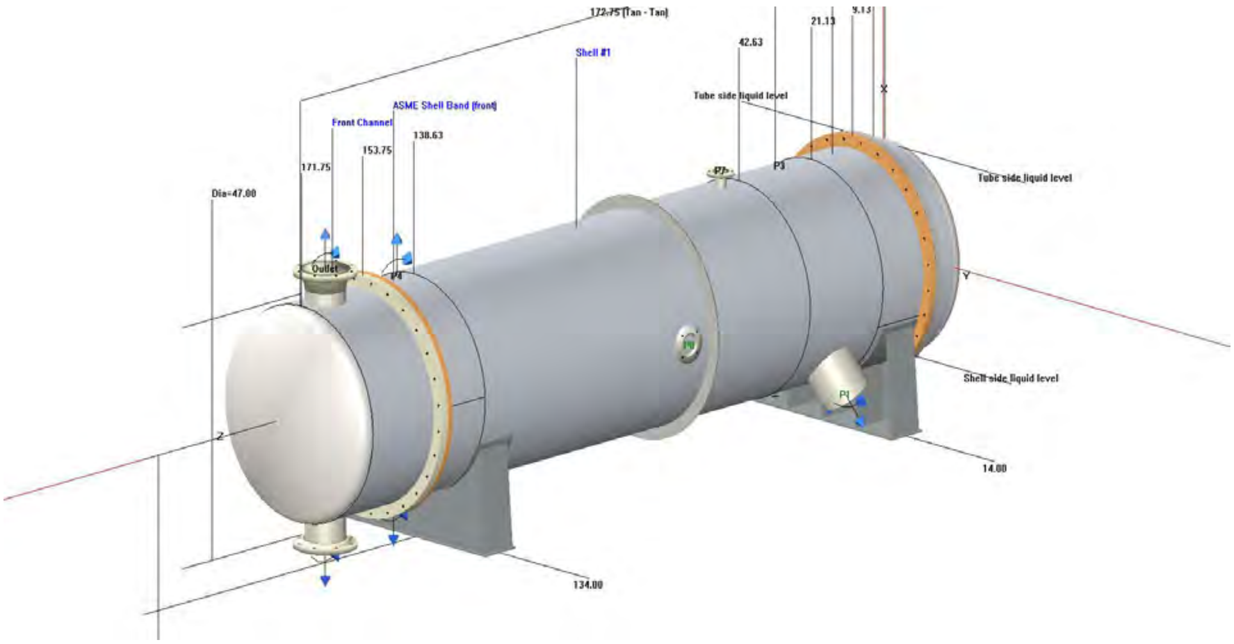
Seitz Stainless

Avon, Minnesota



ASME BPV VIII-1 2019 Heat Exchanger Design Calculations

NB 355 HEAT EXCHANGER MAIN BODY ONLY CALCULATIONS

Vessel No: Horizontal Heat Exchanger NB # 335

Customer: Caloris Engineering, Easton, MD

Contract: Merit Functional Foods

Item: Horizontal Heat Exchanger

Date: May, 2020

Designer:

Fabricated to ASME BPV Section VIII Div 1, 2019 Rules

A 52" diameter bustle (vapor band), 36" long is included in the design, which is not shown in this calculation. The vapor band is treated by Code as a conventional jacket, and is subject to the rules and calculations of Appendix 9. Beneath the vapor band are three windows cut from the main shell for vapor passage.

Due to limitations in Compress software heat exchanger mode, this set of calculations models only the main heat exchanger, not including the vapor band or the window cutouts. The vapor band is modeled as a separate set of Compress calculations, and the vapor windows were modeled by modifying the results of the shell calculations contained herein. This was done by determining the available shell stress as calculated by Compress without the windows, multiplying those calculated stresses by the ratio of remaining shell material after the windows were removed, as prescribed in UHX Section 13.5.10, step 10 for the eight cases of the Operating Condition. Shell stresses were acceptable.

Both sets of calculations, the vapor band and the shell vapor window cut-outs, are modeled and presented under separate cover.

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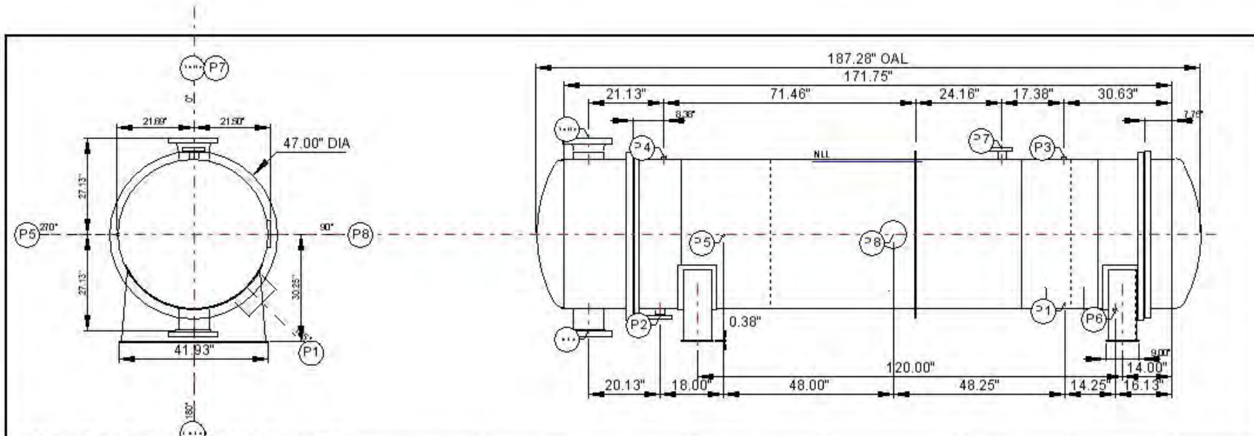


D E S I G N D A T A	S H E L L	T U B E
Design Pressure	25 psi	60 psi
Vacuum Pressure	-15 psi	N/A
Test Pressure (Shop)	112.25 psi	114.33 psi
Design Temperature	300 °F	300 °F
MDMT	-20 °F	40 °F
Corrosion Allowance	0"	0"
Number of Passes	1	6
Radiography	None	None
PWHT	None	None

Estimated Weights

Dry: 6,201 lb Wet: 11,031 lb
Bundle: 3,102 lb
Weight at left saddle: 6,613 lb (Oper), 8,611 lb (Test)
Weight at right sadd 4,419 lb (Oper), 6,051 lb (Test)

Materials

Channel: SA-240 S32205
Shell: SA-240 304
Tubesheets: SA-240 S32205
Baffles: SA-240
Tubes: SA-789 Wld tube S32205
Tubes (342) 1.5" OD x 0.049" x 144" LONG
Tube Pitch = 1.875" Rotated Triangular (60°)
Tube Surface Area = 232,075.73 in²
Gaskets:

NOZZLE SCHEDULE

MARK	NOZZLE	SIZE & SCH	FLANGE	MARK	NOZZLE	SIZE & SCH	FLANGE
P3	Press Relief	NPS 0.75 Class 30					
P1	SS Vapor Inlet	NPS 10 Sch 10S					
P7	Cleanout	NPS 2 Sch 10S	NPS 2 SO Class 1				
P8	Sight Glass	7.5 OD x 1.75					
P5	SS Vent	NPS 0.25 Class 30					
P4	Capped Vent Port	NPS 0.5 Class 300					
P2	SS Condensate Dr	NPS 2.5 Sch 40S (	NPS 2.5 SO Class				
Inlet	TS Product Inlet	NPS 8 Sch 10S	NPS 8 SO Class 1				
Outlet	TS Product Outlet	NPS 8 Sch 10S	NPS 8 WN Class	P6	Capped Vent Port	NPS 0.5 Class 300	

REVISIONS

REV	DATE	DESCRIPTION
0	01/24/20	FOR APPROV

Seitz Stainless
17578 400th Street
Avon, MN 56310

ASME VIII-1 2019 Edition TEMA Type: BEM
Size: 42-144 TEMA Class:
DWN BY:
CHK BY:
145685-1

General Arrangement

DWG NO. DATE: Rev 0

20-3776_PVE_Verification.CW7

Deficiencies Summary

No deficiencies found.

Nozzle Schedule

Specifications										
Nozzle mark	Identifier	Size	Service	Materials		Impact Tested	Normalized	Fine Grain	Flange	Blind
Inlet	TS Product Intlet	NPS 8 Sch 10S	IN	Nozzle	SA-790 Smls pipe S32205	No	No	No	NPS 8 Class 150 SO A182 F51	No
Outlet	TS Product Outlet	NPS 8 Sch 10S	OUT	Nozzle	SA-790 Smls pipe S32205	No	No	No	NPS 8 Class 150 WN A182 F51	No
P1	SS Vapor Inlet	NPS 10 Sch 10S	IN	Nozzle	SA-312 TP304 Wld pipe	No	No	No	N/A	No
				Pad	SA-240 304L	No	No	No		
P2	SS Condensate Drain	NPS 2.5 Sch 40S (Std)	DRN	Nozzle	SA-312 TP304L Wld pipe	No	No	No	NPS 2 1/2 Class 150 SO A105	No
P3	Press Relief	NPS 0.75 Class 3000 - Threaded Half Coupling	PRV	Nozzle	SA-312 TP304 Wld pipe	No	No	No	N/A	No
P4	Capped Vent Port	NPS 0.5 Class 3000 - Threaded Half Coupling	VENT	Nozzle	SA-312 TP304 Wld pipe	No	No	No	N/A	No
P5	SS Vent	NPS 0.25 Class 3000 - Threaded Half Coupling		Nozzle	SA-312 TP304 Wld pipe	No	No	No	N/A	No
P6	Capped Vent Port	NPS 0.5 Class 3000 - Threaded Half Coupling	DRN	Nozzle	SA-312 TP304 Wld pipe	No	No	No	N/A	No
P7	Cleanout	NPS 2 Sch 10S	CLEANOUT	Nozzle	SA-312 TP304 Wld & smls pipe	No	No	No	NPS 2 Class 150 SO A105	No
P8	Sight Glass	7.5 OD x 1.75	SG	Nozzle	SA-240 304	No	No	No	N/A	No

Nozzle Summary

Dimensions												
Nozzle mark	OD (in)	t_n (in)	Req t_n (in)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (in)	A_a/A_r (%)
						Nom t (in)	Design t (in)	User t (in)	Width (in)	t_{pad} (in)		
Inlet	8.625	0.148	0.148	Yes	Yes	0.25	0.1761		N/A	N/A	0	100.0
Outlet	8.625	0.148	0.148	Yes	Yes	0.25	0.1779		N/A	N/A	0	100.0
P1	10.75	0.165	0.1454	Yes	Yes	0.1874	0.1697		1.7829	0.1672	0	100.0
P2	2.875	0.203	0.203	Yes	Yes	0.1874	N/A		N/A	N/A	0	Exempt
P3	1.38	0.16	0.0714	Yes	Yes	0.1874	N/A		N/A	N/A	0	Exempt
P4	1.12	0.14	0.0714	Yes	Yes	0.1874	N/A		N/A	N/A	0	Exempt
P5	0.75	0.11	0.0714	Yes	Yes	0.1874	N/A		N/A	N/A	0	Exempt
P6	1.12	0.14	0.0714	Yes	Yes	0.1874	N/A		N/A	N/A	0	Exempt
P7	2.375	0.109	0.1089	Yes	Yes	0.1874	N/A		N/A	N/A	0	Exempt
P8	7.5	1.75	0.1874	Yes	Yes	0.1874	0.1874		N/A	N/A	0	215.0

Definitions	
t_n	Nozzle thickness
Req t_n	Nozzle thickness required per UG-45/UG-16 Increased for pipe to account for 12.5% pipe thickness tolerance
Nom t	Vessel wall thickness
Design t	Required vessel wall thickness due to pressure + corrosion allowance per UG-37
User t	Local vessel wall thickness (near opening)
A_a	Area available per UG-37, governing condition
A_r	Area required per UG-37, governing condition
Corr	Corrosion allowance on nozzle wall

Pressure Summary

Component Summary for Tube side chamber									
Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MAEP (psi)	T_e external (°F)	MDMT (°F)	MDMT Exemption	Impact Tested
Front Head	60	250	98.18	101.16	46.65	250	-20	Note 1	No
Straight Flange on Front Head	60	250	134.74	138.27	23.18	250	-20	Note 2	No
Front Channel	60	250	222.08	226.91	129.6	250	-20	Note 3	No
Tubesheet (see Maximum Pressure Rating note)	75	300	114.91	157.11	204.96	300	-20	Note 4	Yes
Rear Tubesheet (see Maximum Pressure Rating note)	75	300	114.91	157.11	204.96	300	-20	Note 4	Yes
Rear Channel	60	250	222.08	226.91	161.55	250	-20	Note 4	Yes
Straight Flange on Rear Channel Head	60	250	269.98	275.54	161.55	250	-20	Note 6	No
Rear Channel Head	60	250	98.18	101.16	46.65	250	-20	Note 5	No
Tubes	75	300	1,303.18	1,351.45	492.02	300	-20	Note 7	No
Tube Side Flange (front)	60	250	86.65	89.46	150	250	-20	Note 8	Yes
Tube Side Flange (rear)	60	250	86.65	89.46	150	250	-20	Note 8	Yes
TS Product Intlet (Inlet)	60	250	164.57	168.56	53.69	250	40	Note 9	No
TS Product Outlet (Outlet)	60	250	166.08	168.56	55.17	250	40	Note 10	No

Chamber Summary for Tube side chamber	
Design MDMT	40 °F
Rated MDMT	40 °F @ 86.65 psi
MAWP hot & corroded	86.65 psi @ 250 °F
MAP cold & new	89.46 psi @ 70 °F
MAEP	23.18 psi @ 250 °F

Component Summary for Shell side chamber									
Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MAEP (psi)	T_e external (°F)	MDMT (°F)	MDMT Exemption	Impact Tested
Tubesheet (see Maximum Pressure Rating note)	40	300	204.96	226.15	114.91	300	-20	Note 4	Yes
ASME Shell Band (front)	25	300	118.31	125.38	16.36	300	-320	Note 11	No
Shell #1	25	300	118.31	125.38	16.36	300	-320	Note 11	No
Shell #2	25	300	118.31	125.38	20.53	300	-320	Note 11	No
ASME Shell Band (rear)	25	300	118.31	125.38	20.53	300	-320	Note 11	No
Rear Tubesheet (see Maximum Pressure Rating note)	40	300	204.96	226.15	114.91	300	-20	Note 4	Yes
Tubes	40	300	492.02	492.02	1,303.18	300	N/A	N/A	No
Rings #1	N/A	N/A	N/A	N/A	16.36	300	N/A	N/A	No
Saddle #1	25	300	86.35	N/A	N/A	N/A	N/A	N/A	N/A
SS Vapor Inlet (P1)	25	300	115.1	120.38	15.74	300	-320	Nozzle: Note 12	No
								Pad: Note 11	No
SS Condensate Drain (P2)	25	300	169.08	179.12	16.36	300	-55	Note 13	No
Press Relief (P3)	25	300	169.26	179.12	20.53	300	-320	Note 14	No
Capped Vent Port (P4)	25	300	169.26	179.12	16.36	300	-320	Note 15	No
SS Vent (P5)	25	300	169.26	179.12	16.36	300	-320	Note 16	No
Capped Vent Port (P6)	25	300	169.08	179.12	20.53	300	-320	Note 15	No
Cleanout (P7)	25	300	86.35	91.37	16.36	300	-55	Note 17	No
Sight Glass (P8)	25	300	169.26	179.12	16.36	300	-55	Note 18	No

Chamber Summary for Shell side chamber	
Design MDMT	40 °F
Rated MDMT	-20 °F @ 86.35 psi
MAWP hot & corroded	86.35 psi @ 300 °F
MAP cold & new	91.37 psi @ 70 °F
MAEP	15.74 psi @ 300 °F

Notes for Maximum Pressure Rating	
Note #	Details
1.	The largest tubesheet MAWP/MAP values have been selected from the multiple design conditions to maximize the hydrotest pressure and to comply with UG-20(b). The MAWP/MAP selected for the shell side may not be coincident with the MAWP/MAP selected for the tube side (and vice versa).
2.	The chamber MAWP listed above is based on the largest tubesheet MAWP values from the multiple design conditions. The lowest tubesheet MAWP values should be considered when determining the final chamber MAWP. Refer to the Tubesheet Maximum Pressure Report for the lowest tubesheet maximum pressure ratings.

Notes for MDMT Rating		
Note #	Exemption	Details
1.	Straight Flange governs MDMT	
2.	Rated MDMT per UHA-51(d)(3)(a) = -20°F	
3.	Impact test exempt per UHA-51(g) (coincident ratio = 0.3094)	
4.	Material is impact tested to -20°F per UHA-51(a).	
5.	Straight Flange governs MDMT	
6.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2706)	
7.	Impact test exempt per UHA-51(g) (coincident ratio = 0.0666)	
8.	Flange Material is impact tested to -20°F per UHA-51(a).	Bolts rated MDMT per Fig UCS-66 note (c) = -55°F
9.	Flange rating governs: Flange rated MDMT per UHA-51(g) = 40°F (Coincident ratio = 0.3047) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	
10.	Flange rating governs: Flange rated MDMT per UHA-51(g) = 40°F (Coincident ratio = 0.2988) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	
11.	Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	
12.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1839)	
13.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.3039) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	
14.	Impact test exempt per UHA-51(g) (coincident ratio = 0.0193)	
15.	Impact test exempt per UHA-51(g) (coincident ratio = 0.0175)	
16.	Impact test exempt per UHA-51(g) (coincident ratio = 0.014)	
17.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.303) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	
18.	Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	Bolts rated MDMT per Fig UCS-66 note (c) = -55°F

Revision History

Revisions			
No.	**Date**	**Operator**	**Notes**
0	1/22/2020	jeffh	New vessel created Heat Exchanger. [COMPRESS 2018 Build 7800]
1	2/13/2020	jeffh	Converted from ASME Section VIII Division 1, 2017 Edition to ASME Section VIII Division 1, 2019 Edition. During the conversion, changes may have been made to your vessel (some may be listed above). Please check your vessel carefully.

Settings Summary

COMPRESS 2020 Build 8000	
ASME Section VIII Division 1, 2019 Edition	
Units	U.S. Customary
Datum Line Location	0.00" from right 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	2"
Juncture calculations for α > 30 only	Yes
Preheat P-No 1 Materials > 1.25" and <= 1.50" thick	No
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 for Tube side chamber	1.00
Test liquid specific gravity for Shell side chamber	1.00
Maximum stress during test	90% of yield
Required Marking - UG-116	
Tube Side	
UG-116(e) Radiography	None
UG-116(f) Postweld heat treatment	None
Shell Side	
UG-116(e) Radiography	None
UG-116(f) Postweld heat treatment	None
Code Cases\Interpretations	
Use Code Case 2547	No
Use Appendix 46	No
Use UG-44(b)	No
Use Code Case 2955	No
Apply interpretation VIII-1-83-66	Yes
Apply interpretation VIII-1-86-175	Yes
Apply interpretation VIII-1-01-37	Yes

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	Yes
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	Yes
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	Seitz Stainless
License	Commercial
License Key ID	23841
Support Expires	May 24, 2021

Radiography Summary

UG-116 Radiography - Tube Side Chamber							
Component	Longitudinal Seam		Left Circumferential Seam		Right Circumferential Seam		Mark
	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	
Front Head	N/A	Seamless No RT	N/A	N/A	B	None UW-11(c) / Type 1	None
Front Channel	A	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	C	N/A	None
Tube Side Flange (front)	N/A	Seamless No RT	C	N/A	N/A	N/A / Gasketed	N/A
Tubesheet	N/A	Seamless No RT[1]	N/A	N/A / Gasketed	N/A	N/A / Type 7	N/A
Rear Tubesheet	N/A	Seamless No RT[1]	N/A	N/A / Type 7	N/A	N/A / Gasketed	N/A
Rear Channel	A	None UW-11(c) / Type 1	C	N/A	B	None UW-11(c) / Type 1	None
Tube Side Flange (rear)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
Rear Channel Head	N/A	Seamless No RT	B	None UW-11(c) / Type 1	N/A	N/A	None
Tubes	N/A	Welded tube	N/A	N/A / Type 7	N/A	N/A / Type 7	N/A
Nozzle	**Longitudinal Seam**		**Nozzle to Vessel Circumferential Seam**		**Nozzle free end Circumferential Seam**		
TS Product Outlet (Outlet)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
TS Product Intlet (Inlet)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A / Type 4	N/A
Nozzle Flange	**Longitudinal Seam**		**Flange Face**		**Nozzle to Flange Circumferential Seam**		
ASME B16.5/16.47 flange attached to TS Product Outlet (Outlet)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A
ASME B16.5/16.47 flange attached to TS Product Intlet (Inlet)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A / Type 4	N/A
[1]Tubesheets are always considered to be seamless.							
Interpretation VIII-1 01-150 has been applied.							
UG-116(e) Required Marking: **None**							

UG-116 Radiography - Shell Side Chamber							
Component	**Longitudinal Seam**		**Left Circumferential Seam**		**Right Circumferential Seam**		**Mark**
	Category (Fig UW-3)	**Radiography / Joint Type**	**Category (Fig UW-3)**	**Radiography / Joint Type**	**Category (Fig UW-3)**	**Radiography / Joint Type**	
Tubesheet	N/A	Seamless No RT[1]	N/A	N/A / Gasketed	N/A	N/A / Type 7	N/A
ASME Shell Band (front)	A	None UW-11(c) / Type 1	N/A	N/A / Type 7	B	None UW-11(c) / Type 1	None
Shell #1	A	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	None
Shell #2	A	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	None
ASME Shell Band (rear)	A	None UW-11(c) / Type 1	B	None UW-11(c) / Type 1	N/A	N/A / Type 7	None
Rear Tubesheet	N/A	Seamless No RT[1]	N/A	N/A / Type 7	N/A	N/A / Gasketed	N/A
Nozzle	**Longitudinal Seam**		**Nozzle to Vessel Circumferential Seam**		**Nozzle free end Circumferential Seam**		
SS Condensate Drain (P2)	N/A	Welded pipe	D	N/A / Type 7	C	N/A / Type 4	N/A
Capped Vent Port (P4)	N/A	Welded pipe	D	N/A / Type 7	N/A	N/A	N/A
SS Vent (P5)	N/A	Welded pipe	D	N/A / Type 7	N/A	N/A	N/A
Sight Glass (P8)	N/A	Seamless No RT	D	N/A / Type 7	N/A	N/A	N/A
Cleanout (P7)	N/A	Welded pipe	D	N/A / Type 7	C	N/A / Type 4	N/A
SS Vapor Inlet (P1)	N/A	Welded pipe	D	N/A / Type 7	N/A	N/A	N/A
Press Relief (P3)	N/A	Welded pipe	D	N/A / Type 7	N/A	N/A	N/A
Capped Vent Port (P6)	N/A	Welded pipe	D	N/A / Type 7	N/A	N/A	N/A
Nozzle Flange	**Longitudinal Seam**		**Flange Face**		**Nozzle to Flange Circumferential Seam**		
ASME B16.5/16.47 flange attached to SS Condensate Drain (P2)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A / Type 4	N/A
ASME B16.5/16.47 flange attached to Cleanout (P7)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A / Type 4	N/A
[1]Tubesheets are always considered to be seamless.							
Interpretation VIII-1 01-150 has been applied.							
UG-116(e) Required Marking: **None**							

Thickness Summary

Component Data								
Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
Front Head	SA-240 S32205	41.5 ID	7.2636	0.218*	0.1345	0	0.85	Internal
Straight Flange on Front Head	SA-240 S32205	41.5 ID	0.5	0.125	0.1062	0	0.85	External
Front Channel	SA-240 S32205	41.5 ID	18	0.25	0.1066	0	0.70	External
Tubesheet	SA-240 S32205	47 OD	1.25	1.25	0.8706	0	1.00	Unknown
Tubes	SA-789 Wld tube S32205	1.5 OD	144	0.049	0.0189	0	1.00	External
ASME Shell Band (front)	SA-240 304	41.625 ID	12	0.1874	0.1811	0	0.70	External
Shell #1	SA-240 304	41.625 ID	96	0.1874	0.1811	0	0.70	External
Shell #2	SA-240 304	41.625 ID	21.5	0.1874	0.1667	0	0.70	External
ASME Shell Band (rear)	SA-240 304	41.625 ID	12	0.1874	0.1667	0	0.70	External
Rear Tubesheet	SA-240 S32205	47 OD	1.25	1.25	0.8706	0	1.00	Unknown
Rear Channel	SA-240 S32205	41.5 ID	6	0.25	0.0772	0	0.70	External
Straight Flange on Rear Channel Head	SA-240 S32205	41.5 ID	0.5	0.25	0.0772	0	0.85	External
Rear Channel Head	SA-240 S32205	41.5 ID	7.2636	0.218*	0.1345	0	0.85	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

Weight Summary

Weight (lb) Contributed by Vessel Elements											
Component	Metal New*	Metal Corroded	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid		Surface Area ft^2
							New	Corroded	New	Corroded	
Front Head	102.4	102.4	0	0	0	0	234.2	234.2	234.2	234.2	12
Front Channel	158.2	158.2	0	0	0	0	978.4	978.4	983.3	983.3	16
Tubesheet	394.5	394.5	0	0	0	0	0	0	0	0	1
ASME Shell Band (front)	85.3	85.3	0	0	0	0	21.4	21.4	328	328	11
Shell #1	682.7	682.7	0	0	0	0	168.7	168.7	2,622	2,622	88
Shell #2	148.5	148.5	0	0	0	0	49	49	606.1	606.1	19
Tubes	3,102.1	3,102.1	0	0	0	0	2,742.2	2,742.2	2,744.4	2,744.4	N/A
ASME Shell Band (rear)	85.6	85.6	0	0	0	0	21.1	21.1	327.7	327.7	11
Rear Tubesheet	394.5	394.5	0	0	0	0	0	0	0	0	1
Rear Channel	55.5	55.5	0	0	0	0	381.2	381.2	381.5	381.5	5
Rear Channel Head	104.7	104.7	0	0	0	0	234.2	234.2	234.2	234.2	12
Saddle #1	294	294	0	0	0	0	0	0	0	0	40
TOTAL:	**5,607.9**	**5,607.9**	**0**	**0**	**0**	**0**	**4,830.4**	**4,830.4**	**8,461.4**	**8,461.4**	**217**
*Shells with attached nozzles have weight reduced by material cut out for opening.											

Weight (lb) Contributed by Attachments										
Component	Body Flanges		Nozzles & Flanges		Packed Beds	Trays Baffles Pass Partitions	Tray Supports	Rings & Clips	Vertical Loads	Surface Area ft^2
	New	Corroded	New	Corroded						
Front Head	0	0	0	0	0	0	0	0	0	0
Front Channel	188.7	188.7	79.6	79.6	0	0	0	0	0	6
Tubesheet	0	0	0	0	0	0	0	0	0	0
ASME Shell Band (front)	0	0	8.2	8.2	0	0	0	0	0	0
Shell #1	0	0	19.6	19.6	0	27.6[1]	0	38	0	6
Shell #2	0	0	14.8	14.8	0	27.6[1]	0	0	0	1
ASME Shell Band (rear)	0	0	0.1	0.1	0	0	0	0	0	0
Rear Tubesheet	0	0	0	0	0	0	0	0	0	0
Rear Channel	188.7	188.7	0	0	0	0	0	0	0	2
Rear Channel Head	0	0	0	0	0	0	0	0	0	0
TOTAL:	**377.3**	**377.3**	**122.4**	**122.4**	**0**	**55.2**	**0**	**38**	**0**	**15**
[1]Baffle weights are approximated.										

Vessel Totals		
	New	Corroded
Operating Weight (lb)	11,031	11,031
Empty Weight (lb)	6,201	6,201
Test Weight (lb)	14,662	14,662
Surface Area (ft^2)	233	-
Shell side capacity** (US gal)	463	463
Tube side capacity** (US gal)	547	547
**The shell and tube capacity does not include volume of nozzle, piping or other attachments.		

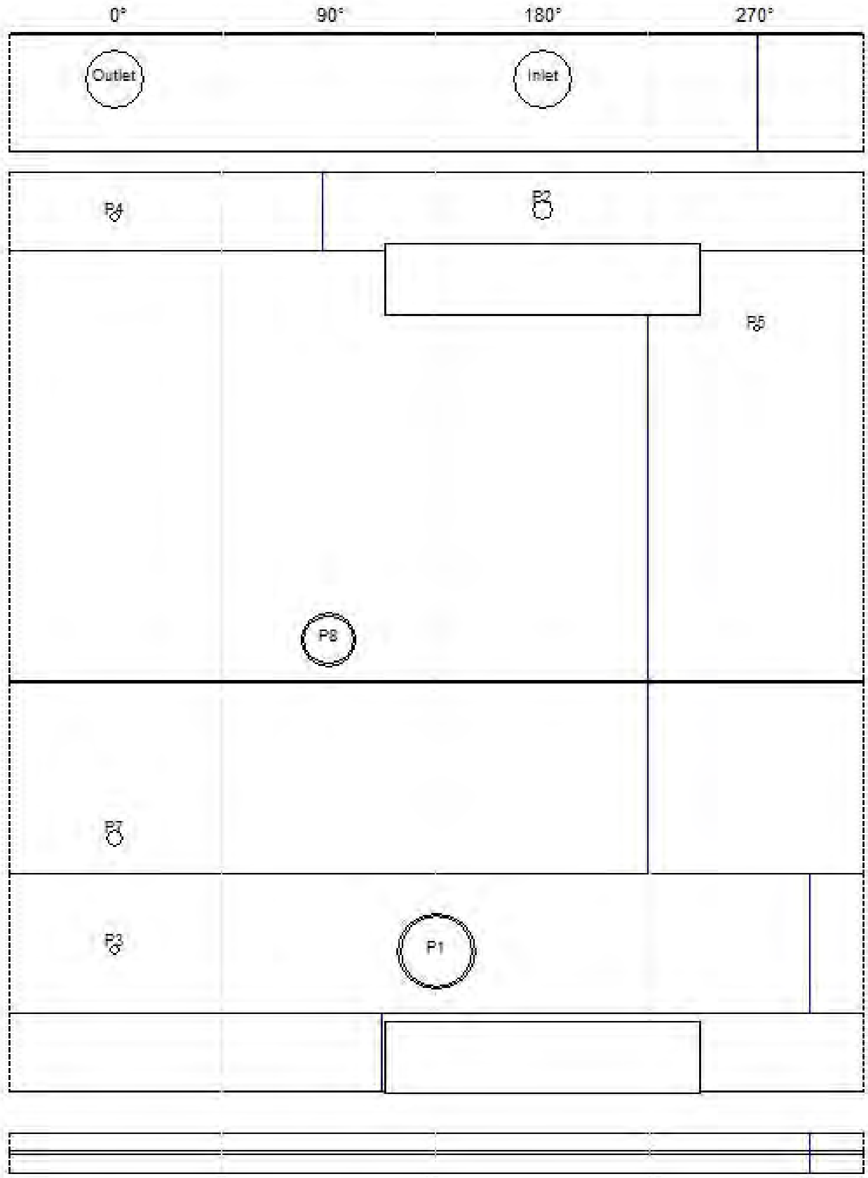
Vessel Lift Condition	
Vessel Lift Weight, New (lb)	6,201
Center of Gravity from Datum (in)	82.0916

Long Seam Summary

Shell Long Seam Angles	
Component	**Seam 1**
Front Channel	270°
ASME Shell Band (front)	87°
Shell #1	224°
Shell #2	292°
ASME Shell Band (rear)	112°
Rear Channel	292°

Shell Plate Lengths		
Component	**Starting Angle**	**Plate 1**
Front Channel	270°	131.1615"
ASME Shell Band (front)	87°	131.3575"
Shell #1	224°	131.3575"
Shell #2	292°	131.3575"
ASME Shell Band (rear)	112°	131.3575"
Rear Channel	292°	131.1615"

Note
1) Plate Lengths use the circumference of the vessel based on the mid diameter of the components.



Shell Rollout

Hydrostatic Test

Horizontal shop hydrostatic test based on MAWP per UG-99(b) for Tube side chamber

Gauge pressure at 70°F $= 1.3 \cdot MAWP \cdot LSR$
$= 1.3 \cdot 86.65 \cdot 1.015$
$= 114.33 \text{ psi}$

Horizontal shop hydrostatic test				
Identifier	**Local test pressure (psi)**	**Test liquid static head (psi)**	**UG-99(b) stress ratio**	**UG-99(b) pressure factor**
Front Head (1)	116.059	1.728	1.015	1.30
Straight Flange on Front Head	116.059	1.728	1.015	1.30
Front Channel	116.059	1.728	1.015	1.30
Rear Channel	116.059	1.728	1.015	1.30
Straight Flange on Rear Channel Head	116.059	1.728	1.015	1.30
Rear Channel Head	116.059	1.728	1.015	1.30
Tubes	116.036	1.706	1.0359	1.30
Tube Side Flange (front)	116.059	1.728	1.015	1.30
Tubesheet	116.059	1.728	1.0344	1.30
Rear Tubesheet	116.059	1.728	1.0344	1.30
Tube Side Flange (rear)	116.059	1.728	1.015	1.30
TS Product Intlet (Inlet)	116.289	1.958	1.015	1.30
TS Product Outlet (Outlet)	114.552	0.221	1.015	1.30
(1) Front Head limits the UG-99(b) stress ratio. (2) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.				

The field test condition has not been investigated for the Tube side chamber.

Horizontal shop hydrostatic test based on MAWP per UG-99(b) for Shell side chamber

Gauge pressure at 70°F $= 1.3 \cdot MAWP \cdot LSR$
$= 1.3 \cdot 86.35 \cdot 1$
$= 112.25 \text{ psi}$

Horizontal shop hydrostatic test				
Identifier	Local test pressure (psi)	Test liquid static head (psi)	UG-99(b) stress ratio	UG-99(b) pressure factor
ASME Shell Band (front)	113.871	1.618	1.0582	1.30
Shell #1	113.871	1.618	1.0582	1.30
Shell #2	113.871	1.618	1.0582	1.30
ASME Shell Band (rear)	113.871	1.618	1.0582	1.30
Tubes	113.846	1.593	N/A	1.30
Tubesheet	113.871	1.618	1.0344	1.30
Rear Tubesheet	113.871	1.618	1.0344	1.30
Capped Vent Port (P4)	112.362	0.108	1.0559	1.30
Capped Vent Port (P6)	113.896	1.642	1.0559	1.30
Cleanout (P7)	112.362	0.108	1.0582	1.30
Press Relief (P3)	112.362	0.108	1.0559	1.30
SS Condensate Drain (P2) (1)	113.95	1.697	1	1.30
SS Vapor Inlet (P1)	113.947	1.693	1	1.30
SS Vent (P5)	113.129	0.876	1.0559	1.30
Sight Glass (P8)	113.192	0.939	1.0582	1.30
(1) SS Condensate Drain (P2) limits the UG-99(b) stress ratio. (2) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.				

The field test condition has not been investigated for the Shell side chamber.

Vacuum Summary

Largest Unsupported Length Le			
Component	Line of Support	Elevation above Datum (in)	Length Le (in)
Front Head	-	179.5136	N/A
-	1/3 depth of Front Head	174.5985	N/A
Straight Flange on Front Head Left	-	172.25	22.5985
Straight Flange on Front Head Right	-	171.75	22.5985
Front Channel Left	-	171.75	22.5985
Front Channel Right	-	153.75	22.5985
-	Tube Side Flange (front)	152	N/A
Tubesheet	-	151.875	N/A
ASME Shell Band (front) Left	-	150.625	79.0875
ASME Shell Band (front) Right	-	138.625	79.0875
Shell #1 Left	-	138.625	79.0875
-	Rings #1	72.1625	71.375
Shell #1 Right	-	42.625	79.0875
Shell #2 Left	-	42.625	63.6625
Shell #2 Right	-	21.125	63.6625
ASME Shell Band (rear) Left	-	21.125	63.6625
ASME Shell Band (rear) Right	-	9.125	63.6625
Rear Tubesheet	-	7.875	N/A
-	Tube Side Flange (rear)	7.75	N/A
Rear Channel Left	-	6	10.5985
Rear Channel Right	-	0	10.5985
Straight Flange on Rear Channel Head Left	-	0	10.5985
Straight Flange on Rear Channel Head Right	-	-0.5	10.5985
-	1/3 depth of Rear Channel Head	-2.8485	N/A
Rear Channel Head	-	-7.7636	N/A
For Rings, the listed value of length Le is Ls per UG-29.			

Bill of Materials

Heads / Tubesheets						
Item #	Type	Material	Thk [in]	Dia. [in]	Wt. [lb] (ea.)	Qty
H1	F&D Head	SA-240 S32205	0.218 (min.)	41.5 ID	102.4	1
H2	F&D Head	SA-240 S32205	0.218 (min.)	41.5 ID	104.7	1
H3	Tubesheet	SA-240 S32205 (Impact (-20 °F))	1.25	47 OD	394.5	2

Shells / Tubes							
Item #	Type	Material	Thk [in]	Dia. [in]	Length [in]	Wt. [lb] (ea.)	Qty
S1	Cylinder	SA-240 S32205	0.25	41.5 ID	18	166.4	1
S2	Cylinder	SA-240 304	0.1874	41.625 ID	12	85.7	2
S3	Cylinder	SA-240 304	0.1874	41.625 ID	96	685.3	1
S4	Cylinder	SA-240 304	0.1874	41.625 ID	21.5	153.5	1
S5	Cylinder	SA-240 S32205 (Impact (-20 °F))	0.25	41.5 ID	6	55.5	1
Tube1	Tube	SA-789 Wld tube S32205	0.049	1.5	144	9.1	342

Rings						
Item #	Type	Material	Thk [in]	Length [in]	Wt. [lb]	Qty
R1	3/8x2.5 Flat Bar	SA-479 304L Bar (low stress)	0.375	139.8	38	1

Nozzles							
Item #	Type	Material	NPS	Thk [in]	Dia. [in]	Length [in]	Wt. [lb]
Noz1	Nozzle	SA-790 Smls pipe S32205	NPS 8 Sch 10S	0.148	8.625 OD	9.5	10.6
Noz2	Nozzle	SA-312 TP304L Wld pipe	NPS 2.5 Sch 40S (Std)	0.203	2.875 OD	2.3	1.1
Noz3	Nozzle	SA-312 TP304 Wld & smls pipe	NPS 2 Sch 10S	0.109	2.375 OD	3.1	0.7
Noz4	Nozzle	SA-312 TP304 Wld pipe	NPS 10 Sch 10S	0.165	10.75 OD	7.1	14.7

Nozzles - Couplings					
Item #	Type	Material	Dia. [in]	Length [in]	Qty
C1	NPS 0.5 Class 3000 - Threaded Half Coupling	SA-312 TP304 Wld pipe	1.12 OD	0.94	2
C2	NPS 0.25 Class 3000 - Threaded Half Coupling	SA-312 TP304 Wld pipe	0.75 OD	0.69	1
C3	NPS 0.75 Class 3000 - Threaded Half Coupling	SA-312 TP304 Wld pipe	1.38 OD	1	1

Nozzles - Studding Outlets							
Item #	Type	Material	# Bolts	Thk [in]	Dia. [in]	Wt. [lb]	Qty
SP1	Studding Outlet Custom Size - Contoured Base	SA-240 304	4	1.19	7.5 OD x 4 ID	13.9	1

Flanges						
Item #	Type	Material	NPS	Dia. [in]	Wt. [lb] (ea.)	Qty
AF1	ASME B16.5 Welding Neck - Class 150	A182 F51	8	13.5 x 7.98	39	1
AF2	ASME B16.5 Slip On - Class 150	A182 F51	8	13.5 x 8.72	30	1
AF3	ASME B16.5 Slip On - Class 150	A105	2.5	7 x 2.94	7	1
AF4	ASME B16.5 Slip On - Class 150	A105	2.0	6 x 2.44	5	1
CF1	Ring type integral	SA-182 F60 (Impact (-20 °F))	-	47 x 41.5	188.7	2

Gaskets				
Item #	Type	Size [in]	Thk [in]	Qty
G1	Not specified	42.9 x 42.6	0.125	2
There are 4 flanges that do not include gasket information.				

