

*HALF PIPE JACKET
RE-RATE*



Premier Boiler & COMBUSTION

Pressure Vessel Design Calculations

Item: C9000 Half Pipe Jacket

Drawing No.: 1-151-A

Alteration Code: NBIC Part 3 - 2023 Edition

Alteration Design Code: ASME Section VIII, Div. 1 - 2023 Edition

Alteration Calculations Revision A
Scope Of Work
Re-rate Half Pipe Jacket to 90psi @ 335°F

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Revision History

Revisions			
No.	Date	Operator	Notes
A	6/10/2024	J Lowry, LLC	New vessel created ASME Section VIII Division 1 [COMPRESS 2024 Build 8400]

Deficiencies Summary

No deficiencies found.

Warnings Summary

Warnings for [Half Pipe Jacket](#)

Longitudinal seam is assumed to be made without filler metal. (warning)

Warnings for Vessel

Supports have not been added to this vessel; combined loads are not being considered. (warning)

Changes to steelmaking practices have increased the risk of brittle fracture at temperatures higher than the ASME impact test exemption temperatures. It is highly recommended that the following supplemental requirements be applied for SA-105, SA-106 B, SA-53 seamless, and SA-234: material composition should have a minimum Mn:C ratio of 5, and SA-105 flanges should require a grain size of 7 or finer. (warning)

ASME B16.5 / B16.47 Flange Warnings Summary

Flange	Applicable Warnings
Flange #3	1
Flange #4	1
Flange #1	1
Flange #2	1

No.	Warning
1	For Class 150 flanges, ASME B16.5 para. 5.4.3 recommends gaskets to be in accordance with Nonmandatory Appendix B, Table B1, Group No. I.

Settings Summary

COMPRESS 2024 Build 8400	
ASME Section VIII Division 1, 2023 Edition	
Units	U.S. Customary
Datum Line Location	0.00" from bottom seam
Vessel Design Mode	Design Mode
Minimum thickness	0.0625" per UG-16(b)
Design for cold shut down only	No
Design for lethal service (full radiography required)	No
Design nozzles for	Design P only
Corrosion weight loss	100% of theoretical loss
UG-23 Stress Increase	1.20
Skirt/legs stress increase	1.0
Minimum nozzle projection	0.25"
Juncture calculations for $\alpha > 30$ only	Yes
Preheat P-No 1 Materials $> 1.25"$ and $\leq 1.50"$ thick	Yes
UG-37(a) shell tr calculation considers longitudinal stress	No
Cylindrical shells made from pipe are entered as minimum thickness	No
Nozzles made from pipe are entered as minimum thickness	No
ASME B16.9 fittings are entered as minimum thickness	No
Butt welds	Tapered per Figure UCS-66.3(a)
Disallow Appendix 1-5, 1-8 calculations under 15 psi	No
Hydro/Pneumatic Test	
Shop Hydrotest Pressure	1.3 times vessel MAWP [UG-99(b)]
Test liquid specific gravity	1.00
Maximum stress during test	90% of yield
Required Marking - UG-116	
Chamber bounded by F&D Head #1 and F&D Head #2	
UG-116(e) Radiography	None
UG-116(f) Postweld heat treatment	None
Half Pipe Jacket	
UG-116(e) Radiography	RT1
UG-116(f) Postweld heat treatment	None
Code Cases/Interpretations	
Use Appendix 46	No
Use UG-44(b)	Yes
Use Code Case 3035	No
Apply interpretation VIII-1-83-66	Yes
Apply interpretation VIII-1-86-175	Yes
Apply interpretation VIII-1-01-37	No
Apply interpretation VIII-1-01-150	Yes
Apply interpretation VIII-1-07-50	Yes
Apply interpretation VIII-1-16-85	Yes
No UCS-66.1 MDMT reduction	No
No UCS-68(c) MDMT reduction	No
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
UG-22(j) Test pressure and coincident static head acting during the test:	No
Note: UG-22(b),(c) and (f) loads only considered when supports are present.	
Note 2: UG-22(d)(1),(e),(f)-snow,(g),(h),(i) are not considered. If these loads are present, additional calculations must be performed.	

License Information	
Company Name	J Lowry
License	Commercial
License Key ID	33620
Support Expires	May 03, 2025
Account Number	415386935659501

Pressure Summary

Component Summary for Chamber bounded by F&D Head #1 and F&D Head #2									
Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MAEP (psi)	T _e external (°F)	MDMT (°F)	MDMT Exemption	Impact Tested
F&D Head #2	15	335	64.03	68.43	18.48	335	-320	Note 1	No
Straight Flange on F&D Head #2	15	335	204.83	219.07	50.56	335	-320	Note 2	No
Cylinder #1	15	335	168.69	180.41	50.56	335	-320	Note 3	No
Straight Flange on F&D Head #1	15	335	204.83	219.07	50.56	335	-320	Note 2	No
F&D Head #1	15	335	64.03	68.43	18.48	335	-320	Note 4	No

Chamber Summary for Chamber bounded by F&D Head #1 and F&D Head #2	
Design MDMT	-20 °F
Rated MDMT	-20 °F @ 64.03 psi
MAWP hot & corroded	64.03 psi @ 335 °F
MAP cold & new	68.48 psi @ 70 °F
MAEP	18.48 psi @ 335 °F
(1) The rated MDMT is limited to the design MDMT based on the setting in the Calculations tab of the Set Mode dialog.	

Component Summary for Half Pipe Jacket							
Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MDMT (°F)	MDMT Exemption	Impact Tested
Head Zone	90	335	556.68	598.6	-320	Note 5	No
Head Zone Outlet Elbow	90	335	199.75	275	-55	N/A	No
Head Zone Inlet Elbow	90	335	199.75	275	-55	N/A	No
Shell Zone 1	90	335	1,118.43	1,196.18	-320	Note 6	No
Shell Zone 1 Outlet Elbow	90	335	199.75	275	-55	N/A	No
Shell Zone 1 Inlet Elbow	90	335	199.75	275	-55	N/A	No

Chamber Summary for Half Pipe Jacket		
	Head Zone	Shell Zone 1
Design MDMT	-20 °F	-20 °F
Rated MDMT	-20 °F	-20 °F
MAWP hot & corroded	199.75 psi @ 335 °F	199.75 psi @ 335 °F
MAP cold & new	275 psi @ 70 °F	275 psi @ 70 °F
(1) These pressure chambers are not designed for external pressure.		
(2) The rated MDMT is limited to the design MDMT based on the setting in the Calculations tab of the Set Mode dialog.		

