.4547 \text{ psi} \end{aligned}$$

Maximum allowable pressure, (at 70.00°F) Appendix 1-1

$$\begin{aligned} P &= S \cdot E \cdot t / (R_o - 0.40 \cdot t) \\ &= 17000 \cdot 0.85 \cdot 0.1645 / (9.0000 - 0.40 \cdot 0.1645) \\ &= 266.0591 \text{ psi} \end{aligned}$$

External Pressure, (Corroded & at 120.00°F) UG-28(c)

$$L/D_o = 93.6659/18.0000 = 5.2037$$

$$D_o/t = 18.0000/0.117530 = 153.1526$$

From table G: A = 0.000123

From table HA-1: B = 1722.9647 psi

$$\begin{aligned} P_a &= 4*B/(3*(D_o/t)) \\ &= 4*1722.9647/(3*(18.0000/0.117530)) \\ &= 15.0000 \text{ psi} \end{aligned}$$

Design thickness for external pressure $P_a = 15.0000$ psi

$$= t + \text{Corrosion} = 0.117530 + 0.0000 = 0.1175"$$

Maximum Allowable External Pressure, (Corroded & at 120.00°F) UG-28(c)

$$L/D_o = 93.6659/18.0000 = 5.2037$$

$$D_o/t = 18.0000/0.1645 = 109.4225$$

From table G: A = 0.000204

From table HA-1: B = 2851.7754 psi

$$\begin{aligned} P_a &= 4*B/(3*(D_o/t)) \\ &= 4*2851.7754/(3*(18.0000/0.1645)) \\ &= 34.7494 \text{ psi} \end{aligned}$$

Flange #1

Flange description:	18 inch Class 150 SO A182 F304
Bolt Material:	SA-193 B7 Bolt <= 2 1/2
Flange rated MDMT: (Per UHA-51(d)(1)(a))	-55°F
(Flange rated MDMT = -320 °F)	
Bolts rated MDMT per Fig UCS-66 note (e) = -55 °F)	
Liquid static head on flange:	0 psi
ASME B16.5 flange rating MAWP:	266 psi @ 120°F
ASME B16.5 flange rating MAP:	275 psi @ 70°F
ASME B16.5 flange hydro test:	425 psi @ 70°F

Straight Flange on Ellipsoidal Head #1

ASME Section VIII Division 1, 2004 Edition, A06 Addenda

Component: Straight Flange
 Material specification: SA-240 304 (II-D p. 82, ln. 38)
 Rated MDMT per UHA-51(d)(1)(a) = -320 °F

Internal design pressure: $P = 165$ psi @ 120°F
 External design pressure: $P_e = 15$ psi @ 120°F

Static liquid head:

$P_s = 2.6622$ psi (SG=0.8000, $H_s=92.1880$ " Operating head)
 $P_{th} = 0.0000$ psi (SG=0.0000, $H_s=17.9020$ ", Horizontal test head)

Corrosion allowance: Inner C = 0.0000" Outer C = 0.0000"

Design MDMT = -320.00°F No impact test performed
 Rated MDMT = -320.00°F Material is not normalized
 Material is not produced to
 Fine Grain Practice
 PWHT is not performed

Radiography: Longitudinal joint - Seamless No RT
 Circumferential joint - None UW-11(c) Type 2

Estimated weight: New = 6.1017 lb corr = 6.1017 lb
 Capacity: New = 2.1121 gal corr = 2.1121 gal

OD = 18.0000"
 Length $L_c = 2.0000$ "
 $t = 0.1880$ "

Design thickness, (at 120.00°F) Appendix 1-1

$$\begin{aligned} t &= P \cdot R_o / (S \cdot E + 0.40 \cdot P) + \text{Corrosion} \\ &= 167.66 \cdot 9.0000 / (20000 \cdot 0.85 + 0.40 \cdot 167.66) + 0.0000 \\ &= 0.0885" \end{aligned}$$

Maximum allowable working pressure, (at 120.00°F) Appendix 1-1

$$\begin{aligned} P &= S \cdot E \cdot t / (R_o - 0.40 \cdot t) - P_s \\ &= 20000 \cdot 0.85 \cdot 0.1880 / (9.0000 - 0.40 \cdot 0.1880) - 2.6622 \\ &= 355.4411 \text{ psi} \end{aligned}$$

