Premier Boiler

& COMBUSTION

Pressure Vessel Design Calculations

Item: C6100-1 Half Pipe Jacket

Drawing No.: 1-146-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

Table of Contents

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
User has limited MAWP to	90 psi
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 α > 30 only	Yes
Preheat P-No 1 Materials > 1.25" and <= 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)	MDMT (°F)	MDMT Exemption	Impact Tested
F&D Head #2	15	335	20.73	28.53	-320	Note 1	No
Straight Flange on F&D Head #2	15	335	69.84	74.69	-320	Note 2	No
Cylinder #1	15	335	86.35	92.35	-320	Note 3	No
Straight Flange on F&D Head #1	15	335	69.84	74.69	-320	Note 2	No
F&D Head #1	15	335	20.73	28.53	-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 @ 20.73 psi
MAWP hot & corroded	20.73 psi @ 335 °F
MAP cold & new	28.53 psi @ 70 °F
(1) The rated MDMT is limited to the design MDMT based on the setting in the Calculations tab of the Set Mode dialog. (2) This pressure chamber is not designed for external pressure.	

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	280.34	303.37	-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	1,123.48	1,201.58	-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 = 0.2362)	
3.	Impact test exempt per UHA-51(g) (coincident ratio = 0.18)	
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 = 0.1149)	

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	114 OD	20.2528	0.1875*	0.146	0	0.85	Internal
Straight Flange on F&D Head #2	SA-240 304	114 OD	1.5	0.25	0.0538	0	0.85	Internal
Cylinder #1	SA-240 304	114 OD	87	0.375	0.0653	0	0.70	Internal
Straight Flange on F&D Head #1	SA-240 304	114 OD	1.5	0.25	0.0538	0	0.85	Internal
F&D Head #1	SA-240 304	114 OD	20.2528	0.1875*	0.146	0	0.85	Internal
Head Zone	SA-312 TP304 Wld & smls pipe	2.375 OD	1.851	0.109	0.0072	0	N/A	Internal
Shell Zone 1	SA-312 TP304 Wld & smls pipe	2.375 OD	3.939	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	0.1875 (min.)	114 OD	699.3	2

Shells							
Item #	Type	Material	Thk [in]	Dia. [in]	Length [in]	Wt. [lb] (ea.)	Qty
S1	Cylinder	SA-240 304	0.375	114 OD	87	3,377.3	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	925.6	208.3
HPJ2	Half Pipe	SA-312 TP304 Wld & smls pipe (welded)	NPS 2 Sch 10S	0.109	2.375 OD	1,969.6	443.2
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, 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
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		4.09	113.4375	1
Dimensions				
Outer Diameter		114"		
Length		87"		
Nominal Thickness		0.375"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		3,377.32		3,793.79
Corroded		3,377.32		3,793.79
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	Internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0653"
Maximum allowable working pressure (MAWP)	86.35 psi
Maximum allowable pressure (MAP)	92.35 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{20.73 \cdot 57}{20{,}000 \cdot 0.7 + 0.4 \cdot 20.73} =$	0.0844"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0844 \cdot 0.8}{0.375 - 0} =$	0.18
Impact test exempt per UHA-51(g) (coincident ratio = 0.18)	
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

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{15 \cdot 57}{18{,}700 \cdot 0.70 + 0.40 \cdot 15} + 0 = 0.0653"$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{18{,}700 \cdot 0.70 \cdot 0.375}{57 - 0.40 \cdot 0.375} - 0 = 86.35 \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{20{,}000 \cdot 0.70 \cdot 0.375}{57 - 0.40 \cdot 0.375} = 92.35 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.375}{56.8125}\right) \cdot \left(1 - \frac{56.8125}{\infty}\right) = 0.33\,\%$$

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

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
Static Liquid Head				
Condition		P_s (psi)	H_s (in)	SG
Test horizontal		4.1	113.625	1
Dimensions				
Outer Diameter		114"		
Crown Radius L		108"		
Knuckle Radius r		6.875"		
Minimum Thickness		0.1875"		
Corrosion	Inner	0"		
	Outer	0"		
Length L_{sf}		1.5"		
Nominal Thickness t_{sf}		0.25"		
Weight and Capacity				
		Weight (lb)[1]		Capacity (US gal)[1]
New		699.33		597.77
Corroded		699.33		597.77
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	internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.146"
Maximum allowable working pressure (MAWP)	20.73 psi
Maximum allowable pressure (MAP)	28.53 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	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{108}{6.875}\right)^{\frac{1}{2}}\right]$	1.7409
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{108}{6.875}\right)^{\frac{1}{2}}\right]$	1.7409