Notes for MDMT Rating		
Note #	Exemption	Details
1.	Straight Flange governs MDMT	
2.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2493)	
3.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2849)	
4.	Straight Flange governs MDMT	
5.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1266)	
6.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1155)	

Radiography Summary

UG-116 Radiography - Chamber bounded by F&D Head #1 and F&D Head #2							
Component	Longitudinal Seam		Top Circumferential Seam		Bottom Circumferential Seam		Mark
	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	
F&D Head #2	N/A	Seamless No RT	N/A	N/A	B	None UW-11(c) / Type 1	None
Cylinder #1	A	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	None
F&D Head #1	N/A	Seamless No RT	B	None UW-11(c) / Type 1	N/A	N/A	None
UG-116(e) Required Marking: None							

UG-116 Radiography - Half Pipe Jacket							
Component	Longitudinal Seam		Top Circumferential Seam		Bottom Circumferential Seam		Marking
	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	
Head Zone							
Head Zone	N/A	Seamless No RT	B	Full UW-11(a) Type 1	B	Full UW-11(a) Type 1	RT1
Head Zone Outlet Elbow	N/A	Seamless No RT	B	Full UW-11(a) / Type 1	C	N/A	RT1
Flange #3	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A / Type 4	N/A
Head Zone Inlet Elbow	N/A	Seamless No RT	B	Full UW-11(a) / Type 1	C	N/A	RT1
Flange #4	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A / Type 4	N/A
Shell Zone 1							
Shell Zone 1	N/A	Seamless No RT	B	Full UW-11(a) Type 1	B	Full UW-11(a) Type 1	RT1
Shell Zone 1 Outlet Elbow	N/A	Seamless No RT	B	Full UW-11(a) / Type 1	C	N/A	RT1
Flange #1	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A / Type 4	N/A
Shell Zone 1 Inlet Elbow	N/A	Seamless No RT	B	Full UW-11(a) / Type 1	C	N/A	RT1
Flange #2	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A / Type 4	N/A
UG-116(a) Required Marking: RT1							

Thickness Summary

Component Data								
Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
F&D Head #2	SA-240 304	78 OD	14.2279	0.25*	0.2192	0	0.85	External
Straight Flange on F&D Head #2	SA-240 304	78 OD	1.5	0.5	0.2804	0	0.85	External
Cylinder #1	SA-240 304	78 OD	81	0.5	0.2804	0	0.70	External
Straight Flange on F&D Head #1	SA-240 304	78 OD	1.5	0.5	0.2804	0	0.85	External
F&D Head #1	SA-240 304	78 OD	14.2279	0.25*	0.2192	0	0.85	External
Head Zone	SA-312 TP304 Wld & smls pipe	2.375 OD	1,180	0.109	0.0072	0	N/A	Internal
Shell Zone 1	SA-312 TP304 Wld & smls pipe	2.375 OD	1,960	0.109	0.0072	0	N/A	Internal
*Head minimum thickness after forming								

Definitions	
Nominal t	Vessel wall nominal thickness
Design t	Required vessel thickness due to governing loading + corrosion
Joint E	Longitudinal seam joint efficiency
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

Bill of Materials

Heads						
Item #	Type	Material	Thk [In]	Dia. [In]	Wt. [lb] (ea.)	Qty
H1	F&D Head	SA-240 304	0.25 (min.)	78 OD	466	2

Shells							
Item #	Type	Material	Thk [in]	Dia. [in]	Length [in]	Wt. [lb] (ea.)	Qty
S1	Cylinder	SA-240 304	0.5	78 OD	81	2,859.6	1

Half Pipe Jacket							
Item #	Type	Material	NPS	Thk [In]	Dia. [In]	Length [In]	Wt. [lb]
HPJ1	Half Pipe	SA-312 TP304 Wld & smls pipe (welded)	NPS 2 Sch 10S	0.109	2.375 OD	589.9	132.7
HPJ2	Half Pipe	SA-312 TP304 Wld & smls pipe (welded)	NPS 2 Sch 10S	0.109	2.375 OD	980.2	220.6
Half pipe length is the total required pipe length.							

ASME B16.9 Fittings				
Item #	Type	Material	Size [In]	Qty
EB1	B16.9 Elbow Long Radius	SA-234 WPB	NPS 2 Sch 10	4

Flanges						
Item #	Type	Material	NPS	Dia. [In]	Wt. [lb] (ea.)	Qty
AF1	ASME B16.5 Slip On - Class 150	A182 F304	2	6 x 2.44	5	4

Fasteners				
Item #	Description	Material	Length [In]	Qty
FB1	5/8" coarse bolt	SA-193 B7 Bolt <= 2 1/2	2.8	16
All listed flange bolts require associated nuts and washers in accordance with Division 1, UCS-11.				

Cylinder #1

ASME Section VIII Division 1, 2023 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 92, In. 14)		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		15	335	-20
External		15	335	
Static Liquid Head				
Condition		P _s (psi)	H _s (In)	SG
Test horizontal		2.79	77.25	1
Dimensions				
Outer Diameter		78"		
Length		81"		
Nominal Thickness		0.5"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		Capacity (US gal)
New		2,859.6		1,632.84
Corroded		2,859.6		1,632.84
Radiography				
Longitudinal seam		None UW-11(c) Type 1		
Top Circumferential seam		None UW-11(c) Type 1		
Bottom Circumferential seam		None UW-11(c) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0447"
Design thickness due to external pressure (t _e)	0.2804"
Maximum allowable working pressure (MAWP)	168.69 psi
Maximum allowable pressure (MAP)	180.41 psi
Maximum allowable external pressure (MAEP)	50.56 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{64.03 \cdot 39}{20,000 \cdot 0.7 + 0.4 \cdot 64.03} =$	0.178"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.178 \cdot 0.8}{0.5 - 0} =$	0.2849
Impact test exempt per UHA-51(g) (coincident ratio = 0.2849)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 335 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{15 \cdot 39}{18,700 \cdot 0.70 + 0.40 \cdot 15} + 0 = \underline{0.0447"}$$

Maximum allowable working pressure, (at 335 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{18,700 \cdot 0.70 \cdot 0.5}{39 - 0.40 \cdot 0.5} - 0 = \underline{168.69} \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{20,000 \cdot 0.70 \cdot 0.5}{39 - 0.40 \cdot 0.5} = \underline{180.41} \text{ psi}$$

External Pressure, (Corroded & at 335 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{93.3186}{78} = 1.1964$$

$$\frac{D_o}{t} = \frac{78}{0.2804} = 278.1741$$

From table G: $A = 0.000240$

From table HA-1: $B = 3,129.4533 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 3,129.45}{3 \cdot (78/0.2804)} = 15 \text{ psi}$$

Design thickness for external pressure $P_a = 15 \text{ psi}$

$$t_a = t + \text{Corrosion} = 0.2804 + 0 = \underline{0.2804"}$$

Maximum Allowable External Pressure, (Corroded & at 335 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{93.3186}{78} = 1.1964$$

$$\frac{D_o}{t} = \frac{78}{0.5} = 156.0000$$

From table G: $A = 0.000575$

From table HA-1: $B = 5,915.145 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 5,915.15}{3 \cdot (78/0.5)} = \underline{50.56} \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f} \right) \cdot \left(1 - \frac{R_f}{R_o} \right) = \left(\frac{50 \cdot 0.5}{38.75} \right) \cdot \left(1 - \frac{38.75}{\infty} \right) = 0.6452 \%$$

ASME Section VIII Division 1 UG-80(a) Out-of-Roundness	
$(D_{\max} - D_{\min})$ shall not exceed 1% of D	
When the cross section passes through an opening or within 1 I.D. of the opening, $(D_{\max} - D_{\min})$ shall not exceed 1% of $D + 2\%$ of the inside diameter of the opening	