Maximum allowable pressure, (at 70.00°F) Appendix 1-1

$$\begin{aligned} P &= S \cdot E \cdot t / (R_o - 0.40 \cdot t) \\ &= 20000 \cdot 0.85 \cdot 0.1880 / (9.0000 - 0.40 \cdot 0.1880) \\ &= 358.1033 \text{ psi} \end{aligned}$$

External Pressure, (Corroded & at 120.00°F) UG-28(c)

$$L/D_o = 93.6659/18.0000 = 5.2037$$

$$D_o/t = 18.0000/0.117530 = 153.1526$$

From table G: A = 0.000123

From table HA-1: B = 1722.9647 psi

$$P_a = 4*B/(3*(D_o/t))$$

$$= 4*1722.9647/(3*(18.0000/0.117530))$$

$$= 15.0000 \text{ psi}$$

Design thickness for external pressure $P_a = 15.0000$ psi

$$= t + \text{Corrosion} = 0.117530 + 0.0000 = 0.1175"$$

Maximum Allowable External Pressure, (Corroded & at 120.00°F) UG-28(c)

$$L/D_o = 93.6659/18.0000 = 5.2037$$

$$D_o/t = 18.0000/0.1880 = 95.7447$$

From table G: A = 0.000247

From table HA-1: B = 3442.8372 psi

$$P_a = 4*B/(3*(D_o/t))$$

$$= 4*3442.8372/(3*(18.0000/0.1880))$$

$$= 47.9447 \text{ psi}$$

% Forming Strain - UHA-44(a)(2)(a)

$$= (50 * t / R_f) * (1 - R_f / R_o)$$

$$= (50 * 0.1880 / 8.9060) * (1 - 8.9060 / \infty)$$

$$= 1.0555 \%$$

Ellipsoidal Head #1

ASME Section VIII, Division 1, 2004 Edition, A06 Addenda

Component: Ellipsoidal Head
 Material Specification: SA-240 304 (II-D p.82, ln. 38)
[Straight Flange](#) governs MDMT

Internal design pressure: P = 165 psi @ 120 °F
 External design pressure: P_e = 15 psi @ 120 °F

Static liquid head:

P_s = 2.7902 psi (SG=0.8, H_s=96.6218" Operating head)

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -320°F No impact test performed
 Rated MDMT = -320°F Material is not normalized
 Material is not produced to fine grain practice
 PWHT is not performed
 Do not Optimize MDMT / Find MAWP

Radiography: Category A joints - Seamless No RT
 Head to shell seam - None UW-11(c) Type 2

Estimated weight*: new = 20.3 lb corr = 20.3 lb
 Capacity*: new = 5.3 US gal corr = 5.3 US gal

* includes straight flange

Outer diameter = 18"
 Minimum head thickness = 0.1325"
 Head ratio D/2h = 2 (new)
 Head ratio D/2h = 2 (corroded)
 Straight flange length L_{sf} = 2"
 Nominal straight flange thickness t_{sf} = 0.188"

Insulation thk*: 0" density: 0 lb/ft³ weight: 0 lb
 Insulation support ring spacing: 0" individual weight: 0 lb total weight: 0 lb
 Lining/ref thk*: 0" density: 0 lb/ft³ weight: 0 lb

* includes straight flange if applicable

Results Summary

The governing condition is internal pressure.
 Minimum thickness per UG-16 = 0.0625" + 0" = 0.0625"
 Design thickness due to internal pressure (t) = 0.0881"
 Design thickness due to external pressure (t_e) = 0.0469"
 Maximum allowable working pressure (MAWP) = 250.8483 psi
 Maximum allowable pressure (MAP) = 253.6385 psi
 Maximum allowable external pressure (MAEP) = 73.9572 psi

K (Corroded)

$$\begin{aligned} K &= (1/6)*[2 + (D / (2*h))^2] \\ &= (1/6)*[2 + (17.735 / (2*4.4338))^2] \\ &= 1 \end{aligned}$$

K (New)

$$\begin{aligned}
 K &= (1/6)*[2 + (D / (2*h))^2] \\
 &= (1/6)*[2 + (17.735 / (2*4.4338))^2] \\
 &= 1
 \end{aligned}$$

Design thickness for internal pressure, (Corroded at 120 °F) Appendix 1-4(c)

$$\begin{aligned}
 t &= P*D_o*K / (2*S*E + 2*P*(K - 0.1)) + \text{Corrosion} \\
 &= 167.7902*18*1 / (2*20000*0.85 + 2*167.7902*(1 - 0.1)) + 0 \\
 &= 0.088"
 \end{aligned}$$

The head internal pressure design thickness is 0.0881".