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

$$t = \frac{P \cdot L_o \cdot M}{2 \cdot S \cdot E + P \cdot (M - 0.2)} + \text{Corrosion} = \frac{15 \cdot 108.1875 \cdot 1.7409}{2 \cdot 18{,}700 \cdot 0.85 + 15 \cdot (1.7409 - 0.2)} + 0 = 0.0888"$$

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

$$0.0005 \le \frac{t_{minhead} - \text{Corrosion}}{L} = \frac{0.1875}{108} = 0.0017 < 0.002$$

$$\frac{r}{D} = 0.0605 \le 0.08$$

$$C_1 = \frac{9.31 \cdot r}{D} - 0.086 = \frac{9.31 \cdot 6.875}{113.625} - 0.086 = 0.4773$$

$$S_e = C_1 \cdot E_T \cdot \left(\frac{t}{r}\right) = 0.4773 \cdot 26.79\text{E}{+}06 \cdot \left(\frac{0.146}{6.875}\right) = 271{,}527 \text{ psi}$$

$$C_2 = 1.25$$

$$\phi = \frac{\sqrt{L \cdot t}}{r} = \frac{\sqrt{108 \cdot 0.146}}{6.875} = 0.577557 \text{ radians}$$

$$a = 0.5 \cdot D - r = 0.5 \cdot 113.625 - 6.875 = 49.9375"$$

$$b = L - r = 108 - 6.875 = 101.125"$$

$$\beta = arccos\left(\frac{a}{b}\right) = arccos\left(\frac{49.9375}{101.125}\right) = 1.05432 \text{ radians}$$

$\phi = 0.5776 < \beta = 1.0543$

$$c = \frac{a}{\cos(\beta - \phi)} = \frac{49.9375}{\cos(1.0543 - 0.5776)} = 56.205222"$$

$$R_e = c + r = 56.2052 + 6.875 = 63.080222"$$

$$P_e = \frac{S_e \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{271{,}527 \cdot 0.146}{1.25 \cdot 63.0802 \cdot \left[\left(\frac{0.5 \cdot 63.0802}{6.875}\right) - 1\right]} = 140.12 \text{ psi}$$

$$P_y = \frac{S_y \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{21{,}800 \cdot 0.146}{1.25 \cdot 63.0802 \cdot \left[\left(\frac{0.5 \cdot 63.0802}{6.875}\right) - 1\right]} = 11.25 \text{ psi}$$

$$\frac{P_e}{P_y} = \frac{140.12}{11.25} = 12.46 > 8.29$$

$P_{ck} = 2 \cdot P_y = 2 \cdot 11.25 = 22.5$ psi

$\frac{P_{ck}}{1.5}$ = 15 psi ≥ Internal design pressure P = 15 psi

$t = t_r + \text{Corrosion} = 0.145986 + 0 = 0.145986$"

Design thickness is acceptable per Appendix 1-4(f) for a design pressure of 15 psi.

The head internal pressure design thickness is 0.146".

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 18{,}700 \cdot 0.85 \cdot 0.1875}{1.7409 \cdot 108.1875 - 0.1875 \cdot (1.7409 - 0.2)} - 0 = 31.7 \text{ psi}$$

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

$$0.0005 \le \frac{t_{minhead} - \text{Corrosion}}{L} = \frac{0.1875}{108} = 0.0017 < 0.002$$

$$\frac{r}{D} = 0.0605 \le 0.08$$

$$C_1 = \frac{9.31 \cdot r}{D} - 0.086 = \frac{9.31 \cdot 6.875}{113.625} - 0.086 = 0.4773$$

$$S_e = C_1 \cdot E_T \cdot \left(\frac{t}{r}\right) = 0.4773 \cdot 26.79\text{E+}06 \cdot \left(\frac{0.1875}{6.875}\right) = 348{,}741 \text{ psi}$$

$C_2 = 1.25$

$$\phi = \frac{\sqrt{L \cdot t}}{r} = \frac{\sqrt{108 \cdot 0.1875}}{6.875} = 0.654545 \text{ radians}$$