ASME Section VIII Division 1 UG-80(b) Out-of-Roundness	
Measured deviation shall not exceed the maximum permissible deviation e	
$\frac{L}{D_o} = \frac{93.3186}{78} =$	1.1964
$\frac{D_o}{t} = \frac{78}{0.5} =$	156
Lower curve factor =	0.6
$y_1 \left(\frac{L}{D_o} = 1.1964 \right) =$	145.4031
Upper curve factor =	0.8
$y_2 \left(\frac{L}{D_o} = 1.1964 \right) =$	220.69
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{156 - 145.4031}{220.69 - 145.4031} \cdot (0.8 - 0.6) + 0.6 =$	0.6282
$e = CF \cdot t = 0.6282 \cdot 0.5 =$	0.3141"

ASME Section VIII Division 1 Figure UG-29.2	
Chord length = $2 \cdot$ arc length determined from Figure UG-29.2	
Lower curve factor =	0.175
$y_1 \left(\frac{L}{D_o} = 1.1964 \right) =$	93.3619
Upper curve factor =	0.15
$y_2 \left(\frac{L}{D_o} = 1.1964 \right) =$	177.096
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{156 - 93.3619}{177.096 - 93.3619} \cdot (0.15 - 0.175) + 0.175 =$	0.1563
$Arc = CF \cdot D_o = 0.1563 \cdot 78 =$	12.1913"
$Chord = 2 \cdot Arc = 2 \cdot 12.1913 =$	24.3826"

F&D Head #1

ASME Section VIII Division 1, 2023 Edition				
Component		F&D Head		
Material		SA-240 304 (II-D p. 92, ln. 14)		
Attached To		Cylinder #1		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		15	335	-20
External		15	335	
Static Liquid Head				
Condition		P _s (psi)	H _s (ln)	SG
Test horizontal		2.8	77.5	1
Dimensions				
Outer Diameter		78"		
Crown Radius L		72"		
Knuckle Radius r		4.75"		
Minimum Thickness		0.25"		
Corrosion	Inner	0"		
	Outer	0"		
Length L _{sf}		1.5"		
Nominal Thickness t _{sf}		0.5"		
Weight and Capacity				
		Weight (lb) ¹		Capacity (US gal) ¹
New		466.04		202.21
Corroded		466.04		202.21
Radiography				
Category A joints		Seamless No RT		
Head to shell seam		None UW-11(c) Type 1		

[†] Includes straight flange

Results Summary	
Governing condition	external pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0588"
Design thickness due to external pressure (t _e)	0.2192"
Maximum allowable working pressure (MAWP)	64.03 psi
Maximum allowable pressure (MAP)	68.48 psi
Maximum allowable external pressure (MAEP)	18.48 psi
Straight Flange governs MDMT	-320°F

Note: Endnote 88 used to determine allowable stress.

Factor M		
$M = \frac{1}{4} \cdot \left[3 + \left(\frac{L}{r} \right)^{\frac{1}{2}} \right]$		
Corroded	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{72}{4.75} \right)^{\frac{1}{2}} \right]$	1.7233
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{72}{4.75} \right)^{\frac{1}{2}} \right]$	1.7233

Design thickness for internal pressure, (Corroded at 335 °F) Appendix 1-4(d)

$$t = \frac{P \cdot L_o \cdot M}{2 \cdot S \cdot E + P \cdot (M - 0.2)} + \text{Corrosion} = \frac{15 \cdot 72.25 \cdot 1.7233}{2 \cdot 18,700 \cdot 0.85 + 15 \cdot (1.7233 - 0.2)} + 0 = \underline{0.0587"}$$

Maximum allowable working pressure, (Corroded at 335 °F) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 18,700 \cdot 0.85 \cdot 0.25}{1.7233 \cdot 72.25 - 0.25 \cdot (1.7233 - 0.2)} - 0 = \underline{64.03} \text{ psi}$$

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 20,000 \cdot 0.85 \cdot 0.25}{1.7233 \cdot 72.25 - 0.25 \cdot (1.7233 - 0.2)} - 0 = \underline{68.48} \text{ psi}$$

Design thickness for external pressure, (Corroded at 335 °F) UG-33(e)

Equivalent outside spherical radius

$R_o = \text{Outside crown radius} = 72.25 \text{ in}$

$$A = \frac{0.125}{R_o / t} = \frac{0.125}{72.25 / 0.219108} = 0.000379$$

From Table HA-1: B = 4,946.1871 psi

$$P_a = \frac{B}{R_o / t} = \frac{4,946.1871}{72.25 / 0.2191} = 15 \text{ psi}$$

$$t = 0.2191" + \text{Corrosion} = 0.2191" + 0" = 0.2191"$$

The head external pressure design thickness (t_e) is 0.2191".

Maximum Allowable External Pressure, (Corroded at 335 °F) UG-33(e)

Equivalent outside spherical radius

$R_o = \text{Outside crown radius} = 72.25 \text{ in}$

$$A = \frac{0.125}{R_o / t} = \frac{0.125}{72.25 / 0.25} = 0.000433$$

From Table HA-1: B = 5,341.5146 psi

$$P_a = \frac{B}{R_o / t} = \frac{5,341.5146}{72.25 / 0.25} = 18.4828 \text{ psi}$$

The maximum allowable external pressure (MAEP) is 18.48 psi.

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

$$EFE = \left(\frac{75 \cdot t}{R_f} \right) \cdot \left(1 - \frac{R_f}{R_o} \right) = \left(\frac{75 \cdot 0.5}{5} \right) \cdot \left(1 - \frac{5}{\infty} \right) = 7.5 \%$$

ASME Section VIII Division 1 UG-81(a) Out-of-Roundness	
Inside surface shall not deviate outside the shape by more than	1.25 % of D
Inside surface shall not deviate inside the shape by more than	0.625 % of D

ASME Section VIII Division 1 UG-80(b) Out-of-Roundness	
Measured deviation shall not exceed the maximum permissible deviation e	
$\frac{L}{D_o} =$	0.5
$\frac{D_o}{t} = \frac{144.5}{0.25} =$	578
Curve factor =	1
$y_2 \left(\frac{L}{D_o} = 0.5 \right) =$	477.0309
$CF =$	1
$e = CF \cdot t = 1 \cdot 0.25 =$	0.25"

ASME Section VIII Division 1 Figure UG-29.2	
Chord length = $2 \cdot$ arc length determined from Figure UG-29.2	
Lower curve factor =	0.075
$y_1 \left(\frac{L}{D_o} = 0.5 \right) =$	510.6207
Upper curve factor =	0.065
$y_2 \left(\frac{L}{D_o} = 0.5 \right) =$	869.7137
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{578 - 510.6207}{869.7137 - 510.6207} \cdot (0.065 - 0.075) + 0.075 =$	0.0731
$Arc = CF \cdot D_o = 0.0731 \cdot 144.5 =$	10.5664"
$Chord = 2 \cdot Arc = 2 \cdot 10.5664 =$	21.1327"