Maximum allowable working pressure, (Corroded at 120 °F) Appendix 1-4(c)

$$\begin{aligned}
 P &= 2*S*E*t / (K*D_o - 2*t*(K - 0.1)) - P_s \\
 &= 2*20000*0.85*0.1325 / (1*18 - 2*0.1325*(1 - 0.1)) - 2.7902 \\
 &= 250.8483 \text{ psi}
 \end{aligned}$$

The maximum allowable working pressure (MAWP) is 250.8483 psi.

Maximum allowable pressure, (New at 70 °F) Appendix 1-4(c)

$$\begin{aligned}
 P &= 2*S*E*t / (K*D_o - 2*t*(K - 0.1)) - P_s \\
 &= 2*20000*0.85*0.1325 / (1*18 - 2*0.1325*(1 - 0.1)) - 0 \\
 &= 253.6385 \text{ psi}
 \end{aligned}$$

The maximum allowable pressure (MAP) is 253.6385 psi.

Design thickness for external pressure, (Corroded at 120 °F) UG-33(d)

Equivalent outside spherical radius (R_o)

$$\begin{aligned}
 R_o &= K_o*D_o \\
 &= 0.8869 * 18 \\
 &= 15.965 \text{ in}
 \end{aligned}$$

$$\begin{aligned}
 A &= 0.125 / (R_o/t) \\
 &= 0.125 / (15.965/0.046817) \\
 &= 0.000367
 \end{aligned}$$

From Table HA-1: B=5,115.1064 psi

$$\begin{aligned}
 P_a &= B/(R_o/t) \\
 &= 5115.106/(15.965/0.046817) \\
 &= 15 \text{ psi}
 \end{aligned}$$

$$t = 0.0468" + \text{Corrosion} = 0.0468" + 0" = 0.0468"$$

Check the external pressure per UG-33(a)(1) Appendix 1-4(c)

$$\begin{aligned}
 t &= 1.67*P_e*D_o*K / (2*S*E + 2*1.67*P_e*(K - 0.1)) + \text{Corrosion} \\
 &= 1.67*15*18*1 / (2*20000*1 + 2*1.67*15*(1 - 0.1)) + 0 \\
 &= 0.0113"
 \end{aligned}$$

The head external pressure design thickness (t_e) is 0.046817".

Maximum Allowable External Pressure, (Corroded at 120 °F) UG-33(d)

Equivalent outside spherical radius (R_o)

$$\begin{aligned} R_o &= K_o * D_o \\ &= 0.8869 * 18 \\ &= 15.965 \text{ in} \end{aligned}$$

$$\begin{aligned} A &= 0.125 / (R_o/t) \\ &= 0.125 / (15.965/0.1325) \\ &= 0.001037 \end{aligned}$$

From Table HA-1: $B=8,911.1270$ psi

$$\begin{aligned} P_a &= B/(R_o/t) \\ &= 8911.127/(15.965/0.1325) \\ &= 73.9572 \text{ psi} \end{aligned}$$

Check the Maximum External Pressure, UG-33(a)(1) Appendix 1-4(c)

$$\begin{aligned} P &= 2 * S * E * t / ((K * D_o - 2 * t * (K - 0.1)) * 1.67) - P_{s2} \\ &= 2 * 20000 * 1 * 0.1325 / ((1 * 18 - 2 * 0.1325 * (1 - 0.1)) * 1.67) - 0 \\ &= 178.6816 \text{ psi} \end{aligned}$$

The maximum allowable external pressure (MAEP) is 73.9572 psi.

% Forming strain - UHA-44(a)(2)(a)

$$\begin{aligned} &= (75 * t / R_f) * (1 - R_f / R_o) \\ &= (75 * 0.188 / 3.109) * (1 - 3.109 / \infty) \\ &= 4.5353\% \end{aligned}$$

Liquid Level bounded by Ellipsoidal Head #1

Location from datum 90.1880"

Operating Liquid Specific Gravity 0.8000

Test liquid specific gravity 0.0000