$a = 0.5 \cdot D - r = 0.5 \cdot 113.625 - 6.875 = 49.9375$"

$b = L - r = 108 - 6.875 = 101.125$"

$$\beta = arccos\left(\frac{a}{b}\right) = arccos\left(\frac{49.9375}{101.125}\right) = 1.05432 \text{ radians}$$

$\phi = 0.6545 < \beta = 1.0543$

$$c = \frac{a}{\cos(\beta - \phi)} = \frac{49.9375}{\cos(1.0543 - 0.6545)} = 54.212189"$$

$R_e = c + r = 54.2122 + 6.875 = 61.087189$"

$$P_e = \frac{S_e \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{348{,}741 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 248.74 \text{ psi}$$

$$P_y = \frac{S_y \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{21{,}800 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 15.55 \text{ psi}$$

$$\frac{P_e}{P_y} = \frac{248.74}{15.55} = 16 > 8.29$$

$P_{ck} = 2 \cdot P_y = 2 \cdot 15.55 = 31.1$ psi

$\frac{P_{ck}}{1.5}$ = 20.73 psi

$P = \frac{P_{ck}}{1.5} - P_s P = \frac{31.1}{1.5} - 0 = 20.73$ psi

The maximum allowable working pressure (MAWP) is 20.73 psi.

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 20{,}000 \cdot 0.85 \cdot 0.1875}{1.7409 \cdot 108.1875 - 0.1875 \cdot (1.7409 - 0.2)} - 0 = 33.9 \text{ psi}$$

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

$$0.0005 \le \frac{t_{minhead} - \text{Corrosion}}{L} = \frac{0.1875}{108} = 0.0017 < 0.002$$

$$\frac{r}{D} = 0.0605 \le 0.08$$

$$C_1 = \frac{9.31 \cdot r}{D} - 0.086 = \frac{9.31 \cdot 6.875}{113.625} - 0.086 = 0.4773$$

$$S_e = C_1 \cdot E_T \cdot \left(\frac{t}{r}\right) = 0.4773 \cdot 28.3\text{E}{+}06 \cdot \left(\frac{0.1875}{6.875}\right) = 368{,}398 \text{ psi}$$

$$C_2 = 1.25$$

$$\phi = \frac{\sqrt{L \cdot t}}{r} = \frac{\sqrt{108 \cdot 0.1875}}{6.875} = 0.654545 \text{ radians}$$

$$a = 0.5 \cdot D - r = 0.5 \cdot 113.625 - 6.875 = 49.9375"$$

$$b = L - r = 108 - 6.875 = 101.125"$$

$$\beta = arccos\left(\frac{a}{b}\right) = arccos\left(\frac{49.9375}{101.125}\right) = 1.05432 \text{ radians}$$

$\phi = 0.6545 < \beta = 1.0543$

$$c = \frac{a}{\cos(\beta - \phi)} = \frac{49.9375}{\cos(1.0543 - 0.6545)} = 54.212189"$$

$$R_e = c + r = 54.2122 + 6.875 = 61.087189"$$

$$P_e = \frac{S_e \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{368{,}398 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 262.76 \text{ psi}$$

$$P_y = \frac{S_y \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{30{,}000 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 21.4 \text{ psi}$$

$$\frac{P_e}{P_y} = \frac{262.76}{21.4} = 12.28 > 8.29$$

$$P_{ck} = 2 \cdot P_y = 2 \cdot 21.4 = 42.8 \text{ psi}$$

$\frac{P_{ck}}{1.5}$ = 28.53 psi

$$P = \frac{P_{ck}}{1.5} - P_s P = \frac{42.8}{1.5} - 0 = 28.53 \text{ psi}$$

The maximum allowable pressure (MAP) is 28.53 psi.