Straight Flange on F&D Head #1

ASME Section VIII Division 1, 2023 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 92, ln. 14)		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		15	335	-20
External		15	335	
Static Liquid Head				
Condition		P _s (psi)	H _s (in)	SG
Test horizontal		2.79	77.25	1
Dimensions				
Outer Diameter		78"		
Length		1.5"		
Nominal Thickness		0.5"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		Capacity (US gal)
New		52.96		30.24
Corroded		52.96		30.24
Radiography				
Longitudinal seam		Seamless No RT		
Top Circumferential seam		None UW-11(c) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<u>0.0368"</u>
Design thickness due to external pressure (t _e)	<u>0.2804"</u>
Maximum allowable working pressure (MAWP)	<u>204.83 psi</u>
Maximum allowable pressure (MAP)	<u>219.07 psi</u>
Maximum allowable external pressure (MAEP)	<u>50.56 psi</u>
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{64.03 \cdot 39}{20,000 \cdot 0.85 + 0.4 \cdot 64.03} =$	0.1467"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.1467 \cdot 0.85}{0.5 - 0} =$	0.2493
Impact test exempt per UHA-51(g) (coincident ratio = 0.2493)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 335 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{15 \cdot 39}{18,700 \cdot 0.85 + 0.40 \cdot 15} + 0 = \underline{0.0368"}$$

Maximum allowable working pressure, (at 335 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{18,700 \cdot 0.85 \cdot 0.5}{39 - 0.40 \cdot 0.5} - 0 = \underline{204.83} \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{20,000 \cdot 0.85 \cdot 0.5}{39 - 0.40 \cdot 0.5} = \underline{219.07} \text{ psi}$$

External Pressure, (Corroded & at 335 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{93.3186}{78} = 1.1964$$

$$\frac{D_o}{t} = \frac{78}{0.2804} = 278.1741$$

From table G: $A = 0.000240$

From table HA-1: $B = 3,129.4533 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 3,129.45}{3 \cdot (78/0.2804)} = 15 \text{ psi}$$

Design thickness for external pressure $P_a = 15 \text{ psi}$

$$t_a = t + \text{Corrosion} = 0.2804 + 0 = \underline{0.2804"}$$

Maximum Allowable External Pressure, (Corroded & at 335 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{93.3186}{78} = 1.1964$$

$$\frac{D_o}{t} = \frac{78}{0.5} = 156.0000$$

From table G: $A = 0.000575$

From table HA-1: $B = 5,915.145 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 5,915.15}{3 \cdot (78/0.5)} = \underline{50.56} \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f} \right) \cdot \left(1 - \frac{R_f}{R_o} \right) = \left(\frac{50 \cdot 0.5}{38.75} \right) \cdot \left(1 - \frac{38.75}{\infty} \right) = 0.6452 \%$$

ASME Section VIII Division 1 UG-80(a) Out-of-Roundness	
$(D_{\max} - D_{\min})$ shall not exceed 1% of D	
When the cross section passes through an opening or within 1 I.D. of the opening, $(D_{\max} - D_{\min})$ shall not exceed 1% of $D + 2\%$ of the inside diameter of the opening	

ASME Section VIII Division 1 UG-80(b) Out-of-Roundness	
Measured deviation shall not exceed the maximum permissible deviation e	
$\frac{L}{D_o} = \frac{93.3186}{78} =$	1.1964
$\frac{D_o}{t} = \frac{78}{0.5} =$	156
Lower curve factor =	0.6
$y_1 \left(\frac{L}{D_o} = 1.1964 \right) =$	145.4031
Upper curve factor =	0.8
$y_2 \left(\frac{L}{D_o} = 1.1964 \right) =$	220.69
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{156 - 145.4031}{220.69 - 145.4031} \cdot (0.8 - 0.6) + 0.6 =$	0.6282
$e = CF \cdot t = 0.6282 \cdot 0.5 =$	0.3141"

ASME Section VIII Division 1 Figure UG-29.2	
Chord length = $2 \cdot$ arc length determined from Figure UG-29.2	
Lower curve factor =	0.175
$y_1 \left(\frac{L}{D_o} = 1.1964 \right) =$	93.3619
Upper curve factor =	0.15
$y_2 \left(\frac{L}{D_o} = 1.1964 \right) =$	177.096
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{156 - 93.3619}{177.096 - 93.3619} \cdot (0.15 - 0.175) + 0.175 =$	0.1563
$Arc = CF \cdot D_o = 0.1563 \cdot 78 =$	12.1913"
$Chord = 2 \cdot Arc = 2 \cdot 12.1913 =$	24.3826"

F&D Head #2

ASME Section VIII Division 1, 2023 Edition				
Component		F&D Head		
Material		SA-240 304 (II-D p. 92, ln. 14)		
Attached To		Cylinder #1		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		15	335	-20
External		15	335	
Static Liquid Head				
Condition		P _s (psi)	H _s (ln)	SG
Test horizontal		2.8	77.5	1
Dimensions				
Outer Diameter		78"		
Crown Radius L		72"		
Knuckle Radius r		4.75"		
Minimum Thickness		0.25"		
Corrosion	Inner	0"		
	Outer	0"		
Length L _{sf}		1.5"		
Nominal Thickness t _{sf}		0.5"		
Weight and Capacity				
		Weight (lb) ¹		Capacity (US gal) ¹
New		466.04		202.21
Corroded		466.04		202.21
Radiography				
Category A joints		Seamless No RT		
Head to shell seam		None UW-11(c) Type 1		

¹ Includes straight flange

Results Summary	
Governing condition	external pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<u>0.0588"</u>
Design thickness due to external pressure (t _e)	<u>0.2192"</u>
Maximum allowable working pressure (MAWP)	<u>64.03</u> psi
Maximum allowable pressure (MAP)	<u>68.48</u> psi
Maximum allowable external pressure (MAEP)	<u>18.48</u> psi
<u>Straight Flange</u> governs MDMT	-320°F

Note: Endnote 88 used to determine allowable stress.

Factor M		
	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{L}{r} \right)^{\frac{1}{2}} \right]$	
Corroded	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{72}{4.75} \right)^{\frac{1}{2}} \right]$	1.7233
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{72}{4.75} \right)^{\frac{1}{2}} \right]$	1.7233

Design thickness for internal pressure, (Corroded at 335 °F) Appendix 1-4(d)

$$t = \frac{P \cdot L_o \cdot M}{2 \cdot S \cdot E + P \cdot (M - 0.2)} + \text{Corrosion} = \frac{15 \cdot 72.25 \cdot 1.7233}{2 \cdot 18,700 \cdot 0.85 + 15 \cdot (1.7233 - 0.2)} + 0 = \underline{0.0587"}$$

Maximum allowable working pressure, (Corroded at 335 °F) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 18,700 \cdot 0.85 \cdot 0.25}{1.7233 \cdot 72.25 - 0.25 \cdot (1.7233 - 0.2)} - 0 = \underline{64.03} \text{ psi}$$

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 20,000 \cdot 0.85 \cdot 0.25}{1.7233 \cdot 72.25 - 0.25 \cdot (1.7233 - 0.2)} - 0 = \underline{68.48} \text{ psi}$$

Design thickness for external pressure, (Corroded at 335 °F) UG-33(e)

Equivalent outside spherical radius

R_o = Outside crown radius = 72.25 in

$$A = \frac{0.125}{R_o / t} = \frac{0.125}{72.25 / 0.219108} = 0.000379$$

From Table HA-1: B = 4,946.1871 psi

$$P_a = \frac{B}{R_o / t} = \frac{4,946.1871}{72.25 / 0.2191} = 15 \text{ psi}$$

$$t = 0.2191" + \text{Corrosion} = 0.2191" + 0" = 0.2191"$$

The head external pressure design thickness (t_e) is 0.2191".