Fasteners				
Item #	**Description**	**Material**	**Length [in]**	**Qty**
FB1	Studding Outlet Bolts 0.5" dia.	SA-193 B7 Bolt <= 2 1/2	-	4
FB2	3/4" coarse bolt	SA-193 B7 Bolt <= 2 1/2	3.5	16
FB3	5/8" coarse bolt	SA-193 B7 Bolt <= 2 1/2	5	56
FB4	5/8" coarse bolt	SA-193 B7 Bolt <= 2 1/2	3	4
FB5	5/8" coarse bolt	SA-193 B7 Bolt <= 2 1/2	2.8	4
SB1	1" series 8 bolt	Saddle bolt material	-	4
All listed flange bolts require associated nuts and washers in accordance with Division 1, UCS-11.				

Plates				
Item #	**Material**	**Thk [in]**	**Wt. [lb]**	**Qty [ft^2]**
Plate1	SA-240 304L	0.1672	46.7	1.12
Plate1 - Note: Applies to nozzle pad				
Plate2	sa240-304	0.25	213.5	21
Plate2 - Note: Applies to saddle wear plate, saddle web plate				
Plate3	sa240-304	0.375	80.1	5.24
Plate3 - Note: Applies to saddle base plate				
Plate4	SA-240	0.25	55.2	5.42
Plate4 - Note: Applies to baffle plates				

Notes	
Note #	**Note**
1.	Tubesheet attachements including Tie Rods, Skid Bars, Seal Bars, and Dummy Tubes, are not included in the Bill of Materials.

Baffle Summary Report

Baffle Data	
Material	SA-240
Type	Single Segmental
Orientation	Vertical
Shell Clearance	0.125 in (0.25 in TEMA (Max))
Thickness	0.25 in (0.25 in TEMA)
Diameter	41.5 in
Count	2
Maximum Tubesheet to Baffle Distance	122 in
Maximum Baffle to Baffle Distance	0 in
Distance between Tubesheet Shell Side Faces	141.5 in
Group Weight	55.2 lb
Material Density (Assumed)	0.283 lb/in³
Tube Hole Diameter	1.5156 in

Baffle Specifications

Baffle Name	Distance from Front Tubesheet (in)	Cut Direction	Cut Distance from Center (in)	Baffle Weight (lb)[1]
Baffle #1	37.375	Right	1	27.6
Baffle #2	122	Left	1	27.6

[1]Baffle weight is approximated.

Data Inputs Summary

General Options					
Identifier	Heat Exchanger				
Codes	ASME VIII-1, 2019 Edition		ASME only design		
Description	Fixed tubesheets	-	One pass shell	-	
	Expansion joint not used		Tubesheets of differing thickness method not used	Perform ASME tube design check	
Tube supports\baffle plates	Maximum tubesheet to tube support distance: 122 in		Maximum tube support separation: 0 in	Baffles support all tubes: No	

Tube Options				
Tube material	SA-789 Wld tube S32205			
Length between outer tubesheet faces: L_t	144 in			
Tube dimensions, new, in	d_o= 1.5	t_t= 0.049 (0.0429 min)	Inner corrosion: 0	Outer corrosion: 0
Tube to tubesheet joint option	Table A-2 Type e, Welded, a ≥1.4*t, and expanded			

Channel and Shell Options						
Shell dimensions new, in	SA-240 304	D_i= 41.625	t_s= 0.1874	Inner corrosion: 0	Outer corrosion: 0	MDMT: -20 °F
Front channel dimensions, new, in	Type: bonnet	Torispherical head		Inner corrosion: 0	Outer corrosion: 0	MDMT: 40 °F
	Cylinder	SA-240 S32205		D_i= 41.5	t_c= 0.25	L= 18
	Closure	SA-240 S32205		D_i= 41.5	t_{min}= 0.218	L_{SF}= 0.5
Rear channel dimensions, new, in	Type: bonnet	Torispherical head		Inner corrosion: 0	Outer corrosion: 0	MDMT: 40 °F
	Cylinder	SA-240 S32205		D_i= 41.5	t_c= 0.25	L= 6
	Closure	SA-240 S32205		D_i= 41.5	t_{min}= 0.218	L_{SF}= 0.5

Tubesheet Options							
Tube Layout	Tube hole: 342 - 1.514 in (Special Close Fit)			Tube pitch: 1.875 in		Pattern: 60° (rotated triangular)	
Tubesheet dimensions, in (front and rear)	Material: SA-240 S32205	T = 1.25	OD = 47	Shell side corrosion = 0	Tube side corrosion = 0	MDMT = 40 °F	Tubesheet pass groove depth = 0
	Is impact tested per UG-84 to -20 °F	Not normalized	Not produced fine grain practice	PWHT not performed		Integral shell side	Gasketed tube side

Design Conditions Summary

Design Conditions						
Description		Operating	Tube side hydrotest	Shell side hydrotest	Operating - Shell Side External Pressure	Operating - Tube Side External Pressure
Tube Side	Design Pressure (psi)	60	114.33	0	60	-15
	Internal Operating Pressure (psi)	60	N/A	N/A	60	0
	External Design Pressure (psi)	15	N/A	N/A	0	0
	External Operating Pressure (psi)	15	N/A	N/A	0	0
	Tubesheet Static Pressure (psi)	1.49	1.73	0	1.49	0
	Design temperature (°F)	250	70	70	250	250
Shell Side	Design Pressure (psi)	25	0	112.25	-15	25
	Internal Operating Pressure (psi)	25	N/A	N/A	0	25
	External Design Pressure (psi)	15	N/A	N/A	0	0
	External Operating Pressure (psi)	15	N/A	N/A	0	0
	Tubesheet Static Pressure (psi)	0	0	1.62	0	0
	Design temperature (°F)	300	70	70	300	300
Tubes	Design temperature (°F)	300	70	70	300	300
	Mean temperature (°F)	250	70	70	250	250
	α_T (in/in/°F)	7.30E-06	7.00E-06	7.00E-06	7.30E-06	7.30E-06
	E_t (psi)	27.85E+06	29E+06	29E+06	27.85E+06	27.85E+06
	S_t (psi)	26,235*	63,000*	63,000*	26,235*	26,235*
	S_y (psi)	57,900	70,000	70,000	57,900	57,900
Shell	Mean temperature (°F)	250	70	70	250	250
	α_s (in/in/°F)	9.10E-06	8.50E-06	8.50E-06	9.10E-06	9.10E-06
	E_s (psi)	27.25E+06	28.3E+06	28.3E+06	27.25E+06	27.25E+06
	S_s (psi)	18,900	27,000	27,000	18,900	18,900
Tubesheet	Design temperature (°F)	300	70	70	300	300
	S (psi)	26,200	58,500	58,500	26,200	26,200

*The allowable tensile stress from Section II-D has been divided by 0.85 as the calculated stresses are longitudinal.

Materials and Gaskets Summary

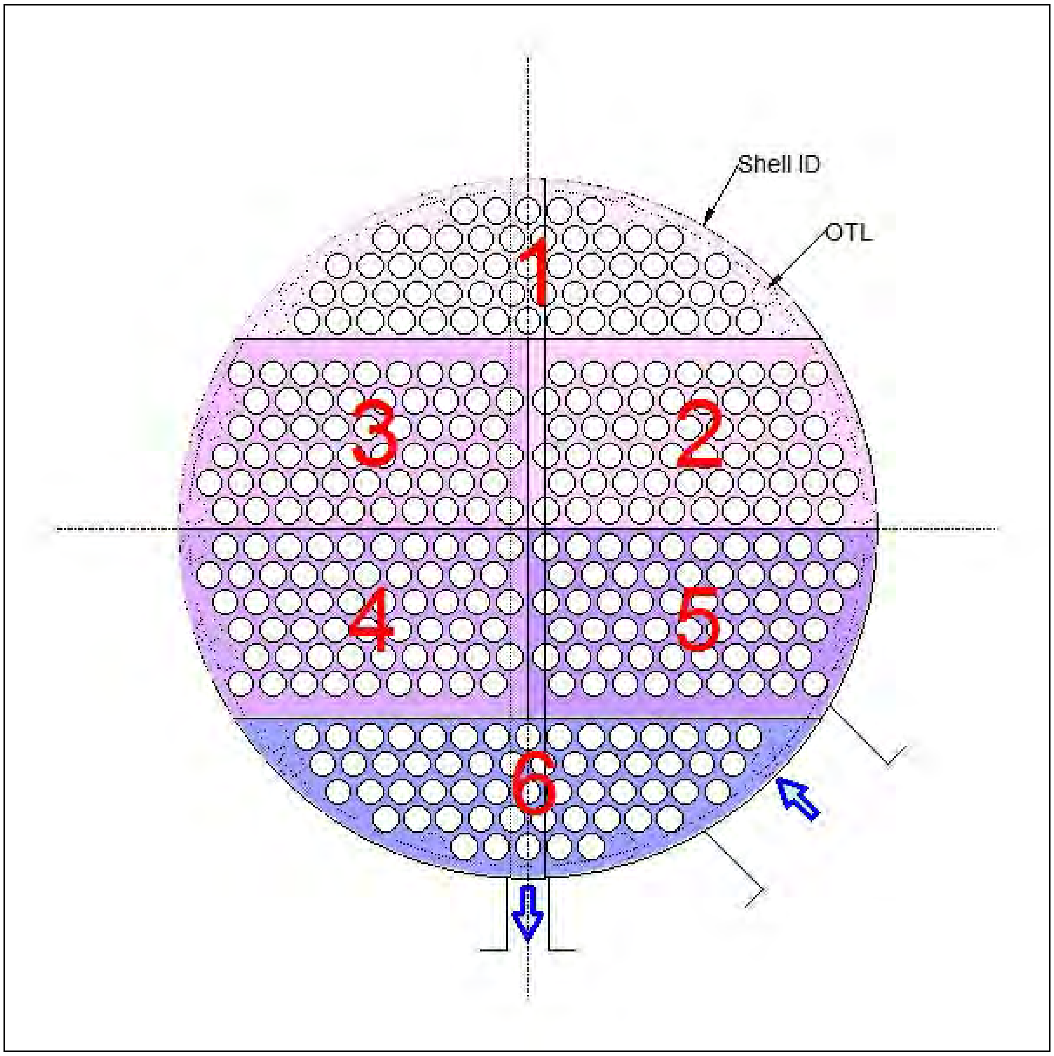
Materials And Gaskets				
Part	Quantity	Size	Material	Gasket
Front torispherical head	1	41.50 ID x 0.218 in min thk	SA-240 S32205	-
Front channel cylinder	1	41.50 ID x 0.25 thk x 18.00 in	SA-240 S32205	-
Tube Side Flange (front)	1	47.00 OD x 1.75 in thk	SA-182 F60	42.90 OD x 42.60 ID x 0.13 in thk
Front tubesheet	1	47.00 OD x 1.25 in thk	SA-240 S32205	
Front Tubesheet flange bolts	28	0.625 in dia. stud x 5.00 in long	SA-193 B7	-
Tubes	342	1.50 OD x 0.049 nom wall (0.0429 min) x 144.00 in	SA-789 Wld tube S32205	-
Front shell band cylinder	1	41.63 ID x 0.1874 in thk x 12.00 in	SA-240 304	-
Shell cylinder course	1	41.63 ID x 0.1874 in thk x 21.50 in	SA-240 304	-
Shell cylinder course	1	41.63 ID x 0.1874 in thk x 96.00 in	SA-240 304	-
Rear shell band cylinder	1	41.63 ID x 0.1874 in thk x 12.00 in	SA-240 304	-
Rear tubesheet	1	47.00 OD x 1.25 in thk	SA-240 S32205	42.90 OD x 42.60 ID x 0.13 in thk
Tube Side Flange (rear)	1	47.00 OD x 1.75 in thk	SA-182 F60	
Rear Tubesheet flange bolts	28	0.625 in dia. stud x 5.00 in long	SA-193 B7	-
Rear channel cylinder	1	41.50 ID x 0.25 thk x 6.00 in	SA-240 S32205	-
Rear torispherical head	1	41.50 ID x 0.218 in min thk	SA-240 S32205	-

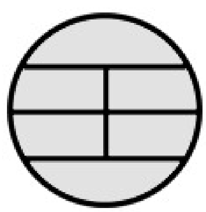
Nozzle Materials And Gaskets				
Part	Quantity	Size	Material	Gasket
TS Product Outlet (Outlet)	1	8 in 150# WN	A182 F51	-
	1	NPS 8 Sch 10S	SA-790 Smls pipe S32205	
Bolts for TS Product Outlet (Outlet)	8	0.75 in dia. bolt x 3.5 in long	SA-193 B7	
TS Product Intlet (Inlet)	1	8 in 150# SO	A182 F51	-
	1	NPS 8 Sch 10S	SA-790 Smls pipe S32205	
Bolts for TS Product Intlet (Inlet)	8	0.75 in dia. bolt x 3.5 in long	SA-193 B7	
SS Condensate Drain (P2)	1	2.5 in 150# SO	A105	-
	1	NPS 2.5 Sch 40S (Std)	SA-312 TP304L Wld pipe	
Bolts for SS Condensate Drain (P2)	4	0.625 in dia. bolt x 3 in long	SA-193 B7	
Capped Vent Port (P4)	1	NPS 0.5 Class 3000 - Threaded Half Coupling	SA-312 TP304 Wld pipe	-
SS Vent (P5)	1	NPS 0.25 Class 3000 - Threaded Half Coupling	SA-312 TP304 Wld pipe	-
Sight Glass (P8)	1	Studding Outlet Custom Size -	SA-240 304	-
Cleanout (P7)	1	2 in 150# SO	A105	-
	1	NPS 2 Sch 10S	SA-312 TP304 Wld & smls pipe	
Bolts for Cleanout (P7)	4	0.625 in dia. bolt x 2.75 in long	SA-193 B7	
SS Vapor Inlet (P1)	1	NPS 10 Sch 10S	SA-312 TP304 Wld pipe	-
	1	10.75 ID x 1.78 wide x 0.1672 in thk pad	SA-240 304L	
Press Relief (P3)	1	NPS 0.75 Class 3000 - Threaded Half Coupling	SA-312 TP304 Wld pipe	-
Capped Vent Port (P6)	1	NPS 0.5 Class 3000 - Threaded Half Coupling	SA-312 TP304 Wld pipe	-

Tubesheet Maximum Pressure Report

ASME Tubesheet Maximum Pressure Ratings						
Description		Operating	Tube side MAP	Shell side MAP	Operating - Shell Side External Pressure	Operating - Tube Side External Pressure
Tube Side	Pressure (psi)	114.91	157.11	0	93.43	-152.2
	Tubesheet Static Pressure (psi)	1.49	0	0	1.49	0
	Design temperature (°F)	250	70	70	250	250
Shell Side	Pressure (psi)	204.96	0	226.15	-45.35	117.63
	Tubesheet Static Pressure (psi)	0	0	0	0	0
	Design temperature (°F)	300	70	70	300	300
Tubes	Design temperature (°F)	300	70	70	300	300
	Mean temperature (°F)	250	70	70	250	250
Shell	Mean temperature (°F)	250	70	70	250	250
Tubesheet	Design temperature (°F)	300	70	70	300	300

Tube Bundle Design



Tube Layout		
Layout	Horizontal mixed or H-banded	
	First pass: top	
Tube OD	1.5"	
Pitch	1.875"	
Pattern	Rotated Triangular (60°)	
Pattern Dimensions	X = 1.875"	
	Y = 3.2476"	

Outer Tube Limit	
Shell ID	41.625"
Design OTL	40.25"
Actual OTL	40.2436" (+0.0064")

Tubes Per Pass - 342 Tubes Total			
Pass #	**Tube Count**	**Mean Tube Count**	**% Deviation from Mean**
1	57	57	0.00%
2	57	57	0.00%
3	57	57	0.00%
4	57	57	0.00%
5	57	57	0.00%
6	57	57	0.00%

Shell and Tube Areas	
Total Shell Area	1,360.8128 in^2
Each Tube Area	1.7671 in^2
Total Tubes	342
Total Tubes Area	604.3639 in^2
Net Free Area	Total Shell Area - Total Tubes Area - Total Tie Rods Area - Total Dummy Tubes Area
	1,360.81 - 604.36 - 0.00 - 0.00
	756.4489 in^2

Baffle Window Areas	
Baffle Cut	47.6% of Shell ID
Baffle Cut Distance from Center	1"
Baffle Window Area	638.7974 in^2
Number of Tubes in Baffle Window	left = 164, right = 164
Baffle Window Tubes Area	left = 289.8119 in^2, right = 289.8119 in^2
Baffle Free Area	Window Area - Tubes Area
	left = 348.9855 in^2, right = 348.9855 in^2
% of Net Free Area	Baffle Free Area / Net Free Area
	left = 46.13%, right = 46.13%

Tubes

ASME Section VIII Division 1, 2019 Edition				
Component		Tube		
Material		SA-789 Wld tube S32205 (II-D p. 128, ln. 46)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	
No	No	No	No	
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		75	300	40
External		40	300	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		1.47	40.6218	1
Operating, Ext		0.15	4.1218	1
Test horizontal		1.71	47.2468	1
Dimensions				
Outer Diameter		1.5"		
Length		144"		
Tube Nominal Thickness		0.049"		
Tube Minimum Thickness[1]		0.0429"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		9.07		0.96
Corroded		9.07		0.96

[1]Tube minimum thickness = nominal thickness times tube tolerance factor of 0.875.

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	Exempt per UG-16(b)(2)
Design thickness due to internal pressure (t)	0.0026"
Design thickness due to external pressure (t_e)	0.0189"
Maximum allowable working pressure (MAWP)	1,303.18 psi
Maximum allowable pressure (MAP)	1,351.45 psi
Maximum allowable external pressure (MAEP)	492.02 psi
Rated MDMT	-20 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{88.11 \cdot 0.75}{23{,}100 \cdot 1 + 0.4 \cdot 88.11} =$	0.0029"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0029 \cdot 1}{0.0429 - 0} =$	0.0666
Impact test exempt per UHA-51(g) (coincident ratio = 0.0666)	
Rated MDMT =	-20°F
Material is exempt from impact testing at the Design MDMT of 40°F.	

Design thickness, (at 300 °F) Appendix 1-1

$$t = \frac{P \cdot R_o}{S \cdot E + 0.40 \cdot P} + \text{Corrosion} = \frac{76.47 \cdot 0.75}{22{,}300 \cdot 1.00 + 0.40 \cdot 76.47} + 0 = \underline{0.0026}"$$

Maximum allowable working pressure, (at 300 °F) Appendix 1-1

$$P = \frac{S \cdot E \cdot t}{R_o - 0.40 \cdot t} - P_s = \frac{22{,}300 \cdot 1.00 \cdot (0.049 \cdot 0.875)}{0.75 - 0.40 \cdot (0.049 \cdot 0.875)} - 1.47 = \underline{1{,}303.18} \text{ psi}$$

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

$$P = S \cdot E \cdot \frac{t}{R_o - 0.40 \cdot t} = 23{,}100 \cdot 1.00 \cdot \frac{0.049 \cdot 0.875}{0.75 - 0.40 \cdot (0.049 \cdot 0.875)} = \underline{1{,}351.45} \text{ psi}$$

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{144}{1.5} = 50.0000$$

$$\frac{D_o}{t} = \frac{1.5}{0.0189} = 79.3210$$

From table G: $A = 0.000177$

From table HA-5: $B = 2{,}388.507 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 2{,}388.51}{3 \cdot (1.5/0.0189)} = 40.15 \text{ psi}$$

Design thickness for external pressure P_a = 40.15 psi

$$t_a = t + \text{Corrosion} = 0.0189 + 0 = \underline{0.0189}"$$

Maximum Allowable External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{144}{1.5} = 50.0000$$

$$\frac{D_o}{t} = \frac{1.5}{0.049 \cdot 0.875} = 34.9854$$

From table G: $A = 0.000955$

From table HA-5: $B = 12{,}914.0049 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} - Pse = \frac{4 \cdot 12{,}914}{3 \cdot (1.5/(0.049 \cdot 0.875))} - 0.15 = \underline{492.02} \text{ psi}$$

Shell side liquid level

ASME Section VIII Division 1, 2019 Edition	
Location from Center Line (in)	-16
Operating Liquid Specific Gravity	1
HX Condition	**Include in tubesheet calculation**
Operating	No

Tube side liquid level

ASME Section VIII Division 1, 2019 Edition	
Location from Center Line (in)	20.5
Operating Liquid Specific Gravity	1
HX Condition	**Include in tubesheet calculation**
Operating	Yes

Front Head

ASME Section VIII Division 1, 2019 Edition				
Component		F&D Head		
Material		SA-240 S32205 (II-D p. 128, ln. 35)		
Attached To		Front Channel		
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		60	250	40
External		15	250	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		1.49	41.25	1
Test horizontal		1.73	47.875	1
Dimensions				
Inner Diameter		41.5"		
Crown Radius L		41.5"		
Knuckle Radius r		2.52"		
Minimum Thickness		0.218"		
Corrosion	**Inner**	0"		
	Outer	0"		
Length L_{sf}		0.5"		
Nominal Thickness t_{sf}		0.125"		
Weight and Capacity				
		Weight (lb)[1]		**Capacity (US gal)**[1]
New		102.38		28.09
Corroded		102.38		28.09
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)	0.1345"
Design thickness due to external pressure (t_e)	0.1237"
Maximum allowable working pressure (MAWP)	98.18 psi
Maximum allowable pressure (MAP)	101.16 psi
Maximum allowable external pressure (MAEP)	46.65 psi
Straight Flange governs MDMT	-20°F

Note: Endnote 90 used to determine allowable stress.

Factor M		
$M = \frac{1}{4} \cdot \left[3 + \left(\frac{L}{r}\right)^{\frac{1}{2}}\right]$		
Corroded	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{41.5}{2.52}\right)^{\frac{1}{2}}\right]$	1.7645
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{41.5}{2.52}\right)^{\frac{1}{2}}\right]$	1.7645

Design thickness for internal pressure, (Corroded at 250 °F) Appendix 1-4(d)

$$t = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P} + \text{Corrosion} = \frac{61.49 \cdot 41.5 \cdot 1.7645}{2 \cdot 19{,}704.8 \cdot 0.85 - 0.2 \cdot 61.49} + 0 = 0.1345"$$

Maximum allowable working pressure, (Corroded at 250 °F) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 19{,}704.8 \cdot 0.85 \cdot 0.218}{41.5 \cdot 1.7645 + 0.2 \cdot 0.218} - 1.49 = 98.18 \text{ psi}$$

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 20{,}000 \cdot 0.85 \cdot 0.218}{41.5 \cdot 1.7645 + 0.2 \cdot 0.218} - 0 = 101.16 \text{ psi}$$

Design thickness for external pressure, (Corroded at 250 °F) UG-33(e)

Equivalent outside spherical radius (R_o) = Outside crown radius $= 41.718$ in

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{41.718 \ / \ 0.123616} = 0.00037$$

From Table HA-5:B = 5,062.2058 psi

$$P_a = \frac{B}{R_o \ / \ t} = \frac{5{,}062.2058}{41.718 \ / \ 0.1236} = 15 \text{ psi}$$

t = 0.1236" + Corrosion = 0.1236" + 0" = 0.1236"

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

$$t = \frac{1.67 \cdot P_e \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot 1.67 \cdot P_e} + \text{Corrosion} = \frac{1.67 \cdot 15 \cdot 41.5 \cdot 1.7645}{2 \cdot 19{,}704.8 \cdot 1 - 0.2 \cdot 1.67 \cdot 15} + 0 = 0.0466"$$

The head external pressure design thickness (t_e) is 0.1236".

Maximum Allowable External Pressure, (Corroded at 250 °F) UG-33(e)

Equivalent outside spherical radius (R_o) = Outside crown radius $= 41.718$ in

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{41.718 \ / \ 0.218} = 0.000653$$

From Table HA-5:B = 8,926.5947 psi

$$P_a = \frac{B}{R_o \ / \ t} = \frac{8{,}926.5947}{41.718 \ / \ 0.218} = 46.6465 \ \text{psi}$$

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{(L \cdot M + 0.2 \cdot t) \cdot 1.67} = \frac{2 \cdot 19{,}704.8 \cdot 1 \cdot 0.218}{(41.5 \cdot 1.7645 + 0.2 \cdot 0.218) \cdot 1.67} = 70.21 \ \text{psi}$$

The maximum allowable external pressure (MAEP) is 46.65 psi.

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

$$EFE = \left(\frac{75 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{75 \cdot 0.125}{2.5825}\right) \cdot \left(1 - \frac{2.5825}{\infty}\right) = 3.6302\,\%$$

Straight Flange on Front Head

ASME Section VIII Division 1, 2019 Edition					
Component		Cylinder			
Material		SA-240 S32205 (II-D p. 128, ln. 35)			
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		60	250	40	
External		15	250		
Static Liquid Head					
Condition		**P_s (psi)**	**H_s (in)**	**SG**	
Operating		1.49	41.25	1	
Test horizontal		1.73	47.875	1	
Dimensions					
Inner Diameter		41.5"			
Length		0.5"			
Nominal Thickness		0.125"			
Corrosion	**Inner**	0"			
	Outer	0"			
Weight and Capacity					
		Weight (lb)		**Capacity (US gal)**	
New		2.3		2.93	
Corroded		2.3		2.93	
Radiography					
Longitudinal seam		Seamless No RT			
Right 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)	0.0564"
Design thickness due to external pressure (t_e)	0.1062"
Maximum allowable working pressure (MAWP)	134.74 psi
Maximum allowable pressure (MAP)	138.27 psi
Maximum allowable external pressure (MAEP)	23.18 psi
Rated MDMT	-20 °F

UHA-51 Material Toughness Requirements	
$t_r = \dfrac{88.14 \cdot 20.75}{27{,}100 \cdot 0.85 - 0.6 \cdot 88.14} =$	0.0796"
$\text{Stress ratio} = \dfrac{t_r \cdot E^*}{t_n - c} = \dfrac{0.0796 \cdot 0.85}{0.125 - 0} =$	0.5411
Rated MDMT per UHA-51(d)(3)(a) = -20°F	
Material is exempt from impact testing at the Design MDMT of 40°F.	

Design thickness, (at 250 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{61.49 \cdot 20.75}{26{,}700 \cdot 0.85 - 0.60 \cdot 61.49} + 0 = 0.0564"$$

Maximum allowable working pressure, (at 250 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{26{,}700 \cdot 0.85 \cdot 0.125}{20.75 + 0.60 \cdot 0.125} - 1.49 = 134.74 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{27{,}100 \cdot 0.85 \cdot 0.125}{20.75 + 0.60 \cdot 0.125} = 138.27 \text{ psi}$$

External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{22.5985}{41.75} = 0.5413$$

$$\frac{D_o}{t} = \frac{41.75}{0.1062} = 393.2098$$

From table G: $A = 0.000324$

From table HA-5: $B = 4{,}423.6091 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 4{,}423.61}{3 \cdot (41.75/0.1062)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.1062 + 0 = 0.1062"$$

Maximum Allowable External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{22.5985}{41.75} = 0.5413$$

$$\frac{D_o}{t} = \frac{41.75}{0.125} = 334.0000$$

From table G: $A = 0.000425$

From table HA-5: $B = 5{,}807.1058 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 5{,}807.11}{3 \cdot (41.75/0.125)} = 23.18 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.125}{20.8125}\right) \cdot \left(1 - \frac{20.8125}{\infty}\right) = 0.3003\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.875/0.125} = 0.000749$$

$$B = 10{,}229 \ \ \text{psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \ \ \text{psi}$$

$S_{cHC} \ = \ \min\left(B, S\right) =$ 10,229 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_cHN = S_cHC = 10{,}229 \ \ \text{psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.875/0.125} = 0.000749$$

$$B = 10{,}614 \ \ \text{psi}$$

$$S = \frac{27{,}100}{1.00} = 27{,}100 \ \ \text{psi}$$

$S_{cCN} \ = \ \min\left(B, S\right) =$ 10,614 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{c\mathbb{C}} = S_{cCN} = 10{,}614 \ \ \text{psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.875/0.125} = 0.000749$$

$$B = 10{,}229 \ \ \text{psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \ \ \text{psi}$$

$S_{cVC} \ = \ \min\left(B, S\right) =$ 10,229 psi

Front Channel

ASME Section VIII Division 1, 2019 Edition

Component	Cylinder
Material	SA-240 S32205 (II-D p. 128, ln. 35)

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	60	250	40
External	15	250	

Static Liquid Head

Condition	P_s (psi)	H_s (in)	SG
Operating	1.49	41.25	1
Test horizontal	1.73	47.875	1

Dimensions

Inner Diameter		41.5"
Length		18"
Nominal Thickness		0.25"
Corrosion	**Inner**	0"
	Outer	0"

Weight and Capacity

	Weight (lb)	Capacity (US gal)
New	158.21	105.4
Corroded	158.21	105.4

Radiography

Longitudinal seam	None UW-11(c) Type 1
Left 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)	0.0685"
Design thickness due to external pressure (t_e)	0.1066"
Maximum allowable working pressure (MAWP)	222.08 psi
Maximum allowable pressure (MAP)	226.91 psi
Maximum allowable external pressure (MAEP)	129.6 psi
Rated MDMT	-20 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{88.14 \cdot 20.75}{27{,}100 \cdot 0.7 - 0.6 \cdot 88.14} =$	0.0967"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0967 \cdot 0.8}{0.25 - 0} =$	0.3094
Impact test exempt per UHA-51(g) (coincident ratio = 0.3094)	
Rated MDMT =	-20°F
Material is exempt from impact testing at the Design MDMT of 40°F.	

Design thickness, (at 250 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{61.49 \cdot 20.75}{26{,}700 \cdot 0.70 - 0.60 \cdot 61.49} + 0 = 0.0685\text{"}$$

Maximum allowable working pressure, (at 250 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{26{,}700 \cdot 0.70 \cdot 0.25}{20.75 + 0.60 \cdot 0.25} - 1.49 = 222.08 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{27{,}100 \cdot 0.70 \cdot 0.25}{20.75 + 0.60 \cdot 0.25} = 226.91 \text{ psi}$$

External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{22.5985}{42} = 0.5381$$

$$\frac{D_o}{t} = \frac{42}{0.1066} = 394.0112$$

From table G: $A = 0.000324$

From table HA-5: $B = 4{,}432.6614 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 4{,}432.66}{3 \cdot (42/0.1066)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.1066 + 0 = 0.1066\text{"}$$

Maximum Allowable External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{22.5985}{42} = 0.5381$$

$$\frac{D_o}{t} = \frac{42}{0.25} = 168.0000$$

From table G: $A = 0.001225$

From table HA-5: $B = 16{,}330.1718 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 16{,}330.17}{3 \cdot (42/0.25)} = 129.6 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.25}{20.875}\right) \cdot \left(1 - \frac{20.875}{\infty}\right) = 0.5988\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-5)

$$A = \frac{0.125}{R_o / t} = \frac{0.125}{21 / 0.25} = 0.001488$$

$$B = 17{,}241 \text{ psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \text{ psi}$$

$$S_{cHC} = \min\,(B, S) = 17{,}241 \text{ psi}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_c HN = S_c HC = 17{,}241 \text{ psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-5)

$$A = \frac{0.125}{R_o / t} = \frac{0.125}{21 / 0.25} = 0.001488$$

$$B = 19{,}232 \text{ psi}$$

$$S = \frac{27{,}100}{1.00} = 27{,}100 \text{ psi}$$

$$S_{cCN} = \min\,(B, S) = 19{,}232 \text{ psi}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{cC} = S_{cCN} = 19{,}232 \text{ psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-5)

$$A = \frac{0.125}{R_o / t} = \frac{0.125}{21 / 0.25} = 0.001488$$

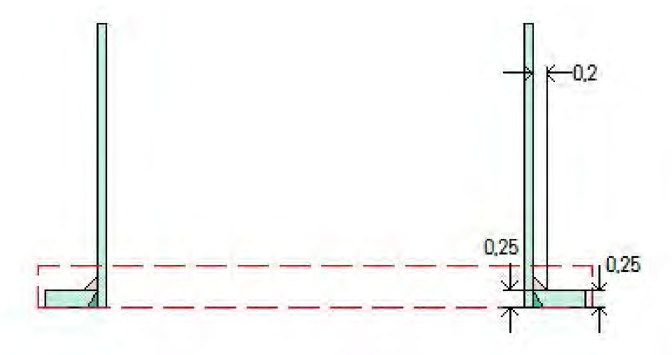
$$B = 17{,}241 \text{ psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \text{ psi}$$

$$S_{cVC} = \min\,(B, S) = 17{,}241 \text{ psi}$$

TS Product Intlet (Inlet)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Front Channel
Orientation	180°
Nozzle center line offset to datum line	164.75"
End of nozzle to shell center	27.125"
Passes through a Category A joint	No
Nozzle	
Service	Inlet (IN)
Description	NPS 8 Sch 10S
Access opening	No
Material specification	SA-790 Smls pipe S32205 (II-D p. 128, ln. 38)
Inside diameter, new	8.329"
Pipe nominal wall thickness	0.148"
Pipe minimum wall thickness[1]	0.1295"
Corrosion allowance	0"
Projection available outside vessel, Lpr	5.977"
Projection available outside vessel to flange face, Lf	6.125"
Local vessel minimum thickness	0.25"
Liquid static head included	1.5 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.2"
Nozzle to vessel groove weld	0.25"

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

ASME B16.5-2013 Flange	
Description	NPS 8 Class 150 SO A182 F51
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 398, ln. 32)
Blind included	No
Rated MDMT	40°F
Liquid static head	1.72 psi
MAWP rating	245 psi @ 250°F
MAP rating	290 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
External fillet weld leg (UW-21)	0.2072" (0.2072" min)
Internal fillet weld leg (UW-21)	0.148" (0.148" min)
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
UW-21 Flange Welds	
$X_{\min} = \min\left[1.4 \cdot t_n, g_0\right] = \left[1.4 \cdot 0.148, 0.485\right] =$	0.2072"
$\text{External Leg}_{\min} = X_{\min} + \frac{C_o}{0.7} = 0.2072 + \frac{0}{0.7} =$	0.2072"
$\text{Internal Leg}_{\min} = \min\left[t_n, 0.25" + \frac{C_i}{0.7}\right] = \min\left[0.148, 0.25 + \frac{0}{0.7}\right] =$	0.148"
Notes	
Flange rated MDMT per UHA-51(g) = 40°F (Coincident ratio = 0.3047) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{88.14 \cdot 4.1645}{27{,}100 \cdot 1 - 0.6 \cdot 88.14} =$	0.0136"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0136 \cdot 1}{0.1295 - 0} =$	0.1048
Impact test exempt per UHA-51(g) (coincident ratio = 0.1048)	
Rated MDMT =	-20°F
Material is exempt from impact testing at the Design MDMT of 40°F.	