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

$$EFE = \left(\frac{75 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{75 \cdot 0.25}{7}\right) \cdot \left(1 - \frac{7}{\infty}\right) = 2.6786\,\%$$

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

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
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		4.1	113.5625	1
Dimensions				
Outer Diameter		114"		
Length		1.5"		
Nominal Thickness		0.25"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		38.86		65.7
Corroded		38.86		65.7
Radiography				
Longitudinal seam		Seamless No RT		
Top Circumferential seam		None UW-11(c) Type 1		

Results Summary	
Governing condition	UG-16
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0538"
Maximum allowable working pressure (MAWP)	69.84 psi
Maximum allowable pressure (MAP)	74.69 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{20.73 \cdot 57}{20{,}000 \cdot 0.85 + 0.4 \cdot 20.73} =$	0.0695"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0695 \cdot 0.85}{0.25 - 0} =$	0.2362
Impact test exempt per UHA-51(g) (coincident ratio = 0.2362)	
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

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{15 \cdot 57}{18{,}700 \cdot 0.85 + 0.40 \cdot 15} + 0 = 0.0538"$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{18{,}700 \cdot 0.85 \cdot 0.25}{57 - 0.40 \cdot 0.25} - 0 = 69.84 \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{20{,}000 \cdot 0.85 \cdot 0.25}{57 - 0.40 \cdot 0.25} = 74.69 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.25}{56.875}\right) \cdot \left(1 - \frac{56.875}{\infty}\right) = 0.2198\,\%$$

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

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
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		4.1	113.625	1
Dimensions				
Outer Diameter		114"		
Crown Radius L		108"		
Knuckle Radius r		6.875"		
Minimum Thickness		0.1875"		
Corrosion	**Inner**	0"		
	Outer	0"		
Length L_{sf}		1.5"		
Nominal Thickness t_{sf}		0.25"		
Weight and Capacity				
		Weight (lb)[1]		**Capacity (US gal)[1]**
New		699.33		597.77
Corroded		699.33		597.77
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	internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.146"
Maximum allowable working pressure (MAWP)	20.73 psi
Maximum allowable pressure (MAP)	28.53 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	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{108}{6.875}\right)^{\frac{1}{2}}\right]$	1.7409
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{108}{6.875}\right)^{\frac{1}{2}}\right]$	1.7409

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

$$t = \frac{P \cdot L_o \cdot M}{2 \cdot S \cdot E + P \cdot (M - 0.2)} + \text{Corrosion} = \frac{15 \cdot 108.1875 \cdot 1.7409}{2 \cdot 18{,}700 \cdot 0.85 + 15 \cdot (1.7409 - 0.2)} + 0 = 0.0888"$$

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

$$0.0005 \le \frac{t_{minhead} - \text{Corrosion}}{L} = \frac{0.1875}{108} = 0.0017 < 0.002$$

$$\frac{r}{D} = 0.0605 \le 0.08$$

$$C_1 = \frac{9.31 \cdot r}{D} - 0.086 = \frac{9.31 \cdot 6.875}{113.625} - 0.086 = 0.4773$$

$$S_e = C_1 \cdot E_T \cdot \left(\frac{t}{r}\right) = 0.4773 \cdot 26.79\text{E}{+06} \cdot \left(\frac{0.146}{6.875}\right) = 271{,}527 \text{ psi}$$

$$C_2 = 1.25$$

$$\phi = \frac{\sqrt{L \cdot t}}{r} = \frac{\sqrt{108 \cdot 0.146}}{6.875} = 0.577557 \text{ radians}$$

$$a = 0.5 \cdot D - r = 0.5 \cdot 113.625 - 6.875 = 49.9375"$$

$$b = L - r = 108 - 6.875 = 101.125"$$

$$\beta = arccos\left(\frac{a}{b}\right) = arccos\left(\frac{49.9375}{101.125}\right) = 1.05432 \text{ radians}$$

$\phi = 0.5776 < \beta = 1.0543$

$$c = \frac{a}{\cos(\beta - \phi)} = \frac{49.9375}{\cos(1.0543 - 0.5776)} = 56.205222"$$

$$R_e = c + r = 56.2052 + 6.875 = 63.080222"$$

$$P_e = \frac{S_e \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{271{,}527 \cdot 0.146}{1.25 \cdot 63.0802 \cdot \left[\left(\frac{0.5 \cdot 63.0802}{6.875}\right) - 1\right]} = 140.12 \text{ psi}$$

$$P_y = \frac{S_y \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{21{,}800 \cdot 0.146}{1.25 \cdot 63.0802 \cdot \left[\left(\frac{0.5 \cdot 63.0802}{6.875}\right) - 1\right]} = 11.25 \text{ psi}$$

$$\frac{P_e}{P_y} = \frac{140.12}{11.25} = 12.46 > 8.29$$

$P_{ck} = 2 \cdot P_y = 2 \cdot 11.25 = 22.5$ psi

$\frac{P_{ck}}{1.5}$ = 15 psi ≥ Internal design pressure P = 15 psi

$t = t_r + \text{Corrosion} = 0.145986 + 0 = 0.145986$"

Design thickness is acceptable per Appendix 1-4(f) for a design pressure of 15 psi.