Maximum Allowable External Pressure, (Corroded at 335 °F) UG-33(e)

Equivalent outside spherical radius

R_o = Outside crown radius = 72.25 in

$$A = \frac{0.125}{R_o / t} = \frac{0.125}{72.25 / 0.25} = 0.000433$$

From Table HA-1: B = 5,341.5146 psi

$$P_a = \frac{B}{R_o / t} = \frac{5,341.5146}{72.25 / 0.25} = 18.4828 \text{ psi}$$

The maximum allowable external pressure (MAEP) is 18.48 psi.

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

$$EFE = \left(\frac{75 \cdot t}{R_f} \right) \cdot \left(1 - \frac{R_f}{R_o} \right) = \left(\frac{75 \cdot 0.5}{5} \right) \cdot \left(1 - \frac{5}{\infty} \right) = 7.5 \%$$

ASME Section VIII Division 1 UG-81(a) Out-of-Roundness	
Inside surface shall not deviate outside the shape by more than	1.25 % of D
Inside surface shall not deviate inside the shape by more than	0.625 % of D

ASME Section VIII Division 1 UG-80(b) Out-of-Roundness	
Measured deviation shall not exceed the maximum permissible deviation e	
$\frac{L}{D_o} =$	0.5
$\frac{D_o}{t} = \frac{144.5}{0.25} =$	578
Curve factor =	1
$y_2 \left(\frac{L}{D_o} = 0.5 \right) =$	477.0309
$CF =$	1
$e = CF \cdot t = 1 \cdot 0.25 =$	0.25"

ASME Section VIII Division 1 Figure UG-29.2	
Chord length = $2 \cdot$ arc length determined from Figure UG-29.2	
Lower curve factor =	0.075
$y_1 \left(\frac{L}{D_o} = 0.5 \right) =$	510.6207
Upper curve factor =	0.065
$y_2 \left(\frac{L}{D_o} = 0.5 \right) =$	869.7137
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{578 - 510.6207}{869.7137 - 510.6207} \cdot (0.065 - 0.075) + 0.075 =$	0.0731
$Arc = CF \cdot D_o = 0.0731 \cdot 144.5 =$	10.5664"
$Chord = 2 \cdot Arc = 2 \cdot 10.5664 =$	21.1327"

Straight Flange on F&D Head #2

ASME Section VIII Division 1, 2023 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 92, ln. 14)		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		15	335	-20
External		15	335	
Static Liquid Head				
Condition		P _s (psi)	H _s (in)	SG
Test horizontal		2.79	77.25	1
Dimensions				
Outer Diameter		78"		
Length		1.5"		
Nominal Thickness		0.5"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		Capacity (US gal)
New		52.96		30.24
Corroded		52.96		30.24
Radiography				
Longitudinal seam		Seamless No RT		
Bottom Circumferential seam		None UW-11(c) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	<u>0.0368"</u>
Design thickness due to external pressure (t _e)	<u>0.2804"</u>
Maximum allowable working pressure (MAWP)	<u>204.83 psi</u>
Maximum allowable pressure (MAP)	<u>219.07 psi</u>
Maximum allowable external pressure (MAEP)	<u>50.56 psi</u>
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{64.03 \cdot 39}{20,000 \cdot 0.85 + 0.4 \cdot 64.03} =$	0.1467"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.1467 \cdot 0.85}{0.5 - 0} =$	0.2493
Impact test exempt per UHA-51(g) (coincident ratio = 0.2493)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 335 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{15 \cdot 39}{18,700 \cdot 0.85 + 0.40 \cdot 15} + 0 = \underline{0.0368"}$$

Maximum allowable working pressure, (at 335 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{18,700 \cdot 0.85 \cdot 0.5}{39 - 0.40 \cdot 0.5} - 0 = \underline{204.83} \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{20,000 \cdot 0.85 \cdot 0.5}{39 - 0.40 \cdot 0.5} = \underline{219.07} \text{ psi}$$

External Pressure, (Corroded & at 335 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{93.3186}{78} = 1.1964$$

$$\frac{D_o}{t} = \frac{78}{0.2804} = 278.1741$$

From table G: $A = 0.000240$

From table HA-1: $B = 3,129.4533 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 3,129.45}{3 \cdot (78/0.2804)} = 15 \text{ psi}$$

Design thickness for external pressure $P_a = 15 \text{ psi}$

$$t_a = t + \text{Corrosion} = 0.2804 + 0 = \underline{0.2804"}$$

Maximum Allowable External Pressure, (Corroded & at 335 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{93.3186}{78} = 1.1964$$

$$\frac{D_o}{t} = \frac{78}{0.5} = 156.0000$$

From table G: $A = 0.000575$

From table HA-1: $B = 5,915.145 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 5,915.15}{3 \cdot (78/0.5)} = \underline{50.56} \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f} \right) \cdot \left(1 - \frac{R_f}{R_o} \right) = \left(\frac{50 \cdot 0.5}{38.75} \right) \cdot \left(1 - \frac{38.75}{\infty} \right) = 0.6452 \%$$

ASME Section VIII Division 1 UG-80(a) Out-of-Roundness	
$(D_{\max} - D_{\min})$ shall not exceed 1% of D	
When the cross section passes through an opening or within 1 I.D. of the opening, $(D_{\max} - D_{\min})$ shall not exceed 1% of $D + 2\%$ of the inside diameter of the opening	

ASME Section VIII Division 1 UG-80(b) Out-of-Roundness	
Measured deviation shall not exceed the maximum permissible deviation e	
$\frac{L}{D_o} = \frac{93.3186}{78} =$	1.1964
$\frac{D_o}{t} = \frac{78}{0.5} =$	156
Lower curve factor =	0.6
$y_1 \left(\frac{L}{D_o} = 1.1964 \right) =$	145.4031
Upper curve factor =	0.8
$y_2 \left(\frac{L}{D_o} = 1.1964 \right) =$	220.69
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{156 - 145.4031}{220.69 - 145.4031} \cdot (0.8 - 0.6) + 0.6 =$	0.6282
$e = CF \cdot t = 0.6282 \cdot 0.5 =$	0.3141"

ASME Section VIII Division 1 Figure UG-29.2	
Chord length = $2 \cdot$ arc length determined from Figure UG-29.2	
Lower curve factor =	0.175
$y_1 \left(\frac{L}{D_o} = 1.1964 \right) =$	93.3619
Upper curve factor =	0.15
$y_2 \left(\frac{L}{D_o} = 1.1964 \right) =$	177.096
$CF = \frac{y - y_1}{y_2 - y_1} (CF_2 - CF_1) + CF_1 = \frac{156 - 93.3619}{177.096 - 93.3619} \cdot (0.15 - 0.175) + 0.175 =$	0.1563
$Arc = CF \cdot D_o = 0.1563 \cdot 78 =$	12.1913"
$Chord = 2 \cdot Arc = 2 \cdot 12.1913 =$	24.3826"