Reinforcement Calculations for MAWP

The thickness requirements of UG-45 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 166.07 psi @ 250 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.0789	1.1336	1.0033	0.0903	–	–	0.04	0.1295	0.1295

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1036	0.14	weld size is adequate

Calculations for internal pressure 166.07 psi @ 250 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[8.329, 4.1645 + (0.148 - 0) + (0.25 - 0)\right]$$
$$= 8.329 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.25 - 0), 2.5 \cdot (0.148 - 0) + 0\right]$$
$$= 0.37 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{166.0666 \cdot 4.1645}{26{,}700 \cdot 1 - 0.6 \cdot 166.0666}$$
$$= 0.026 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{166.0666 \cdot 20.75}{26{,}700 \cdot 1 - 0.6 \cdot 166.0666}$$
$$= 0.1295 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $\frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$

= $\frac{166.0666 \cdot 20.75}{26{,}700 \cdot 0.7 - 0.6 \cdot 166.0666}$

= 0.1854 in

Area required per UG-37(c)

Allowable stresses: S_n = 26,700, S_v = 26,700 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

A = $d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1})$

= $8.329 \cdot 0.1295 \cdot 1 + 2 \cdot 0.148 \cdot 0.1295 \cdot 1 \cdot (1 - 1)$

= 1.0789 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.0033 in^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $8.329 \cdot (1 \cdot 0.25 - 1 \cdot 0.1295) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1295) \cdot (1 - 1)$

= 1.0033 in^2

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $2 \cdot (0.25 + 0.148) \cdot (1 \cdot 0.25 - 1 \cdot 0.1295) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1295) \cdot (1 - 1)$

= 0.0959 in^2

A_2 = smaller of the following= 0.0903 in^2

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

= $5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.25$

= 0.1525 in^2

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

= $5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.148$

= 0.0903 in^2

A_{41} = $Leg^2 \cdot f_{r2}$

= $0.2^2 \cdot 1$

= 0.04 in^2

$Area$ = $A_1 + A_2 + A_{41}$

= $1.0033 + 0.0903 + 0.04$

= 1.1336 in^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.148 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1036 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.2 = 0.14 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{166.2877 \cdot 4.1645}{26{,}700 \cdot 1 - 0.6 \cdot 166.2877} + 0$$

$$= 0.026 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.026, 0\right]$$

$$= 0.026 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{166.0666 \cdot 20.75}{26{,}700 \cdot 1 - 0.6 \cdot 166.0666} + 0$$

$$= 0.1295 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1295, 0.0625\right]$$

$$= 0.1295 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.2818, 0.1295\right]$$

$$= 0.1295 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.026, 0.1295\right]$$

$$= 0.1295 \text{ in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.148 = 0.1295$ in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The thickness requirements of UG-45 govern the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 168.56 psi @ 70 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.079	1.1335	1.0032	0.0903	–	–	0.04	0.1295	0.1295

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

Calculations for internal pressure 168.56 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[8.329, 4.1645 + (0.148 - 0) + (0.25 - 0)\right]$$
$$= 8.329 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.25 - 0), 2.5 \cdot (0.148 - 0) + 0\right]$$
$$= 0.37 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{168.5595 \cdot 4.1645}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595}$$
$$= 0.026 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{168.5595 \cdot 20.75}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595}$$
$$= 0.1295 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{168.5595 \cdot 20.75}{27{,}100 \cdot 0.7 - 0.6 \cdot 168.5595}$$
$$= 0.1854 \text{ in}$$

Area required per UG-37(c)

Allowable stresses: S_n = 27,100, S_v = 27,100 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

$$
\begin{aligned}
A &= d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) \\
&= 8.329 \cdot 0.1296 \cdot 1 + 2 \cdot 0.148 \cdot 0.1296 \cdot 1 \cdot (1 - 1) \\
&= 1.079 \text{ in}^2
\end{aligned}
$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.0032 in^2

$$
\begin{aligned}
&= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\
&= 8.329 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) \cdot (1 - 1) \\
&= 1.0032 \ \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
&= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\
&= 2 \cdot (0.25 + 0.148) \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) \cdot (1 - 1) \\
&= 0.0959 \ \text{ in}^2
\end{aligned}
$$

A_2 = smaller of the following= 0.0903 in^2

$$
\begin{aligned}
&= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t \\
&= 5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.25 \\
&= 0.1525 \ \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
&= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n \\
&= 5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.148 \\
&= 0.0903 \ \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
A_{41} &= Leg^2 \cdot f_{r2} \\
&= 0.2^2 \cdot 1 \\
&= 0.04 \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
Area &= A_1 + A_2 + A_{41} \\
&= 1.0032 + 0.0903 + 0.04 \\
&= 1.1335 \text{ in}^2
\end{aligned}
$$

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

$$
\begin{aligned}
t_{a\text{UG-27}} &= \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion} \\
&= \frac{168.5595 \cdot 4.1645}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595} + 0 \\
&= 0.026 \ \text{ in}
\end{aligned}
$$

$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$

$= \max\left[0.026, 0\right]$

$= 0.026$ in

$t_{b1} = \dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

$= \dfrac{168.5595 \cdot 20.75}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595} + 0$

$= 0.1295$ in

$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$

$= \max\left[0.1295, 0.0625\right]$

$= 0.1295$ in

$t_b = \min\left[t_{b3}, t_{b1}\right]$

$= \min\left[0.2818, 0.1295\right]$

$= 0.1295$ in

$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$

$= \max\left[0.026, 0.1295\right]$

$= 0.1295$ in

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.148 = 0.1295$ in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 53.69 psi @ 250 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.7335	0.7336	0.6152	0.0784	–	–	0.04	0.0625	0.1295

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1036	0.14	weld size is adequate

Calculations for external pressure 53.69 psi @ 250 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[8.329, 4.1645 + (0.148 - 0) + (0.25 - 0)\right]$$
$$= 8.329 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.25 - 0), 2.5 \cdot (0.148 - 0) + 0\right]$$
$$= 0.37 \text{ in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.042 in

From UG-37(d)(1) required thickness t_r = 0.1761 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 26,700, S_v = 26,700 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

$$A = 0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$
$$= 0.5 \cdot (8.329 \cdot 0.1761 \cdot 1 + 2 \cdot 0.148 \cdot 0.1761 \cdot 1 \cdot (1 - 1))$$
$$= 0.7335 \text{ in}^2$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.6152 in^2

$=\quad d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$=\quad 8.329 \cdot (1 \cdot 0.25 - 1 \cdot 0.1761) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1761) \cdot (1 - 1)$

$=\quad 0.6152 \;\; \text{in}^2$

$=\quad 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$=\quad 2 \cdot (0.25 + 0.148) \cdot (1 \cdot 0.25 - 1 \cdot 0.1761) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1761) \cdot (1 - 1)$

$=\quad 0.0588 \;\; \text{in}^2$

A_2 = smaller of the following= 0.0784 in^2

$=\quad 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

$=\quad 5 \cdot (0.148 - 0.042) \cdot 1 \cdot 0.25$

$=\quad 0.1325 \;\; \text{in}^2$

$=\quad 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

$=\quad 5 \cdot (0.148 - 0.042) \cdot 1 \cdot 0.148$

$=\quad 0.0784 \;\; \text{in}^2$

$A_{41} \quad = \quad Leg^2 \cdot f_{r2}$

$=\quad 0.2^2 \cdot 1$

$=\quad$ 0.04 in^2

$Area \quad = \quad A_1 + A_2 + A_{41}$

$=\quad 0.6152 + 0.0784 + 0.04$

$=\quad$ 0.7336 in^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\,[0.75, t_n, t] =$ 0.148 in

$t_{c(\min)} = \min\,[0.25, 0.7 \cdot t_{\min}] =$ 0.1036 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.2 = 0.14 \;\; \text{in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} \quad = \quad 0.042 \;\; \text{in}$

$t_a \quad = \quad \max\,[t_{a\text{UG-28}}, t_{a\text{UG-22}}]$

$=\quad \max\,[0.042, 0]$

$=\quad 0.042 \;\; \text{in}$

$t_{b2} \quad = \quad \dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

$=\quad \dfrac{53.6905 \cdot 20.75}{26{,}700 \cdot 1 - 0.6 \cdot 53.6905} + 0$

$=\quad 0.0418 \;\; \text{in}$

$t_{b2} = \max\left[t_{b2}, t_{bUG16}\right]$

$= \max\left[0.0418, 0.0625\right]$

$= 0.0625$ in

$t_b = \min\left[t_{b3}, t_{b2}\right]$

$= \min\left[0.2818, 0.0625\right]$

$= 0.0625$ in

$t_{UG\text{-}45} = \max\left[t_a, t_b\right]$

$= \max\left[0.042, 0.0625\right]$

$=$ 0.0625 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.148$ = 0.1295 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{6.5726}{8.625} = 0.7620$$

$$\frac{D_o}{t} = \frac{8.625}{0.042} = 205.2231$$

From table G: $A = 0.000605$

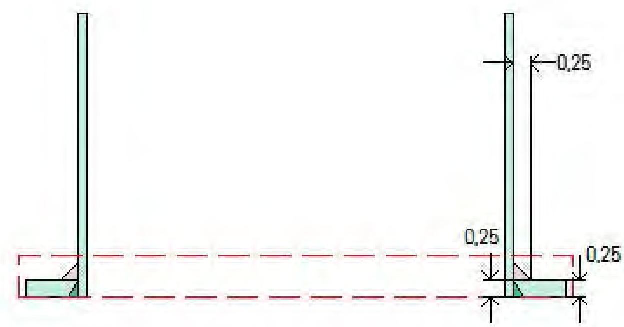
From table HA-5: $B = 8{,}264.0127$ psi

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 8{,}264.01}{3 \cdot (8.625/0.042)} = 53.69 \text{ psi}$$

Design thickness for external pressure P_a = 53.69 psi

$t_a = t + \text{Corrosion} = 0.042 + 0 =$ 0.042"

TS Product Outlet (Outlet)

ASME Section VIII Division 1, 2019 Edition	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Front Channel
Orientation	0°
Nozzle center line offset to datum line	164.75"
End of nozzle to shell center	27.125"
Passes through a Category A joint	No
Nozzle	
Service	Product Outlet (OUT)
Description	NPS 8 Sch 10S
Access opening	No
Material specification	SA-790 Smls pipe S32205 (II-D p. 128, ln. 38)
Inside diameter, new	8.329"
Pipe nominal wall thickness	0.148"
Pipe minimum wall thickness[1]	0.1295"
Corrosion allowance	0"
Projection available outside vessel, Lpr	2.125"
Projection available outside vessel to flange face, Lf	6.125"
Local vessel minimum thickness	0.25"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.25"
Nozzle to vessel groove weld	0.25"

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

ASME B16.5-2013 Flange	
Description	NPS 8 Class 150 WN A182 F51
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 398, ln. 32)
Blind included	No
Rated MDMT	40°F
Liquid static head	0 psi
MAWP rating	245 psi @ 250°F
MAP rating	290 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Notes	
Flange rated MDMT per UHA-51(g) = 40°F (Coincident ratio = 0.2988) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{86.65 \cdot 4.1645}{27{,}100 \cdot 1 - 0.6 \cdot 86.65} =$	0.0133"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0133 \cdot 1}{0.1295 - 0} =$	0.103
Impact test exempt per UHA-51(g) (coincident ratio = 0.103)	
Rated MDMT =	-20°F
Material is exempt from impact testing at the Design MDMT of 40°F.	

Reinforcement Calculations for MAWP

The thickness requirements of UG-45 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 166.08 psi @ 250 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.079	1.156	1.0032	0.0903	–	–	0.0625	0.1295	0.1295

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1036	0.175	weld size is adequate

Calculations for internal pressure 166.08 psi @ 250 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[8.329, 4.1645 + (0.148 - 0) + (0.25 - 0)\right]$$
$$= 8.329 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.25 - 0), 2.5 \cdot (0.148 - 0) + 0\right]$$
$$= 0.37 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{166.0759 \cdot 4.1645}{26{,}700 \cdot 1 - 0.6 \cdot 166.0759}$$
$$= 0.026 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{166.0759 \cdot 20.75}{26{,}700 \cdot 1 - 0.6 \cdot 166.0759}$$
$$= 0.1296 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$t_r = \dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P}$

$= \dfrac{166.0759 \cdot 20.75}{26{,}700 \cdot 0.7 - 0.6 \cdot 166.0759}$

$= 0.1854 \text{ in}$

Area required per UG-37(c)

Allowable stresses: S_n = 26,700, S_v = 26,700 psi

f_{r1} = lesser of 1 or $\dfrac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\dfrac{S_n}{S_v}$ = 1

$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1})$

$= 8.329 \cdot 0.1296 \cdot 1 + 2 \cdot 0.148 \cdot 0.1296 \cdot 1 \cdot (1 - 1)$

= 1.079 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.0032 in^2

$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 8.329 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) \cdot (1 - 1)$

$= 1.0032 \text{ in}^2$

$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 2 \cdot (0.25 + 0.148) \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) \cdot (1 - 1)$

$= 0.0959 \text{ in}^2$

A_2 = smaller of the following= 0.0903 in^2

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

$= 5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.25$

$= 0.1525 \text{ in}^2$

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

$= 5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.148$

$= 0.0903 \text{ in}^2$

$A_{41} = Leg^2 \cdot f_{r2}$

$= 0.25^2 \cdot 1$

= 0.0625 in^2

$Area = A_1 + A_2 + A_{41}$

$= 1.0032 + 0.0903 + 0.0625$

= 1.156 in^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.148 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1036 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.25 = 0.175 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{166.0759 \cdot 4.1645}{26{,}700 \cdot 1 - 0.6 \cdot 166.0759} + 0$$

$$= 0.026 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.026, 0\right]$$

$$= 0.026 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{166.0759 \cdot 20.75}{26{,}700 \cdot 1 - 0.6 \cdot 166.0759} + 0$$

$$= 0.1295 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1295, 0.0625\right]$$

$$= 0.1295 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.2818, 0.1295\right]$$

$$= 0.1295 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.026, 0.1295\right]$$

$$= 0.1295 \text{ in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.148 = 0.1295$ in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The thickness requirements of UG-45 govern the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 168.56 psi @ 70 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.079	1.156	1.0032	0.0903	–	–	0.0625	0.1295	0.1295

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

Calculations for internal pressure 168.56 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[8.329, 4.1645 + (0.148 - 0) + (0.25 - 0)\right]$$
$$= 8.329 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.25 - 0), 2.5 \cdot (0.148 - 0) + 0\right]$$
$$= 0.37 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{168.5595 \cdot 4.1645}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595}$$
$$= 0.026 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{168.5595 \cdot 20.75}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595}$$
$$= 0.1295 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{168.5595 \cdot 20.75}{27{,}100 \cdot 0.7 - 0.6 \cdot 168.5595}$$
$$= 0.1854 \text{ in}$$

Area required per UG-37(c)

Allowable stresses: S_n = 27,100, S_v = 27,100 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

$$\begin{aligned} A &= d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) \\ &= 8.329 \cdot 0.1296 \cdot 1 + 2 \cdot 0.148 \cdot 0.1296 \cdot 1 \cdot (1 - 1) \\ &= 1.079 \text{ in}^2 \end{aligned}$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.0032 in^2

$$\begin{aligned} &= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ &= 8.329 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) \cdot (1 - 1) \\ &= 1.0032 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} &= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ &= 2 \cdot (0.25 + 0.148) \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1296) \cdot (1 - 1) \\ &= 0.0959 \text{ in}^2 \end{aligned}$$

A_2 = smaller of the following= 0.0903 in^2

$$\begin{aligned} &= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t \\ &= 5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.25 \\ &= 0.1525 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} &= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n \\ &= 5 \cdot (0.148 - 0.026) \cdot 1 \cdot 0.148 \\ &= 0.0903 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} A_{41} &= Leg^2 \cdot f_{r2} \\ &= 0.25^{\,2} \cdot 1 \\ &= 0.0625 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} Area &= A_1 + A_2 + A_{41} \\ &= 1.0032 + 0.0903 + 0.0625 \\ &= 1.156 \text{ in}^2 \end{aligned}$$

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

$$\begin{aligned} t_{a\text{UG-27}} &= \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion} \\ &= \frac{168.5595 \cdot 4.1645}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595} + 0 \\ &= 0.026 \text{ in} \end{aligned}$$

$t_a \quad = \quad \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$

$= \quad \max\left[0.026, 0\right]$

$= \quad 0.026 \text{ in}$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{168.5595 \cdot 20.75}{27{,}100 \cdot 1 - 0.6 \cdot 168.5595} + 0$$

$$= 0.1295 \text{ in}$$

$t_{b1} \quad = \quad \max\left[t_{b1}, t_{b\text{UG16}}\right]$

$= \quad \max\left[0.1295, 0.0625\right]$

$= \quad 0.1295 \text{ in}$

$t_b \quad = \quad \min\left[t_{b3}, t_{b1}\right]$

$= \quad \min\left[0.2818, 0.1295\right]$

$= \quad 0.1295 \text{ in}$

$t_{\text{UG-45}} \quad = \quad \max\left[t_a, t_b\right]$

$= \quad \max\left[0.026, 0.1295\right]$

$= \quad 0.1295 \text{ in}$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.148$ = 0.1295 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 55.17 psi @ 250 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.7409	0.741	0.6005	0.078	–	–	0.0625	0.0625	0.1295

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1036	0.175	weld size is adequate

Calculations for external pressure 55.17 psi @ 250 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[8.329, 4.1645 + (0.148 - 0) + (0.25 - 0)\right]$$
$$= 8.329 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.25 - 0), 2.5 \cdot (0.148 - 0) + 0\right]$$
$$= 0.37 \text{ in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.0426 in

From UG-37(d)(1) required thickness t_r = 0.1779 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 26,700, S_v = 26,700 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

$$A = 0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$
$$= 0.5 \cdot (8.329 \cdot 0.1779 \cdot 1 + 2 \cdot 0.148 \cdot 0.1779 \cdot 1 \cdot (1 - 1))$$
$$= 0.7409 \text{ in}^2$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.6005 in^2

$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 8.329 \cdot (1 \cdot 0.25 - 1 \cdot 0.1779) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1779) \cdot (1 - 1)$

$= 0.6005 \ \text{in}^2$

$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 2 \cdot (0.25 + 0.148) \cdot (1 \cdot 0.25 - 1 \cdot 0.1779) - 2 \cdot 0.148 \cdot (1 \cdot 0.25 - 1 \cdot 0.1779) \cdot (1 - 1)$

$= 0.0574 \ \text{in}^2$

A_2 = smaller of the following= 0.078 in^2

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

$= 5 \cdot (0.148 - 0.0426) \cdot 1 \cdot 0.25$

$= 0.1318 \ \text{in}^2$

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

$= 5 \cdot (0.148 - 0.0426) \cdot 1 \cdot 0.148$

$= 0.078 \ \text{in}^2$

$A_{41} = Leg^2 \cdot f_{r2}$

$= 0.25^2 \cdot 1$

$= 0.0625 \ \text{in}^2$

$Area = A_1 + A_2 + A_{41}$

$= 0.6005 + 0.078 + 0.0625$

$= 0.741 \ \text{in}^2$

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.148 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1036 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.25 = 0.175 \ \text{in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 0.0426 \ \text{in}$

$t_a = \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$

$= \max\left[0.0426, 0\right]$

$= 0.0426 \ \text{in}$

$t_{b2} = \dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

$= \dfrac{55.1748 \cdot 20.75}{26{,}700 \cdot 1 - 0.6 \cdot 55.1748} + 0$

$= 0.0429 \ \text{in}$

t_{b2} $= \max[t_{b2}, t_{bUG16}]$

$= \max[0.0429, 0.0625]$

$= 0.0625$ in

t_b $= \min[t_{b3}, t_{b2}]$

$= \min[0.2818, 0.0625]$

$= 0.0625$ in

$t_{UG\text{-}45}$ $= \max[t_a, t_b]$

$= \max[0.0426, 0.0625]$

$=$ 0.0625 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.148$ = 0.1295 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{6.5726}{8.625} = 0.7620$$

$$\frac{D_o}{t} = \frac{8.625}{0.0426} = 202.6939$$

From table G: $A = 0.000614$
From table HA-5: $B = 8{,}387.846$ psi

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 8{,}387.85}{3 \cdot (8.625/0.0426)} = 55.18 \text{ psi}$$

Design thickness for external pressure P_a = 55.18 psi

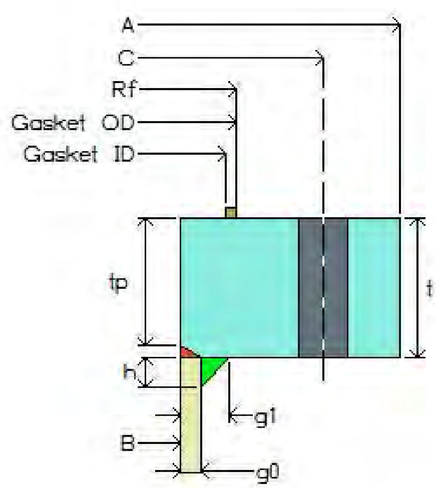
$t_a = t + \text{Corrosion} = 0.0426 + 0 =$ 0.0426"

Tube Side Flange (front)

ASME Section VIII Division 1, 2019 Edition , Appendix 2 Flange Calculations				
Flange Type	Ring type integral			
Attachment Type	Figure UW-13.2 sketch (n)			
Flange Material	SA-182 F60 (II-D p. 128, ln. 43)			
Attached To	Front Channel (Right)			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
Yes (-20°F)	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		60	250	40
External		15	250	

Static Liquid Head	
Condition	**P_s (psi)**
Operating	1.49

Dimensions	
Flange OD, A	47"
Flange ID, B	41.5"
Bolt Circle, C	45.0625"
Gasket OD	42.9"
Gasket ID	42.6"
Raised Face ID	42.9"
Facing Height, t_{rf}	0"
Flange Thickness, t	1.75"
Hub Thickness, g_1	0.6071"
Hub Thickness, g_0	0.25"
Fillet Weld, h	0.375"
Groove Weld, w	0.25"
Edge Distance, t_p	1.6"
Corrosion Bore	0"
Corrosion Flange	0"



Bolting	
Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 398, ln. 32)
Description	28 - 0.625" coarse threaded
Corrosion on root	0"

Gasket	
Factor, m	0
Seating Stress, y	0 psi
Thickness, T	0.125"

Weight (lb)	
New	188.7 lb

Corroded	188.7 lb
Radiography	
Longitudinal seam	Seamless No RT
Left Circumferential seam	N/A

Results Summary		
Flange design thickness:	1.3119"	
Maximum allowable working pressure, MAWP:	86.65 psi @ 250 °F	
Maximum allowable pressure, MAP:	89.46 psi @ 70 °F	
Maximum allowable external pressure, MAEP:	150 psi @ 250 °F	(App 2-14(a) limits)
Rated MDMT	-20 °F	

Note: this flange is an optional type calculated as integral.
The following values are used in the calculations: g_0 = shell/nozzle wall thickness, h = actual length of flange hub plus fillet weld leg attaching hub to shell/nozzle
Appendix 2-14(a) successful service experience active.
Flange rigidity calculations are not performed for conditions where service restrictions are met.

UHA-51 Material Toughness Requirements	
Material impact test temperature per UHA-51(a) =	-20°F
Bolts rated MDMT per Fig UCS-66 note (c) =	-55°F
Design MDMT of 40°F is acceptable.	

Stress Summary											
			P (psi)	S_H (psi)	Allow (psi)	S_R (psi)	S_T (psi)	$(S_H + S_R) / 2$ (psi)	$(S_H + S_T) / 2$ (psi)	Allow (psi)
Design P	Weight Only	Oper	61.49	27,941	40,050	1,187	6,519	14,564	17,230	26,700
		Seating		26,547	40,650	1,128	6,194	13,838	16,371	27,100
Design P_e	Weight Only	Oper	15	1,819	40,050	77	424	948	1,121	26,700
		Seating		16,304	40,650	693	3,804	8,498	10,054	27,100

Bolt Summary						
			P (psi)	W (lb_f)	A_m (in^2)	A_b (in^2)
Design P	Weight Only	Oper	61.49	88,834.5	3.55	5.66
		Seating		0	0	
Design P_e	Weight Only	Oper	15	21,670.83	0	5.66
		Seating		0	0	

Figure UW-13.2 Weld Sizing					
$a + b \geq 3t_n + C_{i,shell} + \dfrac{C_{o,shell}}{0.7}$					
$h \geq \dfrac{\min\,[t_n, t_x] + C_{o,shell}}{0.7}$					
$t_p \geq \min\,[t_n, 0.25"] + C_o$					
Results					
$a + b =$	0.7571"	$\geq$	$3 \cdot 0.25 + 0 + \dfrac{0}{0.7} =$	0.75"	✔
$h =$	0.375"	$\geq$	$\dfrac{\min\,[0.25, 0.5] + 0}{0.7} =$	0.3571"	✔
$g_1 - g_0 =$	0.3571"	$\geq$	$\dfrac{\min\,[0.25, 0.5] + 0}{0.7} =$	0.3571"	✔
$t_p =$	1.6"	$\geq$	$\min\,[0.25, 0.25] + 0 =$	0.25"	✔

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a)

Gasket width N = 0.15 in

$b_0 = \dfrac{N}{2} = 0.075$ in

Effective gasket seating width, $b = b_0 = 0.075$ in

G = OD of contact face = 42.9 in (per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets)

$$h_G = \frac{C - G}{2} = \frac{45.0625 - 42.9}{2} = 1.0813 \text{ in}$$

$$h_D = \frac{R + g_1}{2} = \frac{1.1741 + 0.6071}{2} = 1.4777 \text{ in}$$

$$h_T = \frac{R + g_1 + h_G}{2} = \frac{1.1741 + 0.6071 + 1.0813}{2} = 1.4313 \text{ in}$$

$H_p = 0$ per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets.

$$H = 0.785 \cdot G^2 \cdot P = 0.785 \cdot 42.9^2 \cdot 61.489 = 88{,}834.5 \text{ lb}_f$$

$$H_D = 0.785 \cdot B^2 \cdot P = 0.785 \cdot 41.5^2 \cdot 61.489 = 83{,}131.05 \text{ lb}_f$$

$$H_T = H - H_D = 88{,}834.5 - 83{,}131.05 = 5{,}703.45 \text{ lb}_f$$

$$W_{m1} = H + H_p = 88{,}834.5 + 0 = 88{,}834.5 \text{ lb}_f$$

$$W_{m2} = 3.14 \cdot b \cdot G \cdot y = 3.14 \cdot 0.075 \cdot 42.9 \cdot 0 = 0 \text{ lb}_f$$

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 3.5534 in^2

$$A_{m1} = \frac{W_{m1}}{S_b} = \frac{88{,}834.5}{25{,}000} = 3.5534 \text{ in}^2$$

$$A_{m2} = \frac{W_{m2}}{S_a} = \frac{0}{25{,}000} = 0 \text{ in}^2$$

Total area for 28 - 0.625" coarse threaded bolts, corroded, A_b = 5.656 in^2

$$W = \frac{(A_m + A_b) \cdot S_a}{2} = \frac{(3.5534 + 5.656) \cdot 25{,}000}{2} = 115{,}117.25 \quad \text{lb}_f$$

$$M_D = H_D \cdot h_D = 83{,}131.05 \cdot 1.4777 = 122{,}841 \quad \text{lb}_f\text{-in}$$

$$M_T = H_T \cdot h_T = 5{,}703.45 \cdot 1.4313 = 8{,}163.1 \quad \text{lb}_f\text{-in}$$

$$H_G = W_{m1} - H = 88{,}834.5 - 88{,}834.5 = 0 \quad \text{lb}_f$$

$$M_G = H_G \cdot h_G = 0 \cdot 1.0813 = 0 \quad \text{lb}_f\text{-in}$$

$$M_o = M_D + M_T + M_G = 122{,}841 + 8{,}163.1 + 0 = 131{,}004 \quad \text{lb}_f\text{-in}$$

$$M_g = W \cdot h_G = 115{,}117.25 \cdot 1.0813 = 124{,}470.5 \quad \text{lb}_f\text{-in}$$

Hub and Flange Factors

$g_0 = t_n = 0.25 \text{ in}$

$h_0 = \sqrt{B \cdot g_0} = \sqrt{41.5 \cdot 0.25} = 3.221 \text{ in}$

From FIG. 2-7.1, where $K = \frac{A}{B} = \frac{47}{41.5} = 1.1325$

$T = 1.8653 \quad Z = 8.0765 \quad Y = 15.6248 \quad U = 17.1701$

$\frac{h}{h_0} = 0.1164 \quad \frac{g_1}{g_0} = 2.4286$

$F = 0.9027 \quad V = 0.4101 \quad e = \frac{F}{h_0} = 0.2803$

$$d = \left(\frac{U}{V}\right) \cdot h_0 \cdot g_0^2 = \left(\frac{17.1701}{0.4101}\right) \cdot 3.221 \cdot 0.25^{\,2} = 8.4284 \text{ in}^3$$

Stresses at operating conditions - VIII-1 Appendix 2-7

$f = 4.6818$

$$L = \frac{t \cdot e + 1}{T} + \frac{t^3}{d} = \frac{1.75 \cdot 0.2803 + 1}{1.8653} + \frac{1.75^{\,3}}{8.4284} = 1.4349$$

$$S_H = \frac{f \cdot M_o}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 131{,}004}{1.4349 \cdot 0.6071^{\,2} \cdot 41.5} = \text{27,941 psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_o}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 131{,}004}{1.4349 \cdot 1.75^{\,2} \cdot 41.5} = \text{1,187 psi}$$

$$S_T = \frac{Y \cdot M_o}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 131{,}004}{1.75^{\,2} \cdot 41.5} - 8.0765 \cdot 1{,}187 = \text{6,519 psi}$$

Allowable stress S_{fo} = 26,700 psi
Allowable stress S_{no} = 26,700 psi

S_T does not exceed S_{fo}
S_H does not exceed $\min\left[1.5 \cdot S_{fo}, 1.5 \cdot S_{no}\right] = 40{,}050 \text{ psi}$
S_R does not exceed S_{fo}
$\frac{S_H + S_R}{2}$ = 14,564 psi does not exceed S_{fo}
$\frac{S_H + S_T}{2}$ = 17,230 psi does not exceed S_{fo}

Stresses at gasket seating - VIII-1 Appendix 2-7

$$S_H = \frac{f \cdot M_g}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 124{,}470.5}{1.4349 \cdot 0.6071^{\,2} \cdot 41.5} = \text{26,547 psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_g}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 124{,}470.5}{1.4349 \cdot 1.75^{\,2} \cdot 41.5} = \text{1,128 psi}$$

$$S_T = \frac{Y \cdot M_g}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 124{,}470.5}{1.75^{\,2} \cdot 41.5} - 8.0765 \cdot 1{,}128 = \text{6,194 psi}$$

Allowable stress S_{fa} = 27,100 psi
Allowable stress S_{na} = 27,100 psi

S_T does not exceed S_{fa}

S_H does not exceed $\min\left[1.5 \cdot S_{fa}, 1.5 \cdot S_{na}\right] = 40{,}650$ psi

S_R does not exceed S_{fa}

$\frac{S_H + S_R}{2} =$ 13,838 psi does not exceed S_{fa}

$\frac{S_H + S_T}{2} =$ 16,371 psi does not exceed S_{fa}

Flange calculations for External Pressure + Weight Only per VIII-1, Appendix 2-11

Gasket details from facing sketch Confined gasket 1(a)

Gasket width N = 0.15 in

$b_0 = \frac{N}{2} = 0.075$ in

Effective gasket seating width, $b = b_0 = 0.075$ in

G = OD of contact face = 42.9 in (per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets)

$$h_G = \frac{C - G}{2} = \frac{45.0625 - 42.9}{2} = 1.0813 \text{ in}$$

$$h_D = \frac{R + g_1}{2} = \frac{1.1741 + 0.6071}{2} = 1.4777 \text{ in}$$

$$h_T = \frac{R + g_1 + h_G}{2} = \frac{1.1741 + 0.6071 + 1.0813}{2} = 1.4313 \text{ in}$$

$H_p = 0$ per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets.

$$H = 0.785 \cdot G^2 \cdot P = 0.785 \cdot 42.9^2 \cdot 15 = 21{,}670.83 \text{ lb}_f$$

$$H_D = 0.785 \cdot B^2 \cdot P = 0.785 \cdot 41.5^2 \cdot 15 = 20{,}279.49 \text{ lb}_f$$

$$H_T = H - H_D = 21{,}670.83 - 20{,}279.49 = 1{,}391.33 \text{ lb}_f$$

$$W_{m1} = H + H_p = 21{,}670.83 + 0 = 21{,}670.83 \text{ lb}_f$$

$$W_{m2} = 3.14 \cdot b \cdot G \cdot y = 3.14 \cdot 0.075 \cdot 42.9 \cdot 0 = 0 \text{ lb}_f$$

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 0 in^2

$$A_{m1} = \frac{0.785 \cdot G^2 \cdot (P_m - P_r)}{S_b} = \frac{0.785 \cdot 42.9^2 \cdot 0}{25{,}000} = 0 \text{ in}^2$$

$$A_{m2} = \frac{W_{m2}}{S_a} = \frac{0}{25{,}000} = 0 \text{ in}^2$$

Total area for 28 - 0.625" coarse threaded bolts, corroded, $A_b = 5.656$ in^2

$$W = \frac{(A_{m2} + A_b) \cdot S_a}{2} = \frac{(0 + 5.656) \cdot 25{,}000}{2} = 70{,}700 \text{ lb}_f$$

$$M_o = H_D \cdot (h_D - h_G) + H_T \cdot (h_T - h_G) = 20{,}279.49 \cdot (1.4777 - 1.0813) + 1{,}391.33 \cdot (1.4313 - 1.0813) = 8{,}526.3 \text{ lb}_f\text{-in}$$

$$M_g = W \cdot h_G = 70{,}700 \cdot 1.0813 = 76{,}444.4 \text{ lb}_f\text{-in}$$

Hub and Flange Factors

$g_0 = t_n = 0.25$ in

$h_0 = \sqrt{B \cdot g_0} = \sqrt{41.5 \cdot 0.25} = 3.221$ in

From FIG. 2-7.1, where $K = \dfrac{A}{B} = \dfrac{47}{41.5} = 1.1325$

$T = 1.8653 \quad Z = 8.0765 \quad Y = 15.6248 \quad U = 17.1701$

$\dfrac{h}{h_0} = 0.1164 \quad \dfrac{g_1}{g_0} = 2.4286$

$F = 0.9027 \quad V = 0.4101 \quad e = \dfrac{F}{h_0} = 0.2803$

$$d = \left(\frac{U}{V}\right) \cdot h_0 \cdot g_0^2 = \left(\frac{17.1701}{0.4101}\right) \cdot 3.221 \cdot 0.25^{\,2} = 8.4284 \ \ \text{in}^3$$

Stresses at operating conditions - VIII-1 Appendix 2-7

$f = 4.6818$

$$L = \frac{t \cdot e + 1}{T} + \frac{t^3}{d} = \frac{1.75 \cdot 0.2803 + 1}{1.8653} + \frac{1.75^{\,3}}{8.4284} = 1.4349$$

$$S_H = \frac{f \cdot M_o}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 8{,}526.3}{1.4349 \cdot 0.6071^{\,2} \cdot 41.5} = \text{1,819 psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_o}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 8{,}526.3}{1.4349 \cdot 1.75^{\,2} \cdot 41.5} = \text{77 psi}$$

$$S_T = \frac{Y \cdot M_o}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 8{,}526.3}{1.75^{\,2} \cdot 41.5} - 8.0765 \cdot 77 = \text{424 psi}$$

Allowable stress S_{fo} = 26,700 psi
Allowable stress S_{no} = 26,700 psi

S_T does not exceed S_{fo}
S_H does not exceed $\min\left[1.5 \cdot S_{fo}, 1.5 \cdot S_{no}\right] = 40{,}050$ psi
S_R does not exceed S_{fo}
$\dfrac{S_H + S_R}{2}$ = 948 psi does not exceed S_{fo}
$\dfrac{S_H + S_T}{2}$ = 1,121 psi does not exceed S_{fo}

Stresses at gasket seating - VIII-1 Appendix 2-7

$$S_H = \frac{f \cdot M_g}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 76{,}444.4}{1.4349 \cdot 0.6071^{\,2} \cdot 41.5} = \text{16,304 psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_g}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 76{,}444.4}{1.4349 \cdot 1.75^{\,2} \cdot 41.5} = \text{693 psi}$$

$$S_T = \frac{Y \cdot M_g}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 76{,}444.4}{1.75^{\,2} \cdot 41.5} - 8.0765 \cdot 693 = \text{3,804 psi}$$

Allowable stress S_{fa} = 27,100 psi
Allowable stress S_{na} = 27,100 psi

S_T does not exceed S_{fa}

S_H does not exceed $\min\left[1.5 \cdot S_{fa}, 1.5 \cdot S_{na}\right] = 40{,}650$ psi

S_R does not exceed S_{fa}

$\frac{S_H + S_R}{2} =$ 8,498 psi does not exceed S_{fa}

$\frac{S_H + S_T}{2} =$ 10,054 psi does not exceed S_{fa}

Tubesheet -- ASME

ASME Section VIII Division 1, 2019 Edition	
Type of heat exchanger:	Fixed Both Ends
Type of construction:	Fixed\Stationary tubesheet per Fig. UHX-13.1 Configuration b: shell-side integral, tubesheet extended as a flange
Calculate as simply supported:	No
Tubesheet material specification:	SA-240 S32205 (II-D p. 128, ln. 35)
Normalized	No
Fine Grain Practice	No
Impact Tested	Yes (-20°F)
PWHT	No
Tube layout:	Triangular
Tubesheet outer diameter, A:	47 in
Tubesheet thickness, h:	1.25 in (t_{design} = 0.8706 in)
Number of tubes, N_t:	342
Tube pitch, p:	1.875 in
Tube hole diameter:	1.514 in (Special Close Fit)
Radius to outer tube center, r_o:	19.3718 in
Total area of untubed lanes, A_L:	10 in^2
Pass partition groove depth, h_g:	0 in
Corrosion allowance shell side , c_s:	0 in
Corrosion allowance tube side , c_t:	0 in
Tubesheet poisson's ratio, ν:	0.3
Perimeter of the tube layout, C_p:	130.1745 in
Total area enclosed by C_p, A_p:	1,102.2442 in^2
Consider radial thermal expansion per UHX-13.8:	No
Gasket groove depth shell side:	0 in
Gasket groove depth tube side:	0 in
Shell	
Material specification:	SA-240 304 (II-D p. 88, ln. 37)
Inner diameter, D_s:	41.625 in
Thickness, t_s:	0.1874 in
Inner corrosion allowance:	0 in
Outer corrosion allowance:	0 in
Poisson's ratio, ν_s:	0.31
Circumferential weld joint efficiency, $E_{s,w}$:	0.7
Shell Band	
Material specification:	SA-240 304 (II-D p. 88, ln. 37)
Thickness, $t_{s,1}$:	0.1874 in
Inner corrosion allowance:	0 in
Outer corrosion allowance:	0 in
Length, L_1:	12 in
Length, L_2:	12 in
Circumferential weld joint efficiency, $E_{s,w}$:	0.7
Channel	
Material specification:	SA-240 S32205 (II-D p. 128, ln. 35)
Inner diameter, D_c:	41.5 in

Thickness, t_c:	0.25 in
Inner corrosion allowance:	0 in
Outer corrosion allowance:	0 in
Poisson's ratio, ν_c:	0.3
Tubes	
Tube material specification:	SA-789 Wld tube S32205 (II-D p. 128, ln. 46)
Tube outer diameter, d_t:	1.5 in
Tube nominal thickness, t_t:	0.049 in
Tube minimum thickness, $t_{t,min}$:	0.0429 in
Tube tolerance:	12.5%
Tube length between outer tubesheet faces, L_t:	144 in
Tube inner corrosion allowance:	0 in
Tube outer corrosion allowance:	0 in
Tube expansion depth ratio, ρ:	0.85
Tube poisson's ratio, ν_t:	0.3
Flange	
Bolt circle diameter, C:	45.0625 in
Channel side gasket load reaction diameter, G_c:	42.9 in
Tube Supports	
Tube supports present:	Yes
Support all tubes:	No
Maximum distance from tubesheet to first support:	122 in
Maximum distance between tube supports:	0 in
Tube-To-Tubesheet Joints	
Calculation method:	Appendix A
Joint type:	Table A-2 Type e, Welded, a ≥1.4*t, and expanded

Tube-To-Tubesheet Joint Loads

Summary Tables

Tubesheet Design Thickness Summary	
Condition	**t_{design} (in)**
Operating	0.8705959

Tubesheet Effective Bolt Load		
Condition	**Load Case**	**W^* (lb_f)**
Operating	LC1	88,834.5
	LC2	0
	LC3	88,834.5
	LC4	0
	LC5	115,117.25
	LC6	82,611.01
	LC7	115,117.25
	LC8	82,611.01

Pressures												
Condition	Shell Side						Tube Side					
	$P_{sd,max}$ (psi)	$P_{sd,min}$ (psi)	$P_{sox,max}$ (psi)	$P_{sox,min}$ (psi)	Static Pressure (psi)	Consider Liquid	$P_{td,max}$ (psi)	$P_{td,min}$ (psi)	$P_{tox,max}$ (psi)	$P_{tox,min}$ (psi)	Static Pressure (psi)	Consider Liquid
Operating	25	-15	25	-15	0	No	60	-15	60	-15	1.49	Yes

Temperatures						
Condition	Tubesheet design T (°F)	Shell design T_s (°F)	Channel design T_c (°F)	Tube design T_t (°F)	Shell mean $T_{s,m}$ (°F)	Tube mean $T_{t,m}$ (°F)
Operating	300	300	250	300	250	250

Material Properties						
Condition	Component	Material	Modulus of Elasticity (psi)	Allowable Stress (psi)	Yield Stress (psi)	Mean Coefficient Thermal Expansion
Operating	Shell	SA-240 304	E_s = 27.0E+06	S_s = 18,900	$S_{y,s}$ = 22,400	$\alpha_{s,m}$ = 9.10E-06
	Shell Band	SA-240 304	$E_{s,1}$ = 27.0E+06	$S_{s,1}$ = 18,900	$S_{y,s,1}$ = 22,400	$\alpha_{s,m,1}$ = 9.10E-06
	Channel	SA-240 S32205	E_c = 27.85E+06	S_c = 26,700	$S_{y,c}$ = 55,500	N/A
	Tubesheet	SA-240 S32205	E = 27.5E+06	S = 26,200	S_y = 53,700	N/A
	Tubes	SA-789 Wld tube S32205	E_t = 27.5E+06	S_t = 26,235*	$S_{y,t}$ = 57,900	$\alpha_{t,m}$ = 7.30E-06
			E_{tT} =27.5E+06	S_{tT} =26,235*	N/A	N/A

*The allowable tensile stress from Section II-D has been divided by 0.85 as the calculated stresses are longitudinal.