The head internal pressure design thickness is 0.146".

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 18{,}700 \cdot 0.85 \cdot 0.1875}{1.7409 \cdot 108.1875 - 0.1875 \cdot (1.7409 - 0.2)} - 0 = 31.7 \text{ psi}$$

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

$$0.0005 \le \frac{t_{minhead} - \text{Corrosion}}{L} = \frac{0.1875}{108} = 0.0017 < 0.002$$

$$\frac{r}{D} = 0.0605 \le 0.08$$

$$C_1 = \frac{9.31 \cdot r}{D} - 0.086 = \frac{9.31 \cdot 6.875}{113.625} - 0.086 = 0.4773$$

$$S_e = C_1 \cdot E_T \cdot \left(\frac{t}{r}\right) = 0.4773 \cdot 26.79\text{E+}06 \cdot \left(\frac{0.1875}{6.875}\right) = 348{,}741 \text{ psi}$$

$C_2 = 1.25$

$$\phi = \frac{\sqrt{L \cdot t}}{r} = \frac{\sqrt{108 \cdot 0.1875}}{6.875} = 0.654545 \text{ radians}$$

$a = 0.5 \cdot D - r = 0.5 \cdot 113.625 - 6.875 = 49.9375$"

$b = L - r = 108 - 6.875 = 101.125$"

$$\beta = arccos\left(\frac{a}{b}\right) = arccos\left(\frac{49.9375}{101.125}\right) = 1.05432 \text{ radians}$$

$\phi = 0.6545 < \beta = 1.0543$

$$c = \frac{a}{\cos(\beta - \phi)} = \frac{49.9375}{\cos(1.0543 - 0.6545)} = 54.212189"$$

$R_e = c + r = 54.2122 + 6.875 = 61.087189$"

$$P_e = \frac{S_e \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{348{,}741 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 248.74 \text{ psi}$$

$$P_y = \frac{S_y \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{21{,}800 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 15.55 \text{ psi}$$

$$\frac{P_e}{P_y} = \frac{248.74}{15.55} = 16 > 8.29$$

$P_{ck} = 2 \cdot P_y = 2 \cdot 15.55 = 31.1$ psi

$\frac{P_{ck}}{1.5}$ = 20.73 psi

$$P = \frac{P_{ck}}{1.5} - P_s P = \frac{31.1}{1.5} - 0 = 20.73 \text{ psi}$$

The maximum allowable working pressure (MAWP) is 20.73 psi.

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{M \cdot L_o - t \cdot (M - 0.2)} - P_s = \frac{2 \cdot 20{,}000 \cdot 0.85 \cdot 0.1875}{1.7409 \cdot 108.1875 - 0.1875 \cdot (1.7409 - 0.2)} - 0 = 33.9 \text{ psi}$$

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

$$0.0005 \le \frac{t_{minhead} - \text{Corrosion}}{L} = \frac{0.1875}{108} = 0.0017 < 0.002$$

$$\frac{r}{D} = 0.0605 \le 0.08$$

$$C_1 = \frac{9.31 \cdot r}{D} - 0.086 = \frac{9.31 \cdot 6.875}{113.625} - 0.086 = 0.4773$$

$$S_e = C_1 \cdot E_T \cdot \left(\frac{t}{r}\right) = 0.4773 \cdot 28.3E{+}06 \cdot \left(\frac{0.1875}{6.875}\right) = 368{,}398 \text{ psi}$$

$$C_2 = 1.25$$

$$\phi = \frac{\sqrt{L \cdot t}}{r} = \frac{\sqrt{108 \cdot 0.1875}}{6.875} = 0.654545 \text{ radians}$$

$$a = 0.5 \cdot D - r = 0.5 \cdot 113.625 - 6.875 = 49.9375"$$

$$b = L - r = 108 - 6.875 = 101.125"$$

$$\beta = arccos\left(\frac{a}{b}\right) = arccos\left(\frac{49.9375}{101.125}\right) = 1.05432 \text{ radians}$$