Half Pipe Jacket

ASME Section VIII Division 1, 2023 Edition					
Component	Half Pipe Jacket				
Material	SA-312 TP304 Wld & smls pipe (II-D p. 92, ln. 25) (welded)				
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP	Design MDMT (°F)
No	No	No	No	No	-20
Design Data				Head Zone	Shell Zone 1
Internal Pressure (psi)				90	90
Internal Temperature (°F)				335	335
Static Liquid Head					
Test horizontal, P _s (psi)				2.94	2.96
Test horizontal, H _s (in)				81.3875	82.0785
Test horizontal, SG				1	1
Dimensions					
Pipe				Head Zone	Shell Zone 1
Pipe Description				NPS 2 Sch 10S	NPS 2 Sch 10S
Inside diameter, new (in)				2.157	2.157
Pipe Nominal Thickness, t _p (in)				0.109	0.109
Pipe Minimum Thickness (in)				0.0857	0.0939
Corrosion (in)			Inner	0	0
			Outer	0	0
Pitch (in)				4.75	4.75
Weld Fillet (in)				0.1875	0.1875
Location				Head Zone	Shell Zone 1
Inlet			Angle (deg.)	0	0
			Elev. (in)	-	3.5
			Dist. r (in)	5.25	-
Outlet			Angle (deg.)	0	0
			Elev. (in)	-1.745	41.5
			Dist. r (in)	42.1002	-
Rotation Direction				Standard	Standard
Number of coils				8	8
Weight (lb)					
New				132.7	220.6
Corroded				132.7	220.6
New (total)				353.3	
Corroded (total)				353.3	
Radiography					
Inlet Circumferential seam				Full UW-11(a) Type 1	Full UW-11(a) Type 1
Outlet Circumferential seam				Full UW-11(a) Type 1	Full UW-11(a) Type 1

Results Summary		
	Head Zone	Shell Zone 1
Minimum thickness per UG-16 (in)	$0.0625 + 0 = 0.0625$	$0.0625 + 0 = 0.0625$
Design thickness due to internal pressure (t_p) (in)	0.0072	0.0072
Maximum allowable working pressure (MAWP) (psi)	556.68	1,118.43
Maximum working pressure (MAP) (psi)	598.6	1,196.18
Rated MDMT (°F)	-320	-320
Required Fillet Weld (new) (in)	0.1557	0.1557

UHA-51 Material Toughness Requirements	
Head Zone	
$t_r = \frac{199.75 \cdot 1.0785}{20,000 \cdot 0.85 - 0.6 \cdot 199.75} =$	0.0128"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0128 \cdot 0.85}{0.0857 - 0} =$	0.1266
Impact test exempt per UHA-51(g) (coincident ratio = 0.1266)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	
Shell Zone 1	
$t_r = \frac{199.75 \cdot 1.0785}{20,000 \cdot 0.85 - 0.6 \cdot 199.75} =$	0.0128"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0128 \cdot 0.85}{0.0939 - 0} =$	0.1155
Impact test exempt per UHA-51(g) (coincident ratio = 0.1155)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Minimum Thickness After Bending, T_{min}	
Bend Thinning Factor $F_{bend} = \left(1 + \frac{d_o}{C \cdot R}\right)$	(TEMA RCB 2.3.1)
Min Thickness $T_{min} = \frac{T_{nom} \cdot \text{Material Thinning}}{F_{bend}}$	
TEMA Thinning Constant C =	4
C = 4 for Carbon Steel, low alloy ferritic stainless, austenitic stainless. C = 2 for duplex stainless, martensitic stainless, high nickel alloys	
Head Zone	
Outer diameter, $d_o =$	2.375"
Bend Radius, R =	5.25"
$F_{bend} = \left(1 + \frac{2.375}{4 \cdot 5.25}\right)$	1.1131
Minimum Thickness, $T_{min} = \frac{0.109 \cdot 0.875}{1.1131}$	0.0857"
Shell Zone 1	
Outer diameter, $d_o =$	2.375"
Bend Radius, R =	39"
$F_{bend} = \left(1 + \frac{2.375}{4 \cdot 39}\right)$	1.0152
Minimum Thickness, $T_{min} = \frac{0.109 \cdot 0.875}{1.0152}$	0.0939"

Minimum Required Thickness, T	
$T = \frac{P_1 \cdot r}{0.85 \cdot S_1 - 0.60 \cdot P_1} + \text{Corrosion}$	(EE-2 (2))
Head Zone	
Operating Hot & Corroded	
$T = \frac{90 \cdot 1.0785}{0.85 \cdot 15,895 - 0.60 \cdot 90} + 0 =$	<u>0.0072"</u>
Shell Zone 1	
Operating Hot & Corroded	
$T = \frac{90 \cdot 1.0785}{0.85 \cdot 15,895 - 0.60 \cdot 90} + 0 =$	<u>0.0072"</u>

Allowable Stress, F	
$S' = \max \left[0, \frac{P \cdot D}{4 \cdot t_s} + \left(\frac{W}{A} \right) + \left(\frac{M}{Z} \right) \right]$	
$F = \min [(1.50 \cdot S - S'), 1.50 \cdot S]$	(EE-2)
Longitudinal stress for formed head based on Division 2, paragraph 4.3.6.3, or 4.3.7.2.	
Longitudinal loading, W, M, are not considered for the MAP condition.	
Head Zone	
Operating Hot & Corroded	
$S' = \max \left[0, \frac{15 \cdot 144}{4 \cdot 0.25} \right] =$	2,160 psi
$F = \min [(1.50 \cdot 18,700 - 2,160), 1.50 \cdot 18,700] =$	25,890 psi
Cold & New (MAP)	
$S' = \max \left[0, \frac{15 \cdot 144}{4 \cdot 0.25} \right] =$	2,160 psi
$F = \min [(1.50 \cdot 20,000 - 2,160), 1.50 \cdot 20,000] =$	27,840 psi
Shell Zone 1	
Operating Hot & Corroded	
$S' = \max \left[0, \frac{15 \cdot 77}{4 \cdot 0.5} \right] =$	578 psi
$F = \min [(1.50 \cdot 18,700 - 578), 1.50 \cdot 18,700] =$	27,473 psi
Cold & New (MAP)	
$S' = \max \left[0, \frac{15 \cdot 77}{4 \cdot 0.5} \right] =$	578 psi
$F = \min [(1.50 \cdot 20,000 - 578), 1.50 \cdot 20,000] =$	29,423 psi