Calculations for Operating Condition

Table UHX-13.4-1		
Design Loading Case	Shell Side Design Pressure, P_s (psi)	Tube Side Design Pressure, P_t (psi)
1	-15	61.49
2	25	-15
3	25	61.49
4	-15	-15

Table UHX-13.4-2				
Operating Loading Case	Operating Pressure		Axial Mean Metal Temperature	
	Shell Side, P_s (psi)	Tube Side, P_t (psi)	Tubes, $T_{t,m}$ (°F)	Shell, $T_{s,m}$ (°F)
5	-15	61.49	250	250
6	25	-15		
7	25	61.49		
8	-15	-15		

UHX-9.5				
$h_{r,\text{operating}} = \sqrt{\dfrac{1.9 W_{m1}\, h_G}{S_{fe}\, G}}$				
$h_{r,\text{gasket seating}} = \sqrt{\dfrac{1.9 W\, h_G}{S_a G}}$				
$h_r = \max\left[h_{r,\text{gasket seating}}\, h_{r,\text{operating}}\right]$				
Condition Operating				
Operating				
New or Corr	LC1, 3, 5, 7	$h_r = \sqrt{\dfrac{1.9 \cdot 88{,}834.5 \cdot 1.0813}{26{,}200 \cdot 42.9}}$	=	0.403
	LC2, 4, 6, 8	$h_r = \sqrt{\dfrac{1.9 \cdot 23{,}822.02 \cdot 1.0813}{26{,}200 \cdot 42.9}}$	=	0.2087
Gasket Seating				
New or Corr	LC1, 3, 5, 7	$h_r = \sqrt{\dfrac{1.9 \cdot 115{,}117.25 \cdot 1.0813}{27{,}100 \cdot 42.9}}$	=	0.451
	LC2, 4, 6, 8	$h_r = \sqrt{\dfrac{1.9 \cdot 82{,}611.01 \cdot 1.0813}{27{,}100 \cdot 42.9}}$	=	0.3821
Tubesheet Design Thickness to Maintain h_r = 0.451 + 0 + 0 = 0.451 in				

UHX-13.5.1 Step 1
$D_o = 2r_o + d_t$
$\mu = \dfrac{p - d_t}{p}$
$d^* = \max\left(d_t - 2t_t\left(\dfrac{E_{tT}}{E}\right)\left(\dfrac{S_{tT}}{S}\right)\rho, d_t - 2t_t\right)$
$p^* = \dfrac{p}{\sqrt{1 - \frac{4\min(A_L, 4 D_o p)}{\pi D_o^2}}}$
$\mu^* = \dfrac{p^* - d^*}{p^*}$
$h'_g = \max\left(h_g - c_t, 0\right)$ for pressure load only. For load cases 5, 6, 7, 8 $h'_g = 0.$
$a_o = \dfrac{D_o}{2}$
$\rho_s = \dfrac{a_s}{a_o}$
$\rho_c = \dfrac{a_c}{a_o}$

$x_t = 1 - N_t \left(\frac{d_t - 2t_t}{2a_o} \right)^2$		
$x_s = 1 - N_t \left(\frac{d_t}{2a_o} \right)^2$		
Condition Operating		
New or Corr	$D_o = 2 \cdot 19.3718 + 1.5 =$	40.2436
New or Corr	$\mu = \frac{1.875 - 1.5}{1.875} =$	0.2
New or Corr	$d^* = \max \left(1.5 - 2 \cdot 0.049 \cdot \left(\frac{27.5E+06}{27.5E+06} \right) \cdot \left(\frac{26{,}235}{26{,}200} \right) \cdot 0.85, 1.5 - 2 \cdot 0.049 \right) =$	1.4165878
New or Corr	$p^* = \frac{1.875}{\sqrt{1 - \frac{4 \cdot \min(10, 4 \cdot 40.2436 \cdot 1.875)}{\pi \cdot 40.2436^2}}} =$	1.8824
New or Corr	$\mu^* = \frac{1.8824141 - 1.4165878}{1.8824141} =$	0.247462
New or Corr	$h'_g =$	0
New or Corr	$a_o = \frac{40.2436}{2} =$	20.1218
New or Corr	$\rho_s = \frac{20.8125}{20.1218} =$	1.034327
New or Corr	$\rho_c = \frac{21.45}{20.1218} =$	1.066009
New or Corr	$x_s = 1 - 342 \cdot \left(\frac{1.5}{2 \cdot 20.1218} \right)^2 =$	0.524867
New or Corr	$x_t = 1 - 342 \cdot \left(\frac{1.5 - 2 \cdot 0.049}{2 \cdot 20.1218} \right)^2 =$	0.584923

UHX-13.5.2 Step 2
$K_s^* = \dfrac{\pi(D_s + t_s)}{\frac{L - l_1 - l_1'}{E_s t_s} + \frac{l_1 + l_1'}{E_{s,1} t_{s,1}}}$
$K_t = \dfrac{\pi t_t (d_t - t_t) E_t}{L}$
$K_{s,t} = \dfrac{K_s^*}{N_t K_t}$
$J = \dfrac{1}{1 + \frac{K_s^*}{K_J}}$
$\beta_s = \dfrac{\sqrt[4]{12(1-\nu_s^2)}}{\sqrt{(D_s + t_{s,1}) t_{s,1}}}$
$k_s = \beta_s \dfrac{E_{s,1} t_{s,1}^3}{6(1-\nu_s^2)}$
$\lambda_s = \dfrac{6 D_s}{h^3} k_s \left(1 + h\beta_s + \dfrac{h^2 \beta_s^2}{2}\right)$
$\delta_s = \dfrac{D_s^2}{4 E_{s,1} t_{s,1}} \left(1 - \dfrac{\nu_s}{2}\right)$
β_c, k_c, λ_c, & δ_c = 0 for configuration b

Condition Operating		
New or Corr	$K_s^* = \dfrac{\pi \cdot (41.625 + 0.1874)}{\frac{141.5 - 12 - 12}{27.0E{+}06 \cdot 0.1874} + \frac{12 + 12}{27.0E{+}06 \cdot 0.1874}} =$	4,697,122.43
New or Corr	$K_t = \dfrac{\pi \cdot 0.049 \cdot (1.5 - 0.049) \cdot 27.5E{+}06}{141.5} =$	43,409.98
New or Corr	$K_{s,t} = \dfrac{4{,}697{,}122.43}{342 \cdot 43{,}409.98} =$	0.316385
New or Corr	J = 1 as no expansion joint used	
New or Corr	$\beta_s = \dfrac{\sqrt[4]{12 \cdot (1 - 0.31^{2})}}{\sqrt{(41.625 + 0.1874) \cdot 0.1874}} =$	0.648318
New or Corr	$k_s = 0.648318 \cdot \dfrac{27.0E{+}06 \cdot 0.1874^{3}}{6 \cdot (1 - 0.31^{2})} =$	21,241.68
New or Corr	$\lambda_s = \dfrac{6 \cdot 41.625}{1.25^{3}} \cdot 21{,}241.68 \cdot \left(1 + 1.25 \cdot 0.648318 + \dfrac{1.25^{2} \cdot 0.648318^{2}}{2}\right) =$	5,809,361
New or Corr	$\delta_s = \dfrac{41.625^{2}}{4 \cdot 27.0E{+}06 \cdot 0.1874} \cdot \left(1 - \dfrac{0.31}{2}\right) =$	7.2339E-05

UHX-13.5.3 Step 3		
$\frac{E^*}{E} = \alpha_0 + \alpha_1 \mu^* + \alpha_2 \mu^{*2} + \alpha_3 \mu^{*3} + \alpha_4 \mu^{*4}$		
$\nu^* = \beta_0 + \beta_1 \mu^* + \beta_2 \mu^{*2} + \beta_3 \mu^{*3} + \beta_4 \mu^{*4}$		
$X_a = \sqrt[4]{24(1-\nu^{*2}) N_t \frac{E_t t_t (d_t - t_t) a_o^2}{E^* L h^3}}$		
Condition Operating		
New or Corr	$\frac{h}{p} = \frac{1.25}{1.875} =$	0.6667
New or Corr	from Fig. UHX-11.5.2-1(a) $\rightarrow \frac{E^*}{E} =$	0.2581
New or Corr	$E^* = 0.2581129 \cdot 27.5\text{E+06} =$	7,098,105
New or Corr	from Fig. UHX-11.5.2-1(b) $\rightarrow \nu^* =$	0.3089
New or Corr	$X_a = \sqrt[4]{24 \cdot \left(1 - 0.3089124^{\ 2}\right) \cdot 342 \cdot \frac{27.5\text{E+06} \cdot 0.049 \cdot (1.5 - 0.049) \cdot 20.1218^{\ 2}}{7{,}098{,}105 \cdot 141.5 \cdot 1.25^{\ 3}}} =$	7.3985
New or Corr	$Z_d =$	0.0036942
New or Corr	$Z_v =$	0.0186744
New or Corr	$Z_m =$	0.1970454
New or Corr	$Z_w =$	0.0186744
New or Corr	$Z_a =$	481.1062487

UHX-13.5.4 Step 4
$K = \dfrac{A}{D_o}$
$F = \left(\dfrac{1-\nu^*}{E^*}\right)(\lambda_s + \lambda_c + E\ln(K))$
$\Phi = (1+\nu^*)F$
$Q_1 = \dfrac{\rho_s - 1 - \Phi Z_v}{1+\Phi Z_m}$
$Q_{z1} = \dfrac{(Z_d + Q_1 Z_w) X_a^4}{2}$
$Q_{z2} = \dfrac{(Z_v + Q_1 Z_m) X_a^4}{2}$
$U = \dfrac{[Z_w + (\rho_s - 1) Z_m] X_a^4}{1+\Phi Z_m}$

Condition Operating

New or Corr	$K = \dfrac{47}{40.2436} =$	1.1678883
New or Corr	$F = \left(\dfrac{1-0.3089124}{7{,}098{,}105}\right) \cdot (5{,}809{,}361.41 + 0 + 27.5\text{E+06} \cdot \ln(1.1679)) =$	0.9811474
New or Corr	$\Phi = (1+0.3089124) \cdot 0.9811474 =$	1.284236
New or Corr	$Q_1 = \dfrac{1.0343266 - 1 - 1.284236 \cdot 0.0186744}{1 + 1.284236 \cdot 0.1970454} =$	0.0082552
New or Corr	$Q_{z1} = \dfrac{(0.0036942 + 0.0082552 \cdot 0.0186744) \cdot 7.3985286^{\ 4}}{2} =$	5.7654
New or Corr	$Q_{z2} = \dfrac{(0.0186744 + 0.0082552 \cdot 0.1970454) \cdot 7.3985286^{\ 4}}{2} =$	30.4138
New or Corr	$U = \dfrac{[0.0186744 + (1.0343266 - 1) \cdot 0.1970454] \cdot 7.3985286^{\ 4}}{1 + 1.284236 \cdot 0.1970454} =$	60.8276

UHX-13.5.5 Step 5
$\gamma_b = \dfrac{G_c - C}{D_o}$

Condition Operating

New or Corr	$\gamma_b = \dfrac{42.9 - 45.0625}{40.2436} =$	-0.0537353

UHX-13.5.5 Step 5
$\gamma^{\cdot} = (T_{t,m} - T_a)\alpha_{t,m}L - (T_{s,m} - T_a)[\alpha_{s,m}(L - l_1 - l_1') + \alpha_{s,m,1}(l_1 + l_1')]$
$\omega_s = \rho_s k_s \beta_s \delta_s (1 + h\beta_s)$
$\omega_c = \rho_c k_c \beta_c \delta_c (1 + h\beta_c)$
$\omega_s^* = a_o^2 \frac{(\rho_s^2 - 1)(\rho_s - 1)}{4} - \omega_s$
$\omega_c^* = a_o^2 \left[\frac{(\rho_c^2 + 1)(\rho_c - 1)}{4} - \frac{\rho_s - 1}{2}\right] - \omega_c$

Condition Operating			
		P_s (psi)	P_t (psi)
LC1		-15	61.49
LC2		25	-15
LC3		25	61.49
LC4		-15	-15
LC5		-15	61.49
LC6		25	-15
LC7		25	61.49
LC8		-15	-15
New or Corr	LC1, 2, 3, 4	$\gamma^* =$	0
	LC5, 6, 7, 8	$\gamma^{\cdot} = (250 - 70) \cdot 7.30\text{E-}06 \cdot 141.5 - (250 - 70) \cdot [9.10\text{E-}06 \cdot (141.5 - 12 - 12) + 9.10\text{E-}06 \cdot (12 + 12)] =$	-0.045846
New or Corr	LC1, 2, 3, 4, 5, 6, 7, 8	$\omega_s = 1.0343266 \cdot 21{,}241.68 \cdot 0.648318 \cdot 7.233889\text{E-}05 \cdot (1 + 1.25 \cdot 0.648318) =$	1.8654
New or Corr	LC1, 2, 3, 4, 5, 6, 7, 8	$\omega_s^* = 20.1218\ ^2 \cdot \frac{(1.0343266\ ^2 - 1) \cdot (1.0343266 - 1)}{4} - 1.8654367 =$	-1.6228
New or Corr	All LCs	$\omega_c = 1.0660087 \cdot 0.0 \cdot 0.0 \cdot 0 \cdot (1 + 1.25 \cdot 0.0) =$	0
New or Corr	LC1, 2, 3, 4, 5, 6, 7, 8	$\omega_c^* = 20.1218\ ^2 \cdot \left[\frac{(1.0660087\ ^2 + 1) \cdot (1.0660087 - 1)}{4} - \frac{1.0343266 - 1}{2}\right] - 0.0 =$	7.325

UHX-13.5.6 Step 6
$P_s' = \left(x_s + 2(1 - x_s)\nu_t + \frac{2}{K_{s,t}}\left(\frac{D_s}{D_o}\right)^2 \nu_s - \frac{\rho_s^2 - 1}{JK_{s,t}} - \frac{(1 - J)\left[D_j^2 - D_s^2\right]}{2JK_{s,t}D_o^2}\right) P_s$
$P_t' = \left(x_t + 2(1 - x_t)\nu_t + \frac{1}{JK_{s,t}}\right) P_t$
$P_\gamma = \frac{N_t K_t}{\pi a_o^2} \gamma^*$

$P_W = -\frac{U\gamma_b}{a_o^2 2\pi} W^*$			
$P_{rim} = -\frac{U}{a_o^2}(\omega_s^* P_s - \omega_c^* P_t)$			
$P_e = \frac{JK_{s,t}}{1 + JK_{s,t}[Q_{Z1} + (\rho_s - 1)Q_{Z2}]}(P_s' - P_t' + P_\gamma + P_W + P_{rim})$			
Condition Operating			
New or Corr	LC1, 4, 5, 8	$P_s' = \left(0.5248666 + 2 \cdot (1 - 0.5248666) \cdot 0.3 + \frac{2}{0.3163852} \cdot \left(\frac{41.625}{40.2436}\right)^2 \cdot 0.31 - \frac{1.0343266^2 - 1}{1.0 \cdot 0.3163852} - \frac{(1 - 1.0) \cdot [0^2 - 41.625^2]}{2 \cdot 1.0 \cdot 0.3163852 \cdot 40.2436^2}\right) \cdot -15 =$	-40.29
	LC2, 3, 6, 7	$P_s' = \left(0.5248666 + 2 \cdot (1 - 0.5248666) \cdot 0.3 + \frac{2}{0.3163852} \cdot \left(\frac{41.625}{40.2436}\right)^2 \cdot 0.31 - \frac{1.0343266^2 - 1}{1.0 \cdot 0.3163852} - \frac{(1 - 1.0) \cdot [0^2 - 41.625^2]}{2 \cdot 1.0 \cdot 0.3163852 \cdot 40.2436^2}\right) \cdot 25 =$	67.14
New or Corr	LC1, 3, 5, 7	$P_t' = \left(0.5849226 + 2 \cdot (1 - 0.5849226) \cdot 0.3 + \frac{1}{1.0 \cdot 0.3163852}\right) \cdot 61.49 =$	245.63
	LC2, 4, 6, 8	$P_t' = \left(0.5849226 + 2 \cdot (1 - 0.5849226) \cdot 0.3 + \frac{1}{1.0 \cdot 0.3163852}\right) \cdot -15 =$	-59.92
New or Corr	LC1, 2, 3, 4	$P_\gamma = \frac{342 \cdot 43{,}409.98}{\pi \cdot 20.1218^2} \cdot 0.0 =$	0
	LC5, 6, 7, 8	$P_\gamma = \frac{342 \cdot 43{,}409.98}{\pi \cdot 20.1218^2} \cdot -0.045846 =$	-535.1
New or Corr	LC1, 3	$P_W = -\frac{60.8276234 \cdot -0.0537353}{20.1218^2 \cdot 2 \cdot \pi} \cdot 88{,}834.5 =$	114.14
	LC2, 4	$P_W = -\frac{60.8276234 \cdot -0.0537353}{20.1218^2 \cdot 2 \cdot \pi} \cdot 0 =$	0
	LC5, 7	$P_W = -\frac{60.8276234 \cdot -0.0537353}{20.1218^2 \cdot 2 \cdot \pi} \cdot 115{,}117.25 =$	147.91
	LC6, 8	$P_W = -\frac{60.8276234 \cdot -0.0537353}{20.1218^2 \cdot 2 \cdot \pi} \cdot 82{,}611.01 =$	106.14
New or Corr	LC1, 5	$P_{rim} = -\frac{60.8276234}{20.1218^2} \cdot (-1.6228004 \cdot -15 - 7.3250067 \cdot 61.49) =$	64.01
	LC2, 6	$P_{rim} = -\frac{60.8276234}{20.1218^2} \cdot (-1.6228004 \cdot 25 - 7.3250067 \cdot -15) =$	-10.41
	LC3, 7	$P_{rim} = -\frac{60.8276234}{20.1218^2} \cdot (-1.6228004 \cdot 25 - 7.3250067 \cdot 61.49) =$	73.76
	LC4, 8	$P_{rim} = -\frac{60.8276234}{20.1218^2} \cdot (-1.6228004 \cdot -15 - 7.3250067 \cdot -15) =$	-20.16

New or Corr	LC1	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (-40.2857 - 245.6285 + 0 + 114.1377 + 64.0094) =$	-10.81
	LC2	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (67.1428 - -59.9201 + 0 + 0 + -10.412) =$	11.7
	LC3	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (67.1428 - 245.6285 + 0 + 114.1377 + 73.7614) =$	0.94
	LC4	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (-40.2857 - -59.9201 + 0 + 0 + -20.164) =$	-0.05
	LC5	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (-40.2857 - 245.6285 + -535.0991 + 147.9067 + 64.0094) =$	-61.09
	LC6	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (67.1428 - -59.9201 + -535.0991 + 106.1415 + -10.412) =$	-31.32
	LC7	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (67.1428 - 245.6285 + -535.0991 + 147.9067 + 73.7614) =$	-49.34
	LC8	$P_e = \frac{1.0 \cdot 0.3163852}{1 + 1.0 \cdot 0.3163852 \cdot [5.7654148 + (1.0343266 - 1) \cdot 30.4138117]} \cdot (-40.2857 - -59.9201 + -535.0991 + 106.1415 + -20.164) =$	-43.08

UHX-13.5.7 Step 7			
$Q_2 = \frac{(\omega_s^* P_s - \omega_c^* P_t) + \frac{\gamma_b}{2\pi} W^*}{1 + \Phi Z_m}$			
$Q_3 = Q_1 + \frac{2Q_2}{P_e a_o^2}$			
F_m is calculated per Table UHX-13.1			
$\sigma = \left(\frac{1.5F_m}{\mu^*}\right)\left(\frac{2a_o}{h - h'_g}\right)^2 P_e$			
If $P_e = 0,\ \sigma = \frac{6Q_2}{\mu^*(h - h'_g)^2}$			
Condition Operating			
	LC1	$Q_2 = \frac{(-1.6228004 \cdot -15 - 7.3250067 \cdot 61.49) + -\frac{0.0537353}{2 \cdot \pi} \cdot 88{,}834.5}{1 + 1.284236 \cdot 0.1970454} =$	-946.328
	LC2	$Q_2 = \frac{(-1.6228004 \cdot 25 - 7.3250067 \cdot -15) + -\frac{0.0537353}{2 \cdot \pi} \cdot 0}{1 + 1.284236 \cdot 0.1970454} =$	55.309

New or Corr	LC3	$Q_2 = \frac{(-1.6228004 \cdot 25 - 7.3250067 \cdot 61.49) + -\frac{0.0537353}{2 \cdot \pi} \cdot 88{,}834.5}{1 + 1.284236 \cdot 0.1970454} =$	-998.1311
	LC4	$Q_2 = \frac{(-1.6228004 \cdot -15 - 7.3250067 \cdot -15) + -\frac{0.0537353}{2 \cdot \pi} \cdot 0}{1 + 1.284236 \cdot 0.1970454} =$	107.1121
	LC5	$Q_2 = \frac{(-1.6228004 \cdot -15 - 7.3250067 \cdot 61.49) + -\frac{0.0537353}{2 \cdot \pi} \cdot 115{,}117.25}{1 + 1.284236 \cdot 0.1970454} =$	-1,125.711
	LC6	$Q_2 = \frac{(-1.6228004 \cdot 25 - 7.3250067 \cdot -15) + -\frac{0.0537353}{2 \cdot \pi} \cdot 82{,}611.01}{1 + 1.284236 \cdot 0.1970454} =$	-508.5211
	LC7	$Q_2 = \frac{(-1.6228004 \cdot 25 - 7.3250067 \cdot 61.49) + -\frac{0.0537353}{2 \cdot \pi} \cdot 115{,}117.25}{1 + 1.284236 \cdot 0.1970454} =$	-1,177.514
	LC8	$Q_2 = \frac{(-1.6228004 \cdot -15 - 7.3250067 \cdot -15) + -\frac{0.0537353}{2 \cdot \pi} \cdot 82{,}611.01}{1 + 1.284236 \cdot 0.1970454} =$	-456.718
New or Corr	LC1	$Q_3 = 0.0082552 + \frac{2 \cdot -946.328}{-10.809 \cdot 20.1218^{2}} =$	0.4407225
	LC2	$Q_3 = 0.0082552 + \frac{2 \cdot 55.309}{11.7 \cdot 20.1218^{2}} =$	0.0316062
	LC3	$Q_3 = 0.0082552 + \frac{2 \cdot -998.1311}{0.9442 \cdot 20.1218^{2}} =$	-5.2137614
	LC4	$Q_3 = 0.0082552 + \frac{2 \cdot 107.1121}{-0.0531 \cdot 20.1218^{2}} =$	-9.9540082
	LC5	$Q_3 = 0.0082552 + \frac{2 \cdot -1{,}125.711}{-61.0922 \cdot 20.1218^{2}} =$	0.0992754
	LC6	$Q_3 = 0.0082552 + \frac{2 \cdot -508.5211}{-31.3243 \cdot 20.1218^{2}} =$	0.0884461
	LC7	$Q_3 = 0.0082552 + \frac{2 \cdot -1{,}177.514}{-49.3391 \cdot 20.1218^{2}} =$	0.1261439
	LC8	$Q_3 = 0.0082552 + \frac{2 \cdot -456.718}{-43.0774 \cdot 20.1218^{2}} =$	0.0606268

Tubesheet Bending Stress			Stress (psi)	Allowable (psi)	Over-stressed?
	LC1	$\sigma = \left(\frac{1.5 \cdot 0.2325361}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^{2} \cdot -10.809 =$	-15,792	39,300	No
	LC2	$\sigma = \left(\frac{1.5 \cdot 0.0439166}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^{2} \cdot 11.7 =$	3,228	39,300	No
	LC3	$\sigma = \left(\frac{1.5 \cdot 2.6086896}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^{2} \cdot 0.9442 =$	15,475	39,300	No
New or	LC4	$\sigma = \left(\frac{1.5 \cdot 4.9847157}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^{2} \cdot -0.0531 =$	-1,663	39,300	No

Corr	LC5	$\sigma = \left(\frac{1.5 \cdot 0.0715178}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^2 \cdot -61.0922 =$	-27,451	107,400	No
	LC6	$\sigma = \left(\frac{1.5 \cdot 0.0668957}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^2 \cdot -31.3243 =$	-13,165	107,400	No
	LC7	$\sigma = \left(\frac{1.5 \cdot 0.0832948}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^2 \cdot -49.3391 =$	-25,821	107,400	No
	LC8	$\sigma = \left(\frac{1.5 \cdot 0.0552905}{0.2474622}\right) \cdot \left(\frac{2 \cdot 20.1218}{1.25 - 0}\right)^2 \cdot -43.0774 =$	-14,964	107,400	No

UHX-13.5.8 Step 8				
$\tau = \left(\frac{1}{4\mu}\right)\left(\frac{1}{h}\left\{\frac{4A_p}{C_p}\right\}\right)\lvert P_e \rvert$			for $\lvert P_e \rvert > \frac{1.6 S \mu h}{a_o}$	
Condition Operating				
				Shear Calc Required
New or Corr	LC1	$\lvert -10.809 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No
	LC2	$\lvert 11.7 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No
	LC3	$\lvert 0.9442 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No
	LC4	$\lvert -0.0531 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No
	LC5	$\lvert -61.0922 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No
	LC6	$\lvert -31.3243 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No
	LC7	$\lvert -49.3391 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No
	LC8	$\lvert -43.0774 \rvert \leq \frac{1.6 \cdot 26{,}200 \cdot 0.2 \cdot 1.25}{20.1218} =$	521	No

UHX-13.5.9 Step 9
$F_t(x) = [Z_d(x) + Q_3 Z_w(x)]\frac{X_a^4}{2}$
If $P_e = 0$, $F_t(x) = Z_w(x)\frac{X_a^4}{2}$
$F_{t,\min} = \min\,[F_t(x)]$
$F_{t,\max} = \max\,[F_t(x)]$
$F_s = \max\,\left[(3.25 - 0.25(Z_d + Q_3 Z_w)X_a^4), 1.25\right]$ but not greater than 2

If $P_e = 0,\ F_s = 1.25$
$\sigma_{t,1} = \frac{1}{x_t - x_s}[(P_s x_s - P_t x_t) - P_e F_{t,\min}]$
$\sigma_{t,2} = \frac{1}{x_t - x_s}[(P_s x_s - P_t x_t) - P_e F_{t,\max}]$
If $P_e = 0,\ \sigma_{t,1} = \frac{1}{x_t - x_s}\left[(P_s x_s - P_t x_t) - \frac{2Q_2}{a_o^2} F_{t,\min}\right]$
If $P_e = 0,\ \sigma_{t,2} = \frac{1}{x_t - x_s}\left[(P_s x_s - P_t x_t) - \frac{2Q_2}{a_o^2} F_{t,\max}\right]$
$l_t = kl$
$r_t = \frac{\sqrt{d_t^2 + (d_t - 2t_t)^{\ 2}}}{4}$
$F_t = \frac{l_t}{r_t}$
$C_t = \sqrt{\frac{2\pi^2 E_t}{S_{y,t}}}$
For $C_t \le F_t,\ S_{tb} = \min\left\{\frac{\pi^2 E_t}{F_s F_t^2}, S_t\right\}$
For $C_t > F_t,\ S_{tb} = \min\left\{\frac{S_{y,t}}{F_s}\left(1 - \frac{F_t}{2C_t}\right), S_t\right\}$
$\sigma_{t,\max} = \max[\lvert\sigma_{t,1}\rvert, \lvert\sigma_{t,2}\rvert]$
$\sigma_{t,\min} = \min[\sigma_{t,1}, \sigma_{t,2}]$

Condition Operating

New or Corr	LC1	$F_{t,\min} = [-0.000213 + 0.4407225 \cdot -0.0050744] \cdot \frac{7.3985286^{\ 4}}{2} =$	-3.6695
	LC2	$F_{t,\min} = [-0.0003557 + 0.0316062 \cdot -0.0039245] \cdot \frac{7.3985286^{\ 4}}{2} =$	-0.7188
	LC3	$F_{t,\min} = [0.0036942 + -5.2137614 \cdot 0.0186744] \cdot \frac{7.3985286^{\ 4}}{2} =$	-140.3302
	LC4	$F_{t,\min} = [0.0036942 + -9.9540082 \cdot 0.0186744] \cdot \frac{7.3985286^{\ 4}}{2} =$	-272.9475
	LC5	$F_{t,\min} = [-0.0003198 + 0.0992754 \cdot -0.004529] \cdot \frac{7.3985286^{\ 4}}{2} =$	-1.1527
	LC6	$F_{t,\min} = [-0.0003324 + 0.0884461 \cdot -0.0043876] \cdot \frac{7.3985286^{\ 4}}{2} =$	-1.0793
	LC7	$F_{t,\min} = [-0.0003045 + 0.1261439 \cdot -0.0046616] \cdot \frac{7.3985286^{\ 4}}{2} =$	-1.3372

	LC8	$F_{t,\min} = [-0.0003424 + 0.0606268 \cdot -0.0042389] \cdot \frac{7.3985286^{4}}{2} =$	-0.898
New or Corr	LC1	$F_{t,\max} = [0.0036942 + 0.4407225 \cdot 0.0186744] \cdot \frac{7.3985286^{4}}{2} =$	17.8645
	LC2	$F_{t,\max} = [0.0036942 + 0.0316062 \cdot 0.0186744] \cdot \frac{7.3985286^{4}}{2} =$	6.4187
	LC3	$F_{t,\max} = [-0.000063 + -5.2137614 \cdot -0.0052141] \cdot \frac{7.3985286^{4}}{2} =$	40.6316
	LC4	$F_{t,\max} = [-0.000063 + -9.9540082 \cdot -0.0052141] \cdot \frac{7.3985286^{4}}{2} =$	77.6594
	LC5	$F_{t,\max} = [0.0036942 + 0.0992754 \cdot 0.0186744] \cdot \frac{7.3985286^{4}}{2} =$	8.3119
	LC6	$F_{t,\max} = [0.0036942 + 0.0884461 \cdot 0.0186744] \cdot \frac{7.3985286^{4}}{2} =$	8.0089
	LC7	$F_{t,\max} = [0.0036942 + 0.1261439 \cdot 0.0186744] \cdot \frac{7.3985286^{4}}{2} =$	9.0636
	LC8	$F_{t,\max} = [0.0036942 + 0.0606268 \cdot 0.0186744] \cdot \frac{7.3985286^{4}}{2} =$	7.2306
New or Corr	LC1	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(-15 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - -10.809 \cdot -3.6695] =$	-1,390
	LC2	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - -15 \cdot 0.5849226) - 11.7 \cdot -0.7188] =$	505
	LC3	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - 0.9442 \cdot -140.3302] =$	1,826
	LC4	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(-15 \cdot 0.5248666 - -15 \cdot 0.5849226) - -0.0531 \cdot -272.9475] =$	-226
	LC5	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(-15 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - -61.0922 \cdot -1.1527] =$	-1,903
	LC6	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - -15 \cdot 0.5849226) - -31.3243 \cdot -1.0793] =$	-198
	LC7	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - -49.3391 \cdot -1.3372] =$	-1,479
	LC8	$\sigma_{t,1} = \frac{1}{0.5849226 - 0.5248666} \cdot [(-15 \cdot 0.5248666 - -15 \cdot 0.5849226) - -43.0774 \cdot -0.898] =$	-629
	LC1	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(-15 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - -10.809 \cdot 17.8645] =$	2,485
	LC2	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - -15 \cdot 0.5849226) - 11.7 \cdot 6.4187] =$	-886
	LC3	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - 0.9442 \cdot 40.6316] =$	-1,019

New or Corr	LC4	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(- 15 \cdot 0.5248666 - - 15 \cdot 0.5849226) - - 0.0531 \cdot 77.6594] =$	84
	LC5	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(- 15 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - - 61.0922 \cdot 8.3119] =$	7,725
	LC6	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - - 15 \cdot 0.5849226) - - 31.3243 \cdot 8.0089] =$	4,542
	LC7	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(25 \cdot 0.5248666 - 61.49 \cdot 0.5849226) - - 49.3391 \cdot 9.0636] =$	7,066
	LC8	$\sigma_{t,2} = \frac{1}{0.5849226 - 0.5248666} \cdot [(- 15 \cdot 0.5248666 - - 15 \cdot 0.5849226) - - 43.0774 \cdot 7.2306] =$	5,201
New or Corr	LC1, 2, 3, 4, 5, 6, 7, 8	$r_t = \frac{\sqrt{1.5^{2} + (1.5 - 2 \cdot 0.049)^{2}}}{4} =$	0.5133
New or Corr	LC1, 2, 3, 4, 5, 6, 7, 8	$F_t = \frac{97.6}{0.5133} =$	190.1428
New or Corr	LC1, 2, 3, 4, 5, 6, 7, 8	$C_t = \sqrt{\frac{2 \cdot \pi^2 \cdot 27.5E{+}06}{57{,}900}} =$	96.826
New or Corr	LC1, 2, 5, 6, 7, 8	$F_s = \min \left\{ \max \left[\left(3.25 - 0.25 \cdot (0.0036942 + 0.4407225 \cdot 0.0186744) \cdot 7.3985286^{4}\right), 1.25 \right], 2 \right\} =$	1.25
	LC3, 4	$F_s = \min \left\{ \max \left[\left(3.25 - 0.25 \cdot (0.0036942 + - 5.2137614 \cdot 0.0186744) \cdot 7.3985286^{4}\right), 1.25 \right], 2 \right\} =$	2
New or Corr	LC1, 2, 5, 6, 7, 8	$S_{tb} = \min \left\{ \frac{\pi^2 \cdot 27.5E{+}06}{1.25 \cdot 190.1428^{2}} = 6,006, 26,235 \right\} =$	6,006
	LC3, 4	$S_{tb} = \min \left\{ \frac{\pi^2 \cdot 27.5E{+}06}{2 \cdot 190.1428^{2}} = 3,754, 26,235 \right\} =$	3,754

Tube Evaluation			Stress (psi)	Allowable (psi)	Over-stressed?
New or Corr	LC1	$\sigma_{t,\max} = \max [\lvert -1{,}390 \rvert, \lvert 2{,}485 \rvert] =$	2,485	26,235	No
	LC2	$\sigma_{t,\max} = \max [\lvert 505 \rvert, \lvert -886 \rvert] =$	886	26,235	No
	LC3	$\sigma_{t,\max} = \max [\lvert 1{,}826 \rvert, \lvert -1{,}019 \rvert] =$	1,826	26,235	No
	LC4	$\sigma_{t,\max} = \max [\lvert -226 \rvert, \lvert 84 \rvert] =$	226	26,235	No
	LC5	$\sigma_{t,\max} = \max [\lvert -1{,}903 \rvert, \lvert 7{,}725 \rvert] =$	7,725	52,471	No
	LC6	$\sigma_{t,\max} = \max [\lvert -198 \rvert, \lvert 4{,}542 \rvert] =$	4,542	52,471	No
	LC7	$\sigma_{t,\max} = \max [\lvert -1{,}479 \rvert, \lvert 7{,}066 \rvert] =$	7,066	52,471	No
	LC8	$\sigma_{t,\max} = \max [\lvert -629 \rvert, \lvert 5{,}201 \rvert] =$	5,201	52,471	No
	LC1	$\sigma_{t,\min} = \min [-1,390, 2,485] =$	-1,390	6,006	No
	LC2	$\sigma_{t,\min} = \min [505, -886] =$	-886	6,006	No
	LC3	$\sigma_{t,\min} = \min [1,826, -1,019] =$	-1,019	3,754	No

New or Corr	LC4	$\sigma_{t,\min} = \min\left[-226, 84\right] =$	-226	3,754	No
	LC5	$\sigma_{t,\min} = \min\left[-1,903, 7,725\right] =$	-1,903	6,006	No
	LC6	$\sigma_{t,\min} = \min\left[-198, 4,542\right] =$	-198	6,006	No
	LC7	$\sigma_{t,\min} = \min\left[-1,479, 7,066\right] =$	-1,479	6,006	No
	LC8	$\sigma_{t,\min} = \min\left[-629, 5,201\right] =$	-629	6,006	No

UHX-13.5.10 Step 10

$$\sigma_{s,m} = \frac{a_o^2}{t_s(D_s + t_s)}\left[P_e + (\rho_s^2 - 1)(P_s - P_t)\right] + \frac{a_s^2}{t_s(D_s + t_s)} P_t$$

Condition Operating

Shell Evaluation			Stress (psi)	S_s*$E_{s,w}$ (psi)	$S_{PS,s}$ (psi)	$S_{s,b}$ (psi)	Over-stressed?
New or Corr	LC1	$\sigma_{s,m} = \frac{20.1218^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-10.809 + (1.0343266^{\,2} - 1) \cdot (-15 - 61.49)\right] + \frac{20.8125^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	2,565	13,230	N/A	N/A	No
	LC2	$\sigma_{s,m} = \frac{20.1218^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[11.7 + (1.0343266^{\,2} - 1) \cdot (25 - -15)\right] + \frac{20.8125^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-80	13,230	N/A	7,619	No
	LC3	$\sigma_{s,m} = \frac{20.1218^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[0.9442 + (1.0343266^{\,2} - 1) \cdot (25 - 61.49)\right] + \frac{20.8125^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	3,316	13,230	N/A	N/A	No
	LC4	$\sigma_{s,m} = \frac{20.1218^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-0.0531 + (1.0343266^{\,2} - 1) \cdot (-15 - -15)\right] + \frac{20.8125^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-832	13,230	N/A	7,619	No
	LC5	$\sigma_{s,m} = \frac{20.1218^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-61.0922 + (1.0343266^{\,2} - 1) \cdot (-15 - 61.49)\right] + \frac{20.8125^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	-34	N/A	56,700	7,619	No
	LC6	$\sigma_{s,m} = \frac{20.1218^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-31.3243 + (1.0343266^{\,2} - 1) \cdot (25 - -15)\right] + \frac{20.8125^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-2,303	N/A	56,700	7,619	No
	LC7	$\sigma_{s,m} = \frac{20.1218^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-49.3391 + (1.0343266^{\,2} - 1) \cdot (25 - 61.49)\right] + \frac{20.8125^{\,2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	718	N/A	56,700	N/A	No

	LC8	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-43.0774 + \left(1.0343266\ ^2 - 1\right) \cdot \left(-15 - -15 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-3,055	N/A	56,700	7,619	No