$\phi = 0.6545 < \beta = 1.0543$

$$c = \frac{a}{\cos(\beta - \phi)} = \frac{49.9375}{\cos(1.0543 - 0.6545)} = 54.212189"$$

$$R_e = c + r = 54.2122 + 6.875 = 61.087189"$$

$$P_e = \frac{S_e \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{368{,}398 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 262.76 \text{ psi}$$

$$P_y = \frac{S_y \cdot t}{C_2 \cdot R_e \cdot \left[\left(\frac{0.5 \cdot R_e}{r}\right) - 1\right]} = \frac{30{,}000 \cdot 0.1875}{1.25 \cdot 61.0872 \cdot \left[\left(\frac{0.5 \cdot 61.0872}{6.875}\right) - 1\right]} = 21.4 \text{ psi}$$

$$\frac{P_e}{P_y} = \frac{262.76}{21.4} = 12.28 > 8.29$$

$$P_{ck} = 2 \cdot P_y = 2 \cdot 21.4 = 42.8 \text{ psi}$$

$\frac{P_{ck}}{1.5}$ = 28.53 psi

$$P = \frac{P_{ck}}{1.5} - P_s P = \frac{42.8}{1.5} - 0 = 28.53 \text{ psi}$$

The maximum allowable pressure (MAP) is 28.53 psi.

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

$$EFE = \left(\frac{75 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{75 \cdot 0.25}{7}\right) \cdot \left(1 - \frac{7}{\infty}\right) = 2.6786\,\%$$

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

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
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		4.1	113.5625	1
Dimensions				
Outer Diameter		114"		
Length		1.5"		
Nominal Thickness		0.25"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		38.86		65.7
Corroded		38.86		65.7
Radiography				
Longitudinal seam		Seamless No RT		
Bottom Circumferential seam		None UW-11(c) Type 1		

Results Summary	
Governing condition	UG-16
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0538"
Maximum allowable working pressure (MAWP)	69.84 psi
Maximum allowable pressure (MAP)	74.69 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{20.73 \cdot 57}{20{,}000 \cdot 0.85 + 0.4 \cdot 20.73} =$	0.0695"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0695 \cdot 0.85}{0.25 - 0} =$	0.2362
Impact test exempt per UHA-51(g) (coincident ratio = 0.2362)	
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

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{15 \cdot 57}{18{,}700 \cdot 0.85 + 0.40 \cdot 15} + 0 = 0.0538"$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{18{,}700 \cdot 0.85 \cdot 0.25}{57 - 0.40 \cdot 0.25} - 0 = 69.84 \text{ psi}$$

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

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} = \frac{20{,}000 \cdot 0.85 \cdot 0.25}{57 - 0.40 \cdot 0.25} = 74.69 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.25}{56.875}\right) \cdot \left(1 - \frac{56.875}{\infty}\right) = 0.2198\,\%$$

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

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)		3.46	4.26
Test horizontal, H_s (in)		95.7658	118.0785
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	0.0944
Corrosion (in)	Inner	0	0
	Outer	0	0
Pitch (in)		4	4
Weld Fillet (in)		0.1875	0.1875
Location		Head Zone	Shell Zone 1
Inlet	Angle (deg.)	0	0
	Elev. (in)	-	4
	Dist. r (in)	5.25	-
Outlet	Angle (deg.)	0	0
	Elev. (in)	-	48
	Dist. r (in)	47.5684	-
Rotation Direction		Standard	Standard
Number of coils		11	11
Weight (lb)			
New		208.3	443.2
Corroded		208.3	443.2
New (total)		651.5	
Corroded (total)		651.5	
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_{rp}) (in)	0.0072	0.0072
Maximum allowable working pressure (MAWP) (psi)	280.34	1,123.48
Maximum working pressure (MAP) (psi)	303.37	1,201.58
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 $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0128 \cdot 0.85}{0.0944 - 0} =$	0.1149
Impact test exempt per UHA-51(g) (coincident ratio = 0.1149)	
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, austinitic 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 =	57"
$F_{bend} = \left(1 + \frac{2.375}{4 \cdot 57}\right)$	1.0104
Minimum Thickness, $T_{\min} = \frac{0.109 \cdot 0.875}{1.0104}$	0.0944"

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	
$T = \frac{90 \cdot 1.0785}{0.85 \cdot 15{,}895 - 0.60 \cdot 90} + 0 =$	0.0072"
Shell Zone 1	
Operating Hot & Corroded	
$T = \frac{90 \cdot 1.0785}{0.85 \cdot 15{,}895 - 0.60 \cdot 90} + 0 =$	0.0072"