Division 2 4.11.6.4 Rating Factor, K_p	
$K_p = C_1 + C_2 \cdot D^{0.50} + C_3 \cdot D + C_4 \cdot D^{1.50} + C_5 \cdot D^2 + C_6 \cdot D^{2.50} + C_7 \cdot D^3 + C_8 \cdot D^{3.50} + C_9 \cdot D^4 + C_{10} \cdot D^{4.50}$	(4.11.5)
Head Zone	
Operating Hot & Corroded	
Vessel Inner Diameter, D =	77.5"
Vessel Shell Thickness, t =	0.25"
$K_p = -1.887404E+04 + 1.786952E+04 \cdot 77.5^{0.50} + -7.284642E+03 \cdot 77.5 +$ $1.672376E+03 \cdot 77.5^{1.50} + -2.364893E+02 \cdot 77.5^2 + 2.110174E+01 \cdot 77.5^{2.50} +$ $-1.160889E+00 \cdot 77.5^3 + 3.602271E-02 \cdot 77.5^{3.50} + -4.830325E-04 \cdot 77.5^4 +$ $0.000000E+00 \cdot 77.5^{4.50} =$	46.5082
Cold & New (MAP)	
Vessel Inner Diameter, D =	77.5"
Vessel Shell Thickness, t =	0.25"
$K_p = -1.887404E+04 + 1.786952E+04 \cdot 77.5^{0.50} + -7.284642E+03 \cdot 77.5 +$ $1.672376E+03 \cdot 77.5^{1.50} + -2.364893E+02 \cdot 77.5^2 + 2.110174E+01 \cdot 77.5^{2.50} +$ $-1.160889E+00 \cdot 77.5^3 + 3.602271E-02 \cdot 77.5^{3.50} + -4.830325E-04 \cdot 77.5^4 +$ $0.000000E+00 \cdot 77.5^{4.50} =$	46.5082
Shell Zone 1	
Operating Hot & Corroded	
Vessel Inner Diameter, D =	77"
Vessel Shell Thickness, t =	0.5"
$K_p = -2.644778E+02 + 1.806695E+02 \cdot 77^{0.50} + -4.929496E+01 \cdot 77 +$ $7.152242E+00 \cdot 77^{1.50} + -5.790007E-01 \cdot 77^2 + 2.475849E-02 \cdot 77^{2.50} +$ $-4.366760E-04 \cdot 77^3 + 0.000000E+00 \cdot 77^{3.50} + 0.000000E+00 \cdot 77^4 +$ $0.000000E+00 \cdot 77^{4.50} =$	13.6019
Cold & New (MAP)	
Vessel Inner Diameter, D =	77"
Vessel Shell Thickness, t =	0.5"
$K_p = -2.644778E+02 + 1.806695E+02 \cdot 77^{0.50} + -4.929496E+01 \cdot 77 +$ $7.152242E+00 \cdot 77^{1.50} + -5.790007E-01 \cdot 77^2 + 2.475849E-02 \cdot 77^{2.50} +$ $-4.366760E-04 \cdot 77^3 + 0.000000E+00 \cdot 77^{3.50} + 0.000000E+00 \cdot 77^4 +$ $0.000000E+00 \cdot 77^{4.50} =$	13.6019

Maximum Permissible Pressure	
$P' = \frac{F}{K} - P_s$	(EE-2 (1))
$P_{drc} = \frac{S \cdot 0.85 \cdot t}{R + 0.60 \cdot t} - P_s$	(UG-27(c)(1))
$P_{max} = \min(P', P_{drc})$	
Head Zone	
Operating Hot & Corroded (MAWP)	
$P' = \frac{25,890}{46.5082} - 0 =$	556.68 psi
$P_{drc} = \frac{15,895 \cdot 0.85 \cdot 0.0857}{1.0785 + 0.60 \cdot 0.0857} - 0 =$	1,024.56 psi
MAWP =	<u>556.68 psi</u>
Cold & New (MAP)	
$P' = \frac{27,840}{46.5082} =$	598.6 psi
$P_{drc} = \frac{17,000 \cdot 0.85 \cdot 0.0857}{1.0785 + 0.60 \cdot 0.0857} =$	1,095.79 psi
MAP =	<u>598.6 psi</u>
Shell Zone 1	
Operating Hot & Corroded (MAWP)	
$P' = \frac{27,473}{13.6019} - 0 =$	2,019.75 psi
$P_{drc} = \frac{15,895 \cdot 0.85 \cdot 0.0939}{1.0785 + 0.60 \cdot 0.0939} - 0 =$	1,118.43 psi
MAWP =	<u>1,118.43 psi</u>
Cold & New (MAP)	
$P' = \frac{29,423}{13.6019} =$	2,163.12 psi
$P_{drc} = \frac{17,000 \cdot 0.85 \cdot 0.0939}{1.0785 + 0.60 \cdot 0.0939} =$	1,196.18 psi
MAP =	<u>1,196.18 psi</u>

EE-2 Minimum Required Fillet Weld		
	Head Zone	Shell Zone 1
Weld Fillet Size (f_a) =	0.1875"	0.1875"
Jacket Thickness (t_j) =	0.109-0 =0.109	0.109-0 =0.109
Shell Thickness (t_s) =	0.5-0 =0.5	0.5-0 =0.5
Minimum Throat Thickness = $\min(t_j, t_s) =$	0.109	0.109
Fillet Weld Throat Thickness = $0.70 \cdot f_a - C =$	$0.70 \cdot 0.1875 - 0$ =0.1312	$0.70 \cdot 0.1875 - 0$ =0.1312
Fillet Weld Throat Thickness Acceptable	OK	OK
Required Fillet Leg = Min Throat + C 0.70	$\frac{0.109+0}{0.70}$ = 0.1557"	$\frac{0.109+0}{0.70}$ = 0.1557"
Groove weld requirements shall be in accordance with paragraph EE-2.		

% Forming strain - UHA-44(a)(2)	
$\epsilon_f = \frac{100 \cdot r}{R}$	
Head Zone	
$\epsilon_f = \frac{100 \cdot 1.1875}{5.25} =$	22.619%
Shell Zone 1	
$\epsilon_f = \frac{100 \cdot 1.1875}{39} =$	3.0449%

Head Zone Inlet Elbow

ASME Section VIII Division 1, 2023 Edition				
Component		ASME B16.9 Elbow		
Type		Long Radius 90-deg		
Material		SA-234 WPB (II-D p. 16, ln. 18)		
Pipe NPS and Schedule		NPS 2 Sch 10		
Attached To		Half Pipe Jacket		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		90	335	-20
Static Liquid Head				
Condition		P _s (psi)	H _s (in)	SG
Test horizontal		1.33	36.9517	1
Dimensions				
Outer Diameter		2.375"		
Nominal Thickness		0.109"		
Minimum Thickness ¹		0.0954"		
Center-to-End, A		3"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		Capacity (US gal)
New		1.03		0.07
Corroded		1.03		0.07
Radiography				
Longitudinal seam		Seamless No RT		
Left Circumferential seam		Full UW-11(a) Type 1		

¹ minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.5-2020 Flange	
Description	NPS 2 Class 150 SO A182 F304
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 418, ln. 32)
Blind Included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	199.75 psi @ 335°F
MAP rating	275 psi @ 70°F
Hydrotest rating	425 psi @ 70°F
External fillet weld leg (UW-21)	0.1526" (0.1526" min)
Internal fillet weld leg (UW-21)	0.109" (0.109" min)
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
UW-21 Flange Welds	
$X_{\min} = \min [1.4 \cdot t_n, g_0] = [1.4 \cdot 0.109, 0.31] =$	0.1526"
External Leg $\min = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
Internal Leg $\min = \min \left[t_n, 0.25" + \frac{C_i}{0.7} \right] = \min \left[0.109, 0.25 + \frac{0}{0.7} \right] =$	0.109"
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320°F Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Results Summary	
Governing condition	UG-16
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0063"
Maximum allowable working pressure (MAWP)	1,418.99 psi
Maximum allowable pressure (MAP)	1,418.99 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
$t_r = \frac{199.75 \cdot 1.1875}{17,100 \cdot 1 + 0.4 \cdot 199.75} =$	0.0138"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	0.1448
Stress ratio ≤ 0.35 , MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 335 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{90 \cdot 1.1875}{17,100 \cdot 1.00 + 0.40 \cdot 90} + 0 = 0.0063"$$

Maximum allowable working pressure, (at 335 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} - 0 = 1,418.99 \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} = 1,418.99 \text{ psi}$$