Shell Band Evaluation			Stress (psi)	$S_{s,1}$*$E_{s,w}$ (psi)	$S_{PS,s,1}$ (psi)	$S_{s,b,1}$ (psi)	Over-stressed?
New or Corr	LC1	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-10.809 + \left(1.0343266\ ^2 - 1\right) \cdot \left(-15 - 61.49 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	2,565	13,230	N/A	N/A	No
	LC2	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[11.7 + \left(1.0343266\ ^2 - 1\right) \cdot \left(25 - -15 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-80	13,230	N/A	7,619	No
	LC3	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[0.9442 + \left(1.0343266\ ^2 - 1\right) \cdot \left(25 - 61.49 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	3,316	13,230	N/A	N/A	No
	LC4	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-0.0531 + \left(1.0343266\ ^2 - 1\right) \cdot \left(-15 - -15 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-832	13,230	N/A	7,619	No
	LC5	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-61.0922 + \left(1.0343266\ ^2 - 1\right) \cdot \left(-15 - 61.49 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	-34	N/A	56,700	7,619	No
	LC6	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-31.3243 + \left(1.0343266\ ^2 - 1\right) \cdot \left(25 - -15 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-2,303	N/A	56,700	7,619	No
	LC7	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-49.3391 + \left(1.0343266\ ^2 - 1\right) \cdot \left(25 - 61.49 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	718	N/A	56,700	N/A	No
	LC8	$\sigma_{s,m} = \frac{20.1218\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left[-43.0774 + \left(1.0343266\ ^2 - 1\right) \cdot \left(-15 - -15 \right) \right] + \frac{20.8125\ ^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-3,055	N/A	56,700	7,619	No

UHX-13.5.11 Step 11

$$\sigma_{s,m} = \frac{a_o^2}{t_{s,1}(D_s + t_{s,1})}\left[P_e + \left(\rho_s^2 - 1\right)(P_s - P_t)\right] + \frac{a_s^2}{t_{s,1}(D_s + t_{s,1})} P_t$$

$$\sigma_{s,b} = \frac{6}{t_{s,1}^2} k_s \left\{ \beta_s \delta_s P_s + \frac{6(1-\nu^{*2})}{E^*} \left(\frac{a_o^3}{h^3}\right) \left(1 + \frac{h\beta_s}{2}\right) \left[P_e (Z_v + Z_m Q_1) + \frac{2 Z_m Q_2}{a_o^2} \right] \right\}$$

$$\sigma_s = |\sigma_{s,m}| + |\sigma_{s,b}|$$

Condition Operating

Minimum shell length $= 1.8 \cdot \sqrt{D_s \cdot t_{s,1}} = 5.0273$ in where thickness $t_{s,1} = 0.1874$ in

		Shell Band Evaluation	Stress (psi)	1.5*S_s (psi)	$S_{PS,s}$ (psi)	Over-stressed?
	LC1	$\sigma_{s,m} = \frac{20.1218^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot (-10.809 + (1.0343266^2 - 1) \cdot (-15 - 61.49)) + \frac{20.8125^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	2,565	28,350	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^2} \cdot 21{,}241.68 \cdot (0.648318 \cdot 7.233889\text{E-}05 \cdot -15 + \frac{6 \cdot (1 - 0.3089124^2)}{7{,}098{,}105} \cdot \left(\frac{20.1218^3}{1.25^3}\right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2}\right) \cdot \left(-10.809 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot -946.328}{20.1218^2}\right)) =$	-21,104			
		$\sigma_s = \lvert 2{,}565 \rvert + \lvert -21{,}104 \rvert =$	23,669			
	LC2	$\sigma_{s,m} = \frac{20.1218^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot (11.7 + (1.0343266^2 - 1) \cdot (25 - -15)) + \frac{20.8125^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-80	28,350	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^2} \cdot 21{,}241.68 \cdot (0.648318 \cdot 7.233889\text{E-}05 \cdot 25 + \frac{6 \cdot (1 - 0.3089124^2)}{7{,}098{,}105} \cdot \left(\frac{20.1218^3}{1.25^3}\right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2}\right) \cdot \left(11.7 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot 55.309}{20.1218^2}\right)) =$	8,994			
		$\sigma_s = \lvert -80 \rvert + \lvert 8{,}994 \rvert =$	9,074			
	LC3	$\sigma_{s,m} = \frac{20.1218^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot (0.9442 + (1.0343266^2 - 1) \cdot (25 - 61.49)) + \frac{20.8125^2}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	3,316	28,350	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^2} \cdot 21{,}241.68 \cdot (0.648318 \cdot 7.233889\text{E-}05 \cdot 25 + \frac{6 \cdot (1 - 0.3089124^2)}{7{,}098{,}105} \cdot \left(\frac{20.1218^3}{1.25^3}\right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2}\right) \cdot \left(0.9442 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot -998.1311}{20.1218^2}\right)) =$	-11,235			
		$\sigma_s = \lvert 3{,}316 \rvert + \lvert -11{,}235 \rvert =$	14,551			

New or Corr	LC4	$\sigma_{s,m} = \frac{20.1218^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left(-0.0531 + \left(1.0343266^{2} - 1\right) \cdot (-15 - -15)\right) + \frac{20.8125^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-832	28,350	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^{2}} \cdot 21{,}241.68 \cdot \Bigl(0.648318 \cdot 7.233889E\text{-}05 \cdot -15 + \frac{6 \cdot \left(1 - 0.3089124^{2}\right)}{7{,}098{,}105} \cdot \left(\frac{20.1218^{3}}{1.25^{3}}\right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2}\right) \cdot \left(-0.0531 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot 107.1121}{20.1218^{2}}\right)\Bigr) =$	-875			
		$\sigma_s = \lvert -832 \rvert + \lvert -875 \rvert =$	1,707			
	LC5	$\sigma_{s,m} = \frac{20.1218^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left(-61.0922 + \left(1.0343266^{2} - 1\right) \cdot (-15 - 61.49)\right) + \frac{20.8125^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	-34	N/A	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^{2}} \cdot 21{,}241.68 \cdot \Bigl(0.648318 \cdot 7.233889E\text{-}05 \cdot -15 + \frac{6 \cdot \left(1 - 0.3089124^{2}\right)}{7{,}098{,}105} \cdot \left(\frac{20.1218^{3}}{1.25^{3}}\right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2}\right) \cdot \left(-61.0922 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot -1{,}125.711}{20.1218^{2}}\right)\Bigr) =$	-40,548			
		$\sigma_s = \lvert -34 \rvert + \lvert -40{,}548 \rvert =$	40,581			
	LC6	$\sigma_{s,m} = \frac{20.1218^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left(-31.3243 + \left(1.0343266^{2} - 1\right) \cdot (25 - -15)\right) + \frac{20.8125^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-2,303	N/A	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^{2}} \cdot 21{,}241.68 \cdot \Bigl(0.648318 \cdot 7.233889E\text{-}05 \cdot 25 + \frac{6 \cdot \left(1 - 0.3089124^{2}\right)}{7{,}098{,}105} \cdot \left(\frac{20.1218^{3}}{1.25^{3}}\right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2}\right) \cdot \left(-31.3243 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot -508.5211}{20.1218^{2}}\right)\Bigr) =$	-14,139			
		$\sigma_s = \lvert -2{,}303 \rvert + \lvert -14{,}139 \rvert =$	16,443			
	LC7	$\sigma_{s,m} = \frac{20.1218^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left(-49.3391 + \left(1.0343266^{2} - 1\right) \cdot (25 - 61.49)\right) + \frac{20.8125^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot 61.49 =$	718	N/A	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^{2}} \cdot 21{,}241.68 \cdot \Bigl(0.648318 \cdot 7.233889E\text{-}05 \cdot 25 + \frac{6 \cdot \left(1 - 0.3089124^{2}\right)}{7{,}098{,}105} \cdot \left(\frac{20.1218^{3}}{1.25^{3}}\right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2}\right) \cdot \left(-49.3391 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot -1{,}177.514}{20.1218^{2}}\right)\Bigr) =$	-30,679			

		$\sigma_s = \lvert 718 \rvert + \lvert -30{,}679 \rvert =$	31,397			
	LC8	$\sigma_{s,m} = \frac{20.1218^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot \left(-43.0774 + \left(1.0343266^{2} - 1\right) \cdot (-15 - -15) \right) + \frac{20.8125^{2}}{0.1874 \cdot (41.625 + 0.1874)} \cdot -15 =$	-3,055	N/A	56,700	No
		$\sigma_{s,b} = \frac{6}{0.1874^{2}} \cdot 21{,}241.68 \cdot (0.648318 \cdot 7.233889\text{E-}05 \cdot -15 + \frac{6 \cdot \left(1 - 0.3089124^{2}\right)}{7{,}098{,}105} \cdot \left(\frac{20.1218^{3}}{1.25^{3}} \right) \cdot \left(1 + \frac{1.25 \cdot 0.648318}{2} \right) \cdot \left(-43.0774 \cdot (0.0186744 + 0.1970454 \cdot 0.0082552) + \frac{2 \cdot 0.1970454 \cdot -456.718}{20.1218^{2}} \right)) =$	-24,008			
		$\sigma_s = \lvert -3{,}055 \rvert + \lvert -24{,}008 \rvert =$	27,063			

Tube-To-Tubesheet Joint Loads

ASME Tube To Tubesheet Joint Loads - Periphery Of Bundle			
$W_j = \sigma_{t,o} A_t$			
$L_{\max} = A_t S_a f_r$			
Condition Operating			lb_f
New or corroded	Load case 1	$W_j = 2{,}485 \cdot 0.2234 =$	555.1294
		$L_{\max} = 0.2234 \cdot 26{,}235 \cdot 0.8 =$	4,688.0182
	Load case 2	$W_j = 886 \cdot 0.2234 =$	197.8782
		$L_{\max} = 0.2234 \cdot 26{,}235 \cdot 0.8 =$	4,688.0182
	Load case 3	$W_j = 1{,}826 \cdot 0.2234 =$	407.8162
		$L_{\max} = 0.2234 \cdot 26{,}235 \cdot 0.8 =$	4,688.0182
	Load case 4	$W_j = 226 \cdot 0.2234 =$	50.565
		$L_{\max} = 0.2234 \cdot 26{,}235 \cdot 0.8 =$	4,688.0182
	Load case 5	$W_j = 7{,}725 \cdot 0.2234 =$	***1,725.5583***
		$L_{\max} = 0.2234 \cdot 52{,}471 \cdot 0.8 =$	***9,376.0364***
	Load case 6	$W_j = 4{,}542 \cdot 0.2234 =$	1,014.4977
		$L_{\max} = 0.2234 \cdot 52{,}471 \cdot 0.8 =$	9,376.0364
	Load case 7	$W_j = 7{,}066 \cdot 0.2234 =$	1,578.2451
		$L_{\max} = 0.2234 \cdot 52{,}471 \cdot 0.8 =$	9,376.0364
	Load case 8	$W_j = 5{,}201 \cdot 0.2234 =$	1,161.8109
		$L_{\max} = 0.2234 \cdot 52{,}471 \cdot 0.8 =$	9,376.0364
$\lvert W_j \rvert <= L_{max}$ indicates the joint strength is adequate for the Operating condition.			

ASME Shell Band (front)

ASME Section VIII Division 1, 2019 Edition				
Component	Cylinder			
Material	SA-240 304 (II-D p. 88, ln. 37)			
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		25	300	-20
External		15	300	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		0.17	4.8125	1
Test horizontal		1.62	44.8125	1
Dimensions				
Inner Diameter		41.625"		
Length		12"		
Nominal Thickness		0.1874"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		85.26		39.3
Corroded		85.26		39.3
Radiography				
Longitudinal seam		None UW-11(c) Type 1		
Right 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)	0.0397"
Design thickness due to external pressure (t_e)	0.1811"
Maximum allowable working pressure (MAWP)	118.31 psi
Maximum allowable pressure (MAP)	125.38 psi
Maximum allowable external pressure (MAEP)	16.36 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{86.52 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 86.52} =$	0.1291"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.1291 \cdot 0.8}{0.1874 - 0} =$	0.5511
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 300 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{25.17 \cdot 20.8125}{18{,}900 \cdot 0.70 - 0.60 \cdot 25.17} + 0 = \underline{0.0397}"$$

Maximum allowable working pressure, (at 300 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{18{,}900 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} - 0.17 = \underline{118.31} \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{20{,}000 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} = \underline{125.38} \text{ psi}$$

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{79.0875}{41.9998} = 1.8830$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1811} = 231.9293$$

From table G: $A = 0.000198$

From table HA-1: $B = 2{,}609.2194 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 2{,}609.22}{3 \cdot (41.9998/0.1811)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.1811 + 0 = \underline{0.1811}"$$

Maximum Allowable External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{79.0875}{41.9998} = 1.8830$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1874} = 224.1185$$

From table G: $A = 0.000209$

From table HA-1: $B = 2{,}750.0218 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 2{,}750.02}{3 \cdot (41.9998/0.1874)} = \underline{16.36} \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f} \right) \cdot \left(1 - \frac{R_f}{R_o} \right) = \left(\frac{50 \cdot 0.1874}{20.9062} \right) \cdot \left(1 - \frac{20.9062}{\infty} \right) = 0.4482\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cHC} = \min\,(B, S) = 7{,}619 \text{ psi}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_c HN = S_c HC = 7{,}619 \quad \text{psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 9{,}371 \quad \text{psi}$$

$$S = \frac{20{,}000}{1.00} = 20{,}000 \quad \text{psi}$$

$$S_{cCN} = \min\,(B, S) = 9{,}371 \text{ psi}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{c\mathbb{C}} = S_{cCN} = 9{,}371 \quad \text{psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

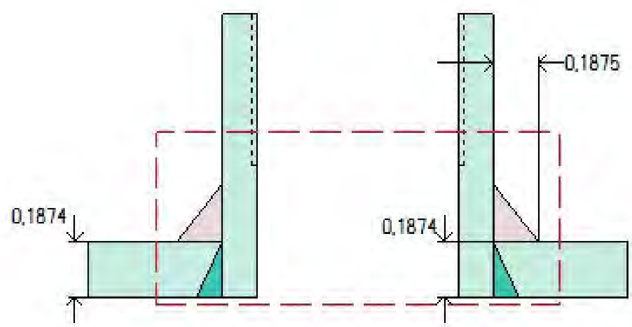
$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cVC} = \min\,(B, S) = 7{,}619 \text{ psi}$$

Capped Vent Port (P4)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	ASME Shell Band (front)
Orientation	0°
Nozzle center line offset to datum line	143.625"
End of nozzle to shell center	21.745"
Passes through a Category A joint	No
Nozzle	
Service	Vent (VENT)
Description	NPS 0.5 Class 3000 - Threaded Half Coupling
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 92, ln. 3)
Inside diameter, new	0.84"
Pipe nominal wall thickness	0.14"
Pipe minimum wall thickness[1]	0.1225"
Corrosion allowance	0"
Projection available outside vessel, Lpr	0.7451"
Local vessel minimum thickness	0.1874"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.1875"
Nozzle to vessel groove weld	0.1874"

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

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{86.35 \cdot 0.42}{17{,}000 \cdot 1 - 0.6 \cdot 86.35} =$	0.0021"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0021 \cdot 1}{0.1225 - 0} =$	0.0175
Impact test exempt per UHA-51(g) (coincident ratio = 0.0175)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 169.26 psi @ 300 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.1225

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0937	0.1312	weld size is adequate

Calculations for internal pressure 169.26 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[0.84, 0.42 + (0.14 - 0) + (0.1874 - 0)\right]$$
$$= 0.84 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0) + 0\right]$$
$$= 0.35 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{169.2631 \cdot 0.42}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631}$$
$$= 0.0038 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 169.2631}$$

$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.14 in

$t_{c(\min)} = \min\left[0.09375, 0.7 \cdot t_{\min}\right] =$ 0.0937 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2631 \cdot 0.56}{16{,}100 \cdot 1 + 0.4 \cdot 169.2631} + 0$$

$$= 0.0059 \text{ in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ t_{b\text{UG16}}\right]$$

$$= \max\left[0.0059,\ 0.0625\right]$$

$$= 0.0625 \text{ in}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.14$ = 0.1225 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 179.12 psi @ 70 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.1225

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

Calculations for internal pressure 179.12 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[0.84, 0.42 + (0.14 - 0) + (0.1874 - 0)\right]$$
$$= 0.84 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0) + 0\right]$$
$$= 0.35 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 0.42}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.0038 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 179.1185}$$
$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{179.1185 \cdot 0.56}{17{,}000 \cdot 1 + 0.4 \cdot 179.1185} + 0$$

$$= 0.0059 \quad \text{in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ t_{b\text{UG16}}\right]$$

$$= \max\left[0.0059,\ 0.0625\right]$$

$$= 0.0625 \quad \text{in}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.14$ = 0.1225 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 16.36 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.1225

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0937	0.1312	weld size is adequate

Calculations for external pressure 16.36 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[0.84, 0.42 + (0.14 - 0) + (0.1874 - 0)\right]$$
$$= 0.84 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0) + 0\right]$$
$$= 0.35 \text{ in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.0032 in

From UG-37(d)(1) required thickness t_r = 0.1874 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.14 in

$t_{c(\min)} = \min\left[0.09375, 0.7 \cdot t_{\min}\right] =$ 0.0937 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-28}} = 0.0032 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$$
$$= \max\left[0.0032, 0\right]$$
$$= 0.0032 \text{ in}$$

t_{b2} = $\frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

= $\frac{16.3605 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 16.3605} + 0$

= $0.018 \quad \text{in}$

$t_{b2} = \max\left[t_{b2}, t_{b\text{UG16}}\right]$

$= \max\left[0.018, 0.0625\right]$

$= 0.0625 \quad \text{in}$

$t_b = \min\left[t_{b3}, t_{b2}\right]$

$= \min\left[0.1164, 0.0625\right]$

$= 0.0625 \quad \text{in}$

$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$

$= \max\left[0.0032, 0.0625\right]$

= 0.0625 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.14$ = 0.1225 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{0.7525}{1.12} = 0.6719$$

$$\frac{D_o}{t} = \frac{1.12}{0.0032} = 346.0660$$

From table G: $A = 0.000322$
From table HA-1: $B = 4{,}247.0545 \quad \text{psi}$

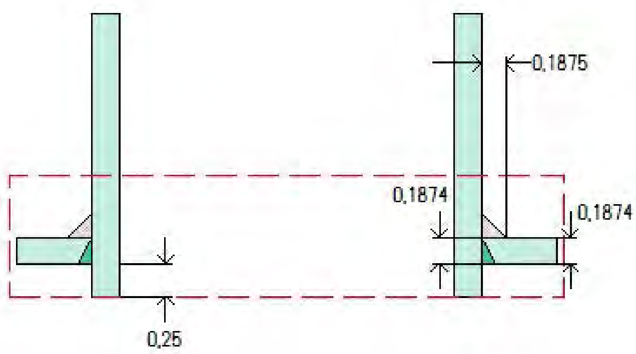
$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 4{,}247.05}{3 \cdot (1.12/0.0032)} = 16.36 \quad \text{psi}$$

Design thickness for external pressure P_a = 16.36 psi

$t_a = t + \text{Corrosion} = 0.0032 + 0 =$ 0.0032"

SS Condensate Drain (P2)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	ASME Shell Band (front)
Orientation	180°
Nozzle center line offset to datum line	144.625"
End of nozzle to shell center	23"
Passes through a Category A joint	No
Nozzle	
Service	Drain (DRN)
Description	NPS 2.5 Sch 40S (Std)
Access opening	No
Material specification	SA-312 TP304L Wld pipe (II-D p. 84, ln. 40)
Inside diameter, new	2.469"
Pipe nominal wall thickness	0.203"
Pipe minimum wall thickness[1]	0.1776"
Corrosion allowance	0"
Projection available outside vessel, Lpr	1.7971"
Internal projection, h_{new}	0.25"
Projection available outside vessel to flange face, Lf	2.0001"
Local vessel minimum thickness	0.1874"
Liquid static head included	0.18 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.1875"
Lower fillet, Leg_{43}	0"
Nozzle to vessel groove weld	0.1874"

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

ASME B16.5-2013 Flange	
Description	NPS 2.5 Class 150 SO A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 398, ln. 32)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0.25 psi
MAWP rating	230 psi @ 300°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
External fillet weld leg (UW-21)	0.2842" (0.2842" min)
Internal fillet weld leg (UW-21)	0.203" (0.203" min)
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
UW-21 Flange Welds	
$X_{\min} = \min\left[1.4 \cdot t_n, g_0\right] = \left[1.4 \cdot 0.203, 0.31\right] =$	0.2842"
$\text{External Leg}_{\min} = X_{\min} + \frac{C_o}{0.7} = 0.2842 + \frac{0}{0.7} =$	0.2842"
$\text{Internal Leg}_{\min} = \min\left[t_n, 0.25" + \frac{C_i}{0.7}\right] = \min\left[0.203, 0.25 + \frac{0}{0.7}\right] =$	0.203"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.3039) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{86.53 \cdot 1.2345}{14{,}200 \cdot 1 - 0.6 \cdot 86.53} =$	0.0076"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0076 \cdot 1}{0.1776 - 0} =$	0.0425
Impact test exempt per UHA-51(g) (coincident ratio = 0.0425)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 169.26 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1776	0.1776

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1312	0.1312	weld size is adequate

Calculations for internal pressure 169.26 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[2.469, 1.2345 + (0.203 - 0) + (0.1874 - 0)\right]$$
$$= 2.469 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.203 - 0) + 0\right]$$
$$= 0.4685 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[0.25, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.203 - 0 - 0)\right]$$
$$= 0.25 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{169.2629 \cdot 1.2345}{16{,}700 \cdot 1 - 0.6 \cdot 169.2629}$$
$$= 0.0126 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{169.2629 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2629}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2629 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 169.2629}$$

$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.1874 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1312 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{169.3351 \cdot 1.2345}{14{,}200 \cdot 1 - 0.6 \cdot 169.3351} + 0$$

$$= 0.0148 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.0148, 0\right]$$

$$= 0.0148 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2629 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2629} + 0$$

$$= 0.1874 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1874, 0.0625\right]$$

$$= 0.1874 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.1776, 0.1874\right]$$

$$= 0.1776 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.0148, 0.1776\right]$$

$$= 0.1776 \text{ in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.203 =$ 0.1776 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 179.12 psi @ 70 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1776	0.1776

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

Calculations for internal pressure 179.12 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[2.469, 1.2345 + (0.203 - 0) + (0.1874 - 0)\right]$$
$$= 2.469 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.203 - 0) + 0\right]$$
$$= 0.4685 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[0.25, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.203 - 0 - 0)\right]$$
$$= 0.25 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 1.2345}{16{,}700 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.0133 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 179.1185}$$

$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{179.1185 \cdot 1.2345}{14{,}200 \cdot 1 - 0.6 \cdot 179.1185} + 0$$

$$= 0.0157 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.0157, 0\right]$$

$$= 0.0157 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185} + 0$$

$$= 0.1874 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1874, 0.0625\right]$$

$$= 0.1874 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.1776, 0.1874\right]$$

$$= 0.1776 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.0157, 0.1776\right]$$

$$= 0.1776 \text{ in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.203 = 0.1776$ in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 16.36 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.1776

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1312	0.1312	weld size is adequate

Calculations for external pressure 16.36 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[2.469, 1.2345 + (0.203 - 0) + (0.1874 - 0)\right]$$
$$= 2.469 \ \text{in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.203 - 0) + 0\right]$$
$$= 0.4685 \ \text{in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[0.25, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.203 - 0 - 0)\right]$$
$$= 0.25 \ \text{in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.0085 in

From UG-37(d)(1) required thickness t_r = 0.1874 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.1874 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1312 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \ \text{in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 0.0085 \text{ in}$

$$\begin{aligned} t_a &= \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right] \\ &= \max\left[0.0085, 0\right] \\ &= 0.0085 \text{ in} \end{aligned}$$

$$\begin{aligned} t_{b2} &= \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion} \\ &= \frac{16.3605 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 16.3605} + 0 \\ &= 0.018 \text{ in} \end{aligned}$$

$$\begin{aligned} t_{b2} &= \max\left[t_{b2}, t_{b\text{UG16}}\right] \\ &= \max\left[0.018, 0.0625\right] \\ &= 0.0625 \text{ in} \end{aligned}$$

$$\begin{aligned} t_b &= \min\left[t_{b3}, t_{b2}\right] \\ &= \min\left[0.1776, 0.0625\right] \\ &= 0.0625 \text{ in} \end{aligned}$$

$$\begin{aligned} t_{\text{UG-45}} &= \max\left[t_a, t_b\right] \\ &= \max\left[0.0085, 0.0625\right] \\ &= 0.0625 \text{ in} \end{aligned}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.203$ = 0.1776 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{2.0494}{2.875} = 0.7128$$

$$\frac{D_o}{t} = \frac{2.875}{0.0085} = 338.0546$$

From table G: $A = 0.000313$
From table HA-3: $B = 4{,}148.3003 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 4{,}148.3}{3 \cdot (2.875/0.0085)} = 16.36 \text{ psi}$$

Design thickness for external pressure P_a = 16.36 psi

$t_a = t + \text{Corrosion} = 0.0085 + 0 =$ 0.0085"

Shell #1

ASME Section VIII Division 1, 2019 Edition					
Component		Cylinder			
Material		SA-240 304 (II-D p. 88, ln. 37)			
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		25	300	-20	
External		15	300		
Static Liquid Head					
Condition		**P_s (psi)**	**H_s (in)**	**SG**	
Operating		0.17	4.8125	1	
Test horizontal		1.62	44.8125	1	
Dimensions					
Inner Diameter		41.625"			
Length		96"			
Nominal Thickness		0.1874"			
Corrosion	**Inner**	0"			
	Outer	0"			
Weight and Capacity					
		Weight (lb)		**Capacity (US gal)**	
New		682.65		314.37	
Corroded		682.65		314.37	
Radiography					
Longitudinal seam		None UW-11(c) Type 1			
Left Circumferential seam		None UW-11(c) Type 1			
Right 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)	0.0397"
Design thickness due to external pressure (t_e)	0.1811"
Maximum allowable working pressure (MAWP)	118.31 psi
Maximum allowable pressure (MAP)	125.38 psi
Maximum allowable external pressure (MAEP)	16.36 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{86.52 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 86.52} =$	0.1291"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.1291 \cdot 0.8}{0.1874 - 0} =$	0.5511
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 300 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{25.17 \cdot 20.8125}{18{,}900 \cdot 0.70 - 0.60 \cdot 25.17} + 0 = 0.0397"$$

Maximum allowable working pressure, (at 300 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{18{,}900 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} - 0.17 = 118.31 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{20{,}000 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} = 125.38 \text{ psi}$$

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{79.0875}{41.9998} = 1.8830$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1811} = 231.9293$$

From table G: $A = 0.000198$

From table HA-1: $B = 2{,}609.2194 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 2{,}609.22}{3 \cdot (41.9998/0.1811)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.1811 + 0 = 0.1811"$$

Maximum Allowable External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{79.0875}{41.9998} = 1.8830$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1874} = 224.1185$$

From table G: $A = 0.000209$

From table HA-1: $B = 2{,}750.0218 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 2{,}750.02}{3 \cdot (41.9998/0.1874)} = 16.36 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.1874}{20.9062}\right) \cdot \left(1 - \frac{20.9062}{\infty}\right) = 0.4482\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cHC} \;=\; \min\,(B, S) = 7{,}619 \text{ psi}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_cHN = S_cHC = 7{,}619 \quad \text{psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 9{,}371 \quad \text{psi}$$

$$S = \frac{20{,}000}{1.00} = 20{,}000 \quad \text{psi}$$

$$S_{cCN} \;=\; \min\,(B, S) = 9{,}371 \text{ psi}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{c\mathbb{C}} = S_{cCN} = 9{,}371 \quad \text{psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

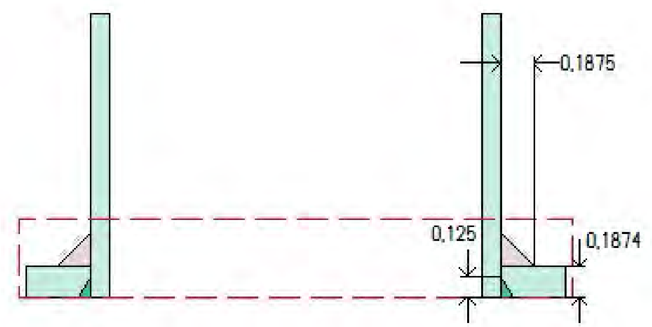
$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cVC} \;=\; \min\,(B, S) = 7{,}619 \text{ psi}$$

Cleanout (P7)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Shell #1
Orientation	0°
Nozzle center line offset to datum line	48"
End of nozzle to shell center	24"
Passes through a Category A joint	No

Nozzle	
Service	Cleanout Port (CLEANOUT)
Description	NPS 2 Sch 10S
Access opening	No
Material specification	SA-312 TP304 Wld & smls pipe (II-D p. 92, ln. 1)
Inside diameter, new	2.157"
Pipe nominal wall thickness	0.109"
Pipe minimum wall thickness[1]	0.0954"
Corrosion allowance	0"
Projection available outside vessel, Lpr	2.8911"
Projection available outside vessel to flange face, Lf	3.0001"
Local vessel minimum thickness	0.1874"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Welds	
Inner fillet, Leg_{41}	0.1875"
Nozzle to vessel groove weld	0.125"

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 150 SO A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 398, ln. 32)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	230 psi @ 300°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
External fillet weld leg (UW-21)	0.2156" (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	
$X_{\min} = \min\left[1.4 \cdot t_n, g_0\right] = \left[1.4 \cdot 0.109, 0.31\right] =$	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 UCS-66(b)(3) = -155°F (Coincident ratio = 0.303) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{86.35 \cdot 1.0785}{20{,}000 \cdot 1 - 0.6 \cdot 86.35} =$	0.0047"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0047 \cdot 1}{0.0954 - 0} =$	0.049
Impact test exempt per UHA-51(g) (coincident ratio = 0.049)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

The thickness requirements of UG-45 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 86.35 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0953	0.0954

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0763	0.1312	weld size is adequate
Combined weld check (t_1 + t_2)	0.1362	0.2562	weld size is adequate
Nozzle to shell groove (Lower)	0.0763	0.125	weld size is adequate

Calculations for internal pressure 86.35 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[2.157, 1.0785 + (0.109 - 0) + (0.1874 - 0)\right]$$
$$= 2.157 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.109 - 0) + 0\right]$$
$$= 0.2725 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{86.3487 \cdot 1.0785}{18{,}900 \cdot 1 - 0.6 \cdot 86.3487}$$
$$= 0.0049 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{86.3487 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 86.3487}$$
$$= 0.0953 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{86.3487 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 86.3487}$$

$$= 0.1364 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(d) Weld Check

$t_{\min} = \min\left[0.75, t_n, t\right] = 0.109$ in

$t_{1(\min)}$ or $t_{2(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.0763 in

$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1312$ in

The weld size t_1 is satisfactory.

$t_{2(actual)} = 0.125$ in

The weld size t_2 is satisfactory.

$t_1 + t_2 = 0.2562 \geq 1.25 \cdot t_{\min} =$ 0.1362

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{86.3487 \cdot 1.0785}{18{,}900 \cdot 1 - 0.6 \cdot 86.3487} + 0$$

$$= 0.0049 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.0049, 0\right]$$

$$= 0.0049 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{86.3487 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 86.3487} + 0$$

$$= 0.0953 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.0953, 0.0625\right]$$

$$= 0.0953 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.1348, 0.0953\right]$$

$$= 0.0953 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.0049, 0.0953\right]$$

$$= 0.0953 \text{ in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.109$ = 0.0954 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The thickness requirements of UG-45 govern the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 91.37 psi @ 70 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0953	0.0954

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

Calculations for internal pressure 91.37 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[2.157, 1.0785 + (0.109 - 0) + (0.1874 - 0)\right]$$
$$= 2.157 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.109 - 0) + 0\right]$$
$$= 0.2725 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{91.3715 \cdot 1.0785}{20{,}000 \cdot 1 - 0.6 \cdot 91.3715}$$
$$= 0.0049 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{91.3715 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 91.3715}$$
$$= 0.0953 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{91.3715 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 91.3715}$$
$$= 0.1364 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{91.3715 \cdot 1.0785}{20{,}000 \cdot 1 - 0.6 \cdot 91.3715} + 0$$

$$= 0.0049 \quad \text{in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.0049, 0\right]$$

$$= 0.0049 \quad \text{in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{91.3715 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 91.3715} + 0$$

$$= 0.0953 \quad \text{in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.0953, 0.0625\right]$$

$$= 0.0953 \quad \text{in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.1348, 0.0953\right]$$

$$= 0.0953 \quad \text{in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.0049, 0.0953\right]$$

$$= 0.0953 \quad \text{in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.109 = 0.0954$ in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 16.36 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.0954

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0763	0.1312	weld size is adequate
Combined weld check (t_1 + t_2)	0.1362	0.2562	weld size is adequate
Nozzle to shell groove (Lower)	0.0763	0.125	weld size is adequate

Calculations for external pressure 16.36 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[2.157, 1.0785 + (0.109 - 0) + (0.1874 - 0)\right]$$
$$= 2.157 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.109 - 0) + 0\right]$$
$$= 0.2725 \text{ in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.0091 in

From UG-37(d)(1) required thickness t_r = 0.172 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(d) Weld Check

$$t_{\min} = \min\left[0.75, t_n, t\right] = 0.109 \text{ in}$$

$$t_{1(\min)} \text{ or } t_{2(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] = 0.0763 \text{ in}$$

$$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1312 \text{ in}$$

The weld size t_1 is satisfactory.

$$t_{2(actual)} = 0.125 \text{ in}$$

The weld size t_2 is satisfactory.

$$t_1 + t_2 = 0.2562 \geq 1.25 \cdot t_{\min} = 0.1362$$

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} \quad = \quad 0.0091 \text{ in}$

$$t_a = \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$$
$$= \max\left[0.0091, 0\right]$$
$$= 0.0091 \text{ in}$$

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$
$$= \frac{16.3605 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 16.3605} + 0$$
$$= 0.018 \text{ in}$$

$$t_{b2} = \max\left[t_{b2}, t_{b\text{UG16}}\right]$$
$$= \max\left[0.018, 0.0625\right]$$
$$= 0.0625 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b2}\right]$$
$$= \min\left[0.1348, 0.0625\right]$$
$$= 0.0625 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$
$$= \max\left[0.0091, 0.0625\right]$$
$$= 0.0625 \text{ in}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.109$ = 0.0954 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{3.0337}{2.375} = 1.2773$$
$$\frac{D_o}{t} = \frac{2.375}{0.0091} = 262.3238$$

From table G: $A = 0.000244$

From table HA-1: $B = 3{,}218.5949 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 3{,}218.59}{3 \cdot (2.375/0.0091)} = 16.36 \text{ psi}$$

Design thickness for external pressure P_a = 16.36 psi

$t_a = t + \text{Corrosion} = 0.0091 + 0 =$ 0.0091"

Rings #1

ASME Section VIII Division 1, 2019 Edition	
Attached to	Shell #1
Ring type	Flat bar
Description	3/8x2.5 Flat Bar
Material	SA-479 304L Bar (low stress) (II-D p. 84, ln. 46)
External design pressure	15 psi
External design temperature	300°F
Corrosion allowance	0"
Distance from ring neutral axis to datum	72.1625"
Distance to previous support	79.0875"
Distance to next support	63.6625"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.1875"
Vessel thickness at weld location, new	0.1874"
Vessel corrosion allowance at weld location	0"
Stiffener thickness at weld location	0.375"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	1.25"
Ring area	0.9375 in^2
Ring inertia	0.4883 in^4

External Pressure, (Corroded & at 300°F) UG-29(a)

$$\frac{L}{D_o} = \frac{79.0875}{41.9998} = 1.883$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1811} = 231.874$$

From Table G: $A = 1.9828E\text{-}04$

From Table HA-1: $B = 2{,}610.22 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o \ / \ t)} = \frac{4 \cdot 2{,}610.22}{3 \cdot (41.9998 \ / \ 0.181132)} = 15.01 \text{ psi}$$

$$B = \frac{3}{4} \cdot \left(\frac{P \cdot D_o}{t + A_s \ / \ L_s} \right) = \frac{3}{4} \cdot \left(\frac{15 \cdot 41.9998}{0.1811 + 0.9375 \ / \ 71.375} \right) = 2{,}433 \text{ psi}$$

From Table HA-3: $A = 0.00018349$ (ring, 300°F)

From Table HA-1: $A = 0.00018462$ (shell, 300°F)

$$I_s' = \frac{D_o^2 \cdot L_s \cdot (t + A_s \ / \ L_s) \cdot A}{10.9}$$

$$= \frac{41.9998^{\ 2} \cdot 71.375 \cdot (0.1811 + 0.9375 \ / \ 71.375) \cdot 0.00018462}{10.9}$$

$$= 0.4142 \text{ in}^4$$

I' for the composite corroded shell-ring cross section is 1.1358 in^4

As $I' >= I_s'$ a 3/8x2.5 Flat Bar stiffener is adequate for an external pressure of 15 psi.

Check the stiffener ring attachment welds per UG-30

UG-30(f) minimum weld size $= \min\left[0.25, 0.1874 - 0 - 0, 0.375\right] + 0 = 0.1874 \ \ \text{in}$

The fillet weld size of 0.1875 in is adequate per UG-30(f).

Radial pressure load, $P \cdot L_s = 15 \cdot 71.375 = 1{,}070.63 \ \ \text{lb}_f/\text{in}$

Radial shear load, $V = 0.01 \cdot P \cdot L_s \cdot D_o = 0.01 \cdot 15 \cdot 71.375 \cdot 41.9998 = 449.66 \ \ \text{lb}_f$

First moment of area, $Q = 0.58 \cdot 0.831 = 0.4806 \ \ \text{in}^3$

Weld shear flow, $q = \dfrac{V \cdot Q}{I'} = 190.2748 \ \ \text{lb}_f/\text{in}$

Combined weld load, $f_w = \sqrt{1{,}070.625^{\ 2} + 190.2748^{\ 2}} = 1{,}087.4 \ \ \text{lb}_f/\text{in}$

Allowable weld stress per UW-18(d) $S_w = 0.55 \cdot S = 0.55 \cdot 12{,}800 = 7{,}040 \ \ \text{psi}$

Fillet weld size required to resist radial pressure and shear

$$t_w = \frac{f_w \cdot (d_{\text{weld segment}} + d_{\text{toe}})}{S_w \cdot d_{\text{weld total}}} + \text{corrosion} = \frac{1{,}087.4 \cdot (1+0)}{7{,}040 \cdot 2} + 0 = 0.0772 \ \ \text{in}$$

The fillet weld size of 0.1875 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 300°F) UG-29(a)

$$\frac{L}{D_o} = \frac{79.0875}{41.9998} = 1.883$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1874} = 224.1185$$

From Table G: $A = 2.0886\text{E-}04$

From Table HA-1: $B = 2{,}750.02 \ \ \text{psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o \ / \ t)} = \frac{4 \cdot 2{,}750.02}{3 \cdot (41.9998 \ / \ 0.1874)} = 16.36 \ \ \text{psi}$$

$$B = \frac{3}{4} \cdot \left(\frac{P \cdot D_o}{t + A_s \ / \ L_s}\right) = \frac{3}{4} \cdot \left(\frac{16.36 \cdot 41.9998}{0.1874 + 0.9375 \ / \ 71.375}\right) = 2{,}570 \text{ psi}$$

From Table HA-3: $A = 0.00019384$ (ring, 300°F)

From Table HA-1: $A = 0.00019501$ (shell, 300°F)

$$I_s' = \frac{D_o^2 \cdot L_s \cdot (t + A_s \ / \ L_s) \cdot A}{10.9}$$

$$= \frac{41.9998^{\ 2} \cdot 71.375 \cdot (0.1874 + 0.9375 \ / \ 71.375) \cdot 0.00019501}{10.9}$$

$$= 0.4517 \ \ \text{in}^4$$

I' for the composite corroded shell-ring cross section is 1.1358 in^4

As $I' >= I_s'$ a 3/8x2.5 Flat Bar stiffener is adequate for an external pressure of 16.36 psi.