Allowable Stress, F	
$S' = \max\left[0, \frac{P \cdot D}{4 \cdot t_s} + \left(\frac{W}{A}\right) + \left(\frac{M}{Z}\right)\right]$	
$F = \min\left[(1.50 \cdot S - S'), 1.50 \cdot S\right]$	(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	
$S' = \max\left[0, \frac{15 \cdot 216}{4 \cdot 0.1875}\right] =$	4,320 psi
$F = \min\left[(1.50 \cdot 18{,}700 - 4{,}320), 1.50 \cdot 18{,}700\right] =$	23,730 psi
Cold & New (MAP)	
$S' = \max\left[0, \frac{15 \cdot 216}{4 \cdot 0.1875}\right] =$	4,320 psi
$F = \min\left[(1.50 \cdot 20{,}000 - 4{,}320), 1.50 \cdot 20{,}000\right] =$	25,680 psi
Shell Zone 1	
Operating Hot & Corroded	
$S' = \max\left[0, \frac{15 \cdot 113.25}{4 \cdot 0.375}\right] =$	1,133 psi
$F = \min\left[(1.50 \cdot 18{,}700 - 1{,}133), 1.50 \cdot 18{,}700\right] =$	26,918 psi
Cold & New (MAP)	
$S' = \max\left[0, \frac{15 \cdot 113.25}{4 \cdot 0.375}\right] =$	1,133 psi
$F = \min\left[(1.50 \cdot 20{,}000 - 1{,}133), 1.50 \cdot 20{,}000\right] =$	28,868 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 =	113.625"
Vessel Shell Thickness, t =	0.1875"
$K_p = -3.667451E+01 + 1.230699E+01 \cdot 113.625^{0.50} + 3.570168E+00 \cdot 113.625 + -7.951658E-01 \cdot 113.625^{1.50} + 5.879104E-02 \cdot 113.625^{2} + -1.536540E-03 \cdot 113.625^{2.50} + 0.000000E+00 \cdot 113.625^{3} + 0.000000E+00 \cdot 113.625^{3.50} + 0.000000E+00 \cdot 113.625^{4} + 0.000000E+00 \cdot 113.625^{4.50} =$	84.6484
Cold & New (MAP)	
Vessel Inner Diameter, D =	113.625"
Vessel Shell Thickness, t =	0.1875"
$K_p = -3.667451E+01 + 1.230699E+01 \cdot 113.625^{0.50} + 3.570168E+00 \cdot 113.625 + -7.951658E-01 \cdot 113.625^{1.50} + 5.879104E-02 \cdot 113.625^{2} + -1.536540E-03 \cdot 113.625^{2.50} + 0.000000E+00 \cdot 113.625^{3} + 0.000000E+00 \cdot 113.625^{3.50} + 0.000000E+00 \cdot 113.625^{4} + 0.000000E+00 \cdot 113.625^{4.50} =$	84.6484
Shell Zone 1	
Operating Hot & Corroded	
Vessel Inner Diameter, D =	113.25"
Vessel Shell Thickness, t =	0.375"
$K_p = 4.008378E+02 + -5.702911E+02 \cdot 113.25^{0.50} + 3.198970E+02 \cdot 113.25 + -9.428621E+01 \cdot 113.25^{1.50} + 1.639176E+01 \cdot 113.25^{2} + -1.743122E+00 \cdot 113.25^{2.50} + 1.116018E-01 \cdot 113.25^{3} + -3.954959E-03 \cdot 113.25^{3.50} + 5.964421E-05 \cdot 113.25^{4} + 0.000000E+00 \cdot 113.25^{4.50} =$	23.9415
Cold & New (MAP)	
Vessel Inner Diameter, D =	113.25"
Vessel Shell Thickness, t =	0.375"
$K_p = 4.008378E+02 + -5.702911E+02 \cdot 113.25^{0.50} + 3.198970E+02 \cdot 113.25 + -9.428621E+01 \cdot 113.25^{1.50} + 1.639176E+01 \cdot 113.25^{2} + -1.743122E+00 \cdot 113.25^{2.50} + 1.116018E-01 \cdot 113.25^{3} + -3.954959E-03 \cdot 113.25^{3.50} + 5.964421E-05 \cdot 113.25^{4} + 0.000000E+00 \cdot 113.25^{4.50} =$	23.9415