Head Zone Outlet Elbow

ASME Section VIII Division 1, 2023 Edition				
Component		ASME B16.9 Elbow		
Type		Long Radius 90-deg		
Material		SA-234 WPB (II-D p. 16, ln. 18)		
Pipe NPS and Schedule		NPS 2 Sch 10		
Attached To		Half Pipe Jacket		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		90	335	-20
Static Liquid Head				
Condition		P _s (psi)	H _s (in)	SG
Test horizontal		0.11	2.9992	1
Dimensions				
Outer Diameter		2.375"		
Nominal Thickness		0.109"		
Minimum Thickness ¹		0.0954"		
Center-to-End, A		3"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		Capacity (US gal)
New		1.03		0.07
Corroded		1.03		0.07
Radiography				
Longitudinal seam		Seamless No RT		
Left Circumferential seam		Full UW-11(a) Type 1		

¹ minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.5-2020 Flange	
Description	NPS 2 Class 150 SO A182 F304
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 418, ln. 32)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	199.75 psi @ 335°F
MAP rating	275 psi @ 70°F
Hydrotest rating	425 psi @ 70°F
External fillet weld leg (UW-21)	0.1526" (0.1526" min)
Internal fillet weld leg (UW-21)	0.109" (0.109" min)
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
UW-21 Flange Welds	
$X_{\min} = \min [1.4 \cdot t_n, g_0] = [1.4 \cdot 0.109, 0.31] =$	0.1526"
External Leg $\min = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
Internal Leg $\min = \min \left[t_n, 0.25" + \frac{C_i}{0.7} \right] = \min \left[0.109, 0.25 + \frac{0}{0.7} \right] =$	0.109"
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320°F Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Results Summary	
Governing condition	UG-16
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0063"
Maximum allowable working pressure (MAWP)	1,418.99 psi
Maximum allowable pressure (MAP)	1,418.99 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
$t_r = \frac{199.75 \cdot 1.1875}{17,100 \cdot 1 + 0.4 \cdot 199.75} =$	0.0138"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	0.1448
Stress ratio ≤ 0.35 , MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 335 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{90 \cdot 1.1875}{17,100 \cdot 1.00 + 0.40 \cdot 90} + 0 = 0.0063"$$

Maximum allowable working pressure, (at 335 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} - 0 = 1,418.99 \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} = 1,418.99 \text{ psi}$$

Shell Zone 1 Inlet Elbow

ASME Section VIII Division 1, 2023 Edition				
Component		ASME B16.9 Elbow		
Type		Long Radius 90-deg		
Material		SA-234 WPB (II-D p. 16, ln. 18)		
Pipe NPS and Schedule		NPS 2 Sch 10		
Attached To		Half Pipe Jacket		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		90	335	-20
Static Liquid Head				
Condition		P _s (psi)	H _s (in)	SG
Test horizontal		0.11	3	1
Dimensions				
Outer Diameter		2.375"		
Nominal Thickness		0.109"		
Minimum Thickness ¹		0.0954"		
Center-to-End, A		3"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		Capacity (US gal)
New		1.03		0.07
Corroded		1.03		0.07
Radiography				
Longitudinal seam		Seamless No RT		
Left Circumferential seam		Full UW-11(a) Type 1		

¹ minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.5-2020 Flange	
Description	NPS 2 Class 150 SO A182 F304
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 418, ln. 32)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	199.75 psi @ 335°F
MAP rating	275 psi @ 70°F
Hydrotest rating	425 psi @ 70°F
External fillet weld leg (UW-21)	0.1526" (0.1526" min)
Internal fillet weld leg (UW-21)	0.109" (0.109" min)
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
UW-21 Flange Welds	
$X_{\min} = \min [1.4 \cdot t_n, g_0] = [1.4 \cdot 0.109, 0.31] =$	0.1526"
External Leg $\min = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
Internal Leg $\min = \min \left[t_n, 0.25" + \frac{C_i}{0.7} \right] = \min \left[0.109, 0.25 + \frac{0}{0.7} \right] =$	0.109"
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320°F Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Results Summary	
Governing condition	UG-16
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0063"
Maximum allowable working pressure (MAWP)	1,418.99 psi
Maximum allowable pressure (MAP)	1,418.99 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
$t_r = \frac{199.75 \cdot 1.1875}{17,100 \cdot 1 + 0.4 \cdot 199.75} =$	0.0138"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	0.1448
Stress ratio ≤ 0.35 , MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 335 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{90 \cdot 1.1875}{17,100 \cdot 1.00 + 0.40 \cdot 90} + 0 = 0.0063"$$

Maximum allowable working pressure, (at 335 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} - 0 = 1,418.99 \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} = \underline{1,418.99} \text{ psi}$$

Shell Zone 1 Outlet Elbow

ASME Section VIII Division 1, 2023 Edition				
Component		ASME B16.9 Elbow		
Type		Long Radius 90-deg		
Material		SA-234 WPB (II-D p. 16, In. 18)		
Pipe NPS and Schedule		NPS 2 Sch 10		
Attached To		Half Pipe Jacket		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	No	No	No
		Design Pressure (psi)	Design Temperature (°F)	Design MDMT (°F)
Internal		90	335	-20
Static Liquid Head				
Condition		P _s (psi)	H _s (in)	SG
Test horizontal		0.11	3	1
Dimensions				
Outer Diameter		2.375"		
Nominal Thickness		0.109"		
Minimum Thickness ¹		0.0954"		
Center-to-End, A		3"		
Corrosion	Inner	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		Capacity (US gal)
New		1.03		0.07
Corroded		1.03		0.07
Radiography				
Longitudinal seam		Seamless No RT		
Left Circumferential seam		Full UW-11(a) Type 1		

¹ minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.5-2020 Flange	
Description	NPS 2 Class 150 SO A182 F304
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 418, ln. 32)
Blind Included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	199.75 psi @ 335°F
MAP rating	275 psi @ 70°F
Hydrotest rating	425 psi @ 70°F
External fillet weld leg (UW-21)	0.1526" (0.1526" min)
Internal fillet weld leg (UW-21)	0.109" (0.109" min)
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
UW-21 Flange Welds	
$X_{\min} = \min [1.4 \cdot t_n, g_0] = [1.4 \cdot 0.109, 0.31] =$	0.1526"
External Leg $\min = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
Internal Leg $\min = \min \left[t_n, 0.25" + \frac{C_i}{0.7} \right] = \min \left[0.109, 0.25 + \frac{0}{0.7} \right] =$	0.109"
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320°F Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Results Summary	
Governing condition	UG-16
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0063"
Maximum allowable working pressure (MAWP)	1,418.99 psi
Maximum allowable pressure (MAP)	1,418.99 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
$t_r = \frac{199.75 \cdot 1.1875}{17,100 \cdot 1 + 0.4 \cdot 199.75} =$	0.0138"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	0.1448
Stress ratio ≤ 0.35 , MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 335 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{90 \cdot 1.1875}{17,100 \cdot 1.00 + 0.40 \cdot 90} + 0 = 0.0063"$$

Maximum allowable working pressure, (at 335 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} - 0 = 1,418.99 \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{17,100 \cdot 1.00 \cdot (0.109 \cdot 0.875)}{1.1875 - 0.40 \cdot (0.109 \cdot 0.875)} = 1,418.99 \text{ psi}$$