Check the stiffener ring attachment welds per UG-30

UG-30(f) minimum weld size $= \min\left[0.25, 0.1874 - 0 - 0, 0.375\right] + 0 = 0.1874 \ \ \text{in}$

The fillet weld size of 0.1875 in is adequate per UG-30(f).

Radial pressure load, $P \cdot L_s = 16.36 \cdot 71.375 = 1{,}167.73 \ \ \text{lb}_f/\text{in}$

Radial shear load, $V = 0.01 \cdot P \cdot L_s \cdot D_o = 0.01 \cdot 16.36 \cdot 71.375 \cdot 41.9998 = 490.44 \quad \text{lb}_f$

First moment of area, $Q = 0.58 \cdot 0.831 = 0.4806 \quad \text{in}^3$

Weld shear flow, $q = \dfrac{V \cdot Q}{I'} = 207.5323 \quad \text{lb}_f/\text{in}$

Combined weld load, $f_w = \sqrt{1{,}167.728^{\ 2} + 207.5323^{\ 2}} = 1{,}186.03 \quad \text{lb}_f/\text{in}$

Allowable weld stress per UW-18(d) $S_w = 0.55 \cdot S = 0.55 \cdot 12{,}800 = 7{,}040 \quad \text{psi}$

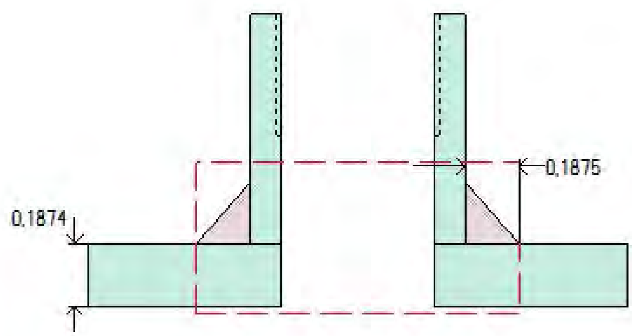
Fillet weld size required to resist radial pressure and shear

$$t_w \quad = \quad \frac{f_w \cdot (d_{\text{weld segment}} + d_{\text{toe}})}{S_w \cdot d_{\text{weld total}}} + \text{corrosion} \quad = \quad \frac{1{,}186.03 \cdot (1+0)}{7{,}040 \cdot 2} + 0 \quad = \quad 0.0842 \quad \text{in}$$

The fillet weld size of 0.1875 in is adequate to resist radial pressure and shear.

SS Vent (P5)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Shell #1
Orientation	270°
Nozzle center line offset to datum line	126.625"
End of nozzle to shell center	21.6866"
Passes through a Category A joint	No
Nozzle	
Description	NPS 0.25 Class 3000 - Threaded Half Coupling
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 92, ln. 3)
Inside diameter, new	0.53"
Pipe nominal wall thickness	0.11"
Pipe minimum wall thickness[1]	0.0963"
Corrosion allowance	0"
Projection available outside vessel, Lpr	0.6867"
Local vessel minimum thickness	0.1874"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.1875"

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

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \dfrac{86.35 \cdot 0.265}{17{,}000 \cdot 1 - 0.6 \cdot 86.35} =$	0.0014"
$\text{Stress ratio} = \dfrac{t_r \cdot E^*}{t_n - c} = \dfrac{0.0014 \cdot 1}{0.0963 - 0} =$	0.014
Impact test exempt per UHA-51(g) (coincident ratio = 0.014)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 169.26 psi @ 300 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.0963

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0953	0.1312	weld size is adequate

Calculations for internal pressure 169.26 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[0.53, 0.265 + (0.11 - 0) + (0.1874 - 0)\right]$$
$$= 0.5624 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.11 - 0) + 0\right]$$
$$= 0.275 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{169.2631 \cdot 0.265}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631}$$
$$= 0.0024 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 169.2631}$$

$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

Check the weld - From UW-16(f)(3)(a)(3)(a)

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2631 \cdot 0.375}{16{,}100 \cdot 1 + 0.4 \cdot 169.2631} + 0$$

$$= 0.0039 \text{ in}$$

$$t_a = \max\left[t_{a\text{App 1-1}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.0039, 0\right]$$

$$= 0.0039 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631} + 0$$

$$= 0.1874 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1874, 0.0625\right]$$

$$= 0.1874 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.0954, 0.1874\right]$$

$$= 0.0954 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.0039, 0.0954\right]$$

$$= 0.0954 \text{ in}$$

$$t_{w(actual)} = 0.7 \cdot Leg = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$$

The fillet weld size is satisfactory.

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2631 \cdot 0.375}{16{,}100 \cdot 1 + 0.4 \cdot 169.2631} + 0$$

$$= 0.0039 \text{ in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ t_{b\text{UG16}}\right]$$

$$= \max\left[0.0039,\ 0.0625\right]$$

$$= 0.0625 \text{ in}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.11$ = 0.0963 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 179.12 psi @ 70 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.0963

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

Calculations for internal pressure 179.12 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[0.53, 0.265 + (0.11 - 0) + (0.1874 - 0)\right]$$
$$= 0.5624 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.11 - 0) + 0\right]$$
$$= 0.275 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 0.265}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.0024 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 179.1185}$$
$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$
$$= \frac{179.1185 \cdot 0.375}{17{,}000 \cdot 1 + 0.4 \cdot 179.1185} + 0$$
$$= 0.0039 \text{ in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ t_{b\text{UG16}}\right]$$
$$= \max\left[0.0039,\ 0.0625\right]$$
$$= 0.0625 \text{ in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.11$ = 0.0963 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 16.36 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.0963

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0625	0.1312	weld size is adequate

Calculations for external pressure 16.36 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[0.53, 0.265 + (0.11 - 0) + (0.1874 - 0)\right]$$
$$= 0.5624 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.11 - 0) + 0\right]$$
$$= 0.275 \text{ in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.0025 in

From UG-37(d)(1) required thickness t_r = 0.1874 in

This opening does not require reinforcement per UG-36(c)(3)(a)

Check the weld - From UW-16(f)(3)(a)(3)(a)

$$t_{a\text{UG-28}} = 0.0025 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$$
$$= \max\left[0.0025, 0\right]$$
$$= 0.0025 \text{ in}$$

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$
$$= \frac{16.3605 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 16.3605} + 0$$
$$= 0.018 \text{ in}$$

t_{b2} $= \max\left[t_{b2}, t_{b\text{UG16}}\right]$

$= \max\left[0.018, 0.0625\right]$

$= 0.0625$ in

t_b $= \min\left[t_{b3}, t_{b2}\right]$

$= \min\left[0.0954, 0.0625\right]$

$= 0.0625$ in

$t_{\text{UG-45}}$ $= \max\left[t_a, t_b\right]$

$= \max\left[0.0025, 0.0625\right]$

$=$ 0.0625 in

$t_{w(actual)} = 0.7 \cdot Leg = 0.7 \cdot 0.1875 = 0.1313$ in

The fillet weld size is satisfactory.

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}}$ $= 0.0025$ in

t_a $= \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$

$= \max\left[0.0025, 0\right]$

$= 0.0025$ in

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{16.3605 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 16.3605} + 0$$

$= 0.018$ in

t_{b2} $= \max\left[t_{b2}, t_{b\text{UG16}}\right]$

$= \max\left[0.018, 0.0625\right]$

$= 0.0625$ in

t_b $= \min\left[t_{b3}, t_{b2}\right]$

$= \min\left[0.0954, 0.0625\right]$

$= 0.0625$ in

$t_{\text{UG-45}}$ $= \max\left[t_a, t_b\right]$

$= \max\left[0.0025, 0.0625\right]$

$=$ 0.0625 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.11$ = 0.0963 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{0.69}{0.75} = 0.9200$$

$$\frac{D_o}{t} = \frac{0.75}{0.0025} = 299.2250$$

From table G: $A = 0.000279$
From table HA-1: $B = 3{,}671.3456 \quad \text{psi}$

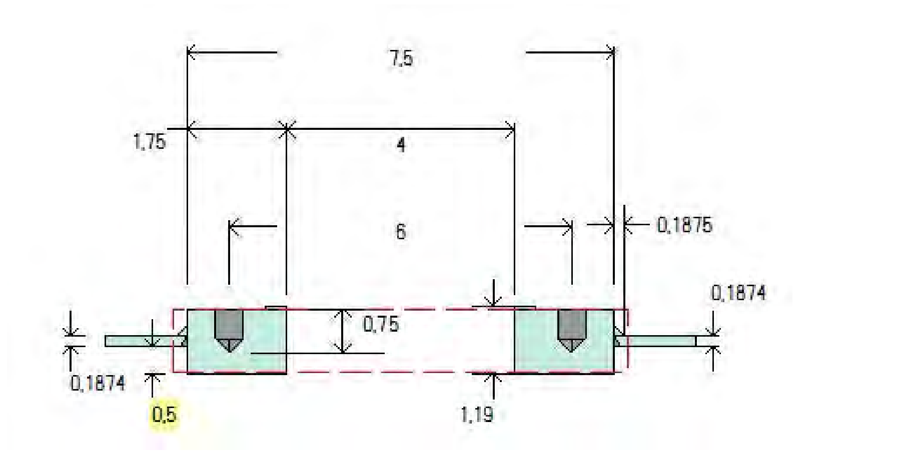
$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 3{,}671.35}{3 \cdot (0.75/0.0025)} = 16.36 \quad \text{psi}$$

Design thickness for external pressure P_a = 16.36 psi

$t_a = t + \text{Corrosion} = 0.0025 + 0 =$ 0.0025"

Sight Glass (P8)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Note: Thread engagement shall comply with the requirements of UG-43(g).

Location and Orientation	
Located on	Shell #1
Orientation	90°
Nozzle center line offset to datum line	78.625"
End of nozzle to shell center	21.5025"
Passes through a Category A joint	No

Nozzle	
Service	Sight Glass (SG)
Description	Studding Outlet Custom Size - Contoured
Access opening	No
Material specification	SA-240 304 (II-D p. 88, ln. 37)
Bolt material specification	SA-193 B7 Bolt <= 2 1/2 (II-D p. 398, ln. 32)
Bolt rated MDMT	-55°F
Pad inner diameter	4"
Pad outer diameter, D_p	7.5"
Pad thickness	1.19"
Figure UG-40 thickness, t_e	0.4426"
Tapped hole diameter	0.5"
Tapped hole depth	0.75"
Tapped hole bolt circle	6"
Raised face height	0.06"
Raised face outer diameter	4.75"
Corrosion allowance	0"
Projection available outside vessel, Lpr	0.4426"
Internal projection, h_{new}	0.5"
Local vessel minimum thickness	0.1874"
Liquid static head included	0 psi

Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.1875"
Lower fillet, Leg_{43}	0"
Nozzle to vessel groove weld	0.1874"

UHA-51 Material Toughness Requirements Pad	
$t_r = \frac{86.35 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 86.35} =$	0.0901"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0901 \cdot 1}{0.1874 - 0} =$	0.4807
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	
Bolts rated MDMT per Fig UCS-66 note (c) =	-55°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 169.26 psi @ 300 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.4996	3.2241	–	–	1.6398	1.5491	0.0352	0.1874	1.75

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Pad to shell fillet (Leg_{41})	0.1312	0.1312	weld size is adequate

Calculations for internal pressure 169.26 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[4, 2 + (0) + (0.1874 - 0)\right]$$
$$= 4 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0) + 0.4426\right]$$
$$= 0.4426 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[0.5, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (1.75 - 0 - 0)\right]$$
$$= 0.4685 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$

$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 169.2631}$

$= 0.2683 \text{ in}$

Area required per UG-37(c)

Allowable stresses: S_n = 18,900, S_v = 18,900, S_p = 18,900 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) + \text{Tapped hole area loss}$

$= 4 \cdot 0.1874 \cdot 1 + 2 \cdot 1.75 \cdot 0.1874 \cdot 1 \cdot (1 - 1) + 0.75$

= 1.4996 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 4 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) - 2 \cdot 1.75 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) \cdot (1 - 1)$

$= 0 \text{ in}^2$

$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 2 \cdot (0.1874 + 0) \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) - 2 \cdot 1.75 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) \cdot (1 - 1)$

$= 0 \text{ in}^2$

Area A_2 is not included in these calculations.
A_3 = smaller of the following= 1.6398 in^2

$= 5 \cdot t \cdot t_i \cdot f_{r2}$

$= 5 \cdot 0.1874 \cdot 1.75 \cdot 1$

= 1.6398 in^2

$= 5 \cdot t_i \cdot t_i \cdot f_{r2}$

$= 5 \cdot 1.75 \cdot 1.75 \cdot 1$

= 15.3125 in^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= 2 \cdot 0.5 \cdot 1.75 \cdot 1$

= 1.75 in^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= 0.1875^{\ 2} \cdot 1$

= 0.0352 in^2

$A_5 = (D_p - \text{Pad ID}) \cdot t_e \cdot f_{r4}$

$= (7.5 - 4) \cdot 0.4426 \cdot 1$

$= 1.5491$ in^2

$Area = A_1 + A_3 + A_{42} + A_5$

$= 0 + 1.6398 + 0.0352 + 1.5491$

$= 3.2241$ in^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_e, t\right] =$ 0.1874 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1312 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313$ in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2631 \cdot 2}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631} + 0$$

$$= 0.018 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.018, 0\right]$$

$$= 0.018 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631} + 0$$

$$= 0.1874 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1874, 0.0625\right]$$

$$= 0.1874 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.2818, 0.1874\right]$$

$$= 0.1874 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.018, 0.1874\right]$$

$$= 0.1874 \text{ in}$$

Available nozzle wall thickness new, t_n = 1.75 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 179.12 psi @ 70 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.4996	3.2241	–	–	1.6398	1.5491	0.0352	0.1874	1.75

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

Calculations for internal pressure 179.12 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[4, 2 + (0) + (0.1874 - 0)\right]$$
$$= 4 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0) + 0.4426\right]$$
$$= 0.4426 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[0.5, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (1.75 - 0 - 0)\right]$$
$$= 0.4685 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 179.1185}$$
$$= 0.2683 \text{ in}$$

Area required per UG-37(c)

Allowable stresses: S_n = 20,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) + \text{Tapped hole area loss}$

= $4 \cdot 0.1874 \cdot 1 + 2 \cdot 1.75 \cdot 0.1874 \cdot 1 \cdot (1 - 1) + 0.75$

= 1.4996 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $4 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) - 2 \cdot 1.75 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) \cdot (1 - 1)$

= $0 \ \text{in}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $2 \cdot (0.1874 + 0) \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) - 2 \cdot 1.75 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) \cdot (1 - 1)$

= $0 \ \text{in}^2$

Area A_2 is not included in these calculations.

A_3 = smaller of the following= 1.6398 in^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $5 \cdot 0.1874 \cdot 1.75 \cdot 1$

= 1.6398 in^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $5 \cdot 1.75 \cdot 1.75 \cdot 1$

= 15.3125 in^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $2 \cdot 0.5 \cdot 1.75 \cdot 1$

= 1.75 in^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $0.1875^{\ 2} \cdot 1$

= 0.0352 in^2

A_5 = $(D_p - \text{Pad ID}) \cdot t_e \cdot f_{r4}$

= $(7.5 - 4) \cdot 0.4426 \cdot 1$

= 1.5491 in^2

$Area$ = $A_1 + A_3 + A_{42} + A_5$

= $0 + 1.6398 + 0.0352 + 1.5491$

= 3.2241 in^2

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{179.1185 \cdot 2}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185} + 0$$

$$= 0.018 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.018, 0\right]$$

$$= 0.018 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185} + 0$$

$$= 0.1874 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1874, 0.0625\right]$$

$$= 0.1874 \text{ in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.2818, 0.1874\right]$$

$$= 0.1874 \text{ in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.018, 0.1874\right]$$

$$= 0.1874 \text{ in}$$

Available nozzle wall thickness new, t_n = 1.75 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 16.36 psi @ 300 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.1248	3.2241	–	–	1.6398	1.5491	0.0352	0.0625	1.75

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Pad to shell fillet (Leg_{41})	0.1312	0.1312	weld size is adequate

Calculations for external pressure 16.36 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[4, 2 + (0) + (0.1874 - 0)\right]$$
$$= 4 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0) + 0.4426\right]$$
$$= 0.4426 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[0.5, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (1.75 - 0 - 0)\right]$$
$$= 0.4685 \text{ in}$$

From UG-37(d)(1) required thickness t_r = 0.1874 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 18,900, S_v = 18,900, S_p = 18,900 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A	=	$0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1})) + \text{Tapped hole area loss}$
	=	$0.5 \cdot (4 \cdot 0.1874 \cdot 1 + 2 \cdot 1.75 \cdot 0.1874 \cdot 1 \cdot (1 - 1)) + 0.75$
	=	1.1248 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

	=	$d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$
	=	$4 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) - 2 \cdot 1.75 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) \cdot (1 - 1)$
	=	$0 \ \text{in}^2$
	=	$2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$
	=	$2 \cdot (0.1874 + 0) \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) - 2 \cdot 1.75 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1874) \cdot (1 - 1)$
	=	$0 \ \text{in}^2$

Area A_2 is not included in these calculations.
A_3 = smaller of the following= 1.6398 in^2

	=	$5 \cdot t \cdot t_i \cdot f_{r2}$
	=	$5 \cdot 0.1874 \cdot 1.75 \cdot 1$
	=	1.6398 in^2
	=	$5 \cdot t_i \cdot t_i \cdot f_{r2}$
	=	$5 \cdot 1.75 \cdot 1.75 \cdot 1$
	=	15.3125 in^2
	=	$2 \cdot h \cdot t_i \cdot f_{r2}$
	=	$2 \cdot 0.5 \cdot 1.75 \cdot 1$
	=	1.75 in^2
A_{42}	=	$Leg^2 \cdot f_{r4}$
	=	$0.1875\ ^2 \cdot 1$
	=	0.0352 in^2
A_5	=	$(D_p - \text{Pad ID}) \cdot t_e \cdot f_{r4}$
	=	$(7.5 - 4) \cdot 0.4426 \cdot 1$
	=	1.5491 in^2
$Area$	=	$A_1 + A_3 + A_{42} + A_5$
	=	$0 + 1.6398 + 0.0352 + 1.5491$
	=	3.2241 in^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_e, t\right] =$ 0.1874 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1312 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313$ in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 0.0127 \text{ in}$

$$
\begin{aligned}
t_a &= \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right] \\
&= \max\left[0.0127, 0\right] \\
&= 0.0127 \text{ in}
\end{aligned}
$$

$$
\begin{aligned}
t_{b2} &= \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion} \\
&= \frac{16.3605 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 16.3605} + 0 \\
&= 0.018 \text{ in}
\end{aligned}
$$

$$
\begin{aligned}
t_{b2} &= \max\left[t_{b2}, t_{b\text{UG16}}\right] \\
&= \max\left[0.018, 0.0625\right] \\
&= 0.0625 \text{ in}
\end{aligned}
$$

$$
\begin{aligned}
t_b &= \min\left[t_{b3}, t_{b2}\right] \\
&= \min\left[0.2818, 0.0625\right] \\
&= 0.0625 \text{ in}
\end{aligned}
$$

$$
\begin{aligned}
t_{\text{UG-45}} &= \max\left[t_a, t_b\right] \\
&= \max\left[0.0127, 0.0625\right] \\
&= 0.0625 \text{ in}
\end{aligned}
$$

Available nozzle wall thickness new, t_n = 1.75 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{0.8401}{7.5} = 0.1120$$

$$\frac{D_o}{t} = \frac{7.5}{0.0127} = 591.8222$$

From table G: $A = 0.000969$

From table HA-1: $B = 7{,}261.6484 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 7{,}261.65}{3 \cdot (7.5/0.0127)} = 16.36 \text{ psi}$$

Design thickness for external pressure P_a = 16.36 psi

$t_a = t + \text{Corrosion} = 0.0127 + 0 = 0.0127$"

Shell #2

ASME Section VIII Division 1, 2019 Edition					
Component		Cylinder			
Material		SA-240 304 (II-D p. 88, ln. 37)			
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		25	300	-20	
External		15	300		
Static Liquid Head					
Condition		**P_s (psi)**	**H_s (in)**	**SG**	
Operating		0.17	4.8125	1	
Test horizontal		1.62	44.8125	1	
Dimensions					
Inner Diameter		41.625"			
Length		21.5"			
Nominal Thickness		0.1874"			
Corrosion	**Inner**	0"			
	Outer	0"			
Weight and Capacity					
		Weight (lb)		**Capacity (US gal)**	
New		148.47		70.41	
Corroded		148.47		70.41	
Radiography					
Longitudinal seam		None UW-11(c) Type 1			
Left Circumferential seam		None UW-11(c) Type 1			
Right 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)	0.0397"
Design thickness due to external pressure (t_e)	0.1667"
Maximum allowable working pressure (MAWP)	118.31 psi
Maximum allowable pressure (MAP)	125.38 psi
Maximum allowable external pressure (MAEP)	20.53 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{86.52 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 86.52} =$	0.1291"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.1291 \cdot 0.8}{0.1874 - 0} =$	0.5511
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 300 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{25.17 \cdot 20.8125}{18{,}900 \cdot 0.70 - 0.60 \cdot 25.17} + 0 = \underline{0.0397}"$$

Maximum allowable working pressure, (at 300 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{18{,}900 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} - 0.17 = \underline{118.31} \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{20{,}000 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} = \underline{125.38} \text{ psi}$$

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{63.6625}{41.9998} = 1.5158$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1667} = 252.0221$$

From table G: $A = 0.000215$

From table HA-1: $B = 2{,}835.245 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 2{,}835.25}{3 \cdot (41.9998/0.1667)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.1667 + 0 = \underline{0.1667}"$$

Maximum Allowable External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{63.6625}{41.9998} = 1.5158$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1874} = 224.1185$$

From table G: $A = 0.000262$

From table HA-1: $B = 3{,}451.429 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 3{,}451.43}{3 \cdot (41.9998/0.1874)} = \underline{20.53} \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.1874}{20.9062}\right) \cdot \left(1 - \frac{20.9062}{\infty}\right) = 0.4482\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cHC} \; = \; \min\,(B, S) = 7{,}619 \text{ psi}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_c HN = S_c HC = 7{,}619 \quad \text{psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 9{,}371 \quad \text{psi}$$

$$S = \frac{20{,}000}{1.00} = 20{,}000 \quad \text{psi}$$

$$S_{cCN} \; = \; \min\,(B, S) = 9{,}371 \text{ psi}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{c\mathbb{C}} \; = S_{cCN} \; = 9{,}371 \quad \text{psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

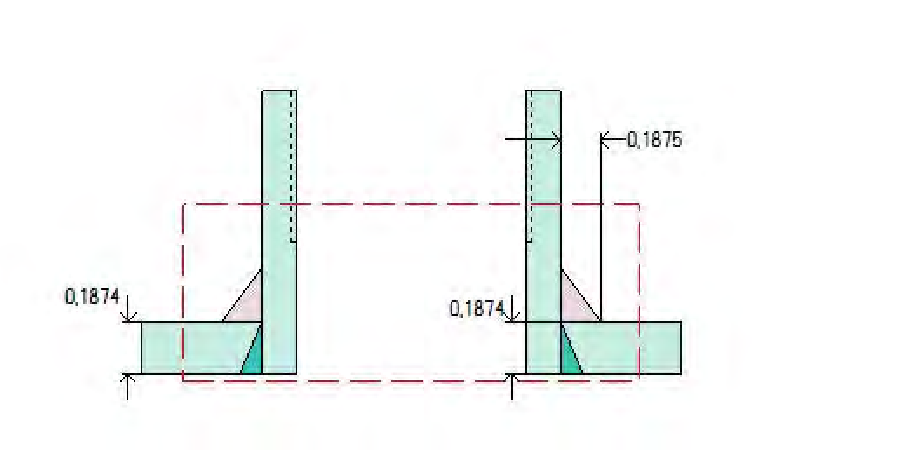
$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cVC} \; = \; \min\,(B, S) = 7{,}619 \text{ psi}$$

Press Relief (P3)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Shell #2
Orientation	0°
Nozzle center line offset to datum line	30.625"
End of nozzle to shell center	21.8011"
Passes through a Category A joint	No
Nozzle	
Service	Pressure Relief Valve (PRV)
Description	NPS 0.75 Class 3000 - Threaded Half Coupling
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 92, ln. 3)
Inside diameter, new	1.06"
Pipe nominal wall thickness	0.16"
Pipe minimum wall thickness[1]	0.14"
Corrosion allowance	0"
Projection available outside vessel, Lpr	0.8012"
Local vessel minimum thickness	0.1874"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.1875"
Nozzle to vessel groove weld	0.1874"

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

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{86.35 \cdot 0.53}{17{,}000 \cdot 1 - 0.6 \cdot 86.35} =$	0.0027"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0027 \cdot 1}{0.14 - 0} =$	0.0193
Impact test exempt per UHA-51(g) (coincident ratio = 0.0193)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 169.26 psi @ 300 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.14

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0937	0.1312	weld size is adequate

Calculations for internal pressure 169.26 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[1.06, 0.53 + (0.16 - 0) + (0.1874 - 0)\right]$$

$$= 1.06 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.16 - 0) + 0\right]$$

$$= 0.4 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2631 \cdot 0.53}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631}$$

$$= 0.0048 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2631 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2631}$$

$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $\dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P}$

= $\dfrac{169.2631 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 169.2631}$

= 0.2683 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.16 in

$t_{c(\min)} = \min\left[0.09375, 0.7 \cdot t_{\min}\right] =$ 0.0937 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2631 \cdot 0.69}{16{,}100 \cdot 1 + 0.4 \cdot 169.2631} + 0$$

$$= 0.0072 \text{ in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ t_{b\text{UG16}}\right]$$

$$= \max\left[0.0072,\ 0.0625\right]$$

$= $ 0.0625 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.16$ = 0.14 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 179.12 psi @ 70 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.14

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

Calculations for internal pressure 179.12 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[1.06, 0.53 + (0.16 - 0) + (0.1874 - 0)\right]$$
$$= 1.06 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.16 - 0) + 0\right]$$
$$= 0.4 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 0.53}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.0048 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 179.1185}$$
$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{179.1185 \cdot 0.69}{17{,}000 \cdot 1 + 0.4 \cdot 179.1185} + 0$$

$$= 0.0072 \text{ in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ t_{b\text{UG16}}\right]$$

$$= \max\left[0.0072,\ 0.0625\right]$$

$$= 0.0625 \text{ in}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.16$ = 0.14 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 20.53 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.14

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0937	0.1312	weld size is adequate

Calculations for external pressure 20.53 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[1.06, 0.53 + (0.16 - 0) + (0.1874 - 0)\right]$$
$$= 1.06 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.16 - 0) + 0\right]$$
$$= 0.4 \text{ in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.0041 in

From UG-37(d)(1) required thickness t_r = 0.1874 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.16 in

$t_{c(\min)} = \min\left[0.09375, 0.7 \cdot t_{\min}\right] =$ 0.0937 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-28}} = 0.0041 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$$
$$= \max\left[0.0041, 0\right]$$
$$= 0.0041 \text{ in}$$

t_{b2} = $\frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

= $\frac{20.5334 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 20.5334} + 0$

= 0.0226 in

$t_{b2} = \max\left[t_{b2}, t_{b\text{UG16}}\right]$

$= \max\left[0.0226, 0.0625\right]$

$= 0.0625 \text{ in}$

$t_b = \min\left[t_{b3}, t_{b2}\right]$

$= \min\left[0.1225, 0.0625\right]$

$= 0.0625 \text{ in}$

$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$

$= \max\left[0.0041, 0.0625\right]$

$=$ 0.0625 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.16$ = 0.14 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{0.8125}{1.38} = 0.5888$$

$$\frac{D_o}{t} = \frac{1.38}{0.0041} = 333.5423$$

From table G: $A = 0.000389$
From table HA-1: $B = 5{,}137.1212 \text{ psi}$

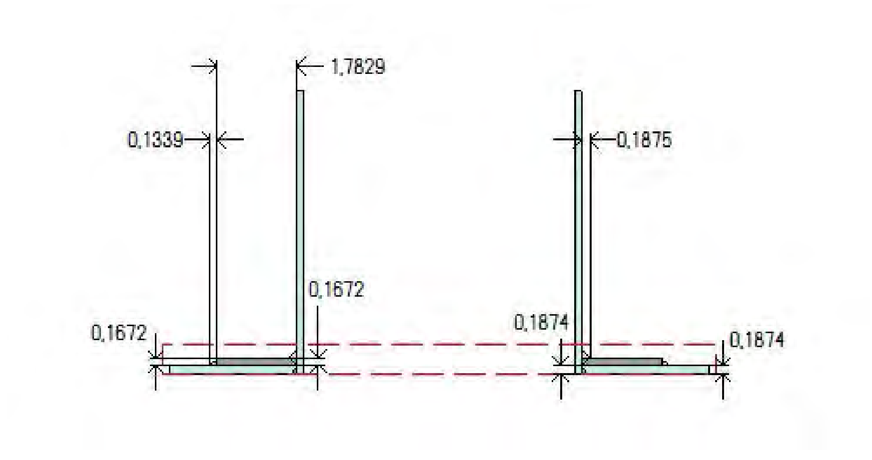
$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 5{,}137.12}{3 \cdot (1.38/0.0041)} = 20.54 \text{ psi}$$

Design thickness for external pressure P_a = 20.54 psi

$t_a = t + \text{Corrosion} = 0.0041 + 0 =$ 0.0041"

SS Vapor Inlet (P1)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Shell #2
Orientation	135°
Nozzle center line offset to datum line	30.375"
End of nozzle to shell center	27.1874"
Passes through a Category A joint	No
Nozzle	
Service	Inlet (IN)
Description	NPS 10 Sch 10S
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 92, ln. 3)
Inside diameter, new	10.42"
Pipe nominal wall thickness	0.165"
Pipe minimum wall thickness[1]	0.1444"
Corrosion allowance	0"
Projection available outside vessel, Lpr	6.1875"
Local vessel minimum thickness	0.1874"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-240 304L (II-D p. 84, ln. 33)
Diameter, D_p	14.3158"
Thickness, t_e	0.1672"
Is split	No
Welds	
Inner fillet, Leg_{41}	0.1875"
Outer fillet, Leg_{42}	0.1339"

Nozzle to vessel groove weld	0.1874"
Pad groove weld	0.1672"

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

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{86.35 \cdot 5.21}{17{,}000 \cdot 1 - 0.6 \cdot 86.35} =$	0.0265"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0265 \cdot 1}{0.1444 - 0} =$	0.1839
Impact test exempt per UHA-51(g) (coincident ratio = 0.1839)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UHA-51 Material Toughness Requirements Pad	
$t_r = \frac{86.35 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 86.35} =$	0.0901"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0901 \cdot 1}{0.1874 - 0} =$	0.4807
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 115.1 psi @ 300 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.3255	1.3257	0.6272	0.1248	–	0.5268	0.0469	0.1272	0.1444

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
13,573.81	13,201.72	55,557.83	4,115.32	104,126.57	14,370.54	68,897.28

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1155	0.1312	weld size is adequate
Pad to shell fillet (Leg_{42})	0.0836	0.0937	weld size is adequate

Calculations for internal pressure 115.1 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[10.42, 5.21 + (0.165 - 0) + (0.1874 - 0)\right]$$
$$= 10.42 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.165 - 0) + 0.1672\right]$$
$$= 0.4685 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{115.0967 \cdot 5.21}{18{,}900 \cdot 1 - 0.6 \cdot 115.0967}$$
$$= 0.0318 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{115.0967 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 115.0967}$$
$$= 0.1272 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{115.0967 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 115.0967}$$

$$= 0.182 \ \text{in}$$

Area required per UG-37(c)

Allowable stresses: S_n = 18,900, S_v = 18,900, S_p = 16,700 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8836

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 0.8836

$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1})$$

$$= 10.42 \cdot 0.1272 \cdot 1 + 2 \cdot 0.165 \cdot 0.1272 \cdot 1 \cdot (1 - 1)$$

= 1.3255 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.6272 in^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= 10.42 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1272) - 2 \cdot 0.165 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1272) \cdot (1 - 1)$$

$$= 0.6272 \ \text{in}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= 2 \cdot (0.1874 + 0.165) \cdot (1 \cdot 0.1874 - 1 \cdot 0.1272) - 2 \cdot 0.165 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1272) \cdot (1 - 1)$$

$$= 0.0424 \ \text{in}^2$$

A_2 = smaller of the following= 0.1248 in^2

$$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$$

$$= 5 \cdot (0.165 - 0.0318) \cdot 1 \cdot 0.1874$$

$$= 0.1248 \ \text{in}^2$$

$$= 2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$$

$$= 2 \cdot (0.165 - 0.0318) \cdot (2.5 \cdot 0.165 + 0.1672) \cdot 1$$

$$= 0.1544 \ \text{in}^2$$

A_{41} = $Leg^2 \cdot f_{r3}$

= $0.1875^{\ 2} \cdot 0.8836$

= 0.0311 in^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $0.1339^{\ 2} \cdot 0.8836$

= 0.0158 in^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $(14.3158 - 10.42 - 2 \cdot 0.165) \cdot 0.1672 \cdot 0.8836$

= 0.5268 in^2

$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$

$= 0.6272 + 0.1248 + 0.0311 + 0.0158 + 0.5268$

$=$ 1.3257 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: $t_{\min} = \min\left[0.75, t_n, t_e\right] =$ 0.165 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1155 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313$ in

Outer fillet: $t_{\min} = \min\left[0.75, t_e, t\right] =$ 0.1672 in

$t_{w(\min)} = 0.5 \cdot t_{\min} = 0.0836$ in

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1339 = 0.0937$ in

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{115.2131 \cdot 5.21}{16{,}100 \cdot 1 - 0.6 \cdot 115.2131} + 0$$

$$= 0.0374 \text{ in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.0374, 0\right]$$

$$= 0.0374 \text{ in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{115.0967 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 115.0967} + 0$$

$$= 0.1272 \text{ in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1272, 0.0625\right]$$

$$= 0.1272 \text{ in}$$

t_b $= \min\left[t_{b3}, t_{b1}\right]$

$= \min\left[0.3194, 0.1272\right]$

$= 0.1272$ in

$t_{\text{UG-45}}$ $= \max\left[t_a, t_b\right]$

$= \max\left[0.0374, 0.1272\right]$

$= 0.1272$ in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.165$ = 0.1444 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	$0.74 \cdot 18{,}900$ =	13,986 psi
Nozzle wall in shear:	$0.7 \cdot 16{,}100$ =	11,270 psi
Inner fillet weld in shear:	$0.49 \cdot 16{,}100$ =	7,889 psi
Outer fillet weld in shear:	$0.49 \cdot 16{,}700$ =	8,183 psi
Upper groove weld in tension:	$0.74 \cdot 16{,}700$ =	12,358 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 10.75 \cdot 0.1875 \cdot 7{,}889$ = 24,977.65 lb_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 14.3158 \cdot 0.1339 \cdot 8{,}183$ = 24,639.31 lb_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 10.585 \cdot 0.165 \cdot 11{,}270$ = 30,918.51 lb_f

(4) Groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 10.75 \cdot 0.1874 \cdot 13{,}986$ = 44,257.97 lb_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 10.75 \cdot 0.1672 \cdot 12{,}358$ = 34,890.95 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(1.3255 - 0.6272 + 2 \cdot 0.165 \cdot 1 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1272)) \cdot 18{,}900$

= 13,573.81 lb_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(0.1248 + 0.5268 + 0.0311 + 0.0158) \cdot 18{,}900$

= 13,201.72 lb_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(0.1248 + 0 + 0.0311 + 0 + 2 \cdot 0.165 \cdot 0.1874 \cdot 1) \cdot 18{,}900$

= 4,115.32 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(0.1248 + 0 + 0.5268 + 0.0311 + 0.0158 + 0 + 2 \cdot 0.165 \cdot 0.1874 \cdot 1) \cdot 18{,}900$

= 14,370.54 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 13,201.72 lb_f
Path 1-1 through (2) & (3) = 24,639.31 + 30,918.51 = 55,557.83 lb_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 4,115.32 lb_f
Path 2-2 through (1), (4), (6) = 24,977.65 + 44,257.97 + 34,890.95 = 104,126.57 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 13,573.81 lb_f
Path 3-3 through (2), (4) = 24,639.31 + 44,257.97 = 68,897.28 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 120.38 psi @ 70 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.31	1.31	0.6427	0.1251	–	0.4978	0.0444	0.1257	0.1444

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
13,753.14	13,346.57	57,286.19	4,326.84	107,633.27	14,583.41	71,473.14

Calculations for internal pressure 120.38 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[10.42, 5.21 + (0.165 - 0) + (0.1874 - 0)\right]$$

$$= 10.42 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.165 - 0) + 0.1672\right]$$

$$= 0.4685 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{120.3763 \cdot 5.21}{20{,}000 \cdot 1 - 0.6 \cdot 120.3763}$$

$$= 0.0315 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{120.3763 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 120.3763}$$

$$= 0.1257 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $\frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$

= $\frac{120.3763 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 120.3763}$

= $0.1799 \ \text{in}$

Area required per UG-37(c)

Allowable stresses: S_n = 20,000, S_v = 20,000, S_p = 16,700 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.835

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 0.835

A = $d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1})$

= $10.42 \cdot 0.1257 \cdot 1 + 2 \cdot 0.165 \cdot 0.1257 \cdot 1 \cdot (1 - 1)$

= 1.31 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.6427 in^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $10.42 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1257) - 2 \cdot 0.165 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1257) \cdot (1 - 1)$

= $0.6427 \ \text{in}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $2 \cdot (0.1874 + 0.165) \cdot (1 \cdot 0.1874 - 1 \cdot 0.1257) - 2 \cdot 0.165 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1257) \cdot (1 - 1)$

= $0.0435 \ \text{in}^2$

A_2 = smaller of the following= 0.1251 in^2

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

= $5 \cdot (0.165 - 0.0315) \cdot 1 \cdot 0.1874$

= $0.1251 \ \text{in}^2$

= $2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$

= $2 \cdot (0.165 - 0.0315) \cdot (2.5 \cdot 0.165 + 0.1672) \cdot 1$

= $0.1548 \ \text{in}^2$

A_{41} = $Leg^2 \cdot f_{r3}$

= $0.1875^{\ 2} \cdot 0.835$

= 0.0294 in^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $0.1339^{\,2} \cdot 0.835$

= 0.015 in^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $(14.3158 - 10.42 - 2 \cdot 0.165) \cdot 0.1672 \cdot 0.835$

= 0.4978 in^2

$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$

$= 0.6427 + 0.1251 + 0.0294 + 0.015 + 0.4978$

= 1.31 in^2

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{120.3763 \cdot 5.21}{17{,}000 \cdot 1 - 0.6 \cdot 120.3763} + 0$$

$$= 0.037 \ \text{in}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[0.037, 0\right]$$

$$= 0.037 \ \text{in}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{120.3763 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 120.3763} + 0$$

$$= 0.1257 \ \text{in}$$

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[0.1257, 0.0625\right]$$

$$= 0.1257 \ \text{in}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[0.3194, 0.1257\right]$$

$$= 0.1257 \ \text{in}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[0.037, 0.1257\right]$$