Maximum Permissible Pressure	
$P' = \frac{F}{K} - P_s$	(EE-2 (1))
$P_{circ} = \frac{S \cdot 0.85 \cdot t}{R + 0.60 \cdot t} - P_s$	(UG-27(c)(1))
$P\ \max\ =\ \min\ (P', P_{circ})$	
Head Zone	
Operating Hot & Corroded (MAWP)	
$P' = \frac{23{,}730}{84.6484} - 0$ =	280.34 psi
$P_{circ} = \frac{15{,}895 \cdot 0.85 \cdot 0.0857}{1.0785 + 0.60 \cdot 0.0857} - 0$ =	1,024.56 psi
MAWP =	280.34 psi
Cold & New (MAP)	
$P' = \frac{25{,}680}{84.6484}$ =	303.37 psi
$P_{circ} = \frac{17{,}000 \cdot 0.85 \cdot 0.0857}{1.0785 + 0.60 \cdot 0.0857}$ =	1,095.79 psi
MAP =	303.37 psi
Shell Zone 1	
Operating Hot & Corroded (MAWP)	
$P' = \frac{26{,}918}{23.9415} - 0$ =	1,124.3 psi
$P_{circ} = \frac{15{,}895 \cdot 0.85 \cdot 0.0944}{1.0785 + 0.60 \cdot 0.0944} - 0$ =	1,123.48 psi
MAWP =	1,123.48 psi
Cold & New (MAP)	
$P' = \frac{28{,}868}{23.9415}$ =	1,205.75 psi
$P_{circ} = \frac{17{,}000 \cdot 0.85 \cdot 0.0944}{1.0785 + 0.60 \cdot 0.0944}$ =	1,201.58 psi
MAP =	1,201.58 psi

EE-2 Minimum Required Fillet Weld		
	Head Zone	**Shell Zone 1**
Weld Fillet Size (fa) =	0.1875"	0.1875"
Jacket Thickness (t_j) =	0.109−0 =0.109	0.109−0 =0.109
Shell Thickness (t_s) =	0.1875−0 =0.1875	0.375−0 =0.375
Minimum Throat Thickness = min(t_j, t_s) =	0.109	0.109
Fillet Weld Throat Thickness = $0.70 \cdot fa - C =$	$0.70 \cdot 0.1875 - 0$ =0.1312	$0.70 \cdot 0.1875 - 0$ =0.1312
Fillet Weld Throat Thickness Acceptable	OK	OK
Required Fillet Leg = $\frac{\text{Min Throat} + \text{C}}{0.70}$ =	$\frac{0.109+0}{0.70}$ = 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)	
$\varepsilon_f = \frac{100 \cdot r}{R}$	
Head Zone	
$\varepsilon_f = \frac{100 \cdot 1.1875}{5.25} =$	22.619%
Shell Zone 1	
$\varepsilon_f = \frac{100 \cdot 1.1875}{57} =$	2.0833%

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		1.58	43.8886	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"
$\text{External Leg}_{\min} = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
$\text{Internal Leg}_{\min} = \min\left[t_n, 0.25" + \frac{C_i}{0.7}\right] = \min\left[0.109, 0.25 + \frac{0}{0.7}\right] =$	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"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	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		0.05	1.3551	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"
$\text{External Leg}_{\min} = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
$\text{Internal Leg}_{\min} = \min\left[t_n, 0.25" + \frac{C_i}{0.7}\right] = \min\left[0.109, 0.25 + \frac{0}{0.7}\right] =$	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"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	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"
$\text{External Leg}_{\min} = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
$\text{Internal Leg}_{\min} = \min\left[t_n, 0.25" + \frac{C_i}{0.7}\right] = \min\left[0.109, 0.25 + \frac{0}{0.7}\right] =$	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"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	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 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	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"
$\text{External Leg}_{\min} = X_{\min} + \frac{C_o}{0.7} = 0.1526 + \frac{0}{0.7} =$	0.1526"
$\text{Internal Leg}_{\min} = \min\left[t_n, 0.25" + \frac{C_i}{0.7}\right] = \min\left[0.109, 0.25 + \frac{0}{0.7}\right] =$	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"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0138 \cdot 1}{0.0954 - 0} =$	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

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