= 0.1257 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.165$ = 0.1444 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	$0.74 \cdot 20{,}000$ =	14,800 psi
Nozzle wall in shear:	$0.7 \cdot 17{,}000$ =	11,900 psi
Inner fillet weld in shear:	$0.49 \cdot 16{,}700$ =	8,183 psi
Outer fillet weld in shear:	$0.49 \cdot 16{,}700$ =	8,183 psi
Upper groove weld in tension:	$0.74 \cdot 16{,}700$ =	12,358 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 10.75 \cdot 0.1875 \cdot 8{,}183$ = 25,908.49 lb_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 14.3158 \cdot 0.1339 \cdot 8{,}183$ = 24,639.31 lb_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 10.585 \cdot 0.165 \cdot 11{,}900$ = 32,646.88 lb_f

(4) Groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 10.75 \cdot 0.1874 \cdot 14{,}800$ = 46,833.83 lb_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 10.75 \cdot 0.1672 \cdot 12{,}358$ = 34,890.95 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$
= $(1.31 - 0.6427 + 2 \cdot 0.165 \cdot 1 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1257)) \cdot 20{,}000$
= 13,753.14 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$
= $(0.1251 + 0.4978 + 0.0294 + 0.015) \cdot 20{,}000$
= 13,346.57 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$
= $(0.1251 + 0 + 0.0294 + 0 + 2 \cdot 0.165 \cdot 0.1874 \cdot 1) \cdot 20{,}000$
= 4,326.84 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$
= $(0.1251 + 0 + 0.4978 + 0.0294 + 0.015 + 0 + 2 \cdot 0.165 \cdot 0.1874 \cdot 1) \cdot 20{,}000$
= 14,583.41 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 13,346.57 lb_f
Path 1-1 through (2) & (3) = 24,639.31 + 32,646.88 = 57,286.19 lb_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 4,326.84 lb_f
Path 2-2 through (1), (4), (6) = 25,908.49 + 46,833.83 + 34,890.95 = 107,633.27 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 13,753.14 lb_f
Path 3-3 through (2), (4) = 24,639.31 + 46,833.83 = 71,473.14 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 15.74 psi @ 300 °F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.8843	0.8843	0.1841	0.1265	–	0.5268	0.0469	0.0625	0.1444

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1155	0.1312	weld size is adequate
Pad to shell fillet (Leg_{42})	0.0836	0.0937	weld size is adequate

Calculations for external pressure 15.74 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[10.42, 5.21 + (0.165 - 0) + (0.1874 - 0)\right]$$
$$= 10.42 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.165 - 0) + 0.1672\right]$$
$$= 0.4685 \text{ in}$$

Nozzle required thickness per UG-28 t_{rn} = 0.03 in

From UG-37(d)(1) required thickness t_r = 0.1697 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 18,900, S_v = 18,900, S_p = 16,700 psi

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8836

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 0.8836

$A = 0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

$= 0.5 \cdot (10.42 \cdot 0.1697 \cdot 1 + 2 \cdot 0.165 \cdot 0.1697 \cdot 1 \cdot (1 - 1))$

$=$ 0.8843 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.1841 in^2

$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 10.42 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1697) - 2 \cdot 0.165 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1697) \cdot (1 - 1)$

$= 0.1841 \ \text{in}^2$

$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= 2 \cdot (0.1874 + 0.165) \cdot (1 \cdot 0.1874 - 1 \cdot 0.1697) - 2 \cdot 0.165 \cdot (1 \cdot 0.1874 - 1 \cdot 0.1697) \cdot (1 - 1)$

$= 0.0125 \ \text{in}^2$

A_2 = smaller of the following= 0.1265 in^2

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

$= 5 \cdot (0.165 - 0.03) \cdot 1 \cdot 0.1874$

$= 0.1265 \ \text{in}^2$

$= 2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$

$= 2 \cdot (0.165 - 0.03) \cdot (2.5 \cdot 0.165 + 0.1672) \cdot 1$

$= 0.1565 \ \text{in}^2$

$A_{41} = Leg^2 \cdot f_{r3}$

$= 0.1875^{\,2} \cdot 0.8836$

$=$ 0.0311 in^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= 0.1339^{\,2} \cdot 0.8836$

$=$ 0.0158 in^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= (14.3158 - 10.42 - 2 \cdot 0.165) \cdot 0.1672 \cdot 0.8836$

$=$ 0.5268 in^2

$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$

$= 0.1841 + 0.1265 + 0.0311 + 0.0158 + 0.5268$

$=$ 0.8843 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: $t_{\min} = \min\left[0.75, t_n, t_e\right] =$ 0.165 in

$t_{c(\min)} = \min\left[0.25, 0.7 \cdot t_{\min}\right] =$ 0.1155 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313$ in

Outer fillet: $t_{\min} = \min\left[0.75, t_e, t\right] =$ 0.1672 in

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 0.0836 in

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1339 = 0.0937$ in

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 0.03$ in

$t_a = \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$

$= \max\left[0.03, 0\right]$

$= 0.03$ in

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{15.7409 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 15.7409} + 0$$

$= 0.0173$ in

$t_{b2} = \max\left[t_{b2}, t_{b\text{UG16}}\right]$

$= \max\left[0.0173, 0.0625\right]$

$= 0.0625$ in

$t_b = \min\left[t_{b3}, t_{b2}\right]$

$= \min\left[0.3194, 0.0625\right]$

$= 0.0625$ in

$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$

$= \max\left[0.03, 0.0625\right]$

$=$ 0.0625 in

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.165 = 0.1444$ in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{6.887}{10.75} = 0.6407$$

$$\frac{D_o}{t} = \frac{10.75}{0.03} = 358.3940$$

From table G: $A = 0.000321$

From table HA-1: $B = 4{,}230.9173$ psi

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 4{,}230.92}{3 \cdot (10.75/0.03)} = 15.74 \text{ psi}$$

Design thickness for external pressure P_a = 15.74 psi

$t_a = t + \text{Corrosion} = 0.03 + 0 = 0.03$"

ASME Shell Band (rear)

ASME Section VIII Division 1, 2019 Edition					
Component		Cylinder			
Material		SA-240 304 (II-D p. 88, ln. 37)			
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		25	300	-20	
External		15	300		
Static Liquid Head					
Condition		P_S (psi)	H_S (in)	SG	
Operating		0.17	4.8125	1	
Test horizontal		1.62	44.8125	1	
Dimensions					
Inner Diameter		41.625"			
Length		12"			
Nominal Thickness		0.1874"			
Corrosion	Inner	0"			
	Outer	0"			
Weight and Capacity					
		Weight (lb)		Capacity (US gal)	
New		85.61		39.3	
Corroded		85.61		39.3	
Radiography					
Longitudinal seam		None UW-11(c) Type 1			
Left 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)	0.0397"
Design thickness due to external pressure (t_e)	0.1667"
Maximum allowable working pressure (MAWP)	118.31 psi
Maximum allowable pressure (MAP)	125.38 psi
Maximum allowable external pressure (MAEP)	20.53 psi
Rated MDMT	-320 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{86.52 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 86.52} =$	0.1291"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.1291 \cdot 0.8}{0.1874 - 0} =$	0.5511
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320°F	
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 300 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{25.17 \cdot 20.8125}{18{,}900 \cdot 0.70 - 0.60 \cdot 25.17} + 0 = 0.0397"$$

Maximum allowable working pressure, (at 300 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{18{,}900 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} - 0.17 = 118.31 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{20{,}000 \cdot 0.70 \cdot 0.1874}{20.8125 + 0.60 \cdot 0.1874} = 125.38 \text{ psi}$$

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{63.6625}{41.9998} = 1.5158$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1667} = 252.0221$$

From table G: $A = 0.000215$

From table HA-1: $B = 2{,}835.245 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 2{,}835.25}{3 \cdot (41.9998/0.1667)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.1667 + 0 = 0.1667"$$

Maximum Allowable External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{63.6625}{41.9998} = 1.5158$$

$$\frac{D_o}{t} = \frac{41.9998}{0.1874} = 224.1185$$

From table G: $A = 0.000262$

From table HA-1: $B = 3{,}451.429 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 3{,}451.43}{3 \cdot (41.9998/0.1874)} = 20.53 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.1874}{20.9062}\right) \cdot \left(1 - \frac{20.9062}{\infty}\right) = 0.4482\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cHC} = \min(B, S) = 7{,}619 \text{ psi}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_cHN = S_cHC = 7{,}619 \quad \text{psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

$$B = 9{,}371 \quad \text{psi}$$

$$S = \frac{20{,}000}{1.00} = 20{,}000 \quad \text{psi}$$

$$S_{cCN} = \min(B, S) = 9{,}371 \text{ psi}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{c\mathbb{C}} = S_{cCN} = 9{,}371 \quad \text{psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{20.9999/0.1874} = 0.001115$$

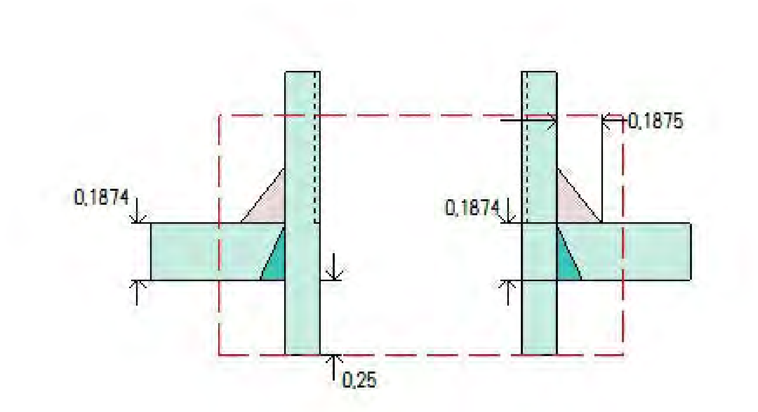
$$B = 7{,}619 \quad \text{psi}$$

$$S = \frac{18{,}900}{1.00} = 18{,}900 \quad \text{psi}$$

$$S_{cVC} = \min(B, S) = 7{,}619 \text{ psi}$$

Capped Vent Port (P6)

ASME Section VIII Division 1, 2019 Edition	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	ASME Shell Band (rear)
Orientation	180°
Nozzle center line offset to datum line	16.125"
End of nozzle to shell center	21.495"
Passes through a Category A joint	No

Nozzle	
Service	Drain (DRN)
Description	NPS 0.5 Class 3000 - Threaded Half Coupling
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 92, ln. 3)
Inside diameter, new	0.84"
Pipe nominal wall thickness	0.14"
Pipe minimum wall thickness[1]	0.1225"
Corrosion allowance	0"
Projection available outside vessel, Lpr	0.4951"
Internal projection, h_{new}	0.25"
Local vessel minimum thickness	0.1874"
Liquid static head included	0.18 psi
Longitudinal joint efficiency	1

Welds	
Inner fillet, Leg_{41}	0.1875"
Lower fillet, Leg_{43}	0"
Nozzle to vessel groove weld	0.1874"

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

UHA-51 Material Toughness Requirements Nozzle	
$t_r = \frac{86.53 \cdot 0.42}{17{,}000 \cdot 1 - 0.6 \cdot 86.53} =$	0.0021"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0021 \cdot 1}{0.1225 - 0} =$	0.0175
Impact test exempt per UHA-51(g) (coincident ratio = 0.0175)	
Rated MDMT =	-320°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 169.26 psi @ 300 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.1225

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0937	0.1312	weld size is adequate

Calculations for internal pressure 169.26 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[0.84, 0.42 + (0.14 - 0) + (0.1874 - 0)\right]$$

$$= 0.84 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0) + 0\right]$$

$$= 0.35 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[0.25, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0 - 0)\right]$$

$$= 0.25 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2629 \cdot 0.42}{18{,}900 \cdot 1 - 0.6 \cdot 169.2629}$$

$$= 0.0038 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2629 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 169.2629}$$

$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{169.2629 \cdot 20.8125}{18{,}900 \cdot 0.7 - 0.6 \cdot 169.2629}$$

$$= 0.2683 \text{ in}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.14 in

$t_{c(\min)} = \min\left[0.09375, 0.7 \cdot t_{\min}\right] =$ 0.0937 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{169.2808 \cdot 0.56}{16{,}100 \cdot 1 + 0.4 \cdot 169.2808} + 0$$

$$= 0.0059 \text{ in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ t_{b\text{UG16}}\right]$$

$$= \max\left[0.0059,\ 0.0625\right]$$

$$= 0.0625 \text{ in}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.14$ = 0.1225 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-44 Summary (in)	
For P = 179.12 psi @ 70 °F							The nozzle passes UG-44	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.1225

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

Calculations for internal pressure 179.12 psi @ 70 °F

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[0.84, 0.42 + (0.14 - 0) + (0.1874 - 0)\right]$$
$$= 0.84 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0) + 0\right]$$
$$= 0.35 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[0.25, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0 - 0)\right]$$
$$= 0.25 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 0.42}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.0038 \text{ in}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$
$$= \frac{179.1185 \cdot 20.8125}{20{,}000 \cdot 1 - 0.6 \cdot 179.1185}$$
$$= 0.1874 \text{ in}$$

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $\dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P}$

= $\dfrac{179.1185 \cdot 20.8125}{20{,}000 \cdot 0.7 - 0.6 \cdot 179.1185}$

= $0.2683 \quad \text{in}$

This opening does not require reinforcement per UG-36(c)(3)(a)

UG-44 Thickness Check - ASME B16.11 Coupling

$$t_{a\text{App 1-1}} = \frac{P \cdot R_o}{S_n \cdot E + 0.4 \cdot P} + \text{Corrosion}$$

$$= \frac{179.1185 \cdot 0.56}{17{,}000 \cdot 1 + 0.4 \cdot 179.1185} + 0$$

$$= 0.0059 \quad \text{in}$$

$$t_{a\text{UG-44}} = \max\left[t_{a\text{App 1-1}},\ \ t_{b\text{UG16}}\right]$$

$$= \max\left[0.0059,\ \ 0.0625\right]$$

= 0.0625 in

Available nozzle wall thickness new, t_n = $0.875 \cdot 0.14$ = 0.1225 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 20.53 psi @ 300 °F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0625	0.1225

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.0937	0.1312	weld size is adequate

Calculations for external pressure 20.53 psi @ 300 °F

Parallel Limit of reinforcement per UG-40

$L_R = \max\left[d, R_n + (t_n - C_n) + (t - C)\right]$

$= \max\left[0.84, 0.42 + (0.14 - 0) + (0.1874 - 0)\right]$

$= 0.84 \text{ in}$

Outer Normal Limit of reinforcement per UG-40

$L_H = \min\left[2.5 \cdot (t - C), 2.5 \cdot (t_n - C_n) + t_e\right]$

$= \min\left[2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0) + 0\right]$

$= 0.35 \text{ in}$

Inner Normal Limit of reinforcement per UG-40

$L_I = \min\left[h, 2.5 \cdot (t - C), 2.5 \cdot (t_i - C_n - C)\right]$

$= \min\left[0.25, 2.5 \cdot (0.1874 - 0), 2.5 \cdot (0.14 - 0 - 0)\right]$

$= 0.25 \text{ in}$

Nozzle required thickness per UG-28 t_{rn} = 0.0031 in

From UG-37(d)(1) required thickness t_r = 0.1874 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: $t_{\min} = \min\left[0.75, t_n, t\right] =$ 0.14 in

$t_{c(\min)} = \min\left[0.09375, 0.7 \cdot t_{\min}\right] =$ 0.0937 in

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 0.1875 = 0.1313 \text{ in}$

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 0.0031$ in

$t_a = \max\left[t_{a\text{UG-28}}, t_{a\text{UG-22}}\right]$

$= \max\left[0.0031, 0\right]$

$= 0.0031$ in

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{20.5334 \cdot 20.8125}{18{,}900 \cdot 1 - 0.6 \cdot 20.5334} + 0$$

$= 0.0226$ in

$t_{b2} = \max\left[t_{b2}, t_{b\text{UG16}}\right]$

$= \max\left[0.0226, 0.0625\right]$

$= 0.0625$ in

$t_b = \min\left[t_{b3}, t_{b2}\right]$

$= \min\left[0.1164, 0.0625\right]$

$= 0.0625$ in

$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$

$= \max\left[0.0031, 0.0625\right]$

$=$ 0.0625 in

Available nozzle wall thickness new, $t_n = 0.875 \cdot 0.14 = 0.1225$ in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 300 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{0.5025}{1.12} = 0.4487$$

$$\frac{D_o}{t} = \frac{1.12}{0.0031} = 363.7734$$

From table G: $A = 0.000456$

From table HA-1: $B = 5{,}600.7271$ psi

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 5{,}600.73}{3 \cdot (1.12/0.0031)} = 20.53 \text{ psi}$$

Design thickness for external pressure P_a = 20.53 psi

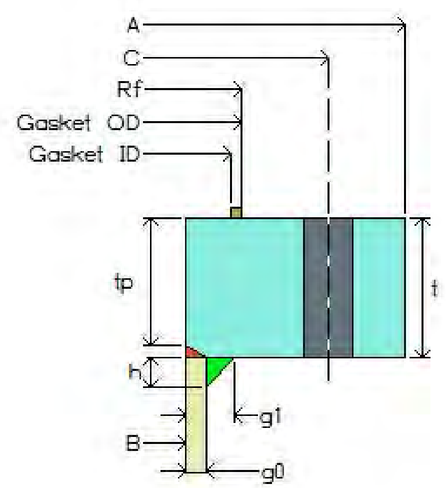
$t_a = t + \text{Corrosion} = 0.0031 + 0 = 0.0031$"

Tube Side Flange (rear)

ASME Section VIII Division 1, 2019 Edition , Appendix 2 Flange Calculations					
Flange Type		Ring type integral			
Attachment Type		Figure UW-13.2 sketch (n)			
Flange Material		SA-182 F60 (II-D p. 128, ln. 43)			
Attached To		Rear Channel (Left)			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**	
Yes (-20°F)	No	No	No	No	
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**	
Internal		60	250	40	
External		15	250		

Static Liquid Head	
Condition	**P_s (psi)**
Operating	1.49

Dimensions	
Flange OD, A	47"
Flange ID, B	41.5"
Bolt Circle, C	45.0625"
Gasket OD	42.9"
Gasket ID	42.6"
Raised Face ID	42.9"
Facing Height, t_{rf}	0"
Flange Thickness, t	1.75"
Hub Thickness, g_1	0.6071"
Hub Thickness, g_0	0.25"
Fillet Weld, h	0.375"
Groove Weld, w	0.25"
Edge Distance, t_p	1.6"
Corrosion Bore	0"
Corrosion Flange	0"



Bolting	
Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 398, ln. 32)
Description	28 - 0.625" coarse threaded
Corrosion on root	0"

Gasket	
Factor, m	0
Seating Stress, y	0 psi
Thickness, T	0.125"

Weight (lb)	
New	188.7 lb

Corroded	188.7 lb
Radiography	
Longitudinal seam	Seamless No RT
Right Circumferential seam	N/A

Results Summary		
Flange design thickness:	1.3119"	
Maximum allowable working pressure, MAWP:	86.65 psi @ 250 °F	
Maximum allowable pressure, MAP:	89.46 psi @ 70 °F	
Maximum allowable external pressure, MAEP:	150 psi @ 250 °F	(App 2-14(a) limits)
Rated MDMT	-20 °F	

Note: this flange is an optional type calculated as integral.
The following values are used in the calculations: g_0 = shell/nozzle wall thickness, h = actual length of flange hub plus fillet weld leg attaching hub to shell/nozzle
Appendix 2-14(a) successful service experience active.
Flange rigidity calculations are not performed for conditions where service restrictions are met.

UHA-51 Material Toughness Requirements	
Material impact test temperature per UHA-51(a) =	-20°F
Bolts rated MDMT per Fig UCS-66 note (c) =	-55°F
Design MDMT of 40°F is acceptable.	

Stress Summary											
			P (psi)	**S_H (psi)**	**Allow (psi)**	**S_R (psi)**	**S_T (psi)**	**$(S_H + S_R) / 2$ (psi)**	**$(S_H + S_T) / 2$ (psi)**	**Allow (psi)**
Design P	Weight Only	Oper	61.49	27,941	40,050	1,187	6,519	14,564	17,230	26,700
		Seating		26,547	40,650	1,128	6,194	13,838	16,371	27,100
Design P_e	Weight Only	Oper	15	1,819	40,050	77	424	948	1,121	26,700
		Seating		16,304	40,650	693	3,804	8,498	10,054	27,100

Bolt Summary						
			P (psi)	**W (lb_f)**	**A_m (in^2)**	**A_b (in^2)**
Design P	Weight Only	Oper	61.49	88,834.5	3.55	5.66
		Seating		0	0	
Design P_e	Weight Only	Oper	15	21,670.83	0	5.66
		Seating		0	0	

Figure UW-13.2 Weld Sizing					
$a+b \geq 3t_n + C_{i,shell} + \frac{C_{o,shell}}{0.7}$					
$h \geq \frac{\min\left[t_n, t_x\right] + C_{o,shell}}{0.7}$					
$t_p \geq \min\left[t_n, 0.25''\right] + C_o$					
Results					
$a+b=$	0.7571"	$\geq$	$3 \cdot 0.25 + 0 + \frac{0}{0.7} =$	0.75"	✔
$h=$	0.375"	$\geq$	$\frac{\min\left[0.25, 0.5\right] + 0}{0.7} =$	0.3571"	✔
$g_1 - g_0 =$	0.3571"	$\geq$	$\frac{\min\left[0.25, 0.5\right] + 0}{0.7} =$	0.3571"	✔
$t_p =$	1.6"	$\geq$	$\min\left[0.25, 0.25\right] + 0 =$	0.25"	✔

Flange calculations for Internal Pressure + Weight Only

Gasket details from facing sketch Confined gasket 1(a)

Gasket width N = 0.15 in

$b_0 = \frac{N}{2} = 0.075$ in

Effective gasket seating width, $b = b_0 = 0.075$ in

G = OD of contact face = 42.9 in (per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets)

$$h_G = \frac{C-G}{2} = \frac{45.0625 - 42.9}{2} = 1.0813 \text{ in}$$

$$h_D = \frac{R+g_1}{2} = \frac{1.1741 + 0.6071}{2} = 1.4777 \text{ in}$$

$$h_T = \frac{R+g_1+h_G}{2} = \frac{1.1741 + 0.6071 + 1.0813}{2} = 1.4313 \text{ in}$$

$H_p = 0$ per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets.

$$H = 0.785 \cdot G^2 \cdot P = 0.785 \cdot 42.9^2 \cdot 61.489 = 88{,}834.5 \text{ lb}_f$$

$$H_D = 0.785 \cdot B^2 \cdot P = 0.785 \cdot 41.5^2 \cdot 61.489 = 83{,}131.05 \text{ lb}_f$$

$$H_T = H - H_D = 88{,}834.5 - 83{,}131.05 = 5{,}703.45 \text{ lb}_f$$

$$W_{m1} = H + H_p = 88{,}834.5 + 0 = 88{,}834.5 \text{ lb}_f$$

$$W_{m2} = 3.14 \cdot b \cdot G \cdot y = 3.14 \cdot 0.075 \cdot 42.9 \cdot 0 = 0 \text{ lb}_f$$

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 3.5534 in^2

$$A_{m1} = \frac{W_{m1}}{S_b} = \frac{88{,}834.5}{25{,}000} = 3.5534 \text{ in}^2$$

$A_{m2} = \frac{W_{m2}}{S_a} = \frac{0}{25{,}000} =$ 0 in^2

Total area for 28 - 0.625" coarse threaded bolts, corroded, A_b = 5.656 in^2

$$W = \frac{(A_m + A_b) \cdot S_a}{2} = \frac{(3.5534 + 5.656) \cdot 25{,}000}{2} = 115{,}117.25 \ \ \text{lb}_f$$

$$M_D = H_D \cdot h_D = 83{,}131.05 \cdot 1.4777 = 122{,}841 \ \ \text{lb}_f\text{-in}$$

$$M_T = H_T \cdot h_T = 5{,}703.45 \cdot 1.4313 = 8{,}163.1 \ \ \text{lb}_f\text{-in}$$

$$H_G = W_{m1} - H = 88{,}834.5 - 88{,}834.5 = 0 \ \ \text{lb}_f$$

$$M_G = H_G \cdot h_G = 0 \cdot 1.0813 = 0 \ \ \text{lb}_f\text{-in}$$

$$M_o = M_D + M_T + M_G = 122{,}841 + 8{,}163.1 + 0 = 131{,}004 \ \ \text{lb}_f\text{-in}$$

$$M_g = W \cdot h_G = 115{,}117.25 \cdot 1.0813 = 124{,}470.5 \ \ \text{lb}_f\text{-in}$$

Hub and Flange Factors

$g_0 = t_n = 0.25 \ \text{in}$

$h_0 = \sqrt{B \cdot g_0} = \sqrt{41.5 \cdot 0.25} = 3.221 \ \text{in}$

From FIG. 2-7.1, where $K = \dfrac{A}{B} = \dfrac{47}{41.5} = 1.1325$

$T = 1.8653 \quad Z = 8.0765 \quad Y = 15.6248 \quad U = 17.1701$

$\dfrac{h}{h_0} = 0.1164 \quad \dfrac{g_1}{g_0} = 2.4286$

$F = 0.9027 \quad V = 0.4101 \quad e = \dfrac{F}{h_0} = 0.2803$

$$d = \left(\frac{U}{V}\right) \cdot h_0 \cdot g_0^2 = \left(\frac{17.1701}{0.4101}\right) \cdot 3.221 \cdot 0.25^{\,2} = 8.4284 \ \text{in}^3$$

Stresses at operating conditions - VIII-1 Appendix 2-7

$f = 4.6818$

$$L = \frac{t \cdot e + 1}{T} + \frac{t^3}{d} = \frac{1.75 \cdot 0.2803 + 1}{1.8653} + \frac{1.75^{\,3}}{8.4284} = 1.4349$$

$$S_H = \frac{f \cdot M_o}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 131{,}004}{1.4349 \cdot 0.6071^{\,2} \cdot 41.5} = \text{27,941 psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_o}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 131{,}004}{1.4349 \cdot 1.75^{\,2} \cdot 41.5} = \text{1,187 psi}$$

$$S_T = \frac{Y \cdot M_o}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 131{,}004}{1.75^{\,2} \cdot 41.5} - 8.0765 \cdot 1{,}187 = \text{6,519 psi}$$

Allowable stress S_{fo} = 26,700 psi
Allowable stress S_{no} = 26,700 psi

S_T does not exceed S_{fo}
S_H does not exceed $\min\left[1.5 \cdot S_{fo}, 1.5 \cdot S_{no}\right] = 40{,}050 \ \text{psi}$
S_R does not exceed S_{fo}
$\dfrac{S_H + S_R}{2} =$ 14,564 psi does not exceed S_{fo}
$\dfrac{S_H + S_T}{2} =$ 17,230 psi does not exceed S_{fo}

Stresses at gasket seating - VIII-1 Appendix 2-7

$$S_H = \frac{f \cdot M_g}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 124{,}470.5}{1.4349 \cdot 0.6071^{\,2} \cdot 41.5} = \text{26,547 psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_g}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 124{,}470.5}{1.4349 \cdot 1.75^{\,2} \cdot 41.5} = \text{1,128 psi}$$

$$S_T = \frac{Y \cdot M_g}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 124{,}470.5}{1.75^{\,2} \cdot 41.5} - 8.0765 \cdot 1{,}128 = \text{6,194 psi}$$

Allowable stress S_{fa} = 27,100 psi
Allowable stress S_{na} = 27,100 psi

S_T does not exceed S_{fa}

S_H does not exceed $\min\left[1.5 \cdot S_{fa}, 1.5 \cdot S_{na}\right] = 40{,}650$ psi

S_R does not exceed S_{fa}

$\frac{S_H + S_R}{2} = $ 13,838 psi does not exceed S_{fa}

$\frac{S_H + S_T}{2} = $ 16,371 psi does not exceed S_{fa}

Flange calculations for External Pressure + Weight Only per VIII-1, Appendix 2-11

Gasket details from facing sketch Confined gasket 1(a)

Gasket width N = 0.15 in

$b_0 = \frac{N}{2}$ = 0.075 in

Effective gasket seating width, b = b_0 = 0.075 in

G = OD of contact face = 42.9 in (per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets)

$$h_G = \frac{C - G}{2} = \frac{45.0625 - 42.9}{2} = 1.0813 \text{ in}$$

$$h_D = \frac{R + g_1}{2} = \frac{1.1741 + 0.6071}{2} = 1.4777 \text{ in}$$

$$h_T = \frac{R + g_1 + h_G}{2} = \frac{1.1741 + 0.6071 + 1.0813}{2} = 1.4313 \text{ in}$$

H_p = 0 per VIII-1 Appendix 2-5 (c)3(a) for self energizing gaskets.

$$H = 0.785 \cdot G^2 \cdot P = 0.785 \cdot 42.9^2 \cdot 15 = 21{,}670.83 \text{ lb}_f$$

$$H_D = 0.785 \cdot B^2 \cdot P = 0.785 \cdot 41.5^2 \cdot 15 = 20{,}279.49 \text{ lb}_f$$

$$H_T = H - H_D = 21{,}670.83 - 20{,}279.49 = 1{,}391.33 \text{ lb}_f$$

$$W_{m1} = H + H_p = 21{,}670.83 + 0 = 21{,}670.83 \text{ lb}_f$$

$$W_{m2} = 3.14 \cdot b \cdot G \cdot y = 3.14 \cdot 0.075 \cdot 42.9 \cdot 0 = 0 \text{ lb}_f$$

Required bolt area, A_m = greater of A_{m1}, A_{m2} = 0 in^2

$$A_{m1} = \frac{0.785 \cdot G^2 \cdot (P_m - P_r)}{S_b} = \frac{0.785 \cdot 42.9^2 \cdot 0}{25{,}000} = 0 \text{ in}^2$$

$$A_{m2} = \frac{W_{m2}}{S_a} = \frac{0}{25{,}000} = 0 \text{ in}^2$$

Total area for 28 - 0.625" coarse threaded bolts, corroded, A_b = 5.656 in^2

$$W = \frac{(A_{m2} + A_b) \cdot S_a}{2} = \frac{(0 + 5.656) \cdot 25{,}000}{2} = 70{,}700 \text{ lb}_f$$

$$M_o = H_D \cdot (h_D - h_G) + H_T \cdot (h_T - h_G) = 20{,}279.49 \cdot (1.4777 - 1.0813) + 1{,}391.33 \cdot (1.4313 - 1.0813) = 8{,}526.3 \text{ lb}_f\text{-in}$$

$$M_g = W \cdot h_G = 70{,}700 \cdot 1.0813 = 76{,}444.4 \text{ lb}_f\text{-in}$$

Hub and Flange Factors

$g_0 = t_n = 0.25 \text{ in}$

$h_0 = \sqrt{B \cdot g_0} = \sqrt{41.5 \cdot 0.25} = 3.221 \text{ in}$

From FIG. 2-7.1, where $K = \frac{A}{B} = \frac{47}{41.5} = 1.1325$

$T = 1.8653 \quad Z = 8.0765 \quad Y = 15.6248 \quad U = 17.1701$

$\frac{h}{h_0} = 0.1164 \quad \frac{g_1}{g_0} = 2.4286$

$F = 0.9027 \quad V = 0.4101 \quad e = \frac{F}{h_0} = 0.2803$

$$d = \left(\frac{U}{V}\right) \cdot h_0 \cdot g_0^2 = \left(\frac{17.1701}{0.4101}\right) \cdot 3.221 \cdot 0.25^2 = 8.4284 \text{ in}^3$$

Stresses at operating conditions - VIII-1 Appendix 2-7

$f = 4.6818$

$$L = \frac{t \cdot e + 1}{T} + \frac{t^3}{d} = \frac{1.75 \cdot 0.2803 + 1}{1.8653} + \frac{1.75^3}{8.4284} = 1.4349$$

$$S_H = \frac{f \cdot M_o}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 8{,}526.3}{1.4349 \cdot 0.6071^2 \cdot 41.5} = 1{,}819 \text{ psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_o}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 8{,}526.3}{1.4349 \cdot 1.75^2 \cdot 41.5} = 77 \text{ psi}$$

$$S_T = \frac{Y \cdot M_o}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 8{,}526.3}{1.75^2 \cdot 41.5} - 8.0765 \cdot 77 = 424 \text{ psi}$$

Allowable stress S_{fo} = 26,700 psi
Allowable stress S_{no} = 26,700 psi

S_T does not exceed S_{fo}
S_H does not exceed $\min\left[1.5 \cdot S_{fo}, 1.5 \cdot S_{no}\right] = 40{,}050 \text{ psi}$
S_R does not exceed S_{fo}
$\frac{S_H + S_R}{2} =$ 948 psi does not exceed S_{fo}
$\frac{S_H + S_T}{2} =$ 1,121 psi does not exceed S_{fo}

Stresses at gasket seating - VIII-1 Appendix 2-7

$$S_H = \frac{f \cdot M_g}{L \cdot g_1^2 \cdot B} = \frac{4.6818 \cdot 76{,}444.4}{1.4349 \cdot 0.6071^2 \cdot 41.5} = 16{,}304 \text{ psi}$$

$$S_R = \frac{(1.33 \cdot t \cdot e + 1) \cdot M_g}{L \cdot t^2 \cdot B} = \frac{(1.33 \cdot 1.75 \cdot 0.2803 + 1) \cdot 76{,}444.4}{1.4349 \cdot 1.75^2 \cdot 41.5} = 693 \text{ psi}$$

$$S_T = \frac{Y \cdot M_g}{t^2 \cdot B} - Z \cdot S_R = \frac{15.6248 \cdot 76{,}444.4}{1.75^2 \cdot 41.5} - 8.0765 \cdot 693 = 3{,}804 \text{ psi}$$

Allowable stress S_{fa} = 27,100 psi
Allowable stress S_{na} = 27,100 psi

S_T does not exceed S_{fa}

S_H does not exceed $\min\left[1.5 \cdot S_{fa}, 1.5 \cdot S_{na}\right] = 40{,}650 \text{ psi}$

S_R does not exceed S_{fa}

$\dfrac{S_H + S_R}{2} =$ 8,498 psi does not exceed S_{fa}

$\dfrac{S_H + S_T}{2} =$ 10,054 psi does not exceed S_{fa}

Rear Channel

ASME Section VIII Division 1, 2019 Edition				
Component		Cylinder		
Material		SA-240 S32205 (II-D p. 128, ln. 35)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
Yes (-20°F)	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		60	250	40
External		15	250	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		1.49	41.25	1
Test horizontal		1.73	47.875	1
Dimensions				
Inner Diameter		41.5"		
Length		6"		
Nominal Thickness		0.25"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		55.48		35.13
Corroded		55.48		35.13
Radiography				
Longitudinal seam		None UW-11(c) Type 1		
Right 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)	0.0685"
Design thickness due to external pressure (t_e)	0.0772"
Maximum allowable working pressure (MAWP)	222.08 psi
Maximum allowable pressure (MAP)	226.91 psi
Maximum allowable external pressure (MAEP)	161.55 psi
Rated MDMT	-20 °F

UHA-51 Material Toughness Requirements	
Material impact test temperature per UHA-51(a) =	-20°F
Design MDMT of 40°F is acceptable.	

Design thickness, (at 250 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{61.49 \cdot 20.75}{26{,}700 \cdot 0.70 - 0.60 \cdot 61.49} + 0 = 0.0685"$$

Maximum allowable working pressure, (at 250 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{26{,}700 \cdot 0.70 \cdot 0.25}{20.75 + 0.60 \cdot 0.25} - 1.49 = 222.08 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{27{,}100 \cdot 0.70 \cdot 0.25}{20.75 + 0.60 \cdot 0.25} = 226.91 \text{ psi}$$

External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{10.5985}{42} = 0.2523$$

$$\frac{D_o}{t} = \frac{42}{0.0772} = 543.8976$$

From table G: $A = 0.000448$

From table HA-5: $B = 6{,}118.8911 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 6{,}118.89}{3 \cdot (42/0.0772)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.0772 + 0 = 0.0772"$$

Maximum Allowable External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{10.5985}{42} = 0.2523$$

$$\frac{D_o}{t} = \frac{42}{0.25} = 168.0000$$

From table G: $A = 0.002861$

From table HA-5: $B = 20{,}355.4701 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 20{,}355.47}{3 \cdot (42/0.25)} = 161.55 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.25}{20.875}\right) \cdot \left(1 - \frac{20.875}{\infty}\right) = 0.5988\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{21/0.25} = 0.001488$$

$$B = 17{,}241 \ \text{psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \ \text{psi}$$

$S_{cHC} = \min(B, S) =$ 17,241 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_cHN = S_cHC = 17{,}241 \ \text{psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{21/0.25} = 0.001488$$

$$B = 19{,}232 \ \text{psi}$$

$$S = \frac{27{,}100}{1.00} = 27{,}100 \ \text{psi}$$

$S_{cCN} = \min(B, S) =$ 19,232 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{cC} = S_{cCN} = 19{,}232 \ \text{psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{21/0.25} = 0.001488$$

$$B = 17{,}241 \ \text{psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \ \text{psi}$$

$S_{cVC} = \min(B, S) =$ 17,241 psi

Straight Flange on Rear Channel Head

ASME Section VIII Division 1, 2019 Edition					
Component		Cylinder			
Material		SA-240 S32205 (II-D p. 128, ln. 35)			
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		60	250		40
External		15	250		
Static Liquid Head					
Condition		**P_s (psi)**	**H_s (in)**		**SG**
Operating		1.49	41.25		1
Test horizontal		1.73	47.875		1
Dimensions					
Inner Diameter		41.5"			
Length		0.5"			
Nominal Thickness		0.25"			
Corrosion	**Inner**	0"			
	Outer	0"			
Weight and Capacity					
		Weight (lb)			**Capacity (US gal)**
New		4.62			2.93
Corroded		4.62			2.93
Radiography					
Longitudinal seam		Seamless No RT			
Left 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)	0.0564"
Design thickness due to external pressure (t_e)	0.0772"
Maximum allowable working pressure (MAWP)	269.98 psi
Maximum allowable pressure (MAP)	275.54 psi
Maximum allowable external pressure (MAEP)	161.55 psi
Rated MDMT	-20 °F

UHA-51 Material Toughness Requirements	
$t_r = \frac{88.14 \cdot 20.75}{27{,}100 \cdot 0.85 - 0.6 \cdot 88.14} =$	0.0796"
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0796 \cdot 0.85}{0.25 - 0} =$	0.2706
Impact test exempt per UHA-51(g) (coincident ratio = 0.2706)	
Rated MDMT =	-20°F
Material is exempt from impact testing at the Design MDMT of 40°F.	

Design thickness, (at 250 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{61.49 \cdot 20.75}{26{,}700 \cdot 0.85 - 0.60 \cdot 61.49} + 0 = 0.0564\text{"}$$

Maximum allowable working pressure, (at 250 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{26{,}700 \cdot 0.85 \cdot 0.25}{20.75 + 0.60 \cdot 0.25} - 1.49 = 269.98 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{27{,}100 \cdot 0.85 \cdot 0.25}{20.75 + 0.60 \cdot 0.25} = 275.54 \text{ psi}$$

External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{10.5985}{42} = 0.2523$$

$$\frac{D_o}{t} = \frac{42}{0.0772} = 543.8976$$

From table G: $A = 0.000448$

From table HA-5: $B = 6{,}118.8911 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 6{,}118.89}{3 \cdot (42/0.0772)} = 15 \text{ psi}$$

Design thickness for external pressure P_a = 15 psi

$$t_a = t + \text{Corrosion} = 0.0772 + 0 = 0.0772\text{"}$$

Maximum Allowable External Pressure, (Corroded & at 250 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{10.5985}{42} = 0.2523$$

$$\frac{D_o}{t} = \frac{42}{0.25} = 168.0000$$

From table G: $A = 0.002861$

From table HA-5: $B = 20{,}355.4701 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 20{,}355.47}{3 \cdot (42/0.25)} = 161.55 \text{ psi}$$

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

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.25}{20.875}\right) \cdot \left(1 - \frac{20.875}{\infty}\right) = 0.5988\,\%$$

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{21/0.25} = 0.001488$$

$$B = 17{,}241 \quad \text{psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \quad \text{psi}$$

$S_{cHC} = \min\,(B, S) =$ 17,241 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_cHN = S_cHC = 17{,}241 \quad \text{psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{21/0.25} = 0.001488$$

$$B = 19{,}232 \quad \text{psi}$$

$$S = \frac{27{,}100}{1.00} = 27{,}100 \quad \text{psi}$$

$S_{cCN} = \min\,(B, S) =$ 19,232 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_{cC} = S_{cCN} = 19{,}232 \quad \text{psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-5)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{21/0.25} = 0.001488$$

$$B = 17{,}241 \quad \text{psi}$$

$$S = \frac{26{,}700}{1.00} = 26{,}700 \quad \text{psi}$$

$S_{cVC} = \min\,(B, S) =$ 17,241 psi

Rear Channel Head

ASME Section VIII Division 1, 2019 Edition				
Component		F&D Head		
Material		SA-240 S32205 (II-D p. 128, ln. 35)		
Attached To		Rear Channel		
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		60	250	40
External		15	250	
Static Liquid Head				
Condition		P_s (psi)	H_s (in)	SG
Operating		1.49	41.25	1
Test horizontal		1.73	47.875	1
Dimensions				
Inner Diameter		41.5"		
Crown Radius L		41.5"		
Knuckle Radius r		2.52"		
Minimum Thickness		0.218"		
Corrosion	Inner	0"		
	Outer	0"		
Length L_{sf}		0.5"		
Nominal Thickness t_{sf}		0.25"		
Weight and Capacity				
		Weight (lb)[1]		Capacity (US gal)[1]
New		104.7		28.09
Corroded		104.7		28.09
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)	0.1345"
Design thickness due to external pressure (t_e)	0.1237"
Maximum allowable working pressure (MAWP)	98.18 psi
Maximum allowable pressure (MAP)	101.16 psi
Maximum allowable external pressure (MAEP)	46.65 psi
Straight Flange governs MDMT	-20°F

Note: Endnote 90 used to determine allowable stress.

Factor M		
$M = \frac{1}{4} \cdot \left[3 + \left(\frac{L}{r}\right)^{\frac{1}{2}}\right]$		
Corroded	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{41.5}{2.52}\right)^{\frac{1}{2}}\right]$	1.7645
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{41.5}{2.52}\right)^{\frac{1}{2}}\right]$	1.7645

Design thickness for internal pressure, (Corroded at 250 °F) Appendix 1-4(d)

$$t = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P} + \text{Corrosion} = \frac{61.49 \cdot 41.5 \cdot 1.7645}{2 \cdot 19{,}704.8 \cdot 0.85 - 0.2 \cdot 61.49} + 0 = 0.1345"$$

Maximum allowable working pressure, (Corroded at 250 °F) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 19{,}704.8 \cdot 0.85 \cdot 0.218}{41.5 \cdot 1.7645 + 0.2 \cdot 0.218} - 1.49 = 98.18 \text{ psi}$$

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 20{,}000 \cdot 0.85 \cdot 0.218}{41.5 \cdot 1.7645 + 0.2 \cdot 0.218} - 0 = 101.16 \text{ psi}$$

Design thickness for external pressure, (Corroded at 250 °F) UG-33(e)

Equivalent outside spherical radius (R_o) = Outside crown radius $= 41.718$ in

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{41.718 \ / \ 0.123616} = 0.00037$$

From Table HA-5:B = 5,062.2058 psi

$$P_a = \frac{B}{R_o \ / \ t} = \frac{5{,}062.2058}{41.718 \ / \ 0.1236} = 15 \text{ psi}$$

t = 0.1236" + Corrosion = 0.1236" + 0" = 0.1236"

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

$$t = \frac{1.67 \cdot P_e \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot 1.67 \cdot P_e} + \text{Corrosion} = \frac{1.67 \cdot 15 \cdot 41.5 \cdot 1.7645}{2 \cdot 19{,}704.8 \cdot 1 - 0.2 \cdot 1.67 \cdot 15} + 0 = 0.0466"$$

The head external pressure design thickness (t_e) is 0.1236".

Maximum Allowable External Pressure, (Corroded at 250 °F) UG-33(e)

Equivalent outside spherical radius (R_o) = Outside crown radius $= 41.718$ in

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{41.718 \ / \ 0.218} = 0.000653$$

From Table HA-5:B = 8,926.5947 psi

$$P_a = \frac{B}{R_o \ / \ t} = \frac{8{,}926.5947}{41.718 \ / \ 0.218} = 46.6465 \ \ \text{psi}$$

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

$$P = \frac{2 \cdot S \cdot E \cdot t}{(L \cdot M + 0.2 \cdot t) \cdot 1.67} = \frac{2 \cdot 19{,}704.8 \cdot 1 \cdot 0.218}{(41.5 \cdot 1.7645 + 0.2 \cdot 0.218) \cdot 1.67} = 70.21 \ \ \text{psi}$$

The maximum allowable external pressure (MAEP) is 46.65 psi.

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

$$EFE = \left(\frac{75 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{75 \cdot 0.25}{2.645}\right) \cdot \left(1 - \frac{2.645}{\infty}\right) = 7.0888\,\%$$

Saddle #1

ASME Section VIII Division 1, 2019 Edition		
Saddle Material	sa240-304	
Saddle Construction	Web at edge of rib	
Welded to Vessel	Yes	
Saddle Allowable Stress, S_s	20,000 psi	
Saddle Yield Stress, S_y	38,000 psi	
Saddle on Steel Foundation	Yes	
Design Pressure	**Left Saddle**	**Right Saddle**
Operating	86.52 psi	
Test	113.87 psi	
Vacuum	15 psi	
Dimensions		
Right saddle distance to datum	14"	
Tangent To Tangent Length, L	172.75"	
Saddle separation, L_s	120"	
Vessel Radius, R	20.9999"	
Tangent Distance Left, A_l	38.25"	
Tangent Distance Right, A_r	14.5"	
TubeSheet Distance Left,	17.25"	
Tubesheet Distance Right,	5.5"	
Saddle Height, H_s	30.25"	
Saddle Contact Angle, θ	124°	
Web Plate Thickness, t_s	0.25"	
Base Plate Length, E	41.9333"	
Base Plate Width, F	9"	
Base Plate Thickness, t_b	0.375"	
Number of Stiffening Ribs, n	5	
Largest Stiffening Rib Spacing, d_i	10.1708"	
Stiffening Rib Thickness, t_w	0.25"	
Saddle Width, b	8"	
Reinforcing Plate		
Thickness, t_p	0.25"	
Width, W_p	11"	
Contact Angle, θ_w	132°	
Bolting		
Material		
Bolt Allowable Shear	15,000 psi	
Description	1" series 8 threaded	
Corrosion on root	0"	

Anchor Bolts per Saddle	2
Base coefficient of friction, μ	0.45
Hole Diameter	1.25"
Slotted Hole in Which Saddle	Right Saddle
Slotted Hole Length	0.5"

Weight		
	Operating, Corroded	**Hydrotest**
Weight on Left Saddle	6,466 lb	8,464 lb
Weight on Right Saddle	4,272 lb	5,904 lb
Weight of Saddle Pair	294 lb	

Notes
(1) Saddle calculations are based on the method presented in "Stresses in Large Cylindrical Pressure Vessels on Two Saddle Supports" by L.P. Zick. (2) If CL of tubesheet is located within a distance of R_o / 2 to CL of saddle, the shell is assumed stiffened as if tubesheet is a bulk head.

Stress Summary

Load	Condition	Saddle	Bending + pressure between saddles (psi)				Bending + pressure at the saddle (psi)			
			S_1 (+)	allow (+)	S_1 (-)	allow (-)	S_2 (+)	allow (+)	S_2 (-)	allow (-)
Weight	Operating	Right Saddle	5,260	13,230	456	7,619	4,822	18,900	18	7,619
		Left Saddle					6,463	18,900	1,659	7,619
	Test	Right Saddle	6,953	18,900	630	9,371	6,347	27,000	24	9,371
		Left Saddle					8,542	27,000	2,219	9,371
	Vacuum	Right Saddle	456	13,230	1,289	7,619	18	18,900	851	7,619
		Left Saddle					1,659	18,900	2,492	7,619

Stress Summary

Load	Condition	Saddle	Tangential shear (psi)		Circumferential stress (psi)		Stress over saddle (psi)		Splitting (psi)	
			S_3	allow	S_4 (horns)	allow (+/-)	S_5	allow	S_6	allow
Weight	Operating	Right Saddle	886	15,120	-2,776	28,350	1,463	11,200	200	13,333
		Left Saddle	1,111	15,120	-10,803	28,350	2,214	11,200	303	13,333
	Test	Right Saddle	1,225	21,600	-3,837	27,000	2,022	27,000	277	34,200
		Left Saddle	1,433	21,600	-14,141	27,000	2,899	27,000	396	34,200
	Vacuum	Right Saddle	886	15,120	-2,776	28,350	1,463	11,200	200	13,333
		Left Saddle	1,111	15,120	-10,803	28,350	2,214	11,200	303	13,333

Load Case 1: Weight, Operating

Longitudinal stress between saddles (Weight, Operating, right saddle loading and geometry govern)

$$S_1 = \pm \frac{3 \cdot K_1 \cdot Q \cdot (L \;/\; 12)}{\pi \cdot R^2 \cdot t} = \frac{3 \cdot 0.6358 \cdot 4{,}272 \cdot (172.75 \;/\; 12)}{\pi \cdot 20.9062^{\;2} \cdot 0.1874} = 456 \quad \text{psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{86.52 \cdot 20.8125}{2 \cdot 0.1874} = 4{,}805 \text{ psi}$$

Maximum tensile stress S_{1t} = S_1 + S_p = 5,260 psi
Maximum compressive stress (shut down) S_{1c} = S_1 = 456 psi

Tensile stress is acceptable ($\leq S \cdot E = 13{,}230$ psi)

Compressive stress is acceptable ($\leq S_c = 7{,}619$ psi)

Longitudinal stress at the right saddle (Weight, Operating)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 7.2636}{3} + 172.75 + \frac{2 \cdot 7.2636}{3} = 182.4348 \text{ in}$$

$$w = \frac{W_t}{L_e} = \frac{10{,}738}{182.4348} = 58.86 \text{ lb}_f\text{/in}$$

Bending moment at the right saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_r \cdot A_r}{3} + \frac{A_r^2}{2} - \frac{R^2 - H_r^2}{4}\right)$$

$$= 58.86 \cdot \left(\frac{2 \cdot 7.2636 \cdot 14.5}{3} + \frac{14.5^{\,2}}{2} - \frac{20.9999^{\,2} - 7.2636^{\,2}}{4}\right)$$

$$= 4{,}607.5 \text{ lb}_f\text{-in}$$

$$S_2 = \pm \frac{M_q \cdot K_1{}'}{\pi \cdot R^2 \cdot t} = \frac{4{,}607.5 \cdot 1}{\pi \cdot 20.9062^{\,2} \cdot 0.1874} = 18 \text{ psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{86.52 \cdot 20.8125}{2 \cdot 0.1874} = 4{,}805 \text{ psi}$$

Maximum tensile stress S_{2t} = S_2 + S_p = 4,822 psi
Maximum compressive stress (shut down) S_{2c} = S_2 = 18 psi

Tensile stress is acceptable ($\leq S = 18{,}900$ psi)

Compressive stress is acceptable ($\leq S_c = 7{,}619$ psi)

Tangential shear stress in the shell (right saddle, Weight, Operating)

$$S_3 = \frac{K_{2.3} \cdot Q}{R \cdot t} = \frac{0.8127 \cdot 4{,}272}{20.9062 \cdot 0.1874} = 886 \text{ psi}$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot S = 15{,}120$ psi)

The wear plate was not considered in the calculation of S_3 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46°.

Circumferential stress at the right saddle horns (Weight, Operating)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{3 \cdot K_3 \cdot Q}{2 \cdot t^2}$$

$$= \frac{-4{,}272}{4 \cdot 0.1874 \cdot \left(8 + 1.56 \cdot \sqrt{20.9999 \cdot 0.1874}\right)} - \frac{3 \cdot 0.0124 \cdot 4{,}272}{2 \cdot 0.1874^{\,2}}$$

$$= -2{,}776 \text{ psi}$$

Circumferential stress at saddle horns is acceptable ($\leq 1.5 \cdot S_a = 28{,}350$ psi)
The wear plate was not considered in the calculation of S_4 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46° and the wear plate width is not at least $\left\{b + 1.56 \cdot \sqrt{R_o \cdot t}\right\} = 11.0947$ in

Ring compression in shell over right saddle (Weight, Operating)

$$S_5 = \frac{K_5 \cdot Q}{(t + t_p) \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$

$$= \frac{0.7457 \cdot 4{,}272}{(0.1874 + 0.25) \cdot \left(0.25 + 1.56 \cdot \sqrt{20.9999 \cdot 0.4374}\right)}$$

$$= 1{,}463 \ \text{psi}$$

Ring compression in shell is acceptable ($\leq 0.5 \cdot S_y = 11{,}200 \ \text{psi}$)

Saddle splitting load (right, Weight, Operating)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 7 \cdot 0.25 + 0.25 \cdot 11$ = 4.5 in^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{0.2108 \cdot 4{,}272}{4.5} = 200 \ \text{psi}$$

Stress in saddle is acceptable $\left(\leq \frac{2}{3} \cdot S_s = 13{,}333 \ \text{psi}\right)$

Longitudinal stress at the left saddle (Weight, Operating)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 7.2636}{3} + 172.75 + \frac{2 \cdot 7.2636}{3} = 182.4348 \ \text{in}$$

$$w = \frac{W_t}{L_e} = \frac{10{,}738}{182.4348} = 58.86 \ \text{lb}_f/\text{in}$$

Bending moment at the left saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_l \cdot A_l}{3} + \frac{A_l^2}{2} - \frac{R^2 - H_l^2}{4}\right)$$

$$= 58.86 \cdot \left(\frac{2 \cdot 7.2636 \cdot 38.25}{3} + \frac{38.25^{\ 2}}{2} - \frac{20.9999^{\ 2} - 7.2636^{\ 2}}{4}\right)$$

$$= 48{,}246.7 \ \text{lb}_f\text{-in}$$

$$S_2 = \pm \frac{M_q \cdot K_1{}'}{\pi \cdot R^2 \cdot t} = \frac{48{,}246.7 \cdot 8.8457}{\pi \cdot 20.9062^{\ 2} \cdot 0.1874} = 1{,}659 \ \text{psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{86.52 \cdot 20.8125}{2 \cdot 0.1874} = 4{,}805 \ \text{psi}$$

Maximum tensile stress S_{2t} = S_2 + S_p = 6,463 psi
Maximum compressive stress (shut down) S_{2c} = S_2 = 1,659 psi

Tensile stress is acceptable ($\leq S = 18{,}900 \ \text{psi}$)

Compressive stress is acceptable ($\leq S_c = 7{,}619 \ \text{psi}$)

Tangential shear stress in the shell (left saddle, Weight, Operating)

$$Q_{shear} = Q - w \cdot \left(A_l + \frac{2 \cdot H_l}{3}\right) = 6{,}466 - 58.86 \cdot \left(38.25 + \frac{2 \cdot 7.2636}{3}\right) = 3{,}929.61 \ \text{lb}_f$$

$$S_3 = \frac{K_{2.2} \cdot Q_{shear}}{R \cdot t} = \frac{1.1076 \cdot 3{,}929.61}{20.9062 \cdot 0.1874} = 1{,}111 \ \text{psi}$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot S = 15{,}120 \ \text{psi}$)

Circumferential stress at the left saddle horns (Weight, Operating)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{3 \cdot K_3 \cdot Q}{2 \cdot t^2}$$
$$= \frac{-6{,}466}{4 \cdot 0.1874 \cdot \left(8 + 1.56 \cdot \sqrt{20.9999 \cdot 0.1874}\right)} - \frac{3 \cdot 0.0363 \cdot 6{,}466}{2 \cdot 0.1874^{\,2}}$$
$$= \text{-10,803} \;\; \text{psi}$$

Circumferential stress at saddle horns is acceptable ($\leq 1.5 \cdot S_a = 28{,}350 \;\; \text{psi}$)
The wear plate was not considered in the calculation of S_4 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46° and the wear plate width is not at least $\left\{b + 1.56 \cdot \sqrt{R_o \cdot t}\right\} = 11.0947 \;\; \text{in}$

Ring compression in shell over left saddle (Weight, Operating)

$$S_5 = \frac{K_5 \cdot Q}{\left(t + t_p\right) \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$
$$= \frac{0.7457 \cdot 6{,}466}{\left(0.1874 + 0.25\right) \cdot \left(0.25 + 1.56 \cdot \sqrt{20.9999 \cdot 0.4374}\right)}$$
$$= \text{2,214} \;\; \text{psi}$$

Ring compression in shell is acceptable ($\leq 0.5 \cdot S_y = 11{,}200 \;\; \text{psi}$)

Saddle splitting load (left, Weight, Operating)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 7 \cdot 0.25 + 0.25 \cdot 11$ = 4.5 in^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{0.2108 \cdot 6{,}466}{4.5} = \text{303} \;\; \text{psi}$$

Stress in saddle is acceptable $\left(\leq \frac{2}{3} \cdot S_s = 13{,}333 \;\; \text{psi}\right)$

Load Case 2: Weight, Test

Longitudinal stress between saddles (Weight, Test, right saddle loading and geometry govern)

$$S_1 = \pm \frac{3 \cdot K_1 \cdot Q \cdot (L \;/\; 12)}{\pi \cdot R^2 \cdot t} = \frac{3 \cdot 0.6358 \cdot 5{,}904 \cdot (172.75 \;/\; 12)}{\pi \cdot 20.9062^{\,2} \cdot 0.1874} = 630 \;\; \text{psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{113.87 \cdot 20.8125}{2 \cdot 0.1874} = 6{,}323 \;\; \text{psi}$$

Maximum tensile stress S_{1t} = S_1 + S_p = 6,953 psi
Maximum compressive stress (shut down) S_{1c} = S_1 = 630 psi

Tensile stress is acceptable ($\leq 0.9 \cdot S_y \cdot E = 18{,}900 \;\; \text{psi}$)

Compressive stress is acceptable ($\leq S_c = 9{,}371 \;\; \text{psi}$)

Longitudinal stress at the right saddle (Weight, Test)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 7.2636}{3} + 172.75 + \frac{2 \cdot 7.2636}{3} = 182.4348 \;\; \text{in}$$

$$w = \frac{W_t}{L_e} = \frac{14{,}368}{182.4348} = 78.76 \;\; \text{lb}_f/\text{in}$$

Bending moment at the right saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_r \cdot A_r}{3} + \frac{A_r^2}{2} - \frac{R^2 - H_r^2}{4} \right)$$

$$= 78.76 \cdot \left(\frac{2 \cdot 7.2636 \cdot 14.5}{3} + \frac{14.5^{\ 2}}{2} - \frac{20.9999^{\ 2} - 7.2636^{\ 2}}{4} \right)$$

$$= 6{,}165.1 \ \ \mathrm{lb}_f\text{-in}$$

$$S_2 = \pm \frac{M_q \cdot K_1{}'}{\pi \cdot R^2 \cdot t} = \frac{6{,}165.1 \cdot 1}{\pi \cdot 20.9062^{\ 2} \cdot 0.1874} = 24 \ \ \mathrm{psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{113.87 \cdot 20.8125}{2 \cdot 0.1874} = 6{,}323 \ \ \mathrm{psi}$$

Maximum tensile stress S_{2t} = S_2 + S_p = 6,347 psi
Maximum compressive stress (shut down) S_{2c} = S_2 = 24 psi

Tensile stress is acceptable ($\leq 0.9 \cdot S_y = 27{,}000 \ \ \mathrm{psi}$)

Compressive stress is acceptable ($\leq S_c = 9{,}371 \ \ \mathrm{psi}$)

Tangential shear stress in the shell (right saddle, Weight, Test)

$$S_3 = \frac{K_{2.3} \cdot Q}{R \cdot t} = \frac{0.8127 \cdot 5{,}904}{20.9062 \cdot 0.1874} = 1{,}225 \ \ \mathrm{psi}$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot (0.9 \cdot S_y) = 21{,}600 \ \ \mathrm{psi}$)

The wear plate was not considered in the calculation of S_3 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46°.

Circumferential stress at the right saddle horns (Weight, Test)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{3 \cdot K_3 \cdot Q}{2 \cdot t^2}$$

$$= \frac{-5{,}904}{4 \cdot 0.1874 \cdot \left(8 + 1.56 \cdot \sqrt{20.9999 \cdot 0.1874}\right)} - \frac{3 \cdot 0.0124 \cdot 5{,}904}{2 \cdot 0.1874^{\ 2}}$$

$$= -3{,}837 \ \ \mathrm{psi}$$

Circumferential stress at saddle horns is acceptable ($\leq 0.9 \cdot S_y = 27{,}000 \ \ \mathrm{psi}$)
The wear plate was not considered in the calculation of S_4 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46° and the wear plate width is not at least $\left\{b + 1.56 \cdot \sqrt{R_o \cdot t}\right\} = 11.0947 \ \ \mathrm{in}$

Ring compression in shell over right saddle (Weight, Test)

$$S_5 = \frac{K_5 \cdot Q}{(t + t_p) \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$

$$= \frac{0.7457 \cdot 5{,}904}{(0.1874 + 0.25) \cdot \left(0.25 + 1.56 \cdot \sqrt{20.9999 \cdot 0.4374}\right)}$$

$$= 2{,}022 \ \ \mathrm{psi}$$

Ring compression in shell is acceptable ($\leq 0.9 \cdot S_y = 27{,}000 \ \ \mathrm{psi}$)

Saddle splitting load (right, Weight, Test)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 7 \cdot 0.25 + 0.25 \cdot 11$ = 4.5 in^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{0.2108 \cdot 5{,}904}{4.5} = 277 \text{ psi}$$

Stress in saddle is acceptable ($\leq 0.9 \cdot S_y = 34{,}200$ psi)

Longitudinal stress at the left saddle (Weight, Test)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 7.2636}{3} + 172.75 + \frac{2 \cdot 7.2636}{3} = 182.4348 \text{ in}$$

$$w = \frac{W_t}{L_e} = \frac{14{,}368}{182.4348} = 78.76 \text{ lb}_f/\text{in}$$

Bending moment at the left saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_l \cdot A_l}{3} + \frac{A_l^2}{2} - \frac{R^2 - H_l^2}{4} \right)$$

$$= 78.76 \cdot \left(\frac{2 \cdot 7.2636 \cdot 38.25}{3} + \frac{38.25^{\ 2}}{2} - \frac{20.9999^{\ 2} - 7.2636^{\ 2}}{4} \right)$$

$$= 64{,}556.5 \text{ lb}_f\text{-in}$$

$$S_2 = \pm \frac{M_q \cdot K_1{'}}{\pi \cdot R^2 \cdot t} = \frac{64{,}556.5 \cdot 8.8457}{\pi \cdot 20.9062^{\ 2} \cdot 0.1874} = 2{,}219 \text{ psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{113.87 \cdot 20.8125}{2 \cdot 0.1874} = 6{,}323 \text{ psi}$$

Maximum tensile stress S_{2t} = S_2 + S_p = 8,542 psi
Maximum compressive stress (shut down) S_{2c} = S_2 = 2,219 psi

Tensile stress is acceptable ($\leq 0.9 \cdot S_y = 27{,}000$ psi)

Compressive stress is acceptable ($\leq S_c = 9{,}371$ psi)

Tangential shear stress in the shell (left saddle, Weight, Test)

$$Q_{shear} = Q - w \cdot \left(A_l + \frac{2 \cdot H_l}{3} \right) = 8{,}464 - 78.76 \cdot \left(38.25 + \frac{2 \cdot 7.2636}{3} \right) = 5{,}070.18 \text{ lb}_f$$

$$S_3 = \frac{K_{2.2} \cdot Q_{shear}}{R \cdot t} = \frac{1.1076 \cdot 5{,}070.18}{20.9062 \cdot 0.1874} = 1{,}433 \text{ psi}$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot (0.9 \cdot S_y) = 21{,}600$ psi)

Circumferential stress at the left saddle horns (Weight, Test)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{3 \cdot K_3 \cdot Q}{2 \cdot t^2}$$

$$= \frac{-8{,}464}{4 \cdot 0.1874 \cdot \left(8 + 1.56 \cdot \sqrt{20.9999 \cdot 0.1874}\right)} - \frac{3 \cdot 0.0363 \cdot 8{,}464}{2 \cdot 0.1874^{\ 2}}$$

$$= -14{,}141 \text{ psi}$$

Circumferential stress at saddle horns is acceptable ($\leq 0.9 \cdot S_y = 27{,}000$ psi)
The wear plate was not considered in the calculation of S_4 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46° and the wear plate width is not at least $\left\{b + 1.56 \cdot \sqrt{R_o \cdot t}\right\} = 11.0947$ in

Ring compression in shell over left saddle (Weight, Test)

$$S_5 = \frac{K_5 \cdot Q}{(t + t_p) \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$

$$= \frac{0.7457 \cdot 8{,}464}{(0.1874 + 0.25) \cdot \left(0.25 + 1.56 \cdot \sqrt{20.9999 \cdot 0.4374}\right)}$$

$$= 2{,}899 \text{ psi}$$

Ring compression in shell is acceptable ($\leq 0.9 \cdot S_y = 27{,}000$ psi)

Saddle splitting load (left, Weight, Test)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 7 \cdot 0.25 + 0.25 \cdot 11$ = 4.5 in^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{0.2108 \cdot 8{,}464}{4.5} = 396 \text{ psi}$$

Stress in saddle is acceptable ($\leq 0.9 \cdot S_y = 34{,}200$ psi)

Load Case 3: Weight, Vacuum

Longitudinal stress between saddles (Weight, Vacuum, right saddle loading and geometry govern)

$$S_1 = \pm \frac{3 \cdot K_1 \cdot Q \cdot (L \;/\; 12)}{\pi \cdot R^2 \cdot t} = \frac{3 \cdot 0.6358 \cdot 4{,}272 \cdot (172.75 \;/\; 12)}{\pi \cdot 20.9062^{\;2} \cdot 0.1874} = 456 \text{ psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{15 \cdot 20.8125}{2 \cdot 0.1874} = 833 \text{ psi}$$

Maximum tensile stress (shut down) S_{1t} = S_1 = 456 psi
Maximum compressive stress S_{1c} = S_1 + S_p = 1,289 psi

Tensile stress is acceptable ($\leq S \cdot E = 13{,}230$ psi)

Compressive stress is acceptable ($\leq S_c = 7{,}619$ psi)

Longitudinal stress at the right saddle (Weight, Vacuum)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 7.2636}{3} + 172.75 + \frac{2 \cdot 7.2636}{3} = 182.4348 \text{ in}$$

$$w = \frac{W_t}{L_e} = \frac{10{,}738}{182.4348} = 58.86 \text{ lb}_f/\text{in}$$

Bending moment at the right saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_r \cdot A_r}{3} + \frac{A_r^2}{2} - \frac{R^2 - H_r^2}{4}\right)$$

$$= 58.86 \cdot \left(\frac{2 \cdot 7.2636 \cdot 14.5}{3} + \frac{14.5^{\;2}}{2} - \frac{20.9999^{\;2} - 7.2636^{\;2}}{4}\right)$$

$$= 4{,}607.5 \text{ lb}_f\text{-in}$$

$$S_2 = \pm \frac{M_q \cdot K_1{}'}{\pi \cdot R^2 \cdot t} = \frac{4{,}607.5 \cdot 1}{\pi \cdot 20.9062^{\;2} \cdot 0.1874} = 18 \text{ psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{15 \cdot 20.8125}{2 \cdot 0.1874} = 833 \text{ psi}$$

Maximum tensile stress (shut down) S_{2t} = S_2 = 18 psi
Maximum compressive stress S_{2c} = S_2 + S_p = 851 psi

Tensile stress is acceptable ($\leq S = 18{,}900$ psi)

Compressive stress is acceptable ($\leq S_c = 7{,}619$ psi)

Tangential shear stress in the shell (right saddle, Weight, Vacuum)

$$S_3 = \frac{K_{2.3} \cdot Q}{R \cdot t} = \frac{0.8127 \cdot 4{,}272}{20.9062 \cdot 0.1874} = 886 \text{ psi}$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot S = 15{,}120$ psi)

The wear plate was not considered in the calculation of S_3 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46°.

Circumferential stress at the right saddle horns (Weight, Vacuum)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{3 \cdot K_3 \cdot Q}{2 \cdot t^2}$$
$$= \frac{-4{,}272}{4 \cdot 0.1874 \cdot \left(8 + 1.56 \cdot \sqrt{20.9999 \cdot 0.1874}\right)} - \frac{3 \cdot 0.0124 \cdot 4{,}272}{2 \cdot 0.1874^{\,2}}$$
$$= -2{,}776 \text{ psi}$$

Circumferential stress at saddle horns is acceptable ($\leq 1.5 \cdot S_a = 28{,}350$ psi)

The wear plate was not considered in the calculation of S_4 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46° and the wear plate width is not at least $\left\{b + 1.56 \cdot \sqrt{R_o \cdot t}\right\} = 11.0947$ in

Ring compression in shell over right saddle (Weight, Vacuum)

$$S_5 = \frac{K_5 \cdot Q}{(t + t_p) \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$
$$= \frac{0.7457 \cdot 4{,}272}{(0.1874 + 0.25) \cdot \left(0.25 + 1.56 \cdot \sqrt{20.9999 \cdot 0.4374}\right)}$$
$$= 1{,}463 \text{ psi}$$

Ring compression in shell is acceptable ($\leq 0.5 \cdot S_y = 11{,}200$ psi)

Saddle splitting load (right, Weight, Vacuum)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 7 \cdot 0.25 + 0.25 \cdot 11$ = 4.5 in^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{0.2108 \cdot 4{,}272}{4.5} = 200 \text{ psi}$$

Stress in saddle is acceptable $\left(\leq \frac{2}{3} \cdot S_s = 13{,}333 \text{ psi}\right)$

Longitudinal stress at the left saddle (Weight, Vacuum)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 7.2636}{3} + 172.75 + \frac{2 \cdot 7.2636}{3} = 182.4348 \text{ in}$$

$$w = \frac{W_t}{L_e} = \frac{10{,}738}{182.4348} = 58.86 \text{ lb}_f/\text{in}$$

Bending moment at the left saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_l \cdot A_l}{3} + \frac{A_l^2}{2} - \frac{R^2 - H_l^2}{4} \right)$$

$$= 58.86 \cdot \left(\frac{2 \cdot 7.2636 \cdot 38.25}{3} + \frac{38.25^{\ 2}}{2} - \frac{20.9999^{\ 2} - 7.2636^{\ 2}}{4} \right)$$

$$= 48{,}246.7 \quad \mathrm{lb}_f\text{-in}$$

$$S_2 = \pm \frac{M_q \cdot K_1{}'}{\pi \cdot R^2 \cdot t} = \frac{48{,}246.7 \cdot 8.8457}{\pi \cdot 20.9062^{\ 2} \cdot 0.1874} = 1{,}659 \quad \mathrm{psi}$$

$$S_p = \frac{P \cdot R}{2 \cdot t} = \frac{15 \cdot 20.8125}{2 \cdot 0.1874} = 833 \quad \mathrm{psi}$$

Maximum tensile stress (shut down) S_{2t} = S_2 = 1,659 psi
Maximum compressive stress S_{2c} = S_2 + S_p = 2,492 psi

Tensile stress is acceptable ($\leq S = 18{,}900 \quad \mathrm{psi}$)

Compressive stress is acceptable ($\leq S_c = 7{,}619 \quad \mathrm{psi}$)

Tangential shear stress in the shell (left saddle, Weight, Vacuum)

$$Q_{shear} = Q - w \cdot \left(A_l + \frac{2 \cdot H_l}{3} \right) = 6{,}466 - 58.86 \cdot \left(38.25 + \frac{2 \cdot 7.2636}{3} \right) = 3{,}929.61 \quad \mathrm{lb}_f$$

$$S_3 = \frac{K_{2.2} \cdot Q_{shear}}{R \cdot t} = \frac{1.1076 \cdot 3{,}929.61}{20.9062 \cdot 0.1874} = 1{,}111 \quad \mathrm{psi}$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot S = 15{,}120 \quad \mathrm{psi}$)

Circumferential stress at the left saddle horns (Weight, Vacuum)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{3 \cdot K_3 \cdot Q}{2 \cdot t^2}$$

$$= \frac{-6{,}466}{4 \cdot 0.1874 \cdot \left(8 + 1.56 \cdot \sqrt{20.9999 \cdot 0.1874}\right)} - \frac{3 \cdot 0.0363 \cdot 6{,}466}{2 \cdot 0.1874^{\ 2}}$$

$$= -10{,}803 \quad \mathrm{psi}$$

Circumferential stress at saddle horns is acceptable ($\leq 1.5 \cdot S_a = 28{,}350 \quad \mathrm{psi}$)
The wear plate was not considered in the calculation of S_4 because the wear plate contact angle did not exceed the saddle contact angle by at least 11.46° and the wear plate width is not at least $\left\{b + 1.56 \cdot \sqrt{R_o \cdot t}\right\} = 11.0947 \quad \mathrm{in}$

Ring compression in shell over left saddle (Weight, Vacuum)

$$S_5 = \frac{K_5 \cdot Q}{\left(t + t_p\right) \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$

$$= \frac{0.7457 \cdot 6{,}466}{\left(0.1874 + 0.25\right) \cdot \left(0.25 + 1.56 \cdot \sqrt{20.9999 \cdot 0.4374}\right)}$$

$$= 2{,}214 \quad \mathrm{psi}$$

Ring compression in shell is acceptable ($\leq 0.5 \cdot S_y = 11{,}200 \quad \mathrm{psi}$)

Saddle splitting load (left, Weight, Vacuum)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 7 \cdot 0.25 + 0.25 \cdot 11$ = 4.5 in^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{0.2108 \cdot 6{,}466}{4.5} = 303 \quad \mathrm{psi}$$

Stress in saddle is acceptable $\left(\leq \frac{2}{3} \cdot S_s = 13{,}333 \quad \text{psi} \right)$

Shear stress in anchor bolting, one end slotted

Maximum seismic or wind base shear $= 0 \quad \text{lb}_f$

Thermal expansion base shear $= W \cdot \mu$ = 4,419*0.45 $= 1{,}988.55 \quad \text{lb}_f$

Corroded root area for a 1" series 8 threaded bolt $= 0.551 \quad \text{in}^2$ (2 per saddle)

Bolt shear stress = $\frac{1{,}988.55}{0.551 \cdot 1 \cdot 2} = 1{,}804 \quad \text{psi}$

Anchor bolt stress is acceptable (≤ 15,000 psi)

Shear stress in anchor bolting, transverse

Maximum seismic or wind base shear $= 0 \quad \text{lb}_f$

Corroded root area for a 1" series 8 threaded bolt $= 0.551 \quad \text{in}^2$ (2 per saddle)

Bolt shear stress = $\frac{0}{0.551 \cdot 2 \cdot 2} = 0 \quad \text{psi}$

Anchor bolt stress is acceptable (≤ 15,000 psi)

Web plate buckling check (Escoe pg 251)

Allowable compressive stress S_c = min(20,000 , 20,270) = 20,000 psi

$$S_c = \frac{K_i \cdot \pi^2 \cdot E}{12 \cdot \left(1 - 0.3^{\,2}\right) \cdot \left(\frac{d_i}{t_s}\right)^2} = \frac{1.28 \cdot \pi^2 \cdot 29\text{E+06}}{12 \cdot \left(1 - 0.3^{\,2}\right) \cdot \left(\frac{10.1708}{0.25}\right)^2} = 20{,}270 \quad \text{psi}$$

Allowable compressive load on the saddle

$$b_e = \frac{d_i \cdot t_s}{(d_i \cdot t_s) + 2 \cdot t_w \cdot (b - 1)} = \frac{10.1708 \cdot 0.25}{(10.1708 \cdot 0.25) + 2 \cdot 0.25 \cdot (8 - 1)} = 0.4208$$

$$F_b = n \cdot (A_s + 2 \cdot b_e \cdot t_s) \cdot S_c = 5 \cdot (1.9375 + 2 \cdot 0.4208 \cdot 0.25) \cdot 20{,}000 = 214{,}789.48 \quad \text{lb}_f$$

Saddle loading of 8,611 lb_f is ≤ F_b; satisfactory.

Primary bending + axial stress in the saddle due to end loads (assumes one saddle slotted)

$$\sigma_b = \frac{V \cdot (H_s - x_o) \cdot y}{I} + \frac{Q}{A} = \frac{0 \cdot (30.25 - 17.135) \cdot 4.9226}{89.1} + \frac{6{,}466}{18.9584} = 341 \quad \text{psi}$$

The primary bending + axial stress in the saddle ≤ S_s = 20,000 psi; satisfactory.

Secondary bending + axial stress in the saddle due to end loads (includes thermal expansion, assumes one saddle slotted)

$$\sigma_b = \frac{V \cdot (H_s - x_o) \cdot y}{I} + \frac{Q}{A} = \frac{1{,}988.55 \cdot (30.25 - 17.135) \cdot 4.9226}{89.1} + \frac{4{,}272}{18.9584} = 1{,}666 \quad \text{psi}$$

The secondary bending + axial stress in the saddle ≤ 2*S_y = 76,000 psi; satisfactory.

Saddle base plate thickness check (Roark sixth edition, Table 26, case 7a)

where $a = 10.1708, b = 8.75 \quad \text{in}$

$$t_b = \sqrt{\frac{\beta_1 \cdot q \cdot b^2}{1.5 \cdot S_a}} = \sqrt{\frac{0.8654 \cdot 23 \cdot 8.75^{\,2}}{1.5 \cdot 20{,}000}} = 0.2245 \quad \text{in}$$

The base plate thickness of 0.375 in is adequate.